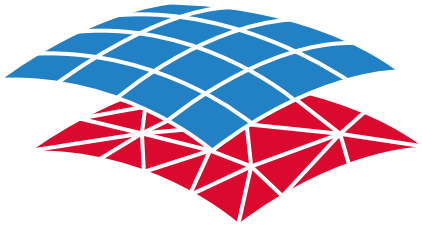


MpCCI
CouplingEnvironment

Part I

—

Overview

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part I Overview
PDF version
October 29, 2023

Fraunhofer Institute for Algorithms and Scientific Computing SCAI
Schloss Birlinghoven 1, 53757 Sankt Augustin, Germany

I Overview – Contents

Preface

"MpCCI Coupling-Environment" is the standard for simulation code coupling.
In this manual MpCCI will be used as abbreviation for "MpCCI Coupling-Environment".

MpCCI has been developed at the Fraunhofer Institute SCAI in order to provide an application independent interface for the coupling of different simulation codes.

Codes Supported by MpCCI

MpCCI enables a direct communication between the coupled codes by providing adapters for a growing number of commercial codes. These code adapters make use of the already existing application programming interfaces (APIs) of the simulation tools. This technique allows for an easy installation of MpCCI at the end users site without changing the standard installation of the simulation codes.

A list of currently supported codes is given in the Release Notes.

Internal Architecture

The MpCCI environment consists of several components:

- MpCCI Code Adapter allow to adapt MpCCI to commercial codes through their standard code APIs without any changes in the source of the simulation code.
- The MpCCI Graphical User Interface provides a comfortable way to define the coupling setup and to start the simulation - independent of the codes involved in the coupled application.
- The MpCCI Coupling Server is the "heart" of the MpCCI system. Environment handling, communication between the codes, neighborhood computation and interpolation are part of this kernel.

Standardized Quantities

One major advantage of having compatible code adapters for all codes supported by MpCCI is the standardization of coupling parameters and procedures independent from the used code pairing. MpCCI provides unified quantity definitions for

- Global quantities: time, iteration, residuals
- Mass source and sink: production species
- Momentum sources: e. g. Lorentz forces
- Energy sources: e. g. joule heat
- Material properties: e. g. electrical conductivity
- Boundary condition values: e. g. temperature or pressure
- Boundary condition gradients: e. g. heat flux density
- Grid data: nodal positions or displacements
- And chemical components: e. g. for reaction kinetics

MpCCI Manuals

The MpCCI documentation is split up into several manuals which are also called parts. Each part aims at a special kind of readers.

Release Notes The Release Notes contain information on changes versus prior versions of MpCCI. They are thus interesting for users, who have some experience with earlier versions of MpCCI.

Installation Guide The Installation Guide describes how to install MpCCI. It also contains information about the licensing.

Getting Started is intended for new users of MpCCI. The most important features of MpCCI are described by following a typical setup of a coupled simulation.

User Manual The User Manual contains a complete overview of the functions and features of MpCCI. This includes information on code coupling, command line options and functions of the MpCCI GUI.

Codes Manual The Codes Manual contains code-specific information. For each code which can be coupled with MpCCI a section is included.

Tutorial is a collection of examples which are explained in detail.

Programmers Guide The Programmers Guide is intended for users who want to write their own code adapters.

How To is a collection of best practice cases.

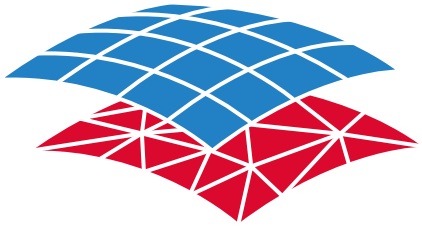
FSIMapper The MpCCI FSIMapper Guide is intended for users who want to transfer quantity values from the CFD to the FEM mesh as one-way file based coupling.

Typographical Conventions

This manual adheres to a set of typographical conventions so that you can recognize actions and items. The following list illustrates each of the conventions:

- Text you enter from the keyboard or outputs is written in a typewriter font and surrounded by a gray box, e. g. : `mpcci gui`
- Filenames are enclosed in quotation marks, `"example.txt"`. All paths are given with a slash (/) as directory separator, e. g. `"mpcci/doc/pdf"`. On Windows systems this must be replaced by a backslash (\).
- Meta variables represent values and are enclosed in angle brackets as in <*MpCCI_home*>. They can appear everywhere and always should be replaced by appropriate values.
- Environment variables are always written in uppercase typewriter letters, like `VARIABLE`.
- Buttons in the MpCCI GUI look like buttons, e. g. Next.
- Entries of the menu have a colored background, sub-menus are separated by an arrow. E. g. File→Open Project means the submenu Open Project of the File menu.
- Other options which can be selected are written like Option.
- Names of software are written in a sans-serif font, like MpCCI.
- Links can be clicked directly in the PDF version of the manual and are marked blue there, this applies to links within the manual like ▷ IV-2 Setting up a Coupled Simulation ◁ or to web pages www.mpcci.de.

Contents of All MpCCI Manuals



MpCCI
CouplingEnvironment

Part II

—

Release Notes

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part II Release Notes
PDF version
October 29, 2023

Fraunhofer Institute for Algorithms and Scientific Computing SCAI
Schloss Birlinghoven 1, 53757 Sankt Augustin, Germany

II Release Notes – Contents

1 Introduction MpCCI 4.7

The release notes relate to MpCCI 4.7.
MpCCI 4.7 represents a new release change over MpCCI 4.6. Please read the changes and features section ▷ 2 Changes and New Features in MpCCI 4.7 ◁ for more details.
MpCCI 4.7 is available as an upgrade from an existing MpCCI 4.6 installation.

2 Changes and New Features in MpCCI 4.7

2.1 MpCCI 4.7.1-1

2.1.0.1 MpCCI CouplingEnvironment

- Enhancement for the optional "mpcci_<CODENAME>.env" environment file to define the environment for the code CODENAME. It supports the capability to source external scripts in order to configure the process environment (▷ V-3.7.1.2 Configure a Simulation Code for Running on a Remote Machine ◁).
- Extend the scope of the -set option of the batch command. This can now be used to also address properties that concern the settings and MpCCI server section of the project file (▷ V-3.7.1.1 Run a Job in Batch Mode with MpCCI Command Line ◁).

2.1.0.2 MpCCI Client

- Resolve deadlock for quasi-transient coupling approach.

2.1.1 Bug Fixes

- The transfer of the convergence value to the relaxation operator in quantity sets has been corrected. This fixes the following error message of the MpCCI server:

```
[MpCCI-SERVER]: *** ERROR *** Internal error in CODE_QINFO_new(code=...):
    The code quantity properties string is bad:
       Bad relaxTolerance (str2real): 'USETOLERANCE'.
    Should be: loc smethod sindex rmethod rindex value [...]
```

- Automatic re-execution of the MpCCI Configurator when the settings for the system of units for a code have been changed in the MpCCI GUI.
- Avoid program abort if an unsuitable configuration file is specified when calling the MpCCI GUI (`mpcci gui project.csp -useConfiguration configurationFile`). Instead, appropriate error messages are output.
- Fix usage of Maximum number of coupling steps. The number of coupling steps defined was not respected if subcycling step was adaptive.

2.1.2 Code Specific Changes

Abaqus

- Support of Abaqus 2023.

Adams

- Support of Adams 2022.2, 2022.3, 2022.4, 2023.1, 2023.2.

ANSYS

- Support of ANSYS 2022 R2, 2023 R1.

ANSYS Icepak

- Support of ANSYS Icepak 2022 R2, 2023 R1.

FLUENT

- Support of FLUENT 2022 R2, 2023 R1.

JMAG

- Support of JMAG 22.0, 22.1.

Marc

- Support of Marc 2022.2, 2022.3, 2022.4, 2023.1, 2023.2.

MSC NASTRAN

- Support of MSC NASTRAN 2022.2, 2022.3, 2022.4, 2023.1, 2023.2.
- Fix co-simulaton data when running steady state analyis type for the tutorial ▷ VII-5 Pipe Nozzle ◁. The MSC NASTRAN provides a correct coupling tag information.

OpenFOAM

- Support of OpenFOAM v2112, v2206, v2212, v2306.

STAR-CCM+

- Support of STAR-CCM+ 2206, 2210, 2302, 2306.
- Discontinue support of STAR-CCM+ 11.02 to 13.06.
- MpCCI remeshing option for STAR-CCM+ 2302 and higher is deprecated. It is recommended to use the STAR-CCM+ internal remeshing model.
- Solution of the problem that the coupled simulation does not start: STAR-CCM+ aborts immediately after startup. Reason: The default temporary folder `"/tmp"` is configured without execute permission (the noexec flag is set). Solution: At startup, `TMPDIR` is set so that the setting from the environment variable `MPCCI_TMPDIR` is used. This allows the code adapter to be loaded without restriction.

TAITherm

- Support of TAITherm 2022.2.

2.2 MpCCI 4.7.0-1

2.2.1 MpCCI Licensing

- New licensing software: for MpCCI 4.7.0 you will need the FlexNet Publisher 11.17 licensing software.

2.2.2 New Features

2.2.2.1 MpCCI GUI

- Predefined coupling specifications for solving specific coupling types are introduced, simplifying the settings of the required parameters (see ▷ V-4.5 Coupling Specifications ◁).
- Smart configuration is introduced for FSI with Abaqus, FLUENT and OpenFOAM to obtain an optimal runtime compared to the default settings in MpCCI GUI (see ▷ V-3.5 Smart Configuration ◁).
- Only installed simulation codes with a valid adapter license are offered by default. The list of codes can also be configured individually using the Configure submenu of the ▷ V-4.4.6 Codes Menu ◁.

2.2.2.2 MpCCI CouplingEnvironment

- New tutorial for biomedical FSI application (▷ VII-6 Blood Vessel ◁) using the newly introduced smart configuration.
- Batch option -checkonly is deprecated and replaced by -prepare.

2.2.2.3 MpCCI FSIMapper

- New source code 6SigmaET for static and transient temperature.
- New source format VMAP for static and transient applications.
- LS-Dyna as target code available.
- EnSight Gold transient temperature mapping support.
- Improved handling for spaces in the file path on Linux systems.

2.2.3 Further Enhancements of Existing Features

2.2.3.1 MpCCI GUI

- Display the final status at the end of a coupled simulation.
- Support for setting up 3-code coupling for experienced users in beta mode (cf. ▷ V-4.7.3 3-Code Coupling for Advanced Users ◁).

2.2.3.2 MpCCI Visualizer and MpCCI Monitor

- New command line option (-np) to modify the default number of cores to use (cf. ▷ V-5.3.4 mpcci monitor ◁, ▷ V-5.3.5 mpcci visualize ◁).

2.2.4 Bug Fixes

- Fixed a problem with the orientation of the element vector normal calculation with respect to the right-hand rule:
  - In the MpCCI server this has no impact on the mapping of quantities.
  - In the MATLAB adapter this function is used to convert automatically the pressure field to a force field along the normal vector orientation. Check your element node sequence definition if the normal vector orientation does not fit the load definition you would like to apply.
- Fixed an issue with the mapping of data from axisymmetric models in MpCCI server.
- Fixed an issue with updating the bounding box.
- Fix abnormal termination of MpCCI server during an implicit coupling on remeshing event.
- Fix abnormal termination of a client when the MpCCI server environment variable is missing.
- Fix abnormal termination of the MpCCI GUI if a code configuration file is incomplete.
- Bug fixing the list of available codes in combination with self-coupling codes in the MpCCI GUI (e.g. when configuring the coupling algorithm).
- Fixed a bug in the MpCCI GUI related to the configuration of coupling regions and quantities for a 3-code coupling.

2.2.5 Code Specific Changes

Abaqus

- Support of Abaqus 2022.

ANSYS

- Support of ANSYS 2021 R2, 2022 R1.

FLUENT

- Support of FLUENT 2021 R2, 2022 R1.
- Fix TUI command used to set the user defined adaptive time step method from FLUENT 2019 R3.
- Improved management of dynamic load balancing, remeshing handling when running FLUENT parallel solver. There were some negative cell volumes when running the tutorial ▷ VII-2 Elastic Flap in a Duct ◁ on multiple cpus.
- Changed the default value set in MpCCI GUI for the Number of inner iterations from 1 to 30 for implicit coupling scheme.

ANSYS Icepak

- Support of ANSYS Icepak 2021 R2, 2022 R1.
- Fix TUI command used to set the user defined adaptive time step method from ANSYS Icepak 2019 R3.

JMAG

- Support of JMAG 20.1, 21.0.

MATLAB

- Fixing for the orientation of element vector normal calculation with respect to the right-hand rule in the MATLAB adapter. This function is used to convert automatically the pressure field to a force field along the normal vector orientation. Check your element node sequence definition if the normal vector orientation does not fit the load definition you would like to apply.

Adams

- Support of Adams 2021.1, 2021.2, 2021.3, 2022.1.

Marc

- Support of Marc 2021.2, 2021.4, 2022.1.

MSC NASTRAN

- Support of MSC NASTRAN 2021.1, 2021.2, 2021.3, 2021.4, 2022.1.

OpenFOAM

- Support of OpenFOAM v2106.

STAR-CCM+

- Support of STAR-CCM+ 2021.2, 2022.1

- Fixed the boundary type recognition for sim file saved from STAR-CCM+ 2019.1. Some boundary parts were not listed in the list of available components to be coupled.
- Fixed the access to the configuration file `"settings.props"` from STAR-CCM+ 2019.1 and newer releases.

TAITherm

- Support of TAITherm 2021.1.2, 2021.2.1, 2021.2.5, 2022.1.
- Fix issue when running TAITherm in Distributed memory parallel. The temperature distribution was not correctly updated before the data transfer. The correction has affected the releases TAITherm 12.6 to the latest release.
- Speed up mesh data extraction performance for large coupled parts (up to 10,000 times faster).

3 Changes and New Features in the Earlier Releases

3.1 MpCCI 4.6.1-1

3.1.1 MpCCI FSIMapper

- Support FLUENT CFF file format from FLUENT 20.0

3.1.2 Bug fixes

- Fix synchronization issue for massive parallel simulation codes.
- Fix management of convergence decision for implicit coupling.
- Additional checks are done to validate the Type of coupling step size in case of Sent by code according to the selected coupling algorithm.
- Fix report by adding parameters with non-existent files when checking the simulation parameters in the Go step. These parameters and those with incorrect values are now also given a note in their input field (▷ V-4.3 Parameter Notes in the MpCCI GUI ◁).
- Fix blocking issue with a project saved at the Models step. The user could not access the Regions step because of following error: There are not enough components respectively quantities for coupling!.
- Adapt shortcuts in the MpCCI GUI to the general standard (Ctrl +<*Key*>).

3.1.3 Code Specific Changes

3.1.3.1 Abaqus

- Support of Abaqus 2021.
- Thermal co-simulation fields changed from Abaqus 2018: coupling with surface film properties is reintroduced.
  Following coupling fields are supported:
  - from Abaqus 2016 to Abaqus 2017: use the predefined coupling type Steady state concentrated heat transfer: exchange WallTemp with FilmTemp and HeatRate.
  - from Abaqus 2018: use the predefined coupling type Steady state surface heat transfer: exchange WallTemp with FilmTemp and WallHTCoeff.

  Abaqus 2018 and 2019 releases require the installation of the latest available patch (▷ VI-2.7 Trouble Shooting, Open Issues and Known Bugs ◁).

3.1.3.2 ANSYS

- Support of ANSYS 2021 R1.

3.1.3.3 FINE/Open

- Support of FINE/Open 10.1. All prior releases of FINE/Open are not supported because of an issue within the morpher solver. NUMECA International will not provide any patches for the older releases.
- The MpCCI GUI co-simulation setting for FINE/Open has been reviewed to fit the current FINE/Open requirements.

3.1.3.4 FINE/Turbo

- Support of FINE/Turbo 15.1.
- It is recommended to save the provided tutorial models for FINE/Turbo in the target release you want to use. MpCCI provides the models from the minimum supported release of FINE/Turbo. You will ensure that the model is properly upgraded by FINE/Turbo prior to the usage (▷ VI-7.5 Trouble Shooting, Open Issues and Known Bugs ◁).

3.1.3.5 FLUENT

- Support of FLUENT 2021 R1.

3.1.3.6 JMAG

- Support of JMAG 20.0.

3.1.3.7 ProLB

- Fix issue by reading the matrices files concerning the shell component. The tools generating this information have been updated.
- Update shell component name automatically for ProLB 2.6.1 from MpCCI 4.5 to MpCCI 4.6 project.

3.1.3.8 Adams

- Update the ▷ VII-12 Spring Mass System ◁ model for Adams to ensure a stable solution.
- Solve adapter loading issue from Adams 2018 and newer releases.

3.1.3.9 MSC NASTRAN

- Support of MSC NASTRAN 2021.0.

3.1.3.10 OpenFOAM

- Support of OpenFOAM 2012.
- Improve insertion of mpcci function object in the controlDict and dynamicMeshDict files: the motion solver keyword motionSolver is supported.
- Improve user interface for the MpCCI morpher configuration settings: only relevant information is shown when a morpher option file is selected.

3.1.3.11 STAR-CCM+

- Support of STAR-CCM+ 2019.1, 2019.2, 2019.3, 2020.1, 2020.2, 2020.3.

3.1.3.12 TAITherm

- Support of TAITherm 2020.2.

3.1.4 MpCCI Tutorial

- Thermal coupling tutorial for Marc (see ▷ VII-8 Exhaust Manifold ◁).

3.2 MpCCI 4.6.0-2

3.2.1 Bug fixes

- The coupling duration has been corrected if the option Set maximum number of coupling steps is used in combination with subcycling. The expected total number of steps matched with the setting in the MpCCI GUI.
- The conversion of old MpCCI project file for Abaqus, ProLB, STAR-CCM+ in MpCCI 4.6.0 properly imports the coupling configuration settings.

3.3 MpCCI 4.6.0-1

3.3.1 MpCCI Licensing

- New licensing software: for MpCCI 4.6.0 you will need the FlexNet Publisher 11.16 licensing software.

3.3.2 New Features

3.3.2.1 MpCCI GUI

- The definition of the coupling algorithm has been restructured and thus simplified by introducing an additional Algorithm step (▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁, ▷ V-4.7 Algorithm Step ◁).
- Additional control parameters:
  - MonitorResidual for monitoring residuals of the Quasi-Newton relaxation method (see Quasi-Newton section of ▷ V-4.10.2 Job ◁).
  - WriteLog for writing a logfile with Quasi-Newton relaxation information (see Quasi-Newton section of ▷ V-4.10.2 Job ◁).
  - ConvergenceRule to define whether all or only one quantity should be converged to consider the current time step done (see ▷ V-4.10.2 Job ◁).

3.3.2.2 MpCCI CouplingEnvironment

- For Quasi transient or Steady state analyses, MpCCI introduces an option to reduce the idle time if one code is solving faster than the other code: the code can use the Delay boundary updates option (see ▷ V-3.4.4 Coupling with Delayed Boundary Updates ◁).

3.3.2.3 MpCCI FSIMapper

- Support ANSYS Maxwell export to Universal file format .unv for mapping forces from surface.
- Extend support of reading vector quantities from EnSight Gold Case format.
- New mapping algorithm conservative is available and appropriated to map integral quantities (cf. ▷ X-7 Theory Guide ◁).

3.3.3 Further Enhancements of Existing Features

3.3.3.1 MpCCI GUI

- Direct access to the individual steps for setting up a coupled simulation is possible. However, a selected step can get stuck on a previous step if configurations are required that have not yet been fulfilled (▷ IV-2.3.2 Navigating through the MpCCI GUI ◁).
- The selection of a model file starts the scanning process directly, without the need for an additional click for the scanning process (▷ V-4.6 Models Step ◁).
- Automatically determine the appropriate analysis type for a simulation by extracting the solution type from the model while it is being scanned (▷ V-4.7.2 Code Specific Algorithm Settings ◁).
- The tolerance value for relaxation convergence was replaced by the tolerance value of the absolute convergence check operator in order to avoid incorrect user input (▷ V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).
- Clearer output from checking the simulation parameters in the Go step:
  - The overall result is listed directly in the header of the code names.
  - Summary information about the coupling configuration is displayed.
  - The check button shows the last overall result.

  (▷ IV-2.8.3 Checking the Application Configuration ◁)
- The output of the running simulation codes can be requested at any time using the Running button, and not only at the end of the simulation. Closing the output window does not terminate the code (▷ V-4.11.4 Status of the Simulation ◁).
- The Edit step has been renamed Settings step for a clearer description (▷ V-4.10 Settings Step ◁).
- The coupled simulation is limited to two codes, since the new definition of the algorithm has to be adapted for more than two codes, which is currently not possible due to the lack of use cases.

3.3.3.2 MpCCI CouplingEnvironment

- Improvement of the Quasi-Newton algorithm:
  - Improvement in terms of robustness and acceleration.
  - Better conditioning of related matrices by adding three filtering methods.
  - Quasi-Newton is now able to relax quantities using information from previous time steps (cf. ▷ V-3.3.3.4 Quasi-Newton Method ◁). This reduced the average number of iterations by almost 30% for the two-dimensional case of ▷ VII-4 Driven Cavity ◁ (5.4 iterations using four previous time steps, while it takes 7.5 iterations on average for version MpCCI 4.5.2-1).
  - The Quasi-Newton method can now also be used for parallel coupling.
- MpCCI is now capable of implicit coupling with an adaptive time step size for the supporting codes (▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁).
- From MpCCI 4.6.0 onwards, OpenJDK will be provided. The java VM is upgraded to OpenJDK Version 11.0.6+10.
- The initial quantity scaling for Quasi-Newton relaxation, which was introduced in version MpCCI 4.5.2-1, has been removed.
- Additional codes (FLUENT, MSC NASTRAN) for the tutorial ▷ VII-4 Driven Cavity ◁.

3.3.3.3 MpCCI Client

- Changes in initialization step for inhouse code adapter: in order to properly define the used coupling scheme and algorithm defined in the MpCCI GUI, the code adapter needs to call an additional function to initialize the code information data structure ▷ VIII-2.7.4 Initialize the Code Information Structure ◁. You can check the changes at ▷ VIII-2.6.1 How to Initialize the Code? ◁.

3.3.3.4 MpCCI Batch

- Support SLURM batch system (see ▷ V-5.7.6 mpcci batch SLURM ◁).
- The `mpcci batch` command provides an additional option (-mpmode) to modify the parallel method mode to be set for the code:
  - none run on one cpu,
  - smp shared memory model,
  - dmp distributed memory model.

  So, the project file needs not to be edited anymore (see ▷ V-3.7.1.1 Run a Job in Batch Mode with MpCCI Command Line ◁).

3.3.3.5 Code Specific Changes

Abaqus

- Support of Abaqus 2019, Abaqus 2020.
- Fix thermal coupling based on heat rate and film temperature quantities.
- Enhancement for implicit coupling, Abaqus supports the negotiate time step size option (▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁).

ANSYS

- Support of ANSYS 19.1, 19.2, 2019R1(19.3), 2019R2(19.4), 2019R3(19.5), 2020R1(20.1), 2020R2(20.2).

FINE/Open

- Support of FINE/Open 7.2, 8.1, 8.2, 9.1, 9.2.

FINE/Turbo

- Support of FINE/Turbo 13.1, 13.2, 14.1, 14.2.

FLUENT

- Support of FLUENT 19.1, 19.2, 2019R1(19.3), 2019R2(19.4), 2019R3(19.5), 2020R1(20.1), 2020R2(20.2).
- Fix thermal coupling based on heat rate quantity calculation.
- Fix thermal coupling with FLUENT running in parallel on Microsoft Windows. In prior MpCCI release the FLUENT computation was blocked.

ANSYS Icepak

- Support of ANSYS Icepak 19.1, 19.2, 2019R1(19.3), 2019R2(19.4), 2019R3(19.5), 2020R1(20.1), 2020R2(20.2).

JMAG

- Support of JMAG 17.1, 18.0, 18.1, 19.0.

- Coupling limitation with JMAG model using multiple parts for the co-simulation for all versions until JMAG 18.0.
  Need to install JMAG 18.0 service pack or use JMAG 18.1 version.

MATLAB

- Support of MATLAB R2019a on Linux platform only, MATLAB R2019b on Microsoft Windows only.

Adams

- Support of Adams 2018.1, 2019, 2019.2, 2020.

Marc

- Support of Marc 2018, 2018.1, 2019, 2020.

MSC NASTRAN

- Support of MSC NASTRAN 2018.2, 2019.0, 2020.0.
- Fix for implicit coupling when the coupling time step has converged. The converged force load is kept until the next time step begins.

OpenFOAM

- Support of OpenFOAM v1806, v1812, v1906, v1912, v2006.
- Older versions than OpenFOAM v1606+ are not maintained anymore. New features are not implemented in the older versions.
- Fix support for customer internal release number.
- Enhancement for implicit coupling, OpenFOAM supports the negotiate time step size option (▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁).
- Fix thermal coupling based on heat rate quantity calculation.
- Improve management of original `"controlDict"` and `"dynamicMeshDict"` files: the file backup is done only once and are assigned with the suffix -mpcci_orig on new model. Direct modification of dictionary files by user will be taken in account for the calculation. If the user deactivates the usage of the MpCCI morpher with OpenFOAM, then the original setting will be restored.

RadTherm

- RadTherm versions have been removed from the maintenance list. Newer versions are available as TAITherm now.

TAITherm

- Support of TAITherm 12.5.2, 12.6.0, 12.7.0, 13.0.0, 13.1.0, 2020.1.0.

STAR-CCM+

- Support of STAR-CCM+ 13.06.
- For thermal simulation, the user can select the type of heat transfer coefficient to be used for the coupling.
- Update morpher setting according to the new STAR-CCM+ releases.
- Fix thermal coupling based on heat rate quantity calculation.

STAR-CD

- Co-simulation with STAR-CD is provided only on demand. It is not part of the software release.

3.4 MpCCI 4.5.2-1

3.4.1 New Features

3.4.1.1 MpCCI CouplingEnvironment

- The relaxation convergence of relaxed iterative couplings can be checked in order to reduce the number of coupling iterations per time step (cf. ▷ V-3.3.3 Quantity Relaxation ◁). When relaxation is activated, the relative difference between the unrelaxed and the relaxed quantity value is computed. In the end of the coupling time step (max. number of iterations or quantity convergence reached) this difference is printed to the log-file. If the value is higher than the user given tolerance (or $1e-5$), a warning is outputted. If the value is lower than the user given tolerance, the quantity state is set to CONVERGED.
- Usually, in the first iteration of an iteratively coupled time step where Quasi-Newton relaxation is used, the relaxed quantity value is equated with the unrelaxed value. Now, it is possible to set the very first relaxed quantity value to the scaled (by ω) unrelaxed value (cf. ▷ V-3.3.3.4 Quasi-Newton Method ◁).
- Additional log file (▷ V-3.8.3 Log Files ◁) with information about the job setup, neighborhood calculation and the elapsed wall clock time per coupling step. The log filename is created by following this rule:
  `"mpcci_<JOB_NAME_PREFIX>_server.log"`.
- New PreCheck mode option available in the Edit Step (▷ V-3.2.5 Pre-Check Mode ◁). The user can perform a partial run until the coupled mesh definition and stop the job. This requires an additional license token.

3.4.2 Further Enhancements of Existing Features

3.4.2.1 MpCCI GUI

- The unit system SI-mm-t-s has been renamed as mm-t-s.
- The methods Jacobi and Broyden have been removed from the MpCCI GUI since the computational effort and the memory requirement of the Anderson Mixing Quasi-Newton method grows only linearly with the number of degrees of freedom.
- Support for finding equally named components which are automatically generated by the scanner (see `%userInfo` in ▷ VIII-2.5.2 Scanner.pm ◁). This feature is used when applying rules for automatic region building (see ▷ V-4.8.5 Automatic Generation of Regions by Rules ◁).
- Enhanced rules lists by offering options for generating only one region as a result of combining some rules. This can be used to extend or reduce the components building a region (▷ V-4.8.5.1 Rules Lists ◁).
- To gain greater insight into the quantity sets in the coupling step of the MpCCI GUI they are now named automatically by default. Their name will also change immediately when quantities are added or removed. (▷ IV-2.6.2 Define Quantities to be Exchanged ◁)
- Simplified look and feel by removal of unused or replaced features (Undo button in edit step; options area for synchronized scrolling and selecting components in components panel of coupling step).

- New user property for automatically saving project data before starting the coupled simulation (▷ V-4.4.2 Edit Menu ◁).
- Improved start-up of the coupled application by offering only one start button which starts the server and also the codes one after the other (▷ IV-2.8.4 Starting the Coupled Simulation ◁).
- The output windows from each code are now hidden and can be opened on demand. The user now recognizes the status of the finalized applications directly and has specific access to the interesting application output (▷ V-4.11.4 Status of the Simulation ◁).

3.4.2.2 MpCCI CouplingEnvironment

- Handle the warning about the usage of a deprecated Perl glob() function. This warning was displayed from Perl 5.26.
- Fix the loading of user specific environment file for a simulation code having a directory as model file. The naming convention for the file supports lowercase and the code name case proposed by MpCCI.
- Enhancement for the syntax rule for the specific code environment file `"mpcci_<CODENAME>.env"`. User can define if a variable should be set by using the symbol = or appended by using the symbol += (▷ V-3.7.1.2 Configure a Simulation Code for Running on a Remote Machine ◁).

3.4.2.3 MpCCI Client

- Signature of the function `ampcci_config` has changed. Please update your code adapter (▷ VIII-2.7.6 Configure the Code Adapter: `ampcci_config` ◁).

3.4.2.4 MpCCI Batch

- The `-np` option of the `mpcci batch` supports the specification of number of cpus for the MpCCI morpher.

3.4.2.5 MpCCI Visualizer and MpCCI Monitor

- Improve the handling of range settings: the range can be set automatically or manually. The automatic range setting offers the option to build the minimum and the maximum of the range from all frames or from the current frame. Moreover, it is possible to build a common range over all views or to build ranges separately for each single view.
- New selection field in Settings Panel: a matching pattern can be defined to select parts from the Table of Parts.
- New option to group automatically the parts by mesh Id.
- Pause the animation during coupling: when new data is coming into the MpCCI Monitor, the automatic jump to the last frame can be suppressed by activating the Pause button.
- Iteration norms are plotted in logarithmic scale.

3.4.2.6 Code Specific Changes

Abaqus

- Support of Abaqus 2018.

- Enable Abaqus/Standard to run parallel using MPI parallel method.
  The run paralle using MPI option has been introduced to enable the distributed memory parallelization method. This menu has been merged with the Abaqus/Explicit settings.
- New Abaqus subcommand restartPoints to help the user construct a restart input deck by displaying the available restart points.
- Quantity WallHTCoeff is replaced by HeatRate.

ANSYS

- Support of ANSYS 18.2, 19.0.

FINE/Open

- Support of FINE/Open 6.2.

FINE/Turbo

- Support of FINE/Turbo 11.2, 12.1, 12.2.

FLUENT

- Support of FLUENT 18.2, 19.0.
- Additional checks before using the scheme function `(mpcci-solve)` to ensure that the case file is initialized.
- Support FLUENT in double precision mode only.

ANSYS Icepak

- Support of ANSYS Icepak 18.2, 19.0.
- Support ANSYS Icepak in double precision mode only.

JMAG

- Support of JMAG 17.0.

Adams

- Support of Adams 2018.

Marc

- Support of Marc 2017.1.

MSC NASTRAN

- Support of MSC NASTRAN 2018.0, 2018.1.
- Fix for iterative coupling definition:
  - In the NLSTEP section: the total time is correctly read out and keep the predefined output interval definition.
  - If the iterative solution converged and the total number of iterations for MSC NASTRAN is not reached, the converged force values are reused until the next time step begins.
- Additional option to select the MPI vendor to use.

OpenFOAM

- Support of OpenFOAM v1712.

- Corrections for the implicit transient coupling case:
  - Fix iterative coupling solution approach with OpenFOAM solver.
  - The time stepping is not allowed to adjust the time step to fit the writeControl option.
- Improve support of restart simulation with mesh morphing. The initial mesh is corrrectly setup for the MpCCI Grid Morpher.
- Support of OpenFOAM velocity motion solver.
- New OpenFOAM subcommand cleanTimeDir to mark time directories of a OpenFOAM case containing empty functionObjectProperties file with `"<time>_DELETE"`.

RadTherm, TAITherm

- Support of TAITherm 12.4.0, 12.4.2, 12.5.1.
- Fix the MPI bootstrap option for using rsh.
- Model with curve setting for the time step size will be kept unchanged for the co-simulation.
- Steady state simulation setup with a tolerance slope value and a coupling iteration start value will compute until the reach of the coupling iteration start without taking in account the tolerance slope setting. After the coupling begins the tolerance slope setting is re-activated.
- Transient simulation setup with a coupling start time t_s now includes the calculated solution for the time period t_s in the exchanged data.
- Changes related to the mpcci radtherm subcommand:
  - The importCFD command accepts the usage of a relative path to the csp file.
  - The importCFD command will not include parts with assigned temperature setting. If parts list contains only parts with boundary type assigned temperature the command will not be executed.
  - The clean command will additionally reset the convection property to none of parts with assigned temperature and activated HandTfluid property. This parts may have been selected for a co-simulation and have been modified for this purpose.
    This command removes the MpCCI hook function properly from the hook list having other user functions.

STAR-CCM+

- Support of STAR-CCM+ 12.04, 12.06.

3.5 MpCCI 4.5.1-1

3.5.1 New Features

3.5.1.1 MpCCI FSIMapper

- New additional variant for the Fourier Transformation: spectrogram analysis can be selected in order to have for each defined subwindow a Fourier transformation. You get as results a complex frequency dependent loads changing over time (▷ X-4.5.2 Apply Fourier Transformation ◁).
  The results are available for Abaqus, ANSYS, MSC NASTRAN codes.
- New support for model defined with mirror symmetric properties. You can select a symmetric model as source to be mapped on a full model. (▷ X-4.3 The “Transformation” Panel ◁)

3.5.2 Further Enhancements of Existing Features

3.5.2.1 MpCCI GUI

- New option to export the Region Rules to a file and share the settings. (▷ V-4.8.5 Automatic Generation of Regions by Rules ◁)
- New option to import the Region Rules from a file. (▷ V-4.8.5 Automatic Generation of Regions by Rules ◁)

3.5.2.2 MpCCI CouplingEnvironment

- Fix issue during error handling and message broadcasting.
- Improve the monitor plot for iterative coupling. The user can visualize the evolution of the value during the iterative process instead of having at the end of the process the updated plot of the completed iterative coupling step.
- Fix OpenSSH installer issue with PATH update.

3.5.2.3 MpCCI Batch

- Bug fixed in case of using the useAbsolutePath option when the MpCCI server will be started on a different file system.

3.5.2.4 Code Specific Changes

Abaqus

- Iterative coupling is not available with Abaqus/Explicit solver.
- Handle recovery restart co-simulation case: the user should provide a restart time in case of performing a recovery co-simulation in order to correctly resynchronize the Abaqus calculation.

ANSYS

- Support of ANSYS 18.1.

FLUENT

- Support of FLUENT 18.1.
- Optimization for the implicit coupling. The solver convergence check is taken into account in addition to the maximum number of iterations within each iterative loop. As soon as one of the criterion is satisfied the next iterative loop will be initiated.
- Fix shifting effect on boundary value with profile. The received values are now correctly considered in the next iteration.

ANSYS Icepak

- Support of ANSYS Icepak 18.1.

JMAG

- Support of JMAG 16.0, JMAG 16.1.

Adams

- Support of Adams 2017.1, Adams 2017.2.

Marc

- Support of Marc 2017.

MSC NASTRAN

- Support of MSC NASTRAN 2017.1.

OpenFOAM

- Support of OpenFOAM v1706.

RadTherm, TAITherm

- Support of TAITherm 12.3.
- Enable Distributed Memory Parallel option for the thermal solution up to RadTherm 11.3, TAITherm 12.0.
- Parallel processing options set from MpCCI GUI are transferred to RadTherm, TAITherm GUI now.
- Additional tdf file version check against the selected RadTherm, TAITherm thermal solver version.
- New command `mpcci radtherm -importCFD` to import CFD convection data from a TCD file in a coupled TDF file. The import CFD setting is based on the selected coupled parts defined in the MpCCI co-simulation project file (▷ VI-17.3 Code-Specific MpCCI Commands ◁).

STAR-CCM+

- Support of STAR-CCM+ 12.04.010.

3.6 MpCCI 4.5.0-1

3.6.1 MpCCI Licensing

- New licensing software: for MpCCI 4.5.0 you will need the FlexNet Publisher 11.14 licensing software.

3.6.2 MpCCI Platforms

- Windows and Linux 32 bit platform is no longer supported.
- Linux 64 bit with glibc 2.3 is no longer supported.

3.6.3 New Features

3.6.3.1 MpCCI License Manager

- MpCCI license version has been updated to FlexNet Publisher 11.14 licensing software. An update of the license server is required.
- MpCCI license start command enhanced by
  - listing the used license file for setting up the license server.
  - listing the current license features if the license server correctly starts up. Otherwise it points the user to the log file to check the issues.

3.6.3.2 MpCCI GUI

- Support for automatic region building (see ▷ V-4.8.5 Automatic Generation of Regions by Rules ◁).
- Region specific definition of neighborhood search properties (▷ V-4.8.6 Applying Region Properties ◁).
- Quantities are defined in own sets which may be assigned to several coupled regions. Among other things, this simplifies the assignment and modification of quantities and their settings (see ▷ IV-2.6.2 Define Quantities to be Exchanged ◁).
- Facility to use operators for transferred quantities which allow to set e. g. limiters, convergence checkers, relaxation methods or scaling functions (▷ V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).
- An overview tab is added which summarizes the setup of the coupled regions. It displays code specific information like the number of coupled and uncoupled components and gives an overview of the built regions and their assigned quantity sets (see ▷ V-4.8.9 Overview of the Coupled Regions ◁).
- Feature to cross-check the application configuration to ensure that formal conditions are fulfilled ahead of starting the coupled simulation (▷ IV-2.8.3 Checking the Application Configuration ◁).
- New preferences file with settings to be used in multiple MpCCI GUI sessions - e. g. rules which are defined for automatic region generation (see ▷ V-4.2 MpCCI GUI Properties ◁).

3.6.3.3 MpCCI CouplingEnvironment

- A new relaxation approach by Quasi-Newton (▷ V-3.3.3.4 Quasi-Newton Method ◁) is available. For example, the Quasi-Newton approach is recommended for fluid-structure interactions application with incompressible gas, models with a density aspect ratio of the materials close to 1. This method treats changes of residuals on the coupled interface starting with a predictor step and further iterations. The aim is to drive the residuals to zero to quickly reach the dynamic and kinematic conservation on the interface. The information from one time-step might be used in following time-steps.
  This can be applied to steady and iterative transient couplings.
- Implementation of quaternion interpolation for angular coordinates.
- Global quantities are synchronized leading to properly coupling of time step size.
- Improved log information: `quit` is logged in the log file.
- New operators: scale, limiter, etc. (see ▷ V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).
- Allow definition of neighborhood multiplicity and normal distance parameters locally per region (▷ V-4.8.6 Applying Region Properties ◁).
- Allow definition of the relaxation method for a quantity locally per region.

3.6.3.4 MpCCI Client

- Subcycling definition with a table function (see ▷ V-4.7.2 Code Specific Algorithm Settings ◁).
- Client library support for Visual Studio 2013, 2015.

3.6.3.5 MpCCI FSIMapper

- Enhanced processing of transient data which is to be transferred to the frequency domain by Fourier transformation, e.g. windowing, time range filtering and result frequency truncation. ▷ X-7.2.1 Fourier Transformation and Windowing ◁

- Introduction of "Harmonic Wizard" tab to map a set of harmonic turbomachinery CFD results at once to a CSM model. ▷X-4.7 The "Harmonic Wizard" Panel◁
- Support for transient nodal force results of JMAG via MSC NASTRAN bulk data format (keywords `TLOAD1`, `DAREA`, `TABLED1`). ▷X-5.13.1 Reading◁
- LS-Dyna added as target structural code format in transient force excitation mapping applications where a Fourier transformation is applied. ▷X-5.11 LS-Dyna ◁

3.6.3.6 Further Enhancements of Existing Features

3.6.3.7 MpCCI GUI

- Navigation buttons now are labelled according to the name of the step they lead to. An additional label also indicates the actual step.
- For more clarity some parameters in the Models and Go Step are arranged in groups which can be collapsed or expanded.
- The Coupling Step has been reworked for a more intuitive setup of the coupled regions (see ▷IV-2.6 Regions Step – Defining Coupling Regions and Quantities◁).
- Regions can be renamed automatically by the name of their added components which leads to an easier distinction between them.
- The state of the coupling regions now is displayed by more different icons. They differentiate between 1:1 and n:m coupled components or between uni- and bidirectional transferred quantities depending on the environment where the regions are listed.
- The settings for orphans are collected in one central area (▷V-4.8.7.3 Orphans Settings for Mesh Based Components◁).

3.6.3.8 MpCCI CouplingEnvironment

- Enhancement for coupling with parallel codes using remeshing and periodic models. Time step and data are better synchronized.
- Fixed handling of models with moving mesh motion with remeshing event. Mesh velocity is not anymore affected by the remeshing event. This enables the fluid model to run massively in parallel for large models. The enhancement focuses on fluid-structure interaction with rotating parts.
  The usual approach to perform such a simulation is to model each part of the solid and the fluid in the same reference frame (also known as lab frame). But when the application takes into account the deformation due to the rotation, it may lead to significant convergence and stability problems. Due to the large rotation and pressure deformation, the solid part introduces large displacement nonlinear geometric effects into the structural stiffness matrix. In order to overcome such stability problem issue, you can mix different reference frame models without affecting the physics of the problem (▷V-3.3.5.2 Mesh Motion Application◁). The improved methodology for such application would be to model the fluid in the lab frame and to model the solid part in a local rotating frame of reference. Using this approach for the solid problem will remove the nonlinear, large displacement effects in the stiffness matrix conducting to a stable and faster computation.

3.6.3.9 MpCCI Client

- Fixed coupling of global quantities. A code which received only a global quantity and sent a mesh-based quantity never got the global quantity value but only the default value.

- Fixed iterative coupling: Gauss-Seidel communication scheme was not repeated for each time step.
- Fix for parallel code coupling having load balancing: avoid blocking issues during synchronisation of parallel processes.

3.6.3.10 MpCCI FSIMapper

- Improved scheme for transient mapping applications where neighborhood now is only computed once.

3.6.3.11 MpCCI Grid Morpher

- Fix for supporting models without fixed boundary conditions.

3.6.3.12 MpCCI Batch

- Improved log output about the job management: process management events are displayed.
- New batch command options (▷ V-3.7.1.1 Run a Job in Batch Mode with MpCCI Command Line ◁):

  -np Specify the number of cores for each code without editing the `".csp"` file with MpCCI GUI.

  -useAbsolutePath Define the current MpCCI installation path as reference installation on the remote machine. The user is not constrained to have a configured user `".profile"` or `".baschrc"` file with the current MpCCI installation. This is mostly set up by a dedicated environment module file under a batch system.
- Define the environment to set before the code runs on a remote machine. The environment defined in a file is automatically exported on each remote connection (▷ V-3.7.1.2 Configure a Simulation Code for Running on a Remote Machine ◁).
- Fixed host list definition for distributed memory code: the master node should be set as master process with rank 0 in the definition.

3.6.3.13 MpCCI Visualizer and MpCCI Monitor

- Fix for plot of steady state calculations. Plot results were shifted with one iteration.
- Enhanced zoom function for the plot. During the monitoring, the zoom of the plot is not reset automatically on new incoming data.
- The plot range can be set constant during the monitoring. The defined range will be kept during the update of the plot in order to monitor the value evolution in this selected range.
- The range values can be displayed with the current minimum and maximum values of the current step.

3.6.3.14 MpCCI Tutorial

- New tutorial for iterative coupling with Quasi-Newton (see ▷ VII-4 Driven Cavity ◁).
- Added Abaqus input deck model for the iterative coupling tutorial Elastic Flap in Water

3.6.3.15 Code Specific Changes

Abaqus

- Support of Abaqus 2016, 2017.
- Fixed iterative coupling to respect the maximum number of coupled iterations.
- Improved support for coupling with MBS code.

ANSYS

- Support of ANSYS 17.0, 17.1, 17.2, 18.0.

FINE/Hexa

- Not supported anymore. Please update to FINE/Open and contact your local NUMECA International office.

FINE/Open

- Support of FINE/Open 4.2, 4.3, 5.1, 5.2, 6.1.

FINE/Turbo

- Support of FINE/Turbo 10.2, 11.1.

FLUX

- Support for FLUX software (FLUX 10.2, 10.3) only on demand. It is not anymore part of the distribution.

FLUENT

- Support of FLUENT 17.0, 17.1, 17.2, 18.0.
- Fixed issue with coupling of multiple FLUENT wall boundaries with Dynamic Mesh option.
- Fixed iterative coupling mesh update for thin wall models.
- Automatic loading of compiler environment settings using FLUENT under Microsoft Windows as it is done by the FLUENT launcher.
- Automatic setting of thermal boundary condition type. The thermal conditions heatflux and temperature will be automatically adjusted.

ANSYS Icepak

- Support of ANSYS Icepak 17.0, 17.1, 17.2, 18.0.

JMAG

- Support ofJMAG 15.0, 15.1.

Adams

- Support of Adams 2015.1, 2016, 2017.
- Support Adams Car application.
- Support static to dynamic simulation.

FMI

- New adapter for the Fraunhofer EAS Master, a simulation platform for FMI coupling (prototype on demand).

Marc

- Support of Marc 2015, 2016.

MSC NASTRAN

- Support of MSC NASTRAN 2016.0, 2016.1, 2017.0.
- Code selection name change from MD NASTRAN to MSC NASTRAN.

OpenFOAM

- Support OpenFOAM 3.0.1, v1606+, v1612+.
- Fixed heat flux calculation.

RadTherm, TAITherm

- Support of TAITherm 12.1, 12.2.
- Option to define the initialization of the calculation by using:
  - Part initial temperature definition.
  - Seed a steady state solution with a loaded tdf file.
  - Transient initialization with a tdf file.
  - Transient restart with a tdf file.
- Automatic calculation of view factors file if the file is not available before the simulation starts.
- Dynamic subcycling option implemented: User can define the convergence criterion to use for the steady state calculation with subcycling. The subcycling iteration may be stopped by a constant maximum number of iterations or by the defined tolerance slope value of the TAITherm solver.
- Configure solver runtime from the MpCCI GUI: e. g. solver time step size, solver duration, total number of iterations for the simulation, etc. .
- Option to write intermediate results during the TAITherm simulation.
- Option to modify the solution frequency output.

STAR-CCM+

- Support of STAR-CCM+ 10.06, 11.02, 11.04, 11.06.
- Java template macro supports subcycling with table definition.

3.7 MpCCI 4.4.2-1

3.7.1 Further Enhancements of Existing Features

3.7.1.1 Coupling Environment

- Fixed issue for a co-simulation between a transient and steady state simulation where both codes are doing a remeshing. Data and simulation code are properly synchronized.
- MpCCI Visualizer provides a new option to open a ccvx file. You can activate the automatic loading of files series having the same stem or the opening of a single file which is the default now.

- Fix issue with cut plane definition with MpCCI Visualizer. The cut plane edit line supports the two type of decimal mark dot and comma.

3.7.1.2 MpCCI FSIMapper

- MpCCI FSIMapper offers the possibility to transform cyclic symmetric source models to the corresponding full model (mesh and quantity). This allows to map data from a periodic section to a full target mesh or to a periodic section with different shape or position, cf. Figure 8 (part X).
- MpCCI FSIMapper supports the mapping of harmonic CFD simulation results, as they are calculated by the "Nonlinear Harmonic method" by FINE/Turbo or the "Harmonic Balance method" by STAR-CCM+. MpCCI FSIMapper maps the pressure excitation (represented as complex pressure field) to the structural mesh where a vibrational analysis is performed.
- For the combination of a cyclic symmetric source mesh and harmonic simulation results (as it is the case for e. g. harmonic turbine simulations) MpCCI FSIMapper supports to define the nodal diameter/cyclic symmetry mode of the excitation, see ▷ X-4.3 The "Transformation" Panel ◁.
- The EnSight Gold format is supported also for transient and harmonic source models.
- Since meshes saved in the EnSight Gold format are always 3D, MpCCI FSIMapper offers for 2D source meshes the virtual format EnSight Gold (2D).
- Besides Abaqus and MSC NASTRAN, MpCCI FSIMapper now also supports the target code ANSYS for harmonic (frequency response) analyses.
- MpCCI FSIMapper tutorials, cf. ▷ X-8 Tutorial ◁:
  - Two tutorials concerning the mapping of harmonic pressure excitations in turbines. The harmonic CFD methods in FINE/Turbo and in STAR-CCM+ are used.
  - One tutorial concerning the mapping of electromagnetic forces in motors for vibrational analyses. The source simulation code is MagNet.

3.7.1.3 Code Specific Changes

Abaqus

- Support of Abaqus 2016 pre-release.

ANSYS

- Support of ANSYS 16.1.0, ANSYS 16.2.0.
- Enhancement for ANSYS mesh smoothing event: only nodes are redefined for the co-simulation.
- Support ANSYS parallel mode with distributed domain solver. The feature is supported for the co-simulation without the exchange of the quantity Nodal Position.
- Option to activate the GPU solver for ANSYS.

FINE/Turbo

- Support of FINE/Turbo 10.1.
- Thermal coupling issue is resolved in FINE/Turbo 10.1.

FLUENT

- Support of FLUENT 16.1.0, FLUENT 16.2.0

ANSYS Icepak

- Support of ANSYS Icepak 16.1.0,ANSYS Icepak 16.2.0

JMAG

- Support ofJMAG 14.1.

Adams

- Support of Adams 2015.
- Support co-simulation Adams/Chassis product template.
- Co-simulation enhancement to support multiple statements for Adams/Car.
- Support the link of additional user subroutines for user element for the co-simulation.

Marc

- Support of Marc 2014.2.

MSC NASTRAN

- Support of MSC NASTRAN 2014.1.

OpenFOAM

- Support of OpenFOAM 2.4.0.
- MpCCI Grid Morpher supports now the definition of a zone for a partial domain morphing.

RadTherm

- Support of RadTherm 12.0.0, RadTherm 12.0.3.

SIMPACK

- Support of SIMPACK 9.8.1.

STAR-CCM+

- Support of STAR-CCM+ 10.04.009.

3.8 MpCCI 4.4.1-1

3.8.1 Further Enhancements of Existing Features

3.8.1.1 Coupling Environment

- Fix missing file for the MpCCI installation on Microsoft Windows.
- Fix number of cores allocation by the MpCCI batch management system when submitting a job with a deactivated MpCCI Grid Morpher. This issue only concerns the simulation codes OpenFOAM and STAR-CD.
- Definition of global variable as monitor set is correctly supported by the MpCCI server. This variable will be defined as X-Y plot.
- The MpCCI GUI displays the option of setting a convergence tolerance for steady state coupling simulation. For the codes which support the convergence check during the iterative process this feature of terminating the coupling process can be used.

- Optional user defined timeout value can be defined for the socket connection between the client simulation code with the MpCCI server, cf. ▷ V-3.6.1 Client-Server Structure of MpCCI ◁. In case of connecting an additional tool like the MpCCI Grid Morpher, the MpCCI Grid Morpher can take some time to start up and perform all checks before accepting the connection with the simulation code using it.
- Fixed bug in mapping error correction procedure for nodal based flux density / integral quantities, e.g. forces.

3.8.1.2 MpCCI FSIMapper

- New option to select parts by using a string matching definition, cf. ▷ X-4.2.1 Parts Selection ◁.
- Improve the support of large EnSight Gold Case file data under Microsoft Windows 64 Bit.
- EnSight Gold Case file support for mapping of transient pressure fields for vibration analysis.
- Extension of the MSC NASTRAN keyword support: the surfaces defined with the following keywords are supported: WETSURF and WETELMG. 2D surface definition is also supported.
- Fix mapping of quantities Temperature and HTC for FLUENT.cas file. This has caused the MpCCI FSIMapper to crash.

3.8.1.3 Code Specific Changes

Abaqus

- Support of Abaqus 6.14-2
- Several fixes and improvements for Abaqus 6.14 have been made:
  - Start issue under Microsoft Windows has been fixed. The start sequence is smoother now and does not hang.
  - Support for pressure quantities has been reintroduced.
  - Coupling with quantity WallHeatFlux is now correctly imported in Abaqus.

ANSYS

- Support of ANSYS 16.0.0.

FINE/Turbo

- Support of FINE/Turbo 9.1.2, FINE/Turbo 9.1.3.
- Add a known bugs list concerning thermal coupling (▷ VI-7.5 Trouble Shooting, Open Issues and Known Bugs ◁).

FLUENT

- Support of FLUENT 16.0.0.

ANSYS Icepak

- Support of ANSYS Icepak 16.0.0.

JMAG

- Support ofJMAG 13.1 and JMAG 14.0.

Adams

- Support of Adams 2014.0.1.
- Fix update of the partial derivatives module in MpCCI adapter when several points are used for the co-simulation.

Marc

- Support of Marc 2014.1.

OpenFOAM

- Improve environment setting to run OpenFOAM simulation. The library environment setting by MpCCI is now similar to the OpenFOAM environment source file.
- Additional support of third party intel MPI vendor, cf. ▷ VI-14.2.6.2 External 3rd party MPI ◁.
- Improve data communication performance with OpenFOAM: the MpCCI Grid Morpher is not called during the subcycling step.
- Support for coupling a decomposed OpenFOAM case project. The list of boundaries is correctly parsed.

RadTherm

- During the coupling process the tolerance slope convergence check is disabled as long as the coupling process does not converge.

SIMPACK

- Fix handling of force element when a duplicated force element has been created in MpCCI GUI. The coupled force and torque quantities were not properly applied to the force element.
- Fix connection issue with MpCCI server for all SIMPACK versions greater than 9.6.

STAR-CCM+

- Support of STAR-CCM+ 9.04.011, STAR-CCM+ 9.06.011 and STAR-CCM+ 10.02.010.

3.9 MpCCI 4.4.0-1

3.9.1 New Features

3.9.1.1 MpCCI FSIMapper

- MpCCI FSIMapper is available as standalone installation and can be started with fsimapper (cf. ▷ X-1 MpCCI FSIMapper Overview ◁).
- Mapping of MagNet results for stationary and transient simulations is supported (cf. ▷ X-5.12 MagNet ◁).
- Extension for Vibration Simulations:
  - a Fourier Transformation can be applied to transient results for usage in frequency response analyses in Abaqus and MSC NASTRAN.
  - Enhanced visualization of complex excitation forces as a function of time (cf. ▷ X-4.5.2 Apply Fourier Transformation ◁).
- Support for FINE/Turbo cgns files.
- Enhancement for Abaqus element types: support of 2d elements.

3.9.1.2 Coupling Environment

- Enhanced support of cyclic symmetric periodic models:
  - Coupling of full and periodic models.
  - Coupling of periodic models with different section definitions, cf. ▷ V-3.3.6 Quantity Transformation for Cyclic Symmetric Meshes ◁.
  - MpCCI GUI supports definition of periodicity, cf. ▷ V-4.8.2.3 Periodic Components ◁.
  - Periodic model can be shown as full model in MpCCI Visualizer and written as .ccvx, cf. ▷ V-4.10 Settings Step ◁.
  - A new tutorial ▷ VII-7 Periodic Rotating Fan Model ◁ – demonstrating the new periodic functionalities – is available.
- Adaptive under-relaxation is available in the MpCCI GUI.
  - Calculation of optimal factor is based on the Aitken's method, cf. ▷ V-3.3.3 Quantity Relaxation ◁.
  - Available for steady state or iteratively transient coupled simulations.
  - The used relaxation factor can be plotted in the MpCCI Monitor, cf. ▷ V-4.10 Settings Step ◁.
- Information about orphaned regions is displayed in the MpCCI Monitor as soon as the neighborhood computation has been performed.
- New managing of tracefiles:
  - MpCCI creates a new tracefile directory for each job based on job name and a time stamp.
  - Option to delete old tracefiles automatically, cf. ▷ V-4.11.1 Configuring the MpCCI Coupling Server ◁.

3.9.2 Further Enhancements of Existing Features

3.9.2.1 Coupling Environment

- Fix for rotating models created not in the SI unit system.
- Java is now part of the MpCCI installation.
- Improved mapping for fluid-structure interactions with large displacement: the deformed geometry is used for integral calculations depending on the quantity type.
- New option for applications with rotating models using different motion types (e. g. rotating and stationary reference frame): not computing new neighborhoods after the initialization permits usage of bigger time steps, cf. ▷ V-4.10.2 Job ◁.
- Improvement for simulations using remeshing: after remeshing the complete mesh information (characteristic length, bounding box,...) is updated.
- Fix for writing orphan, slaves and domain information for some tracefiles, e. g. vtk or EnSight Gold.
- In case of a fatal error the current mesh and quantity information is saved to tracefile. Useful for checking the setup.
- Correct update of the coupling information before the code starts.
- MpCCI GUI: minor fixes for managing batch mode and saving project files in all steps.
- Microsoft Windows 32 bit platform is no longer supported.
- Support of Linux 32 bit platform will end with this release.

3.9.2.2 Code Specific Changes

3.9.2.3 Abaqus

- Support of Abaqus 6.14:
  - MpCCI coupling solution for Abaqus 6.14 is based on SIMULIA's Co-Simulation Services (CSE).
  - Iterative coupling is available starting with Abaqus 6.14.
  - For thermal coupling with Abaqus 6.14 a new quantity configuration should be used: Abaqus receives the quantities concentrated heat flux and ambient temperature. This pair of quantity definition corresponds to HeatRate and FilmTemp MpCCI quantities.
  - For fluid-structure coupling Abaqus 6.14 supports only force quantities (WallForce and RelWallForce).
  - Limitations: Axisymnetric co-simulation surface is not supported by Abaqus 6.14 SIMULIA Co-Simulation Services.
- For Abaqus versions 6.12 and 6.13 the coupling solution is still based on the direct coupling interface. This will remain available for a certain transition period. For the future, Abaqus users are encouraged to migrate to Abaqus 6.14. For the transition period Abaqus users should contact their local support to update or extend their cosimulation license token.
- Point coupling with Abaqus/Explicit 6.12 and 6.13 can be realized with Abaqus user subroutines VUAMP combined with definition of sensors in the input deck.
  Contact the MpCCI support for detailed information about the procedure.

3.9.2.4 ANSYS

- ANSYS 14.5 model files are now recognized by the Scanner.
- Fix for the MpCCI ANSYS remesh command ~mpcci, remesh user request is taken into account and morphed mesh is properly updated in the MpCCI server.

3.9.2.5 FINE/Open

- FINE/Open 3.x is not supported by MpCCI.
- Support of FINE/Open 4.1.

3.9.2.6 Flowmaster

- Additional check if the quantity mass flow rate is positive.
- Proper handling of subcycling for steady state simulations.

3.9.2.7 FLUENT

- Support of FLUENT 15.0.7.
- Coupling a rigid body model with 1D codes is supported.
- Mesh update for steady state FSI simulation is performed automatically by using the MpCCI Run FSI panel from FLUENT or via the TUI command `(mpcci-solve steps)`, cf. ▷ VI-9.2.6.2 The MpCCI Run FSI ◁.
- Improvements for the FLUENT co-simulation control in batch.

- Fix issue with time step size value for FLUENT single precision simulations.
- Fix for sending the calculated time step size to MpCCI in case of adaptive time stepping.
- FLUENT can access additional RP variables to check the MpCCI status.

3.9.2.8 JMAG

- Support scanning of JMAG model file with white spaces.

3.9.2.9 Adams

- Support of Adams 2014.

3.9.2.10 Marc

- Support of Marc 2014.

3.9.2.11 MD NASTRAN

- Support of MD NASTRAN 2014.

3.9.2.12 OpenFOAM

- Support of OpenFOAM 2.2, OpenFOAM 2.3.
- Additional support of third party MPI vendor, e. g. sgi with improvements for starting the application with the proper co-simulation environment, cf. ▷ VI-14.2.6.2 External 3rd party MPI ◁.

3.9.2.13 RadTherm

- Support of RadTherm 11.2, RadTherm 11.3.
- RadTherm scanner now recognizes volume parts.
- Additional checks during the preparation of the tdf file. The type of the H and Tfluid boundary is checked for type “value”.
- Proper handling of user defined part id in RadTherm model.
- Support coupling of a part with imposed wall temperature.

3.9.2.14 SIMPACK

- Support of SIMPACK 9.6, 9.7.

3.9.2.15 STAR-CCM+

- Support of STAR-CCM+ 9.04.009.
- Fix support of models with multiple region definitions.

3.9.2.16 STAR-CD

- Support of STAR-CD 4.18, STAR-CD 4.20, STAR-CD 4.22.

4 Prerequisites for MpCCI Installation

Please see ▷ 5 Supported Platforms in MpCCI 4.7 ◁ for platform-specific prerequisites.

Required Disc Space

A full MpCCI installation (all platforms and all code adapters, plus a multi-platform Java JRE and the MpCCI-RSH and the OpenSSH for Microsoft Windows) requires a free disc space of approx. 1.0 GB.

Third Party Software

Perl

Java

MpCCI-RSH for Windows is provided by MpCCI. This allows access to all Microsoft Windows operating systems (See ▷ III-2.6 MpCCI-RSH for Windows ◁).

5 Supported Platforms in MpCCI 4.7

Platform lists for supported simulation codes are given in the Codes Manual.

5.1 Platforms Supported by the MpCCI 4.7 Server

Platform	Bits	MpCCI arch.	Support
Linux with glibc 2.3 on AMD64 or EM64T processor	32/64	`lnx3_x64`	*not supported*
Linux with glibc 2.4 on AMD64 or EM64T processor	32/64	`lnx4_x64`	OK
Microsoft Windows 32 bit on AMD/Intel	32	`windows_x86`	*not supported*
Microsoft Windows 64 bit on AMD/Intel	32/64	`windows_x64`	OK

The above list is valid for MpCCI alone, i. e. the MpCCI executables. This does not automatically include all code adapters. Some simulation codes can only be coupled on a subset of the above platforms. A list of platforms for the supported codes is given in the following section and for each code in the corresponding chapter of the Codes Manual.

5.2 Codes Supported by MpCCI 4.7 on Different Platforms

Codes can only be supported on platforms they support themselves.

Linux with glibc 2.4 on AMD64 or EM64T processor (`lnx4_x64`)

ANSYS	160, 161, 162, 170, 171, 172, 180, 181, 182, 190, 191, 192, 193, 194, 195, 201, 202, 211, 212, 221, 222, 231
Abaqus	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
Adams	2016, 2017, 2017.1, 2017.2, 2018, 2018.1, 2019, 2019.2, 2020, 2021, 2021.1, 2021.2, 2021.3, 2022.1, 2022.2, 2022.3, 2022.4, 2023.1, 2023.2
FINE/Open	101
FINE/Turbo	111, 112, 121, 122, 131, 132, 141, 142, 151
FLUENT	16.0.0, 16.1.0, 16.2.0, 17.0.0, 17.1.0, 17.2.0, 18.0.0, 18.1.0, 18.2.0, 19.0.0, 19.1.0, 19.2.0, 19.3.0, 19.4.0, 19.5.0, 20.1.0, 20.2.0, 21.1.0, 21.2.0, 22.1.0, 22.2.0, 23.1.0
ANSYS Icepak	16.0.0, 16.1.0, 16.2.0, 17.0.0, 17.1.0, 17.2.0, 18.0.0, 18.1.0, 18.2.0, 19.0.0, 19.1.0, 19.2.0, 19.3.0, 19.4.0, 19.5.0, 20.1.0, 20.2.0, 21.1.0, 21.2.0, 22.1.0, 22.2.0, 23.1.0
JMAG	15.0, 15.1, 16.0, 16.1, 17.0, 17.1, 18.0, 18.1, 19.0, 20.0, 20.1, 21.0, 22.0, 22.1
MATLAB	R2018a, R2019a, R2021a
Marc	2016, 2017, 2017.1, 2018, 2018.1, 2019, 2020, 2021.2, 2021.4, 2022.1, 2022.2, 2022.3, 2022.4, 2023.1, 2023.2
MSC NASTRAN	2018.0, 2018.1, 2018.2, 2019.0, 2020.0, 2021.0, 2021.1, 2021.2, 2021.3, 2021.4, 2022.1, 2022.2, 2022.3, 2022.4, 2023.1, 2023.2
OpenFOAM	v1606+, v1612+, v1706, v1712, v1806, v1812, v1906, v1912, v2006, v2012, v2106, v2112, v2206, v2212, v2306
SIMPACK	9.7, 9.8.1
STAR-CCM+	2019.1, 2019.2, 2019.3, 2020.1, 2020.2, 2020.3, 2021.2, 2022.1, 2206, 2210.0001, 2302, 2306
TAITherm	12.5.1, 12.5.2, 12.6.0, 12.7.0, 13.0.0, 13.1.0, 2020.1.0, 2020.2.0, 2021.1.2, 2021.2.1, 2021.2.5, 2022.1.0, 2022.2.0

Microsoft Windows 64 bit on AMD/Intel (`windows_x64`)

ANSYS	160, 161, 162, 170, 171, 172, 180, 181, 182, 190, 191, 192, 193, 194, 195, 201, 202, 211, 212, 221, 222, 231
Abaqus	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
Adams	2016, 2017, 2017.1, 2017.2, 2018, 2018.1, 2019, 2019.2, 2020, 2021, 2021.1, 2021.2, 2021.3, 2022.1, 2022.2, 2022.3, 2022.4, 2023.1, 2023.2
FINE/Open	101
FINE/Turbo	111, 112, 121, 122, 131, 132, 141, 142, 151
FLUENT	16.0.0, 16.1.0, 16.2.0, 17.0.0, 17.1.0, 17.2.0, 18.0.0, 18.1.0, 18.2.0, 19.0.0, 19.1.0, 19.2.0, 19.3.0, 19.4.0, 19.5.0, 20.1.0, 20.2.0, 21.1.0, 21.2.0, 22.1.0, 22.2.0, 23.1.0
FloMASTER	7.6, 7.7, 7.8, 8.0, 8.1, 8.2, 9.0, 9.2
ANSYS Icepak	16.0.0, 16.1.0, 16.2.0, 17.0.0, 17.1.0, 17.2.0, 18.0.0, 18.1.0, 18.2.0, 19.0.0, 19.1.0, 19.2.0, 19.3.0, 19.4.0, 19.5.0, 20.1.0, 20.2.0, 21.1.0, 21.2.0, 22.1.0, 22.2.0, 23.1.0
JMAG	15.0, 15.1, 16.0, 16.1, 17.0, 17.1, 18.0, 18.1, 19.0, 20.0, 20.1, 21.0, 22.0, 22.1
MATLAB	R2018a, R2019b, R2021a
Marc	2016, 2017, 2017.1, 2018, 2018.1, 2019, 2020, 2021.2, 2021.4, 2022.1, 2022.2, 2022.3, 2022.4, 2023.1, 2023.2
MSC NASTRAN	2017.0, 2017.1, 2018.0, 2018.1, 2018.2, 2019.0, 2020.0, 2021.0, 2021.1, 2021.2, 2021.3, 2021.4, 2022.1, 2022.2, 2022.3, 2022.4, 2023.1, 2023.2
SIMPACK	9.7, 9.8.1
STAR-CCM+	2019.1, 2019.2, 2019.3, 2020.1, 2020.2, 2020.3, 2021.2, 2022.1, 2206, 2210.0001, 2302, 2306
TAITherm	12.5.1, 12.5.2, 12.6.0, 12.7.0, 13.0.0, 13.1.0, 2020.1.0, 2020.2.0, 2021.1.2, 2021.2.1, 2021.2.5, 2022.1.0, 2022.2.0

6 Third Party License Information

6.1 OpenJDK Java

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6.2 LAPACK

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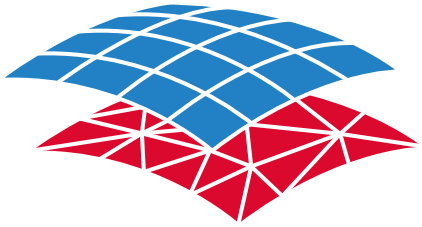

MpCCI
CouplingEnvironment

Part III

—

Installation Guide

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part III Installation Guide
PDF version
October 29, 2023

www.mpcci.de

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III Installation Guide – Contents

1 Installation Overview

Please check the Release Notes for installation prerequisites and supported platforms first.

MpCCI installation does not require much, there are just a few steps you need to do. There are following ways to install MpCCI:

- via *Linux installation*
- via *Windows installer*
- via *Multi-platform installation* which is recommended for installations on a file server or for MpCCI distributors.

Download Account

Before the installation you should contact the MpCCI team at `mpcci@scapos.de` to obtain an account and a password for the software download.

Linux Installation

1. **Download zip archive:**
   - Visit the MpCCI website of Fraunhofer SCAI at www.mpcci.de and navigate to the download area or
   - use directly download.scai.fraunhofer.de

   and download a compressed archive `"mpcci-*-lnx4_x64.zip"` containing the MpCCI software.
2. **Extract MpCCI software:**
   Create a directory and unzip the downloaded file within this directory. The directory contains at least following files:
   - the installer script `"mpcci_install.pl"`
   - the MpCCI end user license agreement `"MpCCI_License_Agreement.txt"`
   - the MpCCI core package `"mpcci-core.zip"`
   - the MpCCI free tools package `"mpcci-free.zip"`

   Execute the installer script `"mpcci_install.pl"` and follow the instructions. The user is requested to provide the path for the MpCCI installation. This one will be extended by the installer with the MpCCI release number. This new sub directory is the MpCCI root directory which is referred to as *<MpCCI_home>*.
3. **Add MpCCI to your `PATH`:**
   Append the MpCCI binaries directory `"<MpCCI_home>/bin"` to your `PATH` environment variable such that the command `mpcci` is available.

A detailed description of this procedure is given in ▷ 3.1 Multi-Platform for Linux and Windows ◁.

Windows Installer

1. **Download Windows installer:**
   - Visit the MpCCI website of Fraunhofer SCAI at www.mpcci.de and navigate to the download area, or
   - use directly download.scai.fraunhofer.de

   and download the Windows installer for MpCCI software.
2. **Run the installer:**
   Start the installer, which also offers to install third-party software needed by MpCCI. The installer also sets up your environment.

See also ▷ 3.2 Local Windows Installation with the MSI ◁.

Multi-Platform Installation

The MpCCI **Multi-Platform Installation** is constructed as the Linux installation. The only difference is the compressed archive `"mpcci-*-allOS.zip"` containing the MpCCI software for all platforms (Linux and Windows).

For the installation, please follow the detailed description of this procedure in ▷ 3.1 Multi-Platform for Linux and Windows ◁.

Licensing

MpCCI uses a FlexNet Publisher license server. The setup is described in ▷ 5 Licensing ◁.

2 Before the Installation

2.1 Downloading MpCCI

For the MpCCI download you need a download account!

MpCCI is only available via internet download:

- Go to the MpCCI homepage www.mpcci.de and navigate to the download area or go directly to download.scai.fraunhofer.de.
- Enter e-mail address (used as username) and password and press Sign In.
- Select MpCCI CouplingEnvironment from the MpCCI menu.
- Expand the MpCCI version you want to download in the list appearing.
- There are three download variants:
  - The Linux download for Linux systems.
  - The Windows Installer download for local installations on Windows systems.
  - The Multi-Platform Download containing all platforms. It is recommended for installation on a file server and for distributors. The installation should be done on a Linux system.

  Choose the appropriate variant and proceed.

Linux Download

- Download the zipped download file "mpcci-<*MpCCI-version*>-lnx4_x64.zip".
- Proceed with the installation as described in ▷ 3.1 Multi-Platform for Linux and Windows ◁.

Windows Installer Download

- Please download the installer "mpcci-<*MpCCI-version*>-windows_x64.exe".
- Proceed with the installation as described in ▷ 3.2 Local Windows Installation with the MSI ◁.

Multi-Platform Download

- Download the zipped download file "mpcci-<*MpCCI-version*>-allOS.zip".
- Proceed with the installation as described in ▷ 3.1 Multi-Platform for Linux and Windows ◁.

2.2 Where to Install

MpCCI is not just a multi-code software but also a multi-platform software. That means all kinds of Linux and Windows platforms can live together within a single directory on any machine, no matter whether it is a Linux or Windows system. The command `mpcci` runs on any platform.

We should mention that Windows is used as a synonym for various Microsoft Windows systems: like Windows 7.

MpCCI uses architecture tokens to identify a platform. The architecture tokens are hereinafter referred to as <*MpCCI_arch*>. The architecture tokens are directory names and used to locate the binary executables.

A list of architecture tokens and currently supported platforms is given in ▷ II-5 Supported Platforms in MpCCI 4.7 ◁.

You may rename the MpCCI home directory or move the MpCCI home directory to a different location or even a different file server later on, since MpCCI never works with absolute pathnames nor is any file patched during the installation. Under Windows MpCCI never depends on any registry key.

As long as you keep your PATH environment variable up-to-date MpCCI will work by just typing mpcci.

System dependent information is collected at runtime and the required system dependent settings are done automatically. There is no need to configure your MpCCI installation for a specific platform or for your local machine. Whatever operating system you are using, MpCCI behaves identical or at least similar.

The major difference between the Linux world and Microsoft Windows is that under Windows the X11 window system is not available per default and you cannot redirect the graphical display output from your local machine to a remote Linux or Windows computer.

If you want to use the remote execution facilities of MpCCI, please ensure that the X11 forwarding mechanism works. The server must allow connections from remote computers and no firewall may block the port 6000.

If you have a computer network and an NFS file server or Samba is available in your local area network, there is definitely no need to have a separate installation on each local desktop computer, whether it is a Linux or Windows system. Nevertheless, if you like you may install MpCCI locally on your desktop computer or copy the MpCCI home directory from the file server onto your local machine.

Windows Only Version and the Microsoft Windows Installer

For standalone Windows systems without access to file servers we offer a separate MSI (Microsoft-Installer) version of MpCCI.

The Microsoft Windows MSI versions of MpCCI are identical with the Windows parts of the multi-platform version. The difference is the installation procedure itself, not the software.

During the MSI installation some Windows registry entries are created which allows uninstalling MpCCI later on using the Windows uninstaller. Furthermore MpCCI is added to the Windows Start-Commands list.

Although you used the MSI version you may move or rename the MpCCI home directory as with the multi-platform installation. MpCCI will still work as before. However your Windows uninstall information is then corrupted since all your links or your desktop icons are lost and the uninstaller will not be able to remove your MpCCI installation.

In fact you do not need to have the MSI version if MpCCI can be installed on a file server. There is no advantage compared to the multi-platform installation. You may simply remove MpCCI from your Windows system by deleting the MpCCI home directory.

Recommendations

Each computer in a network used to run MpCCI jobs needs to have access to an MpCCI installation.

We recommend to have a multi-platform file server installation if you can run the installation on a Linux system, and the MpCCI home directory on the file server is then mounted to your local computer.

Otherwise, in case of a compute cluster with local discs only you would need to copy the MpCCI home directory on each computer separately.

If your HOME directory is shared among the computers in a network you may also have your private MpCCI installation, e. g. under HOME/bin. In this case your HOME directory acts as a file server. This is the preferred method in case you are in trouble with your IT.

Avoid a local installation if possible. A file server installation is the preferred way using MpCCI in a heterogeneous network.

2.3 The Perl Interpreter

Since MpCCI is a multi-platform software you can never fire up any binary executable directly - these executables are wrapped by scripts. To avoid the maintenance of different script languages (Bourne shell `"/bin/sh"` under Linux and `".BAT"` files under Windows) in fact all MpCCI commands are Perl scripts and MpCCI requires a working Perl installation.

Perl is a platform independent script language which allows running identical scripts under Linux as well as under Windows.

Perl was invented by Larry Wall. Perl is a public domain software distributed under the GNU Public License (GPL) and can be downloaded for free from the world wide web. Perl needs to be installed separately on your local computer.

Perl is not part of the MpCCI installation.

If Perl is already installed on your system - this is true for nearly any Linux system - you may check the Perl version by typing

```
perl -version
```

For MpCCI under Linux you need at least Perl 5.6.

Perl for Windows

Perl is never part of your Windows system. We recommend to have the Strawberry Perl 5.8.8 or higher installed. There are several issues with Perl versions before ActivePerl 5.8.0.

To be up to date with your Perl you may follow the link

strawberryperl.com/ resp.

www.activestate.com/Products/ActivePerl.

Strawberry Perl is the best available Windows port of Perl. A 64 bit version of Strawberry Perl for Windows 64 bit is available.

If you need to install Perl or upgrade your Perl installation, please see ▷ 9 Installing Perl ◁.

For MpCCI under Windows you need at least Perl 5.8.

2.4 The Java Runtime Environment

The MpCCI GUI is a Java application based on OpenJDK. At least an OpenJDK Runtime Environment 11 (JRE) or higher is required. This corresponds to Java SE 11.

An OpenJDK Runtime Environment is part of the MpCCI installation and of the Microsoft Windows MSI installation. There is no need to have Java installed before you install MpCCI.

2.5 OpenSSH for Windows

OpenSSH is a free ssh distribution. OpenSSH is required under Windows to execute commands on remote Windows or Linux systems from a Windows or a Linux system. OpenSSH makes Windows interoperable with other Windows systems and Linux.

OpenSSH is part of the MpCCI installation and may be finally installed on the fly. You should not download

OpenSSH for Windows from the web and install it.

In fact you should not have OpenSSH installed before the MpCCI installation.

Recommendations

Do never install OpenSSH separately. Please let MpCCI do this job.

Together with MpCCI some bug fixes for the OpenSSH are installed and the OpenSSH is automatically configured.

OpenSSH for Windows is Already Installed

You are familiar with OpenSSH and already worked with OpenSSH.

Please save your existing "<*Home*>/.ssh" directory - e. g. rename it '_ssh' - to avoid the loss of your already generated and working RSA-keys.

Uninstall OpenSSH. After MpCCI was successfully installed OpenSSH will be installed on the fly.

After the final OpenSSH installation remove the directory "<*Home*>/.ssh".

Do not forget to rename your saved '_ssh' directory back to '.ssh'.

OpenSSH for Windows and cygwin

There are known issues if OpenSSH and cygwin are installed in parallel on the same machine, e. g. both come with an "ls" command accessing different and possibly incompatible versions of the same ".dll" files. In this case the OpenSSH may fail.

Best is to have either the OpenSSH installed or your existing cygwin installation includes a working ssh service. In the latter case the OpenSSH installation is not required.

If you need the OpenSSH and the cygwin installation in parallel then please make sure that the OpenSSH binaries directory is in front of your PATH environment variable.

2.6 MpCCI-RSH for Windows

MpCCI comes with its own rshd and rlogind services for Windows. This package includes both, the services and the rsh and rcp commands. Although this software is part of MpCCI, it is not necessarily bound to MpCCI. Therefore the service is - like the OpenSSH - a separate installation under Windows.

MpCCI-RSH is required under Windows to execute commands on remote Windows or Linux systems from a Windows or a Linux system. MpCCI-RSH makes Windows interoperable with other Windows systems and Linux.

Using the MpCCI Microsoft Windows installer, the MpCCI-RSH package is automatically installed and started.

Otherwise if you have a computer network and an NFS file server or Samba is available in your local area network and you need to install the MpCCI-RSH package, you can execute the installation program "<*MpCCI_home*>\mswin\mpccirsh\setup.exe".

After the installation of MpCCI-RSH you need to prepare the .rhosts file and rsh environment, see ▷ 8.3 Preparing the .rhosts File and the rsh Environment ◁.

3 Installation of the MpCCI Software

If you intend to install MpCCI under Linux or on a file server you should have downloaded a multi-platform distribution file. For a local Windows installation you download an "MSI" file.

3.1 Multi-Platform for Linux and Windows

For all supported platforms you will find a distribution on the MpCCI download site. No matter on which systems you are logged on, Linux or Windows, the installation procedure is identical.

You need not to be a Windows administrator or the Linux root user if you do not extract the MpCCI distribution file within protected directories. MpCCI can be installed everywhere, e. g. in your private MpCCI home directory, "$HOME/MpCCI" or "%USERPROFILE%\MpCCI".

After downloading your MpCCI distribution file you have to

1. Create your temporary directory to extract the content of the downloaded file
2. Change to your temporary directory: `cd <temporary directory path>`
3. Extract the MpCCI files from the downloaded file with the command
   `unzip mpcci-<MpCCI-version>.zip`
4. Execute the installer script "mpcci_install.pl"
5. Accept the license agreement
6. Provide the installation path directory
7. Authorize the extraction of the files
8. Update your user PATH environment with the MpCCI bin directory.

The MpCCI software is now installed on your system.

Do Not Forget to Set Your PATH Environment!

To use MpCCI without having trouble the MpCCI binaries directory "<*MpCCI_home*>/bin" needs to be in the PATH. If the MpCCI binaries directory is not in the PATH a remote connection to this machine from a remote host via any MpCCI software is impossible.

If you already have a previous release of MpCCI in the PATH, please prepend the newest release in front of the PATH and do not append it at the end. Otherwise the `mpcci` command selected will always start the previous release.

According to your login shell under Linux (see "/etc/passwd") you need to set:

Bourne shell ("/bin/sh") users

```
PATH=<MPCCI_HOME>/bin:$PATH
export PATH
```

Korn shell (ksh) and bash users

```
export PATH=<MPCCI_HOME>/bin:$PATH
```

c-shell (csh) and tc-shell (tcsh) users

```
setenv PATH <MPCCI_HOME>/bin:$PATH
```

and under Windows

```
set PATH=<MPCCI_HOME>\bin;%PATH%
```

Under Windows you need to set the PATH if you are using the multi-platform installation zip-file.

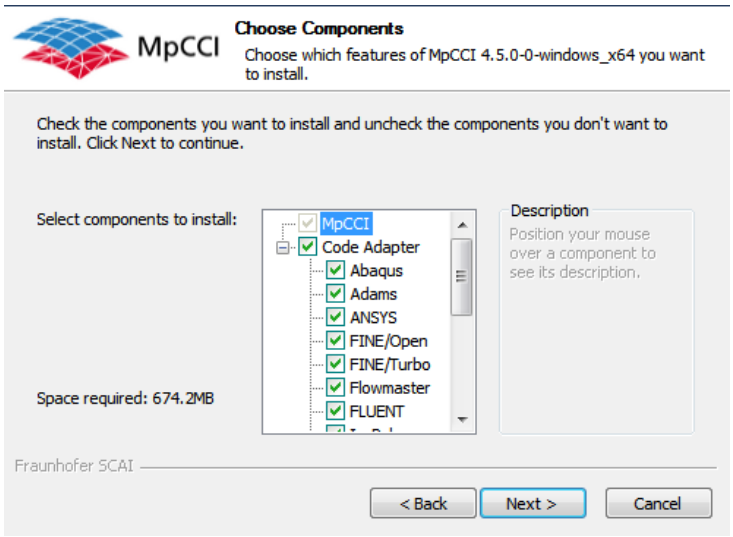
Please keep in mind that a list separator is ':' under Linux and ';' under Windows.

3.2 Local Windows Installation with the MSI

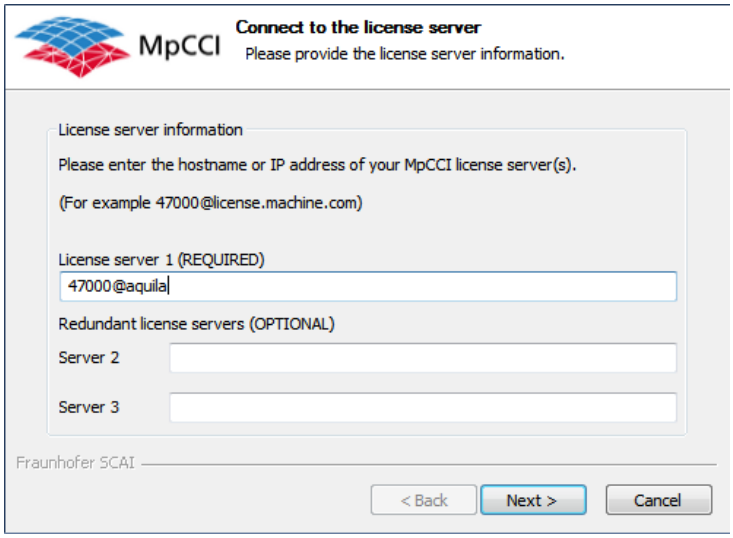
You can execute the installation as an administrator or normal user account.

Please execute the downloaded self-extracting archive, e. g. "mpcci-<*MpCCI-version*>-windows_x64.exe" for Windows 64-bit on Intel x64 processor.

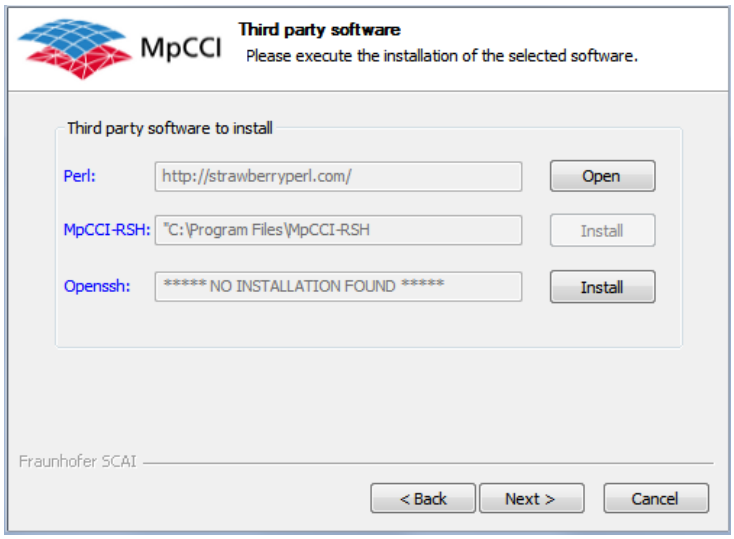
This installation procedure builds a proper MpCCI software environment under Windows.



You pick up those components, e. g. code adapters, you want to install from the components list.



You can provide the license server information, i. e. hostname and port number of your license server.



During the installation the prerequisites are tested and you have the chance to install the missing third party software (MpCCI-RSH, OpenSSH) on the fly. If you need to install Perl follow the provided link which leads you to the Strawberry Perl site and install it (64-bit) apart from the MpCCI installer hereafter (see ▷ 9 Installing Perl ◁).

The MpCCI software is now installed on your system.

There is no need for any further configuration. The environment is automatically updated by the installer. If the installer has not been able to set the path to MpCCI automatically, please set it manually as described in the previous section.

Installation as normal user may show for the first usage some request to enable the firewall settings on the machine. If this dialog is ignored, the tools can still work properly. Otherwise contact your local administrator to include the MpCCI executable from the bin/windows_x64 folder in the firewall rules: mpcci_visualizer.exe, mpcci_ccvxcat.exe, mpcci_test.exe, mpcci_server.exe, mpcci_fsimapper.exe, mpcci_morpher.exe, mpcci_modelcheck.exe, mpcci_nbhsearch.exe, mpcci_nbhcontrol.exe

4 Immediately After the Installation - Quick Installation Tests without a License

4.1 Your Home Directory under Windows

Under Linux your home directory is known to applications via the environment variable `HOME`, which is always defined.

Under Windows the environment variable `HOME` may be defined, however the standard under Windows is to use the variable `USERPROFILE`.

To make Windows behave like a Linux and vice versa MpCCI ignores any existing `HOME` variable and automatically (re)defines the variable `HOME` identical to either

- `HOME=%USERPROFILE%`
- `HOME=%HOMEDRIVE%\%HOMEPATH%`
- `HOME=C:\`

At least `HOMEDRIVE` and `HOMEPATH` should always be defined on Windows.

Your home directory is herein after referred to as <*Home*>.

Under Windows MpCCI strictly ignores any environment variable `HOME`. MpCCI assigns the variable `HOME`.

You need to have read-write-execute access rights for your <*Home*>directory.

4.2 Testing the MpCCI Working Environment and Perl

The first command you should execute is

```
mpcci env
```

If under Windows the OpenSSH and MpCCI-RSH are not installed, MpCCI will then do the post-installations. Please follow the installation instructions.

If you are working under Windows, you need to have administrative rights.

`mpcci env` should not fail and the output then shows the system information collected by MpCCI at runtime.

If you are running under Windows and a virus scanner is installed, the `mpcci env` may be quite slow at the first execution. During the collection of system information a lot of files are visited and executed and the virus scanner has to update it's cache for the first time. Once executed there will be no major delay any longer.

Testing whether Perl Can Really Compile All MpCCI Modules

Type in the command

```
mpcci test -modload
```

The last output line you should see is:

```
Successfully loaded and compiled all Perl modules from the above list.
```

Unfortunately, newer Perl releases do not contain some perl modules any longer, you have to install theses modules additionally. For the normal use of MpCCI you will not need these modules - so you can skip this additional installation and this test.

Other Possible Tests

You may start further tests which do not require an MpCCI license. The command

```
mpcci test
```

will help you to test the MpCCI access and communication with remote systems. For help please just type `mpcci help test`.

4.3 Testing whether MpCCI Finds Your Simulation Codes

Depending on the code adapters you installed together with MpCCI you may now test whether MpCCI is able to find your code installations.

Please type just

```
mpcci
```

and check what codes are listed.

You may see the output

```
Subcommands:
   ANSYS                  Tools related to ANSYS.
   Abaqus                 Tools related to Abaqus.
   Adams                  Tools related to Adams.
   FINEOpen               Tools related to FINEOpen.
   FINETurbo              Tools related to FINETurbo.
   FLUENT                 Tools related to FLUENT.
   FloMASTER              Tools related to FloMASTER.
   IcePak                 Tools related to IcePak.
   JMAG                   Tools related to JMAG.
   MATLAB                 Tools related to MATLAB.
   MSC.Marc               Tools related to MSC.Marc.
   MSC.Nastran            Tools related to MSC.Nastran.
   OpenFOAM               Tools related to OpenFOAM.
   SIMPACK                Tools related to SIMPACK.
   STAR-CCM+              Tools related to STAR-CCM+.
   TAITherm               Tools related to TAITherm.
   codename               Tools related to codename.
```

For each code listed you may type `mpcci <code name>` to get more help on the code specific commands and options.

To list the releases of a code that MpCCI needs to find on your system please type `mpcci <code name> -releases`, or in abbreviated form `mpcci <code name> rel`.

Under Linux the executables for each code must be in the `PATH`. Under Windows MpCCI reads the Windows registry entry for a code. You need to have an ordinary installation of this code.

More detailed information may be listed using the command `mpcci <code name> -information`, or in

abbreviated form `mpcci <code name> info`.

Non Standard Code Installation

If you are a developer of a simulation code and you would like to test your development version of the code - we assume this is not a standard installation and confuses the part of MpCCI which collects information for your code - you may define an environment variable that lists the names of the executable files.

```
MPCCI_CODEWORD_EXENAMES=executable1:executable2:...
```

Currently this feature is implemented for Abaqus and Marc.

5 Licensing

After the installation of MpCCI you need to acquire a license file from Fraunhofer SCAI.

MpCCI uses the FlexNet Publisher based floating license mechanism (formerly known as FLEXlm). The FlexNet Publisher license server has to be started on the license server host for which you require a license file.

For MpCCI 4.7 you will need the current FlexNet Publisher 11.17 licensing software.

If you are working with a previous MpCCI release you will have to stop the running FlexNet Publisher license server and start the new license server. You do not need a new license file if your license file is valid for some time.

The FlexNet Publisher license server requires the Linux Standard Base (LSB) package installation for any Linux distribution if not already installed. If this package is not installed, the license tools executables may not be recognized by the operating system.
You will receive such error message: No such file or directory when you try to execute directly the license server daemon SVD for example (cf. ▷ 5.2.1 Troubleshooting License Start on Linux ◁).
If your license server is running on a Windows system and you try to get a license from a Linux system without the Linux Standard Base (LSB) package you will receive such error message: Failed to get information from license server - Executable lmutil exited with code 255. (cf. ▷ 5.2.2 Troubleshooting Getting License on Linux from a Windows System ◁).

5.1 Request for a License File

We need two pieces of information from you to generate a license file:

1. Information about your license server host
2. Information about your desired MpCCI license features

Decide on which host you would like to run the license server. This could be any host in a network or in case of a local installation it is your local machine. On this computer please type in the command `mpcci license -sysid` or abbreviated `mpcci lic sys`. You should see an output line like

```
SERVER hostname 00087519576d 47000
```

A FlexNet Publisher license is bound to the MAC address of your network device. If you have multiple network devices installed (Ethernet card, Wireless LAN, Docking Station on a Notebook) you may see multiple hostids. For the MpCCI license server daemon the ID of the permanent integrated ethernet card address is the correct one.

Determine the license features you need. We offer license features for:

- MpCCI CouplingEnvironment with the basic license features `mpcci_sessions` and `mpcci_clients` (cf. ▷ 5.1.1 MpCCI CouplingEnvironment License Features ◁) and the `mpcci_adapter_<code>` license feature for the supported code adapters (cf. ▷ V-5.1.1.1 MpCCI Code Adapters License Features ◁).
  In addition, the following add-on features are available for the MpCCI CouplingEnvironment:
  - `mpcci_morpher` for using the MpCCI Grid Morpher (cf. ▷ 5.1.1.2 MpCCI Grid Morpher License Feature ◁).
  - `mpcci_sessions_precheck` and `mpcci_clients_precheck` for preparing the co-simulation coupled regions setup (cf. ▷ 5.1.1.3 MpCCI Precheck License Feature ◁).

- MpCCI FSIMapper with the license feature `mpcci_fsimapper` for using the (cf. ▷ 5.1.2 MpCCI FSIMapper License Feature ◁)

Fill out and submit the license file request form:

1. At www.mpcci.de go to `Download Area`.
2. Click the link `Log into the MpCCI Download Area` which will redirect you to the Fraunhofer SCAI download portal.
3. Enter your account details in the E-Mail and Password input fields.
4. Go to the menu MpCCI and select your desired product:
   `MpCCI CouplingEnvironment` resp.
   `MpCCI FSIMapper`.
5. Then click `License Request`.

Please fill out the form with all required data and all wanted license features and submit it. You will then receive the requested license file by e-mail shortly afterwards.

5.1.1 MpCCI CouplingEnvironment License Features

MpCCI knows two basic FlexNet Publisher features,

```
mpcci_sessions
mpcci_clients
```

which define how many independent coupled sessions (`mpcci_sessions`) can be run simultaneously and the maximum number of coupled MpCCI clients (`mpcci_clients`) that can be executed in total in all concurrent MpCCI sessions.

The feature `mpcci_sessions` is checked out and decremented by 1 during each single MpCCI session (each click on the Start button in the Go step of the MpCCI GUI or each call of `mpcci server` if you start the application manually).

The other feature `mpcci_clients` is reduced by the number of coupled MpCCI clients in the session.

The minimum is 1 for `mpcci_sessions` and 2 for `mpcci_clients`, i. e. you can start MpCCI with e. g. one Abaqus process and one FLUENT process.

With 1 `mpcci_sessions` license you cannot start another coupling job as long as your MpCCI job is running. If you want to run two coupled simulations simultaneously, you need a license with at least 2 `mpcci_sessions` and 4 `mpcci_clients`. If you have several client processes (e. g. running FLUENT in parallel), you need more `mpcci_clients` accordingly.

5.1.1.1 MpCCI Code Adapters License Features

There are MpCCI license features for the supported code adapters: if you couple code `MyCode` using the MpCCI adapter for this code, MpCCI will look for a feature `mpcci_adapter_mycode` on the license server. This feature must be contained in the license file, but it won't be checked out or decremented.

Examples:

```
mpcci_adapter_abaqus
mpcci_adapter_ansys
mpcci_adapter_fluent
mpcci_adapter_starcd
mpcci_adapter_mycode
```

5.1.1.2 MpCCI Grid Morpher License Feature

The MpCCI Grid Morpher (cf. ▷ V-8 MpCCI Grid Morpher ◁) is an extra licensed product used in combination with the MpCCI CouplingEnvironment. You need the license feature

```
mpcci_morpher
```

This feature must be contained in the license file, but it won't be checked out or decremented.

5.1.1.3 MpCCI Precheck License Feature

If you want to use MpCCI CouplingEnvironment to perform only a mesh check with a neighborhood search and without starting the coupled simulation (cf. ▷ V-3.2.5 Pre-Check Mode ◁) you need the precheck features

```
mpcci_sessions_precheck
mpcci_clients_precheck
```

These features are used in the same way as `mpcci_sessions` and `mpcci_clients` features. See ▷ 5.1.1 MpCCI CouplingEnvironment License Features ◁ for more details.

Usually, `mpcci_sessions_precheck` is set to 1 for one precheck session and `mpcci_clients_precheck` is set to 2 for at least two precheck clients.

5.1.2 MpCCI FSIMapper License Feature

The MpCCI FSIMapper (cf. ▷ X-1 MpCCI FSIMapper Overview ◁) is an extra licensed stand-alone product and you need the license feature

```
mpcci_fsimapper
```

5.2 Installing and Activating a License

Please copy your received license file into the file "<*MpCCI_home*>`/license/mpcci.lic`".

Then please start the FlexNet Publisher license server, i.e. the server daemon and the SVD vendor daemon on the license server machine with the command

```
mpcci license -start     or abbreviated: mpcci lic start
```

Under Windows you need to have the write permission in the "<*MpCCI_home*>`/license/`" directory for the log file.

After the daemons were successfully started you can list the available licenses with the command

```
mpcci license -local      or abbreviated: mpcci lic loc
```

If the license server is running with a valid license you will see an output e. g. like this:

```
License server: 47000@aquila
Vendor daemon : SVD v11.17.1, status "UP"

Feature                                  Total  Used   Free
---------------------------------------  -----  -----  -----
mpcci_sessions                               2      0      2
mpcci_clients                               10      0     10
```

```
   mpcci_adapter_abaqus                    1       0       1
   mpcci_adapter_fluent                    1       0       1
   mpcci_adapter_......                    1       0       1
   mpcci_adapter_......                    1       0       1
```

5.2.1 Troubleshooting License Start on Linux

The FlexNet Publisher based license software coming along with MpCCI makes use of the Linux Standard Base (LSB) executable format and does require a present LSB library installation. You can test if your system provides an LSB system installation with the command

```
lsb_release -a
```

If the LSB compatibility is not installed the FlexNet Publisher binaries cannot be executed resulting in the system error message

```
Can't exec license/lnx4_x64/lmgrd  No such file or directory.
mpcci license:
   Failed to launch executable
```

Minimal Ubuntu Linux installations do not include lsb_release as it's not required for core system functionality.

You can upgrade your Linux system with the command

```
sudo apt-get update
sudo apt-get install lsb-release
```

5.2.2 Troubleshooting Getting License on Linux from a Windows System

The FlexNet Publisher based license software coming along with MpCCI makes use of the Linux Standard Base (LSB) executable format and does require a present LSB library installation. You can test if your system provides an LSB system installation (cf. ▷ 5.2.1 Troubleshooting License Start on Linux ◁). If the LSB compatibility is not installed the FlexNet Publisher binaries to list or check out a license cannot be executed resulting in the system error message

```
mpcci license:
   Failed to get information from license server: 47000@aquila
   Executable
       <MPCCI_HOME>/license/lnx4_x64/lmutil
   exited with code 255.
```

Some Red Hat Linux or Scientific Linux installations do not include lsb_release as it's not required for core system functionality.

You can upgrade your Linux system with the command

```
   yum install redhat-lsb
```

5.2.3 Configure a License Manager as Linux Service

On Linux, edit the appropriate boot script, which may be `"/etc/rc.boot"`, `"/etc/rc.local"`, `"/etc/rc2.d/Sxxx"`, `"/sbin/rc2.d/Sxxxx"`, etc. Include commands similar to the following.

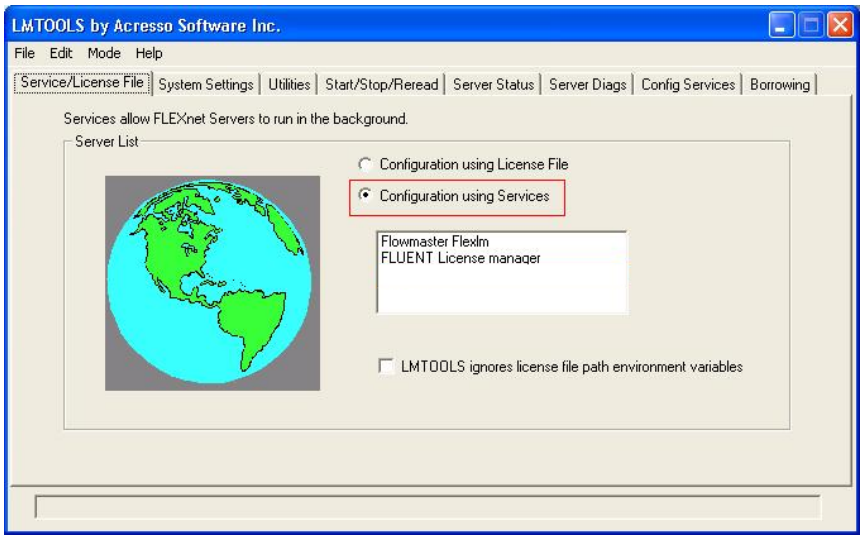
```
<MPCCI_HOME>/bin/mpcci license -start
```

The <*MpCCI_home*> is the full path of the MpCCI installation. This command will create a log file under the directory "<*MpCCI_home*>`/license`" and you have to ensure that the process could write in the directory.

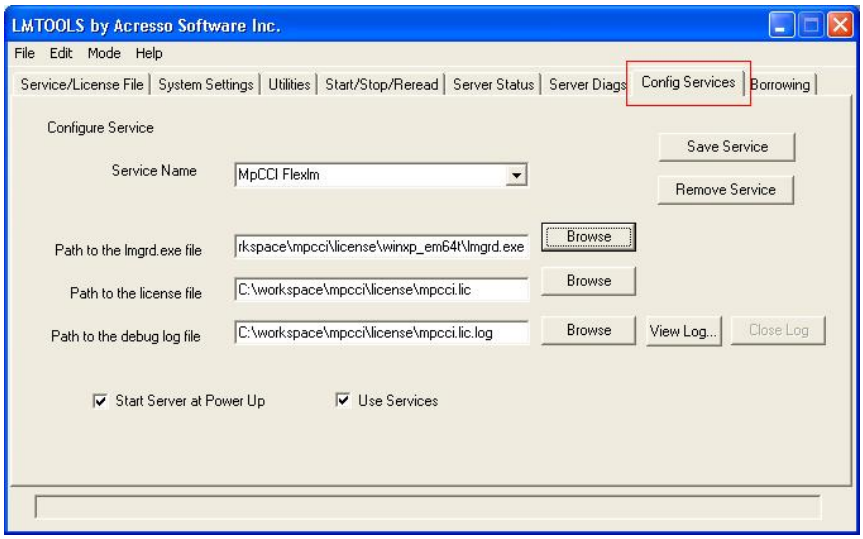
5.2.4 Configure a License Manager as Windows Service

Execute the "`lmtools.exe`" application from the MpCCI installation directory:
"<*MpCCI_home*>`/license/`<*MpCCI_arch*>`/lmtools.exe`"
<*MpCCI_arch*> corresponds to the output of the command:

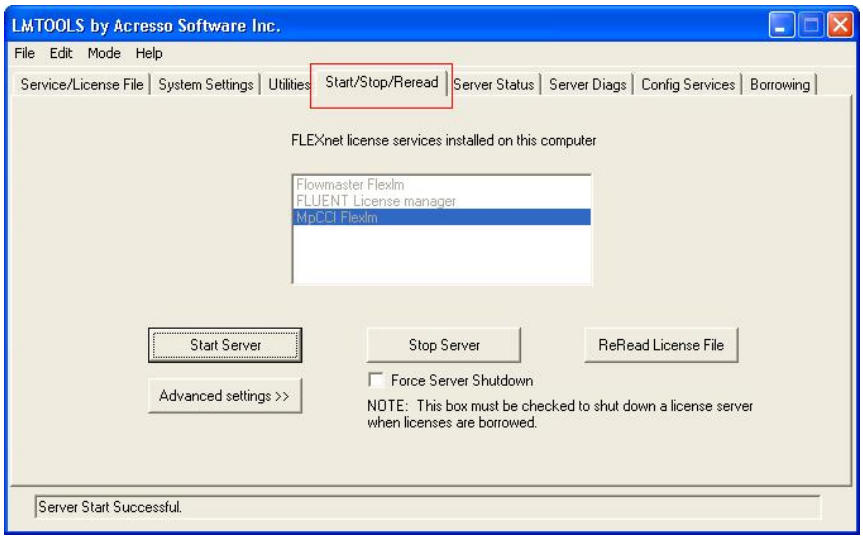
```
mpcci arch
```



- In the Service/License File tab section select the option Configuration using Services.
- Click on the Config Services tab section.



- Enter a service name e. g. MpCCI license manager or MpCCI FLEXlm.
- Select the path of the program `"lmgrd.exe"` via the Browse button: `"<`*MpCCI_home*`>/license/<`*MpCCI_arch*`>/lmgrd.exe"`
- Select the path to the license file `"mpcci.lic"` via the Browse button: `"<`*MpCCI_home*`>/license/mpcci.lic"`
- Activate the Start Server at Power Up option.
- Activate the Use Services option.
- You can optionally add a log file by providing a file name for the Path to the debug log file option.
  Be sure to select a directory where you have the write permission for the log file otherwise you may omit this option.
- Click on the Save Service button.
- Click on the Start/Stop/Reread tab section.



- Select the just configured license service e. g. MpCCI FLEXlm.
- Click on the Start Server button.
- The license server is now running and configured to start at power up.

5.2.4.1 Troubleshooting Starting License Manager as Windows Service

After adding a new FlexNet Publisher Service using the LMTOOLS, you receive the following error when you attempt to start the new service (mostly observed on Windows server 2022 operating system rather than Windows 10):

```
VD is starting, please check vendor daemon's status in debug log
```

But the the service does not start. When you attempt to stop the server, you receive this message:

```
Unable to Stop Server.
```

and the server status reports:

```
Flexnet Licensing error:-15,10. System Error: 10061 ''Winsock: Connection
refused''
```

Cause:
The FlexNet Publisher service is configured as a Local Service account, rather than a Local System account.

Solution:
To update the service setting on your license server:

1. Click the Windows Start button, Administrative Tools, Services. For Windows 10, click Windows Administrative Tools, Computer Management, Services and Applications, Services.
2. Find the name of your FlexNet Service that doesn't start. Right-click the name and select Properties.
3. Click the Log On tab, then select Local System account, then click Apply.
4. Click the General tab, then click the Start button. The service should start in a few seconds.
5. Click OK, and close the Services dialog.

The service should now stop and start normally from LMTOOLS.

5.3 Defining the License Server

We assume that an MpCCI FlexNet Publisher license server is already running.

Before you start your MpCCI session you have to know the hostname of the license server and the port where it is listening. The default port number is 47000, which can be changed by the administrator of the license server.

The location of the license server is defined via the variable MPCCI_LICENSE_FILE.

```
MPCCI_LICENSE_FILE=port@licenseserver
```

before starting any MpCCI session.

MpCCI has built in two mechanisms to check for the MPCCI_LICENSE_FILE variable:

First it checks a FlexNet Publisher resource file located in your <*Home*>directory: under Linux this is "HOME/.flexlmrc" and under Windows it is "%USERPROFILE%\.flexlmrc". MpCCI scans the ".flexlmrc" for a line containing

```
MPCCI_LICENSE_FILE=...
```

Secondly it reads the environment variable MPCCI_LICENSE_FILE. Supposed your license server name is aquila please set MPCCI_LICENSE_FILE as follows:

Bourne shell ("/bin/sh") users

```
MPCCI_LICENSE_FILE=47000@aquila
export MPCCI_LICENSE_FILE
```

Korn shell (ksh) and bash users

```
export MPCCI_LICENSE_FILE=47000@aquila
```

c-shell (csh) and tc-shell (tcsh) users

```
setenv MPCCI_LICENSE_FILE 47000@aquila
```

and under Windows

```
set MPCCI_LICENSE_FILE=47000@aquila
```

The values of both variables from the ".flexlmrc" file and the environment variable MPCCI_LICENSE_FILE are merged.

Recommendations

We recommend to set the MPCCI_LICENSE_FILE environment variable in your resource file ".flexlmrc" for FlexNet Publisher. Environment variables are volatile, the ".flexlmrc" file is not. Environment variables are sometimes not properly defined if a remote MpCCI command is started via rsh or ssh, the ".flexlmrc" file is always accessible.

If you still prefer to use the environment variable MPCCI_LICENSE_FILE instead of the ".flexlmrc" file:

- Under Linux please store the setting in one of your login scripts (".login", ".profile", ".cshrc", ".bashrc", etc.).
- Under Windows please make sure that MPCCI_LICENSE_FILE is a global environment variable for all users.

Sometimes the connection to the FlexNet Publisher license server is too slow and a license check gets a

timeout. In this case you can set the MPCCI_LICENSE_TIMEOUT environment variable. Default value is 30 (seconds).

Under Windows you need to be the administrator to define global system wide variables.

5.4 Multiple License Servers

If you use several redundant FlexNet Publisher license servers you will have several entries of the form port@host - one list entry for each license server.

In this case the entries must be separated by a ":" under Linux respectively by a ";" on Windows. This is an example for Windows:

```
set MPCCI_LICENSE_FILE=47000@aquila;47000@einstein;47000@zuse;...
```

5.5 Testing the License Server

After setting your MPCCI_LICENSE_FILE environment you should check whether licensing works.

```
mpcci license -servers
```

should list the value of MPCCI_LICENSE_FILE.

The command

```
mpcci license -mpcci
```

checks if the license server is running and can be reached from your local machine.

6 Configuring the MpCCI Users Environment

6.1 Accessing Remote Hosts

If all processes of an MpCCI job run on your local machine you may skip the following section or define the environment variable MPCCI_NOREMSH.

General information on running MpCCI in a network is given in ▷ V-3.6 Running MpCCI in a Network ◁.

If you intend to distribute the MpCCI job on multiple hosts in a network - the preferred solution - MpCCI needs to execute commands on remote hosts and may copy files to remote hosts. In this case MpCCI uses either the rsh commands (`rsh, rcp`) or the ssh commands (`ssh, scp`).

rsh and ssh must be properly configured to avoid any password request when executing commands on remote hosts.

Environment Variable MPCCI_NOREMSH: Tell MpCCI Not to Check for rsh or ssh

If all processes of an MpCCI job run on your local machine you may define the environment variable MPCCI_NOREMSH. A non-empty value of MPCCI_NOREMSH will disable the check.

Environment Variable MPCCI_RSHTYPE: Tell MpCCI to Use Either rsh or ssh

To find out whether to use the rsh command set (`rsh`, `remsh` etc. , and `rcp`) or the secure shell commands (`ssh`, `scp`) MpCCI inspects the optional environment variable MPCCI_RSHTYPE. A non-empty value of MPCCI_RSHTYPE may either be “rsh” or “ssh”. Any other value is invalid and will result in an error.

If MPCCI_RSHTYPE is not defined or empty rsh is used as the default.

rsh Configuration under Linux

You should have an `".rhosts"` file - used by rsh and ssh - and additionally may have an `".shosts"` file - used by ssh only - located in your <*Home*>directory. Your `"<`*Home*`>/.rhosts"` just lists - one hostname per line - all remote hosts from which you may log on the local host without a password request. You may test a working rsh environment via

```
rsh hostname ls
```

There should be no password request.

Please make sure that `"<`*Home*`>/.rhosts"` can be accessed from all hosts relevant for MpCCI.

ssh Configuration

If you prefer to use the ssh commands you need to generate your private RSA-keys to avoid a password request. Therefore use the command

```
ssh-keygen
```

Please read the OpenSSH documentation on how to distribute private and public keys to all hosts in a network.

You may test a working ssh environment via

```
ssh hostname ls
```

There should be no password request.

You may further run some tests on your ssh configuration using

```
mpcci ssh [options]
```

For help please enter

```
mpcci help ssh
```

Testing MpCCI Access to Remote Hosts via rsh and ssh

Even under Windows you should create a "<*Home*>/.rhosts" file. You may then test the remote access to all host listed with

```
mpcci test .rhosts
```

The test tries to connect to all hosts, via rsh and/or ssh, prints a protocol in case of failures and finally writes a new "hostlist" file containing all successfully tested hosts.

To get a full help on `mpcci test` please enter

```
mpcci help test
```

For each remote host/hostfile listed on the command line it performs the following tasks:

- Test whether the remote hostname can be resolved by the Domain Name Service (DNS).
- Test whether the remote host is alive and reachable and `ping` gets a reply.
- Test possibility of rsh/ssh connections to the remote host.
- Brief test on the MpCCI installation on the remote host from the local host.
- Test server-client connection on ports 47001 and so on.
- Creation of a protocol host-file "mpcci_test.hostlist" which can be used as an MpCCI hostfile (see ▷ V-3.6.2 Hostlist File ◁).

6.2 Configuring MpCCI via Environment Variables

The behavior of MpCCI can be influenced through environment variables. If MpCCI does not run properly on your system you may be able to fix problems by setting some variables as described in the following. A complete overview of all environment variables used by MpCCI is given in ▷ V-2.3 Environment and Environment Variables ◁.

Environment Variable MPCCI_ARCH

The variable MPCCI_ARCH holds the architecture token of MpCCI and is usually set by MpCCI automatically since MpCCI is capable to figure out the platform it is running on. Only if this mechanism fails or you definitely want to try running a different version of MpCCI, you should set this variable.

MPCCI_ARCH must always contain a valid architecture token as listed in ▷ II-5 Supported Platforms in MpCCI 4.7 ◁.

Please read ▷ V-2.3.1 MPCCI_ARCH - Architecture Tokens ◁ for more information.

Environment Variable MPCCI_DEBUG

If MPCCI_DEBUG is set and not false (any value except empty or 0), then detailed logging output is produced to find out some pitfalls in case of failures. This has the same effect as starting MpCCI with the `-debug` option.

Environment Variable MPCCI_IBATCH

If MPCCI_IBATCH is set and not false (any value except empty or 0), then the MpCCI GUI can be started during an interactive batch session.

7 Testing the MpCCI Installation and Communication

A Simple Test on the Local Machine, "Hello World"

We assume that the above installation step was successful, that you got an MpCCI license file and already started the license server.

The MpCCI distribution contains a "hello world" like example which you should run in order to test the installation. Please run the example via

```
mpcci test -simple
```

First the MpCCI server is started. Then - after some delay - code 1 (test code SINGLE) is started and connects itself to the MpCCI server. Finally after some delay code 2 (test code DOUBLE) is started and connects itself to the MpCCI server. The code 1 will disconnect from the MpCCI server earlier.

Besides the MpCCI Monitor you should see three windows: the two "hello world" application windows and the MpCCI server window.

The resulting output of code SINGLE ends as follows:

```
   [...]
Test code SINGLE now sleeping.
QUIT command sent at <time stamp>
Test code SINGLE finished with success.
```

The resulting output of code DOUBLE ends as follows:

```
   [...]
Test code DOUBLE now sleeping.
QUIT command sent at <time stamp>
Test code DOUBLE finished with success.
```

The resulting output of MpCCI server ends as follows:

```
   [...]
[MpCCI-SERVER]: ** WARNING ** No client is connected to the server.
    Exiting ...
[MpCCI-SERVER]: *** Finished MpCCI server shutdown.
[MpCCI-SERVER]: *** Finished <time stamp>
```

If the output looks like the above the test was successful.

8 Troubleshooting

8.1 Secure Shell in General

Avoid any printout in your login script like ".login", ".profile", ".cshrc", ".bashrc", etc. . This output may confuse the secure shell commands `scp` and `sftp` and may lead to strange and confusing error messages.

8.2 OpenSSH under Windows

Together with OpenSSH an OpenSSH service daemon is installed. The name of the service is `opensshd`.

If you cannot login from a remote host onto the local Windows PC you may have to restart the service daemon.

For a restart of the `opensshd` service please enter

```
net stop  opensshd     : Stop the service
net start opensshd     : Start the service
```

in a command shell.

You need to have administrative rights to restart a service under Windows .

If no remote access is required, you can define the environment variable `MPCCI_NOREMSH` (cf. ▷6.1 Accessing Remote Hosts◁).

8.3 rsh, rcp and rlogin under Windows

By default Windows does not have the UNIX rshd or rlogind services installed.

MpCCI comes with its own rshd and rlogind services for Windows. This package includes both, the services and the rsh and rcp commands. Although this software is part of MpCCI, it is not necessarily bound to MpCCI. Therefore the service is - like the OpenSSH - a separate installation under Windows.

After a successful installation of the MpCCI-RSH program (see ▷2.6 MpCCI-RSH for Windows ◁) under e. g. `"C:\Program Files\MpCCI-RSH "` you need to

- Install and start the rshd and optional rlogind services (▷8.3 Installing the MpCCI rshd, rlogind Service Processes◁)
- Prepare you personal remote hosts file and rsh environment (▷8.3 Preparing the .rhosts File and the rsh Environment◁)

If no remote access is required, you can define the environment variable `MPCCI_NOREMSH` (cf. ▷6.1 Accessing Remote Hosts◁).

Installing the MpCCI rshd, rlogind Service Processes

If not already done during the installation of the MpCCI-RSH package you need to install the services on Windows.

Change into the installation directory of the MpCCI rsh installation, e. g. `"C:\Program Files\MpCCI-RSH\bin"`. Then type

```
rshd    install
rlogind install
```

Now both services should be installed and started. The services are automatically restarted after a reboot of your computer.

You may stop and remove the services later on by either using the Windows services panel or you simply type

```
rshd    remove
rlogind remove
```

You can start/stop the services by either using the Windows services panel or you simply type

```
rshd    stop    or   net stop  mpcci_rshd
rshd    start   or   net start mpcci_rshd
rlogind stop    or   net stop  mpcci_rlogind
rlogind start   or   net start mpcci_rlogind
```

You need to have administrative rights to start or stop a service under Windows .

Preparing the .rhosts File and the rsh Environment

To give a remote user access to your local computer at first you need to create a "%USERPROFILE%\.rhosts" file in which the trusted remote hosts and users are listed. This file may be a copy of your Linux ".rhosts" file.

This file must be located in your "%USERPROFILE%" directory, which on current Windows machines is at most "C:\Users\myname".

If you are a Windows domain account user please make sure that your "%USERPROFILE%" directory is not removed after you logged off the Windows computer. Otherwise the rshd service is not capable to scan the required files before it creates a logon session for you.

The contents of the ".rhosts" file is a list of hostnames and user login names, one host per line.

```
host1 user1 user2 user3 ...

# additional users for host1
host1 myname friend

host2 myself
```

Empty lines are ignored.

Unlike with Linux rshd at least one user login name per host is required. All host names must be fully qualified names (hostname.netname). IP4 names in dot notation are ignored.

For security reasons - e. g. a trojan horse may append new hosts and users to your ".rhosts" file - the rshd and rlogind services do never scan the ".rhosts" file directly but instead use an alternative keys file "%USERPROFILE%\.rsh\keys".

This file is created - with special access right assigned - from the ".rhosts" file by the command

```
   rsh -makekeys
or
   rsh -k
```

The -k option will not check the hostname from the ".rhosts". If you have some trouble to connect to your local machine because of a DNS name resolution problem this option is recommended to be used.

If you add a new host in the ".rhosts" file you should create the "keys" again.

Any modification of the "keys" invalidates this file for use with rshd.

Do not modify the access rights of "%USERPROFILE%\.rsh\keys"

Now you should be able to execute a remote command, e. g.

```
rsh hostname dir
rsh hostname mpcci env
```

If you get Permission denied during a remote login procedure, please check the following items:

- The file ".rhosts" should contain fully qualified host names.
- The name of the host is not correctly resolved by the machine. You may add an entry corresponding to the IP adress from the machine with its fully qualified host name like:
  10.0.0.1 windows-pc.domain.org
  in the file
  "C:\WINDOWS\system32\drivers\etc\hosts".
- If you change the password, you need to re-run the command `rsh -k` to update the keys file "%USERPROFILE%\.rsh\keys".
- If these tips did not solve the Permission denied issue, you may stop rlogind service process with this command:

  ```
  rlogind stop
  ```

  Then start the rlogind service with debug mode -D by using this command:

  ```
  rlogind start -D
  ```

  This will show you the reason of the Permission denied.

  After resolving this issue, please do not forget to stop the rlogind service and just start it without the debug mode -D for security issue.

You may get further help for the rsh command with

```
rsh -help
rsh /?
```

Remote Shell and the Windows Firewall

The rshd and rlogind services accept incoming connection requests on the TCP ports 513 and 514.

The rsh command may ask the rshd to open an additional TCP socket on any unused port in the range 1023, 1022, ...514 and the rshd may then connect to the rsh command on any of these port.

During the installation the rshd, rlogind, rsh and rcp programs have been added to the Windows firewall rules to accept incoming and outgoing connection. The listed ports above must not be blocked by the Windows firewall since the applications themselves have been added to the firewall rules.

Remote Shell and the Windows Environment Variable PATH

The rshd and rlogind create the local processes under the account of the logged on user. Therefore all environment variables - called environment block - for this user have to be set up in advance.

Most of the environment variables are simply individual user variables, but some of them, like the PATH environment, are merged from the global system PATH defined for all users and the users individual PATH.

With Windows Vista Microsoft itroduced a bug in one of it's kernel function calls responsible for the merge. In case the value of the systems PATH environment variable contains a list with more than 1920 charcters, not just the merge process fails, but also the final PATH prepared for the user gets clipped at a length of 1024 characters. In fact the users PATH value then contains only the first 1024 characters from the systems PATH.

On most of the Windows machines you will not have a PATH environment variable with more than 1920 characters and the bug will not be recognised.

In case your system PATH has more than 1920 characters you will run into this issue. The rshd and rlogind will recognise this situation and the users PATH environment then is just a copy of the systems PATH environment variable.

Another workaround for the bug is the PATH file "%USERPROFILE%\.rsh\PATH" which contains a free formatted list of directory search paths, separated by either the standard separator ";" or a newline character.

```
  C:\Windows\system32    ;    C:\Windows    ;   C:\Windows\System32\Wbem
  F:\Perl\site\bin;    F:\Perl\bin
  F:\MpCCI\DEVELOP\bin
#  C:\Program Files\NVIDIA GPU Computing Toolkit\CUDA\v3.2\bin
  C:\Program Files\Common Files\Roxio Shared\DLLShared
  C:\Windows\System32\WindowsPowerShell\v1.0
#  C:\Program Files\QuickTime\QTSystem
  %userprofile%\bin
  F:\Program Files\copSSH\bin
  C:\Program Files\CMake 2.6\bin
```

If the file "%USERPROFILE%\.rsh\PATH" exists the users PATH environment is set up only from the contents of this file. Directories which do not exist are removed from the list. A recursive variable replacement for e.g. a variable like "%userprofile%\bin" is implemented.

9 Installing Perl

9.1 Linux

If you need to install or upgrade Perl under Linux please either download the recent Perl release from www.perl.com/download.csp and compile it on your local machine or use a binary distribution.

A binary distribution for all flavors of Linux platforms can be downloaded from www.perl.com/CPAN/ports/index.html.

The installation is straightforward for a Linux system administrator.

9.2 Windows

If you need to install or upgrade Perl under Windows we recommend to use Strawberry Perl because it's free and it meets our requirements. You also may use the partly free ActivePerl. Please consider their terms of use.

We recommend using a 64 bit version.

The version should be at least Perl 5.8.8. Versions before 5.8.8 had some problems under Windows with signals, fork emulation, the backtick operator and whitespace in filename when executing external commands.

We also recommend using the Microsoft Windows MSI installer version since during the installation the MSI appends the Perl binaries directory to your `PATH` environment and properly modifies or sets the `".pl"` file association in the `HKEY_CLASSES_ROOT` of the Windows registry.


You need admin privileges to install Perl using the Microsoft Windows MSI installer.

9.2.1 Strawberry Perl for Windows

Strawberry Perl is a free of charge Perl for Windows. A 64 bit version is available. The latest version is Perl 5.32 (2020/08/02).

We recommend using the Microsoft Windows MSI installer version but if you don't have admin privileges or want to install a local Perl version Strawberry Perl also provides ZIP and portable releases.

Follow the link strawberryperl.com/ and download your required Perl version.

After downloading the MSI installer distribution file (`"strawberry-perl-5.*-64bit.msi"`), please execute the Strawberry Perl installation program and follow the instructions. The installation is a typical Microsoft Windows MSI installation and is straightforward.

In case downloading a ZIP or portable release (`"strawberry-perl-5.*-64bit.zip"` resp. `"strawberry-perl-5.*-64bit-portable.zip"`), unzip the distribution into your install directory and follow the instructions from the extracted `"README.txt"` file.

Finally, please go on with ▷ 9.2.3 File Name Associations for Perl under Windows ◁.


Please execute at least the `"relocation.pl.bat"` file.
Otherwise you may face following error message on opening an MpCCI project:

```
Error opening project file "myproject.csp"!
Can't locate XML/LibXML.pm in @INC ...
```

9.2.2 ActivePerl for Windows

ActivePerl is free only as community edition. Other editions are fee required. A 64 bit version is available. The latest version is ActivePerl 5.28.

You may follow the link www.activestate.com/Products/ActivePerl to get an overview of the offered ActivePerl distributions.

Download the free ActivePerl community edition from www.activestate.com/activeperl/downloads.

As mentioned above, we recommend using the Microsoft Windows MSI installer version of ActivePerl.

After downloading the distribution file (`"ActivePerl-5.x.x.exe"`), please execute the ActivePerl installation program and follow the instructions. The installation is a typical Microsoft Windows MSI installation and is straightforward.

9.2.3 File Name Associations for Perl under Windows

Please make sure that the `".pl"` filename extension is properly associated with the newest Perl version installed. You may validate this by typing

```
assoc .pl
```

You should see an association pattern like `perl` and use this token as the argument for the `ftype` command

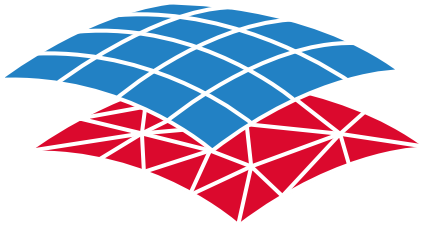
```
ftype perl
```

You should now see a line like

```
"D:\program files\perl\bin\perl.exe" "%1" %*
```

and type in the fully qualified pathname to get the version of Perl:

```
"D:\program files\perl\bin\perl.exe" -version
```



MpCCI
CouplingEnvironment

Part IV

—

Getting Started

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part IV Getting Started
PDF version
October 29, 2023

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IV Getting Started – Contents

1 Multiphysics Computation with MpCCI

1.1 Multiphysics

The purpose of MpCCI is to perform multiphysics simulations. The systems under consideration are known as coupled systems. A coupled system consists of two or more distinct systems. Each system is governed by a characteristic set of differential equations, but both systems share some variables and cannot be solved separately (see also Zienkiewicz and Taylor [2000] for a more precise definition).

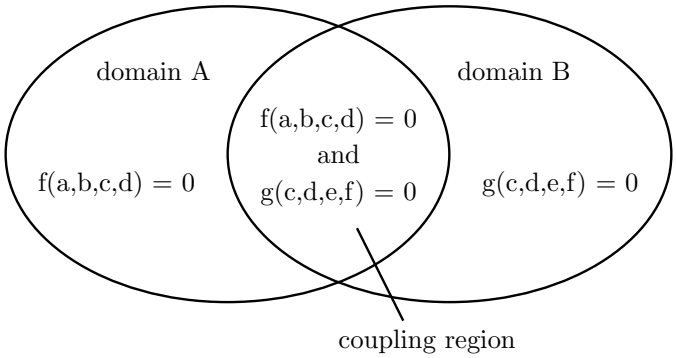


Figure 1: Coupled system: Two domains and a coupling region. Both systems share the variables c and d in the coupling region

Figure 1 shows two coupled systems. In the coupling region, both systems share some variables and the governing equations of both systems must be solved. Depending on the dimension of the coupling region, *surface coupling* and *volume coupling* are distinguished. The shared variables (c and d in Figure 1) are called *coupling quantities*.

Typical multiphysics simulations are:

Fluid-Structure Interaction (FSI):

First system:	Fluid flow (Navier-Stokes equations)
Second system:	Solid mechanics (equilibrium)
Quantities:	Pressure ($1 \rightarrow 2$), deformation($2 \rightarrow 1$)

Thermomechanical coupling

First system:	Solid mechanics (equilibrium)
Second system:	Heat conduction (Fourier's law)
Quantities:	Temperature ($2 \rightarrow 1$), deformation ($1 \rightarrow 2$)

Electrothermal coupling

First system:	Electrical conduction (Maxwell's equations)
Second system:	Heat conduction (Fourier's law)
Quantities:	Temperature/electric conductivity ($2 \rightarrow 1$), power loss/Joule heat ($1 \rightarrow 2$)

1.2 Solution of Coupled Problems

To find a solution for a coupled problem, all governing equations, which can be combined in a large system, must be solved. The solution in this way is called *strong coupling*. However, solving a system with strong coupling is often difficult as different approaches are necessary to solve the sub-problems.

An alternative approach is through *weak coupling*. Here each problem is solved separately and some variables are exchanged and inserted into the equations of the other problem. This procedure usually

yields a less exact solution compared to *strong coupling*. The advantages of the weak coupling are that the sub-problems can be solved faster than the complete system and that specialized solvers can be used for each.

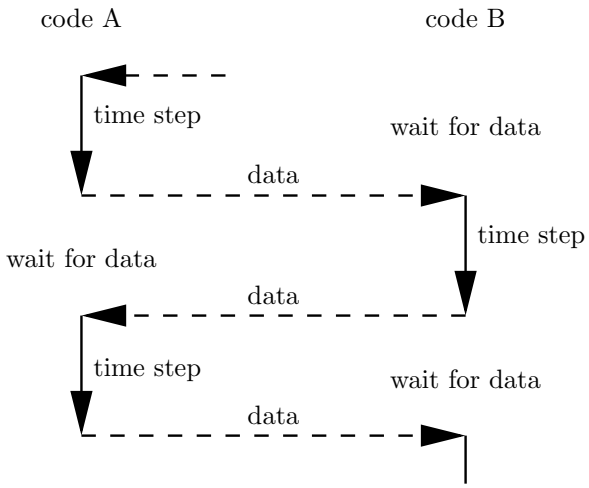


Figure 2: Staggered algorithm for solution of a coupled problem.

The staggered method is sketched in Figure 2, which is one of the weak coupling approaches of MpCCI: Code A computes one step, sends data to code B, which then computes one step and sends data back to code A and so on. In addition to the staggered approach, MpCCI supports parallel execution of both codes. The selection of the coupling algorithm is described in ▷ 2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation ◁.

An important issue is the data exchange. The quantities must be transferred from one code to the other. This process can be divided into two parts:

Association: Each point and/or element of the components of a coupling region is linked to a partner in the other system. The process of finding partners is also called *neighborhood search*, see ▷ V-3.3 Data Exchange ◁.

Interpolation: The quantities must be transferred to the associated partner on the other mesh. In this process, the different mesh geometries, data distributions and the conservation of fluxes must be considered.

MpCCI fully supports the data exchange between non-conforming meshes, i. e. the meshes of each subsystem can be defined to optimize the solution of the subsystem.

1.3 Code Coupling with MpCCI

Running a co-simulation with MpCCI requires the following steps:

Preparation of Model Files. Before starting a co-simulation, each domain must be modeled separately, i. e. a model file must be created for each simulation code. The models must contain a definition of the coupling regions. The preparation of a model file depends on the simulation codes, a detailed description is given in the corresponding sections of the Codes Manual.

Definition of the Coupling Process. Simulation codes and corresponding model files must be selected. The coupled regions, quantities and a coupling algorithm must be selected, further coupling options can be given. This step is completely supported by the MpCCI GUI.

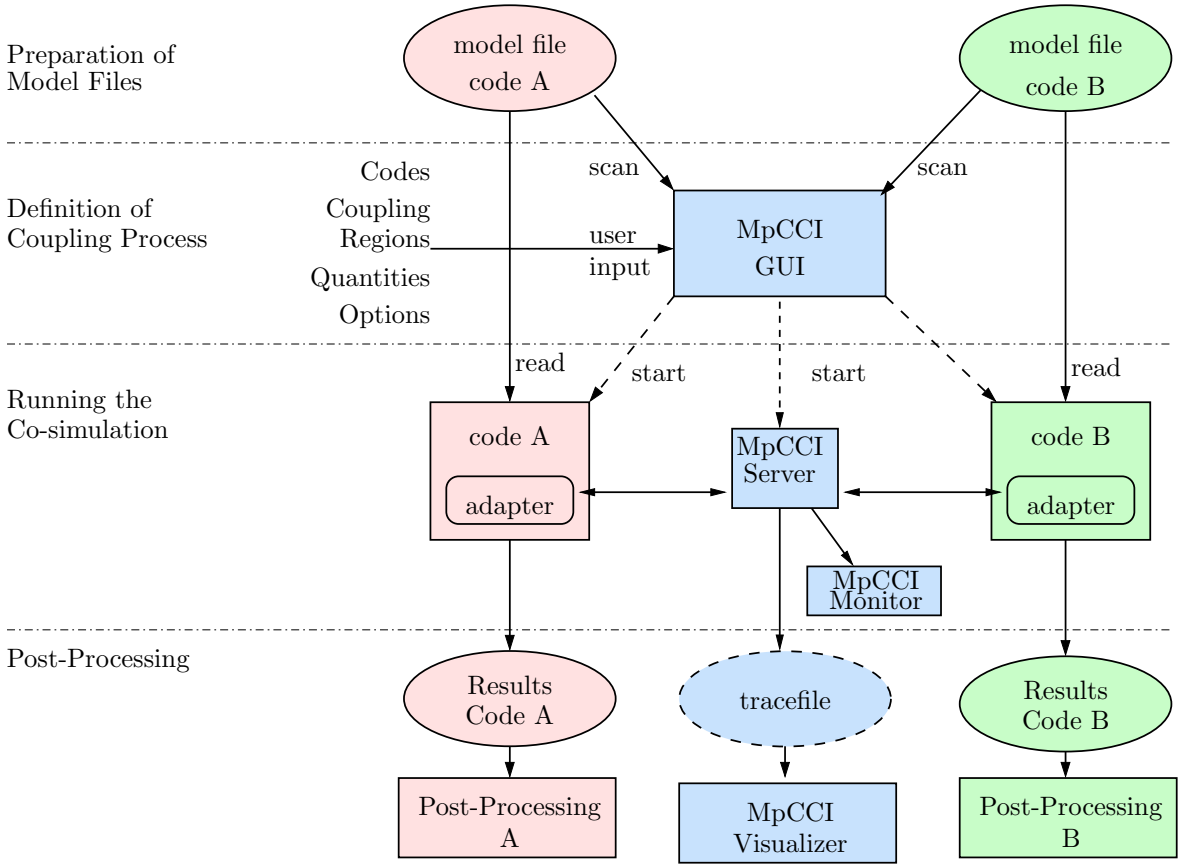


Figure 3: Co-simulation with MpCCI: Overview of the simulation process

Running the Co-simulation. After starting the MpCCI server, both coupled codes are started. Each code computes its part of the problem while MpCCI controls the quantity exchange.

Post-Processing. After the co-simulation, the results can be analyzed with the post-processing tools of each simulation code, with the MpCCI Visualizer or with general-purpose post-processing tools.

The application of MpCCI requires a good knowledge of the employed simulation codes. Therefore, it is recommended to use those codes for a co-simulation the user has already some experience with.

The data exchange between two simulation codes requires a “code adapter”, which constitutes a “code plug-in” for data transfer. Therefore only codes which are supported by MpCCI can be used. It is also possible to develop special code adapters, more details are given in the Programmers Guide.

An overview of the complete co-simulation process is given in Figure 3.

2 Setting up a Coupled Simulation

2.1 A Simple Example

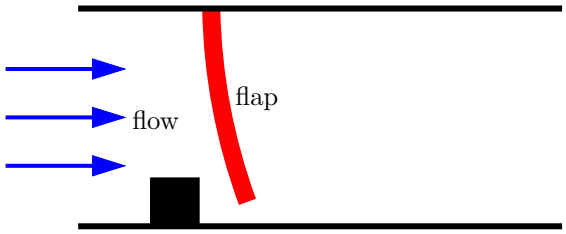


Figure 1: A simple coupled system

Let us look at a simple example to clarify the approach, which was described in the preceding chapter. Figure 1 shows a model of a valve which consists of a flexible flap which can be open or closed depending on the direction of the flow. The purpose of the simulation is to investigate the behavior of the valve depending on inlet and outlet pressure.

The computation of the pressure distribution and the flow rates is achieved using *Computational Fluid Dynamics* (CFD), whereas the deformation of the flap can be computed applying numerical structural mechanics via a *Finite Element* (FE) code. Each domain, has a significant influence on the other, thus the problems cannot be solved separately. The CFD simulation requires the deformation of the flap as a boundary condition, whereas the FE simulation requires the fluid pressure as external load. Thus during a co-simulation, these quantities must be exchanged as shown in Figure 2.

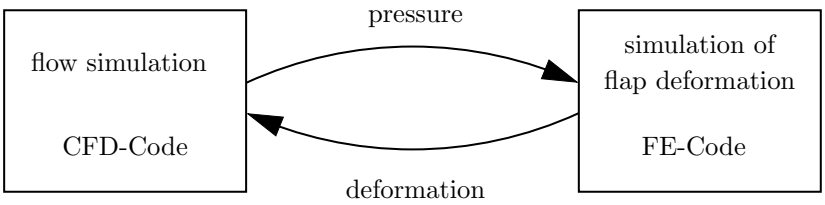


Figure 2: Exchange of quantities in the example FSI simulation.

2.2 Model Preparation

Before starting the coupled simulation, the models must be prepared in each code. In our example, this requires a model of the flow region and a model of the flap structure.

Both models are created in the undeformed condition, i. e. the flap is straight. The computation of such a problem requires a CFD-code which can handle moving/deformable meshes.

It is recommended that you keep your FE and CFD model files in separate directories (see Figure 3) because of the following reasons:

- Clear storage and maintenance of simulation data.
- Ensuring that the codes do not overwrite files of other codes, when identical file names are used.
- Simplification of the porting of the analysis when running the simulation on different platforms.

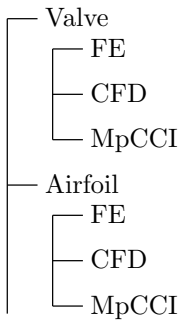


Figure 3: Organization of the directories

2.2.1 CFD Model

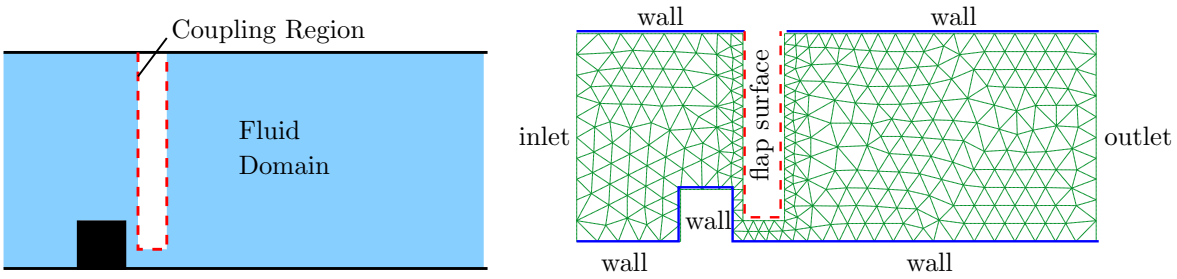


Figure 4: Fluid domain and CFD mesh

To model the fluid domain, define the geometry in the CFD pre-processor and create a mesh. Figure 4 shows a possible mesh for the fluid domain. (Please note that the displayed mesh is rather coarse and would probably not yield good results).

All boundary conditions must be defined as well. They comprise the flap surface, walls, inlet and outlet in Figure 4. Also for the coupling region boundary conditions may be set - this depends on the CFD code applied, please check the Codes Manual for details.

It is recommended to run the fluid problem on its own before starting a coupled simulation to be sure that the model setup is correct. In the present example the coupling region could be defined as a rigid wall for this purpose. If the model is not appropriate for computations with the CFD code alone, it is most likely that a co-simulation will either not run.

2.2.2 FE Model

Compared to the CFD model which covers the fluid domain, the FE model covers the flap itself. Figure 5 shows a mesh of the flap with quadrilateral elements. The element sizes do not need to correspond to those of the fluid domain in any way as MpCCI can handle non-conforming meshes.

The flap is connected to the top wall, i. e. the top nodes of the mesh must be fixed. The surface of the flap must be defined as a boundary to which the pressure load can be applied in the co-simulation. Although the system will not show any deformation without an external load, it is recommended to check the validity of the mesh and boundary conditions (i. e. the fixed nodes here) by running the FE problem alone and/or by performing a problem check if it is available in the FE code. To obtain a deformation you can replace the fluid forces by a similar load.

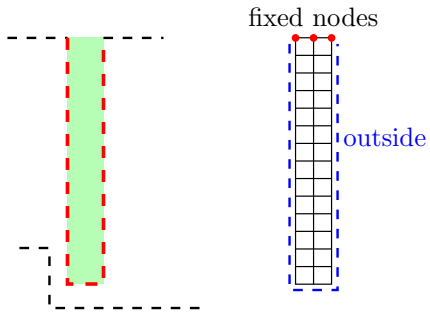


Figure 5: Finite Element model of the flap

2.3 Starting the MpCCI GUI

The MpCCI GUI is started by executing the command `mpcci gui` from a shell console.

The MpCCI GUI guides you through the steps to interconnect the FE and CFD models and to configure and run the coupled simulation.

2.3.1 Choosing a Coupling Specification

The first step when creating a new project is to choose a suitable coupling specification (cf. ▷ V-4.5 Coupling Specifications ◁). Our example is a fluid-structure interaction without consideration of a reference pressure. Therefore select the Gauge Pressure Based Fluid-Structure Interaction as shown in Figure 6.

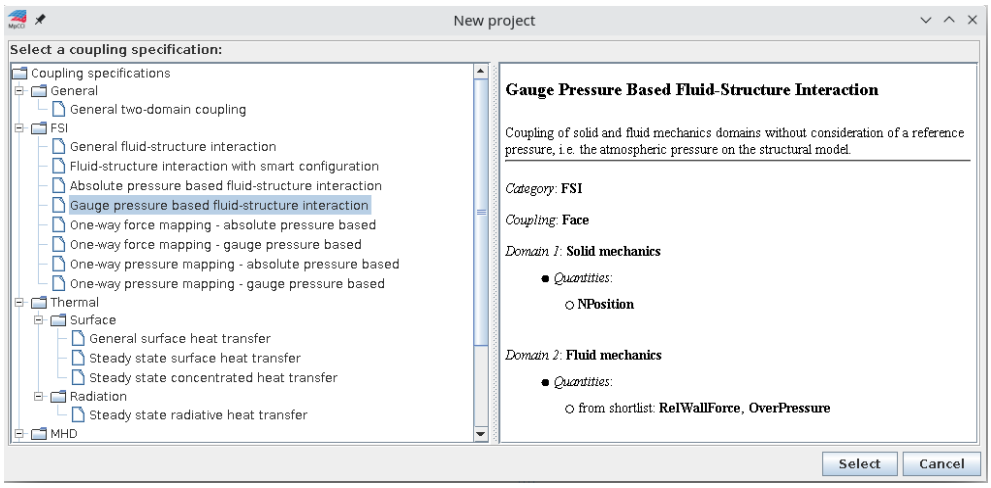


Figure 6: Select a coupling specification

2.3.2 Navigating through the MpCCI GUI

At the bottom of each step there is the navigation bar, which lists all available configuration steps, with the current step highlighted (see Figure 7). The individual steps can be selected one after the other or specifically. However, a directly selected step can get stuck on a previous step if configurations are required

that have not yet been fulfilled. Required steps are marked by a bracketed asterisk (*) behind the step name. These steps must at least be configured and verified in order to run a coupled simulation.

The individual steps are:

1. Models – required step for choosing codes and model files.
2. Algorithm – required step for defining the coupling algorithm.
3. Regions – required step for defining coupling regions and quantities.
4. Monitors – optional step for defining quantities for monitoring.
5. Settings – optional step for specifying further control parameters.
6. Go – required step for configuring the application startup and starting server and codes.

2.4 Models Step – Choosing Codes and Model Files

In the MpCCI Models step, the following steps should be accomplished:

- Select the analysis codes to couple.
- Set some code specific parameters if desired.
- Specify the model files to determine the potential coupling regions.

On top of the Models, Algorithm, and Regions steps the currently selected coupling specification is displayed. If you click on it, a dialog with detailed information about it will open.

For each domain, Domain_1 - Fluid mechanics and Domain_2 - Solid mechanics (Figure 7), a field for selecting and configuring the analysis code is provided in the MpCCI GUI.

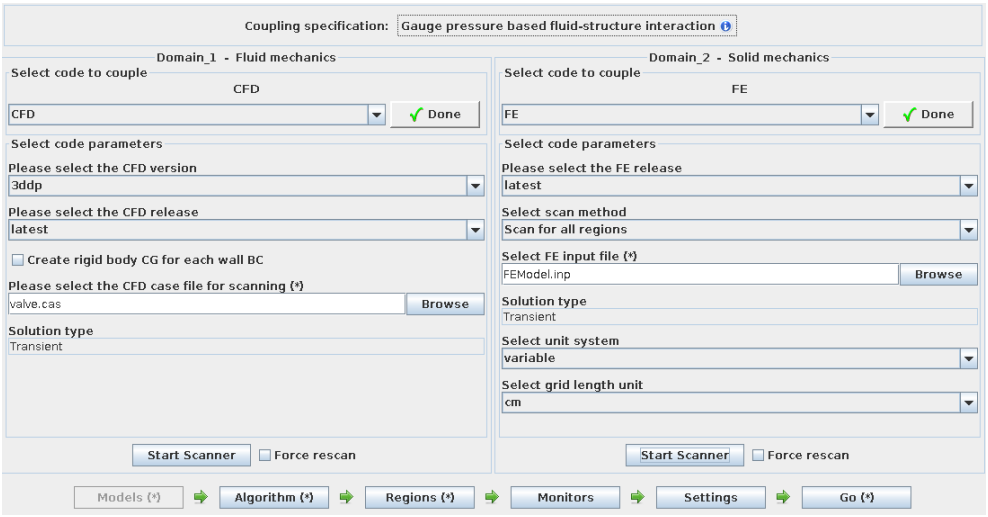


Figure 7: Models step for fluid mechanics and solid mechanics domains

For the fluid mechanics-domain: Select the desired CFD-Code - in this case CFD - from the pull-down menu providing the available codes. After your selection the parameters and settings of the picked solver are shown underneath (see Figure 7).

1. Configure some parameters like the CFD version or release.

2. Select the CFD model file by clicking on the Browse button in order to choose the file via the file browser. A scan of the model file is directly executed by MpCCI. The result is displayed next to the selected code whereas the solution type used for the model is also shown in a field below the model file.

For the solid mechanics-domain: Select the desired FE-Code - in this case FE - from the list provided by the pull-down menu. After your selection the corresponding parameters and settings are shown underneath (see Figure 7).

1. At first you may change the settings for the FE release or the scan method.
2. Select the FE model file via the file browser by clicking on the Browse button. A scan of the model file is directly executed by MpCCI. The result is displayed next to the selected code whereas the solution type used for the model is also shown in a field below the model file.
3. Select the unit system.
4. If the unit system is set to variable an additional parameter will be shown where you can select the grid length unit.

For each scanned model file the status is assigned to the corresponding analysis code:

if the extraction of the interface regions was successful.

if the scanner encountered problems during the scan which may depend on the parameters set for the analysis code.

By clicking on the status button, you get the information that has been extracted from the model file. If the scanning has failed the error message from the scanner is displayed in a pop-up window.

The solution type extracted by the scanner can have the following values:

- Transient for time dependent so called transient problems,
- Steady state for time independent so called stationary problems or
- Undefined when the problem cannot be specified out of the model file.

Depending on the solution type the code's analysis type is set in the Algorithm step. With an undefined solution type, the user can choose between a transient and a stationary analysis and must set the appropriate value by hand as described in ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

If you changed the models, you may start the scan process again via the Start Scanner button at the bottom of each code field.

After performing a successful scan of all model files you may continue with the next step of the coupled simulation setup by clicking on the Algorithm button.

2.5 Algorithm Step – Defining the Coupling Algorithm

In the MpCCI Algorithm step you define the coupling algorithm. It is arranged in the two groups

Common Basics with basic settings which are valid for the whole application and

Code Specifics with code specific settings each shown in a titled frame (see Figure 8).

The common basic algorithm settings define the global analysis type depending on the analysis type of each code, the coupling scheme - explicit or implicit, the type of the coupling step size, the coupling algorithm - parallel or serial and the coupling duration.

The code specific algorithm settings define the analysis type - transient or steady state - depending on the code's model, solver specific settings, the coupling steps if they are not defined globally and the runtime of each code.

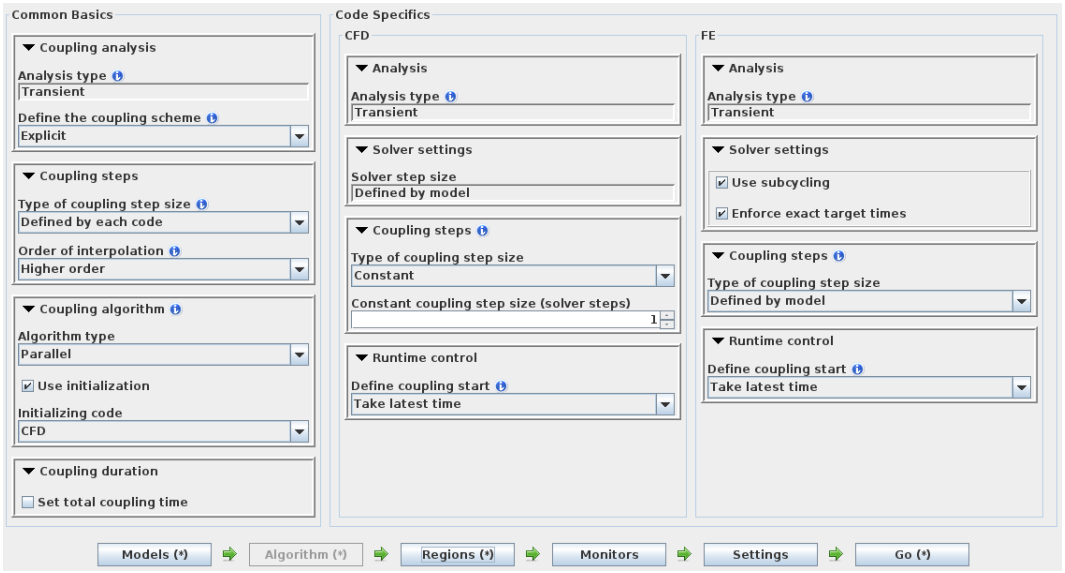


Figure 8: Algorithm step

Some settings may be predefined by the current model and so will automatically be set and maybe not changeable.

For some settings there is brief information, which is represented by the symbol (e. g. Analysis type in Figure 8). If you click this, a dialog window opens with a short description. For a detailed description of the Algorithm step have a look at ▷ V-4.7 Algorithm Step ◁.

In our coupled valve problem we consider that the pressure will initiate the deformation of the flap. Therefore the CFD code will be the initiator and the FE code in our example will request the pressure solution before starting its computation. Both codes run the analysis computation in parallel until a coupled target time is reached. At this target time both analysis codes will exchange their solution quantities.

The Common Basics settings for this scenario are (see Figure 8):

Analysis type Automatically set to Transient because of the chosen models which are both transient.

Coupling scheme Set to Explicit for our analysis.

Type of coupling step size Select Defined by each code because each code has its own coupled target time. Another type of coupling step size would be sending the coupling step size by a global variable (Sent by code). But we haven't defined such a variable.

Order of interpolation Because the coupling times of the codes won't match, the exchanged values must be interpolated. MpCCI offers different interpolation orders. We recommend the Higher order interpolation to get the best approximated values.

Coupling algorithm Set the Parallel algorithm type, select Use initialization and choose CFD code as initializing code.

For the CFD and FE codes no more Code Specifics settings have to be done. The solver resp. coupling step size is defined by each model and coupling will be done after each solver step. No pre-coupling time is needed.

Now the coupling regions can be determined in the next step. Please click on the Regions button to continue.

2.6 Regions Step – Defining Coupling Regions and Quantities

In the MpCCI Regions step the following steps need to be done:

- Build the coupling regions.
- Define the quantities to be exchanged.
- Assign the defined quantities to the built coupling regions.

The Regions step offers configuration panels for the two basic types of components:

Global Variables These components are data structures that are not related to the CFD or FEM grids. They contain global quantities like time or time step size. These components can be found under the Global element type label.

Mesh Based Element Components These components comprise collections of mesh based elements and can be found under the Mesh label. They contain model parts and the related grid based quantities, e. g. nodal positions, heat values or forces. To build up the interconnection, elements should be gathered that are part of the coupling region. Therefore the components of the codes are collected in lists of zero-dimensional integration point elements, zero-dimensional point elements, one-dimensional line elements, two-dimensional face elements and three-dimensional volume elements (see Figure 9).

Figure 9: Integration Point, Point, Line, Face and Volume element labels

To navigate between the two component types you have to click on the corresponding tab: Global or Mesh. Only active element types are offered (see Figure 10).

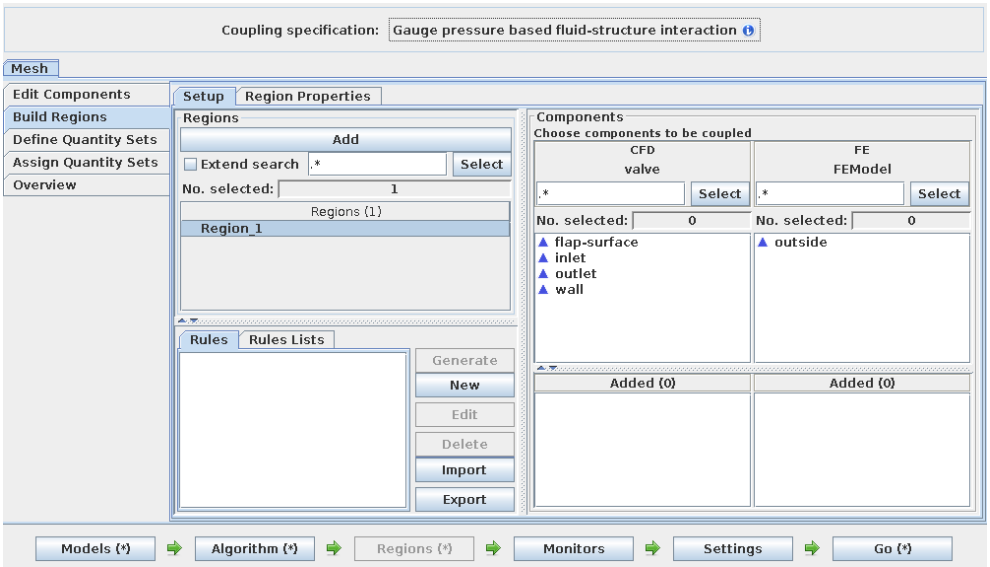


Figure 10: Regions step

In our example only the Mesh label is shown because global variables don't exist in our model files.

2.6.1 Build Coupling Regions

The Build Regions tab is already selected by default. In the Setup tab for setting up regions it shows a Region, Components and Rules area (see Figure 10).

Regions with a list of the created coupling regions.

Components with the lists of code components which may be selected into the coupled components lists, which define the coupling region. Our selected coupling specifications defines the coupled dimension Face so only the component lists with Face elements are shown.

Rules with a list of user defined rules for automatic region building. Not used in our example, see ▷ V-4.8.5 Automatic Generation of Regions by Rules ◁ for more information.

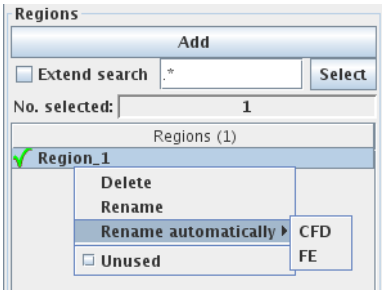


Figure 11: Regions with context menu

The "Regions" area (Figure 11) already defines the default region Region_1. To change its name use Rename or Rename automatically from the menu which pops up when you click with the right mouse button onto the region name. With Rename you can choose a name by your own, Rename automatically is only available if components are added and renames the region by the components of the selected code.

The pop-up menu provides also a Delete entry for deleting coupling regions and an Unused entry for marking regions not to be used in this run. This can be useful for preparing coupling regions for further runs.

To add further coupling regions use the Add button at the top of the regions list.

Figure 12: Empty, Incomplete, Complete and CompleteMore region states and an Unused complete region

Regions may have different states (see Figure 12):

Empty without components

Incomplete not enough components specified

Complete just enough components specified (one component from each code)

CompleteMore more than enough components specified (more than one component from one code)

Unused regions are greyed out.

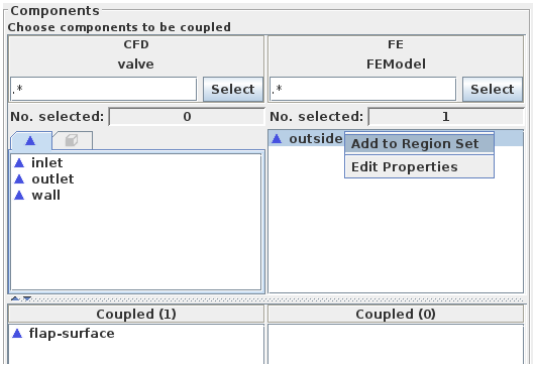


Figure 13: Coupled components selection

2.6.1.1 Select Components for Each Interconnected Code

In the Components area (Figure 13) a list with available components and one with coupled components for each code is shown. The components used for coupling have to be added to the coupled components list.

According to the valve example with the flexible flap this will imply:

For CFD code add the component flap-surface to the coupled list by double clicking on it, using drag & drop or using Add to Region Set from the pop-up menu which is shown by a right click on the desired component (see Figure 13).

For FE code add the component outside in the same way as mentioned above.

Now the region is complete. We can go on with defining and assigning quantities to be exchanged.

2.6.2 Define Quantities to be Exchanged

Quantities are handled in so called Quantity Sets. These sets can be generally defined for the coupling dimensions deduced from the built coupling regions. They need not to be assigned to a coupling region, so quantity sets may be prepared for different runs.

Select the Define Quantity Sets tab. It shows areas for Quantity Sets, Coupling Dimensions and Quantities (see Figure 14).

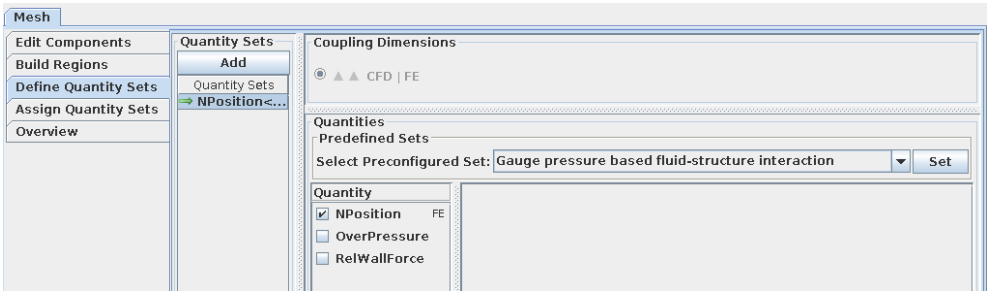


Figure 14: Definition of quantity sets

Quantity Sets with a list of sets with configured quantities to be transferred.

Coupling Dimensions offers the coupled dimensions from the previously built regions.

Quantities with a list of available quantities which may be selected and configured to be transferred from one application to the other.

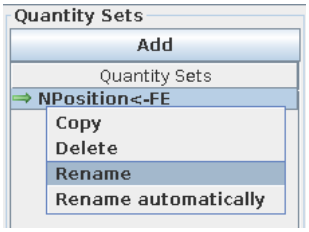


Figure 15: Quantity set with context menu

The "Quantity Sets" (see Figure 15) area is constructed similar to the regions area before. A quantity set NPosition<-FE already exists, because our selected coupling specification defined the quantity NPosition to be transferred. The quantity set can be renamed using Rename or Rename automatically from the pop-up menu where Rename automatically is the default and builds a name depending on the quantities added to the set. Thus the name of the quantity set changes every time the included quantities change. The pop-up menu also provides a Delete entry for deleting quantity sets and a Copy entry for copying the selected quantity set. Thereby a new quantity set with the same quantities and their settings will be constructed.

To add further quantity sets use the Add button at the top of the quantity sets list.

Quantity sets may also have different states indicated by the icon in front of the quantity set's name:

- Needs quantities to be transferred (incomplete).
- Quantities are specified being transferred in only one direction: one code only sends, the other code only receives (unidirectional).
- At least two quantities are specified being transferred bidirectional: each code sends and also receives (bidirectional).

2.6.2.1 Select Quantities to be Transferred

Beside the quantity NPosition which is always transferred in FSI, the Gauge pressure based fluid-structure-interaction provides a shortlist of quantities for selection: OverPressure and RelWallForce. In the quantities list, select the quantities to be transferred by clicking on the checkbox near the name of the quantity (Figure 16). In MpCCI the names of the quantities are standardized. In our example we want to transfer *pressure* and *deformation*. In MpCCI the pressure is handled by the quantity RelWallForce and the deformation by NPosition which stands for "nodal position". For further information on the meaning of quantities see the Quantity Reference in the Appendix and ▷ V-3.1.1 Physical Domains ◁. For our example select and configure the following quantities:

NPosition for exchanging the deformation is already selected. Sender is FE code (see Figure 16). Its deformation unit is not editable because the unit system for the CFD code is fixed to the "SI" unit system. On the other hand you may select the appropriate unit for the FE code because of the "variable" unit system setting in the Models step (see Figure 7).

RelWallForce for exchanging the pressure (see Figure 17). Sender is CFD code. The unit for the pressure may be set as described above.

The resulting quantity set will be automatically named to NPosition<–FE | RelWallForce<–CFD.

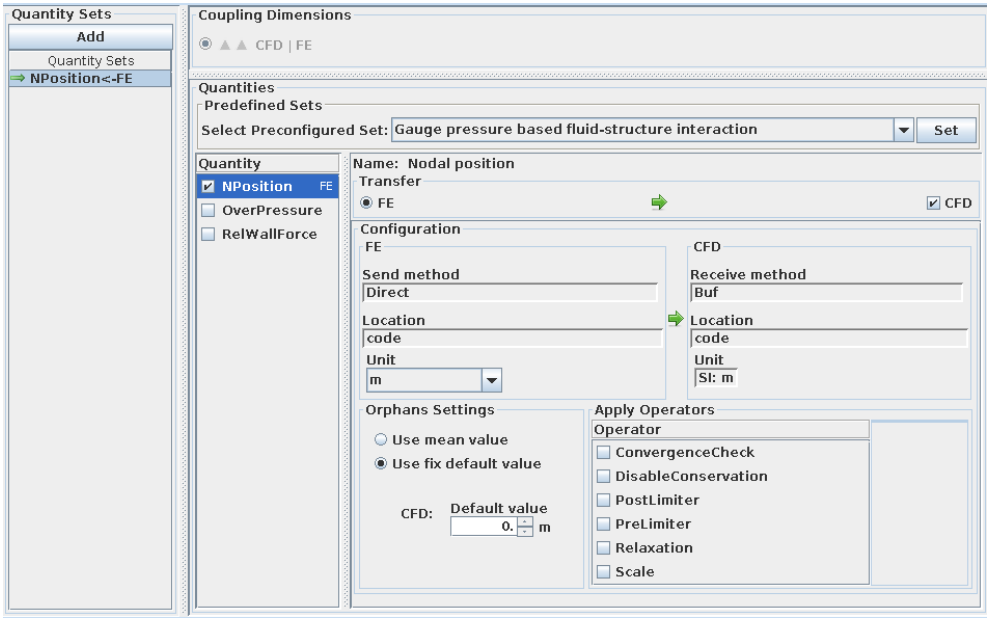


Figure 16: Deformation configuration

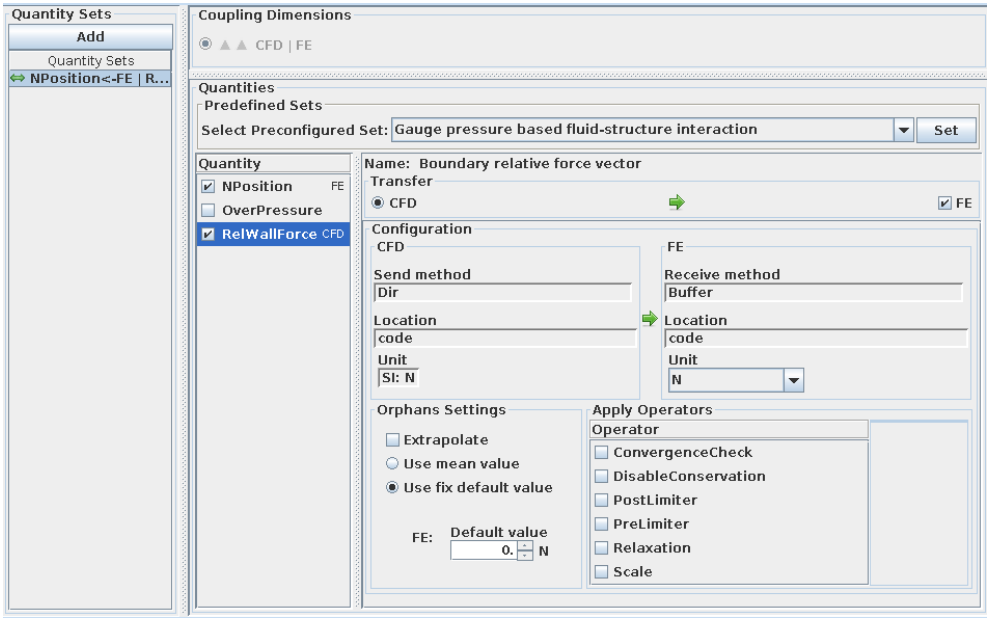


Figure 17: Pressure configuration

2.6.3 Assign Defined Quantities to Built Coupling Regions

Select the Assign Quantity Sets tab. It shows areas for Regions, For selected regions and Quantity Sets (see Figure 18):

Regions with lists of built regions separated by their coupling dimension.

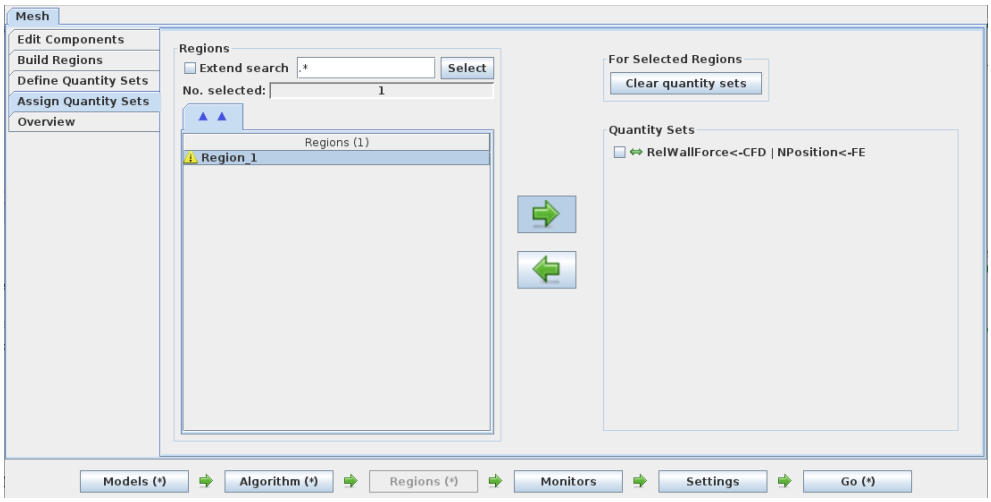


Figure 18: Assignment of quantity sets

For selected regions with actions regarding the selected regions in the region area.

Quantity Sets with quantity sets which may be assigned to the regions of the selected coupling dimension.

The list of built regions only shows regions which are in used state and which are complete meaning that enough components are added.

The shown state of the regions now corresponds to the state of quantity sets (see ▷ 2.6.2 Define Quantities to be Exchanged ◁):

- Region needs quantity sets to be assigned.
- Region is complete with unidirectional quantity transfer.
- Region is complete with bidirectional quantity transfer.

Assigning quantity sets is done by selecting regions and then marking the quantity sets which shall be assigned.

The arrow buttons between the regions and quantity sets areas change the view mode:

Select regions and assign quantity sets to them. This view is also automatically switched to when a region is selected out of the region list.

Show regions with all marked quantity sets assigned.

2.6.3.1 Assign Quantity Set to Coupled Region

In our example we built the coupling region Region_1 and the quantity set NPosition<–FE | RelWallForce<–CFD. Now we assign the quantity set to the coupling region by selecting the region Region_1 and marking the quantity set NPosition<–FE | RelWallForce<–CFD (see Figure 19).

The definition of the coupling interface is completed. For further information have a look at ▷ V-4.8 Regions Step ◁.

The next step is the Monitors step where you can define some quantities for specific code components to be monitored. For the time being we won't apply monitors. Therefor please skip the monitors and click on the Settings button to continue.

Figure 19: Assign quantity set

2.7 Settings Step – Specifying Further Coupling Options

In the MpCCI Settings step you may modify some MpCCI control parameters like

- online monitoring settings,
- attributes of the coupled job,
- parameters for search algorithm,
- switches controlling the output level for debugging or
- tracefile file format.

An overview of all control parameter properties is given in ▷ V-4.10 Settings Step ◁.

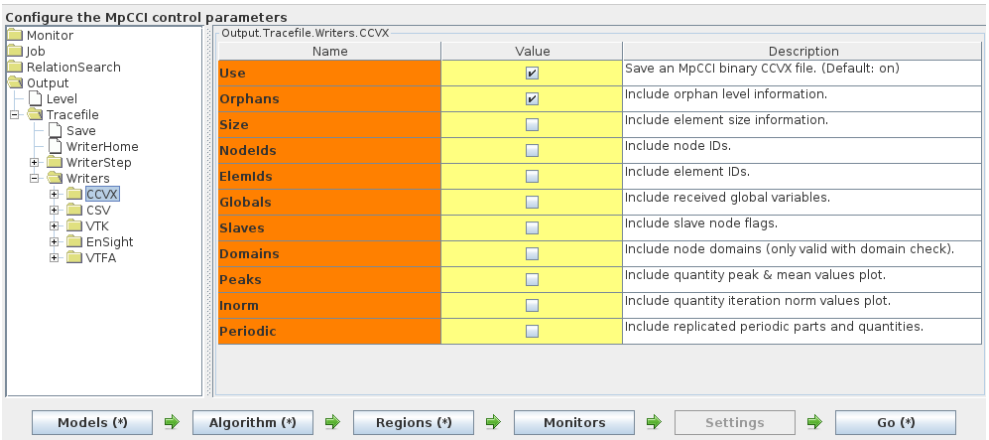


Figure 20: Settings step

The MpCCI GUI provides default values for all properties which can be modified.

The Settings step window displays a tree-like list of parameters on the left. On the right side the corresponding parameters are shown in a table as depicted in Figure 20. This table provides information such as

- the parameter name displayed with an orange background,
- the editable parameter value displayed with a yellow background,
- and a parameter description.

To select a parameter click on its name or its category in the parameters tree-like list. After that edit the value by clicking the cell with the value and select or type in the desired value for this control parameter.

For most cases the default values are appropriate, but for our example you may activate the control parameter for writing orphan level information for the MpCCI Visualizer's CCVX tracefile format which is Orphans in the category Output →TraceFile →Writers →CCVX. Additionally you may edit the output level (parameter Level in category Output) which tells MpCCI how much output will be written during the simulation process. The default value is minimal output - also available are no output, additional output and maximal output.

Now click on the Go button to proceed to the startup window for the coupled simulation.

2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation

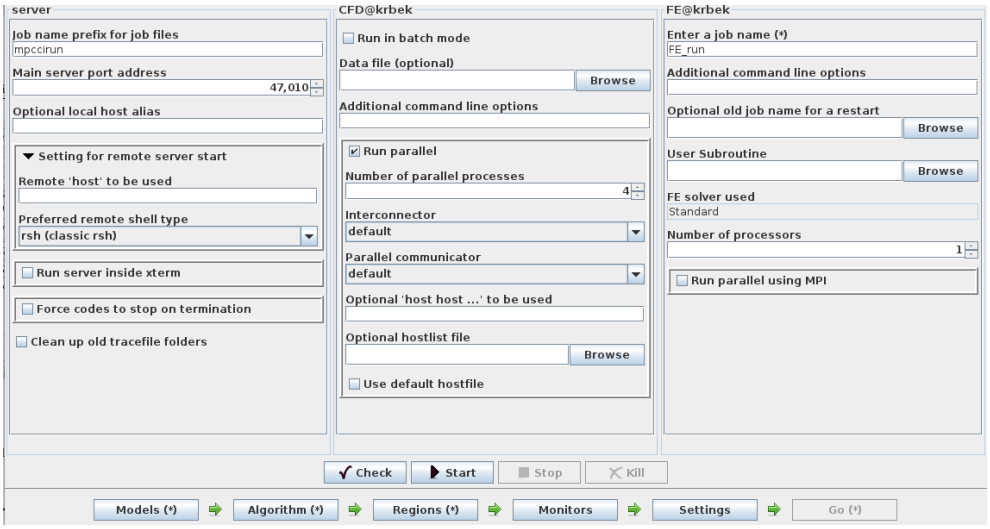


Figure 21: Go step

In the MpCCI Go step each application, MpCCI coupling server included, is shown in its own frame. The frame for the codes is titled with the code's name and the name of the host where they're running (see Figure 21). Below the code frames you find an area with buttons controlling the coupled application - Check, Start, Stop and Kill.

Before starting the coupled simulation you have to configure the startup of the applications. For the MpCCI coupling server you usually may retain the default values. For each analysis code you can set some runtime parameters if necessary.

2.8.1 Setting Runtime Parameters

For the CFD code select the Run parallel option. Now the parameters for running the CFD code in parallel are added to the window as shown in Figure 21. Set the number of processes to be applied e. g. to 4. If no hosts are specified the CFD code will run in parallel on the local machine.

For the FE code no more runtime parameters need to be set.

2.8.2 Creating a Project File

Before checking or starting a coupled simulation you have to establish a project by using Save As from the File menu. This is due to the fact that MpCCI needs the project file to generate its input file and to get information about the settings which were defined in the MpCCI GUI.

If you continue without creating a project, a dialog box appears reminding you to assign one.

2.8.3 Checking the Application Configuration

To cross-check the application configuration a ✓ Check button is provided (see Figure 21). Following check states can occur:

- ✓ Check Check results for the current configuration are not yet available. This is true if no check for the current project has been done or if the user changed the configuration.
- ✓ Check The project setup is verified.
- ⚠ Check The check has warnings but the simulation can be started taking the warnings into account.
- ✗ Check The check failed, so that the simulation cannot be started.

For the general settings it checks

- Whether all required parameters for server and codes are set.
- Whether all files that are specified as parameters are available.
- Whether the selected coupling algorithm configuration is valid and fits to the configuration of the exchanged quantities.
- Whether the optional code specific checkers pass.

At the end of the check a report with the results is shown and a summary of the coupling configuration is displayed as follows:

```
================================================================================
 server:    SUCCESSFUL
================================================================================

Coupling configuration summary:
-------------------------------
   Analysis           : Transient
   Coupling scheme    : Explicit
   Algorithm          : Parallel, CFD initializes
   Coupling frequency : Defined by each code

*** Warning:
  The first grid information for the coupled coordinates 'NPosition' might not be
  received
  when using a parallel algorithm with initializing code while the time steps of the
  codes don't match.

server CHECK SUCCESSFUL with warnings!


================================================================================
 CFD:    SUCCESSFUL
================================================================================
```

```
Coupling configuration summary:
-------------------------------
   Analysis           : Transient
   Algorithm          : Parallel, initializing
   Coupling frequency : Every solver step
   Coupling duration  : Not predictable

CFD CHECK SUCCESSFUL!


================================================================================
 FE:    SUCCESSFUL
================================================================================

Coupling configuration summary:
-------------------------------
   Analysis           : Transient
   Algorithm          : Parallel
   Coupling frequency : Every solver step
   Coupling duration  : Not predictable

FE CHECK SUCCESSFUL!
```

This check allows that the formal conditions are fulfilled ahead of the simulation start. The warning can be ignored because the initializing code sends the coordinates NPosition.

Optional checkers may be provided for each single code. See ▷ V-4.11.2 Checking the Configuration ◁ for more information.

2.8.4 Starting the Coupled Simulation

To start the coupled simulation click on the ▶ Start button (see Figure 21). If no check results are available for the current configuration (▷ 2.8.3 Checking the Application Configuration ◁), this at first cross-checks the application. Depending on the check results - if the check was successful or warnings displayed were accepted - the server is started. When the server is up and waiting for the codes the application codes are automatically launched one after the other. A black running symbol at the bottom of each application frame indicates that the application is running (▷ V-4.11.4 Status of the Simulation ◁).

After pressing the Start button all settings will be locked. It is also not possible to leave the Go step. Closing the MpCCI GUI lets the coupled application continue but it is not possible to connect the MpCCI GUI to it again.

Now the client codes are started and the coupling server starts the initialization phase as follows:

1. Initial handshaking: the CFD code and the FE code contact the server.

```
Waiting for incoming connections on "47010@nemo"...
[MpCCI License] mpcci_adapter_CFD: feature test...
[MpCCI License] mpcci_adapter_CFD: feature test done.
[MpCCI License] mpcci_clients: feature checkout...
[MpCCI License] mpcci_clients: feature checked out.
Waiting for incoming connections on "47010@nemo"...
[MpCCI License] mpcci_adapter_FE: feature test...
[MpCCI License] mpcci_adapter_FE: feature test done.
```

```
[MpCCI License] mpcci_clients: feature checkout...
[MpCCI License] mpcci_clients: feature checked out.
Loading code specific mesh and quantity settings for code "CFD":
   [...]
```

2. Exchange of the interface topology: The coupling server requests the interface topology from each client. The clients send their interface topology.

```
Loading code specific mesh and quantity settings for code "CFD":

   Code specific quantity properties:

      "RelWallForce": Location(CODE), Default(0)
         Send    : Method(0), Index(0)
         Receive : Method(0), Index(-1)

      "NPosition": Location(CODE), Default(0)
         Send    : Method(0), Index(-1)
         Receive : Method(0), Index(0)

   Code specific parts properties:

      "flap-surface": MeshId(1), PartId(1)
         Send   : "RelWallForce"
         Receive: "NPosition"

   Code specific mesh scale: 1

   Code specific mesh transformation:
                1            0            0            0
                0            1            0            0
                0            0            1            0
                0            0            0            1
      Det: 1

Loading code specific mesh and quantity settings for code "FE":

   Code specific quantity properties:

      "RelWallForce": Location(CODE), Default(0)
         Send    : Method(0), Index(-1)
         Receive : Method(0), Index(0)

      "NPosition": Location(CODE), Default(0)
         Send    : Method(0), Index(0)
         Receive : Method(0), Index(-1)

   Code specific parts properties:

      "outside": MeshId(1), PartId(1)
         Send   : "NPosition"
         Receive: "RelWallForce"
```

```
   Code specific mesh scale: 1

   Code specific mesh transformation:
                1           0           0           0
                0           1           0           0
                0           0           1           0
                0           0           0           1
      Det: 1
```

3. MpCCI coupling server performs neighborhood searches and computes the mapping between CFD code and FE code meshes.

```
   [...]
Loaded REL operator library "rel_ml-32d.so".

Loaded MAP operator library "map_ml-32d.so".

Code/Mesh/Part/Quantities relationships:

Code: "CFD", ID(1), nice(64), clients(1), type(Finite Volume).

   Mesh: "CFD/MESH-1", mid(1)
           Coord system: 3D
           Mesh type   : FACE
           Distances   : [0.001 .. 0.00312839]
           Bounding box: [-0.00717758 .. 0.00717758]
                         [-0.023 .. 0.025]
                         [-0.023441 .. 0.023441]
           Domain size : 0.004896

      Send: "RelWallForce"
              Dimension : 1
              Direction : SEND
              Location  : cell
              Default   : 0
              Buffers   : 1

      Recv: "NPosition"
              Dimension : 3
              Direction : RECV
              Location  : vertex
              Default   : 0
              Buffers   : 1
              Source    : "FE/MESH-1" -> rel_ml -> map_ml

      Part: "CFD/MESH-1/flap-surface", pid(1)
              Coord system  : 3D
              Mesh type     : FACE
              NVertices     : 997
              NCells        : 1948
                      Type1 : TRIA3
                      Ntypes: 1
              Total nodeids : 5844
```

```
              Total vertices: 5844
              Distances     : [0.001 .. 0.00312839]
              Bounding box  : [-0.00717758 .. 0.00717758]
                              [-0.023 .. 0.025]
                              [-0.023441 .. 0.023441]
              Domain size   : 0.004896

Code: "FE", ID(0), nice(64), clients(1), type(Finite Element).

   Mesh: "FE/MESH-1", mid(1)
           Coord system: 3D
           Mesh type   : FACE
           Distances   : [0.0005 .. 0.0033941]
           Bounding box: [-0.007178 .. 0.00717784]
                         [-0.023 .. 0.025]
                         [-0.0234407 .. 0.023441]
           Domain size : 0.00489598

      Send: "NPosition"
              Dimension : 3
              Direction : SEND
              Location  : node
              Default   : 0
              Buffers   : 1

      Recv: "RelWallForce"
              Dimension : 1
              Direction : RECV
              Location  : element
              Default   : 0
              Buffers   : 1
              Source    : "CFD/MESH-1" -> rel_ml -> map_ml

      Part: "FE/MESH-1/outside", pid(1)
              Coord system  : 3D
              Mesh type     : FACE
              NNodes        : 2805
              NElements     : 920
                      Type1 : QUAD8
                      Ntypes: 1
              Total nodeids : 7360
              Total vertices: 3680
              Distances     : [0.0005 .. 0.0033941]
              Bounding box  : [-0.007178 .. 0.00717784]
                              [-0.023 .. 0.025]
                              [-0.0234407 .. 0.023441]
              Domain size   : 0.00489598

Neighborhood relationship: "FE/MESH-1" -> "CFD/MESH-1"
rel_ml::create_mapmesh(MESH="FE/MESH-1"): new mesh representation.
rel_ml::create_mapmesh(MESH="CFD/MESH-1"): new mesh representation.
rel_ml::execute(MAPLIB_REL=0x8111728): Configuration:
```

```
  nodetolerance=8.38e-05
  normaldistance=0.000419
  tangentialdistance=0.000419
  distance=0.000419
  precision=1e-06
  multiplicity=15.5513
  orphaninfo=true
Starting closePoints search loop...
rel_ml::execute(MAPLIB_REL=0x8111728)
   -> 0.24 seconds CPU.
Neighborhood relationship: "CFD/MESH-1" -> "FE/MESH-1"
rel_ml::create_mapmesh(MESH="CFD/MESH-1"): using existing mesh representation.
rel_ml::create_mapmesh(MESH="FE/MESH-1"): using existing mesh representation.
rel_ml::execute(MAPLIB_REL=0x825dd00): Configuration:
  nodetolerance=8.38e-05
  normaldistance=0.000419
  tangentialdistance=0.000419
  distance=0.000419
  precision=1e-06
  multiplicity=15.5513
  orphaninfo=true
Starting closePoints search loop...
rel_ml::execute(MAPLIB_REL=0x825dd00)
   -> 0.08 seconds CPU.
   [...]
```

In our example the parallel coupling algorithm is used with CFD as initializing code as shown in Figure 22. Before starting the computation the CFD code sends the surface forces RelWallForce to the FE code (1). Then both codes compute in parallel their solution quantities pressure and deformation until the coupled target time is reached (2). Now the solution quantities are exchanged (3). Possible coupling algorithms are described in detail in ▷ V-3.4.1 Coupling Algorithm ◁.

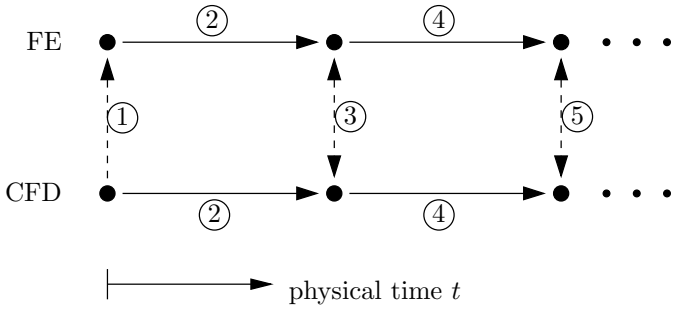


Figure 22: Parallel coupling algorithm with initializing code

When an application exits, the running button changes to a button which gives access to the information collected from the application output.

At the end of the simulation after all applications have ended, a status message is displayed (▷ V-4.11.4 Status of the Simulation ◁).

2.8.5 Interrupting the Computation

While the applications are running, the Stop and Kill buttons (see Figure 21) are enabled and provide following functionalities:

Stop to terminate all applications by sending a stop signal or by executing the `"Stopper"` application module if available. The stop call may not immediately take effect, because it depends on the implementation of the stop procedure in the simulation code.

Kill to terminate all applications by sending a kill signal or by executing the `"Killer"` application module if available.

To modify parameter settings you have to terminate the applications by pressing the Kill button. Otherwise the editing of parameter values is disabled.

3 Checking the Results

3.1 The MpCCI Visualizer

The MpCCI Visualizer is suitable for a quick check whether the coupling process was successful. The coupling region, orphaned nodes and exchanged quantities can be checked to ensure that the specified coupling has really occurred. Here only a short introduction is presented, a concise description of the MpCCI Visualizer is given in ▷ V-7 MpCCI Visualizer ◁.

During the coupling process the MpCCI server writes a "tracefile", i. e. a collection of the exchanged data (see Figure 3 and ▷ 2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation ◁). To obtain a tracefile, the checkbox Use must be selected in the Settings step for the selected Writers. The default name of the tracefile is `"mpccirun-0000.ccvx"`, it can be changed in the Go step of the MpCCI GUI by changing the Job name prefix for job files. This prefix is used to create a directory containing the tracefile. This directory begins with the prefix used, a timestamp and ends with the suffix of the type of writer used,
e. g. mpccirun_<TIMESTAMP>_ccvx.

After a simulation the MpCCI Visualizer can be started by selecting Tools→Visualizer from the MpCCI menu or by entering the command `mpcci visualize`. Tracefiles can even be opened with the MpCCI Visualizer before the completion of a computation.
Example:

```
mpcci visualize mpccirun-0000.ccvx
```

The visualizer starts with the results window, which is depicted in Figure 1. On the left side the data to display can be selected including the exchanged quantities by activating the Result Panel. In Figure 1 the quantity NPosition is additionally displayed as deformation in the window. Both the quantities which are sent, i. e. before the interpolation, and the quantities which are received are displayed. As sent and received data are normally defined at the same locations, both parts can be superimposed or separated by using additional viewports.

Transient analyses consist of several steps, the step number can be selected in the control window.

The MpCCI Visualizer can not replace a post-processing tool, as the tracefile only obtains information from MpCCI, which solely covers the coupling region. Information on other regions of the analysis may be available by creating additional monitors in the Monitor step.

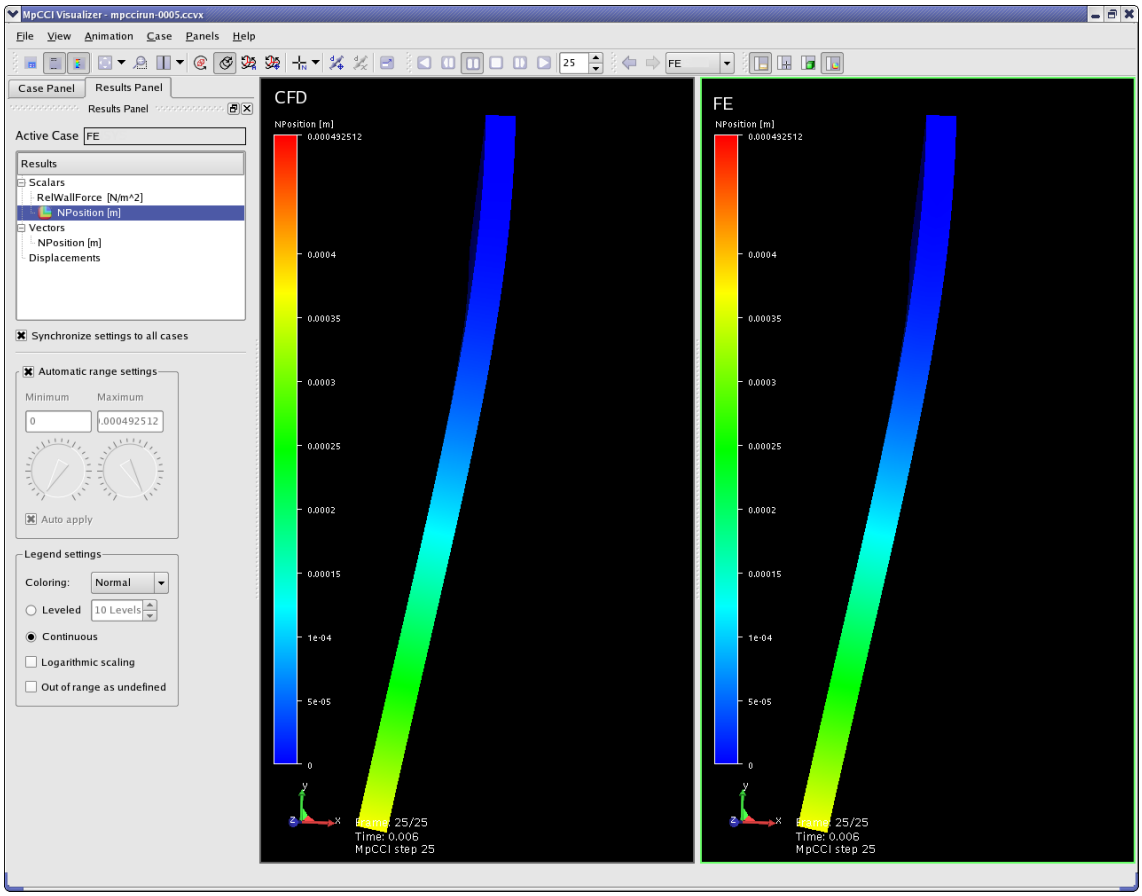
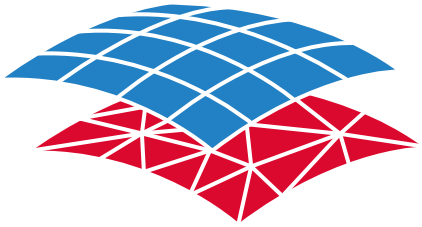


Figure 1: Main window of the MpCCI Visualizer

3.2 Post-Processing

During a coupled simulation both codes should write their results to appropriate files. The visualization of these results can be carried through with built-in tools of the simulation codes. Unfortunately the built-in post-processing tools solely allow the visualization of one part of the problem. In our example this means, that you can display the fluid properties with one tool and the structural properties with the other tool.

There is general post-processing software, which can read output data from different standardized formats and combine results from different files. Describing these tools is however beyond the scope of this manual.



MpCCI
CouplingEnvironment

Part V

—

User Manual

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part V User Manual
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V User Manual – Contents

1 Introduction

This user manual shall give an overview of the basic structures and features of MpCCI. All code-specific issues are discusses in the chapters of the Codes Manual.

1.1 Basic Structure of MpCCI

MpCCI is a software environment which enables the exchange of data between the meshes of two simulation codes in a multiphysics simulation. The architecture of this coupling process is shown in Figure 1.

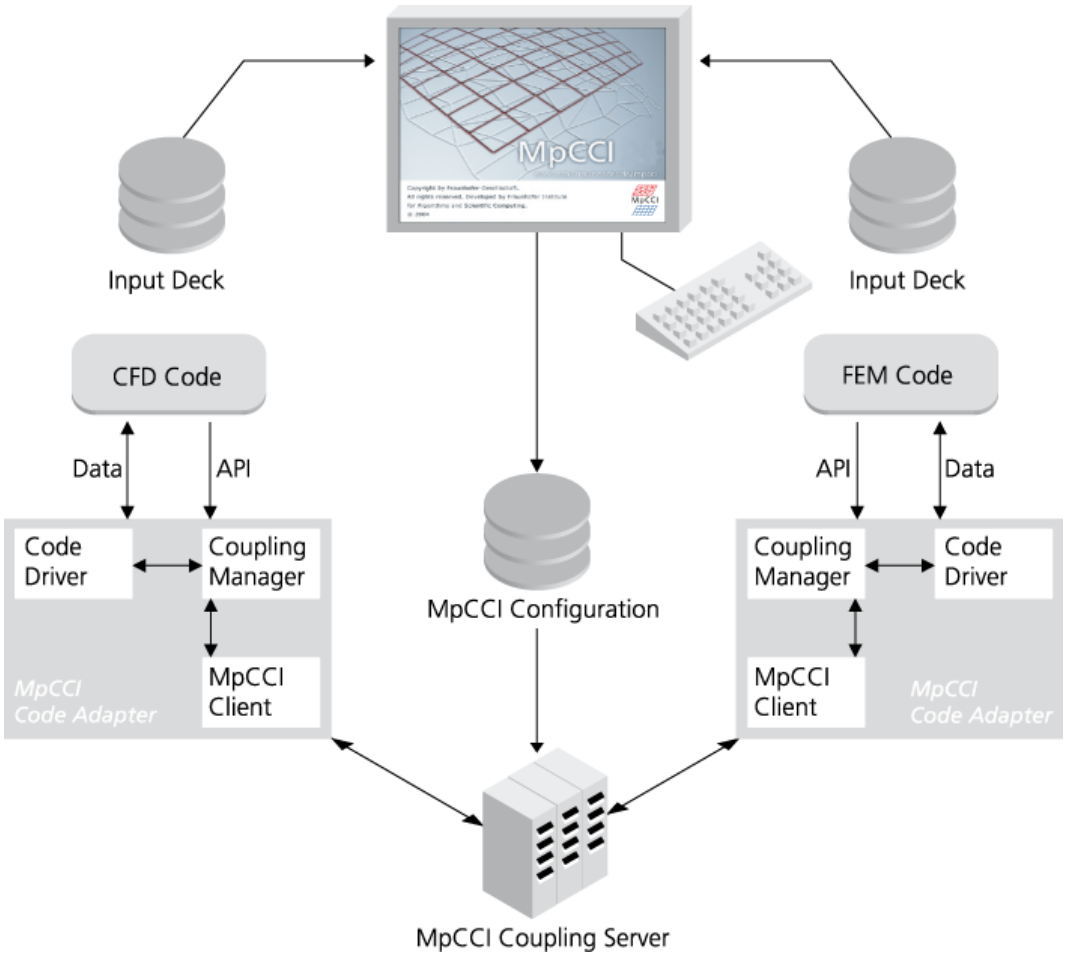


Figure 1: MpCCI architecture

MpCCI enables a direct communication between the coupled codes by providing adapters for each code. These code-adapters make use of already existing application programming interfaces (APIs) of the simulation tools. This technique allows an easy installation of MpCCI at the end users site without changing the standard installation of the simulation codes.

Since the meshes belonging to different simulation codes are not compatible in general, MpCCI performs an interpolation. In case of parallel codes MpCCI keeps track on the distribution of the domains onto different processes. MpCCI allows the exchange of nearly any kind of data between the coupled codes; e. g.

energy and momentum sources, material properties, mesh definitions, or global quantities. The details of the data exchange are hidden behind the concise interface of MpCCI.

The MpCCI environment consists of several components:

- MpCCI code-adapters allow to adapt MpCCI to commercial codes through their standard code APIs without any changes in the source of the simulation code.
- The MpCCI GUI provides a comfortable way to define the coupling setup and to start the simulation - independent of the codes involved in the coupled application, it is described in ▷ 4 Graphical User Interface ◁
- The MpCCI coupling server is the "heart" of the MpCCI system. Environment handling, communication between the codes, neighborhood computation, and interpolation are part of this kernel.

2 The MpCCI Software Package

2.1 Introduction

MpCCI is not a single executable, but a complex software package, which consists of the following parts:

Coupling server and clients. The "heart" of MpCCI, which is responsible for the code coupling process, see ▷ 3 Code Coupling ◁.

MpCCI Visualizer. The MpCCI visualizer is a tool for checking the coupling process. Meshes and transferred quantities can be displayed. See ▷ 7 MpCCI Visualizer ◁ for more information.

Collection of small tools. A variety of small tools is included in the MpCCI software package. These are useful for obtaining information on the computing environment, installation and licensing issues, and job control. A description of these tools is given in ▷ 5 Command Line Interface ◁.

MpCCI Grid Morpher. In some coupled analyses the coupling surface is moving during the simulation. If one of the coupled codes does not provide a morphing tool itself, the MpCCI Grid Morpher can be used, see ▷ 8 MpCCI Grid Morpher ◁.

These parts of MpCCI can basically be accessed in two ways:

- Through the graphical user interface, MpCCI GUI, which offers a convenient way to define a coupled simulation, starting and controlling jobs. Most of the MpCCI tools can be started directly from the MpCCI GUI. An introduction to using the MpCCI GUI can be found in Getting Started. A concise description of all MpCCI GUI features is given in ▷ 4 Graphical User Interface ◁.
- All parts of MpCCI can be run directly from the command line (i. e. by typing commands in a shell in UNIX/Linux or the DOS shell in Windows). Besides starting the main parts of MpCCI, a collection of small tools is offered. These tools can be used to gather important information, to deal with licensing issues and to control the coupling process. All available commands are described in ▷ 5 Command Line Interface ◁.

2.2 The MpCCI Home Directory

MpCCI resides completely within one directory with subdirectories. This MpCCI home directory is referred to as `MPCCI_HOME`.

This directory is created during the installation of MpCCI. For selection of the path, please see the Installation Guide. The only requirement, which must be met to run MpCCI properly is that the MpCCI executable, which is located in `"MPCCI_HOME/bin"` must be included in your `PATH` environment variable.

The `MPCCI_HOME` directory contains a number of subdirectories:

`"bin"` The MpCCI binaries, which contains the MpCCI main program `"mpcci"` or `"mpcci.exe"` and the MpCCI shell `"mpccish"` or `"mpccish.exe"`. The MpCCI shell is executed by MpCCI on remote machines.

`"codes"` contains all code-specific files, in separate subdirectories for each code and one for the MpCCI server. Each subdirectory includes information for the MpCCI GUI (`"gui.xcf"`), and some Perl scripts (`"*.pm"`) for scanning of input files, starting and stopping the coupled codes. These are called by MpCCI during the coupling process.

`"dist"` contains distribution information, which is required for patch updates.

`"doc"` contains the MpCCI documentation, which can be accessed with the `mpcci doc` command, see ▷ 5.5.2 mpcci doc ◁ on page 153

`"gui"` is the base directory of the MpCCI GUI, containing configuration files and the `".jar"` archives of the MpCCI GUI.

`"include"` contains header files, which are necessary for developing code adapters, see Programmers Guide.

`"jre"` contains a Java distribution which is required for MpCCI.

`"lib"` contains libraries, which are necessary for developing code adapters, see Programmers Guide.

`"license"` contains the license software FlexNet Publisher, which is used by MpCCI. All license files should also be placed in this directory.

`"perlmod"` contains various Perl modules, mainly small helper tools.

`"tutorial"` contains the input files needed for trying the examples described in the Tutorial.

Do not edit any of the files in the `MPCCI_HOME` directory unless you know what you do. Improper changing of files may destroy your MpCCI distribution, which makes a new download necessary.

2.3 Environment and Environment Variables

MpCCI uses environment variables to transport information between subprocesses and processes created on remote hosts. Most of the environment variables are volatile, some are not. You may display the MpCCI related environment variables with the command `mpcci env`.

MpCCI distinguishes two categories of variables:

Control variables are named `MPCCI_...` and may be defined before starting MpCCI to control the behavior of MpCCI. An overview of these variables is given below.

Internal variables begin with an underscore `_MPCCI_...` are volatile environment variables used internally by MpCCI and should not be set by the user. Internal variables which are related to a specific code are also named accordingly, i. e. `_MPCCI_`<*code name*>`_...`.

All internal variables are intended for internal use only and are subject to change without notice. Changing these variables may yield malfunction of MpCCI, they should not be used by any external application.

MpCCI Control Variables

The MpCCI control variables are:

`MPCCI_ARCH`	Contains the MpCCI architecture token, which is used to identify the platform	▷ 2.3.1 MPCCI_ARCH - Architecture Tokens ◁
`MPCCI_DEBUG`	If defined, MpCCI runs in debug mode	▷ 2.3.2 MPCCI_DEBUG - for Debugging ◁
`MPCCI_HOSTLIST_FILE`	Path to file which contains a list of possible hosts for parallel runs	▷ 3.6.1 Client-Server Structure of MpCCI ◁
`MPCCI_TINFO`	Passed to the code adapter to determine the coupling algorithm	▷ VIII-2.4.8.1 MPCCI_TINFO Variables ◁
`MPCCI_LICENSE_FILE`	Location of the MpCCI license server	▷ III-5.3 Defining the License Server ◁
`MPCCI_LICENSE_TIMEOUT`	Timeout for license check	▷ III-5.3 Defining the License Server ◁
`MPCCI_REMOTE_HOSTNAME`	Name of the host seen by a remote system	▷ 3.6 Running MpCCI in a Network ◁
`MPCCI_RSHTYPE`	Type of remote shell used by MpCCI	▷ 3.6.3 Remote Shell and Remote Copy ◁
`MPCCI_NETDEVICE`	Define a network interface name to be used for the socket communication between the MpCCI server and the coupled simulation codes	▷ 3.6.1 Client-Server Structure of MpCCI ◁
`MPCCI_NOREMSH`	Disable errors if remote shell tools is not available on the local machine if defined	
`MPCCI_TIMEOUT`	Client connection timeout	▷ 3.6.1 Client-Server Structure of MpCCI ◁
`MPCCI_TMPDIR`	Path to temporary directory	▷ 2.5 Temporary Files ◁

System Variables

In addition to the control variables, MpCCI evaluates some system variables:

General variables (all OS)

JAVA_BINDIR JAVA_HOME JAVA_ROOT JDK_HOME JRE_HOME	These variables are evaluated by MpCCI to find the Java installation.	
PATH	The list of directories which is searched for executables. "MPCCI_HOME/bin" must be included in the path.	▷ III-2 Before the Installation ◁

Windows variables

ALLUSERSPROFILE	location of All Users Profile	
COMSPEC	secondary command interpreter	
HOMEDRIVE HOMEPATH	These variables define the home directory, which is referred to as HOME in this manual.	
PROCESSOR_ARCHITECTURE PROCESSOR_ARCHITEW6432	The MpCCI architecture token is defined according to the values of these variables	
USERPROFILE	Used to determine the home directory of a user on a remote machine.	▷ 2.6.3 Remote Shell and Remote Copy ◁ on page 18

UNIX/Linux variables

HOME	The home directory, which is referred to as HOME in this manual.	

2.3.1 MPCCI_ARCH- Architecture Tokens

MpCCI uses architecture tokens to identify a platform. A list of architecture tokens and currently supported platforms is given in ▷ II-5 Supported Platforms in MpCCI 4.7 ◁.

Before the setting of this variable is really required you should get a list of all installed MpCCI platforms. The command `mpcci list archs` shows all available MpCCI platforms installed on a file server.

The variable MPCCI_ARCH holds the architecture token of MpCCI and is usually set by MpCCI automatically since MpCCI is capable to figure out the platform it is running on. This variable should never be set by the user.

However there may be a situation where this mechanism fails:

- MpCCI is confused to find out the platform
- MpCCI selects a wrong architecture
- MpCCI can not find the installation for your platform

MPCCI_ARCH must be set to a valid architecture token.

Examples:

- You are running under AIX 5.3, but only the `aix51_power` is installed. MpCCI will complain:
  `MPCCI_ARCH=aix51_power`
  solves your problems since 5.1 software can run under 5.3.
- You have a Linux system on an Itanium processor, however `lnx3_ia64` is not installed:
  `MPCCI_ARCH=lnx3_x86`

solves your problem since Itanium is 32 bit x86 compatible.

2.3.2 MPCCI_DEBUG- for Debugging

This variable is optional, it needs not be defined.

If MPCCI_DEBUG is defined and its value is not false (any value except empty or 0), then detailed logging output is produced to find out some pitfalls in case of failures.

Whenever the -debug option appears on the command-line of the mpcci command

```
mpcci arg1 arg2 ... -debug ... argn
```

MPCCI_DEBUG will be set to 1.

2.4 The MpCCI Resource Directory

For storing permanent files related to your personal account MpCCI uses the subdirectory `".mpcci"` within your home directory.

If there is no directory `"<`*Home*`>/.mpcci"` MpCCI will create one whenever you start MpCCI.

`"<`*Home*`>/.mpcci"` contains the following MpCCI related files:

`"mpcci.hosts"` A hostfile listing possible remote MpCCI hosts

`"tmp"` The temporary MpCCI directory

You should avoid to delete this directory once it was created and contains files.

2.5 Temporary Files

At runtime MpCCI needs to store intermediate information and creates temporary scripts - shell scripts under UNIX or '.bat'-files under Microsoft Windows- which wraps commands or are copied from the local host to a remote system via the remote copy commands `rcp` or `scp`. Some of the temporary files are created in the current working directory (where the MpCCI application runs or where the MpCCI server was started) and are removed after successful use, others are kept for the duration of the MpCCI session.

MpCCI maintains a list of these long term temporary files created during a session and tries to remove them at the end. Long living temporary files from the last category are stored per default in the directory `"<HOME>/.mpcci/tmp"`.

In some cases it might happen that MpCCI is killed or dies because of a signal or an exception. To eliminate all temporary files in such a case you may either delete the complete `"tmp"` directory or use the MpCCI command

```
mpcci clean
```

which removes all temporary files.

Never remove temporary files as long as a simulation is running.

An MpCCI temporary directory will be created whenever you start MpCCI.

Environment Variable MPCCI_TMPDIR: Shared HOME and Alternative Directory for Temporary Files

Instead of using the default directory for temporary files you may want to assign a different directory to MpCCI as a temporary directory, e. g.

- `"/tmp"` or `"/var/tmp"` under UNIX
- `"C:\WINDOWS\Temp"` under Microsoft Windows

There are some reasons to redirect the temporary directory:

Your home directory may be physically located on a remote system. Then `"<`*Home*`>/.mpcci/tmp"` is also located on this remote file-server.

Under UNIX this may be an NFS based directory, which is mounted automatically by the `automounter` (NFS is the Network File System). Under Microsoft Windows your `"<`*Home*`>\.mpcci\tmp"` may be either on an Microsoft Windows file-server or a UNIX file-server mounted to your Microsoft Windows PC via the Samba tool.

In the latter case accessing temporary files in `"<`*Home*`>/.mpcci/tmp"` should be quite fast, but also NFS may sometime lead to out-of-sync delays for a few seconds. This delay may interrupt process communication if the timeout-limit has been defined with a too small value (of less than 10 seconds).

If your MpCCI job runs into trouble with timeouts and missing files and if you know about the fact that your home directory is on a remote host and mounted automatically, then it would be better to use a temporary directory on a locally mounted disc.

You may specify the pathname of an alternative temporary directory by setting the environment variable

```
MPCCI_TMPDIR=path_to_a_temporary_directory
```

to a valid directory.

Note that you need to have write access to that directory before starting MpCCI.

If the environment variable MPCCI_TMPDIR is not defined before you start MpCCI, then MpCCI uses the default "<*Home*>/.mpcci/tmp" and sets MPCCI_TMPDIR automatically.

If the environment variable MPCCI_TMPDIR is defined before you start MpCCI, then the value of this variable defines the temporary files directory.

2.6 Third Party Software Used by MpCCI

2.6.1 Perl

A large part of the platform-independent functionality of MpCCI is realized with Perl scripts. Perl is available for all platforms supported by MpCCI and already included in Linux distributions.

The installation of Perl is described in ▷ III-9 Installing Perl ◁.

For more information on Perl please visit the Perl website www.perl.org.

2.6.2 Java

The MpCCI GUI is based on Java. To run the MpCCI GUI a Java virtual machine is required.

2.6.3 Remote Shell and Remote Copy

MpCCI uses the remote shell rsh or secure shell ssh to start processes on remote computers. For copying files rcp or scp are used. See ▷ 3.6 Running MpCCI in a Network ◁ for a detailed description of remote computing.

On Microsoft Windows systems, no remote shell is included in the operating system, therefore the either the MpCCI-RSH or the OpenSSH or both must be installed for MpCCI, see ▷ III-2.6 MpCCI-RSH for Windows ◁,▷ III-2.5 OpenSSH for Windows ◁.

3 Code Coupling

MpCCI is a tool to perform multiphysics computations by coupling independent simulation codes. A general introduction to this approach is already given in ▷IV-1 Multiphysics Computation with MpCCI ◁. Each of the coupled codes is independent. The coupling is achieved by exchanging data in the coupling region. This procedure can be split up into two basic issues: *How* data is transferred and *when* data is transferred. The first issue is the topic of ▷3.3 Data Exchange◁, possible coupling algorithms, which determine the exchange time, are discussed in ▷3.4 Coupling Process◁.

This section only gives a short overview of the methods used in MpCCI and explains the options which can be chosen. The description mainly considers a surface coupling, point, line and volume coupling work analogously.

3.1 Multiphysics

3.1.1 Physical Domains

A physical domain is usually characterized by a set of unknown equations which describe certain properties of a material.

The simulation code can be classified according to the physical domains, i. e. the problems which they can solve. The domains known by MpCCI are:

Domain	**MpCCI Token**
Solid mechanics	`SolidStructure`
Fluid mechanics	`Fluid`
Solid heat transfer	`SolidThermal`
Fluid heat transfer	`FluidThermal`
Acoustics	`SolidAcoustics`
Heat radiation	`Radiation`
Electromagnetism	`ElectroMagnetism`
Fluid hydrodynamics	`FluidHydrodynamics`
System	`System`


In MpCCI physical domains are rather chosen to fit typical capabilities of simulation codes (cf. ▷VIII-2.4.1 Code Information: `<CodeInfo>`◁) than to clearly distinguish branches of physics.

3.1.1.1 Solid Mechanics

Solid mechanics describes the behavior of solid bodies when exposed to external load. Usually deformation, stresses and strains of structures are computed using the Finite Element Method (FEM), thus structural mechanics codes are often simply known as Finite Element codes, although the method is not limited to solid mechanics. The governing equations of solid mechanics problems are the mechanical equilibrium and Newton's laws of motion. These are completed by material equations which describe the behavior of different materials.

3.1.1.2 Fluid Mechanics

Fluid mechanics deals with the behavior of fluids, e. g. flows of liquids or gases. A common term for the numerical simulation of fluid mechanics is Computational Fluid Dynamics (CFD), thus fluid mechanics codes are known as CFD-codes. The governing equations are the Navier-Stokes equations and the continuum hypothesis.

3.1.1.3 Solid Heat Transfer

Heat transfer in solids is based on heat conduction. Usually boundary temperatures and heat sources are given and the heat distribution shall be computed. The governing law of heat conduction can usually be solved by solid mechanics codes. Heat transfer via radiation is discussed separately below.

3.1.1.4 Fluid Heat Transfer

Heat transfer in fluids differs from that in solids as heat is transferred not only by heat conduction but also by convection. Most fluid codes can also compute heat transfer.

3.1.1.5 Acoustics

Acoustics studies sound effects, i. e. wave propagation in solids and fluids. Usually this is coupled with vibration analyses. Physically this is a subbranch of solid or fluid mechanics, but the simulation methods are different.

(The name `SolidAcoustics` in MpCCI refers to solid mechanics codes which can also compute acoustic problems).

3.1.1.6 Heat Radiation

Heat transfer by radiation is separated from solid and fluid heat transfer because specialized simulation codes exist for this issue. They compute the heat distribution caused by electromagnetic radiation (e. g. infrared light), which is emitted by bodies or fluids.

3.1.1.7 Electromagnetism

Electromagnetism deals with the computation of electric and magnetic fields. This includes the computation of electric currents and resulting forces. The governing equations are Maxwell's equations.

3.1.1.8 Fluid Hydrodynamics

The fluid hydrodynamics deals with the motion of fluids and the forces acting on solid bodies immersed in fluids or on liquids, gas in motion.

3.1.1.9 System

System provides computational models at a system level. System could describe:

- a thermo-fluid system modeling fluid mechanics in complex piping and ducting systems. The system simulates flows of gases, liquids, heat and mass transfer.
- a multi-dynamics body system. The system simulates the dynamics of moving bodies and how load and forces ares distributed throughout mechanical systems.

3.1.2 Coupling Types

Among the many possible combinations of physical domains, there are some pairs which are often used in multiphysics simulations together with a typical set of quantities which are exchanged. These combinations

of domains and quantities are called *coupling types* in MpCCI.

The MpCCI GUI offers some predefined coupling specifications to select, see ▷ 4.5 Coupling Specifications ◁. Some typical coupling types will be described in the following.

3.1.2.1 Fluid-Structure Interaction (FSI)

In an FSI simulation, usually a structure deforms due to forces caused by a fluid flow while the deformation changes the fluids boundary. The deformation must be transferred to the CFD code, which corresponds to the quantity "Nodal position" (NPosition), while forces are sent from CFD to the structural code, e. g. "Boundary absolute force vector" (WallForce), "Boundary relative force vector" (RelWallForce), "Absolute pressure" (AbsPressure) or the "Relative pressure" (OverPressure).

CFD codes usually use a reference pressure, i. e. the atmospheric pressure, which is not considered in structural codes. For a coupled simulation it is therefore recommended to transfer the relative pressure only, i. e. RelWallForce or Overpressure instead of WallForce and AbsPressure which include the reference pressure. Please consult the appropriate section of the Codes Manual for more information on the reference pressure in a specific simulation code.

The usage of a force quantity (WallForce, RelWallForce) will automatically take into account any wall shear effects due to the fluid property. The transfer of pressure quantity (AbsPressure, OverPressure) is therefore recommended if these effects are neglectable.

For fluid-structure interaction, there are predefined coupling specifications that can be looked up in ▷ 4.5.2 Category: Fluid-Structure Interaction (FSI) ◁. In some cases a one-way mapping is sufficient.

FSI is used in the following tutorials:
▷ VII-2 Elastic Flap in a Duct ◁
▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁
▷ VII-4 Driven Cavity ◁
▷ VII-5 Pipe Nozzle ◁
▷ VII-6 Blood Vessel ◁
▷ VII-7 Periodic Rotating Fan Model ◁

3.1.2.2 Thermal Coupling

Thermal coupling is applied if heat transfer is to be computed in a system consisting of a structure and a fluid. At the boundary, i. e. the surface of the structure, both share the same temperature and thermal energy is exchanged as heat flux.

There are two basic combinations of quantities which can be exchanged:

- Exchange of temperature (Temperature or WallTemp) and the heat flux (WallHeatFlux). The temperature is typically sent by the structural (or radiation) code, while the fluid code is sender of the heat flux. This corresponds to the predefined coupling specification General Surface Heat Transfer in ▷ 4.5.4 Category: Thermal Surface ◁.
- Exchange of temperature (WallTemp), film temperature (FilmTemp) and the heat coefficient (WallHTCoeff). As above, the wall temperature is sent by the structural code. The fluid code sends the film temperature and wall heat transfer coefficient, a combination which can be directly applied as boundary condition by most structural codes. The heat transfer coefficient h is computed from the heat flux q and the difference between the wall temperature T_w and the adjacent fluid cell temperature T_c in the adapter of the fluid code:

$$h = \frac{q}{T_w - T_c}$$

See coupling specifications in ▷ 4.5.3 Category: Thermal Radiation ◁ and ▷ 4.5.4 Category: Thermal Surface ◁ for predefined configurations.

The second approach is recommended because it is more stable.

Thermal coupling is used in the tutorials
▷ VII-8 Exhaust Manifold ◁
▷ VII-9 Cube in a Duct Heater ◁

3.1.2.3 Electrothermal Analysis

The resistive loss of electric currents corresponds to a heat source while the temperature influences the resistivity of conductors. This problem is addressed with an electrothermal analysis, which combines electromagnetism with heat transfer. The quantities which should actually be exchanged are the electric resistivity and the temperature. However, most heat transfer codes cannot compute the resistivity directly, which is therefore done using user-defined functions. The quantity combination depends on the decision in which code these additional computations are carried through.

The coupling specifications in ▷ 4.5.6 Category: Electrothermal ◁ correspond to this procedure.

A simple example is shown in the tutorials
▷ VII-10 Busbar System ◁
▷ VII-11 Three Phase Transformer ◁

3.1.2.4 Magnetohydrodynamics Analysis

Magnetohydrodynamics analysis consists of the study of the magnetic properties and behaviour of electrically conductive fluids. This analysis addresses the coupling of Maxwells'equations of electromagnetism and Navier-Stokes equations of fluid dynamics. The moving conducting fluids such as plasmas, liquid metals, electrolytes, etc. are influenced by a magnetic field creating an induced current, which polarizes the fluid and alternatively changes the magnetic field itself. The quantities which should actually be exchanged are at least the electric conductivity or resistivity, the Joule heat, the Lorentz force. However, most fluid hydrodynamics codes cannot compute the conductivity, respectively resistivity directly, which is therefore done using user-defined functions.

A special application in this area is electric arc computation.

The coupling specifications in ▷ 4.5.5 Category: Magnetohydrodynamics (MHD) ◁ correspond to this procedure.

3.2 Mesh Checks

After all the codes delivered the mesh information, MpCCI server checks the following information of the coupling regions:

- the mesh id: the coupled mesh must have an identical id.
- the mesh dimension: the coupling dimension type is checked.
- the coordinate system type: Code must work in the same coordinate system.
- the mesh motion type.
- the overlapping and bounding box.
- the quantity must have a source mesh for the mapping.

Additional information concerning the defined mesh for the coupled simulation can be activated. These information may be useful to understand the origin values of the quantity on the source target. It helps to

detect issue in mesh partition or boundaries definition. The setting options are available in the Job section at the MpCCI GUI Settings step (▷ 4.10.2 Job ◁).

The option usage for DomainCheck and Slaves are described in the following section.

3.2.1 Mesh Motion Checks

If the moving mesh transformation within the MpCCI server is enabled (MeshMotion parameter in ▷ 4.10.2 Job ◁), MpCCI verifies if the motion component definitions (translation vector, rotation) are matching.

3.2.2 Bounding Box Checks

The bounding box checks are started before beginning the neighborhood search. For each of the coupled meshes in a coupling region, the bounding box is computed. This box is a rectangular box with sides parallel to the coordinate axes, which contains the whole mesh. The bounding boxes thus represent the total size of the meshes.

The checks cover such issues for the coupling:

- Grid length issue. User has to check the unit system used.
- Coupling region does not overlap at all.
- No proper overlapping of the coupling region.

If the coupling region does not properly overlap as shown in Figure 1 and the user wants to apply default values on the orphaned region, the user should deactivate the overlap check by deselecting the OverlapCheck parameter in ▷ 4.10.2 Job ◁.

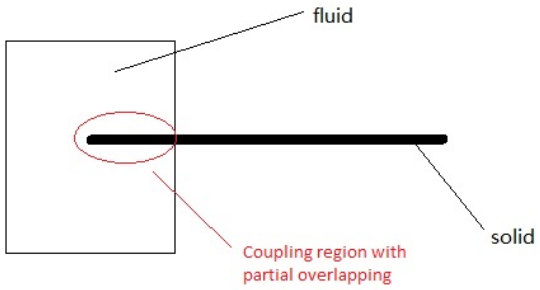


Figure 1: Partial overlapping for the coupling region exceeding 2.5 times the overlapping size in one direction

3.2.3 Domain Check

This option provides the capability to find the total number of domains of a mesh, part. This can be activated from the DomainCheck parameter in ▷ 4.10.2 Job ◁.

This option can be used to check the quality of the mesh partition. Strap elements of a mesh can be isolated and visualized by activating additionally the option for the Monitor and / or Writers. This feature

can be used for understanding some mapping problem especially in the case of partial overlapping meshes. This check is executed for each neighborhood search and is an expensive operation in case of using it with remeshing.
The information output is logged in the MpCCI server log file after the Job information block.

```
[MpCCI-SERVER]: *** Job information:
   Interpolation order       : Higher order
   Mesh motion transformation: Disable
   MRF correction            : Disable
   Overlap check             : Enable
   Domain check              : Enable
   Baffle shift              : Disable
   Conformal mesh mapping    : Disable
   Time tolerance            : 0.001000


Code/Mesh/Part/Quantities relationships:

Code: "RadTherm", ID(0), nice(64), clients(1), type(Radiation).


   Mesh: "RadTherm/MESH-1", mid(1)
       Coord system  : 3D
       Mesh type     : FACE
       NPoints       : 54053
       Bounding box  : [0.0254534 .. 1.84765] [-0.53021 .. 0.530219] [-0.130555 .. 0.308253]
       NFaces        : 53167
       Total nodeids : 212238
       Total vertices: 212238
       Distances     : [1.0443e-05 .. 0.0161794]
       Mean distance : 0.00611897
       Domain size   : 1.45841
       Domain count  : 2
          Domain  0  : 53165 faces
          Domain  1  : 2 faces
```

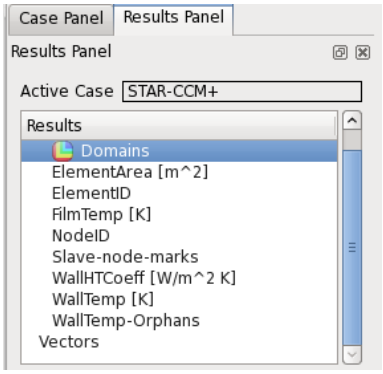
You can find for each coupled mesh the total number of domains (Domain count) and get the information about the number of elements found for each domain.
In order to visualize the different domains in the MpCCI Monitor you can activate the Domains from ▷ 4.10.1 Monitor ◁ in MpCCI GUI or later in the MpCCI Monitor by using the server preferences menu dialog (▷ 7.2.7 Preferences Server Dialog ◁). You have also the option to save this information in the tracefile by activating the Domains parameter for the corresponding writer used (▷ 4.10.4 Output ◁).

All of these options require that the DomainCheck in the job section (▷ 4.10.2 Job ◁) is activated.

3.2.3.1 Domain Check Handling in Visualizer

To visualize the different domains for a model you should

1. Select one viewport
2. Select the code you would like to investigate
3. Select in the Settings Panel a coupled mesh you would like to check. Coupled mesh having the same prefix for example MESH-2 belong to the same set.
4. From the Results Panel activate the Domains results.
5. In the legend the range shows the total number of domains found for the full model. You can deactivate the Automatic range settings and decrease the maximum value until your model has some red colored parts. then you find the total number of domains on the current mesh.



In the Figure 2 you can visualize two different domains: number 0 and 1.

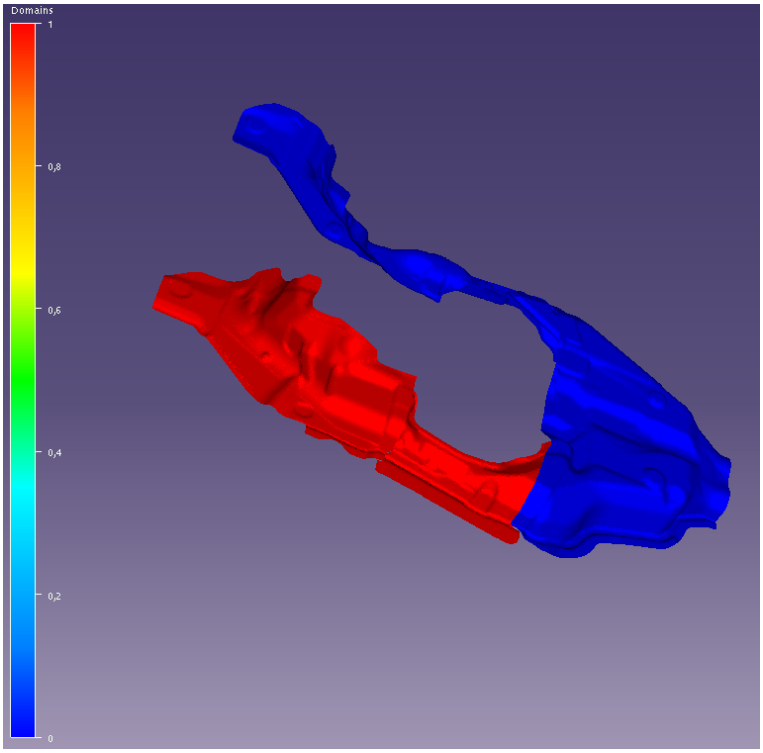


Figure 2: Example of domains visualization

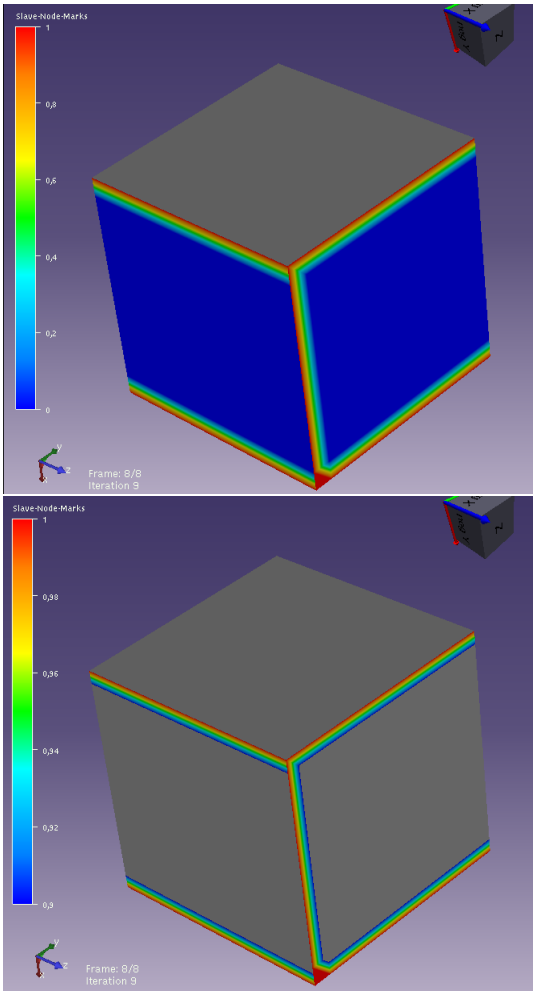
3.2.4 Slave Node Mark

For a mesh composed of several partitions it is possible to visualize the nodes relation at the partition boundary. The partitions connection can be identified. For using this feature the parameter Slaves in

▷ 4.10.1 Monitor ◁ of the MpCCI GUI must be activated.
To visualize the slave node information for the model you should

1. Select one viewport
2. Select the code you would like to investigate
3. Select in the Settings Panel a coupled mesh you would like to check. Coupled mesh having the same prefix for example MESH-2 belong to the same set.
4. From the Results Panel activate the Slave-Node-Marks results.
5. The legend's range varies from 0 to 1. Node marks with value zero are not slave from another node. Parent node are grayed out. The default setting will display nodes which are not slave in blue color. To improve the interpretation of the information you can deactivate the Automatic range settings and increase the minimum value to 0.9 to get a range from 0.9 to 1. Then activate the Out of range as undefined and all values lower than 0.9 are grayed out.

   In that way to get you can better localize the results. On the right side you can visualize the difference through the data processing. The mesh regions which are colored in red show the connection between the nodes.



3.2.5 Pre-Check Mode

If the PreCheck parameter in ▷ 4.10.2 Job ◁ is activated, MpCCI performs only a mesh check with a neighborhood search and terminates the coupled simulation. This feature requires an additional license token. The summary of the neighborhood calculation is stored in the log file `"mpcci_<job name prefix>_server.log"` and the collected coupled regions are saved in ccvx format in the folder `"<job name prefix>_<timestamp>_ccvx_precheck"` (▷ 3.8.3 Log Files ◁). In case of having orphans in the coupled region you can use the MpCCI Visualizer to analyze the regions.

3.3 Data Exchange

Data exchange does not mean that values are shared, as would be the case in a monolithic code, but each quantity is determined by one code, which then sends it to the other. In the sending code, the data is defined on a mesh of some kind and shall be transferred to the mesh of the receiving code. These meshes describe the same geometric entity, but typically differ in element size and node location, which is referred to as "nonmatching grids", see Figure 3.

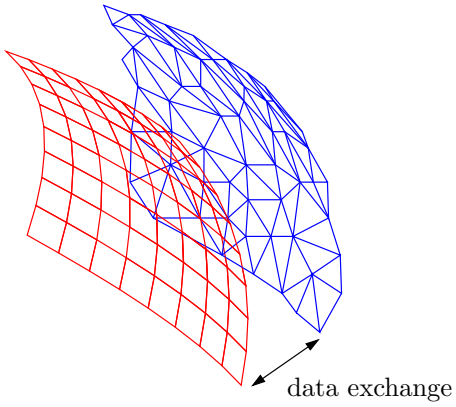


Figure 3: Data exchange between two non-matching grids (distance exaggerated)

The exchange procedure can be split up into following steps:

Association For each node or element of one grid, the "partners" on the other grid must be found. The data will then be exchanged between associated nodes and/or elements. This process is also called neighborhood search and is usually executed one time during the initialization phase as long as no remeshing event during the coupled computation occurs.

Interpolation The data which shall be transferred must be adapted to the target mesh, while e. g. conserving the sum of forces.

Each simulation code may work in its own unit system definition. In order to couple models created in different unit systems, MpCCI internally uses an SI unit system. The MpCCI GUI allows the user to input the unit system used for the model and for the quantities. The grid length unit can also be provided.

Additionally different quantity transformations for mesh motions, e. g. for rotating parts, or cyclic symmetric meshes can be defined which need a special treatment of the coupled quantities.

For convergence reasons quantities can also be relaxed or even scaled.

3.3.1 Association

3.3.1.1 Association between Mesh Based Codes

For each point in the target mesh, the closest element in the source mesh is searched. It results a node-element relation (see Figure 4).
The neighborhood search is based on a Kd-tree implementation for an efficient searching algorithm.

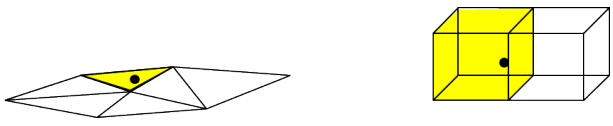


Figure 4: Node-Element relation for surface / volume coupling

The search is based on different geometrical parameters:

- Normal distance and Tangential distance (for surface meshes): searching distance for the closest element in normal and tangential direction (Figure 5).

- Distance (for volume meshes): searching distance for closest element.
- Multiplicity: parameter to control the search distance (Figure 5).
- Node tolerance: to find doubly defined nodes for meshes with multiple parts.

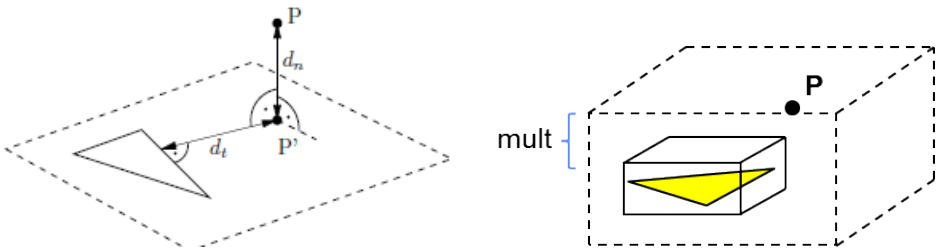


Figure 5: a)Normal distance d_n and tangential distance d_t for a point P b) Multiplicity factor parameter

MpCCI adjusts the neighborhood search parameters depending on the mesh discretization by computing the geometric parameters according to this procedure:

- Characteristic mesh length:
  - $l_{\text{min}} = 0.5 * (l_{\text{minSource}} + l_{\text{minTarget}})$
  - $l_{\text{max}} = \max(l_{\text{maxSource}}, l_{\text{maxTarget}})$
  - $l_{\text{mean}} = 0.5 * (l_{\text{meanSource}} + l_{\text{meanTarget}})$
- Node tolerance: $ntol = \min(l_{\text{minSource}}, l_{\text{minTarget}})/5.0$
- Precision of neighborhood search: $prec = (0.9 * l_{\text{minSource}} + 0.1 * l_{\text{meanSource}})/20$
- Normal distance: $d_n = l_{\text{mean}}$
- Tangential distance: $d_t = l_{\text{min}}$
- Distance: $vdist = 0.9 * l_{\text{min}} + 0.1 * l_{\text{mean}}$
- Multiplicity:
  - $mult = \frac{l_{\text{max}}}{l_{\text{min}}}$ and is clipped to 10.0
  - $mult = mult * mfac$ mfac is the user multiplicity factor.
  - $correction = \frac{\max(l_{\text{minSource}}, l_{\text{minTarget}})}{l_{\text{min}}}$ This correct the averaging from l_{min} in case of degenerated elements and limits to a maximun value of 2.
  - Final multiplicity factor value: $mult = mult * correction$

Parameters for association can be globally set for all coupling regions in the Settings step of the MpCCI GUI, see ▷ 4.10.3 Relation Search ◁. These global parameter properties can be overwritten for selected regions in the Regions Properties tab of the Build Regions in Regions step, see ▷ 4.8.6 Applying Region Properties ◁.

The only parameter to control the neighborhood search is Multiplicity. The parameter enables the iterative neighborhood search which leads to a more robust algorithm. The default value is 1.0. If a bigger value is chosen by the user, the searching radius (distance up to which a point is still regarded as a neighbor) will be enlarged (doubled) step-by-step until the given multiplicity of the starting radius is reached.
Another parameter which may be overwritten is UserNormalDistance. The provided parameter is expressed in SI unit system. This parameter should only be used if the Mutltiplicity parameter failed to reduce the number of orphaned nodes. In this case the Multiplicity parameter provided in the MpCCI GUI is used as parameter instead of using the computed edge ratio value from the meshes.

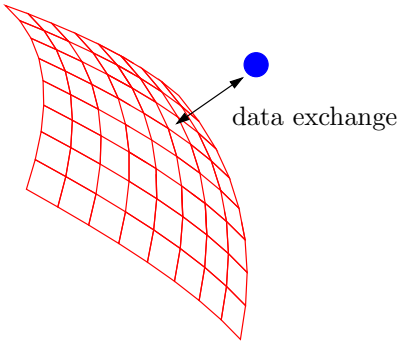


Figure 6: Representation of an integration point coupling with a surface mesh

3.3.1.2 Association between a System Code and a Mesh Based Code

There is no specific association built for an integration point mapping with a surface mesh (Figure 6). MpCCI requires that only one integration point is paired with a surface mesh.
Components under the following dimension icons (Figure 7) could be used together.

Figure 7: Integration Point and Face element labels

3.3.2 Interpolation

3.3.2.1 Interpolation for a Mesh Based Code

MpCCI offers currently one basic approach for association and interpolation the *Shape Function* algorithm. Shape function mapping simply interpolates a field using the shape functions. It can map linear functions exactly if linear elements are used; respectively quadratic functions need quadratic elements (i. e. elements with mid-nodes) to be mapped exactly. Details can be found in Silva et al. [2009].

3.3.2.2 Field Interpolation

In *field* interpolation (Figure 8), it is ensured that the total sum of all values is preserved. This interpolation type is used e. g. for pressures, densities or temperature.

In MpCCI some quantities are considered as *flux density*. This is a different term for *field* values, thus the interpolation is carried through in the same way.

The interpolation type is already defined for each quantity, see the quantities list in the Appendix.

After the data are mapped a global conservative transfer check is realized by comparing the source integral value to the target integral value. If a mapping deviation of 10% maximum occurs, the values will be scaled within this limit.

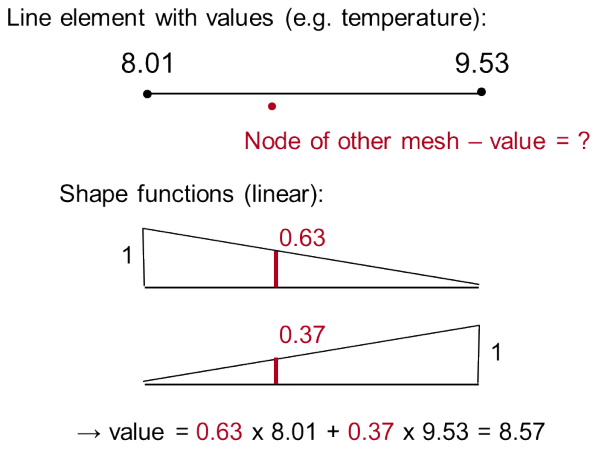


Figure 8: Field interpolation example

3.3.2.3 Orphaned Nodes and Elements

A node is called "orphaned" if it is not associated to an element during the neighborhood search. This also means that this node can not receive any data from the other mesh.
Instead, MpCCI sends the default values, which can be defined for each quantity (see ▷4.8.7.3 Orphans Settings for Mesh Based Components◁).

Besides assigning default values it is possible to extrapolate values (using a diffusion algorithm) from non-orphaned areas. The extrapolated values of the orphans will lie in the range of the lowest and highest values of the bordering non-orphaned areas.

If orphaned nodes are present, they are listed in the tracefile written by coupling server and visible through the MpCCI Monitor during the simulation.

To identify the regions where orphaned nodes appear, it is recommended to use the MpCCI Visualizer, which can display all orphaned nodes in the coupling region, see ▷7 MpCCI Visualizer ◁. In the MpCCI Visualizer orphans information is associated with different values in the color range legend (Figure 9).

- Non orphaned node is displayed with the assigned value 0 or is grayed out. The gray color means that the complete coupled component does not contain any orphaned node.
- A weakly mapped node gets the value 1.
- All orphan information with a value greater than 1 have to be considered as orphaned and potentially critical for the coupled simulation. Depending on the orphan handling method chosen for each coupled region you may see different maximum range values:
  - By default the orphaned nodes are processed by setting a default constant value. In that case these orphaned nodes are marked with the value 6.
  - For the coupled region with an activated extrapolation option orphaned nodes are marked with the value 2.

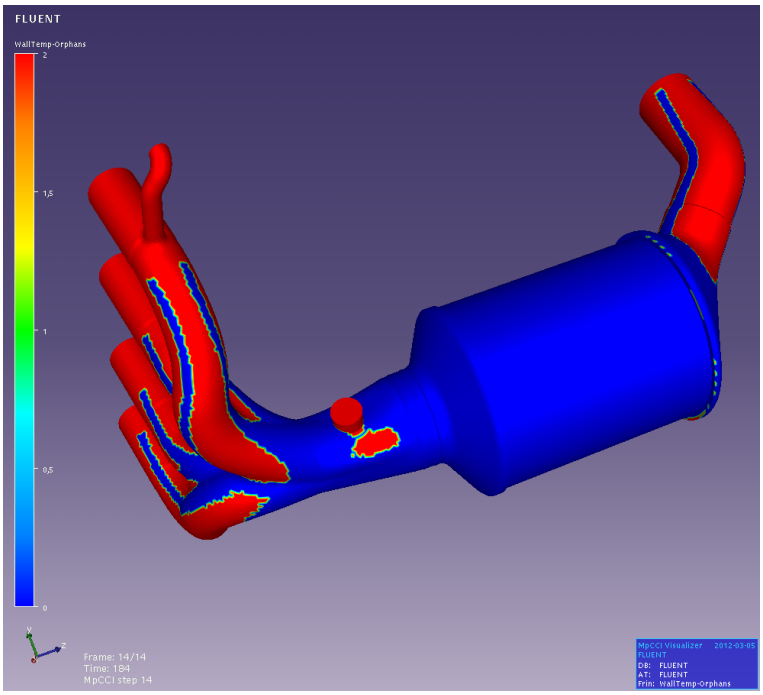


Figure 9: Orphaned nodes representation example

MpCCI server prints additional orphans information after the neighborhood search. The total number of orphaned nodes for the mesh pairing is printed both as absolute value and in percent of the mesh size. The information provides a list of:

- fully orphaned nodes
- weakly mapped nodes
- childless elements: represents elements which can not send any data to the other mesh.

3.3.2.4 Interpolation for an Integration Point with a Mesh Based Code

The quantities are calculated as depicted exemplary for the field quantity temperature T and the flux quantity mass flow m in Figure 10.

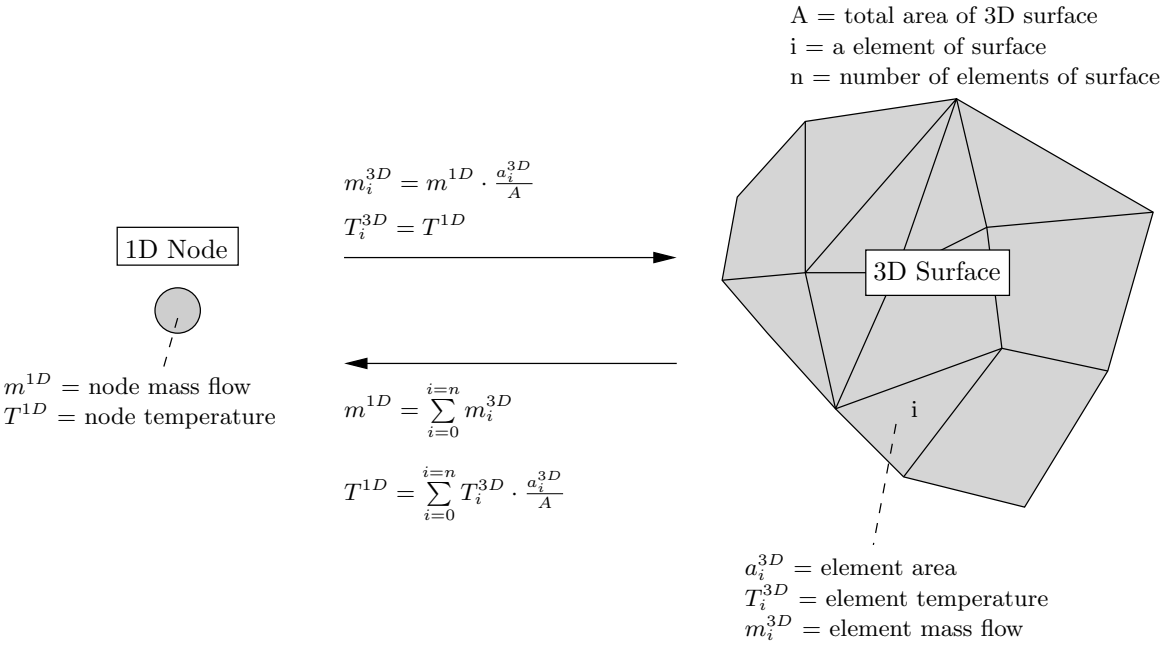


Figure 10: Exemplary calculation of flux quantity mass flow m and field quantity temperature T between 1D and 3D codes

3.3.3 Quantity Relaxation

Relaxation of quantities is a method to stabilize and improve the convergence of the coupled process for some cases. Depending on the coupling scheme, the relaxed coupling iterations refer to:

Coupling steps in explicit steady-state coupling schemes. Here a converged solution is to be achieved at the end of the simulation.

Coupling step iterations in implicit coupling schemes. Here a converged solution is to be achieved at the end of each time step.

Relaxation is only allowed for iterative coupling schemes (▷ 3.4.2 Coupling Schemes ◁), not for explicit transient ones.

The general approach of relaxation is to modify the quantity's value (in an intelligent way) before it is sent to the partner code. This modification is designed such that the actual quantity value Q^k and the relaxed quantity value Q^k_{relax} are approaching each other during the coupling iterations. In the converged state, where $Q^k \approx Q^k_{relax}$, the coupled systems are in equilibrium and the solution is found.

To allow the relaxation to converge, the number of relaxed coupling iterations has to be high enough. This is the maximum number of coupling steps for steady state problems or the maximum number of coupling step iterations for implicit couplings.

The relaxation convergence can be checked in MpCCI by a specified tolerance value ϵ:

$$2\,\frac{||Q^k - Q^k_{relax}||_\infty}{||Q^k||_\infty + ||Q^k_{relax}||_\infty} < \epsilon \tag{1}$$

Parameter Settings in the MpCCI GUI

The relaxation can be activated by applying the Relaxation operator (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).

Parameter settings for the relaxation convergence are:

Meaning in method context	MpCCI GUI parameter	Value
Setting the relaxation convergence check	Check relaxation convergence of operator Relaxation	*true*
The tolerance value ϵ in Eq. (1)	Tolerance value of operator ConvergenceCheck	$]0.0, 1.0[$

The Check relaxation convergence option has to be used in combination with the tolerance value specified in the ConvergenceCheck operator, which must also be selected (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).

The relaxation methods offered are:

- Fixed relaxation - Under- or over-relaxation with a constant relaxation factor.
- Ramping - Special type of relaxation with a linearly increasing or decreasing relaxation factor.
- Aitken relaxation - Builds an adaptively calculated relaxation factor using the Aitken method.
- Quasi-Newton method - Uses the Anderson Mixing Quasi-Newton method to strongly accelerate and stabilize the convergence of the mapped quantities.

These methods are described below.

3.3.3.1 Fixed Relaxation

Instead of sending the current quantity value Q^{k+1}, which was mapped to the receiver's mesh, the following relaxed quantity is sent to the receiver:

$$Q^{k+1}_{\text{relax}} = \alpha \cdot Q^{k+1} + (1 - \alpha) \cdot Q^{k}_{\text{relax}} \tag{2}$$

where

- α is the relaxation factor provided by the user.
- Q^{k+1} is the current mapped value (unrelaxed).
- Q^{k+1}_{relax} is the relaxed value sent to the receiver.
- Q^{k}_{relax} is the last relaxed value sent to the receiver.

Under-relaxation – with a value of α smaller than one – might lead to a more stable solution for some problems, e. g. with large quantity spikes (see Figure 11 and Figure 12). Some steady-state couplings might benefit from an over-relaxation ($\alpha > 1$) because this can improve the convergence of some slowly converging problems.

The physical background of the coupled solution needs to be taken into account when looking for an optimal relaxation parameter for a coupled quantity.

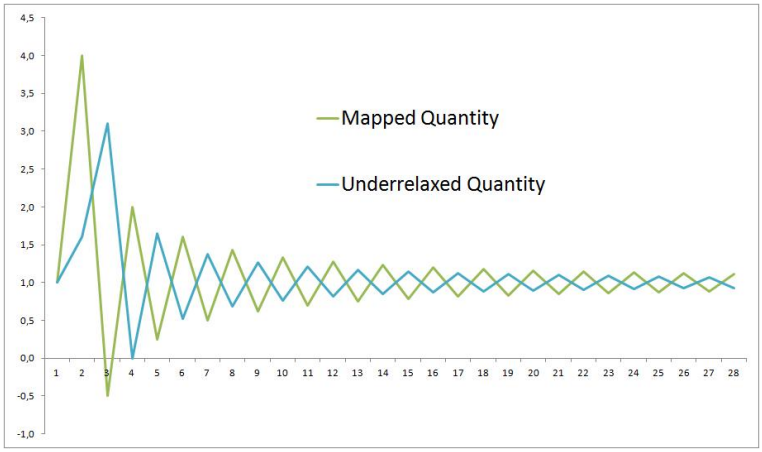


Figure 11: Under Relaxation in case of oscillating quantity values

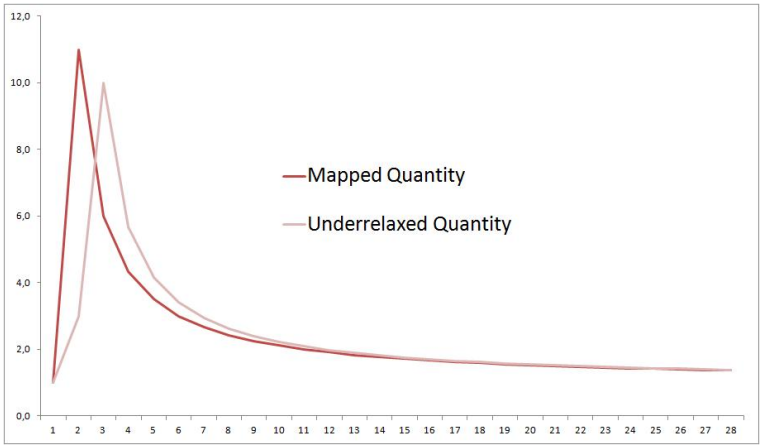


Figure 12: Under relaxation in case of an initial spike

Parameter Settings in the MpCCI GUI

After applying the Relaxation operator (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁) fixed relaxation is activated by choosing the relaxation method Fixed.

Additional parameter settings are:

Meaning in method context	MpCCI GUI parameter	Value
The relaxation factor α in Eq. (2)	Relaxation factor	$[0.0, 2.0]$

3.3.3.2 Ramping

A special kind of relaxation is called Ramping in MpCCI. In the coupling iteration $k+1$, the ramping relaxation factor β^k is computed according to the linear ramping function:

$$\beta^k = \min(1, \beta_0 + k \cdot \beta_d) \quad \text{for under-relaxation ramping} \tag{3}$$

$$\beta^k = \max(1, \beta_0 - k \cdot \beta_d) \quad \text{for over-relaxation ramping} \tag{4}$$

where

- β^k is the ramping relaxation factor in iteration $k+1$.
- β_0 is the initial ramping relaxation factor provided by the user. For under-relaxation, $\beta_0 \in [0, 1]$, for over-relaxation, $\beta_0 \in [1, 2]$.
- β_d is the ramping step value provided by the user, $\beta_d \in [0.001, 1]$.

If ramping is activated, instead of sending the current quantity value Q^{k+1}, a linear combination of Q^{k+1} and the last sent relaxed value Q^k_{relax} is sent to the receiver. The pre-factors depend on β^k and add up to 1:

$$\begin{aligned} Q^{k+1}_{\text{relax}} &= \beta^k \cdot Q^{k+1} + (1 - \beta^k) \cdot Q^k_{\text{relax}} \\ &= Q^k_{\text{relax}} + \beta^k \cdot (Q^{k+1} - Q^k_{\text{relax}}) \end{aligned}$$

where

- Q^{k+1} is the current mapped value (unrelaxed).
- Q^{k+1}_{relax} is the relaxed value sent to the receiver.
- Q^k_{relax} is the last relaxed value sent to the receiver.

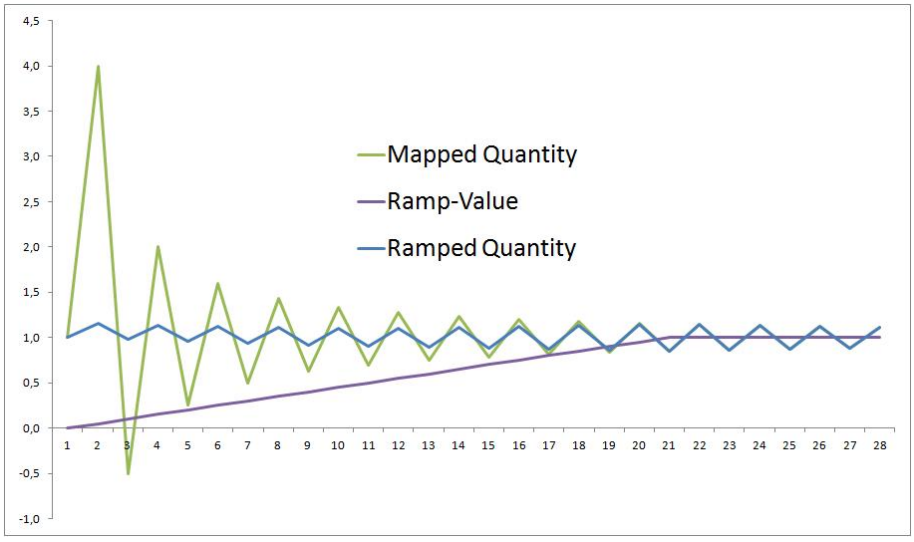


Figure 13: Ramping effect in case of oscillating quantity values

Depending on the initial ramping relaxation factor β_0, the relaxation factor is linearly increasing or decreasing over the iteration counter until a value of 1, i. e. no relaxation, is reached. Starting with an β_0 smaller than 1 (which will be increased to 1) leads to under-relaxation whereas starting with an β_0 bigger than 1 (which will be decreased to 1) leads to over-relaxation. In fact, this is identical with a classical

under- (or over-) relaxation, except that the relaxation factor is increasing (or decreasing) with each new iteration until the final value 1, i. e. no relaxation, is reached. The value of the first iteration Q^0_{relax} is set to the first unrelaxed quantity value Q^0. Ramping might help to avoid the exchange of any unrealistic spikes during the first few iterations (see Figure 14).

A ramping is recommended for forces or pressure to avoid initial pressure spikes.

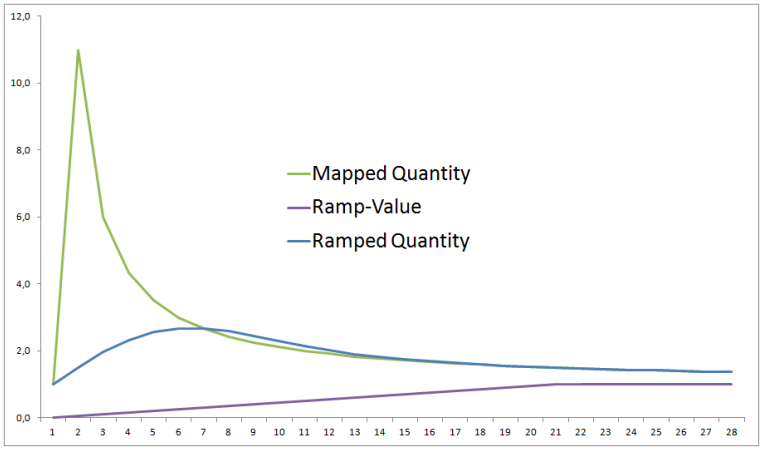


Figure 14: Ramping effect in case of an initial spike

Parameter Settings in the MpCCI GUI

- After applying the Relaxation operator (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁) ramping is activated by choosing the relaxation method Ramping.

  Additional parameter settings are:

Meaning in method context	MpCCI GUI parameter	Value
The initial ramping relaxation factor β_0 in Eq. (3) (4)	Initial factor	$[0.0, 2.0]$
The ramping step value β_d in Eq. (3) (4)	Ramping delta	$[0.001, 1]$

- There are some parameters that can be set via MpCCI in the Settings step (see ▷ 4.10 Settings Step ◁). Following parameters are listed in the Monitor category:

Meaning in method context	MpCCI GUI parameter	Value
Plot the used ramping relaxation factor β^k (Eq. (3) (4)) in the MpCCI Monitor	Relax	*true*

3.3.3.3 Aitken Relaxation

MpCCI offers the possibility to build an adaptively calculated relaxation factor by Aitken's method as can be found in Mok [2001]. The optimal relaxation factor for iteration $k+1$ is built from the following quantity values:

- the last unrelaxed value Q^k
- the current unrelaxed value Q^{k+1}

- the last relaxed value sent to the receiver Q^k_{relax}
- the second last relaxed value sent to the receiver Q^{k-1}_{relax}

The computation of the current Aitken factor μ^k for $k > 0$ is described with the following equations:

$$\Delta Q^{k+1} = Q^k_{\text{relax}} - Q^{k+1} \qquad \Delta Q^k = Q^{k-1}_{\text{relax}} - Q^k$$

$$\mu^k = \mu^{k-1} + (\mu^{k-1} - 1)\frac{(\Delta Q^k - \Delta Q^{k+1})^T \Delta Q^{k+1}}{(\Delta Q^k - \Delta Q^{k+1})^2}$$

For the first iteration $k = 0$ the Aitken factor is set to 0.

The relaxation factor is then defined as

$$\omega^k = 1 - \mu^k \tag{5}$$

and is used as follows:

$$Q^{k+1}_{\text{relax}} = \omega^k \cdot Q^{k+1} + (1 - \omega^k) \cdot Q^k_{\text{relax}}$$

Q^{k+1}_{relax} is sent to the receiver instead of Q^{k+1}.

The calculated optimal relaxation factor ω is limited to the interval between 0.1 and 1.0 to prevent convergence difficulties. During the first iteration a relaxation with 0.1 is applied because the required values are not available.

Parameter Settings in the MpCCI GUI

- After applying the Relaxation operator (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁) Aitken relaxation is activated by choosing the relaxation method Aitken.

  No additional parameter settings are necessary.
- There are some parameters that can be set via MpCCI in the Settings step (see ▷ 4.10 Settings Step ◁). Following parameters are listed in the Monitor category:

Meaning in method context	MpCCI GUI parameter	Value
Plot the used relaxation factor ω^k (Eq. (5)) in the MpCCI Monitor	Relax	*true*

3.3.3.4 Quasi-Newton Method

The Quasi-Newton method can strongly accelerate and stabilize the convergence of the mapped quantities, cf. Koch [2016].

In a multiphysical coupling, the goal is to achieve an equilibrium between (in general) two coupled codes $\mathcal{F}$ and $\mathcal{S}$. Due to the partitioned approach of MpCCI, this is achieved by a consecutive evaluation of the solvers.

Using serial coupling algorithms (described in ▷ 3.4.1 Coupling Algorithm ◁) this procedure is formulated by the following iteration (within each relaxed coupling iteration)

$$\begin{cases} \text{I}: & Q^k_{\mathcal{S}} = \mathcal{S}(Q^k_{\mathcal{F}}) \\ \text{II}: & Q^{k+1}_{\mathcal{F}} = \mathcal{F}(Q^k_{\mathcal{S}}) \end{cases}$$

where

- $Q_{\mathcal{F}}^k$ is the quantity value sent by solver $\mathcal{F}$ in iteration k.
- $Q_{\mathcal{S}}^k$ is the result of solver $\mathcal{S}$ evaluated at $Q_{\mathcal{F}}^k$ (Eq. I). It is sent to solver $\mathcal{F}$ to build the next iteration value.
- $Q_{\mathcal{F}}^{k+1}$ is the result of solver $\mathcal{F}$ where $Q_{\mathcal{S}}^k$ has been inserted into the solver equations (Eq. II).

Inserting equation I into II results in the fixed point iteration

$$Q_{\mathcal{F}}^{k+1} = \mathcal{F}(\mathcal{S}(Q_{\mathcal{F}}^k))$$

In this iteration, only the quantity $Q_{\mathcal{F}}$ occurs while $\mathcal{F}(\mathcal{S}(\cdot))$ corresponds to the serial coupling algorithm.

For parallel coupling, all quantities will be relaxed simultaneously, with the fixed point problem as follows:

$$\begin{bmatrix} Q_{\mathcal{F}}^{k+1} \\ \\ Q_{\mathcal{S}}^{k+1} \end{bmatrix} = \begin{bmatrix} \mathcal{F}(\mathcal{S}(Q_{\mathcal{F}}^k)) \\ \\ \mathcal{S}(\mathcal{F}(Q_{\mathcal{S}}^k)) \end{bmatrix}$$

Generally formulated, the *fixed point iteration* reads

$$Q^{k+1} = \mathcal{C}(Q^k)$$

where for parallel coupling Q consists of $Q_{\mathcal{F}}$ and $Q_{\mathcal{S}}$ in a single block.

The coupling equilibrium is reached if the fixed point iteration reaches a convergence state where $Q^{k+1} = Q^k$. In other words, a quantity Q is to be found that fulfills

$$Q = \mathcal{C}(Q)$$

which is also called *fixed point* of $\mathcal{C}$.

This is where the Quasi-Newton method derivation starts. Instead of finding the fixed point of $\mathcal{C}$, the equation is reformulated as a root problem

$$\mathcal{R}(Q) := \mathcal{C}(Q) - Q = 0$$

Applying the well-known Newton iteration to $\mathcal{R}(Q) = 0$ gives the following *standard* relaxation iteration:

$$\begin{aligned} Q_{\text{relax}}^{k+1} &= Q_{\text{relax}}^k - \left[\frac{\partial \mathcal{R}}{\partial Q}(Q_{\text{relax}}^k)\right]^{-1} \cdot \mathcal{R}(Q_{\text{relax}}^k) && (6) \\ &= Q_{\text{relax}}^k - \left[\frac{\partial \mathcal{R}}{\partial Q}(Q_{\text{relax}}^k)\right]^{-1} \cdot (\mathcal{C}(Q_{\text{relax}}^k) - Q_{\text{relax}}^k) && (7) \\ &= Q_{\text{relax}}^k - \left[\frac{\partial \mathcal{R}}{\partial Q}(Q_{\text{relax}}^k)\right]^{-1} \cdot (Q^{k+1} - Q_{\text{relax}}^k) && (8) \end{aligned}$$

where

- Q^{k+1} is the current mapped value (unrelaxed).
- Q_{relax}^{k+1} is the relaxed value sent to the receiver.
- Q_{relax}^k is the last relaxed value sent to the receiver.

When applying the Newton iteration to $\bar{\mathcal{R}}(Q) := Q - \mathcal{C}^{-1}(Q) = 0$, the *inverse* relaxation iteration is generated as follows:

$$Q_{\text{relax}}^{k+1} = Q^{k+1} - \left[\frac{\partial \bar{\mathcal{R}}}{\partial Q}(Q_{\text{relax}}^k)\right]^{-1} \cdot (Q^{k+1} - Q_{\text{relax}}^k) \quad (9)$$

The value of the first iteration Q^0_{relax} is set to the first unrelaxed quantity value Q^0.

The inverse Jacobian of $\mathcal{R}$ (*standard* method) or of $\bar{\mathcal{R}}$ (*inverse* method) with respect to Q is in general unknown and needs to be approximated (say, by J^k). In the Anderson Mixing method, which is the Quasi-Newton method used by MpCCI, they are constructed in the way that $||J^k - J^0||$ is minimized under the constraint $J^k V = W$:

$$\begin{aligned} J^k &\approx \left[\frac{\partial \mathcal{R}}{\partial Q}(Q^k_{\text{relax}})\right]^{-1} \\ &= J^0 + (W - J^0 V)(V^T V)^{-1} V^T \end{aligned}$$

$$\begin{aligned} \bar{J}^k &\approx \left[\frac{\partial \bar{\mathcal{R}}}{\partial Q}(Q^k_{\text{relax}})\right]^{-1} \\ &= J^0 + (\bar{W} - J^0 V)(V^T V)^{-1} V^T \end{aligned}$$

with the difference matrices

$$\begin{aligned} W &= \left[Q^1_{\text{relax}} - Q^0_{\text{relax}}, \ldots, Q^k_{\text{relax}} - Q^{k-1}_{\text{relax}}\right] \\ \bar{W} &= \left[Q^1 - Q^0, \ldots, Q^k - Q^{k-1}\right] \\ V &= \left[R^1 - R^0, \ldots, R^k - R^{k-1}\right] \end{aligned}$$

and $R^i = Q^{i+1} - Q^i_{\text{relax}}$. Having $\alpha = (V^T V)^{-1} V^T R^k$, the final equation reads:

$$Q^{k+1}_{\text{relax}} = Q^{k+1}_{(\text{relax})} - J^0(R - V\alpha) - \overset{(-)}{W}\alpha \tag{10}$$

where α is calculated using least squares minimization problem. According to this derivation, MpCCI offers three variants of the Anderson Mixing Quasi-Newton method:

- Standard with Q^{k+1}_{relax}, W and $J^0 = -\omega$ Id, $\omega > 0$ in Eq. (10)
- Inverse with Q^{k+1}, $\bar{W}$ and $J^0 = -\omega$ Id, $\omega > 0$ in Eq. (10)
- LeastSquares, with Q^{k+1}, $\bar{W}$ and $J^0 = 0$ in Eq. (10)

For iterations where the matrices V and W are not built, i. e. $k = 0$, the quantity is relaxed as follows:

$$Q^1_{\text{relax}} = \omega \cdot Q^1 + (1 - \omega) \cdot Q^0_{\text{relax}} \tag{11}$$

In order to accelerate the relaxation process for transient simulations, the previous time steps could be taken into account for the Quasi-Newton relaxation. Increase in the number of considered previous time steps might accelerate the convergence. However, very large values might lead to include irrelevant information and thus it might slow the convergence. But generally speaking, the choice of number of considered previous time steps is very problem dependent.

Ill-conditioned matrix V might lead to inefficient results for the minimization problem. In order to overcome this issue and enhance the performance of Quasi-Newton relaxation, three filtering methods are applied on α, V and W, such as the detection and elimination of linear dependent, noisy and unused columns of V. The linear dependent and noisy columns have to be eliminated using QR decomposition of V:

$$V = QU \tag{12}$$

The columns with index i in V and W will be ignored under one of the following circumstances:

$$|U_{ii}| < \epsilon_{linear} |U_{00}| \tag{13}$$

$$|U_{ii}| < \epsilon_{noise} \sqrt{\sum_j U_{ij}^2} \tag{14}$$

The filtering in Eq. (13) will be helpful when the oldest considered iterations have large errors or are irrelevant to the current iteration. It eliminates old linear dependent columns in Quasi-Newton relaxation method for each iteration. Eq. (14) is supposed to ignore noisy iterations in all considered iterations for relaxation. It eliminates noisy columns in Quasi-Newton relaxation method for each iteration. High values of ϵ_{linear} and ϵ_{noise} lead to more eliminations.

More details can be found in Bogaers et al. [2016], Haelterman et al. [2016], Degroote et al. [2010] and Davis et al. [2022].

Furthermore, for implicit schemes at the beginning of each time step, corresponding columns of V and W will be eliminated from the previous time step, if:

$$|\alpha_i| < \epsilon_{window} \tag{15}$$

This filtering is only relevant for transient simulations, when the first iterations of the previous time step did not affect the final iteration. It eliminates first columns in Quasi-Newton relaxation method at the beginning of the new time step. Big values of ϵ_{window} result in a lower number of considered iterations from the last time step. It is irrelevant for steady-state simulations.

The divergence of the Quasi-Newton method is checked by the conditions:

$$\epsilon_1 ||R^{k+1}||_\infty > ||R^k||_\infty \tag{16}$$

$$|\alpha_k| < \epsilon_2 \tag{17}$$

$$||V - \alpha R^k||_\infty > \epsilon_2 \tag{18}$$

For transient simulations a restart in Quasi-Newton is only allowed when residuals' slope is positive, where the slope is calculated by least squares fitting method.

Please note:

- The computational cost and the memory consumption of the Anderson Mixing Quasi-Newton method depend linearly on the quantity's number of degrees of freedom.
- For most multiphysical problems, the Inverse approach converges faster than the Standard approach. For problems with high initial quantity peaks, it is recommended to use the Standard variant since the relaxation iteration is based on the last relaxed quantity value Q^k_{relax} (cf. Eq. (8)) and not (in the case of Inverse) on the current solver solution Q^{k+1} (cf. Eq. (9))
- The LeastSquares Anderson Mixing method has the lowest computational cost but has strict convergence requirements which may not be fulfilled. If the requirements are not fulfilled, the method will not converge.
- For each iteration, Q is divided by its maximum value. In case of parallel coupling, the maximum of each quantity is applied to the corresponding part of Q.
- Increase in number of regions might reduce the stability. If there are several regions, it is recommended to use the same relaxation values for all of them.
- In steady-state simulations, matrices V and W are automatically restarted when MaxIteration is reached (see section about parameter settings in the MpCCI GUI below).

An example using Quasi-Newton methods is the ▷ VII-4 Driven Cavity ◁ tutorial.

Parameter Settings in the MpCCI GUI

- After applying the Relaxation operator (see ▷4.8.7.4 Applying Operators to Quantities of Mesh Based Components◁) Quasi-Newton relaxation is activated by choosing the relaxation method Quasi-Newton.

  Additional parameter settings are:

Meaning in method context	MpCCI GUI parameter	Value
Variants of the Anderson Mixing Quasi-Newton method in Eq. (10)	Type of Anderson Mixing method	Standard Inverse LeastSquares
ω in Eq. (10) and (11)	Omega (ω)	> 0.0
Number of considered previous time steps for the relaxation (for transient problems only)	Number of reused levels	$>= 0$

- There are some parameters that can be set via MpCCI in the Settings step (see ▷4.10 Settings Step◁). Following parameters are listed in the Job.QuasiNewton subcategory:

Meaning in method context	MpCCI GUI parameter	Value
The maximum column number of V and W in Eq. (10) (for steady problems only)	MaxIteration	> 0
The number of iterations that will be taken into account for calculating the residuals' slope Zero deactivates the restart. (for transient problems only)	NbResiduals	$>= 0$
Value of ϵ_{linear} in Eq. (13)	LinearDependencyTol	$[0.0, 1.0]$
Value of ϵ_{noise} in Eq. (14)	NoiseTol	$[0.0, 1.0]$
Value of ϵ_{window} in Eq. (15) (for transient problems only)	WindowTol	$[0.0, 1.0]$
Divergence factor ϵ_1 in Eq. (16)	RestartFactor	$[0.01, 1.0]$
Divergence limit ϵ_2 in Eq. (17)(18)	RestartLimit	$[1.0e^{-4}, 1.0]$
Define whether residuals should be monitored	MonitorResidual	$true$ or $false$
Define whether an additional log file with relaxation information should be written	WriteLog	$true$ or $false$

Restrictions:

- For serial coupling algorithm, the Quasi-Newton relaxation method can be applied to only one code. Moreover, it is not allowed to apply a different relaxation method to one of the remaining quantities.
- For parallel coupling algorithm, the Quasi-Newton parameters Type of Anderson Mixing method, Omega and Number of reused levels must be the same for all coupled quantities within a region.
- Parallel coupling with Quasi-Newton is only possible without initializing code.

3.3.4 Quantity Operators

MpCCI provides some other operators besides relaxation. These concern:

- Enabling the convergence check.
- Disabling conservative mapping correction.

- Defining limits to which exceeding values will be clipped.
- Defining a scaling function.

These operators are described below.

3.3.4.1 Convergence Check

Since iterating is computationally expensive, the possibility to stop the iterations adaptively is essential to keep computation times as low as possible. This operator is only relevant for iterative couplings (▷ 3.4.2 Coupling Schemes ◁). When the coupled quantity values remain more or less constant between consecutive data exchanges, the coupled solution cannot be improved by continuing the iterations.

MpCCI monitors the relative difference between two successively coupled quantities. If Q^k and Q^{k+1} are the quantity values for the iterations k and $k+1$ respectively, it stops iterating when the relative difference between two consecutive quantity values lies beneath the given tolerance, ϵ:

$$2\,\frac{||Q^k - Q^{k+1}||_\infty}{||Q^k||_\infty + ||Q^{k+1}||_\infty} < \epsilon \tag{19}$$

Parameter Settings in the MpCCI GUI

- Convergence check can be activated by applying the ConvergenceCheck operator (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).

  Parameter settings are:

Meaning in method context	MpCCI GUI parameter	Value
Value ϵ in Eq. (19)	Tolerance value	$]0.0, 1.0[$

- There are some parameters that can be set via MpCCI in the Settings step (see ▷ 4.10 Settings Step ◁). Following parameters are listed in the specified category:

Meaning in method context	MpCCI GUI parameter	Value
If the convergence check is assigned to more than one quantity, you may specify whether the convergence of only one quantity should lead to a converged simulation or even all quantities should meet the convergence criterion.	Job.ConvergenceRule	All One
Plot the residuum in Eq. (19) in the MpCCI Monitor	Monitor.Inorm	true

3.3.4.2 Disable Conservative Mapping Correction

MpCCI corrects by default the mapping error due to the mesh difference between codes, by scaling the mapped quantity, Q_m. The scale factor γ is calculated as follows:

$$\gamma = \frac{\int\limits_{\Omega_s} Q_s(x)dx}{\int\limits_{\Omega_m} Q_m(x)dx}$$

where Ω_s and Ω_m denote the coupled space for sender and receiver codes, respectively and Q_s is the sent quantity before mapping.

Parameter Settings in the MpCCI GUI

The conservative mapping correction can be deactivated by applying the DisableConservation operator (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).

No parameter settings are necessary.

3.3.4.3 Define Limits

Each element q of quantity Q can be clipped as follows:

$$q = \begin{cases} l_{low} & \text{for } q < l_{low} \\ q & \text{for } l_{low} \leq q \leq l_{up} \\ l_{up} & \text{for } q > l_{up} \end{cases} \tag{20}$$

This operator exists as pre processor which will be applied before mapping on the sender side and as post processor which will be applied after mapping on the receiver side.

Parameter Settings in the MpCCI GUI

The limits to quantities can be activated by applying the PreLimiter operator (as pre processor) or the PostLimiter operator (as post processor) (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).

Parameter settings are:

Meaning in method context	MpCCI GUI parameter	Value
The lower limit l_{low} in Eq. (20)	Lower limit	*unlimited*
The upper limit l_{up} in Eq. (20)	Upper limit	*unlimited*

3.3.4.4 Scaling

The scaled quantity, Q_s, is calculated by ramping the mapped quantity, Q_m, using scale factor ω and reference value Q_r as follows:

$$Q_s = \omega \cdot Q_m + (1 - \omega) \cdot Q_r \tag{21}$$

where the scale factor ω is calculated using initial factor ω_i, final factor ω_f, scale counter j, and number of scale factor changes n_1:

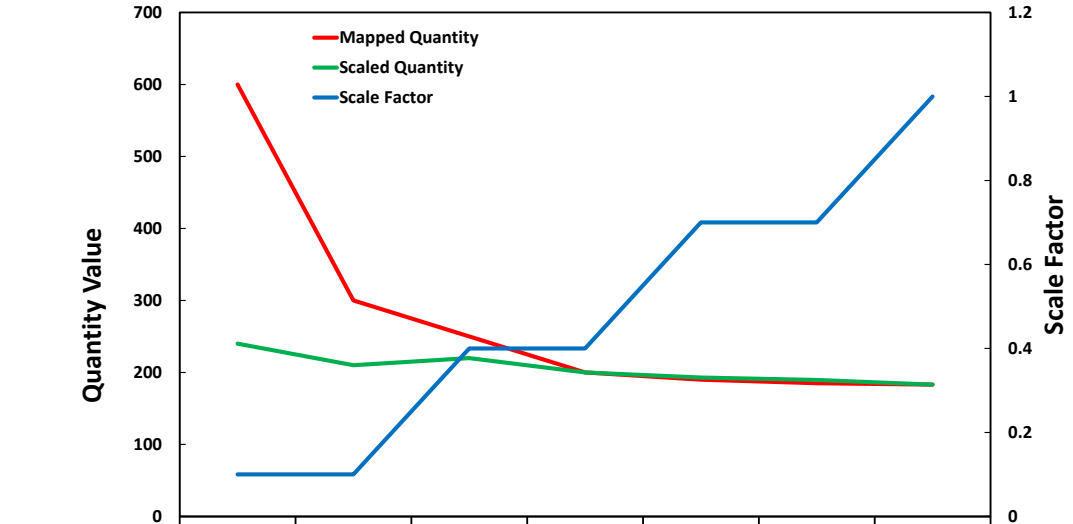
$$\omega = \frac{(\omega_f - \omega_i)j}{n_1} + \omega_i \tag{22}$$

where the scale counter j, which counts the scale factor changes and is limited by n_1, is calculated using the current step number $StepCounter$, and the number of consecutive steps with the same scale factor n_2 as follows:

$$j = min(\lfloor \frac{StepCounter}{n_2} \rfloor, n_1) \tag{23}$$

For example, with the following scale parameters definition you will have the scaling factor plotted on Figure 15:

Reference value Q_r	: 200
Initial factor ω_i	: 0.1
Final factor ω_f	: 1
Number of consecutive steps with the same scale factor n_2	: 2
Number of scale factor changes n_1	: 3



	0	1	2	3	4	5	6
Mapped Quantity	600	300	250	200	190	185	183
Scaled Quantity	240	210	220	200	193	189.5	183
Scale Factor	0.1	0.1	0.4	0.4	0.7	0.7	1

Figure 15: Scaling function on quantity

Scaling could also be used, when the initial conditions of one code lead to huge changes in the other code. Please note that for explicit scheme in transient cases, this option might increase inaccuracy of the co-simulation.

Parameter Settings in the MpCCI GUI

The scaling function can be activated by applying the Scale operator (see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).

Parameter settings are:

Meaning in method context	MpCCI GUI parameter	Value
The reference value Q_r in Eq. (21)	Reference value	*unlimited*
The initial factor ω_i in Eq. (22)	Initial scale factor	*unlimited*
The final factor ω_f in Eq. (22)	Final scale factor	*unlimited*
The number of consecutive steps with the same scale factor n_2 in Eq. (23)	Number of steps with the same scale factor	> 0
The number of scale factor changes n_1 in Eq. (22)(23)	Number of scale factor changes	> 0

3.3.5 Quantity Transformation for Mesh Motion

When defining different mesh motions the MpCCI server should be able to provide the information (coordinates, quantities) in the target calculation frame of the target code.
The incoming quantities are transformed into the SI unit system, pre-processed for any mesh motion and mapped.
The outgoing quantities are transformed in a reverse way: they are post-processed (ramping, relaxation, mesh motion, etc.) into the target unit system.

3.3.5.1 Mesh Motion

A mesh motion is defined as

- A moving reference frame (MRF type):
  From the simulation code point of view, neither the grid is moving nor the quantity is moving in the inertial system.
  The MpCCI server will execute a transformation (which may be a rotational and/or translational motion) of the mesh and of vector based quantities if the simulation code is transient.

- A moving grid (GRID type):
  From the simulation code point of view, the grid and quantities are moved but the moved grid is not necessarily sent continuously to the MpCCI server. The quantities are already sent from the inertial system.
  The MpCCI server will not apply any transformation (rotation and/or translation) on the quantities.

The simulation, respectively the code adapter defines the mesh motion type used by the model. The mesh motion is defined for each part.
The MpCCI server will perform a new neighborhood search at each coupled step if the defined mesh motion types are different, namely a MRF model with a GRID model. Basically data from a MRF transient model are transformed into the inertial system from the MpCCI server.

3.3.5.2 Mesh Motion Application

The principal reason for employing a moving reference frame MRF is to render a problem which is unsteady in the stationary (inertial) frame but steady with respect to the moving frame. It should also be noted that you can run an unsteady simulation in a moving reference frame with constant rotational speed. This would be appropriate if you want to simulate, for example, vortex shedding from a rotating fan blade. The unsteadiness in this case is due to a natural fluid instability (vortex generation) rather than induced from interaction with a stationary component.
When a time-accurate solution (rather than a time-averaged solution) e. g. for a rotor-stator interaction is desired, you must use the moving grid or sliding mesh model to compute the unsteady flow field. The sliding mesh model is the most accurate method for simulating flows in multiple moving reference frames, but also the most computationally demanding. Lately Nonlinear Harmonic Methods which reduce the model size for rotor-stator interactions came into operation.

- Fluid mechanics physical domain

Motion type	Application area
Single/Multiple Reference Frame Mixing Plane or Frozen Rotor	Steady State approximations Weak rotor-stator interaction Initial solution for unsteady flow
Sliding Mesh Model Nonlinear Harmonic Method	Unsteady flow Strong rotor-stator interaction Vortex shedding

- Solid mechanics physical domain

Motion type	Application area
Rotating reference frame	Stress analysis induced from rotation and flow force Operational vibrations
Stationary reference frame	Unsteady flow Strong rotor-stator interaction Vortex shedding

3.3.5.3 Mesh Motion Combination

Definition of the abbreviations:

- MRF for moving reference frame or rotating reference frame.
- GRID for sliding moving mesh or stationary reference frame.

In the following scenarios some recommendations are provided about the usage of the Job.MeshMotion and Job.MRFCorrect features in the Settings step of MpCCI GUI (▷ 4.10.2 Job ◁).
MRFCorrect option only works if the code is transient. In that case the code using a MRF model will get its data transformed by using a prospective time step size.

Scenario 1

- CFD is steady state, MRF
- CSD is steady state, MRF

Motion properties	Use MeshMotion	Use MRFCorrect
Identical	NO	NO
Different	YES	NO

It is not recommended to use different angular velocities. Such modeling does not fit the targeted physical effect you want to study.

Scenario 2

- CFD is transient, GRID
- CSD is transient, MRF

Motion properties	Use MeshMotion	Use MRFCorrect
Different	YES	NO

The mesh motion GRID on CFD side provides an accurate solution of the unsteady flow, rotor-stator interaction.

Scenario 3

- CFD is transient, GRID
- CSD is transient, GRID

Motion properties	Use MeshMotion	Use MRFCorrect
Identical	NO	NO

3.3.5.4 List of codes implementing the mesh motion definition

Abaqus Models defining a rotating reference frame and stationary reference frame are supported.

- MpCCI recognizes the keyword *dload with the option CENT or CENTRIF as a rotating reference frame.
  The keyword CENT needs some additional editing, because it requires the material density corresponding to the moving part:
  The user can redefine manually the definition of the CENT option into a CENTRIF in the MpCCI GUI Regions step. Before adding the components into the list of coupled components you should provide the CENT using the following syntax by editing the component properties (▷ 4.8.2.2 Editing Component Properties ◁):

  ```
  ELSET,CENTRIF,omega^2,x0,y0,z0,ax,ay,az
  ```

  where $x0, y0, z0$ are the coordinate of the origin and ax, ay, az are the rotation axis definition. You should modify the information from the Aux Information field:
  keyword CENT becomes CENTRIF and you should provide $omega^2$ instead of $rho*omega^2$ value after the CENTRIF option. This should be repeated for all the components involved with this motion.
- MpCCI recognizes the keyword

  ```
  *INITIAL CONDITIONS, TYPE=ROTATING VELOCITY,TYPE=COORDINATES
  ```

  as a moving grid motion.

FLUENT Model with a Frame Motion is supported and defined as moving reference frame by MpCCI. MpCCI recognizes the properties defined under the Reference Frame panel.

Model with a Mesh Moving is supported and defined as moving grid by MpCCI. MpCCI recognizes the properties defined under the Mesh Motion Frame panel.

FINE/Open Model with a Rotation definition is supported and defined as moving reference frame by MpCCI. MpCCI defines the rotation axis along the z-axis.

FINE/Turbo Model defining a rotational speed is defined as moving reference frame by MpCCI. MpCCI defines the rotation axis along the z-axis.

STAR-CCM+ Model with a Reference Frames setting is supported and defined as moving reference frame by MpCCI. MpCCI recognizes the properties (origin, rotational speed, rotation axis) defined under the Reference Frames panel.

Model with a Motions setting is supported and defined as moving grid by MpCCI. MpCCI recognizes the properties defined under the Motions panel.

3.3.6 Quantity Transformation for Cyclic Symmetric Meshes

If a model consists of a cyclic symmetric mesh, MpCCI provides the possibility to couple it to a full model or to a periodic model which does not coincide but describes the same virtual full model, cf. Figure 16.

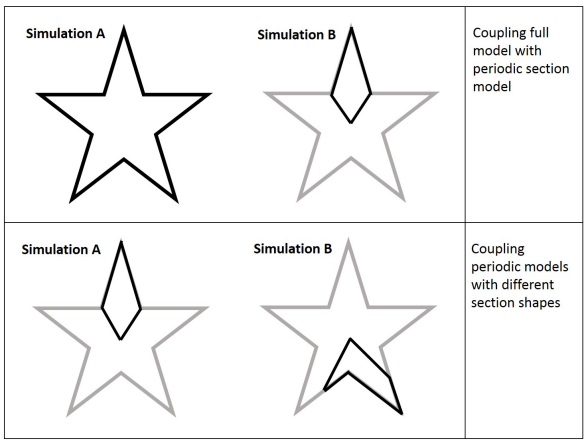


Figure 16: Periodicity panel

The necessary information is inputted into the GUI, cf. ▷ 4.8.2.3 Periodic Components ◁.

Internally, MpCCI server handles periodic meshes as full models. Incoming quantities are transformed into SI unit system and "copied" to the server internal sections building the virtual full model. This special copying rotates vector quantities by the periodic pitch angle; scalar quantities are simply copied to the corresponding nodes or elements. This reconstruction corresponds to cyclic symmetry mode zero, also known as nodal diameter zero.
The mapping is performed on the server internal virtual full models. If the target model is a periodic model, the mapped quantities on the full model are averaged for the target periodic section mesh, which guarantees periodic boundaries. At this stage postprocessing (ramping, relaxation, mesh motion, etc.) into the target unit system is performed. The outgoing quantities correspond to the periodic target model.

3.3.7 Operation Workflow for a Quantity

During the data exchange process, a quantity will be processed through different stages where some quantity operators can be defined by the user (cf. ▷ 4.8.7 Quantity Specifications ◁).
The following table shows the different operators available at different stages where the sequence numbers describe the workflow for a quantity:

Sequence No.	Stage	Operators	Comment
1	Receive operation		MpCCI receives the data.
2	Pre operation	ConvergenceCheck PreLimiter	Selectable operators.
3	Mapping operation		Automatic mapping process controlled by MpCCI.
4	Orphans operation	Orphans settings	You can select the orphans treatment.
5	Adjust operation	DisableConservation	You can disable conservative mapping correction.
6	Post operation	PostLimiter Scale	You can define their rank when applying these operators.
7	Relaxation operation	Relaxation	You can select the operator and specify the relaxation method.
8	Send operation		MpCCI sends the data.

3.4 Coupling Process

Coupling can be realized in two ways:

- The equations of each domain of the coupled systems are combined in one large system of equations, which is solved to obtain the solution. This contradicts the approach of MpCCI, which couples two codes, each of which is highly specialized in its field.

- Each system is solved separately, but data is exchanged during each iteration step, i. e. both codes compute one time step (the only one in a stationary computation) at the same time. If one code has finished a step of the iteration, it sends its data to the other code, which uses it in its own iteration. Both iterations are continued until both converge, yielding a state which fulfills the equation of both physical domains. The only disadvantage in comparison to weak coupling is that convergence is slower, thus the computations are slower, but yield more precise results.

The latter approach is supported by MpCCI and can only be realized if codes support exchanges during iterations.

The coupling process consists of three main phases:

Initialization The codes initialize their data and MpCCI is initialized. MpCCI establishes a connection between the codes and the association (neighborhood search) is carried through.

Iteration Each code computes its part of the problem and data is exchanged at certain moments.

Finalization The computation is ended by disconnecting the codes and stopping all codes and MpCCI.

Before and after the coupling process, the code can define some pre- and post-calculation steps. Such behavior can be defined under the option Runtime control in the Algorithm step (see ▷ 4.7.2 Code Specific Algorithm Settings ◁).

During coupling, the data is exchanged several times. MpCCI cannot control the simulation processes of the coupled codes. Therefore, it is important that whenever one side sends data, the other side should be ready to receive.

It is important to keep in mind, that sending of data is always possible: The data is stored by MpCCI, i. e. it can be received later by the other code. MpCCI can store several sets of data, which are then sent to the other code depending on the synchronization point set by the code.
When one code receives data, it waits until data is available from the other code if its coupling configuration does not use the Delay boundary updates option.

There are multiple coupling algorithms and schemes, which will be discussed in the following sections.

3.4.1 Coupling Algorithm

The coupling algorithm can be set to Parallel or Serial, leading to a Jacobi-type or Gauss-Seidel-type coupling, respectively. In MpCCI the coupling algorithm can be selected via the MpCCI GUI, cf. ▷ 4.7.1 Common Basic Algorithm Settings ◁.

Figure 17 shows the serial coupling algorithm, where Code A leads the coupling, known as "leading code". Knowing the fact that the coupling begins with initial conditions from the lagging code (Code B), the code with more stable and better known initial conditions should be chosen as the lagging code. In Figure 17, Code B sends its data for the first coupling step to Code A (1) to lead the simulation. After Code A finished computation (2), it sends its data from the first coupling step (3) and then waits to receive data for the second coupling step. Now, Code B got its data and starts computing the second coupling step (4), then sends data to Code A (5), which can then start its second coupling step calculation (6). At the end it sends the resulting data (7) and Code B can start the next coupling step.

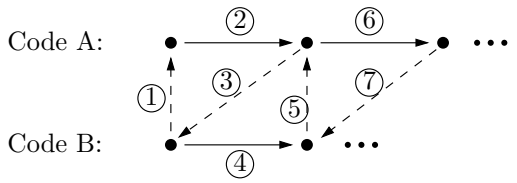


Figure 17: Serial coupling algorithm with leading Code A.

Figure 18 demonstrates the parallel algorithm without initialization and with initializing Code B. In these coupling types, both codes can do the calculation simultaneously.

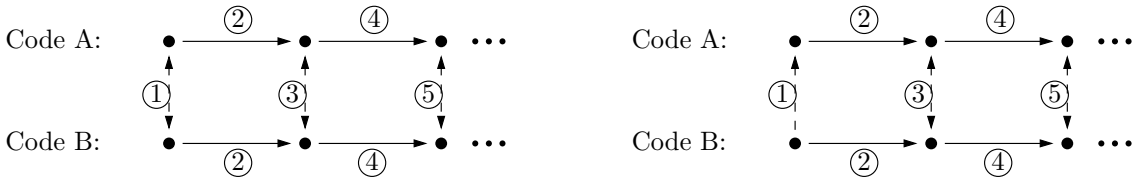


Figure 18: Parallel coupling algorithm without code initialization (on the left) and with initialization by Code B (on the right).

3.4.2 Coupling Schemes

Problems are usually time dependent or independent. In the former, which is called transient studies, the results change as time evolves, where usually the outcome for the new time step is dependent on the previous time steps. In these simulations, the behaviour of system over time is typically of interest. For time independent (steady-state) problems, only the final converged solution is desired.

In MpCCI, there are two available schemes, such as Explicit and Implicit. Explicit coupling can be applied for both steady-state and transient simulations, whereas Implicit coupling is only accessible for transient computations. Explicit steady-state and implicit schemes are referred to as iterative coupling.

3.4.3 Coupling with Subcycling

The idea of subcycling is the definition of extra iteration steps inside a coupling step, which is schematically depicted in Figure 19. There are possibilities to implement subcycling by configuring MpCCI and the employed solvers. The motivation for subcycling may be the implementation of optimal settings for each solver concerning computational costs, stability and accuracy.
For a transient simulation one solver could require smaller time steps for an accurate and/or stable solution process. Forcing the other code to apply the rather small time step might yield an inefficient process. Furthermore in steady-state calculations for thermal problems, heat propagation in fluids is subject to much faster transportation processes than in solid bodies, which will call for subcycling procedures in the fluid domain.

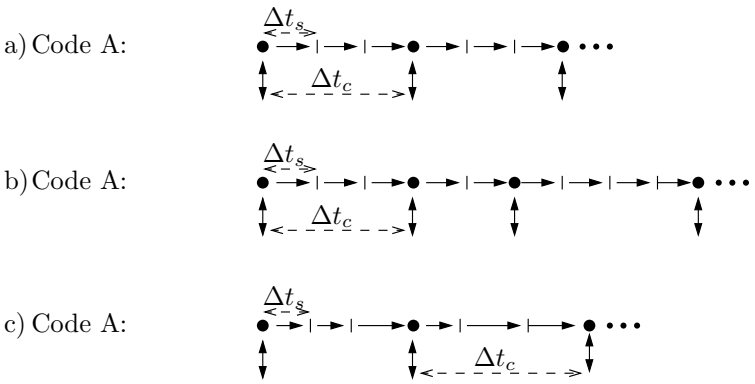


Figure 19: Three examples for coupling algorithms with subcycling for the Code A:
a) The solver step size Δt_s and the coupling step size Δt_c are constant over the total simulation period,
b) The solver step size Δt_s is constant and the coupling step size Δt_c is variable over the total simulation period,
c) The solver step size Δt_s is variable and the coupling step size Δt_c is constant over the total simulation period.

In MpCCI, the configuration of the coupling step size defines the frequency of the data exchange (subcycling) in term of solver steps. MpCCI GUI offers the possibility to configure the subcycling for each solver. The setting is available under the option Coupling steps in the Algorithm step (see ▷ 4.7.2 Code Specific Algorithm Settings ◁).

A tutorial where subcycling is applied for a thermal simulation is ▷ VII-8 Exhaust Manifold ◁.

3.4.4 Coupling with Delayed Boundary Updates

The idea of delaying the boundary update is to reduce the idle time of a waiting code. This feature is enabled for Steady state and Quasi transient analyses and aims to save idle time if one code runs much faster than the other one. This capability is only for codes which do a stationary analysis and support the delayed boundary update. The faster code may go on in its computation without updating its boundaries at the end of a coupling step. It then tries to do the update at a given substep frequency or at a given

number of update tries within the next coupling step. The update is delayed by no more than one coupling step.

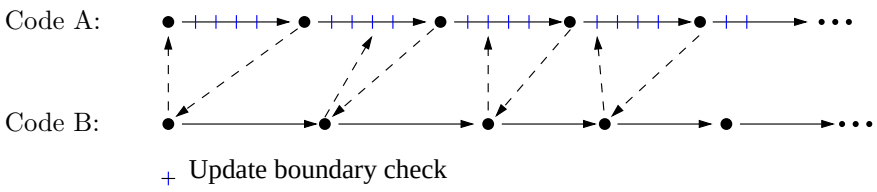


Figure 20: Example of delayed boundary updates applied to Code A

The Code A in Figure 20 uses the Delay boundary updates with a constant substep frequency to check for new values from Code B. The Code A always sends its quantities at the reached coupling point. If the quantities to receive are not yet available at this point, the receive operation is skipped and will be evaluated at the next delay point.

In MpCCI the Delay boundary updates can be selected via MpCCI GUI, cf. ▷ 4.7.1 Common Basic Algorithm Settings ◁.

3.4.5 Coupling with Transient Analysis Type

3.4.5.1 Implicit Coupling

Transient coupling algorithms exchange data once during each time step. For some problems this explicit transient coupling results in severe stability and accuracy problems. Using implicit transient coupling schemes, it is possible to reach a stable solution with moderate time step sizes for these problems.

Implicit coupling schemes are necessary for coupled simulations in which the interaction between the codes is strong. Usually these are fluid-structure interactions with an incompressible fluid and a low-density solid. Other applications might benefit from implicit coupling schemes because of bigger possible time step sizes.

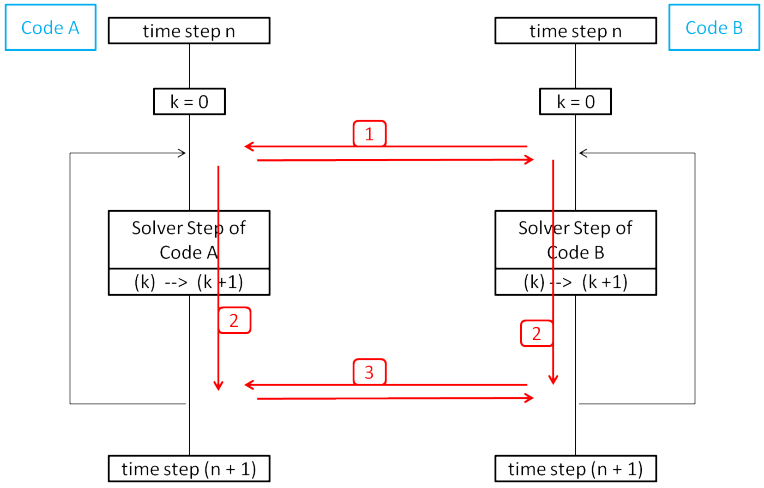


Figure 21: Jacobi algorithm for implicit coupling without any code initialization settings. (n is the time level, k is the coupling step iteration level)

Two different coupling algorithms are possible: a Gauss-Seidel and a Jacobi algorithm corresponding to the usual serial and parallel coupling algorithms which are described in ▷ 3.4.1 Coupling Algorithm ◁. Figure 21 and Figure 22 show these two coupling algorithms.

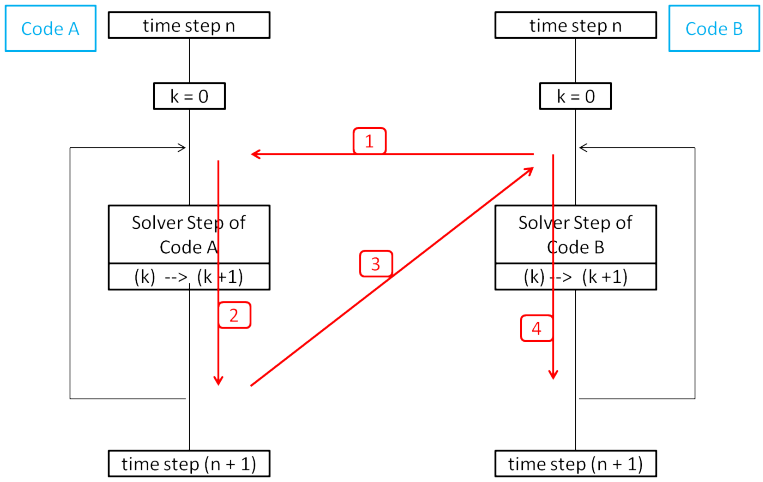


Figure 22: Gauss-Seidel algorithm for implicit coupling with leading Code A settings.

For both coupling algorithms the step from one time step to the next one is handled in a parallel, i. e. a Jacobi-type, way. The coupled step iterations k for each time step n are computed in a serial or in a parallel way.

Each coupling step iteration continues until the convergence criteria are fulfilled (see ▷ 3.3.4.1 Convergence Check ◁) or the maximum number of coupling step iterations is reached (see Coupling duration settings for transient analysis in ▷ 4.7.1 Common Basic Algorithm Settings ◁).

For some applications – especially fluid-structure interactions with incompressible fluids and moving walls – the Gauss–Seidel algorithm should produce a more stable solution.

Make sure that both coupled codes reach the same time at the end of the coupling. If the end time in the input file is wrong or it is not a multiple of the given time step in case of constant time-stepping, numerical inaccuracy or co-simulation errors could be expected at the end of the coupling. Please refer to the adapter description in Codes Manual for more information.

3.4.5.2 Coupling with Exchange of Time Step Size

Instead of using a fixed coupling time step size, it is also possible to use adaptive time stepping.

- Determined by code:
  In this case the time step size is determined by one code and sent to the partner code, which changes its own time step to the received value. MpCCI regards the time step as a global quantity without any special meaning, its name is “PhysicalTime” or “DeltaTime”, depending on whether it is the absolute time or the time difference to the previous step (see ▷ XI-XI Quantity Reference ◁ in the appendix).

  The exchange of time step sizes may yield unwanted effects:

  Time Shift: It depends on when exactly each code determines the time step size and sends it to the partner code. It may happen that the partner code uses the time step size of the previous step. This problem cannot always be solved, try to use a different coupling algorithm.

Convergence Problems: If the time step size is determined by one code it may be simply too large for the partner code. Please choose carefully which code shall determine the size and set reasonable limits.

It is strongly recommended to always define a default time step size in each simulation code, because the value of "PhysicalTime" or "DeltaTime" may not be defined at the beginning of a simulation! This depends on the coupling algorithm settings and how exactly each code evaluates the received value. The default value should be the same for both partner codes.

- Negotiate the time step size:
  Each code exchanges the time step size at the begin of the coupled step and the minimum value is used for the time step (▷ 4.7.1 Common Basic Algorithm Settings ◁). An example for time step size negotiation is provided in ▷ VII-4 Driven Cavity ◁.

3.4.5.3 Coupling with Non-Matching Time Steps

Coupling of Codes with Different Time Step Sizes Setting a fixed coupling step size for all codes might be disadvantageous for some applications. With MpCCI every coupled code can use its own time step size – perhaps a time stepping scheme adapted to the specific problem – and still exchange data with each other. For these asynchronous coupling schemes quantity values are interpolated between different time steps, such that every code receives the values that match its own time step value.

The main principle of the interpolation can be seen in Figure 23. In this example codes A and B each use their own fixed, non-matching time step sizes.

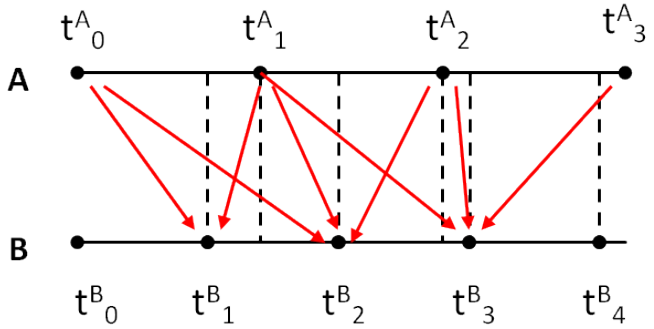


Figure 23: Non-matching time step sizes. Red arrows show which values of code A are used for the interpolation (using a "higher-order" interpolation)

The time step of code B is smaller; the quantity data MpCCI sends to code B at the first step t_1^B is the result of a linear interpolation using the two quantity values sent by code A at time steps t_0^A and t_1^A. This is indicated by the two red arrows pointing from code A to code B.

For time step two of code B (t_2^B) the quantity values from up to three (depending on the selected interpolation method) steps by code A – t_0^A,t_1^A and t_2^A – are used for the interpolation. Obviously, the values that are sent from code B to code A also have to be interpolated. Figure 23 contains only the interpolation for one direction (from code A to code B) because of clarity reasons.

Depending on the selected interpolation method a constant, linear or higher order interpolation is used. The used interpolation method can be selected in the Algorithm step of the MpCCI GUI. The different methods are described in the next section.

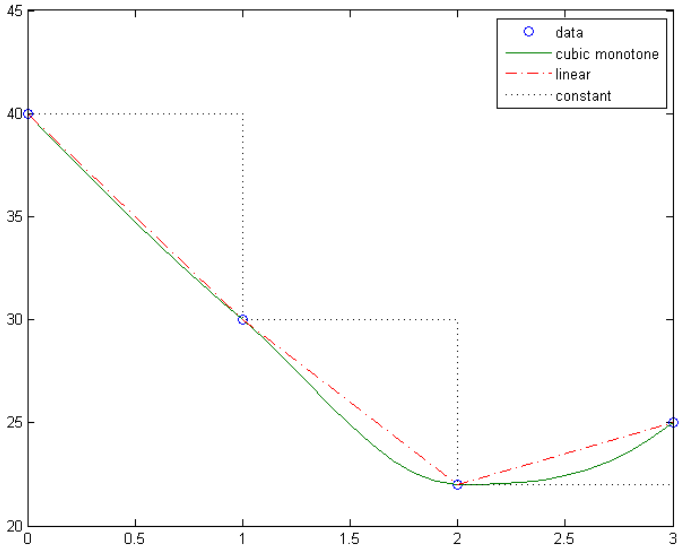


Figure 24: The three different interpolation methods: a piecewise monotone cubic Hermite spline, a linear interpolation and a constant interpolation for four data points.

Interpolation Methods The interpolation is handled automatically by MpCCI when the time step sizes do not match. No additional settings are required. The user can select the interpolation method in the Algorithm step (▷ 4.7.1 Common Basic Algorithm Settings ◁). A constant, linear and higher order interpolation is available. The different interpolation schemes are shown in Figure 24

The constant interpolation function (i. e. zero order) uses the last available value; for a standard linear interpolation (i. e. first order) one value before and one after the requested value is used.

Cubic Hermite spline interpolation (also called cspline) is used to achieve a higher order interpolation. For the definition of a cubic Hermite spline at the interpolation point x^* four values are needed: The two values at x_1 (smaller than x^*) and x_2 (bigger than x^*) and the tangents at these two points. Since the tangent values are not available, finite difference schemes are used to get an approximate value. If it is possible, three values and a central difference scheme are used to calculate an approximation of the tangent at the two points x_1 and x_2. For x_1 this are the values for x_0, x_1 and x_2 respectively.

Depending on the data points these calculated tangent values are scaled to ensure a monotone interpolation. In Figure 24, for example, the interpolating cubic spline between the third and fourth data point is monotonous. This ensures that the higher order interpolation curve does not oscillate or overshoot between the given data points.

The default interpolation method is the higher order interpolation using monotone cubic Hermite splines.

Limitations

Coupling of codes using different time scales

If the coupled simulations use very different time scales, the coupled job might abort with the error output:

```
*** ERROR *** The stored buffer time frame is out of the last grid time xx.
```

```
Either the grid time xx has not been received by the code or the history size
is too small.

Check either the "Coupling Algorithm" option or the "HistorySize" setting.
```

This happens if deformed coordinates (i. e. MpCCI quantity NPosition) are sent from a code with a big time step to a code with a small time step size.

Increasing the Job.HistorySize in the Settings step might help in these cases. The default value of 4 can be set to a larger number (up to 32).

If the used time steps (Δt_{big} and Δt_{small}) are known,

$$\text{HistorySize} \geq \frac{\Delta t_{big}}{\Delta t_{small}} + 4$$

might be a good choice for the value.

Alternatively, this error message might occur, if the Coupling Algorithm settings are not appropriate. When using parallel algorithms, code initialization should be disabled. Otherwise, it might result in the fatal message from above because the first grid information (if the coordinates are a coupled quantity) is not received.

Serial coupling algorithms

Currently, MpCCI does not support extrapolation in time, which leads to some restrictions when codes with different time step sizes are coupled.

Serial coupling algorithms with non-matching time step sizes can only be used when the leading code uses a bigger time step size than the lagging code. Furthermore, the bigger time step size has to be a multiple of the smaller time step – resulting in matching coupling times at each big time step.

Generally it is suggested to avoid using serial algorithms for non-matching time step sizes.

3.4.6 Coupling with Mixed Analysis Types

A transient coupling is challenging because of the great disparities of the physical models between the fluid and the solid. The main difficulty is due to the significant discrepancy of characteristic times since the transient phenomena in the fluid usually take place at a much smaller time scale than those in the solid.

The *Fully Transient Coupling* method describing the transient in both the fluid and the solid leads to a highly accurate solution but is too expensive. For some problems it is not a viable approach for practical design purposes.
Due to the discrepancy of characteristic times for the transient phenomena you can do the assumption that one of the problem having a smaller time scale than those used for modeling the other problem is considered as a steady-state problem. It leads to a computationally cheaper and simplified coupling procedure.
Such approach can be employed for the following application:

- Transient surface heat transfer
  In this coupling procedure you should adopt a coupling interval which is at least equal to the solid time step. The flow solution is considered as a sequence of steady-state solutions and in the solid the fields evolve in a fully transient manner.
  As in Figure 25 explained, the exchange of temperature (Temperature or WallTemp) and the heat flux (WallHeatFlux) is performed after the solid time step and a fluid steady-state step. In the parallel coupling scheme example, both solvers perform an initial calculation step without coupling

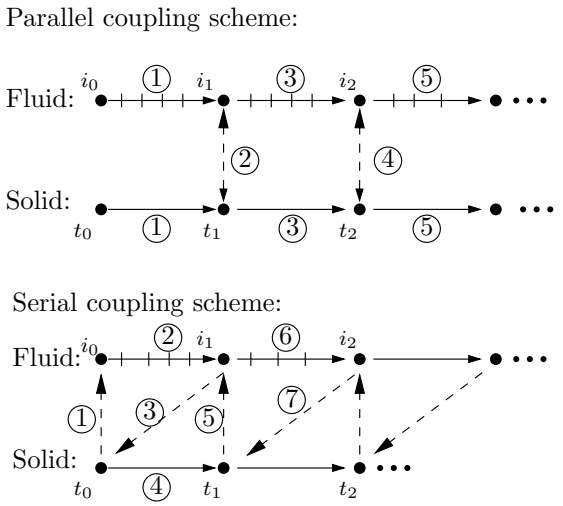


Figure 25: Quasi-transient fluid solid coupling algorithm

by defining a coupling start time t_1 or iteration i_1. The fluid side may optionally perform some subcycling iterations before transmitting the heat fluxes.

- *Electrothermal analysis case: Electric arc simulation*
  In this application you may assume a steady-state computation of the electromagnetic phenomena (Karetta and Lindmayer [1998]) because the electromagnetic phenomena are faster than the gas dynamic. The Maxwell equations will be solved as a sequence of steady-state solutions whereas in the fluid the Navier-Stockes equations evolve in fully transient manner.

By selecting such model you will be warned by the MpCCI GUI that you are currently mixing the solution types (Figure 26). You can process to the next step and set up the coupled simulation as usual.
For these mixed solution types, coupling scheme is automatically set to Explicit.

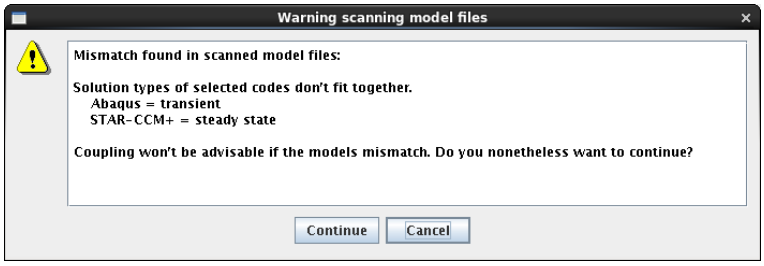


Figure 26: Coupling with mixed solution types

3.4.7 Restarting a Coupled Simulation

One should distinguish between an actual restart and a complex start.

Restart means the simulation is interrupted by killing the simulation or reaching a target time. Then the simulation is restarted seamlessly, i. e. continued as if it had never been interrupted.

Complex Start means that the coupled simulation consists of different analysis steps, which differ in e.g. boundary conditions, simulation analyses (transient/steady state). The second step is then based on the results of the first one.

When restarting a coupled simulation, this consists of three parts. Each of the simulation codes must be restarted separately – the same way it is done without coupling – and MpCCI must be restarted.

A new neighborhood search is performed on the original or deformed meshes depending on the capability of the code to provide the original mesh and may yield different results in comparison to the first search, i. e. the restart may not be really seamless.

Restarting a coupled simulation is an advanced analysis procedure. It is difficult to choose the coupling algorithm such that the time in both codes is still synchronous after a restart. Mostly it should be set to Parallel for the restart. This is also code-dependent, there is information on restarts for some codes in the Codes Manual.

3.5 Smart Configuration

MpCCI Configurator (see ▷ 5.4.2 mpcci configurator ◁) is a tool to provide an MpCCI configuration for the coupled models. The tool extracts some features of the models in order to predict the most appropriate parameters. The algorithms behind MpCCI Configurator are based on optimization and machine learning methods. The objective of the smart configuration is to obtain an optimal runtime compared to the default settings in MpCCI GUI.

MpCCI parameters such as ▷3.3.3 Quantity Relaxation◁, ▷3.3.4 Quantity Operators◁, ▷3.4.1 Coupling Algorithm◁, ▷3.4.2 Coupling Schemes◁ are predicted by the MpCCI Configurator to perform a robust and fast co-simulaton. To achieve the optimal configuration, material features such as the "Young's modulus", "density of fluid", "density ratio between solid and fluid materials" and "fluid compressibility" are extracted from the simulation models. The prediction of the MpCCI parameters is gained from a trained model constructed on data and knowledge-based modelling using machine learning and simulation approaches.

The MpCCI Configurator is actually available from the coupling specification under ▷4.5.2 Category: Fluid-Structure Interaction (FSI)◁. The Fluid-Structure Interaction with Smart Configuration specification is available for the following codes:

Solid Mechanics : Abaqus with only isotropic elastic material definition.

Fluid Mechanics : FLUENT and OpenFOAM. For both codes the simulation environment has to be set up and an available license for FLUENT needs to be available during the execution of MpCCI Configurator.

A simple example is shown in the tutorial ▷VII-6 Blood Vessel◁.

3.6 Running MpCCI in a Network

The use of MpCCI in a network is almost unlimited. MpCCI can couple simulation codes which run on different computers with different operation systems. It is also possible to run one or both of the simulation codes in parallel and to start the coupled simulation on a cluster using a queuing system.

3.6.1 Client-Server Structure of MpCCI

The code coupling of MpCCI is based on a client-server model: The MpCCI processes act as servers while the simulation codes – more precisely the code adapters of the simulation codes – act as clients.

If codes are coupled without parallel execution, one server is started for communication with each simulation code, see Figure 27 a).

If a simulation code is running in parallel, MpCCI starts one server and there are two possible ways of communicating for the simulation code:

- All data which is exchanged with the simulation code is passed via a main process. This is depicted in Figure 27 b) on the left.
- Each subprocess of a simulation code communicates with the MpCCI server as shown in Figure 27 b) on the right.

Distributing MpCCI Server on a Remote Machine

The MpCCI server communication is socket-based. It can be run on a different machine which uses another endianness. (The "endianness" is the order in which bytes are stored or transmitted, which depends on the processor.)

The host for the MpCCI server can be provided in the Go step of the MpCCI GUI. Select the option Distribute server on remote host and enter a name of remote computer (with domain name if necessary) into the field Remote 'host' to be used. See ▷4.11 Go Step◁ for details.

Distributing Simulation Codes on Different Machines

The communication between the simulation code clients and MpCCI server is purely socket-based.

If a simulation code shall be started on a remote computer, the input file must be placed there and selected in the remote file browser (▷4.12 Remote File Browser◁). If the code shall additionally be started in parallel, please select the appropriate options in the Go step, as described in the Codes Manual.

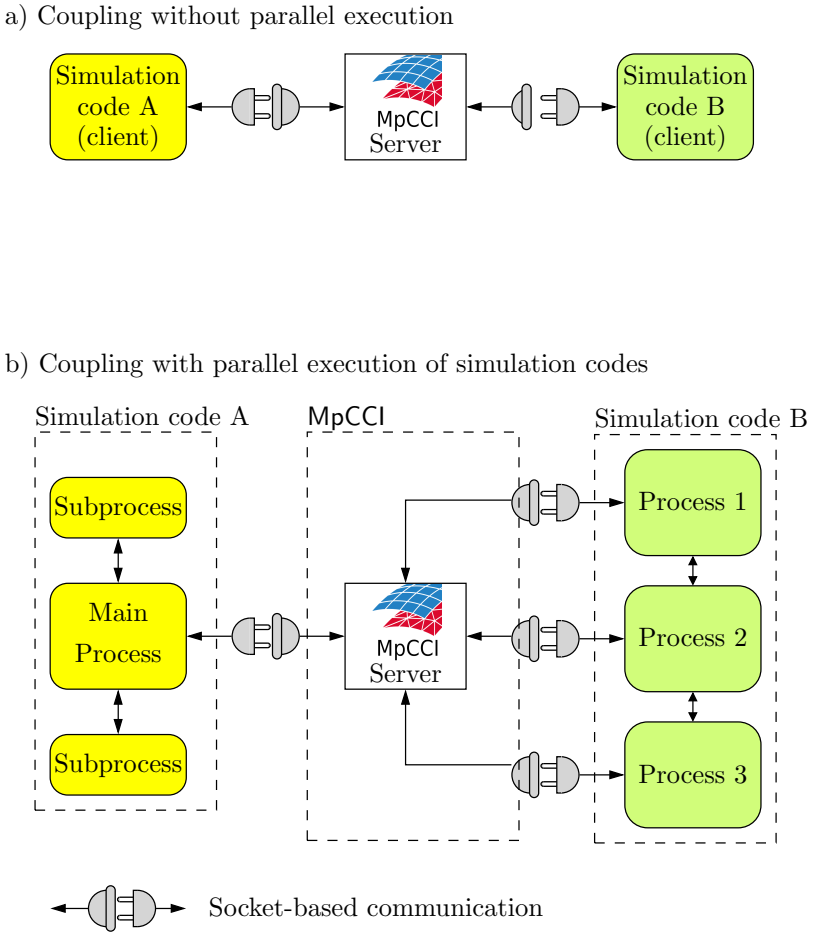


Figure 27: Client-server structure of MpCCI

Port Numbers for Socket Communication

For a coupled simulation MpCCI uses the basic port number for the different socket connections, which can be selected in the MpCCI GUI (▷ 4.11.1 Configuring the MpCCI Coupling Server ◁) or when starting the server with `mpcci server` (▷ 5.7.11 mpcci server ◁).

In the example sketched in Figure 27 a) only one port is used for getting the incoming client connection:
47010 Connection to simulation code A
47010 Connection to simulation code B

For the parallel run of Figure 27 b) only one port is needed:
47010 Connection to main process of simulation code A
47010 Connection to process 1 of simulation code B
47010 Connection to process 2 of simulation code B
47010 Connection to process 3 of simulation code B

Once all connections are established, the ports may be re-used, even if a simulation is still running. Only if you want to start several coupled simulations at the same time, you should use different sets of ports.

If you need to change the ports due to firewall restrictions, please ensure that a sufficient number of

subsequent ports can be accessed.

Socket Communication Timeout

The default socket communication timeout is set to 60 seconds. This timeout can be overwritten by defining the environment variable `MPCCI_TIMEOUT`. This accepts an integer value defining the timeout in seconds. This should be defined as global environment variable for the simulation. Setting the value to `-1` will disable the timeout.

Network Device

The default network device is using the standard default ethernet interface for the socket communication. This setting can be overwritten by defining the environment variable `MPCCI_NETDEVICE`. This accepts a string value defining the name of the interface to be used. The network interface name mostly matches with the device name listed by the command `ifconfig` for Linux operating system. This environment variable should be defined as global environment variable for the simulation.

You can check the device name on the target machine by using the command `mpcci netdevice` (▷ 5.4.5 mpcci netdevice ◁).
Example of testing the infiniband interface: `mpcci netdevice ib0`

3.6.2 Hostlist File

If you run coupled simulations frequently on different computers, it is recommended to use a hostlist file, which contains a list of computers. Each line in the list corresponds to one remote machine. There are two possible line formats, the standard format:

```
[user@]hostname  [#rsh] [#ssh] [#home:path] [#arch:token]
```

or extended (`".rhost"` type) format:

```
hostname [user user user]  [#rsh] [#ssh] [#home:path] [#arch:token]
```

Lines starting with a `#` are treated as comments. The entries `#rsh` and `#ssh` are used to select the network communication method (see ▷ 3.6.3 Remote Shell and Remote Copy ◁ below), the `#home:` option is used to specify the path to the home directory (only needed if not standard directory) and the `#arch:` option can be used to explicitly choose an architecture, see ▷ 2.3.1 MPCCI_ARCH - Architecture Tokens ◁ for details.

Thus a hostlist file might look like:

```
fred@jupiter #ssh #home:/u/fred
saturn.example.com  fred  barney #arch:lnx4_x64
# this line is a comment
mars
```

The standard MpCCI hostlist file is `"<Home>/.mpcci/mpcci.hosts"`, which is located in the MpCCI Resource Directory (▷ 2.4 The MpCCI Resource Directory ◁). If you want to use a different default hostlist file, you can set the environment variable `MPCCI_HOSTLIST_FILE` to the path of the file.

You may list the contents of the hostlist file with `mpcci list -hosts`.

3.6.3 Remote Shell and Remote Copy

To start processes on remote machines and copy files, MpCCI can use either the rsh or the ssh family of commands. The environment variable `MPCCI_RSHTYPE` defines which family of remote commands is used:

MPCCI_RSHTYPE	remote shell	file copy
rsh	rsh or remsh	ftp or rcp
ssh	ssh	scp or sftp

If MPCCI_RSHTYPE is not defined or not set the default is rsh under UNIX and Linux and ssh under Microsoft Windows.

It depends on your network configuration which method should be used.

Please also read ▷III-6.1 Accessing Remote Hosts◁ for testing the remote access facilities.

3.7 Coupled Analysis in Batch Mode

3.7.1 General Approach

To start a batch job with MpCCI, i. e. a simulation without graphical interface, a project file "*.csp" must already be present. The following procedure is recommended:

1. Set up a coupled simulation on a computer with graphical interface. Proceed up to the Go step in the MpCCI GUI and save the project file.

   If a code has to run in parallel, you have to enable the parallel option as described in the Codes Manual

2. Start the coupled analysis with `mpcci -batch` <*project file*> from the MpCCI project directory.

The `mpcci -batch` command will start the simulation and distribute the codes as configured in the project file.

3.7.1.1 Run a Job in Batch Mode with MpCCI Command Line

The `mpcci -batch` command is used to start the simulation. It distributes the codes as configured in the project file. A new project file is created with the prefix "batch_" to the original project file name before starting the simulation. The `mpcci -batch` command offers some additional options to configure the resources settings. Following options are available:

-checkonly (deprecated) see -prepare.

-prepare Create the project file used for the batch job and exit. A new batch system compatible project file will only be created when running the MpCCI job under a batch queuing system. It may help you to adjust the host distribution for example.

-chwd $< PATH >$ Replace the symbolic $(CWD) working directory used inside the project file by the absolute pathname specified in the PATH argument.

-listen $< N >$ Specifies an alternative port number N for the communication between the MpCCI server and the simulation codes. The default port number is 47010.

-mpmode $<$ *codeA* : *mode* $><$ *codeB* : *mode* $>$ Set the parallel method mode for each code with the following option:

- none: run code on one cpu
- smp: activate shared memory parallel mode
- dmp: activate distributed memory parallel mode

-nocontrol Start the MpCCI batch job without activating the termination process management. The user is responsible for terminating the simulation process.

-nolic Do not check for a license before starting the batch job.

-norsa Do neither check for ssh nor ask for ssh assistance if an rsa key file does not exist.

-np $< codeA : N >< codeB : M >$ Bind each code (codeA, codeB) to a specified total number of cores (N,M) to use. You can modify the number of cores to use without need to reedit your project file. Your project file needs to be saved with an activated Run Parallel option for the concerned code if the option -mpmode is not additionally used for this code.

-precheck Start MpCCI in pre-check mode only. The simulation codes will send their mesh data for a neighborhood search calculation. The results of the check are stored in the server log file (▷ 3.8.3 Log Files ◁).

-set $< section : p = v[, p1 = v1, p2.p3 = v3] > [< section2 : p4 = v4 >]$ Modify the property value of the specified section before submitting the job in batch. The section is either one of the reserved keys "server", "settings" or the code id of the code. Where "server" corresponds to the mpcciserver section and "settings" to the edit section of the project file. The property name corresponds to the following rules from the project csp file:

- The property name matches the value of the name attribute (<param name="property"...) if it is unique.
  Otherwise provide a dot separated path to the property, e.g. <group name="CCVX"><param name="Use".../> will use the property "ccvx.use".
- The value to be modified must match the defined type.
- The list of properties of a section is comma-separated.
- A space is used to separate the section list.

-useAbsolutePath Use the current local MpCCI installation directory as reference for any remote computer access.

Example about running only a neighborhood calculation:

```
mpcci batch -precheck test.csp
```

Example about changing the parallel method to use and change the number of cpus for each code:

```
mpcci batch -np abaqus:4 fluent:16 -mpmode abaqus:smp fluent:dmp test.csp
```

Example about changing the output level, disable the monitor, the jobname of the coupling job and setting the additional arguments for STAR-CCM+:

```
mpcci batch -set settings:output.level=2,monitor.enable=false server:jobname=fsi
star-ccm+:cmdopts=-noconnect test.csp
```

If you want to directly submit the calculation on a queuing system, e. g. SGE you can simply add the specific MpCCI batch name options:

```
mpcci batch SGE submit -np abaqus:4 fluent:16 -mpmode abaqus:smp fluent:dmp
test.csp
```

This command calls the submission `qsub` and passes all parameters from the commandline.

3.7.1.2 Configure a Simulation Code for Running on a Remote Machine

Usually, when you have to run distributed computation over several compute nodes, you have to take care that the required environment to start the simulation code is correctly set. In some cases, especially with a job scheduler queuing system, the environment is usually set up in the job shell script where the PATH and license environments are defined. This compute environment is valid on the master node and is not necessarily exported to the slave node when a remote command is started from the master node. In order to address this issue, `mpcci -batch` command can be used with the option -useAbsolutePath which will use the current local MpCCI installation path on the compute node.

Additionally you may define the environment variables to be set up for each code before running the code. For this purpose `mpcci -batch` command looks for the special environment file `"mpcci_<CODENAME>.env"` under the directory containing the model file of the simulation code. To use this feature you need to create the special environment file. The <CODENAME> should be replaced with the name of the code in use, for example Abaqus, FLUENT, etc. . The name of the code can be written in lowercase or can match the naming case convention of MpCCI. This file `"mpcci_<CODENAME>.env"` should define some environment variables to be updated like PATH, LD_LIBRARY_PATH, LM_LICENSE_FILE, etc. .
The following rule syntaxes are available to define a variable:

- To add a value to an existing variable, use the syntax +=. For example: VARIABLE+=value.

- To set a value to a variable, use the syntax =. For example: VARIABLE=value.

For example:

```
LM_LICENSE_FILE=30000@licserver
PATH+=/opt/mycode/bin
LD_LIBRARY_PATH+=/opt/mycode/lib64
```

Each environment variable will be updated with the defined value from the `".env"` file.

In addition to the direct definition of environment variables you can provide a shell script to be sourced in order to load all settings for the code. For example on linux operating systems, you will have following definition:

```
source /usr/app/config/fea_env.sh
```

Basically, all lines from the `"mpcci_<CODENAME>.env"` file which do not contain an equal (=) statement are interpreted as an external program to be executed in order to modify the process environment.

3.7.2 Job Scheduler Environment

To run a coupled computation with a job scheduler (queuing system) on a computing cluster MpCCI provides a set of commands to submit, status, kill a job to/from a job scheduler.

MpCCI supports batch-systems like MS HPC, LSF, PBS, TORQUE,SGE, and SLURM.

When preparing the project files, you cannot already know on which nodes of a cluster your processes will be started. MpCCI automatically detects that it is started by a job scheduler and changes the entries in the project files accordingly, i. e. the jobs are spread onto the reserved nodes by MpCCI. MpCCI will create a new project file containing the new associated hosts for each code. This project file is named by the prefix `"batch_"` to the original project file name.

The following procedure is recommended in order to prepare the project file:

1. Start the MpCCI GUI on a computer with graphical interface.

2. Set up the coupled analysis as a *local* job. This means the model files are selected on the local file system.

3. Proceed up to the Go step in the MpCCI GUI and save the project file.

Please consider following items:

- To distribute the server on a remote host (see ▷ 4.11.1 Configuring the MpCCI Coupling Server ◁), you have to define the Preferred remote shell type and let the Remote 'host' to be used field empty.
- To configure a code to run in parallel, you have to enable the parallel option as described in the Codes Manual for the code and specify the number of processes or threads to use.
- In case that the computing cluster has a different file system than the workstation where you have set up the project file, it is recommended to copy the project directory including all input files for the simulation codes as well as the MpCCI project file `"*.csp"` to the compute head node.

Up to step 3 you have prepared your project file.

Now there are three ways to submit the job:

- The MpCCI GUI may assist you to submit the job to the queue and configure the host allocation for each code if necessary (▷ 3.7.2.4 Submitting a Batch System Job with MpCCI GUI ◁).
- You can submit the job by using the MpCCI command line (▷ 3.7.2.3 Submit a Batch System Job with MpCCI Command Line ◁) which will create a small shell script and send the job to the submission system.
- You can write your own shell script which calls `mpcci -batch` command (▷ 3.7.1.1 Run a Job in Batch Mode with MpCCI Command Line ◁) to run the co-simulation.

3.7.2.1 Host Management under a Job Scheduler Environment

At startup of a coupled job MpCCI checks if corresponding environment variables

- `LSB_MCPU_HOSTS`
- `PBS_NODEFILE`
- `PE_HOSTFILE`
- `CCP_NODES`
- `SLURM_JOB_NODELIST`

are defined. MpCCI then uses the listed host names to start MpCCI coupling server and both coupled codes on these hosts.
The total number of processors/cores for the coupled simulation is equal to the total amount of

- the total number of parallel processes/threads for all simulation codes plus
- the total number of threads used by the MpCCI Grid Morpher if used plus
- one process for the MpCCI server.

MpCCI distributes the available hosts by following this procedure:

1. Check for multi-threaded parallel codes and assign an SMP host:
   - MpCCI searches for a machine having at least the number of required cores for running the multi-threaded parallel code.
   - If no host has been found satisfying the minimal number of threads required, MpCCI will stop the batch process, otherwise the next multi-threaded parallel code is handled.
2. MpCCI checks the rest of available hosts for the parallel codes and warns if the number of processors are not enough or too much.

3. Check for specific code to host allocation resource option (see ▷3.7.2.2 Application Specific Code to Host Allocation◁) and allocate the host to the corresponding code.
4. If no specific code to host allocation option is specified, MpCCI distributes the rest of the hosts by respecting this rule:
   - Try to find pairs of matching cores and code processes and allocate the host to the code.
   - Next try to find a host with a number of cores greater than the number of code processes and allocate the host to the code if found.
   - Otherwise if no host satisfies the minimal number of required processes for a code, try to perform a homogeneous distribution of processes between the hosts.
   - Distribute the codes on the hosts left.
5. Resort the host list with the current host (master node) at the begin of the list if this one is listed.

3.7.2.2 Application Specific Code to Host Allocation

MpCCI allows to specify in more detail the allocation of hosts for specific codes.

If environment variables

- `MPCCI_<`*CODENAME-1*`>_HOSTS = "host-a1 host-a2 host-a3..."`
- `MPCCI_<`*CODENAME-2*`>_HOSTS = "host-b1 host-b2 host-b3 ..."`
- `MPCCI_SERVER_HOSTS = "host-c1 host-c2 host-c3 ..."`

are set, the MpCCI startup procedure will allocate the listed hosts for the code represented by the name <*CODENAME*> or for the server with `MPCCI_SERVER_HOSTS`. It is up to the user to define these environment variables if the MpCCI batch command line is used. Otherwise by submitting the job from MpCCI GUI these environment variables are written into the batch script.
Instead of a list of real hostnames a regular Perl-pattern might be used to define the selection of code-specific hosts extracted from the defined PBS, LSF, SGE or LoadLeveler environment variables:
`MPCCI_<`*CODENAME-1*`>_HOSTS` = "/pattern/".


<*CODENAME-1*> must be a "word" character.

3.7.2.3 Submit a Batch System Job with MpCCI Command Line

The syntax of the command line is the following:
`mpcci -batch` [OPTIONS] <*BATCH_NAME*> `submit` [BATCH-OPTIONS] <*project file*>
with the arguments meaning:

[OPTIONS] represents a list of the MpCCI options for batch mode (cf. ▷3.7.1.1 Run a Job in Batch Mode with MpCCI Command Line◁).

<*BATCH_NAME*> represents the name of the batch system e. g. PBS, SGE, etc.

[BATCH-OPTIONS] represents a list of the original options of the submit command.

<*project file*> is the project file or a shell script.


If the <*project file*> is a shell script this will be simply handed over to the submit command

By using the MpCCI batch command line you have to define the host allocation for each code by yourself. You can pass the host allocation definition as [BATCH-OPTIONS] argument. The variables

- `MPCCI_<`*CODENAME-1*`>_HOSTS="host-a1 host-a2 host-a3..."`
- `MPCCI_<`*CODENAME-2*`>_HOSTS="host-b1 host-b2 host-b3 ..."`

- `MPCCI_SERVER_HOSTS="host-c1 host-c2 host-c3 ..."`

should be given as arguments (see also ▷3.7.2.2 Application Specific Code to Host Allocation◁).
After submitting the job the job id is saved by MpCCI in the directory `"<HOME>/.mpcci/batch"`. You can retrieve the list of submitted jobs with this command: `mpcci list jobs` which returns the job id with the associated batch system:

```
SGE 1532
PBS 8470
```

This information can be used to status or kill the job.

Here is an example of job submission for SGE:

```
$> mpcci -batch SGE submit -J coupled_test -cwd -pe cre 8 MPCCI_SERVER_HOSTS=/.*/
MPCCI_FEM_HOSTS=/.*/ MPCCI_CFD_HOSTS=/.*/ test.csp
```

And this is the generated script `"test.sh"` that is given to the submit command:

```
#!/bin/sh
#$ -S /bin/sh
#$ -v MPCCI_LICENSE_FILE,PATH
#$ -cwd
#$ -N coupled_test
#$ -pe cre 8
MPCCI_CFD_HOSTS=/.*/
MPCCI_SERVER_HOSTS=/.*/
MPCCI_FEM_HOSTS=/.*/
export MPCCI_CFD_HOSTS MPCCI_SERVER_HOSTS MPCCI_FEM_HOSTS
mpcci batch test.csp
```

Status of a Batch System Job with MpCCI Command Line

Each batch system provides a status command:
`mpcci batch <BATCH_NAME> status <JOB ID>`

The job id may be retrieved with the `mpcci list jobs`.


The status command has to be executed on the machine where the job has been submitted.

Kill a Batch System Job with MpCCI Command Line

Each batch system provides a kill command:
`mpcci batch <BATCH_NAME> kill <JOB ID>`

The job id may be retrieved with the `mpcci list jobs`.


The kill command has to be executed on the machine where the job has been submitted.

3.7.2.4 Submitting a Batch System Job with MpCCI GUI

To submit the MpCCI job with the MpCCI GUI you have to start the MpCCI GUI on the head node of your cluster. Usually the batch queue commands are available on the compute head node.
You have to open your project and select Batch→Submit Batch Job in the menu (which is enabled in the Go step). A dialog will pop up and you are able to configure the batch options (cf. ▷4.4.3 Batch Menu◁).

For specifying the host allocation you have the option to provide

- a list of hostnames or
- a pattern (regular expression) to modify/select some hostnames.

If a host allocation field is empty MpCCI will automatically assign the allocated hostnames to the code without any specific hostname processing. The hostname assignment is also explained in section ▷ 3.7.2.2 Application Specific Code to Host Allocation ◁.

By clicking on the Submit Batch Job button MpCCI prepares a script named ("<*project name*>`.[sh|bat]`") to be submitted to the batch system for the current project. This generated script contains all the options provided by the MpCCI GUI for the selected batch system and the call of `mpcci -batch` <*project file*>.

Below follows the description of the configuration dialog for each batch system.

Options Details for an MS HPC System (Figure 28)

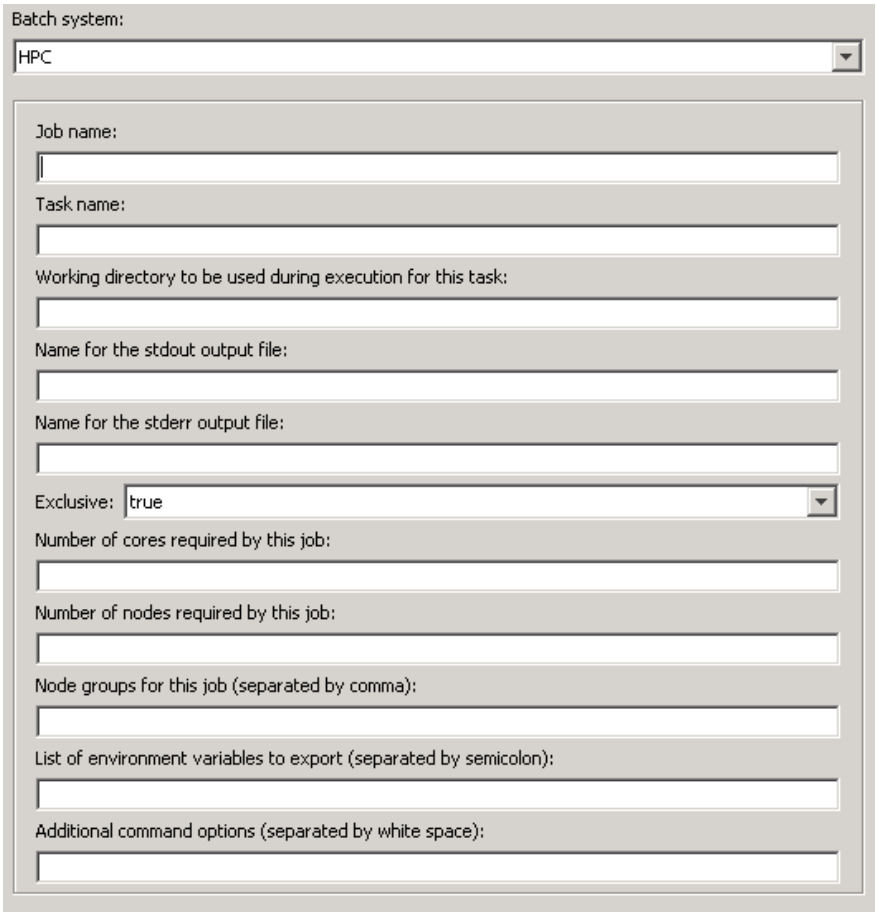


Figure 28: MS HPC options

Job name You can provide the name of this job. This setting represents the option /jobname of the submit command.

Task name You can provide the name of the task. This setting represents the option /name of the submit command.

Working directory to be used during execution of the task This setting represents the option /workdir of the submit command. It is recommended to provide the directory path of the MpCCI project file. This should be either a UNC path or an accessible path from the compute nodes.

Name for the stdout output file You can provide a filename for the stdout collected by the batch system. This setting represents the option /stdout of the submit command.

Name for the stderr output file You can provide a filename for the stderr collected by the batch system. This setting represents the option /stderr of the submit command.

Exclusive If true, no other jobs can be run on a compute node at the same time as this job. This setting represents the option /exclusive of the submit command.

Number of cores required by this job This setting represents the option /numcores of the submit command.

Number of nodes required by this job This setting represents the option /numnodes of the submit command.

Node groups for this job (separated by comma) The job can only be run on nodes that are in all of these groups (e. g. cfd,mpich2). This setting represents the option /nodegroup of the submit command.

List of environment variables to export (separated by semicolon) Specifies the environment variables to set in the task's runtime environment (e. g. TEST_NAME=coupling;TEST_MODE=parallel). This setting represents the option /env of the submit command.

Additional command options (separated by white space) You can provide a list of submit options that are not listed here. These options will be passed on to the submit command.
(e. g. /nodegroup cfd,mpich2)

Options Details for an LSF System (Figure 29)

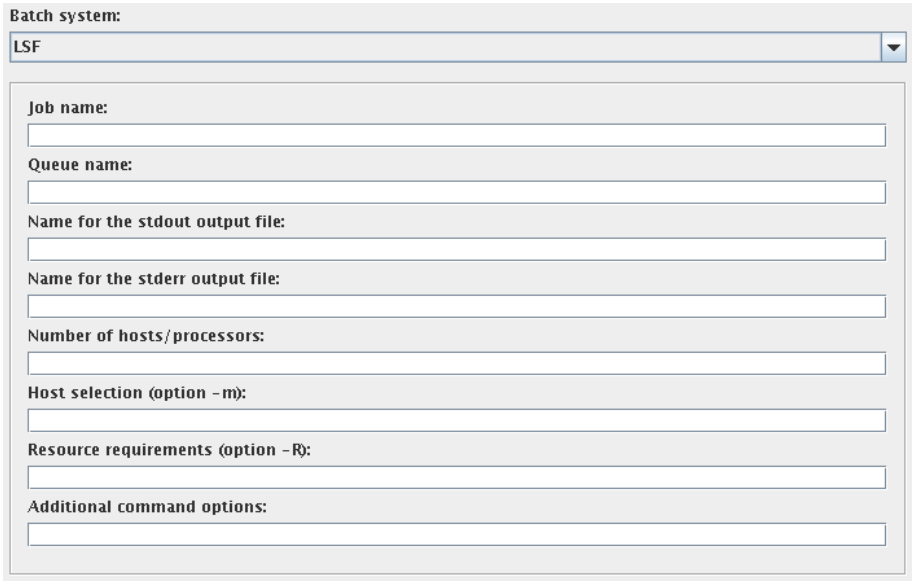


Figure 29: LSF options

Job name You can provide a job name for the coupled analysis. This setting represents the option -J of the submit command.

Queue name You can provide a queue name to submit the job. This setting represents the option -q of the submit command.

Name for the stdout output file You can provide a filename for the stdout collected by the batch system. This setting represents the option -o of the submit command.

Name for the stderr output file You can provide a filename for the stderr collected by the batch system. This setting represents the option -e of the submit command.

Number of hosts/processors You can provide the number of hosts/processors to be reserved for the job. This setting represents the option -n of the submit command.

Host selection (option -m) You can provide a set of candidate hosts for running the coupled analysis. This setting represents the option -m of the submit command.

Resource requirements (option -R) You can provide the resource requirement setting for the coupled analysis. This setting represents the option -R of the submit command.

Additional command options You can provide a list of submit options that are not listed here. These options will be passed on to the submit command.

Options Details for a PBS System (Figure 30)

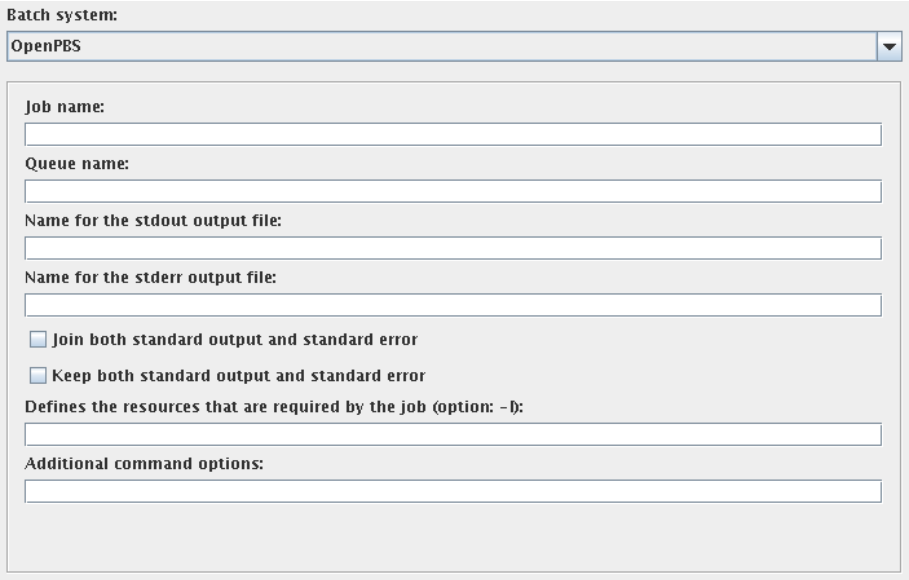


Figure 30: OpenPBS options

The options are identical for the PBS, PBSPro, OpenPBS and Torque batch systems.

Job name You can provide a job name for the coupled analysis. This setting represents the option -N of the submit command.

Queue name You can provide a queue name to submit the job. This setting represents the option -q of the submit command.

Name for the stdout output file You can provide a filename for the stdout collected by the batch system. This setting represents the option -o of the submit command.

Name for the stderr output file You can provide a filename for the stderr collected by the batch system. This setting represents the option -e of the submit command.

Join both standard output and standard error select this option to merge the standard output and standard error. This setting represents the option -j oe of the submit command.

Keep both standard output and standard error select this option to keep both standard output and standard error. This setting represents the option -k oe of the submit command.

Defines the resources that are required by the job (option: -l) You can define a resource requirement for running the coupled analysis. This setting represents the option -l of the submit command.

Additional command options You can provide a list of submit options that are not listed here. These options will be passed on to the submit command.

Options Details for a SGE System (Figure 31)

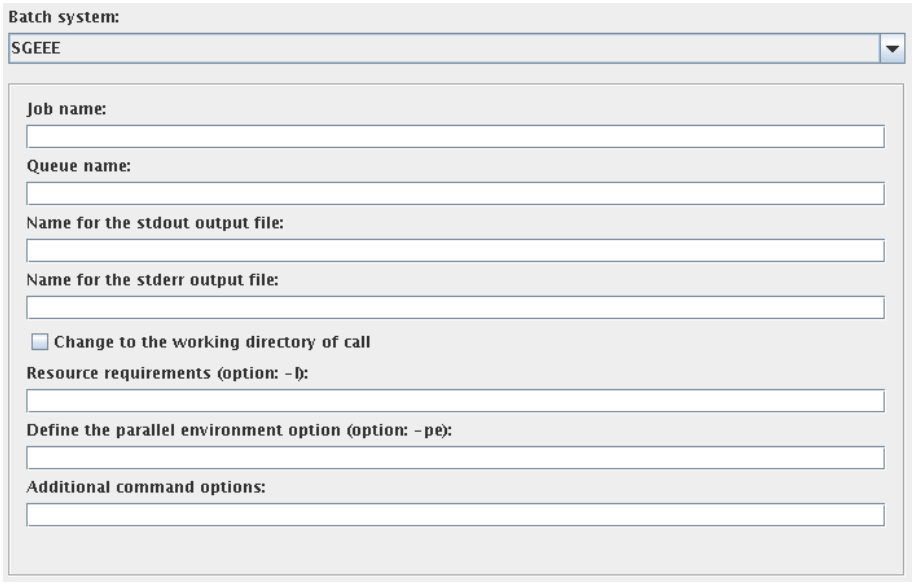


Figure 31: SGE options

The options are identical for the SGE, N1GE and SGEEE batch systems.

Job name You can provide a job name for the coupled analysis. This setting represents the option -J of the submit command.

Queue name You can provide a queue name to submit the job. This setting represents the option -q of the submit command.

Name for the stdout output file You can provide a filename for the stdout collected by the batch system. This setting represents the option -o of the submit command.

Name for the stderr output file You can provide a filename for the stderr collected by the batch system. This setting represents the option -e of the submit command.

Change to the working directory of call Select this option in order to request the batch system to change to the working directory of the submit call. This setting represents the option -cwd of the submit command.

Resource requirements (option -l) You can provide the resource requirements setting for the coupled analysis. This setting represents the option -l of the submit command.

Define the parallel environment option (option: -pe) You can provide the parameter for the parallel environment. This setting represents the option -pe of the submit command.

Additional command options You can provide a list of submit options that are not listed here. These options will be passed on to the submit command.

Options Details for a SLURM System (Figure 32)

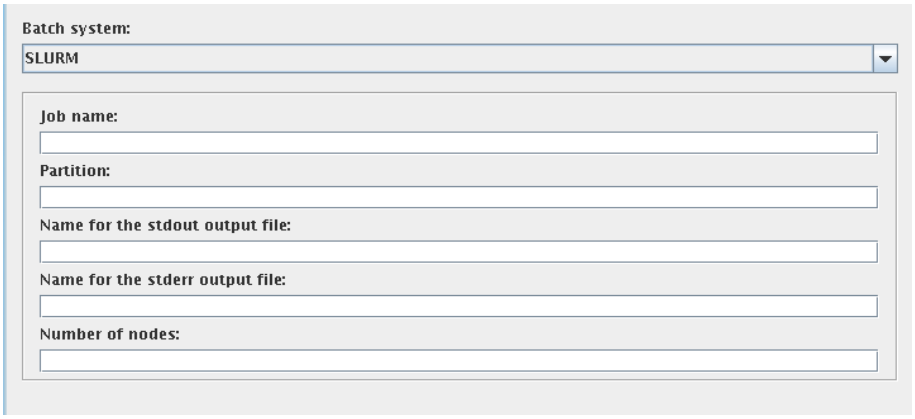


Figure 32: SLURM options

Job name You can provide a job name for the coupled analysis. This setting represents the option --job-name of the submit command.

Partition You can provide a partition name to submit the job. This setting represents the option --partition of the submit command.

Name for the stdout output file You can provide a filename for the stdout collected by the batch system. This setting represents the option --output of the submit command.

Name for the stderr output file You can provide a filename for the stderr collected by the batch system. This setting represents the option --error of the submit command.

Number of nodes You can provide a number of nodes requested for the job. This setting represents the option --nodes of the submit command.

3.7.2.5 Running the MpCCI GUI in an Interactive Batch Session

To enable the usage of the MpCCI GUI during an interactive batch session, the environment variable `MPCCI_IBATCH` should be defined in the current session.
For example, define the environment variable under a Bourne shell:

```
export MPCCI_IBATCH=1
```

3.8 MpCCI Project and Output Files

3.8.1 MpCCI Project Files

The MpCCI project files are named `"*.csp"` and contain all relevant data for a coupled computation in XML format.

3.8.2 MpCCI Server Input Files

The MpCCI server input files are named `"<job name prefix>.prop"` and generated from the project files before the MpCCI server is started.

The contents of the server input files are subject to change without notice. Do not write or modify `"*.prop"` files on your own!

3.8.3 Log Files

In addition to the log files of the coupled simulation codes, MpCCI writes its own files:

`"mpcci_<job name prefix>_<project_name>.log"` The server logs the internal calls of the code coupling interface. If errors appear in any server or simulation codes, the error messages are written to this file.

`"mpcci_<job name prefix>_server.log"` This log contains a summary of your coupled simulation and you can find following information:

About the co-simulation job setting The job setting chosen in the MpCCI GUI (▷ 4.10.2 Job ◁) will be displayed. For each code you will get the properties of the coupled meshes and parts that compose the mesh like: the bounding box, the number of nodes and elements, the mesh characteristics, the quantities defined on this mesh, etc.

About the neighborhood search calculation For each coupled mesh you will a summary about the number of orphaned nodes and elements as well as of the childless nodes and elements for the corresponding multiplicity factor used.

About the wall clock time for the co-simulation You will find a time listing concerning:

- The mesh definition: the total wall clock time to send the mesh to the MpCCI server is measured.
- The time spent per coupling step such as:
  - SEND: the time needs by the code to send all the data to MpCCI.
  - RECEIVE: the time needs by the code to receive all the data from MpCCI. This includes the waiting time for the quantities.
  - SOLVER: the computation time for the simulation between the coupling step.
  - STEP: the total time for this coupling step.

`"<job name prefix>_<timestamp>_<writer_type>"` If you choose to activate some writers in the Edit Step of the MpCCI GUI (see ▷ 4.10 Settings Step ◁) you will have some directories created with the job prefix name (default is mpccirun) given in the Go Step of the MpCCI GUI (see ▷ 4.11 Go Step ◁) and the suffix of the writer (e. g. ccvx,vtk).

`"<job name prefix>_<timestamp>_ccvx_failure"` In case of a failure during the calculation the latest data from the MpCCI server are stored in this directory. You can use the MpCCI Visualizer to check them.

`"<job name prefix>_<timestamp>_ccvx_precheck"` In case of running a pre-check mode calculation the mesh data will be saved in this folder. If any orphans exist you will have the possibility to check the concerning region in the MpCCI Visualizer.

3.8.4 Tracefile

MpCCI server can write tracefile for other visualizer tools:

- The tracefile `"*.ccvx"` is used for the MpCCI Visualizer, see ▷7 MpCCI Visualizer ◁.
- The tracefile `"*.vtk"` is used for the Paraview.
- The tracefile `"*.vtfa"` is used for the GLview Inova.
- The tracefile `"*.case"` is used for the EnSight Gold.
- The tracefile `"*.csv"` is a comma separated value file format. This tracefile contains only output data from a single point coupling system and global variables.

4 Graphical User Interface

4.1 Starting and Exiting MpCCI GUI

4.1.1 Starting MpCCI GUI

When you create a coupled simulation project, the MpCCI GUI generates a set of files containing the definition of the coupled simulation model, e. g. the MpCCI input file and the MpCCI log files. Consequently, before you start the MpCCI GUI, you should move to a directory where you have permission to create files.

You execute MpCCI GUI by running the `mpcci` executable with the `gui` subcommand and the desired options.

```
Usage:
   mpcci gui [OPTIONS] [project] [OPTIONS]


Synopsis:
   'mpcci gui' is used to launch the MpCCI GUI.


Options:
   -chwd  <PATH>
                    Replace the symbolic working directory $(CWD) used inside the
                    project file by the absolute pathname specified in the <PATH>
                    argument.

   -help
                    This screen.

   -new
                    Start the GUI with a new project.

   -nolic
                    Do not check for a license before starting the GUI.
                    This option may be used when no license is available but you
                    would like to prepare a job.

   -norsa
                    Do neither check for ssh nor ask for ssh assistance if an rsa
                    key file does not exist.

   -useAbsolutePath
                    Use current local MpCCI installation path on remote access.

   -useConfiguration  <FILE>
                    Use the configuration in the specified file <FILE>.
                    The format corresponds to what the MpCCI Configurator predicts.
```

Checks at start: If you start the MpCCI GUI without any options like

`mpcci gui`

the following default checks are performed:

- Check and preparation of your environment.
- A check of your secure shell rsa/dsa key files. If no rsa/dsa key files are found you will be asked to create them.
- Check for an existing project file in the current directory in order to load that project to the MpCCI GUI. If more than one project file exists no project will be loaded.
- Check of the license environment. MpCCI GUI tries to check for a license e. g. `MPCCI_LICENSE_FILE` and also informs you when your license will soon expire. In order to disable it use the option `-nolic`.

Batch mode: To start an MpCCI job in batch mode with a well prepared coupled simulation project use:

`mpcci -batch` <*project name*>

New project: If you do not include the <*project name*> to the `mpcci gui` and no or more than one project file exists in the currrent working directory, the MpCCI GUI starts with creating a new project.

Specify new configuration: The useConfiguration option specifies a configuration predicted by the MpCCI Configurator. It can be used in interactive mode as well as in batch mode:

`mpcci gui` <*projectUsingConfigurator*> `-useConfiguration` <*configurationFile*>

`mpcci -batch` <*projectUsingConfigurator*> `-useConfiguration` <*configurationFile*>

The useConfiguration option only takes effect in combination with a project to be opened that has a coupling specification with the MpCCI Configurator option selected (cf. ▷ 4.5 Coupling Specifications ◁). In this case the configuration of the passed coupling specification (<*configurationFile*>) is taken over for the opened project (<*projectUsingConfigurator*>). However, it is a prerequisite that the selected codes and models in the project match those used for the configuration (i. e. the same codes and models must have been used as input for the MpCCI Configurator). For more information - including the format of the configuration file - see ▷ 5.4.2 mpcci configurator ◁.

4.1.2 Exiting MpCCI GUI

You can exit the MpCCI GUI session at any time by selecting File→Exit from the main menu bar, by using the key shortcut Ctrl +Q or by closing the main window of the MpCCI GUI. If you made any changes to the current coupled simulation project, the MpCCI GUI asks if you want to save the changes before exiting the session. MpCCI GUI then closes the current coupled simulation project file and exits the session.

4.2 MpCCI GUI Properties

Some settings in the MpCCI GUI are global and will persist till the next execution of the MpCCI GUI. These settings will be saved in the MpCCI properties file

"<*your home*>`/.mpcci/coupling_environment/preferences.xcf`".

Actually following properties are saved:

- Properties listed under the menu Edit→Properties (see ▷ 4.4.2 Edit Menu ◁),
- The list of configured codes which can be selected for coupling (see ▷ 4.4.6 Codes Menu ◁).
- The defined rules for region building (see ▷ 4.8.5 Automatic Generation of Regions by Rules ◁) and

- The selected columns to be viewed in the region properties table (see ▷4.8.6 Applying Region Properties◁).

All persisting settings are mentioned at their description.

4.3 Parameter Notes in the MpCCI GUI

Parameters that need to be set or corrected are given a note in front of their input field. The note consists of an icon with a tooltip for detailed information:

 Note for a required value that has not yet been set.

 Note for an incorrect entry. Most parameters offer a fixed range from which only values can be selected that are valid. But some parameters such as filename or hostname can be entered directly. This can lead to an error, e.g. non-existent file or unreachable host.

4.4 MpCCI GUI Menus

Before talking about the menus let's have a look at Figure 1 the title of the MpCCI GUI. The title of the main window of the MpCCI GUI contains the following information:

- The name of the currently coupled simulation project or "noname" if no project is specified
- The version of MpCCI you are running

Figure 1: MpCCI GUI title and main menus

Below the title we have the MpCCI GUI menus. They are available all the time while MpCCI GUI is running. The main menus, also shown in Figure 2 are:

File for creating, opening, saving and exiting a coupled simulation project.

Edit for editing global MpCCI GUI properties.

Batch for submitting, querying status and killing a coupled simulation project from a batch queuing system like LSF, PBS, SGE, GLOBUS, etc. . (see also ▷3.7 Coupled Analysis in Batch Mode◁)

License for managing the MpCCI licenses and displaying detailed license information.

Tools for launching various MpCCI commands directly from the MpCCI GUI.

Codes for configuring the list of simulation codes offered and for providing code-specific commands.

Help for requesting help and for getting information about the MpCCI GUI.

The menu entries are:

4.4.1 File Menu

File→New Project creates a new project. The MpCCI GUI will be initialized with its default application values and the first step which is the Models step.

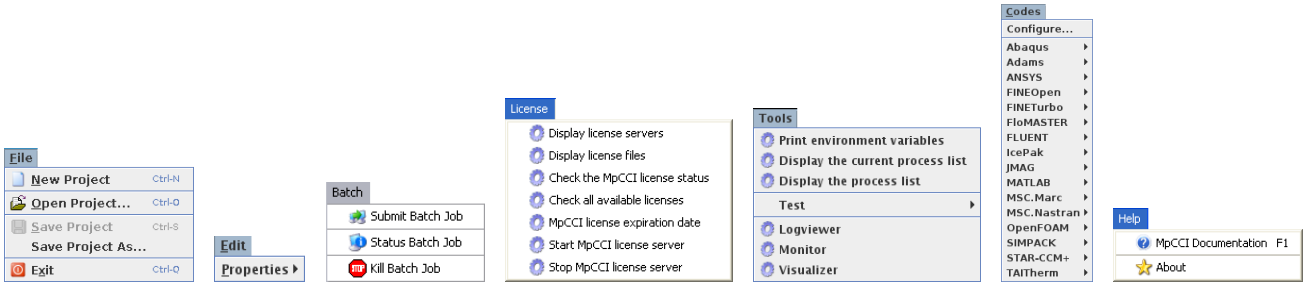


Figure 2: File, Edit, Batch, License, Tools, Codes and Help menus

File→Open Project opens a project file. A file chooser pops up and you are able to select one of your previously saved projects. The project will be opened at the last step you were.

File-Types: "Coupled Simulation Project" - Files (`"*.csp"`)

File→Save Project saves the project. The current project settings are saved under the current project name. This command is available when a project configuration has been opened or if the project already has been saved via File→Save Project As.

File→Save Project As saves the project settings under a specified name. The MpCCI GUI displays the Save As dialog box. The active project can be renamed and saved to a new directory.

File→Exit ends the MpCCI GUI session. MpCCI GUI prompts to save the project with unsaved changes before terminating the application.

4.4.2 Edit Menu

Edit→Properties allows to set preferences for global MpCCI GUI properties (see ▷ 4.2 MpCCI GUI Properties ◁).

→Auto Save Project toggles the option for automatically saving a project with unsaved data. This property is regarded before checking the application configuration and starting the coupled simulation in the Go step. This option will also be set via the Unsaved Project Data dialog shown in Figure 37. It is not taken into account when exiting the MpCCI GUI.

4.4.3 Batch Menu

Batch→Submit Batch Job submits the current project to the batch queuing system. A configuration dialog pops up and shows the available batch systems in a list. By selecting one of the batch systems you will be able to configure some options for the job. The configuration dialog is mostly divided into three parts:

Application specific host allocation: For each application you are able to provide either a list of hostnames or a regular Perl-pattern. This pattern will automatically extract the hosts from the batch environment.

Batch system selection: You can select a queuing system to use.

Specific batch system options: You find a list of options to set up for example the queue, the job name, the output filenames, etc.

Batch→Status Batch Job queries the status of a batch job. You are able to select one of your previously submitted jobs referenced by its job id (see Figure 3).

Batch→Kill Batch Job kills a batch job. You are able to select one of your previously submitted jobs referenced by its job id (see Figure 4).

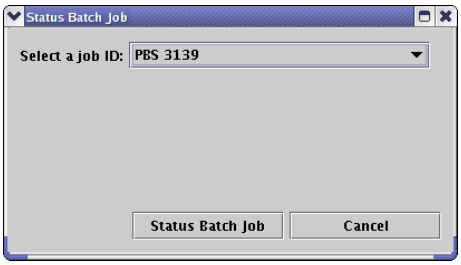


Figure 3: Batch status dialog

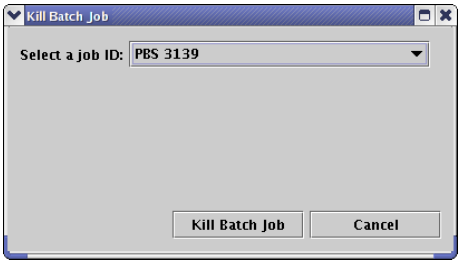


Figure 4: Batch kill dialog

4.4.4 License Menu

License→Display license servers lists all defined license servers.

License→Display license files lists all local license files defined.

License→Check the MpCCI license status displays MpCCI license features and available tokens.

License→Check all available licenses displays all license features and available tokens.

License→MpCCI license expiration date displays the expiration date of the MpCCI license.

License→Start MpCCI license server starts the FHGSCAI vendor daemon on the local host.

License→Stop MpCCI license server stops the FHGSCAI vendor daemon running on the local host.

4.4.5 Tools Menu

Tools→Print environment variables shows a dialog box with the environment used by MpCCI.

Tools→Display the current process list shows a dialog box with a list of the current processes running on the local system.

Tools→Display the process list shows the processes running on the local machine. On Windows it runs the `taskmgr` command and on UNIX systems it runs the `top` command.

Tools→Test Submenu providing test commands delivered with MpCCI (see Figure 5).

- →MpCCI host connect... Test the connection to a specific port@host. Opens a new dialog for entering the port number and host name.
- →MpCCI host listen locally... Test for listening on a specific port@localhost. Opens a new dialog for entering the port number. This command correlates with MpCCI test host connect.... First start this listen command and after that the connect command with the same port and with host localhost.

→MpCCI rsh type connection... Test a rsh type connection to a specific host with MpCCI. Opens a new dialog for entering the host name.

→MpCCI simple test case Run a simple test case delivered with MpCCI (see ▷III-7 A Simple Test on the Local Machine, "Hello World" ◁.

Tools→Logviewer starts the MpCCI Logviewer.

Tools→Monitor starts the MpCCI monitor.

Tools→Visualizer starts the MpCCI Visualizer.

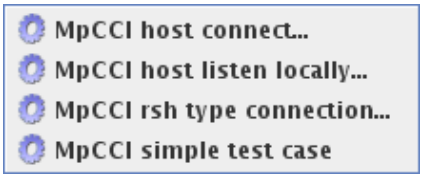


Figure 5: Tools→Test submenu with MpCCI test commands.

4.4.6 Codes Menu

Codes→Configure shows a dialog for configuring the list of codes that are offered for coupling. By default, only installed simulation codes with a valid MpCCI adapter license are offered (see `mpcci list -codes` in ▷5.6.2 mpcci list ◁).

Codes→Codename provides code-specific commands that are defined in the respective code configuration file (see ▷VIII-2.4.2 Codes Menu: `<CodesMenuEntries>` ◁).

4.4.7 Help Menu

Help→MpCCI Documentation displays a help window with the MpCCI documentation.

Help→About displays product information and third party products integrated in the MpCCI GUI.

4.5 Coupling Specifications

A coupled simulation is typically intended to solve a problem of a particular coupling type. Coupling types (cf. ▷3.1.2 Coupling Types ◁) correspond to specific physical domains (cf. ▷3.1.1 Physical Domains ◁), recommended coupling settings, and predefined selection of quantities. To simplify the determination of suitable settings for the user, the MpCCI GUI offers templates with predefined coupling specifications for selection when creating a new project as shown in figure Figure 6.

Only coupling specifications whose domain types match the code types of the currently configured codes (see ▷4.4.6 Codes Menu ◁) are offered.

The coupling specification can be general, in that no or few specifications are made, to detailed elaborated configurations.

Category corresponds to the coupling type (cf. ▷3.1.2 Coupling Types ◁) to which the coupling specification is assigned.

Coupling parameters show the settings done in the Algorithm step (▷4.7 Algorithm Step ◁).

- The analysis may be transient, steady state or quasi transient.

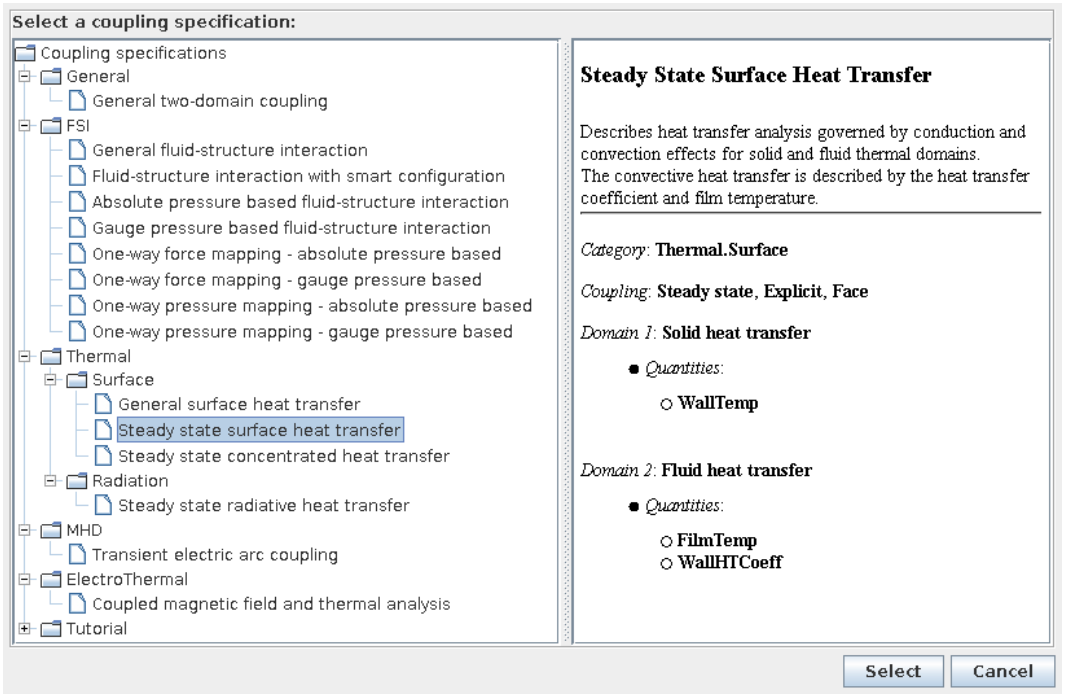


Figure 6: Coupling specifications offered in the MpCCI GUI

- The scheme can be explicit or implicit.
- The algorithm can be parallel or serial.
- The MpCCI Configurator entry indicates that a smart configuration will be used to make the appropriate coupling and quantity settings (see ▷3.5 Smart Configuration◁). This option is only available on a restricted basis for certain coupling specifications and codes.

Domain settings show preselections for the accepted codes, model files, components to be coupled and quantities to be exchanged.

- The domain type specifies code types that can participate in the coupling. Each code may have assigned more than one type (see ▷VIII-2.4.1 Code Information: `<CodeInfo>`◁). The type represents physical domains resp. analysis types which are supported by the code (cf. ▷3.1.1 Physical Domains◁). Only codes that match the listed domain types are available for selection in the Models step.
- The coupling dimension refers to the selection of components for the coupling regions. For the meaning of the symbols and more details see Figure 9 (part IV).
- The solution type corresponds to the analysis and is defined by the model. It can be transient or steady state.
- The quantities sent are either precisely defined or they are restricted to a shortlist.
  Precisely defined quantities are automatically grouped into a quantity set and ready for assignment. These quantities are also available as preconfigured set (see ▷4.8.8 Assigning Preconfigured Quantity Settings◁).
  A shortlist reduces the number of available quantities. All listed quantities are suitable for the coupling specification, but are partially mutually exclusive. They must therefore be selected in a useful way depending on the application.

Operators lists the operators that are assigned to quantities. This table is optional and appears only if

operators are proposed.

The different coupling specifications are listed below. They are grouped according to their categories, which are also briefly described.

Meaning of special entries in the tables below:	
*	No setting is preset and the value is freely selectable.
all	No preselection has been made.
-	The option is not available.
X	The option is selected.

4.5.1 Category: General

General coupling specifications with as few restrictions as possible.

General Two-Domain Coupling

Coupling of two domains with no restriction to domain types, quantities or coupling parameters.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
all	*	*	all
all	*	*	all

4.5.2 Category: Fluid-Structure Interaction (FSI)

In an FSI simulation, usually a structure deforms due to forces caused by a fluid flow while the deformation changes the fluids boundary. The deformation must be transferred to the fluid mechanics code, which corresponds to the quantity "Nodal position" (NPosition), while forces are sent from fluid mechanics to the solid mechanics code, e.g. "Boundary absolute force vector" (WallForce), "Boundary relative force vector" (RelWallForce), "Absolute pressure" (AbsPressure) or the "Relative pressure" (OverPressure).

General Fluid-Structure Interaction

Coupling of solid and fluid mechanics domains by exchanging nodal positions and pressure based quantities.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	*Shortlist:* WallForce, AbsPressure, RelWallForce, OverPressure
SolidStructure	▲	*	NPosition

Fluid-Structure Interaction with Smart Configuration

The configuration depends on the used models and will be set automatically by MpCCI.
It is currently only available for Abaqus, FLUENT and OpenFOAM.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	X

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	*Shortlist:* WallForce, AbsPressure, RelWallForce, OverPressure
SolidStructure	▲	*	NPosition

Absolute Pressure Based Fluid-Structure Interaction

Coupling of solid and fluid mechanics domains without consideration of a reference pressure, i.e. the atmospheric pressure on the structural model.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	*Shortlist:* WallForce, AbsPressure
SolidStructure	▲	*	NPosition

Gauge Pressure Based Fluid-Structure Interaction

Coupling of solid and fluid mechanics domains with consideration of a reference pressure, i.e. the atmospheric pressure on the structural model.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	*Shortlist:* RelWallForce, OverPressure
SolidStructure	▲	*	NPosition

One-Way Force Mapping - Absolute Pressure Based

Recommended for applications assuming that the deformation can be neglected on the fluid side.

In this case the solid mesh generally assumes small displacements and the fluid mesh does not need to be morphed.
The force is derived from absolute pressure including shear force effects. The structural model considers a reference pressure, i.e. atmospheric pressure.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	WallForce
SolidStructure	▲	*	

One-Way Force Mapping - Gauge Pressure Based

Recommended for applications assuming that the deformation can be neglected on the fluid side.
In this case the solid mesh generally assumes small displacements and the fluid mesh does not need to be morphed.
The force is derived from gauge pressure including shear force effects.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	RelWallForce
SolidStructure	▲	*	

One-Way Pressure Mapping - Absolute Pressure Based

Recommended for applications assuming that the deformation can be neglected on the fluid side.
In this case the solid mesh generally assumes small displacements and the fluid mesh does not need to be morphed. The structural model considers a reference pressure, i.e. atmospheric pressure.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	AbsPressure
SolidStructure	▲	*	

One-Way Pressure Mapping - Gauge Pressure Based

Recommended for applications assuming that the deformation can be neglected on the fluid side.
In this case the solid mesh generally assumes small displacements and the fluid mesh does not need to be morphed.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	*	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Fluid	▲	*	OverPressure
SolidStructure	▲	*	

4.5.3 Category: Thermal Radiation

Steady State Radiative Heat Transfer

Describes heat transfer analysis governed by radiative and convection effects for solid and fluid thermal domains.
The convective heat transfer is described by the heat transfer coefficient and film temperature.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
Steady state	Explicit	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
Radiation	▲	Steady state	WallTemp
FluidThermal	▲	Steady state	FilmTemp, WallHTCoeff

4.5.4 Category: Thermal Surface

General Surface Heat Transfer

Describes heat transfer analysis governed by conduction and convection effects for solid and fluid thermal domains.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
*	Explicit	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
SolidThermal	▲	*	WallTemp
FluidThermal	▲	*	*Shortlist:* WallHeatFlux, FilmTemp, WallHTCoeff, HeatRate

Steady State Surface Heat Transfer

Describes heat transfer analysis governed by conduction and convection effects for solid and fluid thermal domains.
The convective heat transfer is described by the heat transfer coefficient and film temperature.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
Steady state	Explicit	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
SolidThermal	▲	Steady state	WallTemp
FluidThermal	▲	Steady state	FilmTemp, WallHTCoeff

Steady State Concentrated Heat Transfer

Describes heat transfer analysis governed by conduction and convection effects for solid and fluid thermal domains.
The convective heat transfer is described by the heat rate and film temperature.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
Steady state	Explicit	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
SolidThermal	▲	Steady state	WallTemp
FluidThermal	▲	Steady state	FilmTemp, HeatRate

4.5.5 Category: Magnetohydrodynamics (MHD)

Magnetohydrodynamics analysis consists of the study of the magnetic properties and behaviour of electrically conductive fluids. This analysis adresses the coupling of Maxwells'equations of electromagnetism and Navier-Stokes equations of fluid dynamics. The moving conducting fluids such as plasmas, liquid metals, electrolytes, etc. are influenced by a magnetic field creating an induced current, which polarizes the fluid and alternatively changes the magnetic field itself. The quantities which should actually be exchanged are at least the electric conductivity or resistivity, the Joule heat, the Lorentz force. However, most fluid hydrodynamics codes cannot compute the conductivity, respectly resistivity directly, which is therefore done using user-defined functions.

Transient Electric Arc Coupling

Magnetohydrodynamics settings to describe a plasma application. The plasma motion is influenced by the Lorentz force and the Joule heat contributes as heat source for the plasma in the Navier-Stokes equations. The resulting plasma conductivity needs to be computed using user-defined functions.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
Quasi transient	Explicit	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
ElectroMagnetism	■	Steady state	LorentzForce, JouleHeat
FluidHydrodynamics	■	Transient	ElectrCond1

4.5.6 Category: Electrothermal

The resistive loss of electric currents corresponds to a heat source while the temperature influences the resistivity of conductors. This problem is addressed with an electrothermal analysis, which combines electromagnetism with heat transfer. The quantities which should actually be exchanged are the electric resistivity and the temperature. However, most heat transfer codes cannot compute the resistivity directly, which is therefore done using user-defined functions. The quantity combination depends on the decision in which code these additional computations are carried through. A special application in this area is electric arc computation.

Coupled Magnetic Field and Thermal Analysis

Recommended for analysing the thermal-magnetic behaviour of electrical machines.
The heat source is defined as Joule heat quantity from the electromagnetism code. The magnetic and electrical material parameters are temperature dependent.

Coupling parameters:

Analysis	*Scheme*	*Algorithm*	*MpCCI Configurator*
Steady state	Explicit	*	-

Domain settings:

Domain type	*Coupling dimension*	*Solution type*	*Quantities sent*
ElectroMagnetism		Steady state	JouleHeat
Fluid		Steady state	Temperature

4.6 Models Step

The MpCCI Models step is the first step for setting up a coupled simulation. Its aim is:

- Select the codes involved in the coupling.
- Select their corresponding model files.
- Extract the components needed to create the coupling regions which is done in the Regions step.

Selecting a model file will immediately launch the scanner to extract the components. At that time you don't need to call the scanner manually. But if you have changed components in the selected model file later on, the changes must be passed on to MpCCI GUI. To do this, the scanner must be started manually by pressing the Start Scanner button. The components are extracted again and are then available in the Regions step.

4.6.1 Code Parameters

Additionally some codes may provide some further parameters to be set by the user: e. g. the version or release of the code to run or the unit system to be used for the grid length and quantities. For a description of the code specific parameters have a look at the Codes Manual.

4.6.2 Requirements

In order to proceed with another step the following requirements have to be fulfilled in this Models step:

- Selection of at least two codes for coupling.

- Setting of all required parameters for each code especially the model files.
- Successful run of the scanner for each code.
- Usage of the same model dimension by the coupled codes. Different dimensions lead to a warning message whereas undefined dimensions are treated to be proper.
- Usage of appropriate solution types by the coupled codes. The solution types will be found by the scanner and may be Steady state, Transient or undefined. Different types in the model files lead to a warning message whereas undefined types are treated as being proper.

All these criteria are checked when leaving the Models step and a dialog with an appropriate message will pop up if the requirements are not fulfilled. In case of a warning the user may decide to continue with the chosen step although it is not recommended by MpCCI. If an error occurs the user can't go on before having corrected the complained items.

4.6.3 Changing the Model - Implications for the Setup

Changing the model file for a code leads to new components and normally implies a new setup of the coupled simulation with all regions and monitors being removed.

But sometimes it might be desirable to keep the setup while doing only some small changes to the model e. g. renaming, splitting or uniting components. Therefore MpCCI compares the components of the new scanned model file with the actual setup.

- If all actually coupled components are still in the new component list, the setup will not change. Old uncoupled components which do not exist anymore will be automatically removed from the code and new components will be added to the code components list.
- If at least one old coupled component doesn't exist anymore a component conflict dialog (see Figure 7) appears where the user has the choice among
  - Keeping all sets with the omitted components removed or replaced by new components if existing
  - Removing sets with omitted components but keeping not affected sets
  - A new setup with all regions and monitors removed

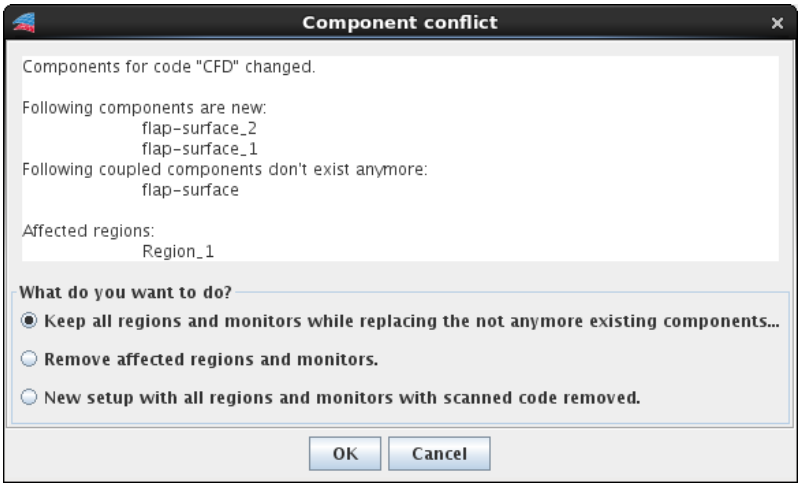


Figure 7: Component conflict after changing the model

The replacement of old components will be done in a special dialog (see Figure 8) where the user can choose

- One old component and one new component (1:1 replacement renaming a component)
- One old component and several new components (1:n replacement splitting one old component into several new components) or
- Multiple old components and one new component (n:1 replacement uniting several old components)

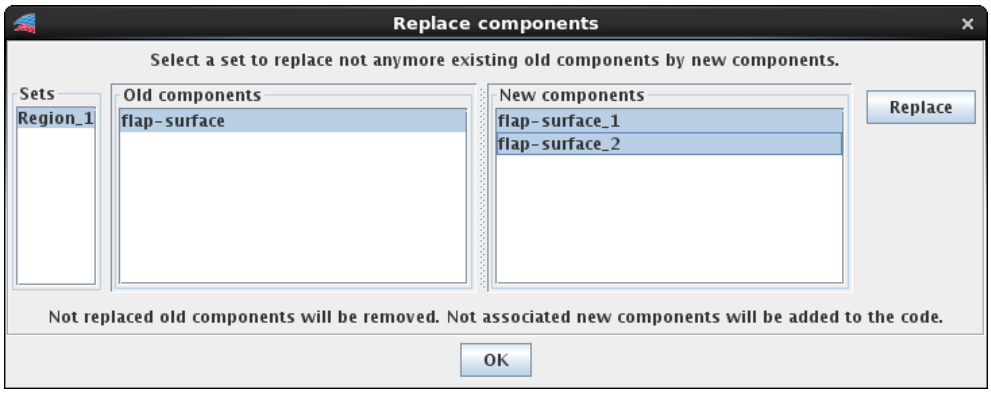


Figure 8: Replacing components in a component conflict

Only those new components will be offered as selectable components which are of the same type as the old components. Old components which are not replaced will be removed from the sets, new remaining components will be added to the code components list.

If an old component with copies is replaced, the copies are transferred to the replacing component. If several components for replacement are selected, only the first component gets the copies, the others remain without copies. When a copied component is replaced it loses its copy state and becomes the new stand-alone component.

4.6.4 Using the MpCCI Configurator

Using a coupling specification with the MpCCI Configurator option ▷ 4.5 Coupling Specifications ◁ leads to executing the MpCCI Configurator when leaving the Models step. The MpCCI Configurator is only executed if it is necessary, e. g. a model file changed. A project file is needed for the execution so that you will be prompted to save your project. After that dialog window will pop up with the results of the configuration as shown in Figure 9.

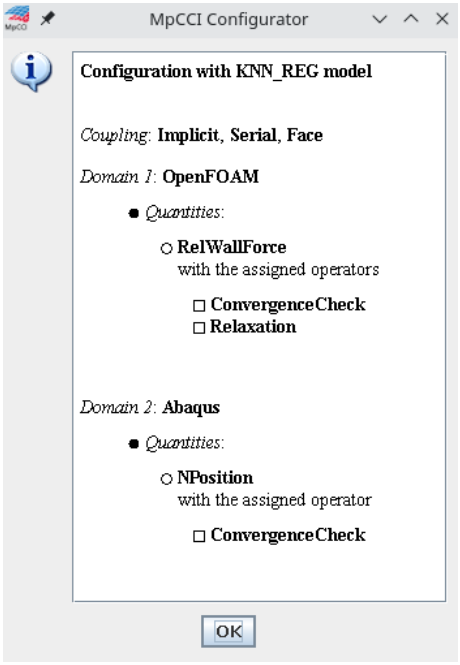


Figure 9: Configuration results from the MpCCI Configurator

4.7 Algorithm Step

In the MpCCI Algorithm step you define the coupling algorithm (see ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁). The settings are separated into Common Basics which define the global view and Codes Specifics defining the code's local view of the algorithm. The algorithm is organized into following subject areas:

- Analysis
- Solver settings
- Coupling steps
- Coupling algorithm (in common basics only)
- Coupling duration (in common basics only)
- Runtime control (in code specifics only)

Only those settings will be visible which are relevant for the current configuration. E. g. the solver settings area in the common view is only visible for iterative coupling. The coupling algorithm and duration are global so they are only shown in the common basics view, whereas the runtime control refers to each code.

4.7.1 Common Basic Algorithm Settings

Following common basic algorithm parameters can be configured (see also Figure 10):

Coupling analysis

Analysis type shows the type of the coupling analysis depending on the analysis type of each code.

Transient if all coupled codes do a transient analysis (see ▷ 3.4 Coupling Process ◁).

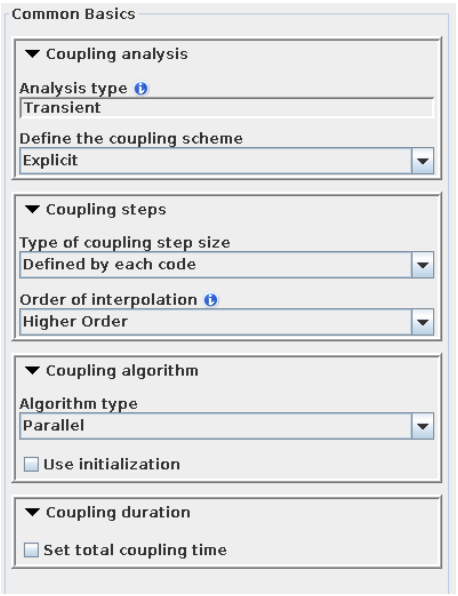


Figure 10: Common basic algorithm settings for an explicit transient analysis

Steady state if all coupled codes do a stationary analysis (see ▷ 3.4 Coupling Process ◁).

Quasi transient if the coupled codes use mixed analysis types - one transient and the other steady state (see ▷ 3.4.6 Coupling with Mixed Analysis Types ◁).

Define the coupling scheme for solving the coupled problem:

Explicit is available for all analysis types.

Implicit defines an iterative coupling for transient analysis (see ▷ 3.4.5.1 Implicit Coupling ◁). It is a feature which is not supported by all codes and only offered when all coupled codes support the iterativeCoupling feature.

Solver settings is only offered for implicit coupling where all codes have to trigger a boundary update at the same time.

Type of solver step size specifies whether the time step size is constant or adaptive.

Constant defines a constant time step size in seconds. The value has to be given in the appearing field Constant solver step size (s).

Sent by code defines an adaptive time step size which will be exchanged by the codes via a global variable (see ▷ 3.4.5.2 Coupling with Exchange of Time Step Size ◁). The definition of a global variable can be looked up in ▷ 4.8.1 Global Variables ◁.

Negotiation defines an adaptive time step size which will also be exchanged by codes. But in this case several codes send the step size and the smallest one will be propagated by the MpCCI server. This is a feature which is not supported by all codes and only offered when all coupled codes support the negotiation feature. It is directly implemented by the codes so no global variable has to be specified.

Initial solver step size (s) defines the step size used for the first solver step when the codes haven't already negotiated a step size.

Minimum solver step size (s) specifies a minimum value for the solver step size to prohibit the usage of a step size which may be too low. Even if the codes negotiate a lower solver step size this minimum step size will be taken.

Coupling steps define the data exchanges of the codes (see ▷ 3.3 Data Exchange ◁) - how they are specified by the codes or if they correlate with the solver steps. The options depend on the chosen coupling

analysis.

Type of coupling step size is offered for explicit analyses only.

Sent by code defines an adaptive coupling step size and can only be chosen for an explicit transient analysis. The time between two data exchanges is sent by one code via a global variable (see ▷ 3.4.5.2 Coupling with Exchange of Time Step Size ◁ and ▷ 3.3 Data Exchange ◁ for more information).

Defined by each code can be chosen for all explicit solutions and is the only option for Quasi transient and Steady state analyses. It says that each code defines its own time or iteration number for the boundary updates. For transient problems this leads to non-matching coupling steps where the exchanged values have to be interpolated.

Coupling step size shows how the point of data exchange is determined.

Every solver step is the fixed setting for implicit coupling. No other options are possible. The value of the solver step size is repeated for a better overview.

Global quantity sent by code is the fixed setting for type Sent by code.

Order of interpolation is offered for transient problems with non-matching coupling steps (see also ▷ 3.4.5.3 Coupling with Non-Matching Time Steps ◁). In this case the interpolation order for the exchanged values can be specified as follows:

Higher order is a cubic Hermite spline interpolation using up to four available quantity values and finite difference schemes to approximate the necessary tangential values.

First order uses one value before and one after the requested value for a standard linear interpolation.

Zero order is a constant interpolation function using the last available value.

Idle time reduction offers the possibility to save idle time if one code runs much faster than the other one but only for Quasi transient and Steady state analyses and only for codes which do a stationary analysis and support the delayed boundary update.

Delay boundary updates has to be selected for using this feature (see Figure 11). The faster code may go on in its computation without updating its boundaries at the end of a coupling step. It then tries to do the update at a given substep frequency or at a given number of update tries within the next coupling step. The update will be delayed by no more than one coupling step.

Implementing code offers codes supporting the delayed boundary update in the current setup. Select the faster code.

Delay definition defines whether the delay is specified by a number of update tries (Number of update tries) or by a substep frequency (Number of substeps).

Type of delayed updates defines a Constant or Variable delay value. A variable type allows different number of update tries resp. substep frequencies per coupling step whereas for a constant type the Delay value remains the same for all coupling steps.

Delay value specifies the constant value resp. variable values for the delayed update. Variable values are a list of `couplingStepNo=delayValue` pairs each defining the coupling step number couplingStepNo from where the delay value will be set to the given value delayValue. This value remains until a new coupling step number with another value is specified or the end of the coupling is reached. The couplingStepNo=delayValue pairs are separated by whitespace (e. g. `1=3 3=5 10=7`).

Coupling algorithm specifies the algorithm for the data exchanges used in the coupled simulation (cf. ▷ 3.4.1 Coupling Algorithm ◁).

Algorithm type specifies a serial (Gauss Seidel) or parallel (Jacobi) algorithm.

Serial needs the leading code to be specified in the field Leading code.

Parallel can be selected with or without initialization. If initialization is used check the appropriate field and select the Initializing code.

Coupling duration specifies the duration of the coupled simulation without runtimes of the codes before and after the coupling. The settings depend on the analysis type whether it is transient or stationary. Quasi transient is a mixed analysis and therefore includes settings for both types.
For transient analysis:

Maximum number of coupling step iterations can be defined for implicit coupling only. It specifies the maximum duration of the coupling step iterations and is used if no other criterion is met to stop the iterations earlier.

Set total coupling time allows to define a maximum time for the coupling process. If no total coupling time is defined the coupling will end when the convergence criteria are achieved.

Total coupling time will not be exceeded for coupling but if other criteria are fulfilled i. e. quantities are converged, the coupling might end earlier.

For steady state analysis:

Minimum number of coupling steps can be defined. This can be useful if the coupling starts with very small changes in the quantities leading to a converged solution already after the first coupling step. In order to prohibit this early coupling end enter a value greater than one.

Set maximum number of coupling steps allows to define a maximum number of coupling steps for the coupling process. If no maximum is defined the coupling will end when the convergence criteria or total simulation time are achieved.

Maximum number of coupling steps will not be exceeded for coupling but if other criteria are fulfilled i. e. quantities are converged, the coupling might end earlier.

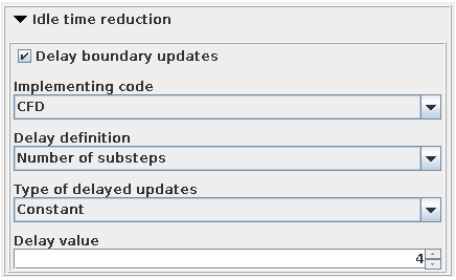


Figure 11: Settings for delayed boundary updates

4.7.2 Code Specific Algorithm Settings

The code specific algorithm parameters may differ slightly from code to code. The most common entries are described below. Additional code specific settings are explained in the respective chapter of the Codes Manual. Please look there for the exact entries of each code.

Following most common entries for the code specific algorithm parameters can be configured (see also Figure 12):

Analysis type shows the type of the coupling analysis of this code and is either Transient for a transient analysis or Steady state for a stationary analysis. It is preset depending on the solution type of the model. If the solution type is undefined, both analysis types are offered and the user can choose one.

Solver settings include the solver step size, which is mostly Defined by model or for implicit coupling already specified in the common basic settings. Other solver specific entries can be looked up in the Codes Manual.

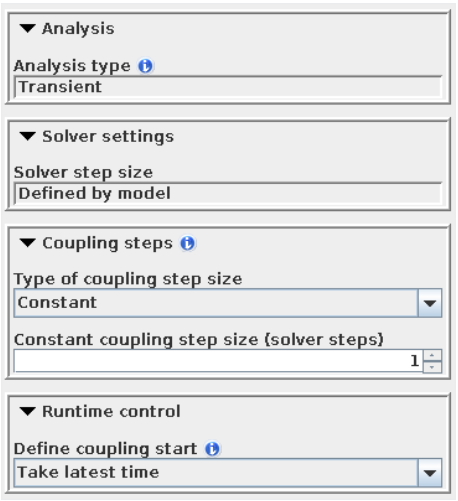


Figure 12: Code specific algorithm settings

Coupling steps define the frequency of the data exchange. Normally it is given in the number of solver steps where more than one solver step leads to subcycling. The step size can be constant or variable. A variable step size allows different number of solver steps per coupling step whereas for a constant type the coupling step size remains the same for all coupling steps.

Type of coupling step size defines if the coupling step size remains constant or variable over the computation.

Constant coupling step size (solver steps) defines the constant number of solver steps without coupling. For transient simulation, the elapsed time between two data exchanges depends on the solver step size used. Only the solver step count will trigger the data exchange.

Variable coupling step size (solver steps) enables to set the number of solver steps without coupling depending on the coupling step number. For Variable coupling step size (solver steps) MpCCI accepts a list of couplingStepNo=nofSteps pairs each defining the coupling step number (couplingStepNo) from where the number of solver steps without coupling will be set to the given value nofSteps. This value remains until a new coupling step number with another value is specified or the end of the coupling is reached. The `couplingStepNo=nofSteps` pairs are separated by whitespace.

For Implicit coupling the coupling step size is constant and restricted to the common solver step size. Subcycling is not possible.

Runtime control specifies the runtime of the codes before and after the coupling.
For transient analysis:

Define coupling start defines the time in the model when the coupling process should start.

Take latest time starts the coupling at the latest time specified in the model. This enables a model that has already been calculated, without specifying the current time of the model. If the precalculated time of the model changes, the time for starting the coupling in the MpCCI GUI is still valid using Take latest time.

Specify time starts the coupling at the point in time of the model which is specified in the field Time of coupling start. This enables some uncoupled calculations to be performed before the coupling starts.

Time of coupling start specifies the model specific point in time for starting the coupling.

When restarting from an interrupted coupled simulation, the start time of the coupling must

be specified explicitly, since the latest time in the model is no longer the start of the coupling. The start time can be 0 s or later.

For steady state analysis:

Define coupling start defines the iteration number in the model when the coupling process should start.

Take latest iteration starts the coupling at the latest iteration number specified in the model. This enables a model that has already been calculated, without specifying the current iteration number of the model. If the precalculated number of iterations of the model changes, the iteration number for starting the coupling in the MpCCI GUI is still valid using Take latest iteration.

Specify iteration starts the coupling at the iteration number of the model which is specified in the field Iteration number for coupling start. This enables some uncoupled calculations to be performed before the coupling starts.

Iteration number for coupling start specifies the model specific iteration number for starting the coupling.

When restarting from an interrupted coupled simulation, the iteration number for starting the coupling must be specified explicitly, since the latest iteration number in the model is no longer the start of the coupling. The iteration number for coupling start can be 0 or higher.

Number of iterations after the coupling allows to define some iterations to be performed after the coupling has ended.

4.7.3 3-Code Coupling for Advanced Users

The algorithm step is designed for 2-code coupling. Nevertheless, the experienced user can set up a 3-code coupling under certain conditions. For this he must choose a parallel coupling algorithm without initialization or a serial algorithm, where only one code can be the leading one. The exchange of the quantities at the start of the calculation is in the parallel variant a sending and receiving, with the serial variant the leading code receives its quantities and starts with its computation, whereby the other two codes send and receive their quantities (cf. ▷ 3.4.1 Coupling Algorithm ◁).

4.8 Regions Step

In the MpCCI Regions step you define the exchange of global variables in the Global tab and create and configure your coupling regions in the Mesh tab by

1. Editing components to be prepared for coupling.
2. Building coupling regions.
3. Defining quantities which will be exchanged.
4. Assigning the quantities to be transferred to the built coupling regions.

Additionally the MpCCI Regions step provides an overview over the coupled setup for the mesh based components.

The basic steps are described in ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁.

Additional features are described in the following:

4.8.1 Global Variables

The definition of sets with global variables to be exchanged differs a little from that of mesh based coupling regions. Figure 13 shows the Global panel. The sets are defined directly with the coupled components and

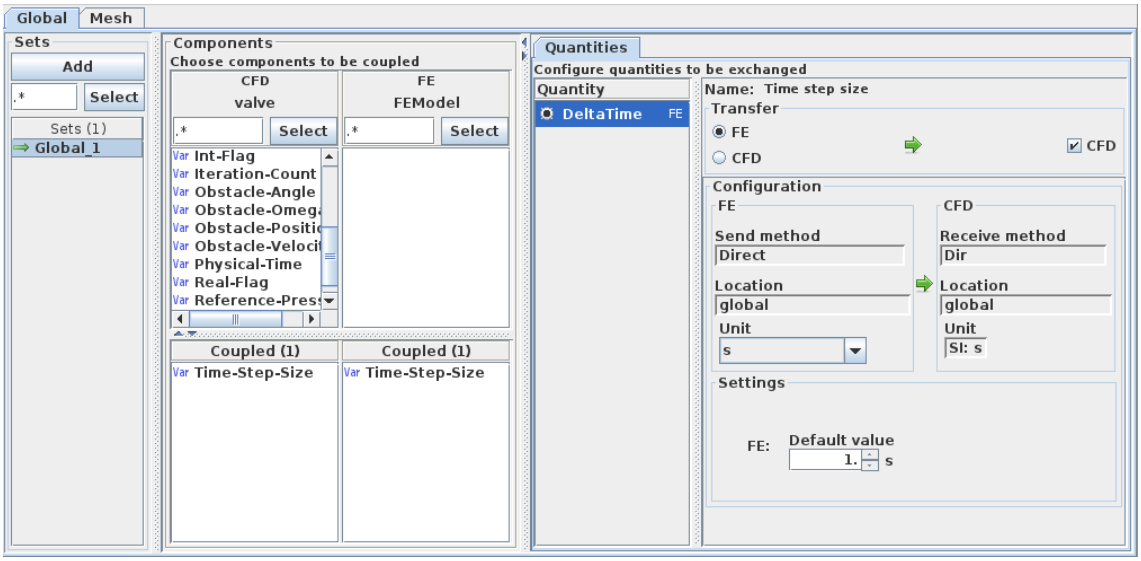


Figure 13: Defining global variables

assigned quantities in the respective area.

Sets area provides a list of defined global variable sets. These sets are handled like regions for mesh based components (see 2.6.1 (part IV) for a description)

Components area with lists of global variables (called components) offered by each code. These lists are similar to those for mesh based components (see ▷IV-2.6.1.1 Select Components for Each Interconnected Code◁). Their type is depicted by the label Var. Global variables can only be coupled 1:1.

Quantities area provides a list of available quantities and their configuration. The selection of the quantities is analogous to those for mesh based quantities (see ▷IV-2.6.2.1 Select Quantities to be Transferred◁). But for global variables only one quantity may be selected per set which is why they are selected by radio buttons instead of checkboxes.

4.8.2 Editing Components

In the Edit Components tab for mesh based components (see Figure 14) the components scanned from the model file can be prepared further for the coupling process. Following choices are offered:

- Copying components if the code allows this feature.
- Editing component properties like component name, its part-id or additional auxiliary information.
- Defining periodic component properties.

The component's popup menu with the entries Edit Properties, Copy and Delete is also available in the components lists of the Build Regions tab.

4.8.2.1 Copying Components

To use the component in another region, too, first your code has to provide the CopyComponents option in the Code Information section of its MpCCI GUI configuration file (see ▷VIII-2.4 MpCCI GUI Configuration File gui.xcf◁).

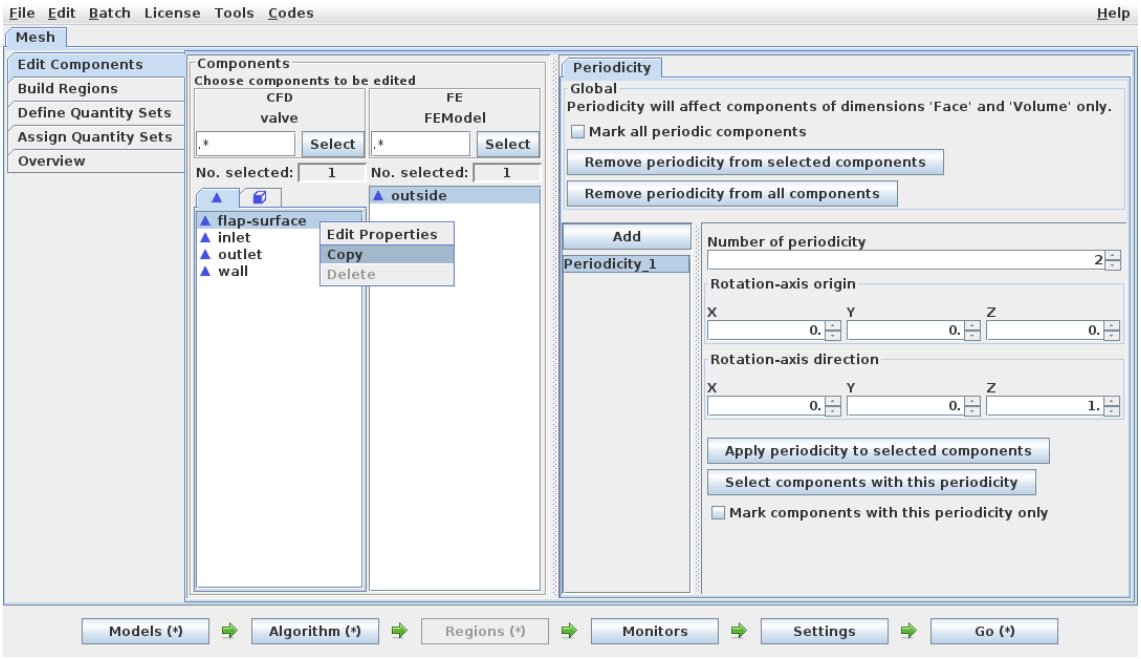


Figure 14: Edit Components tab

After that you can choose Copy from the component's pop-up menu (see Figure 14, also available in the code components lists of the Build Regions tab) to get a new component. This component then can be used in addition to the original component.

Only components determined by the scanner can be copied. Copied components cannot be copied again, but they can be deleted which is not possible for scanned components.

4.8.2.2 Editing Component Properties

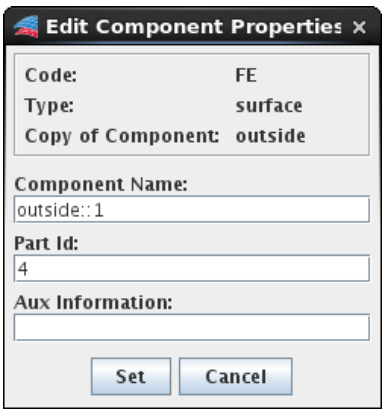


Figure 15: Dialog for editing component properties

The pop-up menu in the components list (Figure 14) provides an Edit Properties entry (also available in

the code and coupled components lists of the Build Regions tab) which launches a dialog for editing some component properties (see Figure 15).

In the upper part of the dialog the component's code and type are listed. If it is a copied component, also the name of the original component is mentioned, for periodic components (▷ 4.8.2.3 Periodic Components ◁) also the assigned periodicity.

The editable fields are the component's name, its part identification number and the additional aux information.

With Set the new values will be overtaken. In doing so the MpCCI GUI checks the new name which it would refuse if it already exists for another component. Cancel dismisses the input.

4.8.2.3 Periodic Components

Sometimes a model may only consist of a cyclic symmetric part and the whole component can be built by replicating the one part. MpCCI handles the quantities on the periodic section during the coupling process as described in ▷ 3.3.6 Quantity Transformation for Cyclic Symmetric Meshes ◁.

The periodicity of the coupled components needs a description of how to reconstruct the whole component out of the partial model. This can be done via the Periodicity tab (see Figure 16) shown in the right area of the Edit Components tab (see Figure 14).

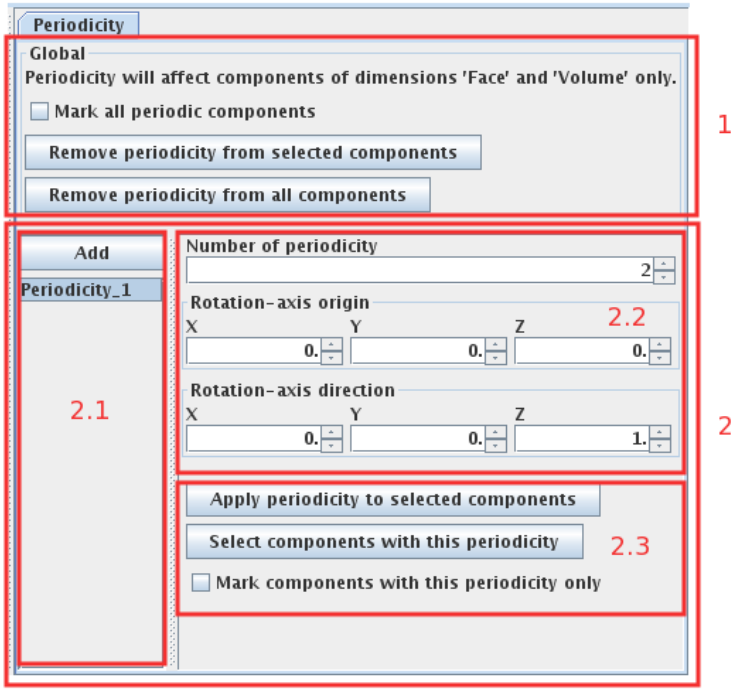


Figure 16: Periodicity panel

The periodicity panel consists of

(1) A global part at the top and

(2) A periodic specific part underneath. This part is divided into three areas:

(2.1) A list of defined periodicities on the left,
(2.2) A specification area for the selected periodicity on the upper right and
(2.3) An action area on the lower right.

The specification of a periodicity is done in the specification area (2.2) by defining the parameters:

- Number of periodicity which numbers the replication factor for getting the whole part. Its minimum value is two.
- Rotation-axis origin specified by its X, Y and Z coordinates and
- Rotation-axis direction also specified by a three-dimensional point. It is interpreted as a vector starting at the rotation-axis origin which is why it must not be (0,0,0).

The periodicity list provides an Add button for getting new periodicities to be specified.

To assign a periodicity select the appropriate components - even from different codes - and click on Apply periodicity to selected components (from the pop-up menu of the selected periodicity (see Figure 17) or from the action area (2.3 in Figure 16).

Only components of dimension Face or Volume can be applied a periodicity.

Selecting and deselecting single components can be done by holding down the Ctrl key when clicking on a component.

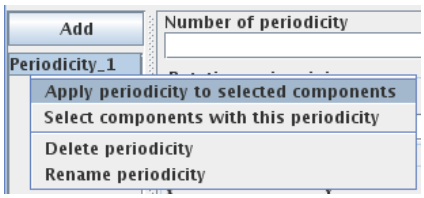


Figure 17: Periodicity pop-up menu

To delete or rename a periodicity choose the appropriate option from the periodicity pop-up menu (see Figure 17, Delete periodicity and Rename periodicity). Deleting a periodicity leads to removing it from all assigned components. Renaming will also affect assigned components.

Identifying periodic components is done in two ways. Firstly those components get a special label:

- Marks a periodic Face element
- Marks a periodic Volume element

And secondly the periodicity panel provides options for marking components. These lead to a visual representation of the periodicity name in the components lists (see Figure 18):

- Mark components with this periodicity only marks components with the selected periodicity. This option can be checked in the action area 2.3.
- Mark all periodic components marks all components assigned any periodicity. This option can be checked in the global part (1) of the periodicity panel as shown in Figure 18.

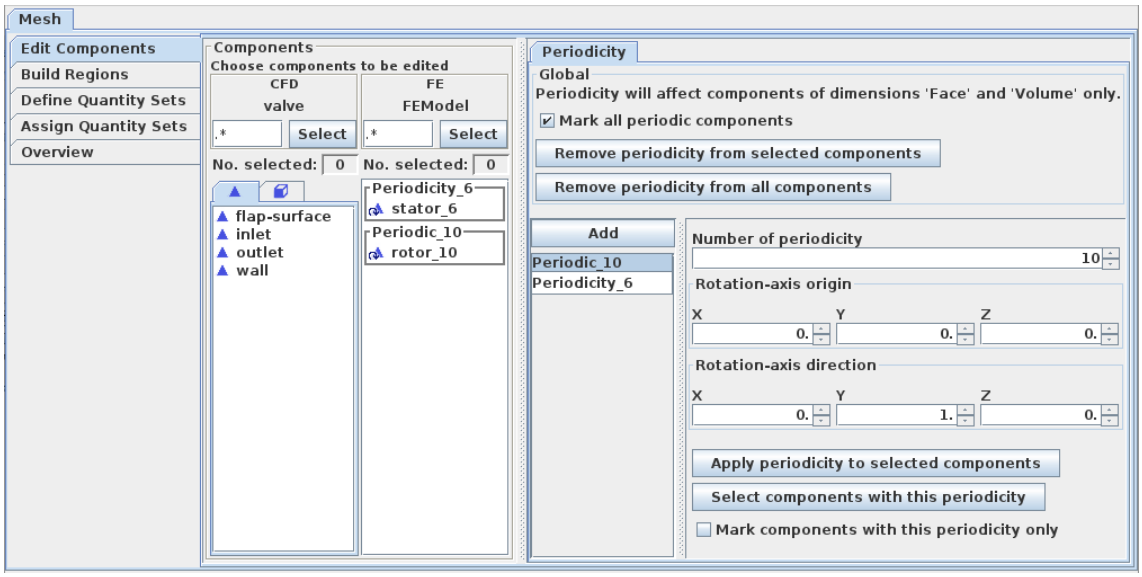


Figure 18: Marked periodic components

Selecting components with a specific periodicity is done by selecting that periodicity and choosing Select components with this periodicity which is available in the periodicity's pop-up menu (Figure 17) and also in the action area 2.3 of the periodicity panel (Figure 16).

Removing periodicity from components is part of the global options (1 in Figure 16) which regard all periodicities and so do not reference the currently selected one:

- Remove periodicity from selected components removes any periodicity from all selected components.
- Remove periodicity from all components removes any periodicity from all components in all code lists. After that no periodic components will exist anymore.

To remove a specific periodicity from all components

1. Select the periodicity to be removed
2. Choose Select components with this periodicity
3. Choose Remove periodicity from selected components

4.8.3 Coupling Components with Different Dimensions

If you want to couple components with different dimensions, there are some restrictions regarding the quantities which may be exchanged. Quantities can only be sent from the components with the higher mesh elements dimension to the components with the lower mesh elements dimension.

So after building the coupling region with e. g. 1-dimensional line elements from code Code_1 and 3-dimensional volume elements from code Code_3, the Define Quantity Sets panel provides only those quantities for the selected coupling dimension (here Line — Volume) fulfilling the above mentioned condition:

- *Code_3* offers the exchanged *quantity* for dimension *volume* to be *sent*.
- *Code_1* offers the exchanged *quantity* for dimension *line* to be *received*.

This implies a unidirectional coupling for coupling regions with components of different dimensions.

An exception is coupling components of dimension point and integration point. In this case quantities can also be sent to components with higher mesh elements dimension.

4.8.4 Simplified Selection

4.8.4.1 Simplified Component Selection

The selection of components out of a large list sometimes may be confusing. To simplify this, following areas exist:

- A selection area for selecting components by their name and
- An options area allowing synchronized scrolling and automatic component selection

Figure 19: Component selection area

The component selection area (see Figure 19) is located at the top of each components list. It consists of a textfield where a regular expression pattern can be given to match the name of the uncoupled components in the list below. Via the Select button all components matching the given pattern will be selected. Be sure to enter a valid regular expression as a pattern (e. g. ".*" to match any character). Syntax errors will be reported but logical errors might be harder to find.

4.8.4.2 Simplified Region Selection

Dealing with a large number of regions may require to select them by their name or also the name of their contained components. For this an area for simplified region selection (see Figure 20) is located at the top of several region lists namely in the tabs Build Regions, Assign Quantity Sets and Overview.

Figure 20: Area for simplified region selection

This area provides a textfield where a regular expression pattern can be given to match the name of the regions in the list below. If the Extend search field is marked, the search will be extended and include the names of the regions' components, too. Otherwise the patterns will be applied to the name of the regions only. Via the Select button those regions matching the given pattern will be selected.

Be sure to enter a valid regular expression as a pattern (e. g. ".*" to match any character). Syntax errors will be reported but logical errors might be harder to find.

4.8.5 Automatic Generation of Regions by Rules

If you have specific component names which may be considered for building coupled regions, you may define rules for a fast automatic region building process. Figure 21 shows an example list of rules in the rules area which is located in the Build Regions tab of the mesh based components panel below the regions area (see Figure 10 (part IV)).

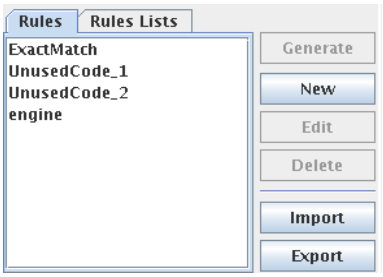


Figure 21: Rules area for automatic region generation

The defined region rules are saved in the MpCCI properties file (see ▷4.2 MpCCI GUI Properties◁) and remain available for later runs of the MpCCI GUI until they are deleted.

To define a new rule click on the New button in the rules area which leads to a dialog for setting the rule properties (see Figure 22).

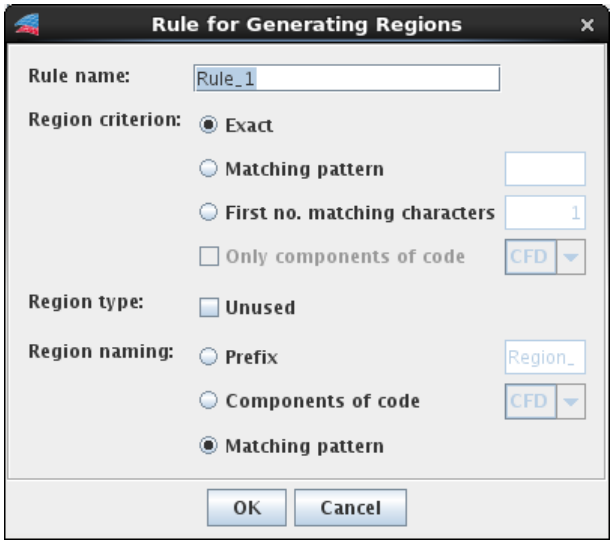


Figure 22: Dialog for setting rule properties

Following properties define a rule:

Rule name The name of the rule.

Region criterion The criterion for finding components fitting to this rule. Every string comparison is done case-insensitive. The region criteria are:

Exact Equally named components build a region. If components have automatically been generated by the scanner, the original name will be taken for comparison. See `%userInfo` in ▷ VIII-2.5.2 Scanner.pm ◁ how automatically generated components are specified.
This region criterion results in building several regions mostly with exactly one component from each code. But if automatically generated components exist, there may be more than one component from one code included.

Matching pattern Components which name match the given pattern build a region. The pattern is handled as a regular expression. If the matching pattern could not be found in the component names, no region will be generated.

First no. matching characters Components which are named equally at the beginning build a region. The number of the first matching characters (n) has to be entered.
This region criterion may result in several regions each containing a group of components equally named by the first n characters where one component's name may be prepended by a prefix like for the Exact criterion.

Only components of code If selected, only components of the selected code are added to the resulting regions.
This criterion may be selected for all region criteria mentioned before except Exact which always uses components of all codes for its execution.

Region type Specifies whether the resulting regions shall be tagged as unused or not.

Region naming Specifies the naming for the resulting regions. The names will be constructed as follows:

Prefix This prefix extended by a serial number for each built region. This is a general naming which doesn't provide insight to the components of the generated region.

Component of code Name of a randomly chosen added component of the selected code. This is useful when using the exact name matching criterion where exactly one component of each code is added. So the name of the regions clarify their contained components.

Matching pattern The matching pattern which led to the selection of the components. This naming is recommended for all region criteria because it allows greater insight into the composition of the built regions. Depending on the chosen region criterion following region names will be constructed.
For Exact criterion the regions take the name of the components' name.
For Matching pattern criterion the resulting region will be named by the given pattern.
For First no. matching characters the regions will be named by the n first equal patterns.

Save the rule by clicking the OK button. Cancel or closing the dialog will dismiss the property settings and won't create a new rule resp. leave the properties unchanged for an edited rule.

Editing a rule is done by a double click on a rule in the rules list or by selecting one rule and clicking the Edit button in the rules area (see Figure 21). After that the dialog for setting rule properties opens (see ▷ 4.8.5 To define a new rule ◁).

Deleting rules is done by selecting the rules and clicking the Delete button in the rules area (see Figure 21). A dialog pops up to confirm the deletion. If only one rule is selected and the rule is part of a rules list (see ▷ 4.8.5.1 Rules Lists ◁), the user will be informed and has to confirm the removal from that list, too. On the other hand several selected rules will be automatically removed from affected rules lists. Rules lists which emptied out after deleting rules will also be deleted.

Generate regions by selecting one rule and clicking the Generate button in the rules area (see Figure 21). The rule will be applied to the code components lists selected in the Components area (see Figure 10 (part IV)). Therefore be sure to select the right component dimension list if more than one element type exists. The generated regions appear in the region list and a dialog will show the results of the applied rule.

Exporting rules and rules lists is done by clicking the Export button in the rules area (see Figure 21). In the upcoming file chooser dialog provide a file name for saving the definitions of all defined Rules and Rules Lists.

Importing rules and rules lists is done by clicking the Import button in the rules area (see Figure 21). In the upcoming file chooser dialog select the file containing the rule definitions (i. e. a file with exported rules and rules lists). If some imported rule names are identical to existing ones, a dialog will appear (see Figure 23) and the user will need to choose an option on how to handle the doubly defined rule name: Replace, Copy or Skip.

Choosing one of the options Replace all, Copy all or Skip all will automatically apply the chosen option to all remaining name conflicts of this import.

Cancel will stop importing this and any further rule and rules list.

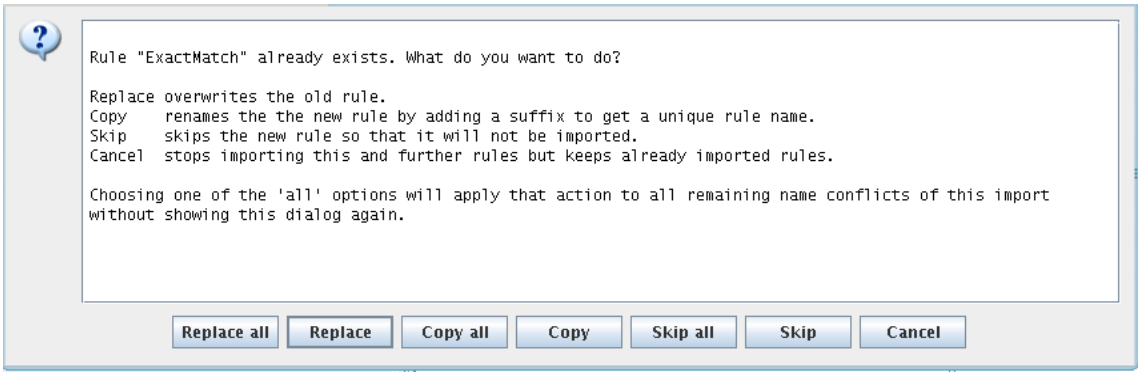


Figure 23: Import dialog for solving rule name conflicts

4.8.5.1 Rules Lists

The defined region rules can be concatenated so that one rule after another will be automatically applied by one call. These rules lists are accessed by the Rules Lists tab in the rules area (see Figure 24).

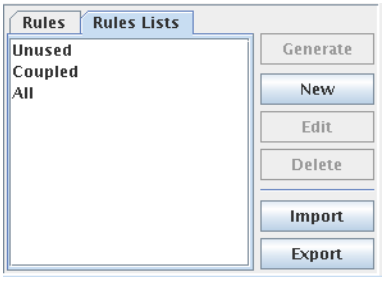


Figure 24: Example rules lists in rules area

Handling rules lists is similar to that of rules. The action buttons New, Edit, Delete and Generate are the same. The defined region rules lists are also saved in the MpCCI properties file (see ▷ 4.2 MpCCI GUI Properties ◁) and remain available for later runs of the MpCCI GUI until they are deleted. They can be

exported and imported together with the rules as described in ▷ 4.8.5 Exporting rules and rules lists ◁ and ▷ 4.8.5 Importing rules and rules lists ◁.

Editing a rules list, while creating a new one via New, editing an existing one via Edit or double clicking a rules list, is done via the dialog shown in Figure 25. A rules list is defined by its name, some region creation options and the list of rules. Therefore the dialog offers following input and editing options:

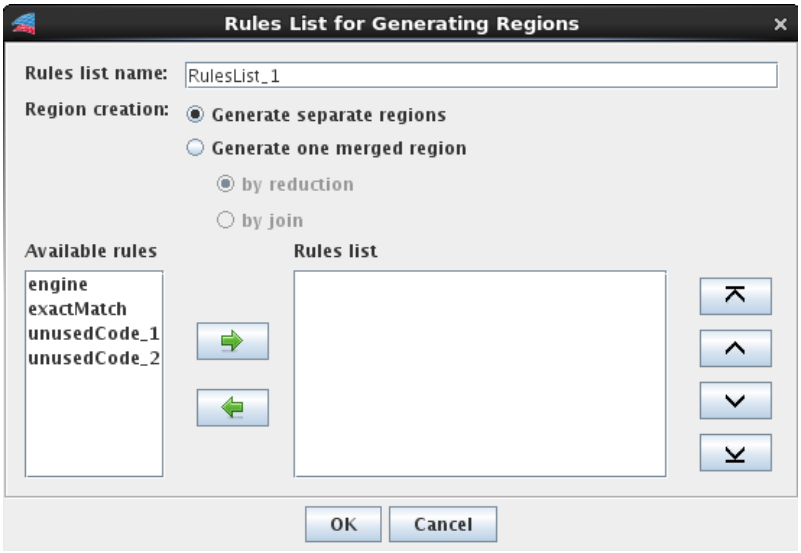


Figure 25: Dialog for editing a rules list

Rules list name The name of the rules list.

Region creation Options for region creation:

Generate separate regions Creates regions from each applied rule. The regions are named as defined by the applied rule.

Generate one merged region Creates only one region as a result of the applied rules. The resulting region will be named after this rules list name.

by reduction Each rule will be applied to the resulting components of the rule before. I. e. the first rule at the top will be applied to all uncoupled components, the second rule to the components selected by the first rule, and so on. The components selected after applying the last rule build the new region.

by join The components selected by each applied rule are collected and put together into one region. This compares to Generate separate regions but joining all regions to one.

Available rules List of rules which are available meaning listed in the Rules tab and not already used in this rules list.

Rules list List of rules building this rules list. The rule at the top will be the first one executed continued by the next one up to the last one at the bottom of the list.

Adding and removing rules is done either by double clicking the respective rule which moves it to the appropriate other list or by using the direction buttons arranged between the two rules lists.

moves the selected available rules to the end of the rules list.

removes the selected rules from the rules list. They will be sorted into the available rules and can be added again.

Using the direction buttons allows to handle more than one rule. The lists allow multiple selection by using the Shift or Ctrl keys or selecting all rules by using the Ctrl+A shortcut.

Editing the rules list is done with the buttons at the right of the rules list.

⤒ Moves the selected rules to the top of the list.

⌃ Moves the selected rules one position to the top.

⌄ Moves the selected rules one position to the bottom.

⤓ Moves the selected rules to the bottom of the list.

Save the rules list by clicking the OK button. Cancel or closing the dialog will dismiss the editing and won't create a new rules list resp. leave the rules list unchanged.

Deleting rules lists is done by selecting the rules lists and clicking the Delete button in the rules area (see Figure 24). A dialog pops up to confirm the deletion.

Generate regions by selecting one rules list and clicking the Generate button in the rules area (see Figure 24). Each rule of the rules list will be applied as described in ▷4.8.5 Generate regions◁. A dialog will show a summary with the results of the applied rules.

4.8.6 Applying Region Properties

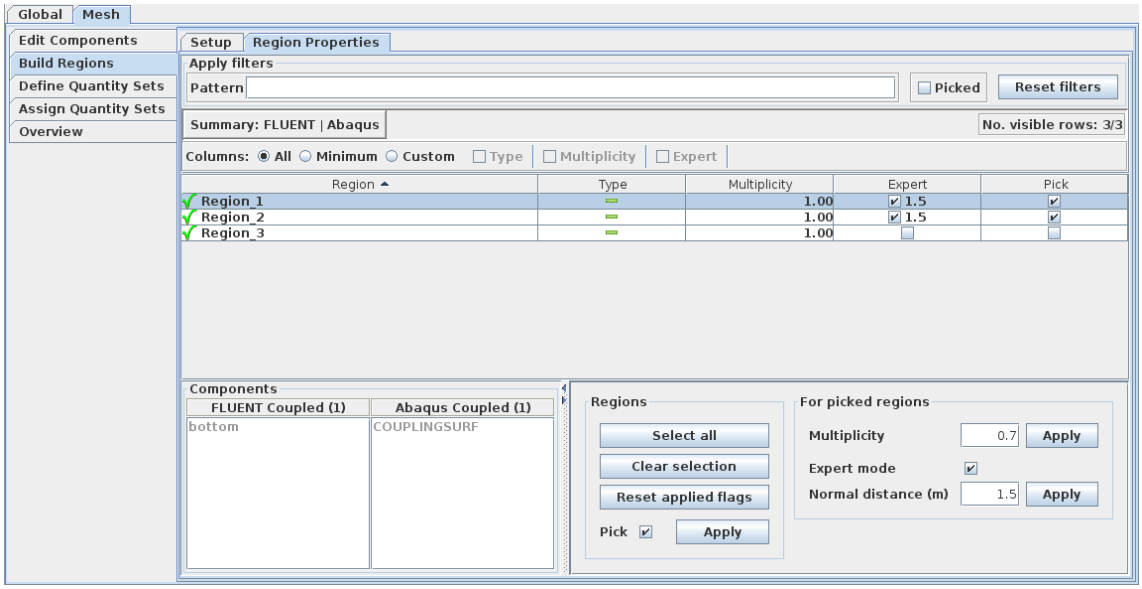


Figure 26: Region properties tab

The attributes for the relation search are globally defined among the control parameters for MpCCI in the Settings step (see ▷4.10.3 Relation Search◁ where they are described in detail). These properties can be overwritten for selected regions in the Region Properties tab of the Build Regions panel shown in Figure 26.

Special relation search parameters for several regions are set by picking the appropriate regions in the table and applying the desired values to the picked regions:

- Picking is done either by checking the pick box of a region in the table or in the Regions area by selecting the appropriate regions in the table and then using the Apply button for the pick flag. This applies the pick flag value to the selected regions.
- Applying relation search values is done by setting the desired values in the For picked regions area and using the Apply button of the desired property to apply its values to the visible picked regions (the selection of the regions is irrelevant and will not be regarded, only the pick flag is the clincher). After that the new values are assigned and will be displayed in the table.

Beyond that the Region Properties tab offers following possibilities:

- Filtering the list of regions. Only regions matching the specified filters will be shown in the table. The Apply filters area offers the filters

  Pattern For specifying a regular expression pattern which will be applied to the names of the visible regions.

  Picked For specifying whether to show only picked regions.

- Configuring table column visibility. The Columns area allows to configure which columns of the table are visible:

  All All table columns are shown.

  Minimum The at least necessary columns are shown.

  Custom The user selected columns are shown.

  This columns choice will be saved in the properties file of the MpCCI GUI (see ▷4.2 MpCCI GUI Properties◁) to remain this way till next run of the MpCCI GUI.

- In the Components area lists of all coupled components of the selected regions are shown.
- Selecting all visible regions is offered by the Select all button.
- Deselecting all visible regions in the table is offered by the Clear selection button.
- Resetting the pick flag for all regions is offered by the Reset applied flags button. Thereby all pick flags will be deselected even the ones of invisible regions.

The region column offers a popup menu with following entries:

Copy region name into clipboard so that the region name can be pasted anywhere else.

Unused marking the selected regions to be unused. This causes that the affected regions will be removed from this list. In this list only *ready* regions are listed, incomplete and unused regions aren't.

4.8.7 Quantity Specifications

4.8.7.1 Quantity Sender

Sometimes a quantity can be sent and received by two or more codes. In that case the user has the option to select the sender of the quantity in the Sender part of the quantity configuration as shown in figure Figure 27.

Figure 27: Selection of the sender/receiver for a quantity

4.8.7.2 Default Value for Global Variables

For the quantities of global variables default values can be specified for the sender. This value will be sent when no computed value is available. The setting is done in the Settings area at the bottom of the quantity configuration (see Figure 13).

4.8.7.3 Orphans Settings for Mesh Based Components

The assignment of values to orphans can be configured in the Orphans settings area of the quantity configuration (see Figure 28) by

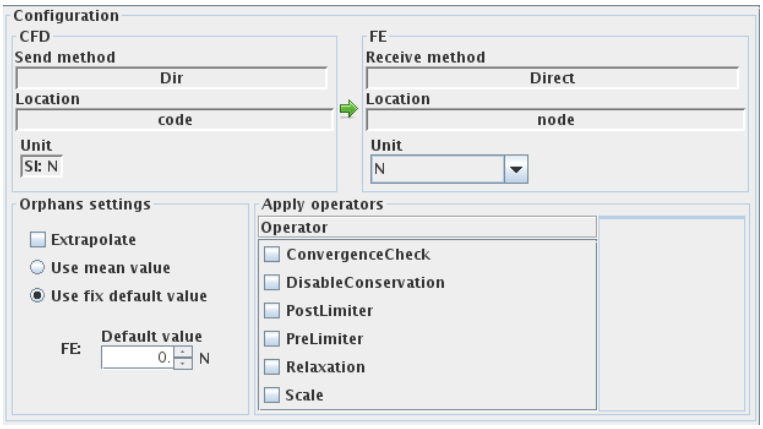


Figure 28: Quantity configuration areas

Use mean value The mean value as an average of the values for this quantity will be set into the orphaned regions.

Use fix default value The given fix default value for the quantity receiver will be set into the orphaned regions.

Extrapolate is an additional option for handling values for orphaned regions. If selected, values will be extrapolated into the orphaned regions where this is possible. For orphans which cannot be extrapolated a mean or default value will be set depending on its selection. If extrapolate isn't selected, all orphaned regions take the mean resp. default value.

4.8.7.4 Applying Operators to Quantities of Mesh Based Components

The MpCCI server provides some operators in the Apply operators area which can be applied to the transferred quantities (see Figure 28). Each operator incorporates a description, a type and usually parameters. By clicking on the operator name the respective description and type will be shown next to the operator list. When an operator is selected the corresponding parameters and the name of the code for which the parameters will be applied (sender code for pre processors, receiver code for post processors) are listed (see Figure 29).

The type of an operator is either pre processor or post processor and the necessary parameters are operator dependent. Following operators are supported by MpCCI.

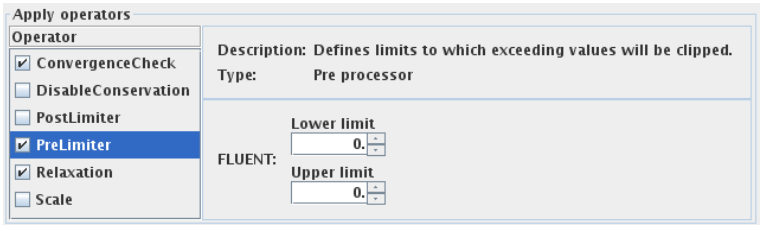


Figure 29: Operators area

ConvergenceCheck Pre processor
Enables convergence check (for iterative couplings only, see ▷ 3.3.4.1 Convergence Check ◁ for details).
Parameters:

Tolerance value	Specifies the convergence criterion. If the variance of a quantity value is below this tolerance between two iterations, the quantity is considered as converged.

DisableConservation Post processor
Disables conservative mapping correction (see ▷ 3.3.4.2 Disable Conservative Mapping Correction ◁ for details) (default: enabled).
<No parameters>

PostLimiter Post processor
Defines limits to which exceeding values will be clipped (see ▷ 3.3.4.3 Define Limits ◁ for details).
Parameters:

Sequence number	The rank of this operator in the list of applied post processors.
Lower limit	The lower limit.
Upper limit	The upper limit.

PreLimiter Pre processor
Defines limits to which exceeding values will be clipped (see ▷ 3.3.4.3 Define Limits ◁ for details).
Parameters:

Lower limit	The lower limit.
Upper limit	The upper limit.

Relaxation Post processor
Enables relaxation (for iterative couplings only, see (▷ 3.3.3 Quantity Relaxation ◁)).
Parameters:

Relaxation method — Specifies the method used for relaxation. The methods offered and their parameters are:

Fixed Uses a constant relaxation factor as described in ▷3.3.3.1 Fixed Relaxation◁.

- Relaxation factor — Specifies the relaxation factor.

Aitken Uses an adaptively calculated relaxation factor as described in ▷3.3.3.3 Aitken Relaxation◁.

Quasi-Newton Uses the Anderson Mixing Quasi-Newton method for relaxation as described in ▷3.3.3.4 Quasi-Newton Method◁.

- Quasi-Newton method — Is limited to Anderson Mixing.
- Type of Anderson Mixing method — Specifies the variant to use. MpCCI offers Inverse, Standard and LeastSquares.
- Omega (ω) — Specifies the *omega* used in the calculation of variants Inverse and Standard.
- Number of reused levels — Determines the number of previous time steps to be taken into account for the Quasi-Newton relaxation (for transient simulations only).

Ramping Is a special kind of relaxation with a relaxation factor varied over the iterations (▷3.3.3.2 Ramping◁).

- Initial factor — Specifies the initial ramping relaxation factor. A value between 0 and 1 leads to under-relaxation whereas a value between 1 and 2 leads to over-relaxation.
- Ramping delta — Specifies the ramping step value.

Check relaxation convergence — Enables a relaxation convergence check. This option has to be used in combination with the ConvergenceCheck operator (▷3.3.4.1 Convergence Check◁) which specifies the tolerance value to be used.

Scale Post processor

Defines a scaling function (see ▷3.3.4.4 Scaling◁ for details).

Parameters:

- Sequence number — The rank of this operator in the list of applied post processors.
- Only first time step — Scale only for the first time step. This option will only be applied for implicit schemes. If this option is activated, no scaling is done for the remaining time steps.
- Reference value — The reference value for the ramping function.
- Initial scale factor — The scale factor at the beginning.
- Final scale factor — The last value for the scale factor, from which it no longer changes. Afterwards, the remaining steps will be scaled with this value.
- Number of steps with the same scale factor — The number of consecutive steps with the same scale factor.
- Number of scale factor changes — Defines how often the scale factor changes.

4.8.8 Assigning Preconfigured Quantity Settings

Furthermore the MpCCI GUI provides some *Predefined Sets* of already preconfigured quantities for the currently chosen coupling specification at the top of the quantities list (see Figure 30). The predefined quantity settings are selectable from a list. To apply the quantities you have to select a Preconfigured Set and click on the Set button. The associated quantities as specified in the coupling specification resp.

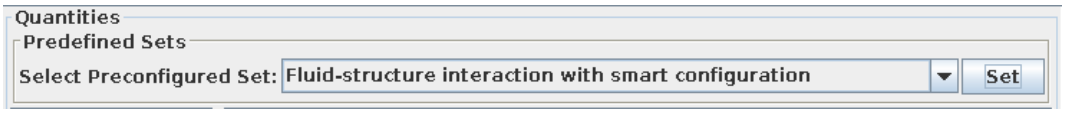


Figure 30: Predefined quantity settings

predicted by the MpCCI Configurator will be selected automatically.

Select Preconfigured Set provides quantity sets which are predefined for the coupling specification selected for the current project. If no specific quantities are configured but only a list of available quantities, this list may be empty.

4.8.9 Overview of the Coupled Regions

To get an overview of the mesh based coupled regions the Mesh tab of the Regions step provides an Overview tab (see Figure 31).

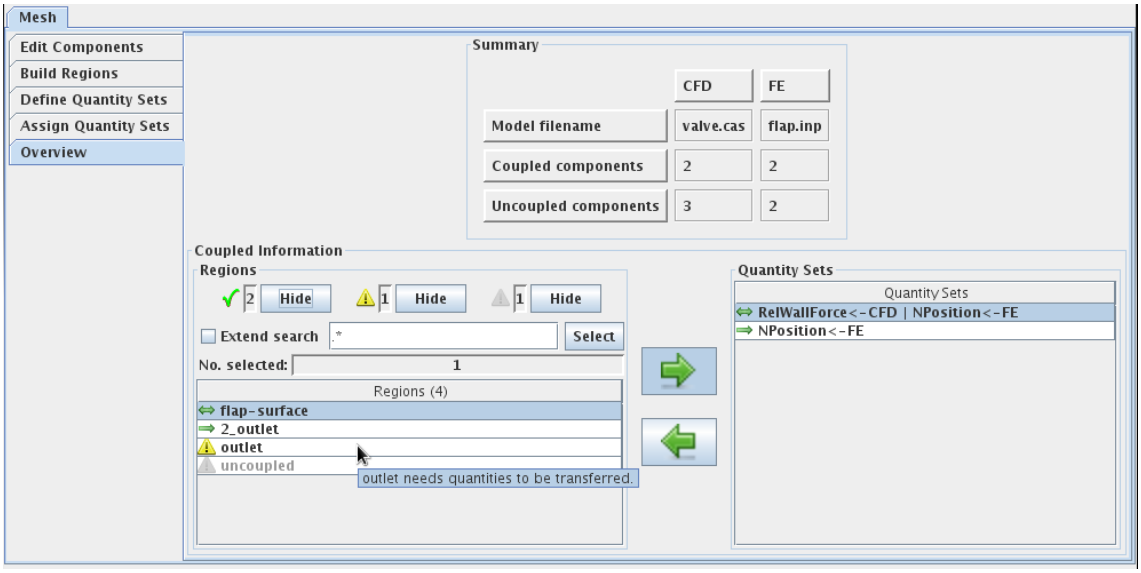


Figure 31: Overview tab

The Overview tab is divided into a Summary and a Coupled Information area.

The Summary area gives an overview of the used codes, their assigned model files and their number of coupled and uncoupled components. Coupled components are those contained in ready and used regions. They will be considered in the coupled simulation run. Uncoupled components are those not added to any region and those contained in not ready and unused regions.

The Coupled Information area gives an overview of the built regions, their state and their assigned quantities. Ready regions are displayed with a quantities transfer direction icon showing a uni- (⇒) or bidirectional (⇔) quantities transfer. Additionally, not ready regions get an ⚠ icon and the icons for unused regions are greyed out. Via the Hide / Show buttons on the top of the Regions area the listed regions can be controlled by showing or hiding regions of a special type. As Figure 31 shows for the incomplete region outlet, the tooltip of a region displays an explanation for not ready regions. For ready regions the tooltip

displays the names of its contained components (three at most). By the direction button  all quantity sets will be marked which are assigned overall to the selected regions. The button  on the other hand marks the regions which have assigned the selected quantity sets.

4.8.10 Requirements

In the Regions step the following requirements have to be fulfilled:

At least

- One coupling region with at least
- Two components of at least
- Two different codes with at least
- One quantity applied

has to be set up.

If one or more of the above mentioned items is missing a click on one of the following step buttons will cause a dialog popping up with an appropriate message and will inhibit the next step.

4.9 Monitors Step

In the MpCCI Monitors step you create and configure a region for monitoring (see Figure 32).

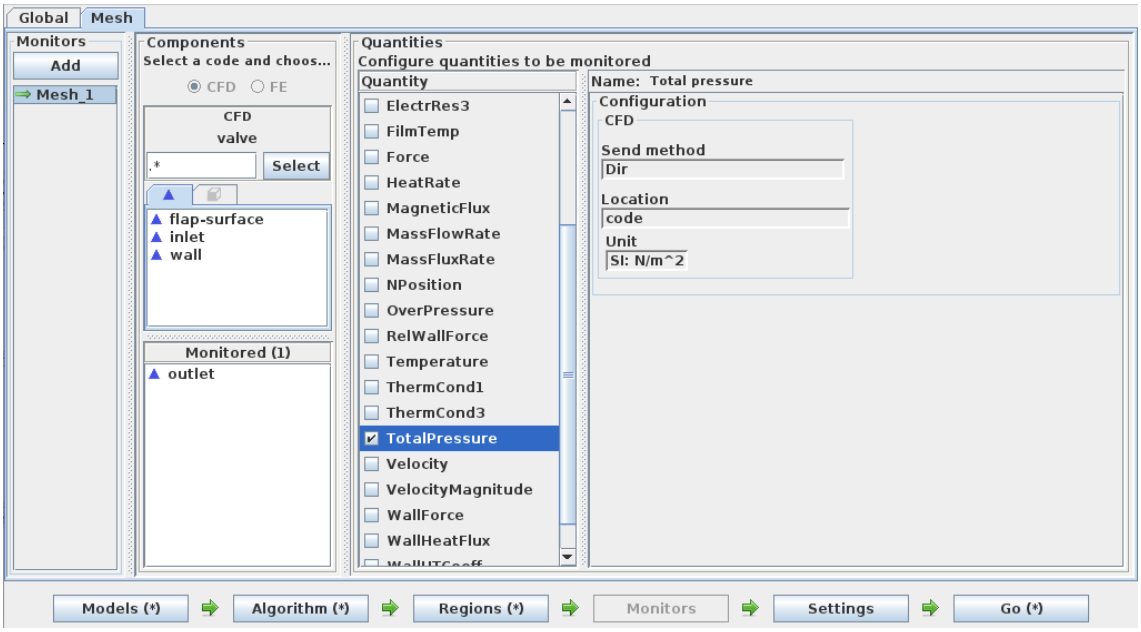


Figure 32: Monitors step

Create a monitor by:

1. Selecting the component type (global variable or mesh based element component).
2. Selecting the code.

3. Selecting the components separated by their dimension for each monitoring region.
4. Specifying the quantities to monitor.

Add additional monitors by clicking the Add button and repeating the procedure.

4.10 Settings Step

The Settings step provides access to the control parameters for MpCCI. They are devided into the main categories Monitor, Job, Relation Search and Output (see Figure 33).

The parameters are shown in a tree-like view on the left. The parameters for the selected category are shown in a table on the right. Here you have columns for the name of the parameter, its value and a description. To change a parameter click on its value. Depending on the value type the field changes to an editable field. A category may also contain subcategories like Output. The table only shows direct parameters of a category. Subcategories must be selected explicitly.

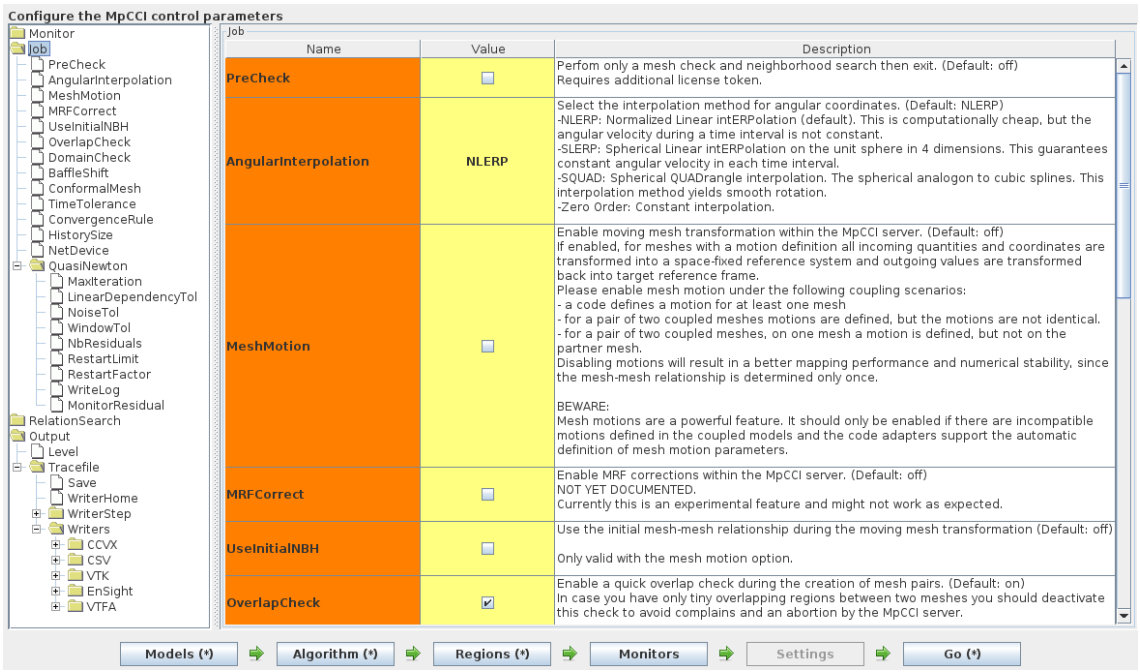


Figure 33: Settings step

Following is a description of the parameters for each main category and its subcategories.

4.10.1 Monitor

In this category you may specify some parameters used by MpCCI to control the online monitor.

Name	Description
Enable	Activate the MpCCI Monitor. (Default: on)
NodeIds	Send the node IDs to the MpCCI Monitor. (Default: off)
ElemIds	Send the element IDs to the MpCCI Monitor. (Default: off)

Name	Description
Size	Send the element sizes information to the MpCCI Monitor. (Default: off)
Orphans	Send the nodal orphan quality level (0...6) to the MpCCI Monitor. (Default: on)
Globals	Monitor global variables. (Default: off)
Slaves	Send slave node flags to the MpCCI Monitor. A slave node flag of 1 identifies a node of a mesh partition as a slave node of another partition of the same coupled mesh. Partitions without any slave node (pure master partitions) are displayed in gray. (Default: off)
Domains	Send the node domains' IDs to the MpCCI Monitor (only active in conjunction with a domain check - see ▷ 4.10.2 Job ◁). If the maximum domain is greater than 0, your coupled mesh is split into multiple separated domains. In case you have to deal with orphaned nodes due to partial overlapping you might consider the fact that orphans are filled with default values instead of some kind of "diffusive" extrapolation. (Default: off)
Normals	Send face normal vectors to the MpCCI Monitor. (Default: off)
Peaks	Send the peak and mean values of a quantity on a partition to the MpCCI Monitor. (Default: off)
AbsDiff	Display the absolute differences between iterations or time steps. (Default: off)
RelDiff	Display the relative differences between iterations or time steps. (Default: off)
Inorm	In case of iterative coupling (whether transient or steady state) send the peak and mean values for the convergence norm to the MpCCI Monitor. (Default: off)
Relax	Include quantity relaxation factor plot. (Default: off)
Periodic	Display the replicated periodic parts and quantities. (Default: off)
Modulo	Set the maximum number of steps kept by the MpCCI Monitor. (Default: 100 steps)
Memory	Set the maximum memory in MB used by the MpCCI Monitor. (Default: 50 MB)
AutoLaunch	Auto launch the MpCCI Monitor by the server. If set to off, the user can use the command `mpcci monitor [options]` to launch the MpCCI Monitor "manually". (Default: on)
Host	Specifies the name of the host machine where the MpCCI Monitor runs. (Default: localhost)
Port	Provide the MpCCI Monitor port address to use. (Default: 47002)
NetDevice	Specify a network device or an IP address for MpCCI Monitor communication. You may provide the network device for e. g. using Infiniband or Myrinet hardware. Under UNIX this is either the network address (IP address of a special socket adapter) or the name of the special device, e. g. ib0 in case of Infiniband. (Default: empty)

4.10.2 Job

In this category you specify the attributes of the coupled job.

Name	Description
PreCheck	Perform only a mesh check and neighborhood search then exit. (Default: off) Requires additional license token.

Name	Description
AngularInterpolation	Select the interpolation method for angular coordinates. (Default: NLERP) **Zero Order** Constant interpolation. **NLERP** Normalized Linear intERPolation. This is computationally cheap, but the angular velocity during a time interval is not constant. **SLERP** Spherical Linear intERPolation on the unit sphere in 4 dimensions. This guarantees constant angular velocity in each time interval. **SQUAD** Spherical QUADrangle interpolation. The spherical analogon to cubic splines. This interpolation method yields smooth rotation.
MeshMotion	Enable moving mesh transformation within the MpCCI server. (Default: off) If enabled, for meshes with a motion definition all incoming quantities and coordinates are transformed into a space-fixed reference system and outgoing values are transformed back into the target reference frame. Please enable mesh motion under the following coupling scenarios: • a code defines a motion for at least one mesh. • for a pair of two coupled meshes motions are defined, but the motions are not identical. • for a pair of two coupled meshes, on one mesh a motion is defined, but not on the partner mesh. Disabling motions will result in a better mapping performance and numerical stability, since the mesh-mesh relationship is determined only once. (!) Mesh motions are a powerful feature. It should only be enabled if there are incompatible motions defined in the coupled models and the code adapters support the automatic definition of mesh motion parameters.
MRFCorrect	Enable MRF corrections within the MpCCI server. (Default: off) (!) NOT YET DOCUMENTED. Currently this is an experimental feature and might not work as expected.
UseInitialNBH	Use the initial mesh-mesh relationship during the moving mesh transformation. (Default: off) Only valid with the mesh motion option.
OverlapCheck	Enable a quick overlap check during the creation of mesh pairs. (Default: on) In case you have only tiny overlapping regions between two meshes you should deactivate this check to avoid complains and an abortion by the MpCCI server.
DomainCheck	Enable a check on the domains of parts or meshes. (Default: off) With an activated domain check the server finds the number of domains of a mesh resp. part and also searches for isolated strap elements resp. cells of a mesh which might cause mapping problems, especially in the case of partial overlapping meshes. (i) A domain check is expensive and should be deactivated in case of production runs with remeshing.
BaffleShift	Enable the shifting of baffle front and rear side for a geometrical separation of the two sides of a baffle. (Default: off) In case of an activated baffle shift there is no need to put the front side and rear side of a baffle into separate coupled meshes. The code-adapter has to support the baffle shift feature and must define the thickness of a baffle to the MpCCI server.

Name	Description
ConformalMesh	Enable the conformal mesh mapping algorithm (Default: off) In case two partner meshes are conformal (geometry and element resp. cell type) a special mapping algorithm can be applied. The relationship is much faster, the mapping does not produce any mapping errors. (!) This is a global switch and all meshes of all partner codes must be geometrically identical. In case of remeshing all partner meshes have to be recreated in the same way. Currently this is an experimental feature and might not always work as expected.
TimeTolerance	Define the (relative) tolerance of any time difference resp. time step size of a code below which the two different times are assumed to be identical. (Default: 0.001) Valid values are in the range]0..1/2[. Any value less than 0 removes the tolerance check and the time difference must be identical to 0. A value $\geq$0.5 resets the value to its default. (!) This value is only relevant for transient cases with multiple buffers.
ConvergenceRule	Specify whether all or only one quantity should have converged if the ConvergenceCheck operator has been assigned to more than one quantity. (Default: All) (See ▷4.8.7.4 Applying Operators to Quantities of Mesh Based Components◁)
HistorySize	Define the minimum number of buffers for storing the quantity history. A number between 4 and 32 may be chosen. (Default: 4)
NetDevice	Specify a network device name or an IP address for MpCCI communication between server and clients. You may provide the network device for e. g. using Infiniband or Myrinet hardware. Under UNIX this is either the network address (IP address of a special socket adapter) or the name of the special device, e. g. ib0 in case of Infiniband. (Default: empty)
QuasiNewton	
MaxIteration	Define the maximum number of saved iteration values to be used in the Quasi-Newton relaxation applied to steady simulations. (Default: 20) For more details see ▷3.3.3.4 Quasi-Newton Method◁.
LinearDependencyTol	Define the tolerance to eliminate linear dependent columns of the approximated Jacobian in the Quasi-Newton relaxation for better conditioning. (Default: 1e-6) A value between 1e-6 and 1e-10 is recommended. Zero deactivates the option. For more details see ▷3.3.3.4 Quasi-Newton Method◁.
NoiseTol	Define the tolerance to eliminate noisy columns of the approximated Jacobian in the Quasi-Newton relaxation for better conditioning. (Default: 1e-4) A value between 1e-2 and 1e-6 is recommended. Zero deactivates the option. For more details see ▷3.3.3.4 Quasi-Newton Method◁.
WindowTol	Define the tolerance to clean up the approximated Jacobian in the Quasi-Newton relaxation for new time steps. It is only relevant for transient simulations. (Default: 1e-5) A value between 1e-3 and 1e-7 is recommended. Zero deactivates the option. For more details see ▷3.3.3.4 Quasi-Newton Method◁.
NbResiduals	Define the number of residuals which are checked to be increasing in a Quasi-Newton relaxation. (Default: 0) If the linear fit to these residuals has a positive slope, a re-initialization of the Jacobian will be allowed (restart). Zero leads to no residual check. For more details see ▷3.3.3.4 Quasi-Newton Method◁.

Name	Description
RestartLimit	Define the limit to be used for a restart of the Quasi-Newton relaxation. (Default: 0.01) For more details see ▷ 3.3.3.4 Quasi-Newton Method ◁.
RestartFactor	Define the growing factor between two consecutive residuals to be used for a restart of the Quasi-Newton relaxation. (Default: 0.1) For more details see ▷ 3.3.3.4 Quasi-Newton Method ◁.
WriteLog	Define whether an additional log file including Quasi-Newton relaxation info should be written. (Default: False)
MonitorResidual	Define whether residuals of Quasi-Newton relaxation info should be monitored. (Default: True)

4.10.3 Relation Search

In this category you specify the attributes of the relation search.

Name	Description
Multiplicity	Neighborhood search default distance factor. (Default: 1.0) Multiplicity is a factor by which the default search distance is multiplied in case of neighborhood search failures (with orphans). For any orphaned object the search is then repeated with a new (larger) search distance until no orphans are left. Proper values are between 1.0 and 4.0. Values less than 1.0 are for rare cases with strange degenerated meshes.
ExpertMode	Overwrite the calculated normal distance based on the mesh size with the value set in UserNormalDistance. (Default: off) (!) This option should only be used for surface coupling. This may create orphaned nodes if the value is not appropriate to the mesh.
UserNormalDistance	Specify the normal distance value in meters. (Default: 0.0) This is an absolute value. The multiplicity factor provided in the MpCCI GUI will be used for the neighborhood search.

4.10.4 Output

In this category you specify the output written by MpCCI and select and configure the writers for which trace files shall be written.

Name	Description
Level	Determines how much output MpCCI writes: 0 no output, 1 minimal output (default), 2 additional output, 3 maximal output - for debug only.
Tracefile	
Save	Save trace files for visualization. (Default: on)
WriterHome	Enter a path to save the trace files. (Default: `$MPCCI_JOBDIR`)
WriterStep	
Enable	Use writer stepping for saving trace files. (Default: off) It allows saving the results at the specified step interval.

Name	Description
CouplingStep	Coupling step size for saving trace files. (Default: 1)
IterationStep	Iteration step size for saving trace files. (Default: -1)
TimeStep	Time step size for saving trace files. (Default: -1.0)
Writers	
CCVX	
Use	Save an MpCCI binary CCVX file. (Default: on)
Orphans	Include orphan level information. (Default: off)
Size	Include element size information. (Default: off)
NodeIds	Include node IDs information. (Default: off)
ElemIds	Include element IDs information. (Default: off)
Globals	Include received global variables. (Default: off)
Slaves	Include slave node flags. (Default: off)
Domains	Include node domains (only valid with domain check - see ▷ 4.10.2 Job ◁). (Default: off)
Peaks	Include quantity peak and mean values plot. (Default: off)
Inorm	Include quantity iteration norm values plot. (Default: off)
Periodic	Include replicated periodic parts and quantities. (Default: off)
CSV	
Use	Save a comma-separated-values file (CSV) for point coupling. (Default: off)
Globals	Include received global variables. (Default: off)
VTK	
Use	Save Paraview VTK files. (Default: off)
Orphans	Include orphan level information. (Default: off)
Size	Include element size information. (Default: off)
Binary	Save in big endian binary format. (Default: off)
NodeIds	Include node IDs information. (Default: off)
ElemIds	Include element IDs information. (Default: off)
Midedge	Include mid-edge nodes on quadratic elements. (Default: off)
Group	File content grouped by mesh or part numbers. (Default: mesh)
Slaves	Include slave node flags. (Default: off)
Domains	Include node domains (only valid with domain check - see ▷ 4.10.2 Job ◁). (Default: off)
Periodic	Include replicated periodic parts and quantities. (Default: off)
EnSight	
Use	Save EnSight Gold binary files. (Default: off)
Sflush	Save all EnSight Gold files at each coupling step. (Default: off)
Orphans	Include orphan level information. (Default: off)
Size	Include element size information. (Default: off)
NodeIds	Include node IDs information. (Default: off)
ElemIds	Include element IDs information. (Default: off)
Midedge	Include mid-edge nodes on quadratic elements. (Default: off)
Slaves	Include slave node flags. (Default: off)
Domains	Include node domains (only valid with domain check - see ▷ 4.10.2 Job ◁). (Default: off)
Periodic	Include replicated periodic parts and quantities. (Default: off)
VTFA	
Use	Save Ceetron VTF ASCII files. (Default: off)
Orphans	Include orphan level information. (Default: off)
Size	Include element size information. (Default: off)
Periodic	Include replicated periodic parts and quantities. (Default: off)

4.11 Go Step

In the MpCCI Go step you configure the startup of the applications. Following is a detailed description of the MpCCI coupling server parameters. The configuration for the analysis codes is described in the appropriate code section of the Codes Manual. How to check, start and interrupt the coupled simulation can be found in ▷IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation◁.

4.11.1 Configuring the MpCCI Coupling Server

For the MpCCI coupling server the following parameters can be configured (see also Figure 34):

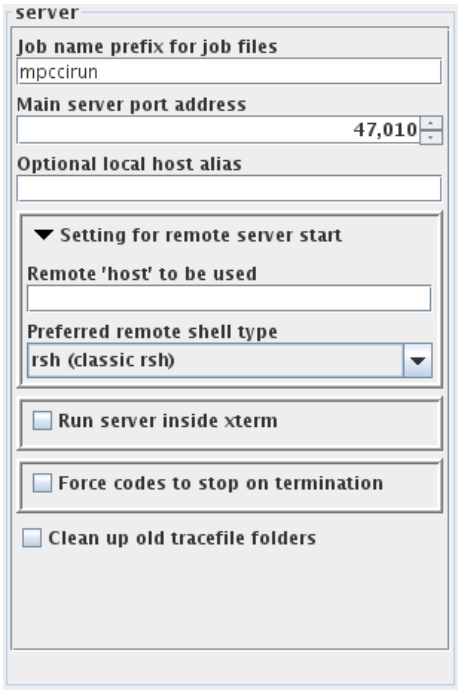


Figure 34: Server settings

Job name prefix for job files is used as prefix to all files generated by MpCCI like "mpccirun_<TIMESTAMP>_ccvx" trace file directory.

Main server port address specifies the port address on which the MpCCI server listens for the client connection. The default port is in most cases acceptable, modifications are only required if firewalls block connections.

Optional local host alias sets a name which is chosen to identify the local host.

Setting for remove server start configures MpCCI to run on a remote host:

Remote 'host' to be used provides a host on which the server process will be started. If the username of the remote host differs from the current one, it must also be specified perhaps associated with a domain name. If this parameter is left empty, the server will be started on the local host.

Preferred remote shell type is used to select the type of the remote shell to start the MpCCI server.

rsh (classic rsh) uses the classic remote shell command rsh.

ssh (secure shell) uses the secure remote shell command ssh.

Run server inside xterm lets the MpCCI GUI open an xterm window for the MpCCI server process on UNIX and Windows platforms. If this parameter is set the panel expands and shows some more options for configuring the xterm (see Figure 35):

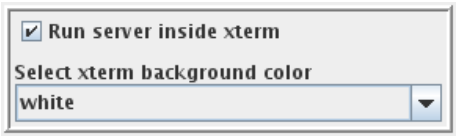


Figure 35: Run server inside xterm settings

Select xterm background color provides colors to be used as background for the xterm which sometimes make it easier to find the right window.

Force codes to stop on termination tells MpCCI to automatically force an exit of remaining running jobs when one code already exited by itself. Perhaps the remaining jobs are blocked when one job already ended. Usually used in batch mode where the user can't interactively stop or kill running jobs. If this parameter is set the panel expands and shows some more options (see Figure 36):

Figure 36: Force codes to stop on termination settings

Timeout in seconds specifies the time to wait between one job is exited and the remaining jobs will be forced to exit. The default value is 60 seconds.

Clean up old tracefile folders tells MpCCI to automatically remove all old tracefile folders beginning with the current job name prefix before the job starts.

4.11.2 Checking the Configuration

As mentioned in ▷ IV-2.8.3 Checking the Application Configuration ◁ optional configuration checkers may be provided for each single code. The existence of a code checker depends on an existing checker environment in the MpCCI GUI configuration file. See ▷ VIII-2.4.8 Environments for Scanner, Checker, Starter, Stopper and Killer ◁ for a detailed description.

4.11.3 Starting the Coupled Simulation

As mentioned in ▷ IV-2.8.4 Starting the Coupled Simulation ◁ the coupled simulation is started via the Start button. If the project has unsaved data a dialog will pop up allowing to save the project. This dialog also provides an option for automatically saving the project (see Figure 37).

If this option (Don't ask again and save automatically in this and all future projects.) is set and the project has successfully been saved via this dialog (choosing Save or Save as... without canceling them) the global property Auto Save Project will be set and this dialog won't appear anymore unless the property is unset. See ▷ 4.4.2 Edit Menu ◁ for more information.

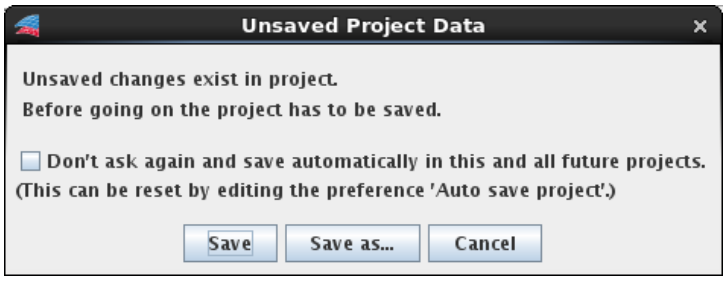


Figure 37: Unsaved data dialog with automatically save option

4.11.4 Status of the Simulation

The status of each application is shown in the Go step at the bottom of the code's frame. In Figure 21 (part IV) no special symbol and no button is shown which means that the codes are not running and no results from a previous run exist for the current configuration. This status is representative for a new or just opened project which has not been started or for a finalized simulation with modified project data.

Following running states may occur after the coupled simulation has been started and is running:

This black symbol indicates that the code is running.

This red symbol indicates that the code got a stop or kill signal and will end soon.

The running states are linked to a button that enables access to the current output of the application. This information is displayed in an xterm that can be closed and opened again throughout the whole simulation.

The output of the server is only available if its option to run in an xterm is activated. Code output is only available when started in batch mode and not for interactive runs.

After the coupled simulation has finished, a message with the current status is displayed. The status is one of the following:

- All codes are successfully done.
- The simulation ended with errors if at least one code failed.
- The simulation was canceled if the user stopped or killed the job.

The final states that can occur for each individual application are:

The code finished normally.

The code failed by itself.

The code finished by getting a stop signal which is sent after clicking the stop button.

The code finished by getting a kill signal. This could be triggered by the kill button or by a failed code.

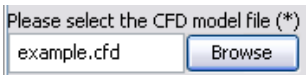
The final states replace the running states and are linked to a button that enables access to the last information from the application output. This information can be accessed as long as the project data has not been changed. After changing some options the application output from the previous run is not valid anymore and will be cleared.

4.12 Remote File Browser

4.12.1 File Browser Handling

By clicking on the button Browse the remote file browser opens. After having selected up a file the file

name is displayed in the text field. If you point the text field with the mouse pointer a tip appears and indicates the location of the file. This information contains the hostname and the absolute file path. If the field is empty the tip shows the message no file specified. In the text field you may enter a file name.



If the name is relative the directory and host of the old file parameter will be taken or if no old file exists the current working directory on the local computer will be taken. Then the file will be located relative to your current working directory.

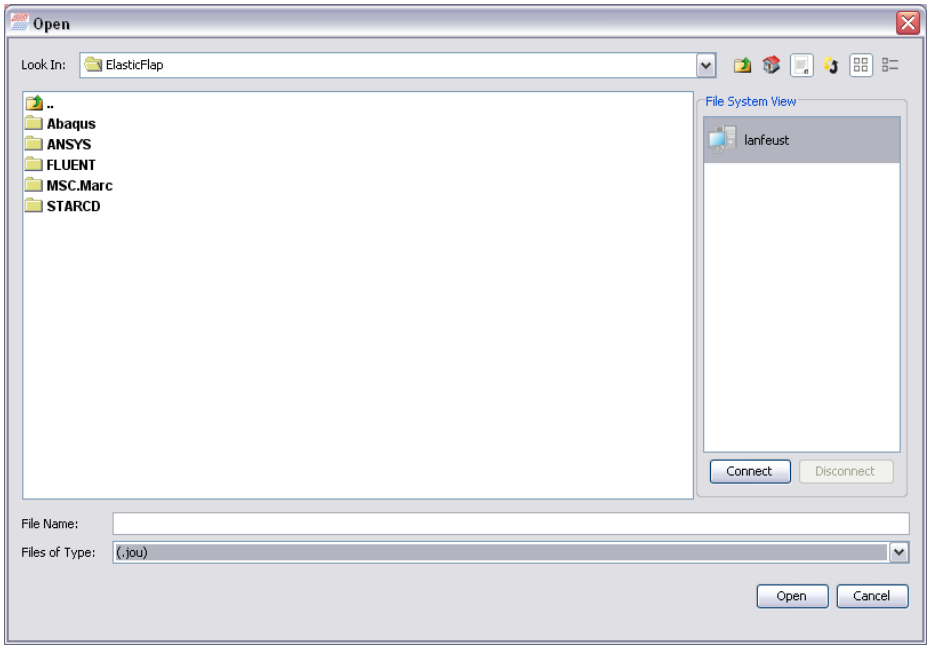


Figure 38: File browser

The remote file browser (Figure 38) displays the files of your current directory in the center and on the right it shows a list of different file systems mounted to this remote file browser. The current directory is represented by the working directory where the MpCCI GUI is running. After you have selected a first file for your application the path of this file represent the current directory for your selected code. Each code has its own working directory.

The default file system view mounted is your local file system represented by the hostname where the MpCCI GUI is running.

If you have more than one file system mounted the current file system is highlighted with a blue background and has the name of the remote machine.

The navigation is performed by using the mouse double click.

The file selection is performed by doing a double click or a simple click to select it, followed by a click on the Open button.

To save a file you have to select the directory by using the mouse and finally enter the file name in the provided text field followed by a click on the Save button.

4.12.2 How to Mount a New File System

On the right side of the remote file browser there are two buttons to Connect and Disconnect a file system.

To disconnect a file system from the file browser, select the corresponding file system in the list and click on the Disconnect button.
The local file system cannot be disconnected and is represented by the figure Figure 39

Figure 39: Local file system symbol

To mount a new file system:

1. You have to open the connection dialog by clicking on the Connect button.
2. You have to enter the hostname of the remote machine and some user information.

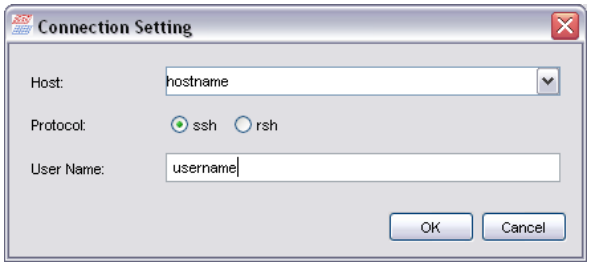


Figure 40: File browser connection dialog

- Select your remote machine.
  At the initialization phase of the MpCCI GUI a list of hosts is searched in the files `".rhosts"` and `".shosts"` from the user home directory. This list is used to provide some predefined hosts to select.

  You may write the name of the remote machine on the Host text field. If you type the hostname on the input field the MpCCI GUI tries to figure out the host name you want from the host list. Otherwise you may directly pick up the machine name to connect to from the combo box.
- Configure the protocol of the remote connection.
  You may use ssh service or rsh.

- Specify the user name.
  You may modify the user to be used for the connection to the remote machine or let the predefined name.

After configuring the connection you must click on the OK button to establish the connection. If the connection to the remote host is successfully established, you will see the name of the new remote machine in the list of the file system view and the remote file system. Each remote file system is characterized by the type of the protocol used for the connection. On figure Figure 41 you have the icon for the secure and non secure connection.

Figure 41: Secure connection icon (left) and a non secure connection icon (right)

3. You have a view on the remote file system and you may navigate to select a file.

5 Command Line Interface

5.1 Using the Command Line Interface

MpCCI has an extensive command line interface, which offers a lot of functionality beyond the actual coupling process, including license information, job control etc.

To use the command line interface, MpCCI must be installed properly. Especially the `PATH` environment variable must be set correctly and contain the binary directory `"MPCCI_HOME/bin"`, see the Installation Guide for details.

To obtain a quick help on the MpCCI commands, it is also possible to enter the command followed by a "help key". If you want to get further information e. g. on starting the MpCCI GUI, which is normally done by entering `mpcci gui`, type

```
mpcci gui -help
```

or

```
mpcci gui ?
```

MpCCI is very flexible in interpreting the command line options. In general dashes (`-`) can be omitted and commands or options can be abbreviated as long as the abbreviation is unique. Further, command interpretation is not case sensitive. The following commands are thus all equivalent, and show the expiry date of your license:

```
mpcci license -expire
mpcci License EXPIRE
mpcci lic -exp
mpcci lic e
```

If less subcommands of options than required are entered, a list of available options is printed. Entering only the command `mpcci` without further options consequently yields basic information:

- Version information.
- Basic usage as described in this section.
- A list of all available commands.

The general description looks like:

```
***********************************************
 MpCCI 4.7.1-0, Build (2010-10-01 ??:??)
 (c) 2004-2023 Fraunhofer Institute SCAI
 Scientific Computing and Algorithms Institute

 Website: http://www.mpcci.de
 Email  : mpcci-support
***********************************************


Usage:
   mpcci SUBCMD [OPTIONS] [ARGS] [HELPKEY] ...


Synopsis:
   'mpcci' is the root for all MpCCI related commands. You need
   to specify at least one subcommand (SUBCMD) on the commandline.
```

```
SUBCMD, OPTIONS (not file name ARGS!) may be typed in lowercase
or UPPERCASE letters or may even be abbreviated as long as there
is no ambiguity.

Since the command and help system is dynamically configured at
runtime some SUBCMDS and OPTIONS may not always appear in the list
below or may suddenly become ambiguous as they are activated only
under certain circumstances (existing file/installation etc.)
If you use 'mpcci' in scripts you should never use the
abbreviated form of SUBCMD or OPTION.

You get online help for most of the SUBCMDS and OPTIONS if the
HELPKEY ([-]help, [-/]? ...) appears on the command line.

Please type either

   "mpcci SUBCMD HELPKEY"    or
   "mpcci HELPKEY SUBCMD"

to get more detailed help on the subcommands.
```

The list of commands is omitted here, a concise list is given in the following section.

5.2 Overview of All Subcommands

In addition to subcommands which are related to the general functions of MpCCI, further code-specific commands are offered, which are described in the corresponding sections of the Codes Manual.

The MpCCI commands are discussed in more detail in following sections, which are sorted by the purpose of the commands. To find a command by its name, the following list shows all MpCCI commands in alphabetical order:

Subcommand	Short Description	Discussed in
`arch [-n]`	Print the MpCCI base architecture without a newline or with a newline `[-n]` at the end and exit. This is different from `mpcci info arch` which prints the used architecture.	▷ 5.5.1 mpcci arch ◁ on page 152
`backup <file ...>`	Make a backup copy of a list of files.	▷ 5.7.1 mpcci backup ◁ on page 168
`batch <project>`	Start an MpCCI batch job with project file `<project>`.	▷ 5.7.2 mpcci batch ◁ on page 169
`ccvxcat <port file ...>`	Catenate and/or send .ccvx files to the MpCCI visualizer.	▷ 5.4.1 mpcci ccvxcat ◁ on page 139
`clean`	Remove all files from the temporary MpCCI directory `<`*Home*`>/.mpcci/tmp`.	▷ 5.7.7 mpcci clean ◁ on page 176
`configurator`	Use the MpCCI configurator	▷ 5.4.2 mpcci configurator ◁ on page 140
`cosimpre`	Use co-simulation pre-check tools	▷ 5.4.3 mpcci cosimpre ◁ on page 144
`doc`	View the MpCCI documentation.	▷ 5.5.2 mpcci doc ◁ on page 153
`env`	Print out the environment used by MpCCI in various formats for further processing.	▷ 5.5.4 mpcci env ◁ on page 156

Subcommand	Short Description	Discussed in
`fsimapper`	Launch the MpCCI visualizer with FSI mapping plugin.	▷ 5.3.1 mpcci fsimapper ◁ on page 132
`gui`	Launch the MpCCI GUI.	▷ 5.3.2 mpcci gui ◁ on page 133
`home [-n]`	Print the MpCCI home directory without a newline or with a newline `[-n]` at the end and exit. This is in fact a shortcut for `mpcci info home`.	▷ 5.5.5 mpcci home ◁ on page 157
`info`	Print general information about MpCCI.	▷ 5.5.3 mpcci info ◁ on page 154
`kill`	Platform independent process kill based on command line pattern matching.	▷ 5.7.8 mpcci kill ◁ on page 177
`license`	Manage the license server and print license related information.	▷ 5.6.1 mpcci license ◁ on page 160
`list`	List information about the MpCCI installation and the supported codes.	▷ 5.6.2 mpcci list ◁ on page 161
`lmutil`	Run the FLEXnet `lmutil [OPTIONS]` command delivered with MpCCI. Avoid running the lmutil command installed by codes other than MpCCI.	▷ 5.6.3 mpcci lmutil ◁ on page 162
`logviewer`	Launch the MpCCI logfile viewer.	▷ 5.3.3 mpcci logviewer ◁ on page 134
`monitor`	Launch the MpCCI online monitor.	▷ 5.3.4 mpcci monitor ◁ on page 135
`morpher`	Launch the MpCCI grid morpher.	▷ 5.4.4 mpcci morpher ◁ on page 145
`netdevice <interface>`	Return the IP adress corresponding to the specified network interface. (under Windows it only returns the IP for the ethernet device.)	▷ 5.4.5 mpcci netdevice ◁ on page 148
`observe`	Start the MpCCI file observer.	▷ 5.4.6 mpcci observe ◁ on page 149
`ps`	Unix `ps -ef` compatible ps for all platforms.	▷ 5.7.9 mpcci ps ◁ on page 179
`ptoj`	Convert an MpCCI project file into an MpCCI job properties file.	▷ 5.7.10 mpcci ptoj ◁ on page 180
`server`	Start the MpCCI server.	▷ 5.7.11 mpcci server ◁ on page 181
`ssh`	Check/fix your ssh installation.	▷ 5.6.4 mpcci ssh ◁ on page 163
`test`	Run some install/communication tests.	▷ 5.6.5 mpcci test ◁ on page 164
`top`	Display process top list / Launch the taskmanager.	▷ 5.7.12 mpcci top ◁ on page 185
`visualize`	Launch the MpCCI visualizer.	▷ 5.3.5 mpcci visualize ◁ on page 136
`where <CMD>`	Find all locations of the executable `<CMD>` in the PATH.	▷ 5.5.6 mpcci where ◁ on page 158
`xterm`	Start a process inside an xterm.	▷ 5.4.7 mpcci xterm ◁ on page 150

5.3 Starting MpCCI

The commands in this section start the different parts of MpCCI. Besides the actual coupling engine, MpCCI offers several helper applications.

Subcommand	Short Description	Discussed in
`fsimapper`	Launch the MpCCI visualizer with FSI mapping plugin.	▷ 5.3.1 mpcci fsimapper ◁ on page 132
`gui`	Launch the MpCCI GUI.	▷ 5.3.2 mpcci gui ◁ on page 133
`logviewer`	Launch the MpCCI logfile viewer.	▷ 5.3.3 mpcci logviewer ◁ on page 134
`monitor`	Launch the MpCCI online monitor.	▷ 5.3.4 mpcci monitor ◁ on page 135
`visualize`	Launch the MpCCI visualizer.	▷ 5.3.5 mpcci visualize ◁ on page 136

5.3.1 mpcci fsimapper

```
Usage:
   mpcci fsimapper [-]option


Synopsis:
   'mpcci fsimapper' is used to launch the MpCCI FSIMapper.


Options:
   -batch  <configFile> <source> [source_quant] <target>
             Use this option to launch the MpCCI FSIMapper in batch mode.
             Provide a configuration file, source and target model files and
             an optional source quantity file.

   -convert  <FORMAT> <model>
             Use this option to convert native ANSYS models into MapLib format.

   -help
             This screen.

   -scan  <FORMAT> <model>
             Use this option to scan models with the MpCCI FSIMapper.
             Supported scanner formats are ABAQUS, ANSYS, LSDYNA, FLUENT, NASTRAN,
             CFXCSV, FLOTHERMMAPLIB, FLOEFDMAPLIB, FLOTHERMXT, FINETURBO, MAXWELL,
             6SIGMAET, VMAP and ENSIGHT.
             The scanner output will be written to stdout.

   -visualize  <file1.ccvx> <...>
             Use this option visualize serveral CCVX files at once.
```

The MpCCI Visualizer is started with the FSI mapping plugin activated. The use of the MpCCI FSIMapper is described in ▷ X-4 MpCCI FSIMapper GUI ◁.

5.3.2 mpcci gui

```
Usage:
   mpcci gui [OPTIONS] [project] [OPTIONS]


Synopsis:
   'mpcci gui' is used to launch the MpCCI GUI.


Options:
   -chwd  <PATH>
                    Replace the symbolic working directory $(CWD) used inside the
                    project file by the absolute pathname specified in the <PATH>
                    argument.

   -help
                    This screen.

   -new
                    Start the GUI with a new project.

   -nolic
                    Do not check for a license before starting the GUI.
                    This option may be used when no license is available but you
                    would like to prepare a job.

   -norsa
                    Do neither check for ssh nor ask for ssh assistance if an rsa
                    key file does not exist.

   -useAbsolutePath
                    Use current local MpCCI installation path on remote access.

   -useConfiguration  <FILE>
                    Use the configuration in the specified file <FILE>.
                    The format corresponds to what the MpCCI Configurator predicts.
```

The MpCCI GUI is started with this command, i. e. the MpCCI GUI pops up, which is described in ▷ 4 Graphical User Interface ◁.

5.3.3 mpcci logviewer

```
Usage:
   mpcci logviewer [OPTIONS] [logfile]


Synopsis:
   'mpcci logviewer' is used to launch the MpCCI logfile viewer.


Options:
   -help    This screen.

   -pf      Read logfile type properties from file (json format).
            The default logfile is $MPCCI_HOME/gui/logviewerTypeProperties.json.

   -q       Be quiet and do not print any information message
            except warning or error messages.
```

The use of the MpCCI Logviewer is described in ▷ 6 MpCCI Logviewer ◁.

5.3.4 mpcci monitor

```
Usage:
   mpcci monitor [OPTIONS]


Synopsis:
   'mpcci monitor' is used to launch the MpCCI visualiser for MpCCI server
   monitoring.


Options:
   -connect  <port@host>
             The monitor connects to the MpCCI server port@host
             as a client of the MpCCI server. This option may be repeated for
             multiple connections to several servers.

   -help
             This screen.

   -jobname  <JOBNAME>
             Specify a job name displayed on the status line.

   -listen  [port]
             The monitor acts as a server and allows multiple
             client connections in parallel to monitor multiple
             MpCCI servers. The default port is 47002.

   -maxmem  <MB>
             Set the maximum memory used by the monitor.

   -modulo  <STEPS>
             Set the step modulus.

   -netdevice  <DEV|IP>
             Specify a network device or IP address.

   -np  <N>
             Define the number of cores to use (default=4).
```

The MpCCI Monitor is suitable for monitoring the coupled quantities during the simulation. You can connect to the coupled simulation with this command. MpCCI Monitor and MpCCI Visualizer are the same application and a description of the MpCCI Monitor is given in ▷ 7 MpCCI Visualizer ◁.

5.3.5 mpcci visualize

```
Usage:
   mpcci visualize [OPTIONS] [user@]host:]filename[nnnn][.ccvx]


Synopsis:
   'mpcci visualize' is used to launch the MpCCI .ccvx tracefile visualizer.

   A tracefile may be located on a remote host. The file name should
   then follow the general notation for remote file names, which is

      [user@]host:path/filename[nnnn][.ccvx]

   In this scenario you need to have a working MpCCI installation on
   the remote host!

   You may visualize a series of files (option -series) as long as the
   file name contains at least four digits within the name at
   any position, e.g.

      job-000011.ccvx
      job-000012.ccvx
      ......


Examples:
   Display a single file

      mpcci visualize name.ccvx
      mpcci visualize my-tracefiles/name

   Display a file located on a remote host

      mpcci visualize remotehost.network.com:/home/user/jobs/tracefiles/last.ccvx

   Display a series of files [job0000.ccvx job0001.ccvx ...]

      mpcci visualize -series tracefiles/job
      mpcci visualize -series remotehost.network.com:/home/user/jobs/tracefiles/job


Options:
   -dir      <PATH>    Define ccvx files directory to search.
   -help               This screen.
   -listen   <port>    Set the communication port number (default=47003).
   -maxmem   <MB>      Set the maximum memory used by the visualizer.
   -modulo   <STEPS>   Set the step modulus for time or coupling steps.
   -np       <N>       Define the number of cores to use (default=4).
   -series             Display a series of files.
   -skipstep <step>    Define how many steps should be skipped.
```

```
-skiptime <dt>      Define the time intervall which should be skipped.
```

The MpCCI Visualizer is suitable for quickly checking whether the coupling process was successful. The coupling region, orphaned nodes and exchanged quantities can be checked to ensure that a coupling has really occurred. A description of the MpCCI Visualizer is given in ▷ 7 MpCCI Visualizer ◁.

5.4 MpCCI Tools

The commands in this section are several helper applications to be used with MpCCI.

Subcommand	Short Description	Discussed in
`ccvxcat <port file ...>`	Catenate and/or send .ccvx files to the MpCCI visualizer.	▷ 5.4.1 mpcci ccvxcat ◁ on page 139
`configurator`	Use the MpCCI configurator	▷ 5.4.2 mpcci configurator ◁ on page 140
`cosimpre`	Use co-simulation pre-check tools	▷ 5.4.3 mpcci cosimpre ◁ on page 144
`morpher`	Launch the MpCCI grid morpher.	▷ 5.4.4 mpcci morpher ◁ on page 145
`observe`	Start the MpCCI file observer.	▷ 5.4.6 mpcci observe ◁ on page 149
`xterm`	Start a process inside an xterm.	▷ 5.4.7 mpcci xterm ◁ on page 150

5.4.1 mpcci ccvxcat

```
Usage:
   mpcci ccvxcat [OPTIONS] [user@]host:]filename[nnnn][.ccvx]


Synopsis:
   'mpcci ccvxcat' is used to catenate one or more .CCVX file and send them to
   the MpCCI visualizer.

   A ccvx tracefile may be located on a remote host. The file name should
   then follow the general notation for remote file names, which is

      [user@]host:path/filename[nnnn][.ccvx]

   In this scenario you need to have a working MpCCI installation on
   the remote host!

   You may catenate a series of files (default) as long as the file name contains
   at least four digits within the name at any position, e.g.

      job-000011.ccvx
      job-000012.ccvx
      ......


Options:
   -connect  <port@host>   Define the socket of the visualizer (default=47003).
   -help                   This screen.
   -jobname  <jobname>     Set the job name for the visualizer communication.
   -nopcheck               Do not check and warn about used port numbers.
   -replace  <old> <new>   Replace string "old" with "new" in part names.
   -single                 Load a single file.
   -skipstep <step>        Define how many steps should be skipped.
   -skiptime <dt>          Define the time intervall which should be skipped.
```

5.4.2 mpcci configurator

```
Usage:
   mpcci configurator [OPTIONS]


Synopsis:
   'mpcci configurator' is used to predict the optimal coupling configuration
   parameters.


Options:
   -help            This screen.
   -input  <file>   The input file for the configurator (required).
   -output <file>   The name of the output file where the predicted configuration
                    should be saved (default: mpcci_configurator_output.xml).
```

The MpCCI Configurator ist used by MpCCI to provide a smart configuration as described in ▷ 3.5 Smart Configuration ◁.

This MpCCI tool is used by MpCCI GUI to provide a smart coupling configuration.

The input file is written in XML. Its format is as follows:

```
<configurator>
   <predict type="FSI" trainedModel="/path/to/models" >
      <coupling scheme="Implicit..." />
      <domain_n codeName="string" model="$(CWD)/path/model"
                executable="/path/to/executable"
                units="string"
                solutionType="transient..."
                refDensity="float-string" refPressure="float-string"/>
   </predict>
</configurator>
```

configurator The root tag for the configurator input.

- **predict** Indicates an input configuration for the MpCCI Configurator.
  - **type** The coupling type of the simulation. Currently only FSI for fluid-structure interaction is supported by MpCCI Configurator.
  - **trainedModel** The path to the trained models which shall be used by the MpCCI Configurator for prediction. MpCCI provides models in `"$MPCCI_HOME/lib/configurator/models/"` which can be used.
- **coupling** Specifies certain coupling settings for which the best configuration is to be searched. It may be omitted to allow all possible coupling configurations.
  - **scheme** Presets the scheme to be used for prediction. Valid values are Explicit and Implicit.
- **domain_n** Specifies a domain involved in the coupling. The numbering corresponds to the domains in the Models step of the MpCCI GUI (▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Each domain involved in the coupling has to be listed. Currently only two-domain coupling is supported, so entries for domain_1 and domain_2 are expected.
  - **codeName** Name of the code set for this domain. Currently only Abaqus, FLUENT and OpenFOAM are supported.

model The full qualified path to the model file. The placeholder `$(CWD)` can be used to reference the current working directory.

executable The full qualified path to the executable of the code. This is only required and evaluated if the codeName is FLUENT.

solutionType The solution type for which the model is set up. Valid values are Transient and Steady state

units The units used in the model. Supported unit systems are SI, british, cgs, mm-t-s, us-ft-lbf-s, and us-in-lbf-s. The default value is SI.

refDensity Specifies a reference density to be used for prediction. It is only required and evaluated if the codeName is OpenFOAM.

refPressure Specifies a reference pressure to be used for prediction. It is only required and evaluated if the codeName is OpenFOAM.

The output file from the MpCCI Configurator is also written in XML format. It includes the predicted coupling specification that is automatically read by the MpCCI GUI and applied to a simulation project. This output can also be used as input for the MpCCI GUI (cf. ▷ 5.3.2 mpcci gui ◁). The format is as follows:

```
<configurator success="bool" message="string" >
   <cplSpec description="text" >
      <coupling scheme="..."
                algorithm="..." initParallelDomain="domain_n" leadingDomain="domain_n"
                stepSizeType="..." stepSize="float" minStepSize="float"
                maxCplIterationSteps="int"
                minCplSteps="int" maxCplSteps="int" totalTime="float"
                delayDomain="domain_n" delayUnit="..." delayValue="string" />
      <domain_n cplStepSize="int" cplStart="int|float" cplPostIter="int" />
      <quantity name="quantityName" domain="domain_n" >
         <operator name="operatorName" parameterName="..." />
      </quantity>
   </cplSpec>
</configurator>
```

configurator The root tag for the configurator output.

- **success** True if a coupling configuration has been predicted so that an cplSpec element exists, False otherwise.
- **message** A message with either the reason for the not succeeded prediction (in case `success="False"`) or with some additional information regarding the predicted coupling specification.
- **cplSpec** The element with the predicted coupling specification if the configuration succeeded.
  - **description** A short description of the predicted configuration (e. g. the used trained model).
  - **coupling** The element with the common basic coupling configuration.
    - **scheme** The coupling scheme to be used - Explicit or Implicit (optional).
    - **algorithm** The coupling algorithm to be used - Serial or Parallel.
    - **initParallelDomain** The initialzing domain for a parallel coupling algorithm (optional).
    - **leadingDomain** The leading domain in case of a serial algorithm.
    - **stepSizeType** Only for an implicit coupling scheme: Specifies the type of the coupling step size to be used. Valid values are Constant and Negotiation.
    - **stepSize** Only for an implicit coupling scheme with constant step size: Specifies the coupling step size in seconds.
    - **minStepSize** Only for an implicit coupling scheme with negotiated step size: Specifies the minimum step size in seconds.
    - **maxCplIterationSteps** Only for an implicit coupling scheme: Specifies the maximum number of coupling step iterations (optional).

minCplSteps Only when a steady state solution is involved: Specifies the minimum number of coupling steps for the coupling duration (optional).

maxCplSteps Only when a steady state solution is involved: Specifies the maximum number of coupling steps for the coupling duration (optional).

totalTime Only when a transient solution is involved: Specifies the total time in seconds for the coupling duration (optional).

delayDomain Only for domains with a steady state solution: Specifies the domain that performs a delayed exchange of its boundary conditions (optional).

delayUnit Only if a delayDomain is specified: specifies how the delay is defined: by a number of substeps or by a number of update attempts. Valid values are Number of substeps and Number of update tries.

delayValue Only if a delayDomain is specified: specifies the value for the delay in seconds. The delay type is automatically determined from the delayValue (constant or variable).

domain_n Specifies a domain involved in the coupling. The numbering corresponds to the domains in the Models step of the MpCCI GUI (▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Currently only two-domain coupling is supported, so entries for domain_1 and domain_2 are expected. The following attributes regard the coupling step size and the runtime for this domain (optional).

cplStepSize Specifies the number of steps / iterations that the solver performs per coupling step (optional).

cplStart Specifies the start of the coupling, if it should be at a later time than specified in the model file. It is the start-time in seconds for transient problems and the start-iteration number for stationary problems (optional).

cplPostIter Specifies the number of iterations after coupling for stationary problems (optional).

quantity Specifies the quantity to be sent.

name The name of the quantity as specified in the configuration file (`"gui.xcf"`).

domain The domain, sending this quantity (i. e. domain_1 or domain_2)

operator Operator to be applied to the quantity (optional).

name The name of the operator (see list below).

parameterName The name-value pairs of the parameters for the specified operator (see list of operators below).

Example for a convergence check operator with a tolerance value of 0.004:
`<operator name="ConvergenceCheck" maxitol="0.004" />`.

List of operators and their parameter names and values resp. value types. Please see ▷ 4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁ for a description of the operators and their parameters.

ConvergenceCheck

Parameter	*Name*	*Value (type)*
Tolerance value	maxitol	(float)

DisableConservation

No operator parameters

PostLimiter

Parameter	*Name*	*Value (type)*
Sequence number	rank	(integer)
Lower limit	min	(float)
Upper limit	max	(float)

PreLimiter

Parameter	*Name*	*Value (type)*
Lower limit	min	(float)
Upper limit	max	(float)

Relaxation

Parameter	*Name*	*Value (type)*
Relaxation method	relaxMethod	Fixed | Aitken | Quasi-Newton | Ramping
Relaxation factor	relaxFactor	(float)
Type of Anderson Mixing method	andersonMixType	LeastSquares | Standard | Inverse
Omega	omega	(float)
Number of reused levels	numLevels	(integer)
Initial factor	ramp0	(float)
Ramping delta	rampd	(float)
Check relaxation convergence	relaxCheck	true | false

Scale

Parameter	*Name*	*Value (type)*
Sequence number	rank	(integer)
Only first time step	onlyFirstTimeStep	true | false
Reference value	refScaleValue	(float)
Initial scale factor	initFactor	(float)
Final scale factor	finalFactor	(float)
Number of steps with the same scale factor	nConstFact	(integer)
Number of scale factor changes	nSubSteps	(integer)

5.4.3 mpcci cosimpre

```
Usage:
   mpcci cosimpre [-]OPTIONS


Synopsis:
   'mpcci cosimpre' is used to prepare the co-simulation coupled regions setup


Options:
   -clean              Clean the working directory from the ccvx files.
   -control    <xcc>   Run the neighborhood control.
   -help               This screen.
   -modelcheck <xcc>   Run the model check.
   -monitor            Activate online monitoring.
   -nbhsearch  <xcc>   Run the neighborhood search.
```

5.4.4 mpcci morpher

```
Usage:
   mpcci morpher [LAUNCH-OPTIONS] <model-name> [OPTIONS]


Synopsis:
   'mpcci morpher' is used to start a morpher daemon.


LAUNCH-OPTIONS:
   -help                     This screen.
   -lhost:[user@]hostname    Launch the morpher on the remote host.
   -lopts:filename           Read additional morpher options from 'filename'.

Relaunching

  "<Home>/work/mp-ce/bin/lnx4_x64/mpcci_morpher.exe"

with 'LD_LIBRARY_PATH'

   "<Home>/work/mp-ce/bin/lnx4_x64"
   "/scaihome/compeng/compiler/icc10.1/linux_em64t/lib"


Grid morpher daemon 3.1B, double precision
   Build Oct 29 2023, 03:19:52
   Copyright (c) 2004-2013, Fraunhofer SCAI.

   License checkout...
   Your license will expire in 63 days.


Usage:
  mpcci_morpher.exe model [OPTIONS]

Parameters [required]
  model             The grid morpher file name

Options: #d=decimal, #f=float, #s=string, #c=char

Optional job id
  -j         #s     Job id string

Options to control the deformation of edges
  -enocheck          Skip all edge checks
  -rlen[gth] #f #f   Min/max allowed relative length change of an edge
                        0.0 < Min length <= 0.9
                        1.0 < Max length < ?
  -alen[gth] #f #f   Min/max allowed absolute edge length

Options to control the deformation of faces
```

```
  -fnocheck          Skip all face checks
  -rar[ea]   #f #f   Min/max allowed relative change of face area
                        0.0 <  Min area <= 0.9
                        1.1 <= Max area < ?
  -aar[ea]   #f #f   Min/max allowed absolute face area
  -fas[pect]    #f   Max. allowed face aspect ratio [1..200]
  -fsk[ew]      #f   Max. allowed skewness of faces [0.1..0.99]

Options to control the deformation of cells
  -cnocheck          Skip all cell checks
  -rvol[ume] #f #f   Min/max allowed relative change of cell volume
                        0.0 < Min volume < 1.0
                        1.0 < Max volume < ?
  -avol[ume] #f #f   Min/max allowed absolute cell volume
  -cas[pect]    #f   Max. allowed cell aspect ratio [1..50]
  -csk[ew]      #f   Max. allowed skewness of cells [0.5..0.99]

Options to control the handling of boundaries
  -dbl[ayers]   #d   Deformed boundary layer level: [0...512]
  -fbl[ayers]   #d   Fixed boundary layer level: [0...512]
  -fixreg[ion]  #d   Add non default fixed boundary regions
                          #d is the region number
  -fltreg[ion]  #d   Add non default floating boundary regions
                          #d is the region number
  -corner       #f   Angle to make node floating along boundaries
                          #f [0.0...20.0] is the angle in degree
                          the angle should not be larger than 5.0 deg
  -project   ......  Analytical surface for sliding nodes
                     (contact support for options)
  -restrict  ......  Analytical surface for sliding nodes
                     (contact support for options)

Options to control the morpher and solver
  -solver gs|lgs|qgs Select a solver (qgs is default)
  -nthreads     #d   Sets the no. of OpenMP threads
  -once      #s #s   Morph only once: infile.vrt outfile.vrt
  -steps        #d   No. of steps for once morphing
  -diag[onal]        Take care for shear in quad faces
                     and hexahedral cells
  -miniter      #d   Min. no. of iterations: [0...?]
  -maxiter      #d   Max. no. of iterations: [0...?]
  -tol[erance]  #f   Convergence tolerance: ]0.0...0.5]
  -initlast          Init displacements from last step
  -residual          Display the solution residual (time consuming)
  -mrelax       #f   Morphing relaxation factor: ]0.0...2.0]
  -local             Avoid a global distribution of deformations
  -mina[ngle]   #f   Min. angle allowed in faces and cells
                          #f [5.0...30.0] is the angle in degrees

Options to control the smoother
  -smooth       #d   No. of smooth sweeps
  -srelax       #f   Smoothing relaxation factor: ]0.0...2.0]
```

```
Auxiliary options
  -listen       #d   Port number for socket communications
  -debug             Save a -morph.vrt file after morphing
  -h[elp]            This screen and exit
  -out[put]     #c   Information output level: [f|v|d|q]
                          f = full, verbose + displacements received
                          v = verbose
                          q = quiet
                          d = default between quiet and verbose
  -s[etup]           List setup and exit
  -csca[le]     #f   Scale vertices read by factor #f
  -dsca[le]     #f   Scale displacements by factor #f
  -wait         #d   Set waiting timeout in seconds, 0=never timeout
  -noparamcheck      Do not check the limits of any parameter
  -trace        #c   Save received vertices in a trace file
  -vis[ualize]       Visualize grid while morphing
```

5.4.5 mpcci netdevice

```
Usage:
   mpcci netdevice [-help] <interface>


Synopsis:
   'mpcci netdevice' is used to return the IP adress
   corresponding to the specified network interface.
   (under Windows it only returns the IP for the ethernet device.)
```

5.4.6 mpcci observe

```
Usage:
   mpcci observe [-help] file file file ....


Synopsis:
   'mpcci observe' is used to launch the file observer. The file observer
   waits until the file exists and then displays the tail of the
   file in a separate xterm. Just try the observer.
```

5.4.7 mpcci xterm

```
Usage:
   mpcci xterm [[xterm]OPTIONS] -cmd <cmd ...>


Synopsis:
   'mpcci xterm' is in fact a wrapper for the standard X11 xterm
   command which is used to run a command <cmd ...> inside
   a new window, the xterm.

   Unlike the X11 'xterm [OPTIONS] -e <commandline>' the
   xterm is launched as a background process and the xterm
   remains opened after the command exited.
   'mpcci xterm' is also available under MS Windows.

   The input stream to the <cmd ...> may be redirected and be
   read from the file -input <FILE>.

   In addition, if -log <FILE> is not empty or "-", a copy of
   the xterm output is logged into the file <FILE>.

   The command <cmd ...> may contain several arguments, therefore
   the item -cmd <cmd ...> must be the last one.


Options: (all options not listed below are passed to the xterm command):
   -cmd     <cmd ...>   Command to fire up.
   -display <DISPLAY>   Set DISPLAY before.
   -help                This screen.
   -home    <HOME>      Set the start directory to <HOME>.
   -input   <FILE>      Redirect stdin to <FILE>.
   -log     <FILE>      Redirect stdout via |tee <FILE>.
   -rev                 Use reverse colors.
   -title   <TITLE>     Define the title of the xterm.
```

5.5 Information and Environment

The commands in this section can be used to obtain information about MpCCI and the environment.

Subcommand	Short Description	Discussed in
`arch [-n]`	Print the MpCCI base architecture without a newline or with a newline `[-n]` at the end and exit. This is different from `mpcci info arch` which prints the used architecture.	▷ 5.5.1 mpcci arch ◁ on page 152
`doc`	View the MpCCI documentation.	▷ 5.5.2 mpcci doc ◁ on page 153
`env`	Print out the environment used by MpCCI in various formats for further processing.	▷ 5.5.4 mpcci env ◁ on page 156
`home [-n]`	Print the MpCCI home directory without a newline or with a newline `[-n]` at the end and exit. This is in fact a shortcut for `mpcci info home`.	▷ 5.5.5 mpcci home ◁ on page 157
`info`	Print general information about MpCCI.	▷ 5.5.3 mpcci info ◁ on page 154
`where <CMD>`	Find all locations of the executable `<CMD>` in the PATH.	▷ 5.5.6 mpcci where ◁ on page 158

5.5.1 mpcci arch

`mpcci arch` is simply a shortcut for `mpcci info arch`, see also ▷ 5.5.3 mpcci info ◁ on page 154.

`mpcci arch` prints the MpCCI architecture token of the platform on which it is run. A list of architecture tokens is given in the ▷ II-5 Supported Platforms in MpCCI 4.7 ◁.

5.5.2 mpcci doc

This command can be used to view MpCCI documentation, the available documentation can be listed with the option `-list`. The documentation is located in the "<*MpCCI_home*>`/doc`" directory and can be accessed directly as well.

Currently two kinds of documentation are available:

`mpcci doc LicenseAdministration` The FlexNet Publisher License Administration

`mpcci doc MpCCIdoc` The MpCCI documentation.

5.5.3 mpcci info

The `mpcci info` command is used to obtain information on the environment that is used by MpCCI:

```
Usage:
   mpcci info [-]OPTIONS


Synopsis:
   'mpcci info' is used to print single tokens to 'stdout' for
   the further use in scripts or .bat files...


Options:
   -arch       MpCCI basic architecture token.
   -arch32     MpCCI 32 bit architecture token.
   -arch64     MpCCI 64 bit architecture token.
   -build      Build date of the installed MpCCI release.
   -help       This screen.
   -home       MpCCI home path.
   -java       Java command used by MpCCI.
   -javaver    Java version of the java command.
   -jobid      Jobid used by MpCCI.
   -liba32     Pathname of the 32 bit libmpcci.a (if available).
   -liba64     Pathname of the 64 bit libmpcci.a (if available).
   -libdl32    Pathname of the 32 bit libmpcci.so (if available).
   -libdl64    Pathname of the 64 bit libmpcci.so (if available).
   -make       Make command used by MpCCI.
   -patches    Patchlevel of the installed MpCCI release.
   -perl       Pathname of the perl command used by MpCCI.
   -perlinc    @INC list used by Perl.
   -perlver    Version of the running Perl.
   -release    Full MpCCI release token.
   -remcp      Pathname of remote copy command used by MpCCI.
   -remsh      Pathname of remote shell command used by MpCCI.
   -rshtype    MpCCI server remote shell type used.
   -userid     Userid used by MpCCI.
   -version    X.Y version number of the installed MpCCI release.
```

The options `-arch`, `-arch32` and `-arch64` list the architecture token of the machine. This token is used to distinguish between different hardware and operating systems. MpCCI has its own tokens for identification, which may differ from those used by the coupled codes. A list of the architecture tokens is given in the ▷ II-5 Supported Platforms in MpCCI 4.7 ◁.

Information on the releases and version number of MpCCI are obtained with `-build`, `-release` and `-version`.

The option `-userid` prints the user which is running MpCCI, i. e. your current user name. This can be useful to check user names on remote machines.

The job id can be obtained with `-jobid`, it is composed of the user name and a time-dependent value, thus changes with every call of MpCCI, but is kept during one run.

MpCCI uses external software installed on your system. Sometimes several versions are installed, thus it is important to know which was found by MpCCI:

Java is needed for the MpCCI GUI (see ▷ 4 Graphical User Interface ◁), the full path to the Java executable is obtained with `-java`, the version of java which was found is obtained with `-javaver`.

Perl The path to the Perl executable is obtained with `-perl`, the version with `-perlver`, and `-perlinc` lists the `@INC` of Perl, which is a list of directories, which is searched for Perl modules. See also ▷ III-9 Installing Perl ◁.

rsh `-rsh` gives the path to the remote shell rsh. There are two types of remote shells rsh and ssh. The type which is currently used by MpCCI is shown by `-rshtype`. The remote shell can be changed by setting the `MPCCI_RSHTYPE` to either type. See ▷ 2.6.3 Remote Shell and Remote Copy ◁ for more information on remote shells.

rcp Gives the path to the rcp command, see also ▷ 2.6.3 Remote Shell and Remote Copy ◁.

5.5.4 mpcci env

`mpcci env` is a lookup-function for environment variables. Its sole purpose is to print a list of all environment variables, which are relevant for MpCCI. More information on these environment variables is given in ▷ 2.3 Environment and Environment Variables ◁. This command is useful for debugging.

The list can be formatted in various formats for use in shell scripts.

```
Usage:
   mpcci env [ [-]FORMAT | environment variable ]


Synopsis:
   The MpCCI environment is set up at runtime and contains
   all informations about your system required by MpCCI.

   'mpcci env' is used to print out the MpCCI environment
   in various formats for the further processing in shell
   scripts or in a MS Windows batch file.

   'mpcci env' is used internally by MpCCI to fetch information
   about the MpCCI configurations on remote hosts.


Examples:
   To save the MpCCI environment in a file which may
   be sent for support reasons type

      "mpcci env pretty > mpcci_env.txt"


Supported formats:
   -bash      UNIX bash format
   -bat       MS-DOS .BAT format
   -csh       UNIX csh format
   -help      this screen
   -java      Java properties format
   -ksh       UNIX ksh format
   -perl      Perl expression format
   -plain     plain format
   -pretty    human readable format (default)
   -sh        UNIX sh format
   -tcsh      UNIX tcsh format
   -xml       XML similar format
```

5.5.5 mpcci home

Prints the full path of the MpCCI home directory. All files which belong to the MpCCI distribution are located in this directory. With

```
mpcci home
```

the path is given without a trailing newline character, whereas

```
mpcci home -n
```

yields the same path followed by a newline character.

The path to the MpCCI home directory is stored in the environment variable `MPCCI_HOME` during a run of MpCCI.

5.5.6 mpcci where

```
Usage:
   mpcci where [-help] command ...


Synopsis:
   'mpcci where' is used to list all commands found by investigating
   the "PATH" environment variable.

   This is useful to find out whether MpCCI catches the correct
   executable file from the "PATH". Sometimes the "PATH" should
   be reordered to help MpCCI find the command really needed.

   For some important commands MpCCI has build in alternative
   methods to find the correct executable. In this case the result
   of where does not show the executable selected by MpCCI.


Examples:
   To find the location of the mpcci command please type

      "mpcci where mpcci"
```

5.6 Installation and Licensing

The commands in this section are needed to check the validity of an installation, also including license information.

Subcommand	Short Description	Discussed in
`license`	Manage the license server and print license related information.	▷5.6.1 mpcci license◁ on page 160
`list`	List information about the MpCCI installation and the supported codes.	▷5.6.2 mpcci list◁ on page 161
`lmutil`	Run the FLEXnet `lmutil [OPTIONS]` command delivered with MpCCI. Avoid running the lmutil command installed by codes other than MpCCI.	▷5.6.3 mpcci lmutil◁ on page 162
`ssh`	Check/fix your ssh installation.	▷5.6.4 mpcci ssh◁ on page 163
`test`	Run some install/communication tests.	▷5.6.5 mpcci test◁ on page 164

5.6.1 mpcci license

```
Usage:
   mpcci license [-pN] [-tT] [-]OPTION ...


Synopsis:
   'mpcci license' is used to manage the MpCCI licenses and to
   display detailed license information.


Options:
   -all        List all features of all available licenses.
   -avail      Brief display the no. of MpCCI sessions and processes available.
   -check      Check compatibility of the FLEXlm client and server license version.
   -clean      Remove all local MpCCI license logfiles.
   -expire     Display the expiration date of the MpCCI license.
   -files      List all local license files defined.
   -help       This screen.
   -info       Print MpCCI related summary.
   -local      MpCCI feature overview for licenses on the local host.
   -log        Display the MpCCI related license logfiles.
   -mpcci      MpCCI feature overview for all hosts in a network.
   -pN         Redefines the port number N used with the SVD
               license server.
               The current port for SVD is "-p47000".
               If used this option must be the first on the commandline.
   -restart    Restart the SVD license server on the local host.
   -servers    List all defined license servers "[port]@host".
   -start      Start the SVD license server on the local host.
   -stop       Stop the SVD license server running on the local host.
   -sysid      MpCCI system ID used for generating a license file.
   -tT         Set license request timeout to T seconds.
               If used this option must be the first/second on the
               commandline.
   -vars       List the relevant environment variables *_LICENSE_FILE.
   -version    Show FLEXlm version of MpCCI installation.
```

5.6.2 mpcci list

```
Usage:
   mpcci list [-]OPTIONS


Synopsis:
   'mpcci list' is used to list information about the
   MpCCI installation.


Options:
   -archs           List all installed MpCCI architectures.
   -batchsystems    List all installed batch systems.
   -codes [all]     List installed simulation codes with valid adapter license.
                    [all] Evaluate installed simulation codes and MpCCI code module.
   -help            This screen.
   -hosts           List default hostlist entries.
   -jobs            List all submitted batch jobs.
   -writers         List all available MpCCI trace file writers.
```

5.6.3 mpcci lmutil

```
lmutil - Copyright (c) 1989-2020 Flexera. All Rights Reserved.
usage:         lmutil lmborrow | lmborrowl -status
        lmutil lmborrow | lmborrowl -purge
        lmutil lmborrow | lmborrowl -purge -status
        lmutil lmborrow | lmborrowl -clear
        lmutil lmborrow | lmborrowl {all|vendor} dd-mmm-yyyy:[time]
        lmutil lmborrow -return [-c licfile] [-d display_name]  [-u username] [-h hostname] [
-fqdn] [-vendor name] feature [-bv version]
        lmutil lmborrowl -return [-c licfile] [-d display_name]  [-u username] [-h hostname]
[-fqdn] [-vendor name] feature
        lmutil lmdiag [-c licfile] [-n]
        lmutil lmdown [-c licfile] [-q] [-all] [-vendor name] [-force] [-help]
        lmutil lmhostid [-ptype (PHY|AMZN|VM)] [-ether|-internet (v4|v6)|-user|-n|
                   -display|-hostname|-hostdomain|-string|-long|-uuid
                   -eip|-ami|-iid|-genid|-flexid]
        lmutil lminstall [-i infile] [-o outfile]
                 [-overfmt {2, 3, 4, 5, 5.1, 6, 7.1, 8}]
                 [-odecimal] [-maxlen n]
        lmutil lmnewlog [-c licfile] vendor new-file [-secondary], or
        lmutil lmnewlog [-c licfile] feature new-file [-secondary]
        lmutil lmpath -status
        lmutil lmpath -override {all | vendor } path
        lmutil lmpath -add {all | vendor } path
        lmutil lmremove [-c licfile] feature user host display
        lmutil lmremove [-c licfile] -h feature host port handle
        lmutil lmremove [-c licfile] [-tsborrow <client_host>] | [-tsborrowstat]
        lmutil lmreread [-c licfile] [-vendor name] [-all]
        lmutil lmswitchr [-c licfile] vendor new-file, or
        lmutil lmswitchr [-c licfile] feature new-file
        lmutil lmstat [-c licfile] [lmstat-args]
        lmutil lmswitch [-c licfile] vendor new-file [-rollover]
        lmutil lmver { flexlm_binary | -fnls }
        lmutil lmvminfo [-long]
        lmutil lmtpminfo [-long]
        lmutil lmlicvalidator [-licfile license_file] [-licserv port@host]
        lmutil -help (prints this message)
        lmutil utility_name -help  (display detailed usage information)
```

5.6.4 mpcci ssh

```
Usage:
   mpcci ssh [-]OPTIONS


Synopsis:
   'mpcci ssh' is used to check/update the secure shell (ssh) installation
   and settings. Some ssh settings should be done to avoid password
   requests for each MpCCI process launched on the local or remote
   hosts when using the secure shell (ssh/scp) set of commands for
   remote shell and remote file copy.

   If you prefer to use the classic rsh/rcp set of commands please
   make sure that in your remote hosts file

      "<Home>/.rhosts"

   the local and all the remote hosts used by MpCCI are listed.


Options:
   -all       Run all the checks below.
   -env       Update the MpCCI environment variables in the ssh login
              environment file.
   -help      This screen.
   -keygen    Check/generate an ssh key for the local host to avoid
              password requests.
   -mode      Test the ssh daemon configuration for "StrictModes".
```

5.6.5 mpcci test

```
Usage:
   mpcci test [OPTIONS] hostname ... hostlist ... hostfile ... [-simple]


Synopsis:
   'mpcci test' is used to perform various tests:
   - MpCCI local and remote installation
   - Remote host connections
   - Perl environment
   - etc.

   The remote hostnames may be specified in various formats.
      hostname: [user@]host
      hostlist: [user@]host[:[user@]host[:...]]...
      hostfile: filename with hostnames (like .rhosts)

   For each host ...
   - test whether the hostname is resolved by the DNS.
   - test whether the host is alive and reachable.
   - test possibility of rsh/ssh connections to the remote host.
   - brief test on MpCCI installation on the remote host from the local host
   - test server-client connection on ports 47111 ++
   - write a protocol hostfile "mpcci.hostlist" which can be used as
     an MpCCI hostfile.


Examples:
   Run a simple testcase delivered with the MpCCI installation:

      on the local host:  mpcci test -simple
      on various hosts :  mpcci test testhost mpcci@server.com -simple

   Test the MpCCI access and communication with remote systems:

      mpcci test [OPTIONS] [ [user@]host[:[user@]host[:...]]] | hostfile ... ]
      mpcci test fred@flintstone.family:wilma@flintstone.family
      mpcci test fred@trex.farm  bmw@stone-cars.manufactory
      mpcci test flintstone.hostlist  aquarium whale@waterworld.future:shark@zoo
      mpcci test ~/.rhosts  ~/.shosts  brontosaurus@jurassic-park.vision


Options:
   -connect <port@hostname>

      INTERNAL USE ONLY: for remote communication test.


   -help

      This screen.
```

```
-known

   Test if each host is already known to ssh.


-listen <port>

   INTERNAL USE ONLY: for remote communication test.


-modload

   Load/compile all eventually MpCCI used Perl modules for a
   validation and exit. This test may help while you are
   integrating your code into MpCCI or to figure out if some
   common Perl modules are not installed on your system.


-port <port>

   Set the client/server communication port no.
   (default=47111).


-remote <hostname>

   For cases with VPN connections, IPSEC tunneling,
   and NAT translation:
   <hostname> is the name or dotaddress of the local
   host seen from the remote hosts. Redefine the local
   hostname if necessary.
   e.g.  -rem 192.168.2.16
   or    -rem myvpnhost.company.com


-rsh

   Test only rsh type connections.


-simple

   Run a simple testcase delivered with MpCCI.
   -simple must be the last option of the commandline.


-ssh

   Test only ssh type connections.
```

```
-wait

   Wait after each error or warning.
```

5.7 Job Control

During a coupled analysis it is often necessary to keep control of the different jobs which are started. The commands in this section help with starting, controlling and interrupting calculations.

Subcommand	Short Description	Discussed in
`backup <file ...>`	Make a backup copy of a list of files.	▷5.7.1 mpcci backup◁ on page 168
`batch <project>`	Start an MpCCI batch job with project file `<project>`.	▷5.7.2 mpcci batch◁ on page 169
`clean`	Remove all files from the temporary MpCCI directory *<Home>*`/.mpcci/tmp`.	▷5.7.7 mpcci clean◁ on page 176
`kill`	Platform independent process kill based on command line pattern matching.	▷5.7.8 mpcci kill◁ on page 177
`ps`	Unix `ps -ef` compatible ps for all platforms.	▷5.7.9 mpcci ps◁ on page 179
`ptoj`	Convert an MpCCI project file into an MpCCI job properties file.	▷5.7.10 mpcci ptoj◁ on page 180
`server`	Start the MpCCI server.	▷5.7.11 mpcci server◁ on page 181
`top`	Display process top list / Launch the taskmanager.	▷5.7.12 mpcci top◁ on page 185

5.7.1 mpcci backup

```
Usage:
   mpcci backup file [file file  ...]


Synopsis:
   'mpcci backup' is used to copy one or more files into
   backup files adding an additional free suffix ".bakNNN".
   This is a system independent backup copy command.


Examples:
   mpcci backup path/to/file.ext  =>  path/to/file.ext.bak000
```

5.7.2 mpcci batch

In the usage output you can see if a queuing system has been detected by MpCCI. To access the specific queuing system command help, execute `MpCCI batch <Batch Name>`.

By specifying the queuing system as the batch name to the `mpcci batch` command, MpCCI provides a way to interact directly with the batch system using the suboptions: submit, kill, status. In addition to the batch system control commands, you are able to set additional options to modify the settings of the codes (see ▷ 3.7.1.1 Run a Job in Batch Mode with MpCCI Command Line ◁).

```
Usage:
   mpcci batch [OPTIONS] <projectname>
   mpcci batch [OPTIONS] SGE ...
   mpcci batch [OPTIONS] TORQUE ...
   mpcci batch [OPTIONS] OPENPBS ...
   mpcci batch [OPTIONS] SLURM ...
   mpcci batch [OPTIONS] LSF ...
   mpcci batch [OPTIONS] PBS ...
   mpcci batch [OPTIONS] PBSPRO ...


Synopsis:
   'mpcci batch' is used to start an MpCCI job in batch mode.
   'mpcci batch SGE' is used to control a SGE batch job.
   'mpcci batch TORQUE' is used to control a TORQUE batch job.
   'mpcci batch OPENPBS' is used to control a OPENPBS batch job.
   'mpcci batch SLURM' is used to control a SLURM batch job.
   'mpcci batch LSF' is used to control a LSF batch job.
   'mpcci batch PBS' is used to control a PBS batch job.
   'mpcci batch PBSPRO' is used to control a PBSPRO batch job.


Options:
   -checkonly
                    Create the project file used for the batch job and exit. A new
                    batch system compatible project file will only be created when
                    running under a batch queuing system.
                    (Deprecated option, use option prepare)

   -chwd  <PATH>
                    Replace the symbolic $(CWD) working directory used inside the
                    project file by the absolute pathname specified in the <PATH>
                    argument.

   -help
                    This screen.

   -listen  <N>
                    Specifies an alternative TCP/IP port number <N> for the
                    communication between the MpCCI server and the clients.
                    The default port number is 47010.

   -mpmode  <codeA:mode> <codeB:mode>
```

```
                    Set the parallel method "mode" for each code with the
                    following option:
                    - "none": run code on one cpu
                    - "smp": activate shared memory parallel mode
                    - "dmp": activate distributed memory parallel mode.

   -nocontrol
                    Start the MpCCI batch job without termination process management.

   -nolic
                    Do not check for a license before starting the batch job.

   -norsa
                    Do neither check for ssh nor ask for ssh assistance if an rsa
                    key file does not exist.

   -np  <codeA:N> <codeB:M>
                    Bind each code to the specified total number of cores.

   -precheck
                    Start MpCCI in pre-check mode only. The simulation codes will send

                    their meshes for a neighborhood calculation and exit.
                    The results of the check are stored in server log file.

   -prepare
                    Create the project file used for the batch job and exit. A new
                    batch system compatible project file will only be created when
                    running under a batch queuing system.

   -set
                    section:p=v[,p1=v1,p2.p3=v3]
                    Modify the property value of a section before submitting the job i
n batch.
                    The section is either the reserved key "server", "settings"
                    or the code Id of the code.
                    The property name respects from the project csp file the following
 rules:
                    - the property name matches the key string
                      (<param name="property"...) if it is unique.
                      Otherwise provide a dot separated path to the property, e.g.
                      <group name="CCVX"><param name="Use".../> will use
                      this property "ccvx.use".
                    - the value to modify should respect the defined type.
                    - the list of properties of a section is comma separated.
                    - a whitespace is used to separate the section list.

   -useAbsolutePath
                    Use current local MpCCI installation path on remote access.

   -useConfiguration  <File>
                    Use the configuration in the specified file <FILE>.
```

```
                The format corresponds to what the MpCCI Configurator predicts.

lsf
                LSF batch system control.

openpbs
                OPENPBS batch system control.

pbs
                PBS batch system control.

pbspro
                PBSPRO batch system control.

sge
                SGE batch system control.

slurm
                SLURM batch system control.

torque
                TORQUE batch system control.
```

See ▷ 3.7 Coupled Analysis in Batch Mode ◁ for details.

5.7.3 mpcci batch LSF

```
Usage:
   mpcci batch LSF submit [BATCH-OPTIONS] <projectname>
   mpcci batch LSF status <jobid>
   mpcci batch LSF kill <jobid>


Synopsis:
   'mpcci batch LSF' is used to manage an MpCCI job running under LSF.


Batch commands:
   -help                                  This screen.

   kill   <jobid>                         Kill a LSF batch job.

   status <jobid>                         Display a LSF batch job status.

   submit [BATCH-OPTIONS] <projectname>   Submit a LSF MpCCI job.
```

See ▷ 3.7 Coupled Analysis in Batch Mode ◁ for details.

5.7.4 mpcci batch PBS

The following PBS family queuing systems are available and supported by MpCCI:

- PBS
- OpenPBS
- PBSPro
- Torque

```
Usage:
   mpcci batch PBS submit [BATCH-OPTIONS] <projectname>
   mpcci batch PBS status <jobid>
   mpcci batch PBS kill <jobid>


Synopsis:
   'mpcci batch PBS' is used to manage an MpCCI job running under PBS.


Batch commands:
   -help                                  This screen.

   kill   <jobid>                         Kill a PBS batch job.

   status <jobid>                         Display a PBS batch job status.

   submit [BATCH-OPTIONS] <projectname>   Submit a PBS MpCCI job.
```

See ▷ 3.7 Coupled Analysis in Batch Mode ◁ for details.

5.7.5 mpcci batch SGE

The following Sun Grid Engine family queuing systems are available and supported by MpCCI:

- SGE
- N1GE
- SGEEE

```
Usage:
   mpcci batch SGE submit [BATCH-OPTIONS] <projectname>
   mpcci batch SGE status <jobid>
   mpcci batch SGE kill <jobid>


Synopsis:
   'mpcci batch SGE' is used to manage an MpCCI job running under SGE.


Batch commands:
   -help                                  This screen.

   kill   <jobid>                         Kill a SGE batch job.

   status <jobid>                         Display a SGE batch job status.

   submit [BATCH-OPTIONS] <projectname>   Submit a SGE MpCCI job.
```

See ▷ 3.7 Coupled Analysis in Batch Mode ◁ for details.

5.7.6 mpcci batch SLURM

```
Usage:
   mpcci batch SLURM submit [BATCH-OPTIONS] <projectname>
   mpcci batch SLURM status <jobid>
   mpcci batch SLURM kill <jobid>


Synopsis:
   'mpcci batch SLURM' is used to manage an MpCCI job running under SLURM.


Batch commands:
   -help                                  This screen.

   kill   <jobid>                         Kill a SLURM batch job.

   status <jobid>                         Display a SLURM batch job status.

   submit [BATCH-OPTIONS] <projectname>   Submit a SLURM MpCCI job.
```

See ▷ 3.7 Coupled Analysis in Batch Mode ◁ for details.

5.7.7 mpcci clean

```
Usage:
   mpcci clean


Synopsis:
   'mpcci clean' is used to remove ALL files from the
   temporary MpCCI directory which is currently

   "<Home>/.mpcci/tmp".


Options:
   -dir  <directory>   Remove ALL files and directories under the provided directory n
ame.

   -help               This screen.
```

5.7.8 mpcci kill

```
Usage:
   mpcci kill [OPTIONS] <pattern1> <pattern2> ...


Synopsis:
   'mpcci kill' is used to kill processes whose commandline matches
   a character pattern. The commandline is read via the "ps -ef"
   command which is also available under Microsoft Windows.

   The <patterns> are strings of printable characters, e.g. a piece
   of the name or an option of a running program. If the <pattern> is
   a decimal number it will be assumed that this number is a true
   process id (PID) and not a command line pattern.

   The options -i, -v and -q (see below) are mutually exclusive. The
   the last option on the commandline overwrites the others.

   'mpcci kill' is self protecting in case of pattern matching:
   You may kill your whole family (childs, brother, sisters, aunts and
   uncles), but never yourself and your parents and grandparents ...

   'mpcci kill' is also used internally by MpCCI to kill a group of
   MpCCI processes on the local or remote hosts.


Examples:
   Kill all MpCCI related processes: "mpcci kill mpcci_"
   Kill process with PID 1234:       "mpcci kill 1234"


Options:
   -f    <prefix>   Special definition of process ids.
                    Collects all files with name

                       "<prefix>.<PID>"

                    where <PID> is a number and is interpreted
                    as a  process id. The files "<prefix>.<PID>"
                    are deleted afterwards. Typically, they are
                    only indicator files of size 0 which were
                    created by 'touch'. Their only purpose is
                    the definition of PID's via their suffix.

   -help            This screen.

   -i               Interactive confirmation (default):
                    Individually confirm each process found.

   -q               Quiet kill, no confirmation and no printout.
```

```
-r              Recursively kill all processes specified via
                PID or pattern AND all their descendants
                (children, grandchildren, ...).

-s    <SIG>     Send signal <SIG> to the processes instead of
                killing them with signal 9 (KILL).

-v              Verbose printout, no confirmation:
                Print a list of process ids before killing them.
```

5.7.9 mpcci ps

```
Usage:
   mpcci ps [PATTERNS]


Synopsis:
   'mpcci ps' is a platform independent Unix style

      "ps -ef [|grep PATTERN]"

   'mpcci ps' is also available under MS Windows!


Examples:
   List all processes, run ps -ef:        "mpcci ps"
   List all MpCCI related processes:      "mpcci ps mpcci"
   List all processes under your account: "mpcci ps scai-cae"


Options:
   -help    This screen.
```

5.7.10 mpcci ptoj

```
Usage:
   mpcci ptoj [OPTIONS] <file> <file> ...


Synopsis:
   'mpcci ptoj' is used to convert an MpCCI .csp project
   file into an MpCCI .prop job properties file.


Options:
   -help    This screen.
```

5.7.11 mpcci server

```
Usage:
   mpcci server [OPTIONS]  jobfile|projectfile


Synopsis:
   'mpcci server' is used to start the MpCCI broker and/or server
   processes on the local host or as an alternative distributed
   on multiple hosts in a network.


Options:
   -cleantrace

      Delete all tracefile folders based on the job name prefix of the
      current job directory.


   -help

      Prints this screen only and exits.


   -host <hostname>

      Launch the server on a remote host. The <hostname> may be given as

         [user@]host


   -hostalias <hostname>

      For cases with VPN connections, IPSEC tunneling and NAT translation.
      <hostname> is the name or dotaddress of the local host seen from the
      remote hosts.


   -jobdir <jobdir>

      Specify a path to save the trace files for visualization.


   -jobid <jobid>

      Specifies the job ID name to use.


   -jobname <jobname>

      Specify a general name prefix for all non temporary MpCCI generated
      output files. The default <jobname> is "mpccirun".
```

```
-killscript <user@host> <jobid> <pid> <jobdir>

   Create a mpcci kill script.


-listen <N>

   Suggest an alternative listening port number <N> for the
   communication between the MpCCI server and the clients.

   The default port no. is 47010.


-monitor <port@host>

   Suggest an alternative listening port@host for the monitor
   in case the monitor is automatically launched by the server.
   The default is 47002@localhost.


-nbuf <N>

   Specifies the number of quantity buffers used by the server.


-netdevice <interface>

   Set device interface name to use for the client server communication.


-noportcheck

   Do not check the provided listening port number.


-out <N>

   Specifies the message output level (0=quiet ... 3=debug).


-remotefs <username@host>

   Indicates the name of the machine where the process as been started


-remotejobfile <user@host> <remoteJobFile> <jobdir> <-[ssh|rsh]

   >Get the MpCCI jobfile from remote.
```

```
-rsh

   Use the (rsh/rcp) set of commands instead of the secure shell.
   The current default setting is defined by the environment variable

      MPCCI_RSHTYPE


-ssh

   Use the secure shell set of commands (ssh,scp) instead of the
   standard settings (rsh,rcp).
   The current default setting is defined by the environment variable

      MPCCI_RSHTYPE


-tmpdir <dir>

   Dependent on the platform MpCCI creates small temporary files (shell
   scripts or .BAT files with few lines only) and logging output.

   The default -tmpdir is defined by the environment variable

      MPCCI_TMPDIR=<Home>/.mpcci/tmp

   and should be located on your local system.

   With -tmpdir you specify an alternative directory for temporary files.


-useAbsolutePath

   Use current local MpCCI installation path on remote access.


-xterm

   Run the server process in a separate X11 xterm.


-xtermbg <color>

   Set xterm background color, e.g. "-xtermbg blue".


-xtermfg <color>

   Set xterm foreground(text) color, e.g. "-xtermfg green".


-xtermopt <opt>
```

```
Add additional X11 xterm options <opt>, e.g.

   "-geometry WxH -132".

Please use only X11 xterm options valid for the local xterm
command.

Microsoft Windows with local MpCCI/xterm emulation:
   All X11 xterm options may also be used since the MpCCI/xterm
   emulation simply ignores any unsupported option.
```

5.7.12 mpcci top

```
Usage:
   mpcci top


Synopsis:
   "mpcci top" displays the process list:

   If it is available the Unix 'top' command is launched in a separate xterm.
   On Windows systems the taskmanager may be launched if 'top' is not available.


Options:
   -help    This screen.
```

6 MpCCI Logviewer

The MpCCI Logviewer is a tool to inspect the logfiles written by MpCCI.

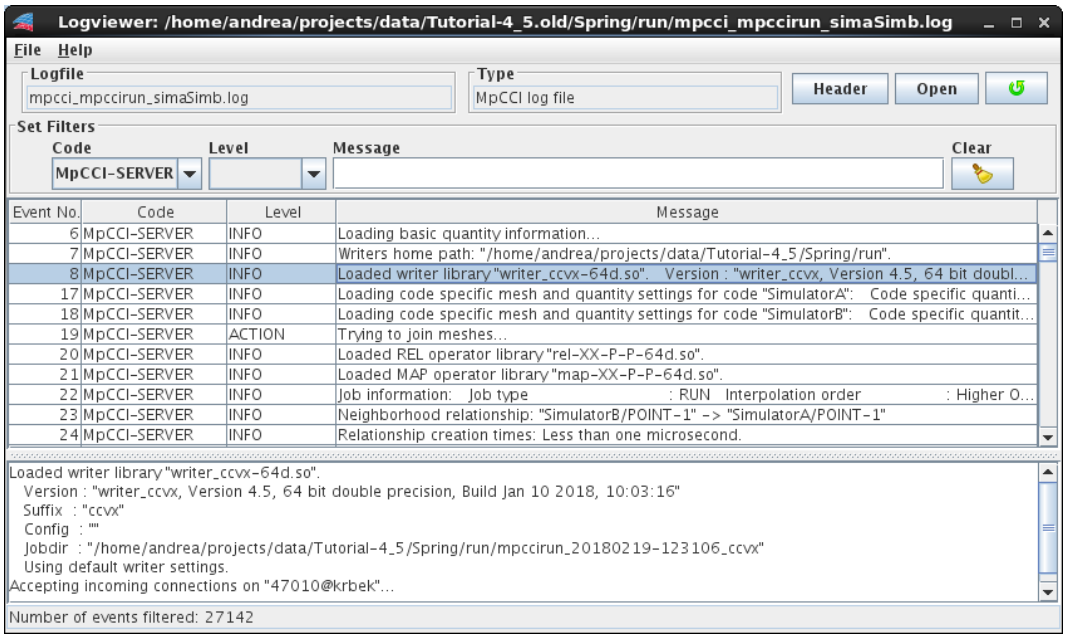


Figure 1: MpCCI Logviewer

As shown in Figure 1 it shows MpCCI logfiles in a table view with numbered chronological events that can be sorted and filtered. Filters can be set for codes, levels and messages. The whole message for a selected entry is shown in the area below the table. The header of the logfile - which is everything from the beginning of the file up to the first code entry - can be shown over the Header button. At the bottom of the window a status bar displays short information messages.

6.1 Starting the MpCCI Logviewer

The MpCCI Logviewer can be started from the MpCCI GUI menu by selecting Tools→Logviewer as well as from the command line with

```
mpcci logviewer [<logfile>]
```

where the name of a logfile can optionally be given.

The command `mpcci logviewer -help` shows up a short help text. See ▷ 5.3.3 mpcci logviewer ◁ for a detailed command description.

6.2 Description

6.2.1 Menus

The menu bar offers the File and Help menus.

File→Open Shows a file chooser for opening an MpCCI logfile which usually ends with `".log"`.

File→Refresh Reloads the currently displayed logfile.

File→Show Header Shows the header of the MpCCI logfile. The header is everything from the beginning of the file up to the first start of an event message.

File→Exit Exits the MpCCI logviewer.

Help→About Shows some information about the MpCCI Logviewer like version number and a short description.

6.2.2 Information

Logfile Displays the name of the loaded logfile.

Type Displays the type of the loaded logfile.

6.2.3 Buttons

Header The same as File→Show Header but if no header data is available the button is disabled.

Open The same as File→Open.

 The same as File→Refresh.

6.2.4 Filters

With the filters you can reduce the information shown in the logfile table and so focus on special entries. Choosing the empty entry removes each filter.

Code Select a code whose entries are to be shown as the only ones in the table. Additionally to the simulation codes used in the coupled simulation the MpCCI-SERVER code and MpCCI License process are also listed here.

Level The entries are marked with a level which is influenced by the output level (see ▷ 4.10.4 Output ◁). Only the levels found in the logfile are listed here. The known levels are:

INFO General information messages mostly sent from MpCCI and printed in output level 1. They regard license information, job settings, quantity mappings and the like.

ACTION More detailed messages regarding the coupling process. They are sent from MpCCI as well as the code adapters typically in output level 2.

DEBUG Detailed debugging messages printed in output level 3 only.

WARNING Warning messages which may worth observing. They are independent of the set output level.

ERROR Error messages which will be printed whatever output level is set.

UNKNOWN Messages with unknown level.

Message This filter looks for the specified string in the messages, highlights it, and only displays the lines that match the input. The input is used as a string that contains all spaces, including those at the beginning and end. Multiple patterns are not supported.

Clear The  button clears all filters so that all logfile entries are shown.

6.2.5 Table with Message Area

The center of the logviewer is occupied by a table holding the event messages sent by the codes and a message area.

6.2.5.1 Table

The table holds all event messages read out of the logfile and displays it in several columns:

Event No. Shows the number of the event messages which are numbered chronological by their appearance in the logfile.

Code Shows the name of the code which sent the event.

Level Shows the level of the message event. See ▷ 6.2.4 Filters ◁ for a detailed level description.

Message Shows the beginning of the event message. Messages which are too long for being displayed in the table cell are marked by ... at the end. The whole message is displayed in the message area below this table by selecting the event in this table.

Each column can be sorted by clicking on its header where the event number column will be sorted numerically the other columns alphabetically. Clicking several times on the header toggles the sort order between ascending and descending.

6.2.5.2 Message Area

The event messages may take several lines where only the beginning is shown in the table. Select a row in the table and the whole message is displayed in the message area. If a message filter is set, the matching strings are highlighted.

6.2.6 Status Line

The status line prints short information about the just opened file, the number of currently filtered events and so on.

6.3 Supported Logfile Types

As mentioned before the MpCCI Logviewer is a tool that was developed to inspect the logfiles written by MpCCI. Because running a coupled simulation produces several logfiles written by various codes it might be useful to inspect these files, too. Therefor the MpCCI Logviewer has been enhanced to be configurable for other logfile types. The configuration is done by a properties file in JSON (JavaScript Object Notation) format.

The properties file used as default is `"$MPCCI_HOME/gui/logviewerTypeProperties.json"` and supports following logfile types:

MpCCI log file `".log"` Logfiles written by the MpCCI server while running a coupled simulation. Usually these files are stored in the project directory of the coupled simulation. This is the default format if no other logfile type is specified.

Abaqus message file `".msg"` Message files written by Abaqus. These files are stored in the Abaqus model directory.

Abaqus CSS logfile `"_CSS.log"` Logfiles written by Abaqus' CSE engine coupled with MpCCI. These files are also stored in the Abaqus model directory.

6.3.1 Definition of a Logfile Type

The logfile type is defined in JSON format. The type structure is a map with a string as key and a structure as value. The key must be unique to all listed types and correlates the typeName.

Here an example of a type definition related to the MpCCI logfile with default as key and type name:

```
"default" : {
  "typeName" : "default",
  "fileSuffix" : ".log",
  "description" : "MpCCI log file",
  "regexEvent" : "^$(source): ($(level))?$(message)$",
  "regexSource" : "\\[([^\\[\\]]+)\\]",
  "regexMessage" : "(.*)",
  "regexLevelError" : "\\*\\*\\* ERROR \\*\\*\\* ",
  "regexLevelWarning" : "\\*\\* WARNING \\*\\* ",
  "regexLevelInfo" : "\\*\\*\\* ",
  "regexLevelAction" : "\\*\\* ",
  "regexLevelDebug" : "\\* "
}
```

The '\' character must be escaped ('\\') in order to be read. All values are strings and must be quoted (" "). The strings before the ':' are keywords and must appear as stated (except default which is the unique key and must be chosen individually).

The logfile structure is defined by a key - here default. This key is a string unique to all listed types. The structure itself consists of keywords which are set as follows:

typeName The internal type name of the defined logfile type which usually correlates the key (here default).

fileSuffix The file suffix identifying this logfile type. If the suffix isn't unique to all file types it is unpredictable which type will be taken for this suffix.

description A description of the logfile type which will be displayed by the MpCCI Logviewer (see ▷ 6.2.2 Information ◁).

regexEvent A regular expression describing the start of a new event in the logfile. All lines following this event-start-line belong to the message of this event until a new event-start is spotted.
The placeholders $(source), $(level) and $(message) will be replaced by the expressions for regexSource, regexLevel* and regexMessage whereas the expressions for each level will be combined to level by or'ing them (`$regexLevelError|$regexLevelWarning|$regexLevelInfo|$regexLevelAction|$regexLevelDebug`). Each placeholder must hold a grouping construct (()) via the regexEvent value (as done for the log level) or via its own values (possible for regexSource and regexMessage). The matching groups will be taken as entries for the code filter resp. as identifiers for level and message.

regexSource A regular expression describing the source for the log event. This source will be listed in the code filter (see ▷ 6.2.4 Filters ◁).

regexMessage A regular expression describing the message of the log event. The message will be extended by the lines following until the start of a new event is spotted. It will be displayed in the message area of the MpCCI Logviewer (see ▷ 6.2.5 Table with Message Area ◁).

regexLevelError, regexLevelWarning, regexLevelInfo, regexLevelAction, regexLevelDebug Regular expressions describing the level of the log event. The level is not necessary and only one, several or even all levels may be omitted. The level may be useful (e. g. the error level) to quickly access this information by filtering it out (see ▷ 6.2.4 Filters ◁).

7 MpCCI Visualizer

The MpCCI Visualizer is suitable for quickly checking whether the coupling process was successful. The coupling region, orphaned nodes and exchanged quantities can be checked to ensure that a coupling has really occurred.

7.1 Using the MpCCI Visualizer

7.1.1 Data Flow

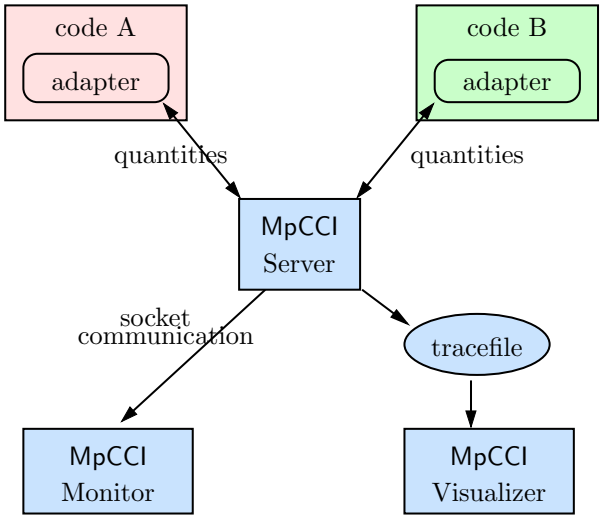


Figure 1: Data flow for the MpCCI Visualizer. The MpCCI Server Process collects the exchanged data and writes them to the tracefile.

During the MpCCI coupling process, the data exchange between the coupled codes can be observed. The exchanged data can be collected by the MpCCI server process, who writes the data into a tracefile, which can finally be read directly by the MpCCI Visualizer for `".ccvx"` or sent directly through socket communication to the MpCCI Monitor.

The tracefile is only written if some writers have been selected in the Settings step. This is achieved by selecting the writer's (e. g. CCVX, VTK or VTFA) option Use in the Settings step of the MpCCI GUI. See ▷ 4.10 Settings Step ◁ for a description of the Settings step and "Getting Started" for a general description of the coupling process.

The name of the tracefile is set in the Settings step of the MpCCI GUI. The default name is `"mpccirun-0000.ccvx"` saved in a subdirectory named `"mpccirun_<TIMESTAMP>_ccvx"`, which is located in the same directory as the corresponding project (`".csp"`) file.

More and more data is added to the tracefile during the coupling process. The file can already be opened before the process is finished to check data during the process. The visualizer can only read data from the tracefile, not manipulate or write data.

7.1.2 Supported Platforms

The MpCCI Visualizer for .ccvx and online monitoring is included in the MpCCI downloads and is at present only available on Microsoft Windows and Linux platforms but the tracefiles may be located on a remote host.

7.1.3 Starting the Monitor

The MpCCI Monitor can be started from the command-line with

```
mpcci monitor
```

as well as from the MpCCI GUI menu by selecting Tools→Monitor.

The command `mpcci monitor -h` or `mpcci monitor -help` or `mpcci help monitor` shows up a short help text.
See ▷ 5.3.4 mpcci monitor ◁ for a detailed command description.

7.1.4 Starting the Visualizer

The MpCCI Visualizer can be started from the command-line with

```
mpcci visualize [<tracefile>]
```

where a filename can be given as well as from the MpCCI GUI menu by selecting Tools→Visualizer.

The command `mpcci visualize -h` or `mpcci visualize -help` or `mpcci help visualize` shows up a short help text.
See ▷ 5.3.5 mpcci visualize ◁ for a detailed command description.

7.2 MpCCI Visualizer for .ccvx and Online Monitoring

7.2.1 Introduction

The MpCCI Visualizer for .ccvx and online monitoring is a new application for viewing of coupling regions. Compared to the old MpCCI Visualizer for `".ccv"`, it does not have distinct windows for controls and viewing, but arranges panels and toolbars around the central viewing area (Figure 2). The panels provide user interfaces for defining what to visualize and how to visualize it:

- The Case Panel shows information on the available cases. In MpCCI there is one case available for every code used in the coupled simulation. A case can be displayed in one of the available views in the viewports area.
- The Selection Panel shows information on the selected item in the active view. Selectable items are mesh nodes, finite elements, and mesh parts. To select an item, one holds down the control key Ctrl and left-clicks onto an item in a view.
- The Settings Panel allows modifying the draw style of mesh parts in the active view by selecting parts from the list and activating different draw style options. A slider on the top allows to control an offset for views that show several superimposed cases.
- The Results Panel allows selecting quantities for visualization. Scalar quantities are mapped onto part surfaces as color fringes. Vector quantities are shown as 3D vector glyphs. To select and deselect a quantity for mapping, one just double-clicks on an entry in the list of quantities. Controls below the list of quantities allow adjusting a variety of mapping parameters.

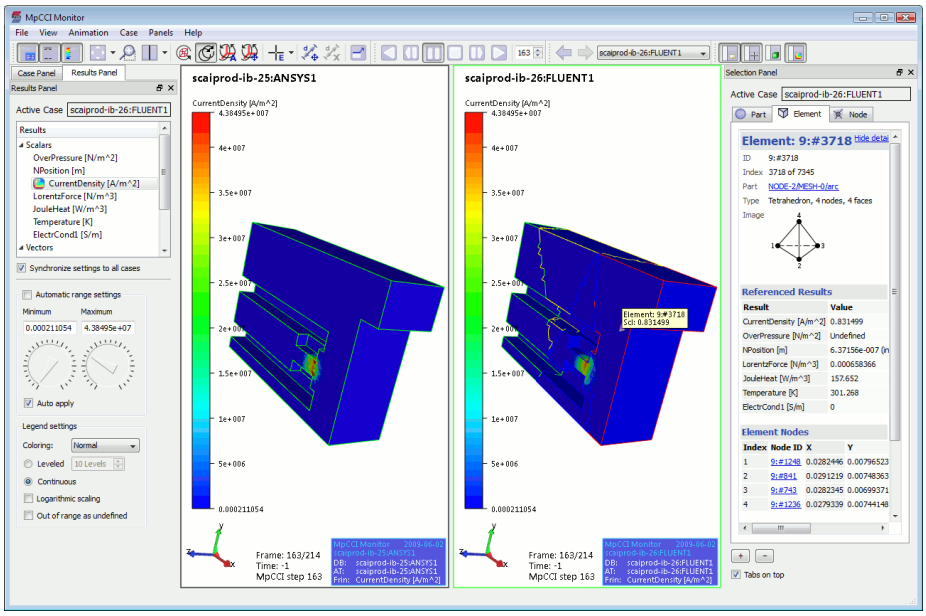


Figure 2: Main window of the MpCCI Visualizer for .ccvx and online monitoring

7.2.2 Main Window

The main window of the MpCCI Visualizer for .ccvx and online monitoring divides into three main areas (see Figure 2): Menus and toolbars on the window top, views in the window center, and panels on the left or on the right side.

7.2.3 Menus and Toolbars

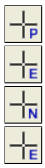
7.2.3.1 "File" Menu

Icon	Option	Key	Description
	File→Open...	Ctrl+O	Browse for a local ccvx file or type a remote ccvx file in the form [[user]@hostname:]path/to/file[.ccvx(.gz)]. This option is available in the visualizer mode.
	File→Connect to Host...	Ctrl+H	Connect to an MpCCI server for monitoring. This menu is available in the monitor mode.
	File→Disconnect from Host...		Disconnect from an MpCCI server. This menu is available in the monitor mode.
	File→Close		Close the current file or monitored job.
	File→Export Image...	Ctrl+S	Export either the active view or all views as image file in a specified resolution. It is recommended to override the text color to black and the background color to white for images which will be used in presentations. Most important file formats such as PNG and JPEG are supported.

File→Copy to Clipboard	-	Export either the active view or all views as image to the clipboard. This option is only available for Windows versions.
File→Preferences...	-	Show the application preferences dialog. See Figure 10.
File→Exit	Alt+F4	Exit the application.

7.2.3.2 "View" Menu

Icon	Option	Key	Description
	View→Info Box	-	Show/hide the info box in the active view.
	View→Text	-	Show/hide textual information in the active view.
	View→Legend	-	Show/hide part and color legends in the active view.
	View→Modify→Reset View	-	Reset the viewpoint of the active view to its initial value.
	View→Modify→Frame Model	-	Reset the viewpoint so that the whole model fits the active view.
	View→Rubber Band Zoom	-	Active rubber band zooming. Define new zoom by dragging a rectangle in one of the views using the left mouse button.
	View→Viewports...	-	Select a viewport configuration. Several configurations are available as illustrated by the icons. A maximum number of four views is supported.
	View→Perspective Projection	-	Switch between perspective and orthographic projection.
	View→Move as Outline	-	Draw the model as outlines when it is being panned or rotated.
	View→Synchronous Navigation	-	Apply navigation to all views synchronously.
	View→Automatic Rotation Point	-	The nearest model surface point will be used as rotation point instead of a fixed point.
	View→Set Rotation Point	-	Select a new fixed rotation point by clicking into one of the views using the left mouse button.
	View→Navigation Mode→Zoom	-	The model will never be penetrated or clipped when zooming into it.
	View→Navigation Mode→Walk	-	The model will be penetrated and clipped when zooming into it. Only compatible with perspective projection.

	View→Spin Model	-	Do not stop rotating once rotation interaction has finished. The model will keep on spinning until halted.
	View→Selection...	-	Activates the part, element, or node selection mode, or selection by element ID. Click into one of the views using the left mouse button to select an item.
	View→Measure Distance	-	Create a measurement of nodes distances and coordinates.
	View→Delete Distance Measurement	-	Delete the last distance measurement.
	View→Show peaks	-	Show the minimum and maximum values on the selected view and for the activated result.
	View→Show value labels	-	Show the result values for each node or element as a label annotation.
	View→Stereo	F10	Enable/disable quad buffered active stereo rendering for all views. This option requires a suitable hardware and driver installation.
	View→Full Screen	F11	Switch application to full screen mode or windowed mode.
	View→XY Plot Mode	-	Switch XY plot mode from continuous lines to sample points.
	View→Regression Curves	-	Switch XY regression plot mode on the current plot data.
	View→Auto Update Plot Range	-	Enable/disable the update of the plot range.

7.2.3.3 "Animation" Menu

Icon	Option	Key	Description
	Animation→Play Backward	-	Play the animation of coupling steps in backward direction.
	Animation→Step Backward	-	Go one animation step backward.
	Animation→Pause	-	Pause the animation of coupling steps. During online monitoring, prevent the automatic skip to the newly received data (last step).
	Animation→Stop	-	Stop the animation of coupling steps and go back to the first step.
	Animation→Step Forward	-	Go one animation step forward.
	Animation→Play	-	Play the animation of coupling steps in forward direction.
	Animation→Record	-	Record the animation of coupling steps as an animated GIF, AVI, WMV, MP4.

7.2.3.4 "Case" Menu

Icon	Option	Key	Description
	Case→Next Case	-	Load the next available case (i.e. coupling results of a code) into the active view.
	Case→Previous Case	-	Load the previous available case into the active view.

7.2.3.5 "Panels" Menu

Icon	Option	Key	Description
	Panels→Case Panel	-	Show/hide the panel containing the list of available cases.
	Panels→Selection Panel	-	Show/hide the panel containing information on the currently selected items in the active view.
	Panels→Settings Panel	-	Show/hide the panel for modification of part draw styles and superimposition offset.
	Panels→Results Panel	-	Show/hide the panel for selection of available quantities for visualization.
	Panels→Extraction Panel	-	Show/hide the panel for extraction features, i.e. cut planes and iso surfaces.
	Panels→FSIMapper	-	Show the FSIMapper panel for file based mapping; only available in FSIMapper mode.

7.2.3.6 "Help" Menu

Icon	Option	Key	Description
	Help→Help Contents	F1	Show help for MpCCI Visualizer.
	Help→About	-	Show application information and system diagnostics.

7.2.4 Panels

7.2.4.1 "Case" Panel

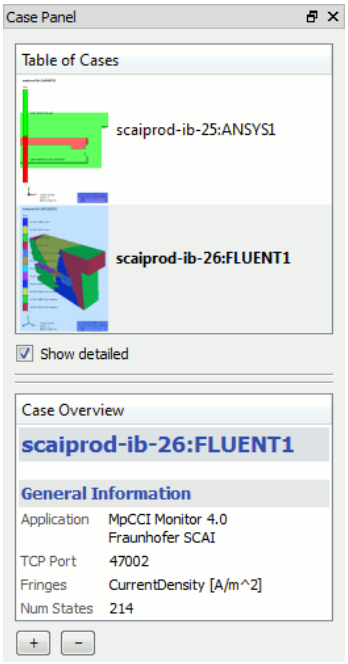


Figure 3: Case panel.

The case panel lists all available cases. In MpCCI, one case is created for every code in the coupled simulation.

The *Table of Cases* shows a case snapshot image along with the case name and date. The case snapshot image might not be available if the case has not been loaded yet. The primary case of the active view is shown in bold font. Superimposed cases, i.e. those which are shown together with the primary case of the active view, are shown in italic font.

The Show detailed checkbox allows switching to a more compact listing.

The description shown in the *Case Overview* area is HTML formatted. Use the context menu to copy it to the clipboard or save it to a file. To modify the font size, one either presses the buttons + - or presses the keys Ctrl + and Ctrl -.

The available mouse interactions with case entries are all related to the assignment of cases to views. Every view has a primary case, and optionally many superimposed cases. The following table lists the mouse interactions with case entries.

Mouse action	Description
Left mouse button click	Select case and show further case information in the *Case Overview* area.
Left mouse button double click	Load case into the active view as primary case.
Left mouse button drag	Drag case entry onto a view to show it as primary case.
Left mouse button drag + ALT	Drag case entry onto a view to superimpose it as additional case.
Right mouse button click	Use the context menu to assign or superimpose the selected case.

7.2.4.2 "Selection" Panel

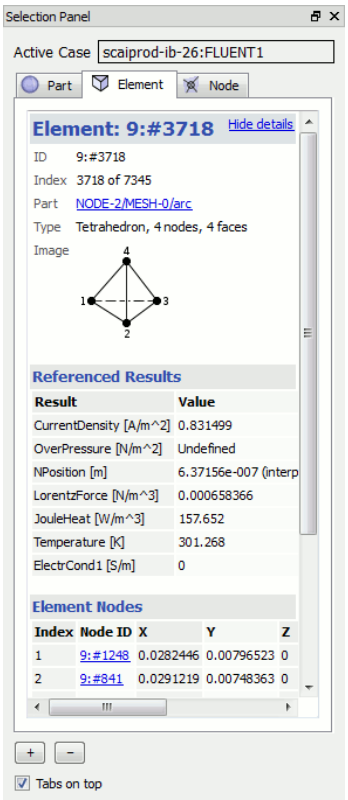


Figure 4: Selection panel.

The selection panel shows information on the currently selected item in the active view. This can either be a part, an element, or a mesh node. By changing the tabs and clicking into the active view with left mouse button and Ctrl pressed, one can easily select new items and change the type of selection.

The description of the selected item is shown in the text area. The options *Show details* and *Hide details* allow to control the amount of information shown.

Depending on the selected item, one can click on several links, which are underlined and highlighted in blue. These links point to other selectable items. That way, one can easily obtain information on the nodes of a selected element, for instance.

Note that the information shown is only valid for the selected item in the associated animation step, since the selected item in one step might not have a corresponding item in other animation steps. Obviously, this is the case if the mesh topology changes, for example. So keep in mind that links are only valid on a "per animation step" basis.

The text and tables shown are HTML formatted. Use the context menu to copy the content to the clipboard or save it to a file. Note that any images shown will not be exported. To modify the font size, one either presses the buttons + - or presses the keys Ctrl + and Ctrl -.

The Tabs on top checkbox allows moving the *Part*, *Element*, and *Node* tabs to the side.

7.2.4.3 "Settings" Panel

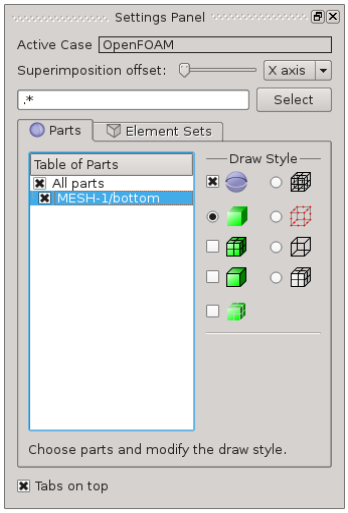


Figure 5: Settings panel.

The settings panel lists the parts of the primary case assigned to the active view. Also, the offset method for superimposition can be changed in the settings panel.

The Superimposition offset option allows controlling the offset factor. The slider sets the offset factor from a minimum (left), i.e. no offset, to a maximum (right).

Offsetting superimposed cases typically helps when one has configured a single view with all cases assigned, i.e. one primary case plus a number of superimposed cases. If the coupling regions associated with the cases are overlapping, then they can be separated using the offset.

Four offset axes are available: The *x-Axis*, *y-Axis*, *z-Axis*, and *Auto* axis, where the latter option selects a suitable axis depending on the current viewing position and viewing orientation.

The second, and more prominent, user interface area of the settings panel shows the list of parts of the active view's primary case. One can select parts from the list and modify their draw style, using several checkboxes and radio-button in the *Draw Style* area right to the list of parts, as outlined in the table below. The part selection can also be done by regular expressions (case insensitive and greedy) entered in the text box. By pressing the *Select* button all matching parts are highlighted.

The Table of Parts lists the parts of the current active case in a hierarchic structure. As default all parts are grouped below the root node. New subgroups can be created by selecting one or multiple items and clicking the right mouse button followed by selecting *New Group* in pop up menu and definition of the group's name. There is also the possibility to create automatically groups of parts per mesh id: select *New Groups from Meshes* in the pop up menu.

Created groups can be deleted by selecting the group item or one of its members and clicking the right mouse button followed by selecting *Delete Group*. All *Draw Style* modifications applied to a group are applied to each group member.

Icon	Option	Description
	Visible	Show or hide the selected parts.
	Show as surface	Show surface geometry of selected parts as surface.
	Show as lines	Show surface geometry of selected parts as lines.
	Show as points	Show surface geometry of selected parts as points.
	Show as outlines	Show surface geometry of selected parts as outlines.
	Show as hidden lines	Show surface geometry of selected parts as lines, with all hidden lines removed.
	Overlay mesh lines	Show the edges of finite elements as lines on top of the surface geometry of parts. Only applies to surface draw style.
	Overlay mesh outlines	Show the outlines over on top of the surface geometry of parts. Only applies to surface draw style.

Shrink finite elements — Shrink all finite elements of the selected parts. Note that this setting can degrade performance significantly. However, it is useful when one superimposes cases without using a superimposition offset.

7.2.4.4 "Results" Panel

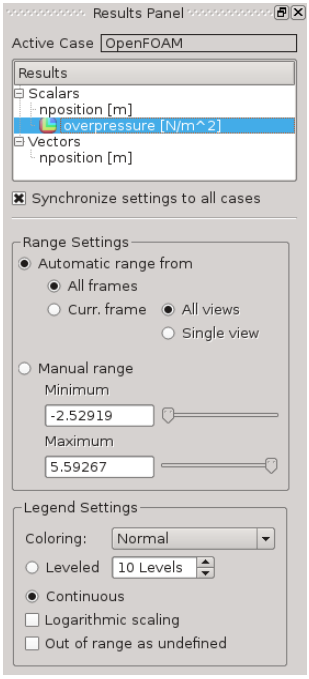


Figure 6: Results panel.

The results panel lists available scalar, vector, and displacement results of the primary case assigned to the active view. Scalar results are visualized as color fringes on the mesh surface, vector results are visualized as glyphs, and displacement results apply to node positions. Note that some datasets automatically supply displaced node positions. Thus even if the mesh appears displaced, it can be that there is no displacement result shown in the list.

One double-clicks on a result to choose it for visualization. Only one scalar result, one vector result, and one displacement result can be visualized at a time. Once a result has been chosen, an icon next to the result name is shown, indicating the currently visualized result. Also the result settings area below the list is activated. Its appearance changes depending on the chosen result type.

The options for scalar results allow to modify color legend settings used for color fringes. The options for vector results allow to modify the appearance of vector glyphs. The options for displacement results allow to modify the displacement multiplication factors, i.e. typically uses when the displacement is very small, but shall be overemphasized for visualization.

The option Synchronize settings to all cases is enabled by default. It allows applying result visualization settings to all cases synchronously. I.e. a scalar result "Wall Temp [C]" will be visualized for all cases if it is available for all cases. Other settings of the results panel are also synchronized. This synchronization is useful since corresponding results are typically available for all associated codes in MpCCI.

Settings for Scalar Results

Option	Description
Automatic range from	The range for color fringes is chosen automatically, depending on the selected options. With the option All frames the range is calculated by the minimum and maximum over all available frames and views. In contrast, the option Curr. frame only considers the data of the currently visible frame. Having selected here the option All views, the range's minimum and maximum are built over all views whereas the option Single view results in minimum and maximum values per view.

Manual range	Choose manually the *Minimum* and the *Maximum* of the range for color fringes. One can either use the numeric input field or the slider. The maximum cannot be lower than the minimum value.
Legend settings	Modify legend coloring used for color fringes.
Coloring	Select a pre-defined color scale for color fringes. The most common color scales are "Default", a rainbow color scale, and "Metal casting".
Leveled	Use a leveled color scale, divided into the given number of color levels. This mode is suited to visualize iso contours for the scalar result.
Continuous	Use a continuous color scale, with smooth transitions from color to color.
Logarithmic	Apply logarithmic scaling to color fringes. This is only supported for leveled color scales.
Out of range as undefined	Draw scalar values outside of the current minimum and maximum value in gray color. Otherwise, clamp to the colors of minimum and maximum value.

Settings for Vector Results

Option	Description
Show absolute vector length	Vector length representation uses the absolute length value.
Draw vetors as lines	Change the vector arrows representation to lines.
Scaling	Scaling factor for vector glyphs. The scaling factor relates the maximum possible glyph size with the dataset's bounding box diagonal.
Draw skip	Option to skip every n'th vector while drawing. This is useful for datasets with many vectors. The skip factor can reduce cluttering and improve rendering performance.
Coloring	Determines glyph coloring, using either a *Constant* color, as defined by the colored button, or *Color by scalar* in which case the glyph color corresponds to the color fringes of the active scalar result.

Settings for Displacement Results

Option	Description
Scaling	Scaling factor for displacement vectors. A scaling factor greater than one visually overemphasizes the displacement.

7.2.4.5 "Extraction" Panel

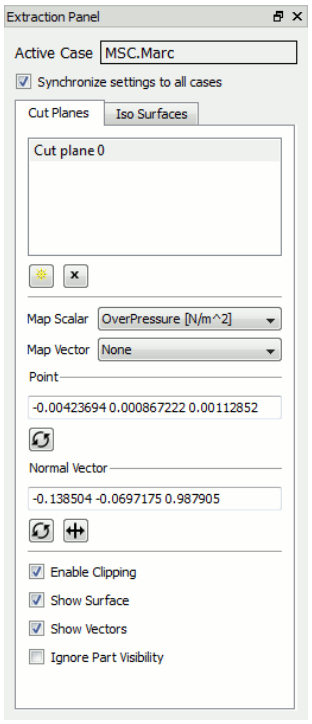


Figure 7: Extraction panel.

The extraction panel allows to create cut planes and iso surfaces for post-processing of volumetric coupling meshes. These extraction features are either created for an individual case or synchronized for all cases, which is the default mode. Use the checkbox *Synchronize settings to all cases* to modify this behavior. All changes to cut plane and iso surface parameters are also synchronized, if possible.

To create and delete extraction features, one activates the corresponding tab in the extraction panel and clicks on the *Create*/*Delete* buttons below the list widget on top of the tab. The list item selection indicates the active cut plane or iso surface. Changes of parameters apply to the active item, as well as to its corresponding items, if synchronization is enabled. Note that the part draw style switches automatically to *Outline* when an iso surface is being created and the current part draw style is set to *Surface*.

The parameters for a cut plane are the mapped scalar and vector result, the plane point, plane normal, and several switches to define the appearance, such as *Show Surface* or *Show Vectors*. It is possible to modify the cut plane point and normal using mouse interaction. Hold down both Ctrl and Shift in addition to the usual mouse button navigation scheme for panning, rotating, and zooming, i.e. displacing the plane in normal direction.

By default, a cut plane clips the part geometry in normal direction. As an alternative, one can disable clipping and switch to *Outline* draw style in the *Settings Panel*.

When *Ignore Part Visibility* is enabled, the cut plane is being computed for all parts, disregarding part visibility settings as defined in the *Settings Panel*.

The main parameter for an iso surface is the scalar for the iso threshold value (*Compute From*). Also, one can map a scalar and vector result onto an iso surface. A line edit and a dial allows to modify the iso threshold value. This interface is the same as used in the *Results Panel*. All other iso surface parameters have the same meaning as for cut planes.

The parameters of color scales and vector glyphs for results which are mapped on extraction features can be changed in the *Results Panel*. Those results referenced by extraction features show a small x in front of the result name.

7.2.5 Viewport Area

The viewport area contains up to four views (see Figure 8). The active view is marked by a green border around it. If only one view is shown, then it is always the active one. Note that most options in the view menu apply to the active view only, except if synchronized interaction is activated (such as for synchronized navigation).

The mouse interaction options for a view are shown in the following section, as well as a description of options available in the context menu of a view.

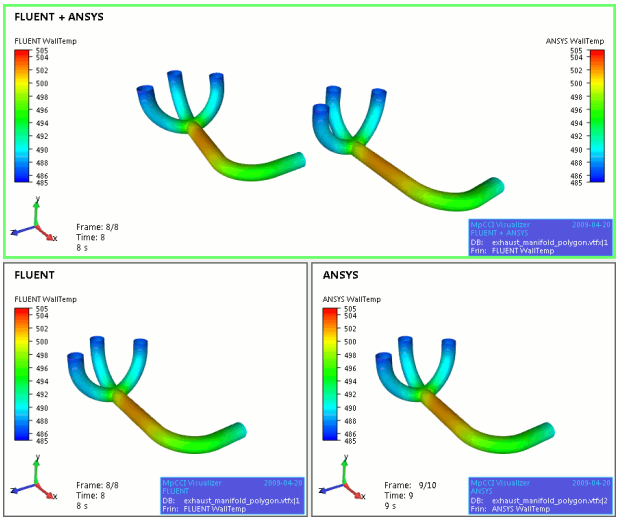


Figure 8: Viewports area. The active view is highlighted by a green border.

7.2.5.1 View Mouse Interaction

Mouse Button	Operation	Key	Description
Left	Drag	-	Rotate
Middle	Drag	-	Zoom
Right	Drag	-	Pan
Mouse wheel	Scroll	-	Zoom
Right	Click	-	Show context menu.
Left	Click	Ctrl	Select item. Item information will be shown in the selection panel. Click into empty view area to clear the item selection.
Right	Click	Ctrl	Show/hide part under cursor. Click into empty view area to show all parts again.
Left	Drag	Ctrl+Shift	Rotate active cut plane
Middle	Drag	Ctrl+Shift	Displace active cut plane into normal direction
Right	Drag	Ctrl+Shift	Pan active cut plane
Mouse wheel	Scroll	Ctrl+Shift	Displace active cut plane into normal direction

7.2.5.2 View Context Menu

The view context menu is available by right-clicking into a view. It bundles a set of important options from the View menu, as well as options to select the primary and superimposed cases for the view.

Option	Description
Select Node	Activates node selection mode. Click into the view using the left mouse button to select a node.
Select Part	Activates part selection mode. Click into the view using the left mouse button to select a part.
Select Element	Activates element selection mode. Click into the view using the left mouse button to select an element.
Reset View	Reset the viewpoint of the view to its initial value.
Frame Model	Reset the viewpoint so that the whole model fits the view.
Show/Hide→Text	Show/hide textual information in the view.

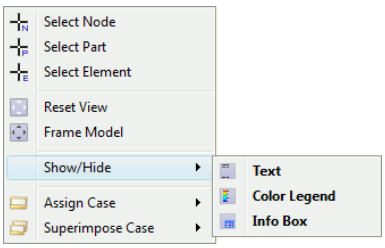


Figure 9: View context menu.

 Show/Hide→Color Legend	Show/hide part and color legends in the view.
 Show/Hide→Info Box	Show/hide the info box in the view.
 Assign Case...	Select a case from a list, and set it as primary case of the view.
 Superimpose Case...	Select a case from a list, and add it as superimposed case to the view.

7.2.6 Preferences Viewer Dialog

The preferences dialog allows setting several fixed application preferences related to file type associations, navigation styles, graphics hardware settings, and stereo rendering options.

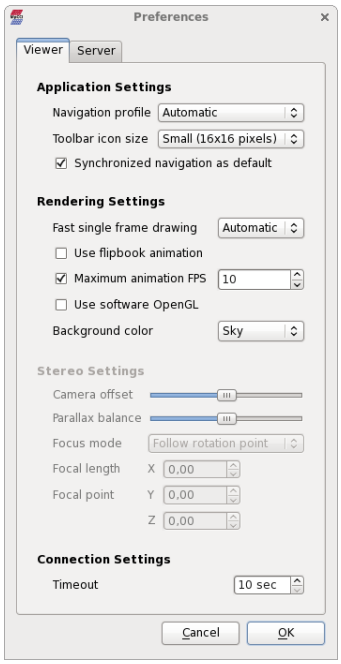


Figure 10: Preferences viewer dialog.

Option	Description
Application Settings	
Navigation profile	Select a default navigation profile for the mouse interaction in views. The default is MpCCI style navigation. The only alternative is currently GLview Inova navigation style.
Toolbar icon size	Use either icons of size 24x24 pixels or 16x16 pixels for button in the toolbar. The latter is beneficial for low resolution screens and automatically chosen for screen widths lower equal 1024 pixels.
Synchronized navigation	Dis/Enable synchronized navigation on application start.
Rendering Settings	
Fast single frame drawing	On/Auto: Draw single frames faster using features of recent graphics hardware, if available. Off: Disable option in case of hardware or graphics driver problems.
Use flipbook animation	Dis/Enable flipbook animation. The flipbook is updated while an animation runs and played back instead of rendering the actual geometry, as long as the viewing setup and contents do not change.
Maximum animation FPS	Define a maximum number of frames per second for a running animation. Typically the size of the dataset limits the frames per second, so this setting is more useful for small datasets.
Use software OpenGL	Use software OpenGL rendering, bypassing the graphics hardware. This option is only available for Windows platforms.

Background color	Background color mode. The entry *Automatic* chooses the default color black or the color defined by a ccvx file. Otherwise, the colors *Black*, *White*, and *Sky* are available.
Stereo Settings	
Camera offset	Define a camera offset factor for stereo rendering. Default is 1.0 (slider middle), allowed range is [0.0 (left) .. 2.0 (right)]. In effect this factor controls the amount of eye channel separation.
Parallax balance	
Focus mode	Defines the mode to compute the reference point of zero parallax. The default value "Follow rotation point" is recommended. Otherwise a fixed focal length or focal reference point may be supplied.
Focal length	Focal length for "Fixed focal length" focus mode.
Focal point	Focal point for "Fixed focal point" focus mode.
Connection Settings	
Timeout	Timeout value in seconds for the monitor connection.

7.2.7 Preferences Server Dialog

The preferences dialog allows setting several monitor preferences related to the co-simulation. Details for each setting can be found at ▷ 4.10.1 Monitor ◁.

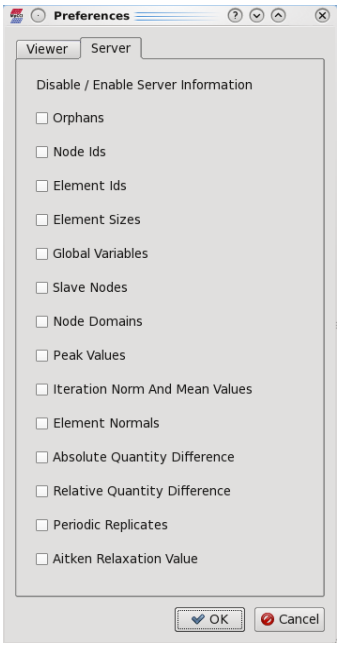


Figure 11: Preferences server dialog.

Option	Description
Server Information	
Orphans	Dis/Enable the send of orphans information.
Node Ids	Dis/Enable the send of node ids.
Element Ids	Dis/Enable the send of element ids.
Element Sizes	Dis/Enable the send of element sizes.
Global Variables	Dis/Enable the send of global variables values.
Slave Nodes	Dis/Enable the send of slaves node.
Node Domains	Dis/Enable the send of node domains information.
Peak Values	Dis/Enable the send of peak values.
Iteration Norm And Mean Values	Dis/Enable the send of iteration norm and mean values.
Element Normals	Dis/Enable the send of element normals.
Absolute Quantity Difference	Dis/Enable the send of absolute quantity difference.
Relative Quantity Difference	Dis/Enable the send of relative quantity difference.
Periodic Replicates	Dis/Enable the send of the replicated periodic parts and quantities.
Aitken Relaxation Value	Dis/Enable the send of the Aitken relaxation value.

7.2.8 Store Animated Files Dialog

The store animated files dialog allows the export of animated GIF's as well as some commonly used video formats. For the latter the MpCCI Visualizer makes use of the free available (L)GPL licensed third party video rendering library Libav (`http://libav.org/`) which is available for Windows and Linux systems and needs a separate installation on user side.

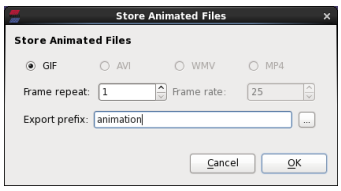


Figure 12: Store Animated Files panel.

Option	Description
Store Animated Files	
GIF	Select GIF export format.
AVI	Select AVI export format.

WMV	Select WMV export format.
MP4	Select MP4 export format.
Frame repeat	Specify the number of frame to repeat.
Frame rate	Specify the frame rate for the video export.
Export prefix	Specify the path and file name prefix for the exported file.

A copy of the Libav can be downloaded via http://libav.org/download.html. The library offers a simple `./configure` and `./install` mechanism on Linux systems whereas on Windows already compiled binaries can be downloaded from http://win32.libav.org/win64/ for 64bit operating system resp. http://win32.libav.org/win32/ for Windows 32bit.

On Linux the user of Libav has to decide which free software license should be used during compilation. As end-user of the library option `--enable-nonfree` would be suitable

Option	Description ([] = default)
–prefix=PREFIX	install binaries in PREFIX []

Licensing options:

–enable-gpl	allow use of GPL code, the resulting libs and binaries will be under GPL [no]
–enable-version3	upgrade (L)GPL to version 3 [no]
–enable-nonfree	allow use of nonfree code, the resulting libs and binaries will be unredistributable [no]

so that a installation of binaries in target folder PREFIX would look like

```
./configure --disable-yasm --prefix=PREFIX --enable-nonfree
make
make install
```

Compiled binaries will then finally be located in folder `PREFIX/bin`.

To make use of Libav in MpCCI Visualizer the user has to extend system 'PATH' variable by Libav's binary executable folder containing the tool 'avconv' which is responsible for video conversion.
To check if 'avconv' is available in system path type `avconv -version` in your system command prompt.

If 'avconv' is not avaiable the export options for AVI, WMV and MP4 will be grayed out. The export of animated GIF's is independent from Libav and does not require an installation.

7.2.9 Error Dialog

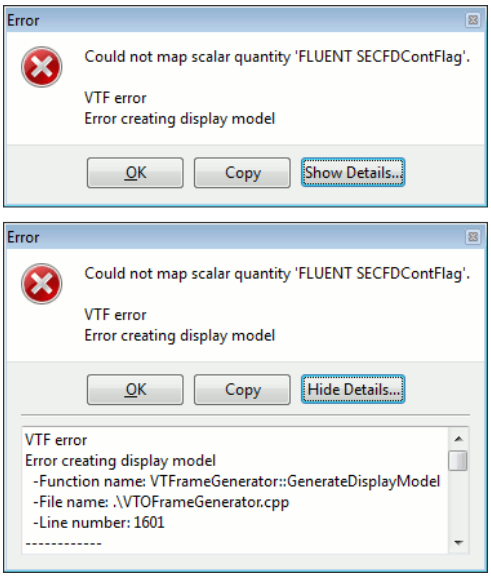


Figure 13: Error dialog with optional details.

An error dialog appears in case of recoverable MpCCI Visualizer errors, showing the error message and optionally further detail information. One can copy the error message and details using the Copy button.

Linux Note: If MpCCI Visualizer dies in case of unrecoverable application errors, one can find the text file *bt_mpcci_visualizer.txt* in the execution path which provides useful debugging information for the MpCCI support.

7.2.10 Command Line Parameters

MpCCI Visualizer for .ccvx and online monitoring calling syntax:

```
mpcci_visualizer.exe <command line options>
```

Command line options (usually set by MpCCI GUI automatically):

```
-help                : Overview of command line options
-listen <port>       : Start listening for incoming connections.
                       Default Monitor port 47002. Default Visualize port 47003.
-connect <port@host> : Connect to one or more servers
-monitor             : Switch from Visualize mode (default) to Monitor mode
-netdevice <string>  : Use the specified network device for monitoring
-modulo <number>     : Save memory by showing only <number> steps
-maxmem <number>     : Save memory by using at most <number> MB per case
-jobname <name>      : Default job name
-updatedelay <ms>    : Scene update after SYNC command limited to once
                       per <ms> milliseconds, default is 0, i.e. no limit
```

7.3 Frequently Asked Questions

Question:
The quantity NPosition is used for the FSI coupled simulation. Should it be equivalent to displacement in the FE post-processing?
Answer:
The MpCCI Visualizer is displaying the displacement for the NPosition quantity. The deformed structure is also displayed.

Question:
FE post-processing can display stresses result. Can the MpCCI Visualizer display the stresses as in the FE post-processing tools?
Answer:
No, MpCCI Visualizer only shows the exchanged quantity values selected in MpCCI GUI for the coupling or monitoring.

8 MpCCI Grid Morpher

The MpCCI Grid Morpher will smooth a grid based on the displacements of some boundary or interior vertices. A moving or morphing grid capability is always required with fluid-structure interactions.

8.1 Using the MpCCI Grid Morpher

MpCCI offers a spring based morphing method which

- supports socket communication with parallel simulation codes.
- allows vertices to float along semi-planar boundaries, e.g. symmetry planes.
- may be monitored within an additional output terminal and a morpher log file in the model working directory (`"mpcci_morpher_`<*model name*>`.log"`).
- can be used as a tool to morph grids in files e. g. geometry variations.

MpCCI Grid Morpher is actually implemented for the following simulation codes:

- ANSYS (▷ VI-4 ANSYS ◁)
- OpenFOAM (▷ VI-14 OpenFOAM ◁)

MpCCI Grid Morpher needs to read a `"gmd"` file which contains the mesh definition of the model. After reading the `"gmd"`, the MpCCI Grid Morpher executable is waiting for the list of nodes to displace. Morphed nodes are then sent back to the simulation code. For each supported code, MpCCI provides a `"gmd"` file converter executable reading the native file mesh of the simulation code.

The MpCCI Grid Morpher executable has a lot more options (see command line options ▷ 5.4.4 mpcci morpher ◁) for better fine control in case of difficult morphing scenarios. In this case the use of an options file instead of the MpCCI GUI is the better alternative.

The morpher controls the results of the morphing step, it may control the length of the edges, the shape and size of faces and also checks the quality of cells. There are options available to limit the compression and elongation of edges.

8.1.1 Options Description

The following options may be adjusted, whereas the default values are in many cases appropriate.

Optional morpher hostname Enter an optional hostname for a remote execution of the MpCCI Grid Morpher.

Morpher port no. Specifies the port address on which the MpCCI Grid Morpher listens for the client connection. The default port is in most cases acceptable, modifications are only required if firewalls block connections or multiple morphers are running in parallel on the same host.

No. of parallel morpher threads. The MpCCI Grid Morpher is multi threaded parallelized. The amount of parallel threads used will never be larger than the number of cores on the host even if more threads are requested. However in case that some of the cores on the morpher host are used by other processes you should reduce the number of threads/cores reserved by the morpher to achieve the best performance.

MpCCI Grid Morpher is multi threaded parallelized on the following platforms: lnx4_x64, windows_x64

Morpher options file Instead of using the selectable options from the list below you may specify an options file as an alternative. The options file should have the suffix `".gmo"`. The options file contains all command line options valid for the morpher executable, except the port number and hostname and the number of threads and the list of cells zone names or cell type ids. The options file contains floating text. You may comment out a line with the # sign.

Please select the output level Activate output level of the MpCCI Grid Morpher.

quiet no output

default medium level output

verbose high level output

full highest level output (verbose and received node displacements)

Check edges Activate to invoke quality checks for edges during morpher run.

Check faces Activate to invoke quality checks for faces during morpher run.

Check cells Activate to invoke quality checks for cells during morpher run.

List of cell type ids (Integers or ALL) ,

List of cell zone names (strings or ALL) Enter the cell table number of the fluid domains where the MpCCI Grid Morpher should be applied. For OpenFOAM the names of the cell zones where the morpher should be used have to be entered as strings, separated by spaces. If you want to involve all fluid domains please enter "ALL".

Min. relative edge length change Enter a lower limit for the ratio of the edge length, calculated by the morpher, to the edge length of the input grid provided to the morpher. A modified value might be interesting if the morpher generates too small edge lengths.

Max. relative edge length change Enter an upper limit for the ratio of the edge length, calculated by the morpher, to the edge length of the input grid provided to the morpher. This might be desired if the morpher generates too large edge lengths.

Min. change of face area Enter a lower limit for the ratio of the face area, calculated by the morpher, to the face area of the input grid provided to the morpher. This might be desired if the morpher generates too small face areas.

Max. change of face area Enter an upper limit for the ratio of the face area, calculated by the morpher, to the face area of the input grid provided to the morpher. This might be desired if the morpher generates too large face areas.

Max. face aspect ratio Enter an upper limit for the cells aspect ratio. For triangular faces the aspect ratio is built by the height to the corresponding maximum edge length.

Min. angle allowed in faces and cells Enter a lower limit for angles in faces and cells to prevent distortion.

Fixed nodes on fixed boundaries Enter the amount of cell levels to be fixed seen from boundaries with fixed nodes.

Fixed nodes on deformed boundaries Enter the amount of cell levels to be fixed seen from boundaries with displaced nodes. The specified number of node levels will be moved with the boundary in a rigid manner.

Optional list of floating boundary regions Enter the boundary region numbers corresponding to the OpenFOAM,... model, where a sliding of vertices is permitted. By default floating is permitted only on symmetry and cyclic boundaries. Vertices on inlet, outlet and wall regions are fixed by default.

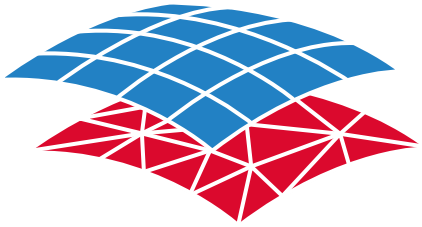
Optional list of fixed boundary regions Enter the boundary region numbers corresponding to the OpenFOAM,... model, where a floating of vertices is explicitly not permitted (e. g. in the case where you might want to fix vertices on a symmetry plane).

Morphing relaxation factor Enter a relaxation factor for solving the equation system. Larger values will speed up convergence. In case of instability it might be helpful to reduce the value.

Max. no. of iterations Number of iterations for solving the equation system.

Convergence tolerance The convergence tolerance is the ratio of the maximum node displacement at the beginning of the morphing iteration to the node displacement of the current morphing iteration step. The iterative process for solving the equation system will stop, when the convergence tolerance is reached.

Smoothing steps Specify the amount of laplacian smoothing steps. Smoothing should be handled with care.



MpCCI
CouplingEnvironment

Part VI

—

Codes Manual

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part VI Codes Manual
PDF version
October 29, 2023

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www.mpcci.de

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VI Codes Manual – Contents

1 Overview

This codes manual contains simulation code-specific information.

There is one chapter for each code, which contains basic information on the code itself and what you should know for preparing a model and running a co-simulation.

This Code Manual cannot replace the actual manuals of the simulation codes. References to further information in the code manuals are given as necessary.

The information given for each code is given in the same structure:

Quick Information – Basic properties of the simulation code and requirements for installation, licensing and further software needed by the simulation code.

Coupling Process – How to prepare and run a model for co-simulation, including code-specific options in the MpCCI GUI.

Code-Specific MpCCI Commands – Subcommands `mpcci` <*code name*> which are needed to get information on the simulation code and prepare models for co-simulation. A number of subcommands is available for several codes, these are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

Code Adapter Reference – Short description of the code adapter.

Trouble Shooting, Open Issues and Known Bugs – List of known issues.

Frequently Asked Questions – List of questions from support and answers.

1.1 Common MpCCI Subcommands for Simulation Codes

mpcci <*codename*> **-releases**

The `releases` subcommand prints a short list of all available releases of a simulation code.

mpcci <*codename*> **-info**

The `info` subcommand prints a more detailed list of the available releases of a simulation code and on the corresponding code adapter. The output looks as follows:

```
> mpcci simulationcode info

SIMULATIONCODE release "3.1":
   HOME: "/opt/simulationcode/sim-3.1"
   EXEC: "/opt/simulationcode/sim-3.1/bin/start-code"
   ARCH: "lnx86-64"

   MpCCI adapter release "3.1": ** NOT INSTALLED **
   HOME: "/home/fritz/mpcci/codes/SIMULATIONCODE/adapters"
   PATH: "/home/fritz/mpcci/codes/SIMULATIONCODE/adapters/3.1/lnx86-64"

SIMULATIONCODE release "2.99":
   HOME: "/opt/simulationcode/sim-2.99"
   EXEC: "/opt/simulationcode/sim-2.99/bin/start-code"
   ARCH: "lnx86-64"

   MpCCI adapter release "2.99":
   HOME: "/home/fritz/mpcci/codes/SIMULATIONCODE/adapters"
   PATH: "/home/fritz/mpcci/codes/SIMULATIONCODE/adapters/2.99/lnx86-64"

Latest SIMULATIONCODE release for MpCCI found: "2.99"
```

Two versions of the code are installed, but a code adapter is only available for version 2.99. Therefore the latest simulation code release which can be used with MpCCI is version 2.99. `HOME` is the main directory of a code installation or adapter, `EXEC` the code executable and `PATH` the path to the code adapter, which does not exist if an adapter is not available. The architecture token given under `ARCH` is the code's architecture token.

mpcci <*codename*> **-align <ARGS>**

The `align` subcommand is used to perform a coordinate transformation. This can be necessary if the coordinate system of the model differs from that of the partner code. The usage is as follows:

```
Usage:
   mpcci SIMULATIONCODE align  <plane-definition-file>  <input-file>  <output-file>


Synopsis:
   'mpcci SIMULATIONCODE align' is used to align/transform the nodal coordinates
   in the <input-file> so that they match with the coordinate system
   used by the coupling partner.

   The transformed result is written into the <output-file> - which is
   identical to the <input-file> except the nodal point coordinates.

   The homogeneous 4x4 transformation matrix resp. the reference coordinate
   systems used are indirectly defined via two planes. Each plane is defined
   via three non co-linear points p1, p2 and p3.

   The six points that define the two planes are specified in the

      <plane-definition-file>

   which contains 18 floating point values in the following order:

      # SIMULATIONCODE source plane specified via 3 point coordinates
         p1-x   p1-y   p1-z
         p2-x   p2-y   p2-z
         p3-x   p3-y   p3-z

      # Target coupling partner code plane specified via 3 point coordinates
         p1-x   p1-y   p1-z
         p2-x   p2-y   p2-z
         p3-x   p3-y   p3-z

   The transformation matrix determined transforms the SIMULATIONCODE plane into
   the "target" plane (rotation and scaling, but without shear) so that:

         SIMULATIONCODE(p1) -> coupling partner(p1)
         SIMULATIONCODE(p2) -> coupling partner(p2)
         SIMULATIONCODE(p3) -> coupling partner(p3)

   To use 'mpcci SIMULATIONCODE align' please just select three characteristic points
   in your SIMULATIONCODE model and the corresponding points in the partner model and
   copy the x-y-z values into the <plane-definition-file> in the above order.
```

mpcci <*codename*> **-scan** <*model file*>

The `scan` subcommand starts the scanner for a model file, which writes basic information about the model into the scan file "`mpcci_`<*model file*>`.scan`". After creating the file, its content is printed on the screen.

If the scan file "`mpcci_`<*model file*>`.scan`" exists already, no new scanning process is started, instead only

the content is printed.

mpcci <*codename*> **-diff** <*model file 1*> <*model file 2*>

The `diff` subcommand runs the scanner on the given two model files and prints the differences.

1.2 Unit Systems

Many simulation codes do not use a given system of units, but do not consider units at all. This has the advantage that users can select any consistent set of units, define all values in this system and will also receive the values in this system.

For coupling a unit-less code with codes which are based on a specific system of units, MpCCI must know which system of units was used to create the model.

MpCCI supports the following unit systems, for each system some units are listed. Of course there are more units in each system, please see what is selected in the MpCCI GUI.

unit system	mass	length	time	forces	el. current	temperature
SI	kg	m	s	N	A	K
British*	lbm	ft	s	lbf	A	K
cgs	g	cm	s	dyn	Bi	K
mm-t-s	t	mm	s	N	A	K
US-ft-lbf-s	slug	ft	s	lbf	A	K
US-in-lbf-s	lbf s^2/in	in	s	lbf	A	K

Alternatively, you can also select the option variable, which allows you to select units individually for each quantity. However, for each quantity only a limited set of units is offered! If the unit system is set to variable an additional parameter will be shown where you can select the grid length unit, which corresponds to the length unit used in your model.

∗: The "British" unit system as defined in the MpCCI GUI is not a consistent unit system – some of the electromagnetic units are inconsistent! Use at own risk.

2 Abaqus

2.1 Quick Information

Company name	SIMULIA
Company homepage	www.3ds.com/products-services/simulia/
Support	www.3ds.com/support/
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁ ▷ VII-4 Driven Cavity ◁ ▷ VII-5 Pipe Nozzle ◁ ▷ VII-6 Blood Vessel ◁ ▷ VII-8 Exhaust Manifold ◁

2.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	Abaqus/Standard	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁ The MpCCI Coupling dimension corresponds to the Abaqus interface type.
		X	
		–	
		X	
		X	
Feature	MpCCI Configurator	X	▷ V-3.5 Smart Configuration ◁
	Negotiation	X	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	X	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	SolidStructure	X	▷ V-3.1.1 Physical Domains ◁
	SolidThermal	X	
	SolidAcoustics	X	

Note: Supported options by both (X), none (–) or one of Abaqus/Explicit or Abaqus/Standard.

2.1.2 Supported Platforms and Versions

The following versions of Abaqus are supported by MpCCI (only the main version is listed):

	Supported versions							
MPCCI_ARCH: Code platform	2016	2017	2018	2019	2020	2021	2022	2023
lnx4_x64: lnx86-64	X	X	X	X	X	X	X	X
windows_x64: win86-64	X	X	X	X	X	X	X	X

Please look at the important hints in ▷ 2.1.4 Adapter Description ◁ and ▷ 2.1.5 Prerequisites for a Coupled Simulation ◁ and see also the System Information section of the Support page at www.simulia.com for details on the platforms supported by Abaqus.

2.1.3 References

Abaqus Documentation The Abaqus documentation is part of your Abaqus installation. Read especially the section "Co-simulation" of the Abaqus Analysis User's Manual (Analysis Techniques).

Abaqus Fluid-Structure Interaction User's Guide This guide is available via the Abaqus support homepage: Log into Abaqus SIMULIA knowledge base and search for "FSI guide".

Besides general information, the FSI guide contains several examples of coupled simulations with Abaqus and FLUENT.

2.1.4 Adapter Description

The code adapter for Abaqus is developed by SIMULIA in cooperation with Fraunhofer SCAI. The adapter is distributed as part of the Abaqus software.

For transient simulations with implicit coupling scheme, if constant time-stepping is chosen but the end time is not dividable by the time step size, Abaqus will reduce the time step size for the last step automatically so that the end time is reached. This might lead to numerical inaccuracies for the last coupled time step.

2.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary Abaqus installation.
- Enough license tokens.
- Co-simulation based on the SIMULIA's Co-Simulation Engine (CSE) requires the token "multi-physics".

2.2 Coupling Process

Please read also ▷ IV-2 Setting up a Coupled Simulation ◁.

2.2.1 Model Preparation

The Abaqus model can be prepared with Abaqus/CAE or as an input file. Please consider the following advice:

- The model can be defined in any of the consistent systems of units supported by MpCCI (see ▷ 1.2 Unit Systems ◁). The basic unit system must be given in the Models step of the MpCCI GUI. Units of single quantities can be set in the Regions step.
- Most Abaqus features can be used in co-simulations. Please see the Abaqus documentation or contact the Abaqus support for further information.
- The Abaqus model must contain a definition of coupling components.
  - This can be either an element-based surface for surface coupling:

    Abaqus/CAE: Create a surface using the Surfaces tool. See also "13.7.6 Using sets and surfaces in the Assembly module" in the Abaqus/CAE User's Manual. You can also use surfaces defined in the Part module.

    Input file: A surface is created with `*SURFACE, NAME=`<*surface name*>`, TYPE=ELEMENT`, see section "2.3.3 Defining element-based surfaces" of the Abaqus Analysis User's Manual.

    The surface which serves as coupling component can be selected in the Models step of the MpCCI GUI.
  - This can be either a discrete point for point coupling:

    Abaqus/CAE: Create a node set using the Set tool. Select only one node for this set. You can also use set defined in the Part module.

    Input file: A node set is created with `*NSET, NSET=`<*point name*>, see section "2.1.1 Node definition" of the Abaqus Analysis User's Manual.
- Code coupling is only run in one step of a simulation (for coupling in several steps, please use a restart). The co-simulation step is selected in the Go step of the MpCCI GUI.

It is recommended to create a complete Abaqus model first and test it separately without co-simulation. The quantities which will be transferred by the partner code can be simulated by appropriate loads or boundary conditions.

In steady thermal couplings which use relaxation, define the heat transfer step as `*STEP, AMPLITUDE=STEP`. Otherwise, Abaqus will ramp the thermal load over time, which is not necessarily compatible with the coupling relaxation.

2.2.2 Restart

For preparing a restart computation the output for restart must be activated for example:
`*Restart, write, frequency=5`
To restart a co-simulation see ▷ 2.5 Co-Simulation Restart ◁.

2.2.3 Models Step

In the Models step, the following options must be chosen:

Abaqus release Select the Abaqus release you wish to use. Only supported releases installed on your system are listed. The selection latest always refers to the latest supported version (default). The release should match the input file. To select a release on a remote machine, please select the remote input file first.

Scan method This can be set to:

- Scan for all regions (default) – The input file is scanned for possible coupling regions.

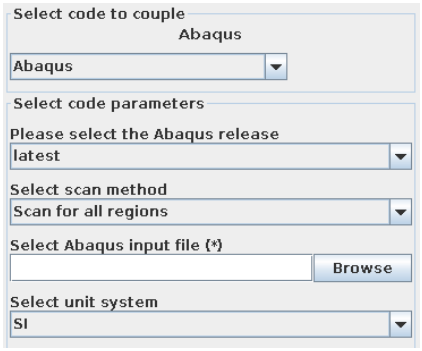


Figure 1: Abaqus options in the Models step

- Scan *CO-SIMULATION option only – This setting is only needed for a restart. In this case the input file only contains the definition of the coupling regions in the `*CO-SIMULATION` section and no ordinary region definitions.

Abaqus input file Select the Abaqus input file `"*.inp"`.

Unit system Select the unit system which was used in Abaqus. Abaqus has no units built into it, a self-consistent set of units should be used (see chapter "1.2.2 Conventions" of the Abaqus Analysis User's Manual for more information). In the Models step you can select from any unit system listed in ▷ 1.2 Unit Systems ◁.

2.2.4 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁. Following options are available in the code specific section in Solver settings.

Use subcycling Check this button if you want allow Abaqus to subcycle, i. e. use a smaller time step size than the coupling time step size. The basic principle of subcycling is described in ▷ V-3.4.3 Coupling with Subcycling ◁.

Enforce exact target times If Abaqus performs some subcycling, you can choose whether Abaqus has to meet the coupling target times in an exact or loose manner by toggling this Enforce exact target times option.

2.2.5 Regions Step

Abaqus supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code		Buffer
Acceleration	Vector	0.0 m/s^2	field	Point	Code	Direct	Buffer
AngularAcceleration	Vector	0.0 rad/s^2	field	Point	Code	Direct	Buffer
AngularCoordinate	Quaternion	0.0	mesh coordinate	Point	Code	Direct	Buffer
AngularVelocity	Vector	0.0 rad/s	field	Point	Code	Direct	Buffer
BodyForce	Vector	0.0 N/m^3	flux dens.	Volume	Code	Direct	Buffer
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	Direct
FilmTemp	Scalar	300.0 K	field	Face	Code		Buffer, Direct

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
Force	Vector	0.0 N	flux integral	Point, Face	Code	Direct	Buffer
HeatRate	Scalar	0.0 W	flux dens.	Face	Code		Buffer
NPosition	Vector	0.0 m	mesh coordinate	Face, Volume	Code	Direct	
OverPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code		Buffer
PointPosition	Vector	0.0 m	mesh coordinate	Point	Code	Direct	Buffer
PorePressure	Scalar	0.0 N/m^2	flux dens.	Face, Volume	Code	Direct	Buffer
PorousFlow	Scalar	0.0 m/s	flux dens.	Face, Volume	Code	Direct	Buffer
RelWallForce	Vector	0.0 N	flux integral	Face	Code		Buffer
Temperature	Scalar	300.0 K	field	Volume	Code	Direct	Buffer
Torque	Vector	0.0 N m	flux integral	Point	Code	Direct	Buffer
Velocity	Vector	0.0 m/s	field	Point, Face, Volume	Code	Direct	Buffer
WallForce	Vector	0.0 N	flux integral	Face	Code	Direct	Buffer
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Code		Buffer
WallHTCoeff	Scalar	0.0 $W/m^2 K$	field	Face	Code		Buffer
WallTemp	Scalar	300.0 K	field	Face	Code	Direct	Buffer

Following changes for thermal coupling to consider:
The Steady state radiative heat transfer coupling type cannot be applied with Abaqus 6.14 based on the SIMULIA's Co-Simulation Engine (CSE).
The previous coupling type based on the exchange of temperature (WallTemp), film temperature (FilmTemp) and the heat transfer coefficient (WallHTCoeff) should be replaced by the exchange of temperature (WallTemp), film temperature (FilmTemp) and the heat rate (HeatRate). Abaqus applies the heat rate and film temperature as concentrated heat flux and ambient temperature. The heat transfer coefficient is computed on the structural side.

2.2.6 Go Step

In the Go step, the following options can be selected:

Enter a job name This is the name of the Abaqus job, which is also used as base for the Abaqus output files.

Enter the co-simulation step number The co-simulation step is the step of the Abaqus simulation which is coupled. You can e. g. run some initial computations first, followed by a coupled step based on the previous results.

Additional command line options Additional command line options for Abaqus can be given here, they will directly be used when Abaqus is started.

MpCCI uses the alternate syntax "-option value" for the Abaqus command line options.

Optional old job name for a restart This option is required for a restart computation. It is handed over to Abaqus as `oldjob=<name>` option.

Recovery restart time (*Option is available if a odb file file has been selected*)
This option is required for a recovery restart computation. The user should provide the time where the restart point will be initiated by the Abaqus computation. The user may analyze the `".msg"` files from the old job to figure out at which time the restart data has been written. You can search for the following key to find this information: RESTART INFORMATION WRITTEN IN STEP....

User Subroutine is the name of a FORTRAN file (source or object file), which is handed to Abaqus as `user=<file>`. See "User subroutines: overview" of the Abaqus Analysis User's Manual.

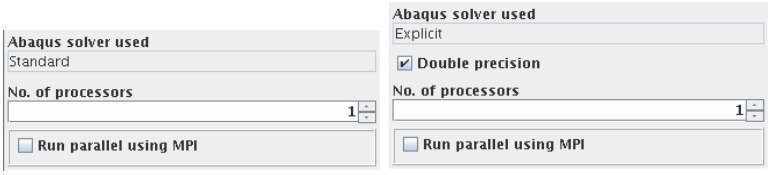


Figure 2: Abaqus solver specific options for solvers Standard and Explicit

Abaqus solver used shows the Abaqus solver used for this computation. The solver type is retrieved from the scanner run.

Double precision Select this option to use the double precision. Only *Explicit* solver type provides this option (cf. Figure 2 Explicit).

No. of processors Enter the number of threads for an Abaqus run. This starts Abaqus with the option -mp_mode=threads.

Run parallel using MPI Select this to start a parallel run distributed on several hosts. This starts Abaqus with the option -mp_mode=mpi. A panel with additional options appears, which are further described in ▷ 2.2.7.1 Parallel Execution ◁.

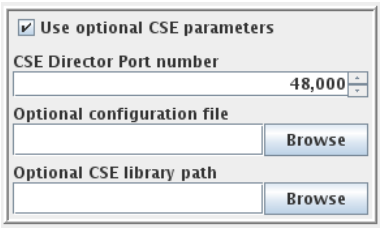


Figure 3: Abaqus CSE parameters in the Go step

Use optional CSE parameters Activate this option in order to access some additional parameters. It is recommended to provide different initial port numbers for an Abaqus-Abaqus co-simulation.

CSE Director Port number Enter the initial port number for the CSE director process. 48000 is the default value if the Optional CSE parameters is not activated.

Optional configuration file Select a configuration file when doing a co-simulation using CSE. It is recommended to use a configuration file generated by MpCCI and rename it for your purpose. This step is highly recommended in order to keep the conventional name for the co-simulation region interface. You may be able to add or activate some features from CSE that are not already automated in MpCCI GUI.

Optional CSE library path Define the PATH to the CSE library installation. This is only recommended if you get the information UNDEFINED CSE LIBRARY PATH from the command `mpcci abaqus info`.

2.2.7 Running the Computation

When the Start button is pressed, Abaqus is started with the options given in the Go step.
The setting for the coupling time step will be checked:
One of the following option is required in order to start Abaqus:

- Exchange the global quantity DeltaTime, or
- Use a constant coupling time step.
- If none of these information has been activated Abaqus will use its own time stepping to perform a co-simulation step.

If the Stop button is pressed, a stop-file is created and Abaqus will stop the next time it checks the presence of a stop file.
You can check during the Abaqus run for the Abaqus log files:

- `".dat"` log file from the Abaqus Pre process which analyzes the input deck.
- `".msg"` log message file from the Abaqus standard or explicit solver.

In case of any issue with Abaqus, please first check the Abaqus log file for further information.

2.2.7.1 Parallel Execution

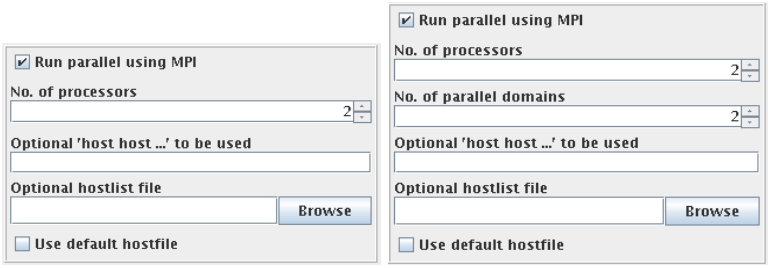


Figure 4: Options for a parallel run for solvers Standard and Explicit

Parallel runs of Abaqus are supported by MpCCI.

In the Go step, a set of additional options can be chosen for a parallel run as shown in Figure 4.

No. of processors Enter the number of processors to use during the analysis. The corresponding Abaqus command line option is -cpus.

No. of parallel domains Enter the number of parallel domains. The corresponding Abaqus command line option is -domains. As parallel Abaqus is always run with the command line option -parallel=domain (-parallel=loop is not available for coupled runs), the value for No. of processors must be a divisor of the value of No. of parallel domains. (Only for *Explicit* solver).

Optional 'host host...' to be used Enter host names for parallel execution of Abaqus.

Optional hostlist file Specify a hostfile, from which host names are extracted ▷ V-3.6.2 Hostlist File ◁.

Use default hostfile A default hostfile can be configured by setting MPCCI_HOSTLIST_FILE ▷ V-3.6.2 Hostlist File ◁.

Please read the Abaqus documentation for a detailed explanation of the possible options.

2.2.7.2 Batch Execution

Abaqus is always run as a batch process, therefore no special settings are necessary for batch execution.

2.2.8 Post-Processing

Post-processing for the Abaqus part of the results can be performed as in ordinary computations, e. g. with Abaqus/CAE. The "<*job name*>.odb" file can be found in the same directory as the input file.

2.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for Abaqus are:

```
Usage:
   mpcci Abaqus [-]option


Synopsis:
   'mpcci Abaqus' is used to get information about Abaqus.


Options:
   -align  <ARGS>
                Do a coordinate transformation on all nodes of an input
                file based on a plane definition file and align the
                nodal coordinates for the coupling partner.

   -diff  <inp1> <inp2>
                Run the scanner on two .inp files and print the differences.

   -help
                This screen.

   -info
                List verbose information about all Abaqus releases.

   -releases
                List all Abaqus releases which MpCCI can find.

   -restartPoints  <oldjob> [RELEASE]
                Check which restart points are written to an old job
                by running an Abaqus datacheck using a dummy project.

   -scan  <input-file>
                Run the scanner and create a scanner output file.

   -solver  <input-file>
                Get the solver 'standard' or 'explicit' from an input deck.
```

The subcommands `align`, `diff`, `info`, `releases` and `scan` are described in ▷1.1 Common MpCCI Subcommands for Simulation Codes◁.

`mpcci abaqus restartPoints <oldjob> [RELEASE]`

The `restartPoints` subcommand launches an Abaqus datacheck for a dummy restart from an old job. Restart points are printed e.g. `STEP 2 INCREMENT 44 HAS BEEN FOUND ON THE RESTART FILE`.

`mpcci abaqus -solver <input-file>`

The `solver` subcommand gets the used solver (standard or explicit) from the specified input deck and prints it to stdout.

2.4 Code Adapter Reference

2.4.1 Patched Input File

Before a coupled simulation is started, MpCCI patches the Abaqus input file. For a file "*.inp" selected in the Models step, a new file "mpcci_*.inp" is created containing a new *CO-SIMULATION block. If the original file already contains *CO-SIMULATION keywords, they are removed.

The lines inserted by MpCCI may e. g. look as follows:

```
**
** MpCCI automatically inserted this *CO-SIMULATION keyword.
** Therefore any existing *CO-SIMULATION keyword was removed.
**
*CO-SIMULATION, NAME=MPCCI, PROGRAM=MULTIPHYSICS
*CO-SIMULATION REGION, TYPE=SURFACE, EXPORT
ASSEMBLY_BLOCK-1_WALL, COORD
*CO-SIMULATION REGION, TYPE=SURFACE, IMPORT
ASSEMBLY_BLOCK-1_WALL, CF
```

The settings in this block reflect the user's choices in the MpCCI GUI:

- The selected coupling components are listed below the *CO-SIMULATION REGION keywords. Here it is ASSEMBLY_BLOCK-1_WALL and the exchanged quantities are
  COORD = NPosition, sender is Abaqus
  CF = RelWallForce, sender is partner code

The *CO-SIMULATION keywords are described in detail in "Preparing an Abaqus analysis for co-simulation" of the Abaqus Analysis User's Manual.

2.4.2 SIMULIA's Co-Simulation Engine (CSE)

Before a coupled simulation with CSE is started, MpCCI generates automatically the proper SIMULIA CSE configuration file for the calculation.

2.5 Co-Simulation Restart

To prepare the input file for restarting the co-simulation follow these steps:

- Create a new input file named for instance "abaqus_run_restart.inp".
- Introduce the Abaqus key *RESTART with the respective option, specifying the time of increment to use.
  The defined time for the restart should also match the time of the partner code. Otherwise the grid position may not match.
- Define your analysis *Step.
- Before closing the Step definition, copy the lines introduced by MpCCI in the input file for the co-simulation, for example:

```
**
** MpCCI automatically inserted this *CO-SIMULATION keyword.
** Therefore any existing *CO-SIMULATION keyword was removed.
**
```

```
*CO-SIMULATION, NAME=MPCCI, PROGRAM=MULTIPHYSICS
*CO-SIMULATION REGION, TYPE=SURFACE, EXPORT
ASSEMBLY_BLOCK-1_WALL, COORD
*CO-SIMULATION REGION, TYPE=SURFACE, IMPORT
ASSEMBLY_BLOCK-1_WALL, CF
```

- Close the Step definition and save the input file.
- In the MpCCI GUI you should use the option Scan *CO-SIMULATION option only for scanning the model you just created.
- In the Go step you should select your odb file for the restart and set the co-simulation step number to 2, because the restart is considered as the step 1.
- If the restart is a recovery calculation, you should provide the time where the restart point of the calculation will begin.

2.6 Known Limitations

- Prescribing a point displacement with Abaqus/Explicit 6.12 and 6.13 does not deliver the correct reaction force. The point coupling can be realized with Abaqus user subroutines VUAMP combined with definition of sensors in the input deck. This allows to obtain the proper reaction forces. Contact the MpCCI support for detailed information about the procedure.
- Axisymmetric co-simulation surface is not supported by SIMULIA Co-Simulation Engine. The workaround consists of formulating your problem in a 3D cyclic symmetric model.

2.7 Trouble Shooting, Open Issues and Known Bugs

Version:
Abaqus 2018, 2019 with MpCCI 4.6
Problem:
For a thermal co-simulation with filmTemp, WallHTCoeff you receive during the initialization with the MpCCI the message:

```
MpCCI-CSE: Create field quantity definition "filmtemp" at element.
MpCCI-CSE: Registering outgoing quantity" filmtemp".
MpCCI-CSE: Create field quantity definition "wallhtcoeff" at element.
MpCCI-CSE: Registering outgoing quantity" wallhtcoeff".
MpCCI-CSE: Create field quantity definition "walltemp" at node.
MpCCI-CSE: Registering incoming quantity "walltemp".
MpCCI-CSE: Director terminated the analysis due to early termination by a
client. Please check for errors for each of the analysis involved in
co-simulation and also verify that the co-simulation duration time specified in
the configuration file is correct.
```

From the Abaqus `".msg"` file you can find this error message:

```
Variable surface_filmprop referenced in the co-simulation configuration file is
not declared as incoming variable in this model.
```

Solution:
Update the Abaqus 2018 or 2019 with the latest hotfix available from SIMULIA: software.3ds.com/

3 Adams

3.1 Quick Information

Company name	HEXAGON
Company homepage	hexagon.com/products/product-groups/computer-aided-engineering-software/adams
Support	simcompanion.hexagon.com
Tutorials	▷ VII-12 Spring Mass System ◁

3.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	X	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		X	
		–	
		–	
		–	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	X	▷ V-4.8.2.1 Copying Components ◁
Domains	System	X	▷ V-3.1.1 Physical Domains ◁

3.1.2 Supported Platforms and Versions

Adams is supported on the following platforms:

	Supported versions																		
MPCCI_ARCH: Code platform	2016	2017	2017.1	2017.2	2018	2018.1	2019	2019.2	2020	2021	2021.1	2021.2	2021.3	2022.1	2022.2	2022.3	2022.4	2023.1	2023.2
lnx4_x64: linux64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: win64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

For details on the platforms supported by Adams see also the Platform Support page at www.mscsoftware.com/support/platform-support.

The template products Adams/Car and Adams/Chassis are supported.

3.1.3 References

Adams Documentation The Adams documentation is part of your Adams installation. The most important parts for the co-simulation is the description of the Adams/Solver.

3.1.4 Adapter Description

The code adapter for Adams is developed and distributed by the Fraunhofer SCAI.

3.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary Adams installation.
- Enough license tokens.
- Compiler, which is supported by Adams, if you use Adams/Car or Adams/Chassis. For a list of required Fortran and C/C++ compilers, refer to the *Hardware and Software specifications* in the installation guide of your Adams installation. Installation guides can be found at simcompanion.mscsoftware.com.

3.2 Coupling Process

Please read also ▷ IV-2 Setting up a Coupled Simulation ◁.

3.2.1 Model Preparation

The Adams model can be prepared with Adams/View or as an input file. Please consider the following advice:

- The model can be defined in any of the consistent systems of units supported by MpCCI (see ▷ 1.2 Unit Systems ◁). The basic unit system must be given in the Models step of the MpCCI GUI. Units of single quantities can be set in the Regions step.
- Please verify the simulation mode used by Adams (e.g. STATICS, DYNAMICS) to be appropriate for the co-simulation partner.
- The Adams model must contain a definition of coupling components. This can be one of the following elements:
  - GFORCE
  - MARKER
  - MOTION
  - VARIABLE

  The element which serves as coupling component can be selected in the Regions step of the MpCCI GUI. Also multiple elements can be selected.
- Code coupling can only run in one single step of a simulation.

It is recommended to create a complete Adams model first and test it separately without co-simulation. The quantities which will be transferred by the partner code can be simulated by appropriate loads or boundary conditions.

3.2.2 Dynamic or Kinematic Simulation

For a dynamic co-simulation the simulation mode on the Adams side must be also set to `DYNAMICS` and the coupling scheme must be Explicit-Transient (see ▷ 3.2.7 Algorithm Step ◁). The step sizes (e. g. `HMAX`) or any other options of the Adams solver are not changed by MpCCI. MpCCI provides the data from the co-simulation to the Adams/Solver as it is requested by the calls of the corresponding subroutines. The communication time points are not controlled by MpCCI. However it is possible to force Adams to match certain time points. The option Synchronized history buffer update in conjunction with semi-implicit mode or partial derivatives support can be used for this purpose (see ▷ 3.2.7 Algorithm Step ◁, ▷ 3.2.8.1 Semi-implicit Mode ◁ and ▷ 3.2.8.2 Partial Derivatives in Adams ◁ for details). Please be sure, that the co-simulation partner also uses a dynamic simulation or at least provide time values for the sent data.

The time steps of the co-simulation partners differ in general. To match the data values between requested and provided time points the server interpolates the quantities in time.

Adams/Car and Adams/Chassis simulations usually consist of static initialization analyses, followed by one or more dynamic or kinematic analyses. If Explicit is selected as the coupling scheme, MpCCI will only exchange data once at the beginning and once at the end of all static analyses and begin co-simulation in the dynamic or kinematic steps, see also ▷ 3.2.4 Multiple Statements ◁.

3.2.3 Static Simulation

For a static co-simulation the simulation mode on the Adams side must be also set to `STATICS`. The setup of a quasi-static simulation corresponds to the setup of a dynamic simulation (see ▷ 3.2.2 Dynamic or Kinematic Simulation ◁). All the parameters which you can use for the dynamic mode are also available.

Adams/Car and Adams/Chassis simulations usually consist of static initialization analyses, followed by one or more dynamic or kinematic analyses. In steady-state simulations, MpCCI will only exchange data during the static analyses and quit the co-simulation before the dynamic or kinematic steps start, see also ▷ 3.2.4 Multiple Statements ◁.

3.2.4 Multiple Statements

You can use multiple `SIMULATE` statements in your Adams simulation. In that case please ensure that the tags used for the exchanged quantities are unique. E. g. it is not possible to go back in time during a co-simulation.

If you switch between static and dynamic simulation (e. g. to compute a static equilibrium), please note that for an explicit co-simulation the data exchange is done only once for a time point. In this case the static equilibrium is calculated without co-simulation.

3.2.5 Adams Template Products

3.2.5.1 Adams/Car

The preparation of the co-simulation with Adams/Car usually includes following steps:

- Creation of `".acf"`, `".adm"` and `".xml"` files from the Adams/Car model. This can be done e.g. by running the desired analysis without co-simulation using the `Simulate` tab from within the Adams/Car GUI.
- Adjustment of the model for the coupling (e.g. deactivation of some elements, introduction of new elements which serve as interfaces for the co-simulation or for the model consistency).
- Configuration of the co-simulation (see ▷ 3.2.8 Regions Step ◁)

- Selection of the co-simulation scheme. MpCCI interprets events defined by `CONTROL/FUNC=USER(...)` in the `".acf"` file (see Adams/Chassis documentation) as static co-simulation. Statements started using the `EventRunAll`, `EventRunFor`, `EventRunNext` and `EventRunUntil` command operate on a list of events read from an `".xml"` file. These events consist of a set of dynamic maneuvers, possibly preceeded by a static analysis.

  Please note, that for the static co-simulation the transient analysis, if included in the same `".acf"` file, will not be treated right by MpCCI (e.g. an error arises). For the transient co-simulation there will be no transfer in the static events. It means, that the value of the co-simulation element keeps constant. This may cause difficulties with the convergence of the static solvers. So please be careful by setting up the co-simulation for large models.

3.2.5.2 Adams/Chassis

The preparation of the co-simulation with Adams/Chassis usually includes following steps:

- Creation of `".acf"` and `".adm"` files, and possibly of an `".xml"` file from the Adams/Chassis model. This can be done with the `build model` command from the Adams/Chassis GUI.
- Adjustment of the model for the coupling (e.g. deactivation of some elements, introduction of new elements which serve as interfaces for the co-simulation or for the model consistency).
- Configuration of the co-simulation (see ▷ 3.2.8 Regions Step ◁)
- Selection of the co-simulation scheme. MpCCI interprets events defined by `CONTROL/FUNC=USER(...)` in the `".acf"` file (see Adams/Chassis documentation) as static co-simulation. Events started by `SIMULATE` will lead to a transient co-simulation. Statements started using the `EventRunAll` command run a list of events read from an `".xml"` file. These events consist of a set of dynamic maneuvers, possibly preceeded by a static analysis.

  Please note, that for the static co-simulation the transient analysis, if included in the same `".acf"` file, will not be treated right by MpCCI (e.g. an error arises). For the transient co-simulation there will be no transfer in the static events. It means, that the value of the co-simulation element keeps constant. This may cause difficulties with the convergence of the static solvers. So please be careful by setting up the co-simulation for large models.

3.2.6 Models Step

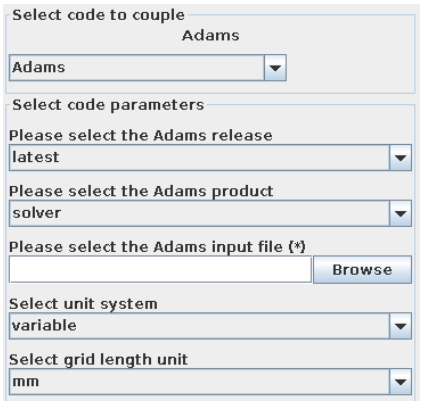


Figure 1: Adams options in the Models step

In the Models step, the following options must be chosen:

Adams release Select the Adams release you wish to use. Only supported releases installed on your system are listed. The selection latest always refers to the latest supported version (default). The release should match the input file.

Adams product type This can be set to solver or any of the supported Adams template products e.g. acar for Adams/car.

Adams input file Select the Adams input file `"*.adm"` or `"*.acf"`. In the case you select an `"*.adm"` file MpCCI assumes that the command file `"*.acf"` has the same name. If you select an `"*.acf"` MpCCI reads the `"*.adm"` defined in the `"*.acf"` file.

Unit system Select the unit system which was used in Adams (see ▷ 1.2 Unit Systems ◁).
Default is set to variable for the unit system with mm for the grid length unit.

3.2.7 Algorithm Step

In the Algorithm step, some additional options are available in the code specific section. For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

Following options can additionally be set in Solver settings (cf. Figure 2):

Use semi-implicit interpolation Check this option to use the semi-implicit interpolation. In this case Adams locally mirrors the sent and received data. This saved information is then used to provide a local approximation (for the current co-simulation state) of the received quantities with respect to the sent quantities. Basically this feature aids the explicit co-simulation. In this case Adams can update the received quantities for each iteration utilizing the available approximation. See ▷ 3.2.8.1 Semi-implicit Mode ◁ and ▷ VII-12 Spring Mass System ◁ for more details.

Relaxation for the interpolation coefficients For this option the values between 0.0 and 1.0 can be used. The adapter considers this parameter to relax the calculated coefficients (used with semi-implicit interpolation or partial derivatives). New values are then calculated from the actual approximation multiplied with the relaxation parameter and the old approximation multiplied with 1.0 minus the relaxation parameter.

Number of saved states The number of data points saved by the adapter to calculate the approximations for the semi-implicit mode or partial derivatives.

Communication delay of the co-simulation This parameter is used for the approximation of the semi-implicit mode or partial derivatives. This is the communication offset, introduced by the co-simulation. The reaction on the data, sent at some time points is received by the next communication. This is the general case for the parallel explicit co-simulation. For the implicit co-simulation the offset is 0 as the reaction is received at the same time point. Due to technical reasons, the offset by the co-simulation with the Abaqus adapter is to be set to 2. These are the communication scenarios which are supported by the MpCCI CouplingEnvironment for now. Wrong setting of this parameter results in errors by the calculation of approximation for the semi-implicit and partial derivatives modes.

Synchronized history buffer update Check this parameter for the Adams adapter to update the saved states only at certain time points. This can be used e. g. if the co-simulation partner takes different time step sizes for the simulation. In this case, data provided as reaction and saved outgoing quantities have to be adjusted.

Time step for buffer update This option sets a constant step size for the updates. If this value is negative, the adapter tries to use a Time-Step-Size control variable (see ▷ 3.2.8 Regions Step ◁).

Initial time for saving states With this option the adapter can skip some time interval at the beginning of the co-simulation and starts to save data after the specified time point is reached. This can help to avoid approximation errors for the semi-implicit mode or partial derivatives due to inconsistent initial conditions in the models.

Use constant mass Check this option to allow the calculation of the relation between incoming quantities (e. g. a force) to the outgoing acceleration or angular acceleration only at the start of the co-simulation. This option can help to determine the approximation coefficients with respect to acceleration very precisely. However, only if the initial values of the incoming quantities are close to zero or negligible, the approximation with respect to the other parameters (e. g. position) will still change with the co-simulation progress. Please see ▷ VII-12 Spring Mass System ◁ for more details.

Value of the mass coefficient Set the value of the mass coefficient, that will be used to relate incoming forces to outgoing accelerations or angular accelerations.

Provide partials to Adams If this option is checked, Adams will provide the partial derivatives of the received quantities with respect to the sent quantities. This helps the process of solving the nonlinear equations in the corrector iterations. See ▷ 3.2.8.2 Partial Derivatives in Adams ◁ and

▷ VII-12 Spring Mass System ◁ for more details.

Minimum value for derivatives This is the minimum (negative!) value which can be used for the approximation of the partial derivatives. The numerical approximation of the value in the Adams adapter will be restricted by this parameter. Values of the partial derivatives which are greater than 0.0 result in the interior instability of the Adams model (for the applications, which utilize this option like e. g. controller design, iterative coupling must be used). Large negative values of the partial derivatives define very stiff components (e. g. `GFORCE`) and increase the numerical effort for the solution of the system. Please see ▷ VII-12 Spring Mass System ◁ for more details.

Maximum value for derivatives This is the maximum (negative!) value which can be used for the approximation of the partial derivatives (see the option Minimum value for derivatives above for more details).

Initial value for derivatives This parameter provides the initial value for the partial derivatives. This value is used before the Adams adapter has enough data to make an approximation.

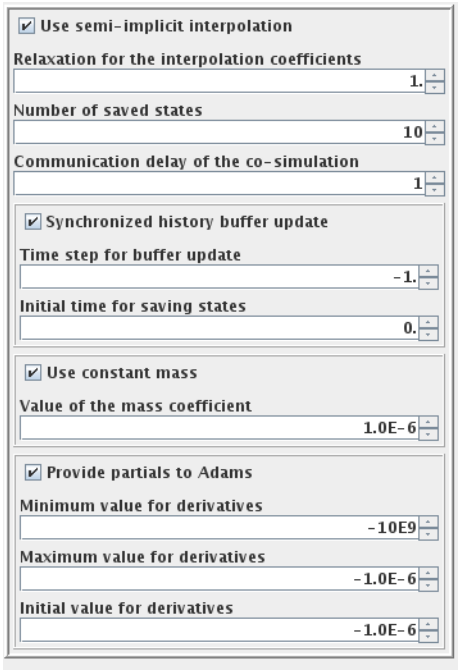


Figure 2: Additional Adams options in the Algorithm step for Explicit coupling scheme in transient studies

For Implicit coupling scheme following option is available in the code specific section:

Analysis

Analysis type Select Transient.

The Implicit option from Define the coupling scheme in Common Basics - Coupling analysis section should be selected.

Adams uses a Newton–type solver and exchanges data in every iteration until the Maximum number of coupling step iterations is reached. Since Adams adaptively changes its time step size, it is possible that Adams does several time steps before it reaches the next coupling point. In this case, Adams only exchanges data in the last time step before the next coupling point and keeps the exchanged data constant in the preceeding time steps.

3.2.8 Regions Step

Adams supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
Acceleration	Vector	0.0 m/s^2	field	Point	Node	Direct	Usermemory
AngularAcceleration	Vector	0.0 rad/s^2	field	Point	Node	Direct	Usermemory
AngularCoordinate	Quaternion	0.0	mesh coordinate	Point	Node	Direct	Usermemory
AngularVelocity	Vector	0.0 rad/s	field	Point	Node	Direct	Usermemory
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	Usermemory
Force	Vector	0.0 N	flux integral	Point	Node	Direct	Usermemory
PointPosition	Vector	0.0 m	mesh coordinate	Point	Node	Direct	Usermemory
RealFlag	Scalar	0.0	g-max	Global	global	Direct	Usermemory
Torque	Vector	0.0 N m	flux integral	Point	Node	Direct	Usermemory
Velocity	Vector	0.0 m/s	field	Point	Node	Direct	Usermemory

In this step user can select the elements of the Adams-model and set the quantities to be exchanged by the co-simulation. Please note, that appropriate elements must be selected for certain quantities. E.g. the GFORCE element cannot receive any kinematic quantities like position or velocity. The following table shows the possible combinations between elements and quantities:

Element	**Receive**	**Send**
`GFORCE`	Force, Torque	PointPosition, Velocity, Acceleration, Angular-Coordinates, -Velocity, -Acceleration
`MARKER`		PointPosition, Velocity, Acceleration, Angular-Coordinates, -Velocity, -Acceleration
`MOTION`	Acceleration, AngularAcceleration	
`VARIABLE`	Value of the Variable (one-dimensional!)	Value for the Variable (one-dimensional!)

In the case of `GFORCE` element the outgoing quantities are requested from the `I-MARKER`.

Furthermore the time step size to control the simulation process can be received by Adams. For this purpose an additional element `Time-Step-Size` is provided in the variables list, which can only receive the time step size. MpCCI uses this value to control calculation of partial derivatives (see ▷ 3.2.7 Algorithm Step ◁). If the user requires time step size to be sent by Adams, the operation is ignored.

3.2.8.1 Semi-implicit Mode

The data exchange between Adams and MpCCI server is done for every single time step in case of the dynamic explicit simulation or every iteration in case of a static simulation or dynamic implicit simulation. However the internal solution algorithms are in general iterative. As consequence, there are variations of the local state for each iteration at a single time point. These changes are not regarded in the case of dynamic explicit co-simulation. To improve this, the semi-implicit approach saves time history for the exchanged quantities. Those values are used to provide an approximation of the received quantities (e. g. force) with respect to the outgoing quantities (e. g. position). With this approximation it is then possible to consider the internal state changes also in case of the explicit dynamic co-simulation.

The user has to set an additional option (see ▷ 3.2.7 Algorithm Step ◁) to allow the adapter to use the semi-implicit mode. Otherwise the incoming quantities stay constant for the different iterations of a single time point. The concept of the semi-implicit mode is very similar to the usage of the `SYSFNC` in Adams.

The only elements, which may use this option are `GFORCE` and `MOTION`. However because of the `MOTION` statement introduces a constraint, it is not recommended to use the `SYSFNC` in this statement (see Adams documentation for more details). That's why the `GFORCE` element is the only one which uses the semi-implicit mode.

The relations between outgoing and incoming quantities can be adjusted in a very detailed manner. It is possible to introduce a dependency between any `MARKER` in the Adams model and any `GFORCE` element. For this purpose the user can

- Copy the desired `MARKER` in the components selection list (press right mouse button and select copy).
- Introduce a mesh on which the `MARKER` sends some information (e. g. velocity).
- Add the copy of the `MARKER` to the mesh with the `GFORCE`.

Now the Adams adapter knows that there is a relation between outgoing velocity on the `MARKER` and the incoming values of the `GFORCE` element. If the `MARKER` is not copied to the mesh with the `GFORCE` element, no dependency is defined. In this case the velocity is just sent to the partner code.

It is also possible to copy the `GFORCE` element itself and define multiple meshes with the same `GFORCE` element. The Adams adapter collects all these definitions to a single coupling element. It is e. g. possible to copy the `GFORCE` and introduce two meshes. On the first one the `GFORCE` element will receive e. g. a force. On the second mesh the `GFORCE` element will send the acceleration (of the `I-MARKER`). This is necessary if the co-simulation partner provides two different elements for those quantities (e. g. two variables in MATLAB, see ▷ VII-12 Spring Mass System ◁).

3.2.8.2 Partial Derivatives in Adams

In Adams the predictor-corrector-approach (see Adams documentation) is implemented to solve the equation of motion. In corrector iterations a system of nonlinear equations is considered. For this purpose Adams uses e. g. the Newton method. This algorithm utilizes partial derivatives with respect to generalized coordinates for solving nonlinear equations.

The Adams adapter can provide the partial derivatives of the incoming quantities with respect to the outgoing quantities. To allow this the user must check the option Provide partials ((semi-)implicit mode only).

To provide the partial derivatives the Adams adapter will store the incoming and outgoing quantities. These saved values are then used to calculate a numerical approximation of the partial derivatives. Different parameters can be adjusted to control the calculation (see ▷ 3.2.7 Algorithm Step ◁).

The partial derivatives are only provided for the quantities which relate to each other within the scope of the co-simulation. The definition of the dependencies is described in ▷ 3.2.8.1 Semi-implicit Mode ◁. Please see ▷ VII-12 Spring Mass System ◁ for more details.

3.2.9 Go Step

In the Go step following options are general and can be set independent of the selected coupling scheme (cf. Figure 3):

No. of parallel threads Number of parallel threads for the Adams execution. The maximum value is 8.

Enter a job name This name is used to concatenate the job name, which is saved by Adams. With this option one can produce different co-simulation scenarios with different names for the same Adams model.

Optional Adams subroutines file Provide a subroutine list file to include with the creation of an Adams customized solver code. This file with suffix .lst contains the absolute pathname to the file to include per line. This could be a FORTRAN source file (`".f"`) or an object file (`".o"` or `".obj"`).

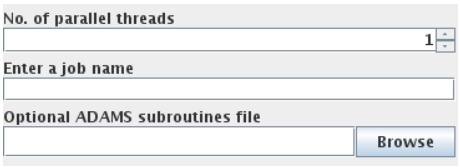


Figure 3: General Adams options in the Go step

For a Steady state analysis following options are additionally available in the Go step (cf. Figure 4):

Choose set of allowed EQUILIBRIUM methods Select this option to specify a set of particular methods to be used for the equilibrium solution. The selected methods are handed over to Adams via the `MSC_USE_ALTERNATE_SOLVERS` variable. See Adams documentation for a description of the methods in more detail. If no method is selected, ORIGINAL will be used as default method.

ORIGINAL
ORIGINAL+Krylov
ORIGINAL+UMF
Newton+Krylov
Tensor-Krylov block-3
Tensor-Krylov block-2+
Broyden-Armijo
Trust-Region
Hooke-Jeeves

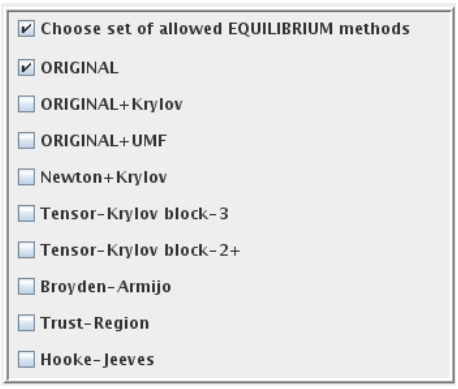


Figure 4: Additional Adams options in the Go step for steady-state studies

3.2.10 Running the Computation

With the Start button Adams is started with the options given in the Go step.

In the explicit mode Adams sends and receives data for each time step. In the implicit mode also for each iteration within the time step.

If the Stop button is pressed, Adams receives a `STOP` command from the adapter and terminates the simulation.

During the Adams run you can check for the Adams log file. The messages of the co-simulation progress and of the Adams simulation can be found there. In case of any issue with Adams, please first check the Adams log file for further information.

3.2.10.1 Batch Execution

Adams always runs as a batch process, therefore no special settings are necessary for batch execution.

3.2.11 Post-Processing

Post-processing for the Adams part of the results can be performed as in ordinary computations, e. g. with Adams/View. The "<*job name*>`.res`" file can be found in the same directory as the input file.

3.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for Adams are:

```
Usage:
   mpcci Adams [-]option


Synopsis:
   'mpcci Adams' is used to get information about Adams.


Options:
   -diff     <ACF|ADM> <ACF|ADM>   Run the scanner on two <ACF|ADM>
                                   control files and print the differences.
   -help                           This screen.
   -info                           List verbose information about all Adams releases.
   -products                       List all available licensed Adams products.
   -releases                       List all Adams releases which MpCCI can find.
   -scan     <ACF|ADM>             Run the scanner on the Adams <ACF|ADM>
                                   control file and create a scanner output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

The subcommand `products` lists the available Adams products, e. g. those for which licenses are available. The list looks like:

```
> mpcci adams -products
acar
carride
driveline
```

3.4 Code Adapter Reference

3.4.1 Data Exchange

Coupling scheme	Data exchange
Explicit	at the end of the time step
Implicit	before each iteration and at the end of the time step

3.4.2 Patched Input File

Before a coupled simulation is started, MpCCI patches the Adams model file. For the files `"*.adm"` and `"*.acf"` selected in the Models step, new files `"mpcci_*.adm"` and `"mpcci_*.acf"` are created. The `"mpcci_*.adm"` contains the modified definition of the selected co-simulation elements, e. g. `GFORCE`. The original element statement is removed.

For the `MOTION` also the complete definition is replaced by MpCCI. Especially if only one quantity, e. g. position, is received on this element and the definition does not determine the complete set of the degree of freedom. In this case the further boundary conditions, e. g. the angular coordinates, are removed. The definition of the element then consists only of the constraints for the position. The complete `MOTION` statement is considered to be provided by MpCCI and therefore the angular coordinates are assumed to be zero. If this is not desired, the user can provide an additional `MOTION` element for the same marker, which is then selected for the co-simulation.

It is also possible to couple the `VARIABLE` statement in Adams. One can provide the values of the `VARIABLE` to the partner code or receive any information. In both cases the values must be scalar. The special option is to receive the Time-Step-Size. One can assign the value to any `VARIABLE` for e. g. monitor purpose. However the value will be used internally by the Adams adapter to adjust the communication step size.

In addition to the element statement, the patched `"*.adm"` file will contain some arrays which provide information requested by the adapter. This arrays are placed right after the element statements. The lines inserted by MpCCI may e. g. look as follows for the `GFORCE` statement:

```
!     adams_view_name='ActFrontLeft'
GFORCE/6
, I = 1023
, JFLOAT = 1025
, RM = 1024
,FUNCTION = USER(3,6,0)\
,ROUTINE = /.../libadamsmpcci.so::mpcci_c_gforce
!
!
!
!     adams_view_name='mpcci user function GFORCE-6::ActFrontLeft support array'
ARRAY/1133
, IC
, SIZE = 10
, NUMBERS = 1,7,3,6,898822979,7,1023,0,0,6
!
```

The settings in this block reflect the user's choices in the MpCCI GUI. The support array contains information about outgoing and received quantities.

In the `"*.acf"` file the `SIMULATE` statement is replaced by the calls to `CONSUB` routine which is provided by the adapter. The modified statement may look as follows:

```
CONTROL/FUNCTION = USER(2,3,5E-3,1E-3,1e-09,1E-3,1E-5,0.0)\
ROUTINE=/.../libadamsmpcci.so::mpcci_c_consub
```

In case Adams/Car or Adams/Chassis is used calls to

- EventRunAll
- EventRunNext
- EventRunFor
- EventRunUntil

are also replaced by the calls to the MpCCI `CONSUB` routine.

For Adams/Chassis, simulations started by `CONTROL/FUNC=USER(...)` (see Adams/Chassis documentation) will not be replaced by the `CONSUB` from MpCCI. But the co-simulation starts normally in the events defined by `CONTROL/FUNC=USER(...)` also in this case. However, MpCCI skips the transfers for those events if the coupling scheme Explicit for transient studies is selected.

4 ANSYS

4.1 Quick Information

Company name	ANSYS, Inc.
Company homepage	www.ansys.com
Support	ANSYS Customer portal at support.ansys.com
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁ ▷ VII-5 Pipe Nozzle ◁ ▷ VII-8 Exhaust Manifold ◁ ▷ VII-10 Busbar System ◁

4.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		X	
		X	
		X	
		X	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	X	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	SolidStructure	X	▷ V-3.1.1 Physical Domains ◁
	SolidThermal	X	
	SolidAcoustics	X	
	ElectroMagnetism	X	

4.1.2 Supported Platforms and Versions

The following versions of ANSYS are supported by MpCCI:

	Supported versions																				
MPCCI_ARCH: Code platform	160	161	162	170	171	172	180	181	182	190	191	192	193	194	195	201	202	211	212	221	222	231
lnx4_x64: linx64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: winx64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

4.1.3 References

The ANSYS installation contains a detailed documentation. We especially refer to:

ANSYS APDL Programmer's Guide. The ANSYS Parametric Design Language (APDL) is needed to run a co-simulation.

4.1.4 Adapter Description

The ANSYS adapter is a shared library which is loaded by ANSYS. The adapter functions must be called from an APDL script. The adapter offers via the APDL command (▷ 4.2.2.2 Available Commands ◁) the usage of the MpCCI morpher.

4.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary ANSYS installation.
- Know the list of available ANSYS products you may use (see section 4.1.6). This is required to start the ANSYS code.
- Set the ANSYS license environment variables properly for a ANSYS standalone computation. In order to let MpCCI figuring out the available ANSYS product you may use MpCCI is inspecting the following environment variable: `ANSYSLMD_LICENSE_FILE`.
  This environment variable should be set to the FLEXlm license server with a similar information value: `portnumber@server`.
  This may be checked by executing the command `mpcci ansys product` which lists the available product installed at your site.
  If the command fails because of some license connection issue, you can set the following environment variable `MPCCI_ANSYS_PRODUCT_LIST` containing the list of products separated by colon, semicolon or space. For example:
  `export MPCCI_ANSYS_PRODUCT_LIST=ansys:ane3fl:strucds`
  It is required that ANSYS can run in standalone correctly and can get a license without any issue.

4.1.6 Supported ANSYS Product Variable

The following table shows all ANSYS products and their associated feature name as used in the ANSYS license file INCREMENT lines supported by MpCCI.

Product	Feature Names
ANSYS Multiphysics/LS-DYNA	ane3flds
ANSYS Multiphysics 1	ane3fl1
ANSYS Multiphysics 2	ane3fl2
ANSYS Multiphysics 3	ane3fl3
ANSYS Multiphysics/LS-DYNA PrepPost	ane3fldp
ANSYS Mechanical	ansys, ansysul, ansysuh, ansysrf
ANSYS Mechanical/Emag	ane3
ANSYS Mechanical/FLOTRAN	anfl
ANSYS Mechanical/LS-DYNA	ansysds
ANSYS Mechanical/Emag/LS-DYNA	ane3ds
ANSYS Mechanical/CFD-Flo/LS-DYNA	anflds
ANSYS Mechanical/LS-DYNA PrepPost	ansysdp
ANSYS Mechanical/Emag/LS-DYNA PrepPost	ane3dp
ANSYS Mechanical/CFD-Flo/LS-DYNA PrepPost	anfldp
ANSYS Structural	struct, struct1, struct,2, struct3
ANSYS Structural/Emag	ste3
ANSYS Structural/FLOTRAN	stfl
ANSYS Structural/Emag/CFD-Flo	ste3fl
ANSYS Structural/LS-DYNA	structds
ANSYS Structural/Emag/LS-DYNA	ste3ds
ANSYS Structural/CFD-Flo/LS-DYNA	stflds
ANSYS Structural/Emag/CFD-Flo/LS-DYNA	ste3flds
ANSYS Structural/LS-DYNA PrepPost	structdp
ANSYS Structural/Emag/LS-DYNA PrepPost	ste3dp
ANSYS Structural/CFD-Flo/LS-DYNA PrepPost	stfldp
ANSYS Structural/Emag/CFD-Flo/LS-DYNA PrepPost	ste3fldp
ANSYS Professional NLT	prf
ANSYS Professional/Emag	prfe3
ANSYS Professional/FLOTRAN	prffl
ANSYS Professional/Emag/FLOTRAN	prfe3fl
ANSYS Emag	emag
ANSYS Emag/FLOTRAN	emagfl
ANSYS Mechanical PrepPost	preppost
ANSYS PrepPost/LS-DYNA PrepPost	prpostdy
ANSYS FLOTRAN	flowtran
ANSYS Academic Teaching Advanced	aa_t_a, aa_mcad, aa_ds
ANSYS Academic Research	aa_r, aa_mcad

4.2 Coupling Process

Please read also ▷IV-2 Setting up a Coupled Simulation◁.

4.2.1 Model Preparation

There are some issues which you should consider while creating an ANSYS model for a co-simulation:

Supported element types. Not all ANSYS element types are supported, the supported types are given in Table 1.

Dummy surface elements for surface coupling. For surface coupling, additional surface elements must be used for quantity exchange. For instance SHELL63 elements for a fluid structure interaction or SHELL57 elements for thermal coupling can be used as dummy elements to receive forces from the partner code. The dummy elements must have the corresponding quantities you want to receive or send. Only these elements take part in the coupling process and must be either be deselected when the solution is performed or defined so weak that they do not influence the solution in case of fluid structure interaction. They can be deselected before solution is executed if only nodal quantities are sent or received, because the data transfer will then put the values to the nodes and the nodes of dummy elements are shared by the "real" solid model elements. In case of thermal coupling the dummy elements can not be deselected because the quantities wall heat transfer coefficient, wall temperature and wall heat flux are only supported as element quantities. Therefore the additional layer of shell elements (SHELL57) have to be a part of the solution. To reduce the influence on the solution you should give the shell elements the same material properties as the adjacent solid elements and a small thickness. In case of line coupling on area elements in fluid structure interaction BEAM3 elements can be used. The attached example cases for 2D and 3D fluid structure interaction contains such dummy elements. Such dummy elements are shown in Figure 1

Put elements for coupling in a component. The elements of the coupling region must be grouped into one or more element components using the `cm` command.

Predefined loads on dummy surface elements. If element based quantities WallHTCoeff, FilmTemp, WallHeatFlux, AbsPressure or OverPressure are received by ANSYS using dummy surface elements, you have to predefine surface loads on these elements in order to enable the MpCCI ANSYS adapter to select the correct element sides to store the received values. Therefore select the coupled element set and the attached nodes and define a dummy load, depending on the received quantities:

- WallHTCoeff and FilmTemp: `~SF, ALL, CONV, 1, 300`
- WallHeatFlux: `~SF, ALL, HFLUX, 1`
- AbsPressure or OverPressure: `~SF, ALL, PRES, 1`

Exchange of global quantities. For each global quantity a corresponding scalar parameter must be defined. E. g. for the time step size a parameter named "DeltaTime" is needed. Please also assign a dummy value to the parameter. This parameter must be set to the correct value in the APDL script if it is received, or the parameter must be evaluated in the APDL script. Global quantities can thus be regarded as simple variables which can be filled with values by `~mpcci, receive` or whose values are read by `~mpcci, send`.

Assign unique material property numbers. Every element of your model must be assigned a unique material property number if you want to send material property values to ANSYS, e. g. the electrical resistivity. In ANSYS you define such numbers with the `mp` command.

Possible quantities depend on degrees of freedom. Normally the degree of freedom of the elements involved in the coupling process determines which quantities can be transferred. It is laborious to find out if all degrees of freedom are actually supported by the ANSYS API. As this API is used for the MpCCI ANSYS–adapter, it is not guaranteed that all theoretically supported degrees of freedom are valid.

Not carefully tested. Only few of the element type mappings are already validated with certain quantities. The compatibility index in Table 2 shows the validated element-quantity pairs. It is constantly added. Please contact us if you have problems with other combinations or need additional capabilities.

Binary database file required. You need to set up your model and store it in a binary database file (db file) because the coupled components will be extracted from this during the MpCCI scanning process.

APDL script required. For managing the co-simulation, an APDL script is required. This is described in detail in ▷ 4.2.2 APDL Script ◁.

ANSYS Element Types	Comments
BEAM3, BEAM4, BEAM23, BEAM24, BEAM44, BEAM54, BEAM188, BEAM189, SHELL51, SHELL61, SHELL208, SURF151, SURF153, SURF251 PIPE288, PIPE289, ELBOW290, MPC184,	MPCCI_ETYP_LINE2, MPCCI_ETYP_LINE3
PLANE13, PLANE25, PLANE42, PLANE55, PLANE67, PLANE181, PLANE182, SHELL28, SHELL41, SHELL43, SHELL57, SHELL63, SHELL131 SHELL143, SHELL157, HYPER56, VISCO106, CPT212, SURF252,	MPCCI_ETYP_TRIA3, MPCCI_ETYP_QUAD4
PLANE2, PLANE35	MPCCI_ETYP_TRIA3, MPCCI_ETYP_TRIA6
SHELL91, SHELL93, SHELL99, SHELL132, SHELL150, SHELL281 PLANE53, PLANE145,PLANE223, PLANE77, PLANE78, PLANE82, PLANE83, PLANE121, PLANE183, PLANE146, PLANE230 SURF152, SURF154 CPT213, HYPER74, VISCO88, VISCO108,	MPCCI_ETYP_TRIA6, MPCCI_ETYP_QUAD4, MPCCI_ETYP_QUAD8
SOLID5, SOLID45, SOLID46, SOLID62, SOLID64, SOLID65, SOLID69, SOLID70, SOLID96, SOLID97, SOLID164, SOLID285, SOLID185, HYPER58, HYPER86, VISCO107, SOLSH190, CPT215	MPCCI_ETYP_TET4, MPCCI_ETYP_WEDGE6, MPCCI_ETYP_HEX8, MPCCI_ETYP_PYRAM5
SOLID87, SOLID92, SOLID98, SOLID123, SOLID127, SOLID148, SOLID168, SOLID186,SOLID187, SOLID227, SOLID232,SOLID237, CPT217	MPCCI_ETYP_TET4, MPCCI_ETYP_TET10
SOLID90, SOLID95, SOLID122, SOLID117, SOLID122, SOLID128, SOLID147, SOLID186, SOLID191, SOLID226, SOLID231, SOLID236, VISCO89, CPT216	MPCCI_ETYP_TET4, MPCCI_ETYP_TET10, MPCCI_ETYP_WEDGE6, MPCCI_ETYP_WEDGE15, MPCCI_ETYP_HEX8, MPCCI_ETYP_HEX20, MPCCI_ETYP_PYRAM5, MPCCI_ETYP_PYRAM13
MESH200	MPCCI_ETYP_LINE2, MPCCI_ETYP_TRIA3, MPCCI_ETYP_QUAD4, MPCCI_ETYP_QUAD8

Table 1: Supported ANSYS element types

Quantity / *Element*	Joule Heat Density	Lorentz Force Density	Electric Resistivity	Nodal Positions	Wall Forces	Relative Wall Forces	Film Temperature	Wall Heat-transfer Coefficient	Wall Temperature
BEAM3				+	+	+			
SOLID5	+		+	+	+	+			
PLANE13	+	+	+						
SOLID45			+	+	+	+			
SHELL57							+	+	+
SHELL63				+	+	+			
SOLID69	+	+	+						
SHELL93				+	+	+			
SOLID97	+	+	+						
SOLID117	+	+	+						
SURF151							+	+	+
MESH200				+					
PLANE230	+		+						
SOLID231	+		+						
SOLID236	+	+	+						

Table 2: Quantities supported for different ANSYS elements.

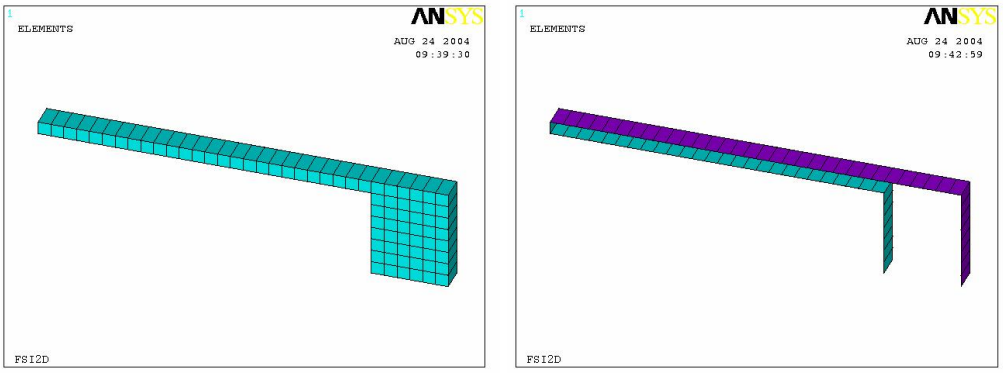


Figure 1: ANSYS Flap and Additional SHELL63 elements for coupling

4.2.2 APDL Script

In ANSYS, the coupling process is controlled via an APDL script, which calls functions provided by MpCCI.

4.2.2.1 Sample APDL Script

```
/batch
resume, ansys, db             ! resume ANSYS database "ansys.db"
/com > > >
/com > > >  set initial transfer tag (before MpCCI initialization!)
/com > > >
!             time, iter
~mpcci, settag, -1, 0

~mpcci, init, 2D              ! initialize MpCCI for 2D analysis
fini

/solu
antype, transient, new        ! new transient analysis
trnopt, full                  ! full Newton-Rhapson


/com > > >
/com > > > initial data transfer controlled via 'Initial quantities transfer' setting:
/com > > > send / receive / exchange
\todo{update the above mentioned commands based on the new gui}

~mpcci, exchange     ! exchange data


*do, i, 1, steps+1
  *if, i, ne, 1, then         ! first run is dummy
    esel, all $ nsle          ! make sure to have all of the model
    cmsel, u, TOP             ! deselect the beam elements,
    cmsel, u, BOTTOM          ! only used for transfer of values
    nsle
    time, PhysicalTime        ! time at the end of this loadstep
    solve                     ! solve this time step
    ~mpcci, settag, PhysicalTime, i
    ~mpcci, exchange          ! exchange data via MpCCI
  *endif
*enddo

fini                          ! finish solution routine
~mpcci, stop                  ! finalize the co-simulation
/exit, nosa                   ! quit ANSYS
```

Before initializing MpCCI the transfer tag should be set. This transfer tag assigns to the quantity value a time and/or iteration information.
MpCCI is initialized by `~mpcci, init, 2D`. This means the model is two dimensional.

First we do an Initial quantities transfer call by executing the command `~mpcci, exchange`. In MpCCI GUI depending on the value set the script will automatically execute one of the actions:

- `receive`. ANSYS receives data.
- `send`. ANSYS sends data.
- `exchange`. ANSYS exchanges data.

Next the loop for the coupled simulation starts with one dummy run first. ANSYS sometimes has problems without this dummy run. Afterwards the solution `~mpcci, settag, PhysicalTime, i` sets the current time and iteration for the solution quantity and `~mpcci, exchange` sends the nodal positions to the partner code. ANSYS will wait until the partner code has received this data. Following it waits for the partner code to finish the solution and receives the results. The loop continues until the final step is reached.

The command `~mpcci, stop` is finishing the MpCCI process regularly and ANSYS could be finished.


If element table items should be transferred, generate them before the send or exchange command is executed.

4.2.2.2 Available Commands

The command for MpCCI calls within ANSYS is `~mpcci` followed by command line options. The following command line options are valid, where `*` marked values are default values and options in square brackets `[]` are optional.

```
~mpcci, FSIMAP, filename.ml
~mpcci, WRCPL, filename.cpl
~mpcci, WRGMD, filename.gmd, element-component,
               fixed-nodes-component, floating-nodes-component
~mpcci, MORPH  [, node-component | EXIT ]
~mpcci, SETTAG [, time [, iter  ]]
~mpcci, STATUS
~mpcci, *HELP
~mpcci, INIT     [, 2D | 3D | AX | *AUTO]
~mpcci, SEND     [, ALWAYS | ONEWAIT | ALLWAIT ]
~mpcci, RECEIVE  [, ALL | ANY | AVAILABLE | COMPLETE ]
~mpcci, EXCHANGE [, ALWAYS | ONEWAIT | ALLWAIT [, ALL | ANY | AVAILABLE | COMPLETE ]]
~mpcci, REMESH   [,  MOVE | *TOTAL ]
~mpcci, QSTAT
~mpcci, STOP
~mpcci, QUIT
```

The available commands have the following functionality:

~mpcci, FSIMAP, <*filename*>**.ml**
: Writes a component list file with all defined element components with the mesh information in "<*filename*>.ml". This file is normally generated and used by the MpCCI FSIMapper, but can also be generated with the `fsimap` command option. Then the MpCCI FSIMapper will use this file for the file based mapping.

Only for internal use.

~mpcci, WRCPL, <*filename*>**.cpl**
: Writes a component list file with all defined components and variables into "<*filename*>.cpl". This file is normally generated and used by the MpCCI GUI, but can also be generated with the `wrcpl`

command option. Then the GUI will use this file for the "<*filename*>.db" file.
Only for internal use.

~mpcci, WRGMD, <*filename*>.gmd, element-component, fixed-nodes-component, floating-nodes-component
Writes an MpCCI Grid Morpher data file.

~mpcci, MORPH [, node-component | EXIT]
Executes the MpCCI Grid Morpher. If EXIT is given the MpCCI Grid Morpher exits.

~mpcci, SETTAG [, time [, iter]]
Defines the current time, iteration for the solution quantities to request.

~mpcci, STATUS
Print the actual MpCCI status.

~mpcci, HELP
Print list of available commands.

~mpcci, INIT [, 2D | 3D | AX | *AUTO]
Initializes the MpCCI process.

~mpcci, SEND [, ALWAYS | ONEWAIT | ALLWAIT]
Performs a SEND transfer action, sending data from ANSYS to the partner code.

- If ALWAYS is given, ANSYS always sends all requested quantities.
- If ONEWAIT is given, ANSYS is waiting for at least one partner code (which is using the quantities) before sending all quantities for an uni-directional coupling scheme. For a bi-directional coupling scheme, ANSYS sends the data only if at least one partner code is ready to receive the data, otherwise this operation is skipped.
- If ALLWAIT is given, ANSYS is waiting for all partner codes (which is using the quantities) before sending all quantities for an uni-directional coupling scheme. For a bi-directional coupling scheme, ANSYS sends the data when all partner codes are ready to receive the data, otherwise this operation is skipped.

~mpcci, RECEIVE [, *ALL | ANY | AVAILABLE | COMPLETE]
Performs a RECEIVE transfer action, receive data from the partner code.

- If ALL is given, ANSYS always waits for all requested quantities.
- If ANY is given, ANSYS receives all quantities if at least one quantity is available from the partner code, if not, ANSYS will continue and no data will be transferred.
- If AVAILABLE is given, ANSYS does not wait and get the available new data from the partner code.
- If COMPLETE is given,ANSYS receives only if all quantities are available, if not ANSYS will continue and no data will be transferred.

~mpcci, EXCHANGE [, ALWAYS | ONEWAIT | ALLWAIT [, ALL | ANY | AVAILABLE | COMPLETE]
Performs EXCHANGE transfer operation, first SEND followed by RECEIVE.

- The first optional argument corresponds to the send operation mode.
- The second optional argument corresponds to the receive operation mode.

~mpcci, REMESH [, MOVE | *TOTAL]
Notifies MpCCI that a remesh has been requested by user. If MOVE is given, this represents a mesh deformation, in opposite to TOTAL which is a remeshing of the domain.

~mpcci, QSTAT
Queries the MpCCI server about the capability to receive quantities.

- MPCCI_QSTAT > 0 ANSYS can receive.
- MPCCI_QSTAT < 0 there is no need to receive.
- MPCCI_QSTAT $= 0$ ANSYS cannot receive.

~mpcci, STOP
Performs an MpCCI `stop` and stops the whole MpCCI process.

~mpcci, QUIT
Performs an MpCCI `quit` and quits the MpCCI process within ANSYS.

4.2.2.3 Data Access

In the GUI-option receive/send method there are two methods:

Direct direct read or store of data using "UPF" (user programmable feature) subroutines

ETAB only send possible (no receive of values into "ETAB")

Here the ETAB option means that a quantity is read out of an element-table ("ETAB"). It is only valid when sending an element based quantity.
If the quantity is a scalar quantity with dim=1 (e. g. Joule heat density), choose a storage index sindex. The user has to generate a element table fulfilling the naming convention:

```
etab, MPCCI_<sindex>, <item>, <component>
```

For example: To get joule heat density from storage index 0 the APDL command should be:

```
etab, MPCCI_00, jheat
```

(see ANSYS documentation of `ETABLE` command for details)
The user has to fill the "ETAB" with sensible values before the quantities are sent to the partner application.
If the quantity has a dimension >1 (vector quantity) then you have to generate element tables following this naming convention:

```
etab, MPCCI_<sindex>,   <item>, <component>
etab, MPCCI_<sindex+1>, <item>, <component>
etab, MPCCI_<sindex+2>, <item>, <component>
```

For example: to get define Lorentz force density vector into element tables starting with storage index 5 the APDL command could be:

```
etab, volu, volu                ! element volume
sexp, MPCCI_05, lfx, volu,,-1   ! lorentz force density
sexp, MPCCI_06, lfy, volu,,-1
sexp, MPCCI_07, lfz, volu,,-1
```

4.2.3 Models Step

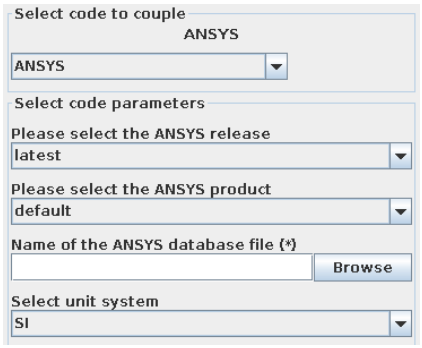


Figure 2: ANSYS options in the Models step

In the Models step, the following options must be chosen:

ANSYS Release Select the ANSYS release you wish to use. Only supported releases are listed. latest always refers to the latest supported version (default). The release should match the input file.

ANSYS product to run Choose one of the ANSYS products you have licensed, see also section 4.1.6.

ANSYS database file (*) Select the ANSYS database which contains your model definitions.

Unit system Select the unit system which was used in ANSYS (see ▷ 1.2 Unit Systems ◁).

4.2.4 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁. There is no special specified setting for ANSYS.

4.2.5 Regions Step

ANSYS supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Line, Face, Volume	Element	Direct, ETAB	Direct
BodyForce	Vector	0.0 N/m^3	flux dens.	Volume	Node, Element	ETAB	
CGAngle	Vector	0.0 rad	g-max	Global	global	APDL	APDL
CGOmega	Vector	0.0 rad/s	g-max	Global	global	APDL	APDL
CGPosition	Vector	0.0 m	g-max	Global	global	APDL	APDL
CGVelocity	Vector	0.0 m/s	g-max	Global	global	APDL	APDL
ChargeDensity	Scalar	0.0 C/m^3	field	Line, Volume	Element	ETAB	Direct
Current1	Scalar	0.0 A	g-max	Global	global	APDL	APDL
Current2	Scalar	0.0 A	g-max	Global	global	APDL	APDL
Current3	Scalar	0.0 A	g-max	Global	global	APDL	APDL
Current4	Scalar	0.0 A	g-max	Global	global	APDL	APDL

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
CurrentDensity	Vector	0.0 A/m^2	flux dens.	Line, Face, Volume	Element	Direct	Direct
DeltaTime	Scalar	1.0 s	g-min	Global	global	APDL	APDL
ElectrCond1	Scalar	0.0 S/m	field	Line, Face, Volume	Element	Direct	Direct
ElectrCond3	Vector	0.0 S/m	field	Line, Face, Volume	Element	Direct	Direct
ElectrCondX	Scalar	0.0 S/m	field	Line, Face, Volume	Element	Direct	Direct
ElectrCondY	Scalar	0.0 S/m	field	Line, Face, Volume	Element	Direct	Direct
ElectrCondZ	Scalar	0.0 S/m	field	Line, Face, Volume	Element	Direct	Direct
ElectricField	Vector	0.0 V/m	field	Line, Volume	Element	ETAB	
ElectricFlux	Vector	0.0 C/m^2	flux dens.	Line, Volume	Element	ETAB	
ElectricPot	Scalar	0.0 V	field	Line, Face, Volume	Node	Direct	Direct
ElectrRes1	Scalar	0.0 ohm m	field	Line, Face, Volume	Element	Direct	Direct
ElectrRes3	Vector	0.0 ohm m	field	Line, Face, Volume	Element	Direct	Direct
ElectrResX	Scalar	0.0 ohm m	field	Line, Face, Volume	Element	Direct	Direct
ElectrResY	Scalar	0.0 ohm m	field	Line, Face, Volume	Element	Direct	Direct
ElectrResZ	Scalar	0.0 ohm m	field	Line, Face, Volume	Element	Direct	Direct
Enthalpy	Scalar	0.0 W/m^3	flux dens.	Volume	Node, Element	ETAB	
FilmTemp	Scalar	300.0 K	field	Face	Element		Direct
Force	Vector	0.0 N	flux integral	Point	Node	Direct	Direct
HeatFlux	Vector	0.0 W/m^2	flux dens.	Volume	Node, Element	ETAB	
HeatSource	Scalar	0.0 W/m^3	flux dens.	Volume	Node, Element	ETAB	
IntFlag	Scalar	0	g-max	Global	global	APDL	APDL
IterationNo	Scalar	0	g-max	Global	global	APDL	APDL
JouleHeat	Scalar	0.0 W/m^3	flux dens.	Volume	Element	Direct, ETAB	Direct
LorentzForce	Vector	0.0 N/m^3	flux dens.	Volume	Node, Element	Direct, ETAB	Direct
MagneticField	Vector	0.0 A/m	field	Line, Volume	Element	ETAB	
MagneticFlux	Vector	0.0 T	flux dens.	Line, Face, Volume	Element	Direct	
NPosition	Vector	0.0 m	mesh coordinate	Line, Face, Volume	Node	Direct	

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
OverPressure	Scalar	0.0 N/m^2	flux dens.	Line, Face, Volume	Element	Direct, ETAB	Direct
PhysicalTime	Scalar	0.0 s	g-min	Global	global	APDL	APDL
PointPosition	Vector	0.0 m	mesh coordinate	Point	Node	Direct	Direct
RealFlag	Scalar	0.0	g-max	Global	global	APDL	APDL
RefPressure	Scalar	1.12e5 N/m^2	g-max	Global	global	APDL	APDL
RelWallForce	Vector	0.0 N	flux integral	Face	Node		Direct
Residual	Scalar	0.0	g-max	Global	global	APDL	APDL
Temperature	Scalar	300.0 K	field	Line, Volume	Node, Element	Direct, ETAB	Direct
ThermCond1	Scalar	0.0 W/m K	field	Line, Face, Volume	Element	Direct	
ThermCond3	Vector	0.0 W/m K	field	Line, Face, Volume	Element	Direct	
ThermCondX	Scalar	0.0 W/m K	field	Line, Face, Volume	Element	Direct	
ThermCondY	Scalar	0.0 W/m K	field	Line, Face, Volume	Element	Direct	
ThermCondZ	Scalar	0.0 W/m K	field	Line, Face, Volume	Element	Direct	
TimeStepNo	Scalar	0	g-max	Global	global	APDL	APDL
Torque	Vector	0.0 N m	flux integral	Point	Node	Direct	Direct
Velocity	Vector	0.0 m/s	field	Volume	Element		Direct
Voltage1	Scalar	0.0 V	g-max	Global	global	APDL	APDL
Voltage2	Scalar	0.0 V	g-max	Global	global	APDL	APDL
Voltage3	Scalar	0.0 V	g-max	Global	global	APDL	APDL
Voltage4	Scalar	0.0 V	g-max	Global	global	APDL	APDL
WallForce	Vector	0.0 N	flux integral	Face	Node		Direct
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Element	Direct	Direct
WallHTCoeff	Scalar	0.0 W/m^2 K	field	Face	Element		Direct
WallTemp	Scalar	300.0 K	field	Face	Node, Element	Direct	Direct

4.2.6 Go Step

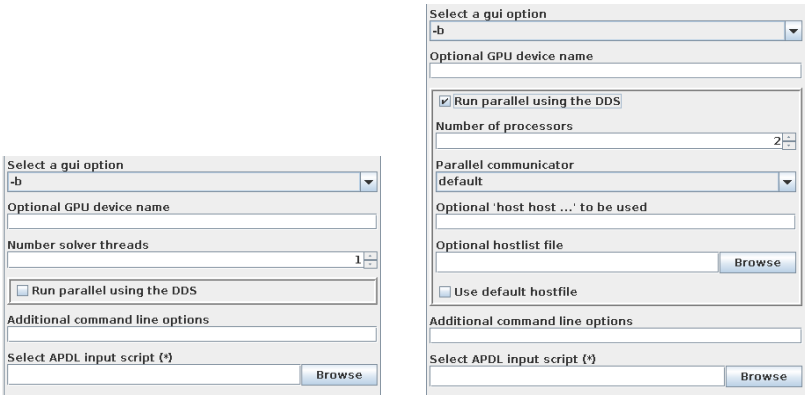


Figure 3: ANSYS options in the Go step with SMP (left) and DDS (right)

In the Go step, the following options can be selected:

Select a gui option It is recommended to select -b to start ANSYS in the batch mode.
With -g ANSYS is started with a graphical user interface with one of the graphics devices: -d X11 is the standard UNIX device, use -d X11C to activate light-shading on devices with more than 16 colors. -d WIN32 and -d WIN32C are the corresponding devices for Windows. The option -d 3D should be used if you have a 3-D graphics device.

Optional GPU device name Define the GPU device name (intel, nvidia) to be used by ANSYS.
ANSYS command line option is `-acc`.
For example: `-acc intel -na 1`

No. solver threads Set the number of solver threads used by ANSYS with SMP (Shared Memory Parallel).
ANSYS command line option is `-np`.

Run parallel using the DDS Setting this option activates the Distributed Domain Solver.
ANSYS command line option is `-dis`.
Feature is not supported if the quantity NPosition is exchanged.

No. of processors Enter the number of processors to use during the analysis.
ANSYS command line option is -np.

Parallel communicator Select the parallel communicator as given in the ANSYS manual, this is passed as option `-mpi=` to ANSYS.

Optional 'host host ...' to be used Enter host names for parallel execution of ANSYS.

Optional hostlist file Specify a hostfile, from which host names are extracted.

Use default hostfile A default hostfile can be configured by setting `MPCCI_HOSTLIST_FILE`, see ▷ V-3.6.2 Hostlist File ◁.

Additional command line options You can specify additional ANSYS command line options here, which are described in "3.1 Starting an ANSYS Session from the Command Level" of the ANSYS documentation.

Select APDL input script Select the file containing the APDL script you created for the analysis (see ▷ 4.2.2 APDL Script ◁).

4.2.7 Running the Computation

When the Start button is pressed, ANSYS is started with the options given in the Go step. If the Stop button is pressed, a stop-file `"*.ABT"` is created (see also "Basic Analysis Guide, 3.8 Terminating a Running Job" in the ANSYS documentation) and ANSYS will stop the next time it checks the presence of a stop file.

4.3 Code-Specific MpCCI Commands

The MpCCI commands which are available for ANSYS are:

```
Usage:
   mpcci ANSYS [-]option


Synopsis:
   'mpcci ANSYS' is used to get information about ANSYS.


Options:
   -align  <ARGS>
            Do a coordinate transformation on all nodes of a .cdb
            file based on a plane definition file and align the
            nodal coordinates for the coupling partner.

   -convert  <db file> [product] [release]
            Run the converter and create an FSIMapper input file.

   -dbcheck  <db file> [release]
            Check a .db or .cdb file.

   -dbsave  <jobname> <folder_name>
            Copy all esav, osav, emat, rst files with the job name
            to the archive folder.

   -help
            This screen.

   -info
            List verbose information about all ANSYS releases.

   -products
            List all available licensed ANSYS products.

   -releases
            List all ANSYS releases which MpCCI can find.

   -scan  <db file> [product] [release]
            Run the scanner and create a scanner output file.
```

The subcommands `align`, `info`, `releases` and `scan` are described in ▷1.1 Common MpCCI Subcommands for Simulation Codes◁.

`mpcci ansys -convert <db file> [product] [release]`

The `convert` subcommand runs the converter for the given ANSYS db file and creates an MpCCI FSIMapper input file. Optionally the ANSYS product and release can be specified. The defaults are ansys product and latest release.

```
Usage:
   mpcci ANSYS convert <db file> [product] [release]
```

```
Examples:
   mpcci ANSYS convert manifold.db
   mpcci ANSYS convert busbar.db emag
   mpcci ANSYS convert elastic_flap.db ansys 11
   mpcci ANSYS convert nozzle.cdb 11
```

mpcci ansys -dbcheck <db file> [release]

The `dbcheck` subcommand checks a `".db"` or `".cdb"` file for an optional given release. The latest release will be taken as default.

```
Usage:
   mpcci ANSYS dbcheck <db file> [release]

Examples:
   mpcci ANSYS dbcheck manifold.db
   mpcci ANSYS dbcheck busbar.db latest
   mpcci ANSYS dbcheck elastic_flap.cdb 11
```

mpcci ansys -dbsave <jobname> <folder_name>

The `dbsave` subcommand copies all esav, osav, emat and rst files with the given job name to the specified archive folder.

```
Usage:
   mpcci ANSYS dbsave <jobname> <folder_name>

Examples:
   mpcci ANSYS dbsave mpccirun mpccirun.db
```

mpcci ansys -products

The `products` subcommand lists the available ANSYS products, e. g. those for which licenses are available. The list looks like:

```
> mpcci ansys -products
ane3fl
ansys
emag
structds
```

See also “Installation and Licensing Documentation, 3.4 Product Variable Table” in the ANSYS documentation.

4.4 Code Adapter Reference

Within the MpCCI distribution the "adapters" directory contains the necessary software to connect the simulation programs to MpCCI depending on your license. The files are located within the subdirectory "<*MpCCI_home*>/codes/ANSYS/adapters".

This subdirectory is further divided by several release subdirectories, e. g. "110" and "120". The version directories are further divided by several architectures (e. g. "linia32"). There you find the library files of the ANSYS adapter (e. g. "libansysmpcci.so"). The connection to MpCCI is established using these shared libraries. The binding to the APDL command `mpcci` is set in the "ans_ext.tbl" file.

To enable coupling capabilities the `mpcci` command is added to the standard APDL commands. By the command line options you decide which coupling function is called. The basic tasks of the command are to initialize the coupling and to manage the data transfer to MpCCI commands.

Ensure that the directory path of your MpCCI-APDL scripts on Windows do not contain any whitespace!

4.5 Frequently Asked Questions

Question:
Could ANSYS use automatic time stepping scheme for the coupling?
Answer:
Currently ANSYS adapter does not support it. Instead a user defined time stepping has to be implemented in the APDL script as done for example in the ▷ VII-2 Elastic Flap in a Duct ◁.

Question:
In MpCCI Regions step I can't find any component for coupling the time step size in the Global Panel. How can I activate the Global Panel?
Answer:
In ANSYS model you need to create a parameter name DELTATIME for instance with the command: `*SET,DELTATIME,1` where DELTATIME is the name of the parameter and 1 the default value. That parameter name will be also used for setting the quantity tag information (see APDL example in ▷ VII-2 Elastic Flap in a Duct ◁).

You will be to save your ANSYS model and rescan it in the MpCCI GUI.

Question:
I would like to use shell elements rather than solid ones to model a flexible wall. I wonder whether I should use two layers of plate elements to model my flexible wall: one real and one dummy.
Answer:
By using shell elements without solid for the modeling you do not need dummy elements as recommended in ▷ 4.2.1 Model Preparation ◁ and do not need two layers. You can directly use shell elements.

It is required to orient the shell element normal for the surface definition in the same direction and to apply a predefined load.

Question:
I noticed that the result of "OverPressure" transferred is quite different than with "RelWallForce". I used shell elements for modeling my wall and have defined a default load on the surface. What happens?
Answer:
In that case the surface contains a mixed orientation of the shell elements. The default load on one side of the shell element is used to know where to apply the load coming from MpCCI. By having mixed orientation of shell elements provide for force values different results than using pressure load. The model has to provide a homogeneous orientation of the shell face.

Question:
In MpCCI GUI by selecting the ANSYS product, I get the message error:

`"No valid license files or servers found."`

How can I select a product for scanning?
Answer:
Set the environment variable `ANSYSLMD_LICENSE_FILE` to the FLEXlm license server for the ANSYS product.

Execute the command `mpcci ansys product` to check ANSYS product license availability.

Question:
In MpCCI GUI by selecting the ANSYS product or by executing the command `mpcci ANSYS -products`, I get the message error:

```
mpcci ANSYS products:
   Executable
        "/home/software/MpCCI/license/linux_em64t/lmutil"
         exited with code 244.
   *** lmutil - Copyright (c) 1989-2006 Macrovision Europe Ltd. and/or
       Macrovision Corporation. All Rights Reserved.
   *** Flexible License Manager status on Tue 7/13/2010 15:43
   *** Error getting status: Invalid returned data from license server
       system. (-12,16)

mpcci ANSYS products:
   No valid license files or servers found.

mpcci ANSYS products:
   No ANSYS product found or the license is temporarily unavailable.
```

The variable `ANSYSLIC_ADMIN` is set in my user setting environments to 1056@license.com and MpCCI did not found any products.
Answer:
Set the environment variable `ANSYSLMD_LICENSE_FILE` to the FLEXlm license server for the ANSYS product.

The FLEXlm message error:
`Error getting status: Invalid returned data from license server system. (-12,16)` indicates that the port 1056 is not associate with a FLEXlm server but with the ANSYS Licensing Interconnect server.

Ask the IT for more information about the license file used for ANSYS especially for the following lines:

```
SERVER license.com  00469f763f3f 1055
VENDOR ansyslmd port=1056
```

You need to set the `ANSYSLMD_LICENSE_FILE` variable to 1055@license.com in that example.

Execute the command `mpcci ANSYS -products` to check ANSYS product license availability.

5 ANSYS Icepak

5.1 Quick Information

Company name	Fluent Inc. is a wholly owned subsidiary of ANSYS, Inc.
Company homepage	www.ansys.com
Support	ANSYS Customer portal at support.ansys.com
Tutorials	No dedicated tutorial available

ANSYS Icepak is based on FLUENT solver technology and is dedicated for 3D CFD thermal analysis applications.
For setting up the coupling with MpCCI, please refer to the FLUENT ▷9.2 Coupling Process◁.

5.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷V-3.4.2 Coupling Schemes◁
	Implicit	X	
Dimension		–	▷IV-2.6 Regions Step – Defining Coupling Regions and Quantities◁
		–	
		–	
		X	
		X	
Feature	MpCCI Configurator	–	▷V-3.5 Smart Configuration◁
	Negotiation	–	▷V-3.4.5.2 Coupling with Exchange of Time Step Size◁
	Self-Coupler	–	▷VIII-2.4.1 Code Information: `<CodeInfo>`◁
	CopyComponents	–	▷V-4.8.2.1 Copying Components◁
Domains	Fluid	X	▷V-3.1.1 Physical Domains◁
	FluidThermal	X	

5.1.2 Supported Platforms and Versions

	Supported versions																					
MPCCI_ARCH: Code platform	16.0.0	16.1.0	16.2.0	17.0.0	17.1.0	17.2.0	18.0.0	18.1.0	18.2.0	19.0.0	19.1.0	19.2.0	19.3.0	19.4.0	19.5.0	20.1.0	20.2.0	21.1.0	21.2.0	22.1.0	22.2.0	23.1.0
lnx4_x64: lnamd64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: win64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

5.1.3 Supported Quantities

ANSYS Icepak supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
DeltaTime	Scalar	1.0 s	g-min	Global	global	Dir	Dir
Enthalpy	Scalar	0.0 W/m^3	flux dens.	Volume	Code	Dir	UDM
FilmTemp	Scalar	300.0 K	field	Face	Code	Dir	UDM
HeatFlux	Vector	0.0 W/m^2	flux dens.	Volume	Code	UDM	UDM
HeatSource	Scalar	0.0 W/m^3	flux dens.	Volume	Code	UDM	UDM
IntFlag	Scalar	0	g-max	Global	global	Dir	Dir
IterationNo	Scalar	0	g-max	Global	global	Dir	Dir
JouleHeat	Scalar	0.0 W/m^3	flux dens.	Volume	Code	UDM	UDM
JouleHeatLin	Scalar	0.0 W/m^3 K	flux dens.	Volume	Code	UDM	UDM
PhysicalTime	Scalar	0.0 s	g-min	Global	global	Dir	Dir
RealFlag	Scalar	0.0	g-max	Global	global	Dir	Dir
Residual	Scalar	0.0	g-max	Global	global	Dir	Dir
SpecificHeat	Scalar	1.0 J/kg K	field	Volume	Code	Dir	UDM
Temperature	Scalar	300.0 K	field	Volume	Code	Dir	UDM
ThermCond1	Scalar	0.0 W/m K	field	Face, Volume	Code	Dir	UDM
ThermCond3	Vector	0.0 W/m K	field	Face, Volume	Code	Dir	UDM
ThermCondX	Scalar	0.0 W/m K	field	Volume	Code	Dir	UDM
ThermCondY	Scalar	0.0 W/m K	field	Volume	Code	Dir	UDM
ThermCondZ	Scalar	0.0 W/m K	field	Volume	Code	Dir	UDM
TimeStepNo	Scalar	0	g-max	Global	global	Dir	Dir
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Code	Dir	UDM
WallHTCoeff	Scalar	0.0 W/m^2 K	field	Face	Code	Dir	UDM
WallTemp	Scalar	300.0 K	field	Face	Code	Dir	UDM

5.2 Code-Specific MpCCI Commands

The MpCCI subcommands available for ANSYS Icepak are:

```
Usage:
   mpcci IcePak [-]option


Synopsis:
   Use 'mpcci IcePak' to get information about IcePak and to
   build/install your private adapter ...


Options:
   -diff  <cas1> <cas2>
            Run the scanner on two case files and print the differences.

   -help
            This screen.

   -info
            List verbose information about all IcePak releases.
```

```
-libmpcci  <RELEASE> [-64] <VERSION>
         Install the IcePak

            "libmpcci/ARCH/VERSION/libudf.so"

         in your current working directory - where the .cas and
         .dat files are located - by either just copying the MpCCI
         libudf's or remaking the libudf from MpCCI and your own
         sources located in "libmpcci/src".
         You do NOT need to have a "libmpcci/Makefile" and/or
         "libmpcci/src/makefile" prepared since the makefiles are
         generated automatically from your IcePak installation.

         RELEASE: The IcePak release.
         ARCH   : The IcePak architecture token
                  (automatically determined by MpCCI)
         VERSION: The version 2d, 3d_node etc.

         Please specify the IcePak release (e.g. 13.0.0) you
         would like to use and a list of versions (2d, 3d_node etc.).

         For more information type "mpcci IcePak libmpcci".

-libudf  <RELEASE> [-64] <VERSION> [MSVC_VERSION]
         Compile the IcePak

            "libudf/ARCH/VERSION/libudf.so"

         from your current working directory - where the .cas and
         .dat files are located - by making the libudf with your own
         sources located in "libudf/src".

         RELEASE     : The IcePak release.
         ARCH        : The IcePak architecture token
                       (automatically determined by MpCCI)
         VERSION     : The version 2d, 3d_node etc.
         MSVC_VERSION: The version of MSVC compiler to use
                       (MSVC_100, MSVC_110, MSVC_120, MSVC_140, MSVC).

         Please specify the IcePak release (e.g. 13.0.0) you
         would like to use and a list of versions (2d, 3d_node etc.).

         For more information type "mpcci IcePak libudf".

-releases
         List all IcePak releases which MpCCI can find.

-scan  <casfile>
         Run the scanner and create a scanner output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

The subcommands `libmpcci` and `libudf` are described in detail above.

6 FINE/Open

6.1 Quick Information

Company name	NUMECA International
Company homepage	www.numeca.com
Support	support@numeca.com
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁

6.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		X	
		–	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: <CodeInfo> ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	Fluid	X	▷ V-3.1.1 Physical Domains ◁
	FluidThermal	X	

6.1.2 Supported Platforms and Versions

	Supported versions
MPCCI_ARCH: Code platform	101
lnx4_x64: x86_64	X
windows_x64: win64	X

6.1.3 References

FINE/Open Documentation is part of the FINE/Open distribution. The section "Co-simulation using MpCCI " describes some expert parameter options.

6.1.4 Adapter Description

The code adapter for FINE/Open is developed by NUMECA International in cooperation with Fraunhofer SCAI. The code adapter for FINE/Open is based on a dynamic library `"libmpcci_cadapt_64.[so|dll]"`, which is loaded by FINE/Open. It includes the necessary interface functions.

6.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary FINE/Open installation.
- License feature (Solver_MPCCI) for coupled simulation using MpCCI and for mesh deformation module.

6.2 Coupling Process

6.2.1 Model Preparation

There are two options to prepare the FINE/Open model for a MpCCI coupled simulation:

1. If you are not familiar with FINE/Open, MpCCI can prepare the model `".run"` file for the coupling. In this step the boundaries will be automatically activated by MpCCI before the code starts. Therefore the FINE/Open model must be set up for a standalone simulation run.
2. If you are familiar with FINE/Open, you can set up your model as usual and activate the boundaries by yourself for the coupling.
   In this scenario you will have a scan method option in the Models Step of MpCCI GUI to select only the boundaries you have prepared for the MpCCI coupling.

The FINE/Open model (`".run"` file) has to be prepared with FINE/Open GUI. Please consider the following approach for model preparation:

- The FINE/Open solver internally operates only in SI units. The geometrical dimensions should best defined in meters. However, it is possible to define a scaling factor in FINE/Open GUI.
- During the model preparation you must assign appropriate names to the boundaries. These ones may be used for the coupling.
- When receiving the wall temperature in FINE/Open set the boundary condition of coupled walls to "Temperature Imposed", otherwise you will get an error message.
- For a 2D co-simulation analysis, the parameter iMpCCIzSize should be set to the length of the cell in z-direction (default value is 1 m). This parameter can be set from the Local parameters in the Advanced menu of the Control Variables in the Computation Control section.
- The FINE/Open computation must run in standalone.

6.2.2 Models Step

In the Models step, the following options must be chosen:

FINE/Open release Select the FINE/Open release you wish to use. Only supported releases installed on your system are listed. The selection latest always refers to the latest supported version (default).

Scan method This can be set to:

- Scan for all regions (default) – The model file is scanned for possible coupling regions.

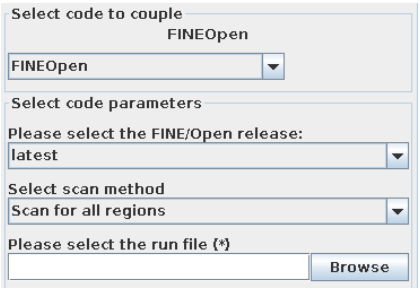


Figure 1: FINE/Open options in the Models step

- Scan predefined COUPLING regions only – The model file is scanned for the already activated coupling regions only (prepared in the FINE/Open GUI).

Run file Select the FINE/Open input file `"*.run"`.

6.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

In the Algorithm step, following additional option is available:

Solver settings

Compute steady solution This is an advanced parameter setting the FINE/Open parameter iMpCCISteadyMode_. This option forces the unsteady solver to compute a steady solution. Please consult the NUMECA International support team to get more information about the application case.

6.2.4 Regions Step

FINE/Open supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Face	Node, Element	Direct	
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	
Density	Scalar	1.0 kg/m^3	field	Volume	Node, Element	Direct	
IterationNo	Scalar	0	g-max	Global	global	Direct	
NPosition	Vector	0.0 m	mesh coordinate	Face	Node		Direct
OverPressure	Scalar	0.0 N/m^2	flux dens.	Face	Node, Element	Direct	
PhysicalTime	Scalar	0.0 s	g-min	Global	global	Direct	
RefPressure	Scalar	1.12e5 N/m^2	g-max	Global	global	Direct	
RelWallForce	Vector	0.0 N	flux integral	Face	Element	Direct	
TimeStepNo	Scalar	0	g-max	Global	global	Direct	
Velocity	Vector	0.0 m/s	field	Face	Node, Element	Direct	
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Element	Direct	

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
WallTemp	Scalar	300.0 K	field	Face	Element	Direct	Direct

It is not possible for FINE/Open solver to receive DeltaTime quantity. The time step can only be sent to the counterpart code.

6.2.5 Go Step

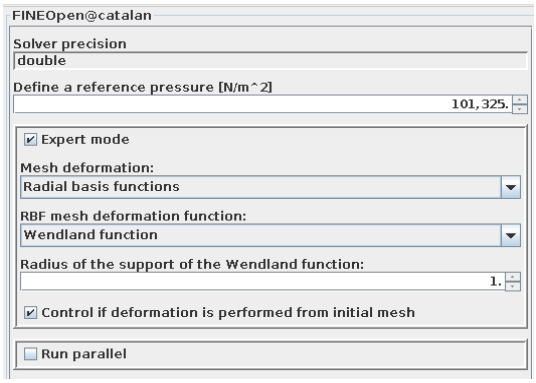


Figure 2: FINE/Open options in the Go step

Solver precision Solver precision is double.

Define a reference pressure [N/m^2] If you exchange relative pressure (e. g. RelWallForce or Overpressure), you must set the reference pressure to an appropriate value, which usually corresponds to the atmospheric pressure. The unit of this value is assumed as $\frac{N}{m^2}$.

Expert mode For FSI problems with mesh deformation involved some expert parameters have to be set correctly to choose the most appropriate deformer. Remeshing is not possible during a computation. MpCCI offers the basic FINE/Open mesh deformation settings.

Mesh deformation: Select the mesh deformation to use. This option refers to the FINE/Open parameter mov_iMovingGridMeth_.

Inverse distance weighting (if available) Use morphing method based on inverse distance weighting interpolation.

The option is available since FINE/Open 6.1. If this method is selected with an older version, the default method Radial basis functions will be applied automatically.

Quaternions method The solving of Laplace equation computing the displacement.

Radial basis functions The radial basis function interpolating the displacement on boundary nodes. (default)

If this method is selected an additional setting RBF mesh deformation function: appears with the following options:

- Thin plate spline
- Wendland function By selecting this function you will be able to define a radius for the Wendland function under the Radius of the support of the Wendland function corresponding to the FINE/Open parameter mov_rad_ (default is 1).

Control if deformation is performed from initial mesh This option refers to the FINE/Open parameter mov_iFromInitMesh_.

You can access further expert mode parameters for the mesh deformation method by using the FINE/Open GUI like:

- Coarsening level of the mesh boundary: mov_iLevelCoarse_ parameter.
- etc.

Please refer to FINE/Open documentation describing further options for the mesh deformation module.

Run parallel Select this to start a parallel run. A panel with additional options appears, which are further described in ▷ 6.2.6.1 Parallel Execution ◁.

6.2.6 Running the Computation

When the Start button is pressed, MpCCI will prepare the ".run" file corresponding to the FINE/Open project.
All the options for activating the coupling in FINE/Open are automatically done by MpCCI like:

- the coupling definition is set up for the corresponding boundary with the corresponding coupling definition (Thermal coupling, Mechanic coupling, Thermo-mechanic coupling) depending on the selected quantity to couple. Figure 3.
- the definition of the reference pressure and the activation of the Force and Torque Figure 4.

MpCCI creates a new ".run" file having a prefix "mpcci_") of the original ".run".

If the Stop button is pressed, a stop-file is created in the directory of the computation and FINE/Open will stop the next time it checks the presence of a stop file.

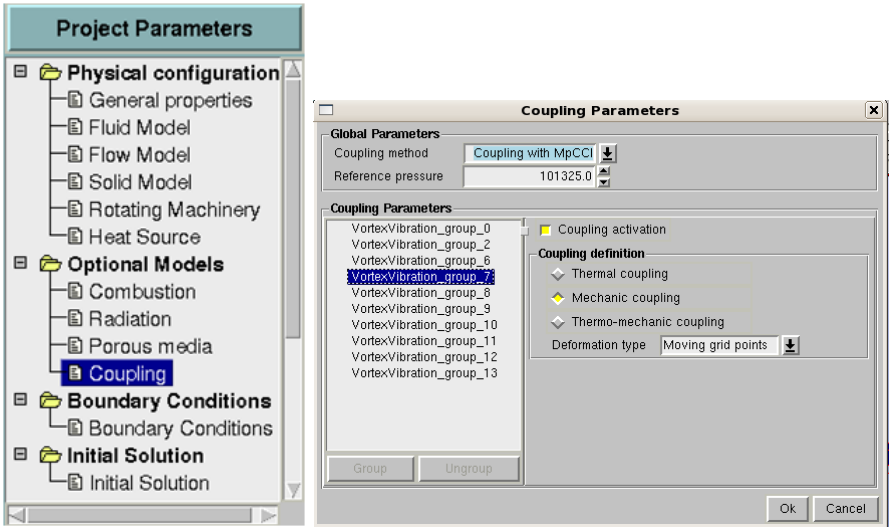


Figure 3: Identifying boundaries in FINE/Open GUI

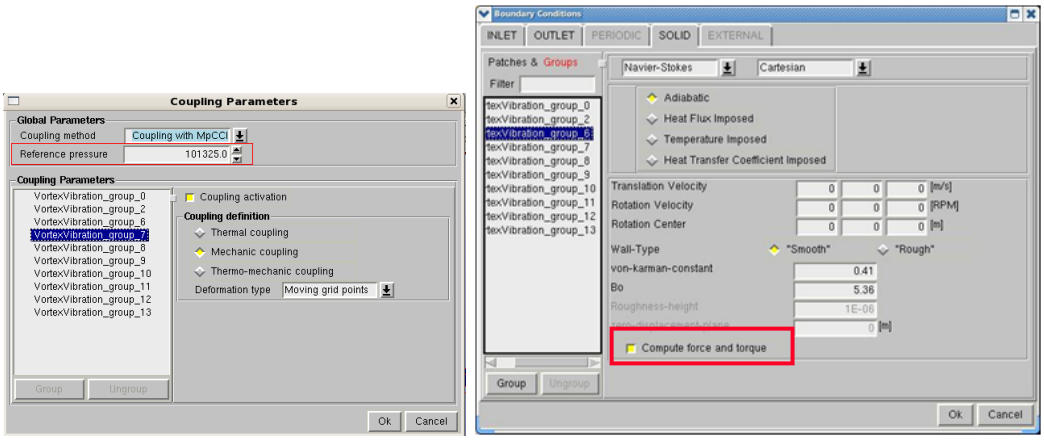


Figure 4: Setting a reference pressure and Force and Torque in FINE/Open GUI

6.2.6.1 Parallel Execution

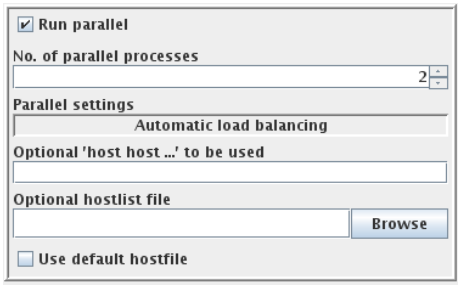


Figure 5: Parallel options

Parallel runs of FINE/Open are supported by MpCCI.

In the Go step, a set of additional options can be chosen for a parallel run as shown in Figure 5.

No. of parallel processes Enter the number of processes to use during the analysis.

Parallel settings The Automatic load balancing is used as default method for the mesh decomposition.

Optional 'host host...' to be used Enter host names for parallel execution of FINE/Open.

Optional hostlist file Specify a hostfile, from which host names are extracted ▷ V-3.6.2 Hostlist File ◁.

Use default hostfile A default hostfile can be configured by setting MPCCI_HOSTLIST_FILE ▷ V-3.6.2 Hostlist File ◁.

6.2.6.2 Batch Execution

FINE/Open always runs as a batch process.

6.2.7 Post-Processing

Post-processing for the FINE/Open part of the results can be performed as in ordinary computations, e. g. with CFVIEW, which is part of FINE/Open package.

6.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for FINE/Open are:

```
Usage:
   mpcci FINEOpen [-]option


Synopsis:
   'mpcci FINEOpen' is used to get information about FINEOpen.


Options:
   -diff  <run1> <run2>
            Run the scanner on two .run files and print the differences.
```

```
-help
        This screen.

-info
        List verbose information about all FINEOpen releases.

-releases
        List all FINEOpen releases which MpCCI can find on the local system.

-scan  <input-file>
        Run the scanner and create an output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

6.4 Code Adapter Reference

The code adapter is distributed as a dynamic library, which is located in

"<*MpCCI_home*>`/codes/FINEOpen/adapters/`".

A link to the corresponding dynamic library has to be created in FINE/Open installation directory as explained in documentation. This dynamic library is used to establish connection between MpCCI and FINE/Open.
FINE/Open supports data exchange after solution.

6.5 Limitations

- Solver is always in double precision.
- FINE/Open does not run in parallel under Microsoft Windows platform if no pvm daemon has been started.
  You can not launch a remote batch job on windows if no pvm daemon is running. Additionally you should take care of correctly configuring the MPI daemon.

7 FINE/Turbo

7.1 Quick Information

Company name	NUMECA International
Company homepage	www.numeca.com
Support	support@numeca.com
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁

7.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		X	
		–	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: <CodeInfo> ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	Fluid	X	▷ V-3.1.1 Physical Domains ◁
	FluidThermal	X	

7.1.2 Supported Platforms and Versions

	Supported versions								
MPCCI_ARCH: Code platform	111	112	121	122	131	132	141	142	151
lnx4_x64: x86_64	X	X	X	X	X	X	X	X	X
windows_x64: win64	X	X	X	X	X	X	X	X	X

7.1.3 References

FINE/Turbo Documentation is part of the FINE/Turbo distribution. The section "Co-simulation using MpCCI " describes some expert parameter options.

7.1.4 Adapter Description

The code adapter for FINE/Turbo is developed by NUMECA International in cooperation with Fraunhofer SCAI. The adapter is distributed as part of MpCCI software.

7.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary FINE/Turbo installation.
- License feature (Solver_MPCCI) for coupled simulation using MpCCI and for mesh deformation module.

7.2 Coupling Process

7.2.1 Model Preparation

The FINE/Turbo model (`".run"` file) may be prepared with the FINE/Turbo GUI. Please consider the following approach for model preparation in FINE/Turbo GUI:

- During the model preparation in FINE/Turbo you should assign appropriate names to the boundaries you intend to couple. It might be clearer for the coupling process to group coupled boundaries. The default boundary names correspond to the FINE/Turbo block zones respectively `"rows"`.
- When sending relative wall force (RelWallForce) or relative pressure (e. g. Overpressure) a reference pressure must be defined in the Reference Values Panel in Flow Model, which usually corresponds to the atmospheric pressure (see Figure 1).
- When receiving the wall temperature in FINE/Turbo set the boundary condition of coupled walls to `"Temperature Imposed"`, otherwise you will get an error message.
- The FINE/Turbo computation should in any case run in standalone.

When starting the simulation MpCCI will make a patched copy of the `".run"` file and activate certain parts which FINE/Turbo requires for a coupled simulation run. One of these operation is that the coupled surfaces are flagged. There are two options to prepare the FINE/Turbo model for a MpCCI coupled simulation:

1. If you are not so familiar with FINE/Turbo GUI, MpCCI can prepare the model `".run"` file for the coupling. In this step the boundaries will be automatically flagged by MpCCI before the code starts.
2. If you are familiar with FINE/Turbo, you can set up your model as usual and activate the boundaries by yourself for the coupling (▷ 7.2.1 Model Preparation ◁) in FINE/Turbo GUI:
   Optional Models - Fluid Structure - Thermal or Mechanical (see Figure 2, Figure 3).
   In this scenario you will have a scan method option in the Models Step of MpCCI GUI to select only the boundaries you have prepared for the MpCCI coupling (see ▷ 7.2.2 Models Step ◁).

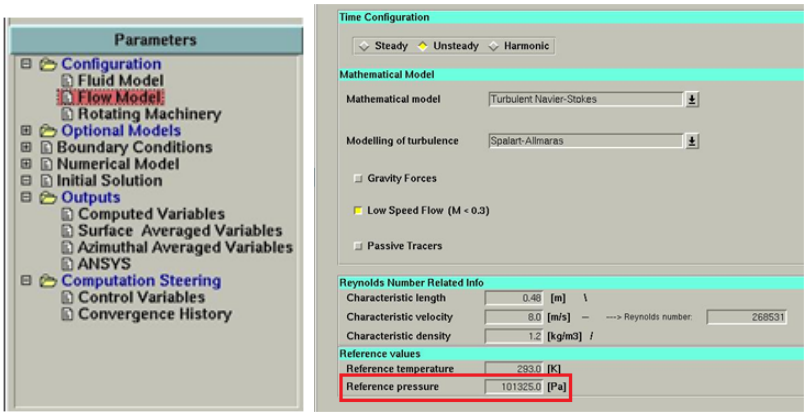


Figure 1: Setting the reference pressure in FINE/Turbo GUI

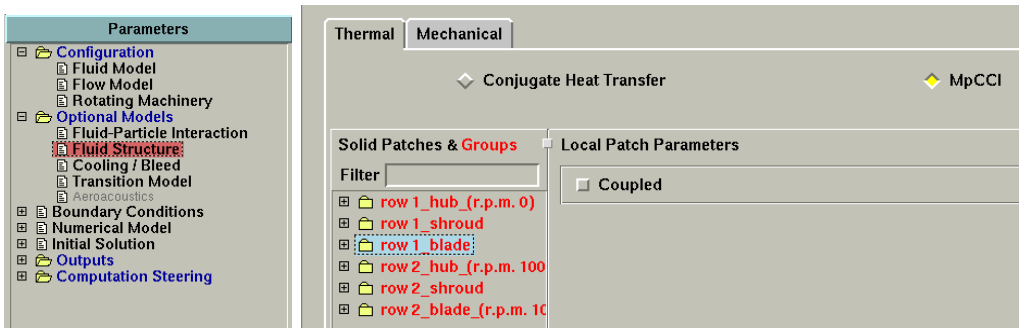


Figure 2: Setting coupled thermal boundaries in FINE/Turbo GUI

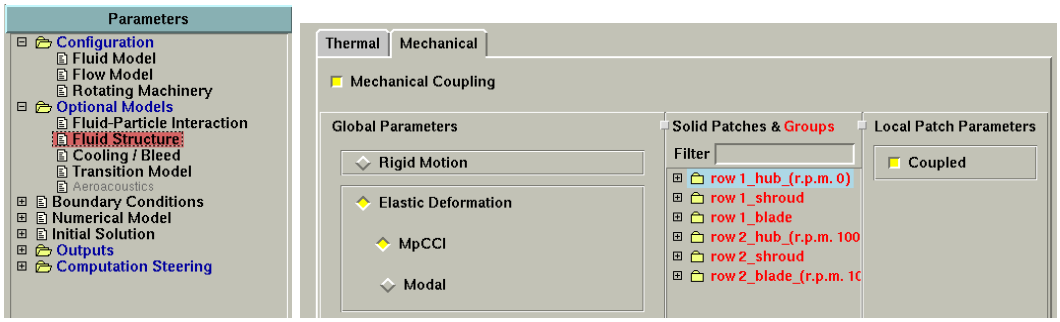


Figure 3: Setting coupled mechanical boundaries in FINE/Turbo GUI

7.2.2 Models Step

In the Models step, the following options must be chosen:

FINE/Turbo release Select the FINE/Turbo release you wish to use. Only supported releases installed on your system are listed. The selection latest always refers to the latest supported version (default).

Scan method This can be set to:

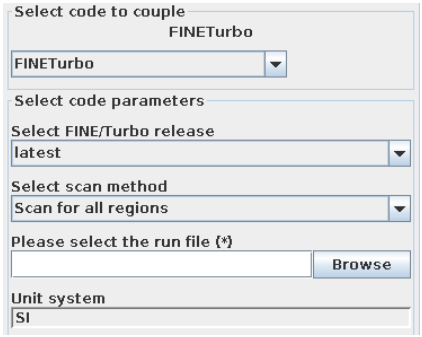


Figure 4: FINE/Turbo options in the Models step

- Scan for all regions (default) – The model file is scanned for possible coupling regions.
- Scan predefined COUPLING regions only – The model file is scanned for the already activated coupling regions only (prepared in the FINE/Turbo GUI).

Run file Select the FINE/Turbo input file `"*.run"`.

Unit system As FINE/Turbo works in SI units, no choice is given for the unit system to the user.

7.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁. There is no special specified setting for FINE/Turbo.

7.2.4 Regions Step

FINE/Turbo supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Direct	
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	
Density	Scalar	1.0 kg/m^3	field	Volume	Code	Direct	
NPosition	Vector	0.0 m	mesh coordinate	Face	Code		Direct
OverPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Direct	
PhysicalTime	Scalar	0.0 s	g-min	Global	global	Direct	
RefPressure	Scalar	1.12e5 N/m^2	g-max	Global	global	Direct	
RelWallForce	Vector	0.0 N	flux integral	Face	Code	Direct	
WallForce	Vector	0.0 N	flux integral	Face	Code	Direct	
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Code	Direct	
WallTemp	Scalar	300.0 K	field	Face	Code	Direct	Direct

It is not possible for FINE/Turbo solver to receive DeltaTime or PhysicalTime quantity. The time step can only be sent to the counterpart code.

7.2.5 Go Step

Solver precision Select the solver precision to use.

Set the requested memory Define the memory size to use for the computation. The first two fields show the current setting from the FINE/Turbo run file.

Expert mode For FSI problems with mesh deformation involved some expert parameters have to be set correctly to choose the most appropriate deformer. Remeshing is not possible during a computation. MpCCI offers the basic FINE/Turbo mesh deformation settings.

Mesh deformation Select the mesh deformation to use.

- Laplacian smoothing: the solving of Laplace equation computing the displacement.

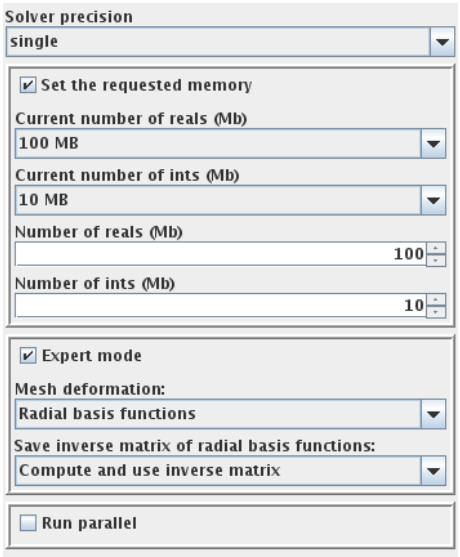


Figure 5: FINE/Turbo options in the Go step

You can access further expert mode parameters for the mesh deformation method by using the FINE/Turbo GUI like:

- Smoothing method: IMVWEI parameter.
- Choice of RBF function: MOVRBF parameter.
- etc.

Please refer to FINE/Turbo Physical Models chapter documentation describing further options for the mesh deformation module.

Run parallel Select this to start a parallel run. A panel with additional options appears, which are further described in ▷ 7.2.6.1 Parallel Execution ◁.

7.2.6 Running the Computation

When the Start button is pressed, MpCCI will prepare the `".run"` file corresponding to the FINE/Turbo project.
All the options for activating the coupling in FINE/Turbo are automatically done by MpCCI if needed. MpCCI creates a new `".run"` file having a prefix `"mpcci_"`) of the original `".run"`.

If the Stop button is pressed, a stop-file is created in the directory of the computation and FINE/Turbo will stop the next time it checks the presence of a stop file.

7.2.6.1 Parallel Execution

Parallel runs of FINE/Turbo are supported by MpCCI.

In the Go step, a set of additional options can be chosen for a parallel run as shown in Figure 6.

No. of processors Enter the number of processors to use during the analysis.

Parallel settings The automatic load balancing is used as default method for the mesh decomposition.

Optional 'host host...' to be used Enter host names for parallel execution of FINE/Turbo.

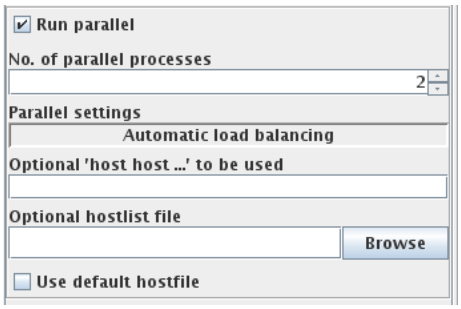


Figure 6: FINE/Turbo options for a parallel run

Optional hostlist file Specify a hostfile, from which host names are extracted ▷ V-3.6.2 Hostlist File ◁.

Use default hostfile A default hostfile can be configured by setting MPCCI_HOSTLIST_FILE ▷ V-3.6.2 Hostlist File ◁.

Running FINE/Turbo in parallel the number of processors may be modified by FINE/Turbo itself if the number of processors wished is higher than the number of blocks available in the model.

7.2.6.2 Batch Execution

FINE/Turbo always runs in batch mode.

7.2.7 Post-Processing

Post-processing for the FINE/Turbo part of the results can be performed as in ordinary computations, e. g. with CFVIEW, which is part of FINE/Turbo package.

7.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for FINE/Turbo are:

```
Usage:
   mpcci FINETurbo [-]option


Synopsis:
   'mpcci FINETurbo' is used to get information about FINETurbo.


Options:
   -diff  <run1> <run2>
            Run the scanner on two .run files and print the differences.

   -help
            This screen.

   -info
            List verbose information about all FINETurbo releases.
```

```
-intmem  <RUN-file>
         Show the number of ints used by this computation.

-realmem  <RUN-file>
         Show the number of reals used by this computation.

-releases
         List all FINETurbo releases which MpCCI can find on the local system.

-scan  <RUN-file>
         Run the scanner and create an output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci fineturbo -intmem <RUN-file>`

The `intmem` subcommand shows the number of ints used by the computation for the given run file.

`mpcci fineturbo -realmem <RUN-file>`

The `realmem` subcommand shows the number of reals used by the computation for the given run file.

7.4 Code Adapter Reference

The code adapter is distributed as a dynamic library, which is located in
"<*MpCCI_home*>`/codes/FINETurbo/adapters/`".
FINE/Turbo supports exchange before solution.

7.5 Trouble Shooting, Open Issues and Known Bugs

Problem:
The MpCCI tutorial example with FINE/Turbo crashes after the MpCCI adapter library has been loaded. The message just points to an error which may be a parameter issue.
Workaround:
Please open and resave the project file under the FINE/Turbo release you want to run the computation. Since the project file has been created from the oldest supported release by MpCCI, it may require an upgrade in the project file format.

8 FloMASTER

8.1 Quick Information

Company name	Siemens
Company homepage	www.plm.automation.siemens.com/global/en/products/simcenter/flomaster.html
Support	www.plm.automation.siemens.com/global/en/support/
Tutorials	▷ VII-13 Y-Junction ◁

8.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		X	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		–	
		–	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	System	X	▷ V-3.1.1 Physical Domains ◁

8.1.2 Supported Platforms and Versions

MpCCI supports coupling with FloMASTER 8.0 and higher.

8.1.3 References

FloMASTER documentation is part of the FloMASTER distribution.

8.1.4 Adapter Description

The FloMASTER adapter is an executable based on the FloMASTER COM interface.

8.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary FloMASTER installation.

8.2 Coupling Process

You have to create and validate a FloMASTER model.

8.2.1 Model Preparation

Both prescribed flow (inlet/outlet) and pressure boundaries in a CFD model can be incorporated into an MpCCI co-simulation with FloMASTER. The connection to boundaries in a CFD model is realized within a FloMASTER network by a combination of flow and/or pressure sources. Figure 1 and Figure 2 show the components used to represent a prescribed flow boundary and a pressure boundary respectively.

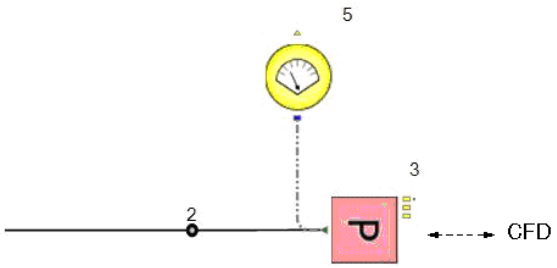


Figure 1: A FloMASTER pressure source connects to CFD mass flow boundary

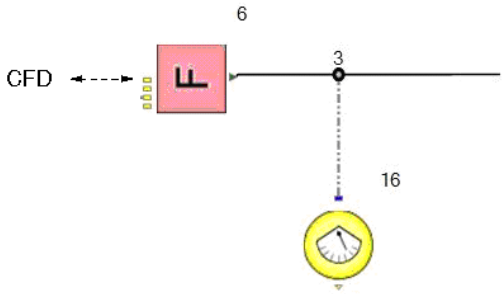


Figure 2: A FloMASTER flow source connects to CFD pressure boundary

Note that the CFD prescribed flow boundary incorporates in FloMASTER a pressure source (Figure 1) whereas the CFD pressure boundary requires a FloMASTER flow source as coupling partner (Figure 2). Components within the FloMASTER network, which are attached to the coupled boundaries, are connected to the nodes of the attached network in the normal manner.

- For each boundary component you have to activate the external boundary property of the component.
- For each flow source component you need to specify a flow value to initialize the flow source.

You have to create the fmlink file in order to export the information of your system to MpCCI code scanner (see Figure 3). The necessary steps in FloMASTER are:

1. Enter the report dialog and choose the MpCCI ASCII file.
2. Select a boundary component.
3. Click on Add in order to fill the list.
4. Mark the selected component and give a name for this component.
5. Repeat step 1 to 4 for all your boundary components.
6. Select the directory to save your file.
7. Enter the name of your system model with the file suffix `".fmlink"`.
8. Click on Create ASCII file.

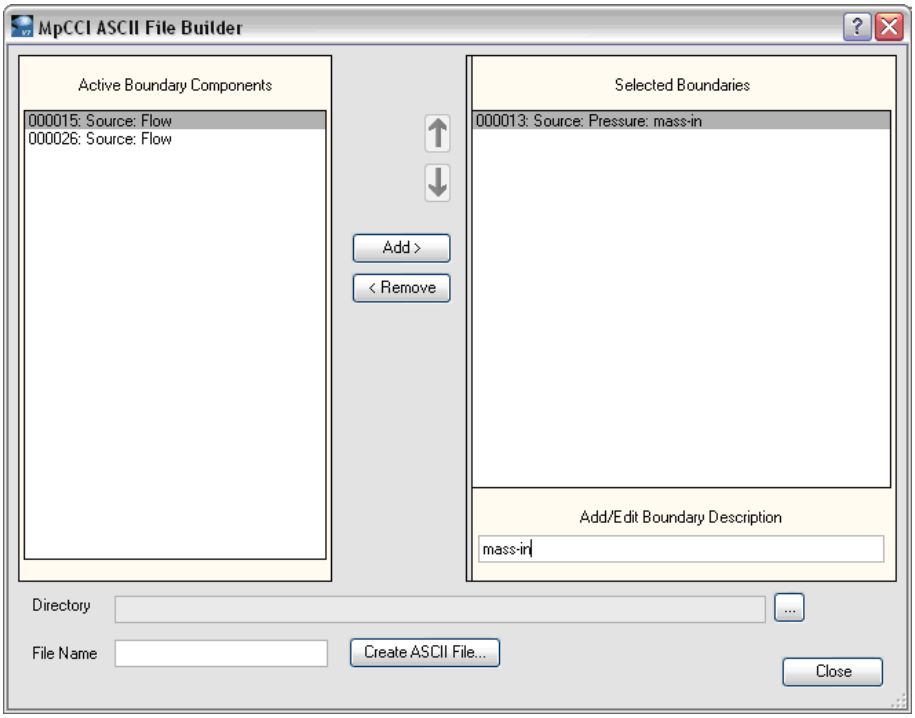


Figure 3: Export FloMASTER boundaries dialog

8.2.2 Models Step

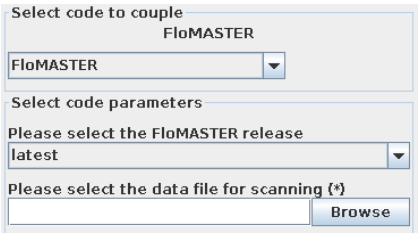


Figure 4: FloMASTER options in the Models step

In the Models step, the following options must be chosen:

FloMASTER release Select the release of FloMASTER you want to use. latest (default) will select the latest version which is installed on your system.

Data file Select the Data file of your FloMASTER project.

The MpCCI scanner uses the FloMASTER data file to extract model information. This file has the suffix `".fmlink"`.

8.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁. There is no special specified setting for FloMASTER.

8.2.4 Regions Step

The FloMASTER adapter only stores quantities directly ("Direct"). FloMASTER supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	Direct
MassFlowRate	Scalar	0.0 kg/s	flux integral	Point	Code	Direct	Direct
MassFluxRate	Scalar	0.0 kg/m^2 s	flux dens.	Point	Code	Direct	Direct
PhysicalTime	Scalar	0.0 s	g-min	Global	global	Direct	Direct
Temperature	Scalar	300.0 K	field	Point	Code	Direct	Direct
TotalPressure	Scalar	0.0 N/m^2	flux dens.	Point	Code	Direct	Direct
VelocityMagnitude	Scalar	0.0 m/s	field	Point	Code	Direct	Direct

The quantities are calculated as depicted exemplary for the field quantity temperature T and the flux quantity mass flow $m.$ in Figure 5

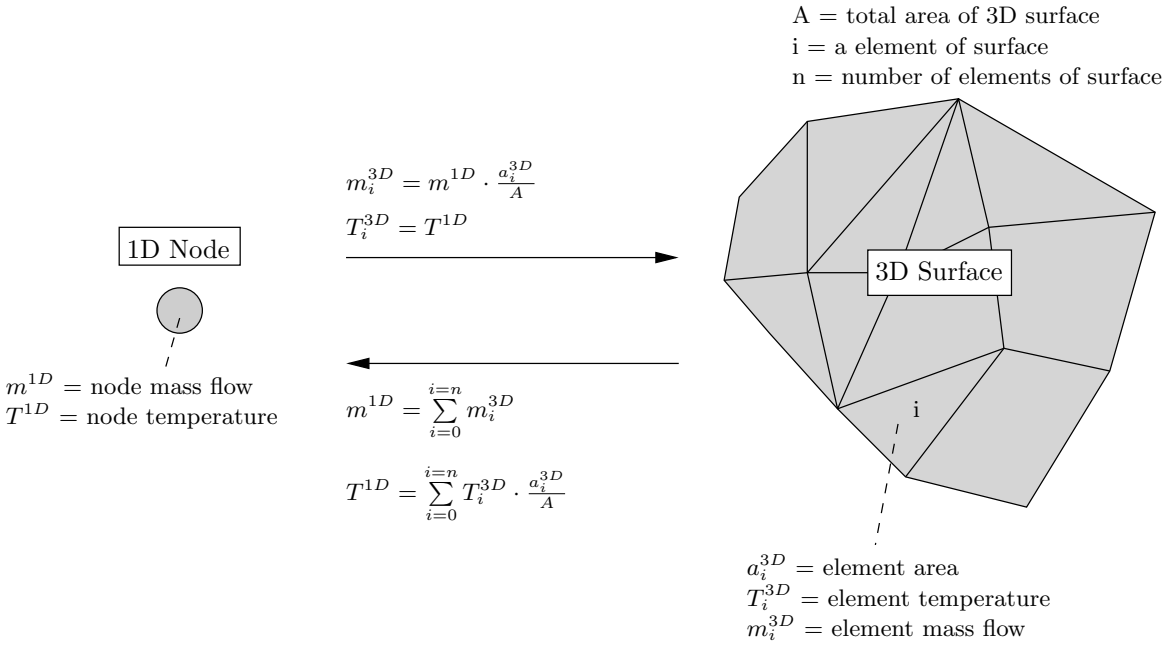


Figure 5: Exemplary calculation of flux quantity mass flow m and field quantity temperature T between 1D and 3D codes

8.2.5 Go Step

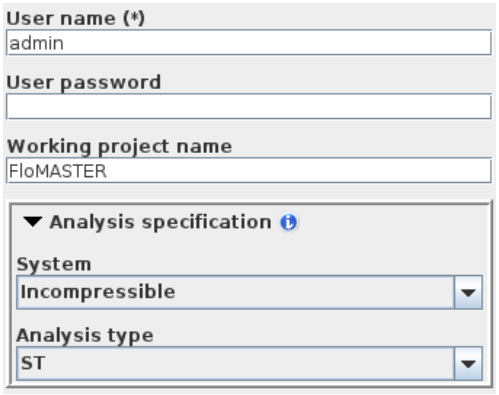


Figure 6: FloMASTER options in the Go step

FloMASTER offers a number of options in the Go step, see Figure 6.

User name You have to provide the user name to log in the database.

User password The password to authenticate the database server.

Working project mame The full project tree to the current project containing the system.
For example, the default root project name is “FloMASTER” and you have two sub-projects “coupling” and “testcases” with the following hierarchy: “FloMASTER\coupling\testcases”.

The project “testcases” contains some system models, one of which was chosen for the simulation. Then you will have to provide the following working project name: “FloMASTER\coupling”.

Analysis specification The analysis used for the simulation is specified by the Analysis type which depends on whether the System is compressible or incompressible:

- Incompressible system
  SS Steady state simulation.
  SSH Steady state simulation with heat transfer.
  ST Transient simulation.
  STH Transient simulation with heat transfer.
- Compressible system
  CS Steady state simulation.
  CT Transient simulation.

8.2.5.1 Running the Computation

By pressing the Start button in the Go step of the MpCCI GUI, MpCCI starts the FloMASTER application. The output of the FloMASTER simulation is logged in a window and a file `"mpcci_<model name>.log"`.

8.2.5.2 Post-Processing

You may use the FloMASTER interface and analyze the results by querying the database or creating a report.

8.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for FloMASTER are:

```
Usage:
   mpcci FloMASTER [-]option


Synopsis:
   'mpcci FloMASTER' is used to get information about FloMASTER.


Options:
   -diff     <file1> <file2>   Run the scanner on two .fmlink files and print the
                               differences.

   -help                       This screen.

   -info                       List verbose information about all FloMASTER releases.

   -releases                   List all FloMASTER releases which MpCCI can find.

   -scan     <input-file>      Run the scanner and create a scanner output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

8.4 Code Adapter Reference

Within the MpCCI distribution the "adapters" directory contains the necessary software to connect the simulation programs to MpCCI. The files are located within the subdirectory "<*MpCCI_home*>/FloMASTER/adapters".

This subdirectory is further divided by several release subdirectories, e. g. "7.6". The version directories contain one architecture folder "mswin". There you find the executable of the FloMASTER adapter, e. g. "MpCCILink.exe". The connection to MpCCI is established using this executable and the implementation is based on the FloMASTER COM API.
For a prescribed flow boundary, the boundary component (component 3 in Figure 2) sets the pressure of the source provided by MpCCI via FloMASTER adapter. After the system analysis is completed the mass flow is read by the boundary component and returned to FloMASTER adapter.

Depending on the FloMASTER analysis type the following data exchange strategy is applied:

- Steady-state analysis
  1. FloMASTER receives the data.
  2. FloMASTER analysis is requested.
  3. FloMASTER sends the data.
- Transient analysis
  1. FloMASTER exchanges the data (send and receive).
  2. FloMASTER analysis is requested.

8.5 Trouble Shooting, Open Issues and Known Bugs

Problem:
The FloMASTER adapter failed just after starting the application
with the message: `Failed to create the Flowmaster Application interface`
Version:
7.7
Fix:
You have to register three FloMASTER dynamic library files in the
assembly cache (GAC) of the Microsoft Windows machine:

- `"Flowmaster.Automation.Gui.dll"`
- `"Flowmaster.Automation.Analysis.dll"`
- `"Flowmaster.Interfaces.dll"`

These files are located under the FloMASTER installation.

1. Open two file explorers, one pointing to `"C:/WINDOWS/assembly"`
   and the other to the FloMASTER installation directory
   e. g. `"C:/Program files/Flowmaster/FlowmasterV7"`.
2. Per drag and drop, move the dll files to the assembly directory.

Then use the program `"regasm.exe"` to register the three previous dlls. You can find the `"regasm.exe"` program under `"%SystemRoot%/Microsoft.NET/Framework/v2.0.50727"`.
Execute the commands from the FloMASTER installation directory:

- `regasm Flowmaster.Automation.Gui.dll`
- `regasm Flowmaster.Automation.Analysis.dll`
- `regasm Flowmaster.Interfaces.dll`

You should get the following message: `Types registered successfully`.
You need to have administrator privileges to execute these commands.
References:
Contact FloMASTER support about how to register dlls to the GAC or assembly registry.

9 FLUENT

9.1 Quick Information

Company name	Fluent Inc. is a wholly owned subsidiary of ANSYS, Inc.
Company homepage	www.ansys.com
Support	ANSYS Customer portal at support.ansys.com
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁ ▷ VII-4 Driven Cavity ◁ ▷ VII-5 Pipe Nozzle ◁ ▷ VII-8 Exhaust Manifold ◁ ▷ VII-9 Cube in a Duct Heater ◁ ▷ VII-10 Busbar System ◁ ▷ VII-11 Three Phase Transformer ◁ ▷ VII-13 Y-Junction ◁

9.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	X	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		X	
		–	
		X	
		X	
Feature	MpCCI Configurator	X	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	X	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	X	▷ V-4.8.2.1 Copying Components ◁
Domains	Fluid	X	▷ V-3.1.1 Physical Domains ◁
	FluidThermal	X	
	FluidPlasma	X	

9.1.2 Supported Platforms and Versions

MPCCI_ARCH: Code platform	Supported versions																				
	16.0.0	16.1.0	16.2.0	17.0.0	17.1.0	17.2.0	18.0.0	18.1.0	18.2.0	19.0.0	19.1.0	19.2.0	19.3.0	19.4.0	19.5.0	20.1.0	20.2.0	21.1.0	21.2.0	22.1.0	22.2.0	23.1.0
lnx4_x64: lnamd64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: win64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

9.1.3 References

FLUENT Documentation is part of the FLUENT distribution.

9.1.4 Adapter Description

MpCCI uses the user-defined function ("UDF") interface, which is provided by FLUENT. A set of such functions is included in the MpCCI distribution as a shared library, which must be loaded by FLUENT.

The user-defined functions must be called at appropriate stages of the simulation. For this, FLUENT offers a number of so-called "function hooks", where these functions must be "hooked".

9.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary FLUENT installation.

9.2 Coupling Process

9.2.1 Model Preparation

Models can be prepared as usually. The coupled surface or cell zones must be defined as separate surfaces or volumes. Figure 1 shows the list of surfaces defined in a FLUENT model, which then appear in the Coupling Step of the MpCCI GUI.

If you exchange a relative pressure (e. g. RelWallForce or Overpressure), you must set the reference pressure to an appropriate value, which usually corresponds to the atmospheric pressure. For more information on relative and absolute pressures see ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁. In FLUENT the reference pressure is set in the Reference Values panel, which can be found under Report→Reference Values.

All further options required for coupling can be set in the MpCCI GUI.

9.2.1.1 Setting UDF-Hooks

The user-defined functions for the MpCCI interface must be hooked to perform initialization of the coupled simulation and data transfer. It is recommended to let MpCCI handle loading and hooking of these functions automatically. Please choose the corresponding options in the Go Step of the MpCCI GUI:

- Auto install/make libmpcci for installation of the user-defined library,

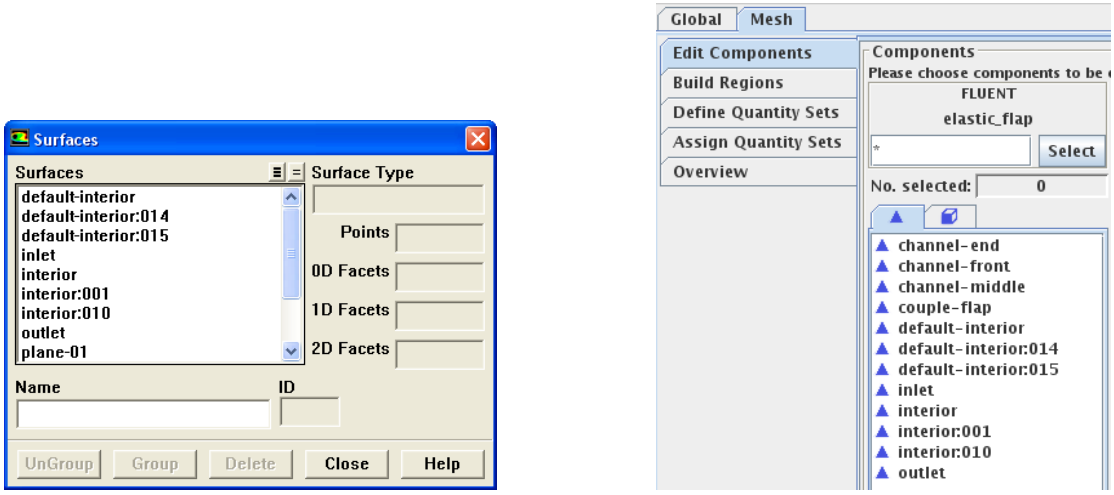


Figure 1: List of surfaces in FLUENT (left) and in the Regions step of the MpCCI GUI (right).

- Auto load libmpcci to load it,
- Auto hook functions to hook the library functions, i. e. they will be called at certain stages of the simulation.

See ▷ 9.2.5 Go Step ◁ for a complete description of the Go Step options.

In some cases it is preferable not to use these automatic settings. Instead the necessary functions can also be hooked manually. A description of the functions is given in ▷ 9.4 Code Adapter Reference ◁.

Some functions can also be called while running the computation via the MpCCI Control Panel in the FLUENT GUI, see ▷ 9.2.6.1 The MpCCI Control Panel ◁.

9.2.1.2 Using Own UDFs and MpCCI

The MpCCI functions are stored in the separate directory `"libmpcci"`. Therefore the MpCCI interface functions do not directly interfere with other interface functions - you can define and hook functions as if you were not using MpCCI.

It is not possible to hook your own user-defined functions at places where MpCCI functions need to be hooked for data transfer. It does not make sense to receive data and set the same values by a user-defined function!

9.2.1.3 Deforming Meshes

In typical FSI problems, deformations are computed by the solid mechanics code and sent to FLUENT, i. e. FLUENT has to move boundaries and deform the mesh.

The FLUENT settings to achieve this are made automatically if you select Auto hook functions as well as Auto set MDM zones ("MDM" stands for Moving and Deforming Meshes) from the Go Step of the MpCCI GUI. This enables mesh motion, however the exact parameters cannot be chosen by MpCCI and should be set when preparing the model or before starting the iteration.

To set up the mesh deformation without using the MpCCI GUI, the dynamic mesh option must be enabled by selecting Define→Dynamic Mesh→Parameters... and selecting Dynamic Mesh in FLUENT. It is recommended to use Smoothing and Remeshing as Mesh Methods.

The coupled zones must be defined as dynamic mesh zones which is described in ▷9.4.2 UDF-Hooks◁.

- For a transient FSI problem, FLUENT will automatically update the mesh and the deformations are then imported on the boundaries.
- For steady state FSI problems, MpCCI activates the mesh update by calling the `(steady-update-dynamic-mesh)` during the calculation. Otherwise the deformations are not imported in FLUENT. MpCCI provides for this purpose a new menu entry in FLUENT user interface at MpCCI→MpCCI Run FSI (▷9.2.6.2 The MpCCI Run FSI◁).

The MpCCI default setting defines a cell height value of 0 m for the adjacent zone. In the latest FLUENT 15.0 release the option Deform Adjacent Boundary Layer with Zone is not activated.
If you have a symmetry plane zone adjacent to the coupled wall zone boundary, you will need to define the zone as deforming in the dynamic mesh zones. Otherwise you will encounter issues during the mesh morphing step which will not properly deform the symmetry plane with the coupled zones.

Current limitation: remeshing is not supported during an iterative coupling with FLUENT.

9.2.1.4 Rigid Body Motion

In some FSI problems a rigid body motion can be computed by the solid mechanics code or the multi body code and sent to FLUENT.

The FLUENT settings to achieve this are made automatically if you select Auto hook functions as well as Auto set MDM zones ("MDM" stands for Moving and Deforming Meshes) from the Go Step of the MpCCI GUI. This enables mesh motion, however the exact parameters cannot be chosen by MpCCI and should be set when preparing the model or before starting the iteration.

To set up the mesh deformation without using the MpCCI GUI, the dynamic mesh option must be enabled by selecting Define→Dynamic Mesh→Parameters... and selecting Dynamic Mesh in FLUENT. It is recommended to use Smoothing and Remeshing as Mesh Methods.

The MpCCI default setting defines the center of gravity at (0,0,0) with a center of gravity orientation theta-z of 0 deg. The layering type is constant with a cell height value of 0 m.

9.2.2 Models Step

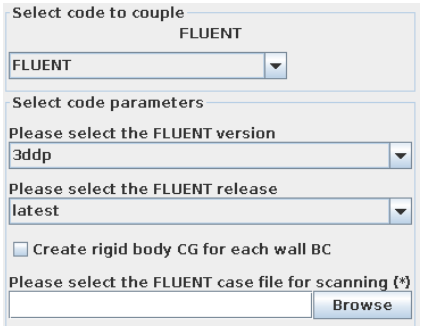


Figure 2: FLUENT options in the Models step

In the Models step, the following options must be chosen:

FLUENT version Select the FLUENT version from 2d, 2ddp, 3d, 3ddp. The version must match your case file.

FLUENT release Select the release of FLUENT you want to use. The version must match your case file. latest (default) will select the latest version which is installed on your system.

Create rigid body CG for each wall BC A new component with the prefix mpcci_cg will be created in association with the wall boundary condition.

FLUENT case file Select the case file of your FLUENT model.

9.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

In the Algorithm step, following additional option is available:

Coupling steps

Number of inner iterations *(Only for Implicit coupling scheme.)* Provide the number of inner iterations to perform within a coupling step iteration. The value will be automatically imported into FLUENT, for internal iterations.

9.2.4 Regions Step

The FLUENT adapter only stores some quantities directly ("Dir"), most quantities are first written to user-defined memory ("UDM").

FLUENT supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Face, Volume	Code	Dir	UDM
AcstPressure	Scalar	0.0 N/m^2	flux dens.	Volume	Code	Dir	UDM
AngularVelocity	Vector	0.0 rad/s	field	Point	Code		Buf
BodyForce	Vector	0.0 N/m^3	flux dens.	Volume	Code	UDM	UDM
CGAngle	Vector	0.0 rad	g-max	Global	global	Dir	Dir
CGOmega	Vector	0.0 rad/s	g-max	Global	global	Dir	Dir
CGPosition	Vector	0.0 m	g-max	Global	global	Dir	Dir
CGVelocity	Vector	0.0 m/s	g-max	Global	global	Dir	Dir
ChargeDensity	Scalar	0.0 C/m^3	field	Volume	Code	UDM	UDM
Current1	Scalar	0.0 A	g-max	Global	global	Dir	Dir
Current2	Scalar	0.0 A	g-max	Global	global	Dir	Dir
Current3	Scalar	0.0 A	g-max	Global	global	Dir	Dir
Current4	Scalar	0.0 A	g-max	Global	global	Dir	Dir
CurrentDensity	Vector	0.0 A/m^2	flux dens.	Face, Volume	Code	UDM, UDS	UDM
DeltaTime	Scalar	1.0 s	g-min	Global	global	Dir	Dir
Density	Scalar	1.0 kg/m^3	field	Volume	Code	Dir	UDM
DynPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Dir	
ElectrCond1	Scalar	0.0 S/m	field	Face, Volume	Code	UDM	UDM
ElectrCond3	Vector	0.0 S/m	field	Face, Volume	Code	UDM	UDM
ElectrCondX	Scalar	0.0 S/m	field	Volume	Code	UDM	UDM
ElectrCondY	Scalar	0.0 S/m	field	Volume	Code	UDM	UDM

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
ElectrCondZ	Scalar	0.0 S/m	field	Volume	Code	UDM	UDM
ElectricField	Vector	0.0 V/m	field	Volume	Code	UDM, UDS	UDM
ElectricFlux	Vector	0.0 C/m^2	flux dens.	Face, Volume	Code	UDM, UDS	UDM
ElectrRes1	Scalar	0.0 ohm m	field	Face, Volume	Code	UDM	UDM
ElectrRes3	Vector	0.0 ohm m	field	Face, Volume	Code	UDM	UDM
ElectrResX	Scalar	0.0 ohm m	field	Volume	Code	UDM	UDM
ElectrResY	Scalar	0.0 ohm m	field	Volume	Code	UDM	UDM
ElectrResZ	Scalar	0.0 ohm m	field	Volume	Code	UDM	UDM
Enthalpy	Scalar	0.0 W/m^3	flux dens.	Volume	Code	Dir	UDM
FilmTemp	Scalar	300.0 K	field	Face	Code	Dir	UDM
Force	Vector	0.0 N	flux integral	Face	Code	Dir	
HeatFlux	Vector	0.0 W/m^2	flux dens.	Volume	Code	UDM	UDM
HeatRate	Scalar	0.0 W	flux dens.	Face	Code	Dir	
HeatSource	Scalar	0.0 W/m^3	flux dens.	Volume	Code	UDM	UDM
IntFlag	Scalar	0	g-max	Global	global	Dir	Dir
IterationNo	Scalar	0	g-max	Global	global	Dir	Dir
JouleHeat	Scalar	0.0 W/m^3	flux dens.	Volume	Code	UDM	UDM
JouleHeatLin	Scalar	0.0 W/m^3 K	flux dens.	Volume	Code	UDM	UDM
LorentzForce	Vector	0.0 N/m^3	flux dens.	Volume	Code	UDM	UDM
MagneticField	Vector	0.0 A/m	field	Volume	Code	UDM, UDS	UDM
MagneticFlux	Vector	0.0 T	flux dens.	Face, Volume	Code	UDM, UDS	UDM
MassFlowRate	Scalar	0.0 kg/s	flux integral	Face	Code	Dir	UDM
MassFluxRate	Scalar	0.0 kg/m^2 s	flux dens.	Face	Code	Dir	UDM
NPosition	Vector	0.0 m	mesh coordinate	Face, Volume	Code	Dir	Buf
OverPressure	Scalar	0.0 N/m^2	flux dens.	Face, Volume	Code	Dir	UDM
PhysicalTime	Scalar	0.0 s	g-min	Global	global	Dir	Dir
PorePressure	Scalar	0.0 N/m^2	flux dens.	Volume	Code	Dir	UDM
RealFlag	Scalar	0.0	g-max	Global	global	Dir	Dir
RefPressure	Scalar	1.12e5 N/m^2	g-max	Global	global	Dir	Dir
RelWallForce	Vector	0.0 N	flux integral	Face	Code	Dir	UDM
Residual	Scalar	0.0	g-max	Global	global	Dir	Dir
SpecificHeat	Scalar	1.0 J/kg K	field	Volume	Code	Dir	UDM
Temperature	Scalar	300.0 K	field	Face, Volume	Code	Dir	UDM
ThermCond1	Scalar	0.0 W/m K	field	Face, Volume	Code	Dir	UDM
ThermCond3	Vector	0.0 W/m K	field	Face, Volume	Code	Dir	UDM
ThermCondX	Scalar	0.0 W/m K	field	Volume	Code	Dir	UDM
ThermCondY	Scalar	0.0 W/m K	field	Volume	Code	Dir	UDM
ThermCondZ	Scalar	0.0 W/m K	field	Volume	Code	Dir	UDM
TimeStepNo	Scalar	0	g-max	Global	global	Dir	Dir

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
TotalPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Dir	UDM
Velocity	Vector	0.0 m/s	field	Point, Face, Volume	Code	Dir	UDM, Buf
VelocityMagnitude	Scalar	0.0 m/s	field	Face	Code	Dir	UDM
Voltage1	Scalar	0.0 V	g-max	Global	global	Dir	Dir
Voltage2	Scalar	0.0 V	g-max	Global	global	Dir	Dir
Voltage3	Scalar	0.0 V	g-max	Global	global	Dir	Dir
Voltage4	Scalar	0.0 V	g-max	Global	global	Dir	Dir
WallForce	Vector	0.0 N	flux integral	Face	Code	Dir	UDM
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Code	Dir	UDM
WallHTCoeff	Scalar	0.0 W/m^2 K	field	Face	Code	Dir	UDM
WallTemp	Scalar	300.0 K	field	Face	Code	Dir	UDM

9.2.5 Go Step

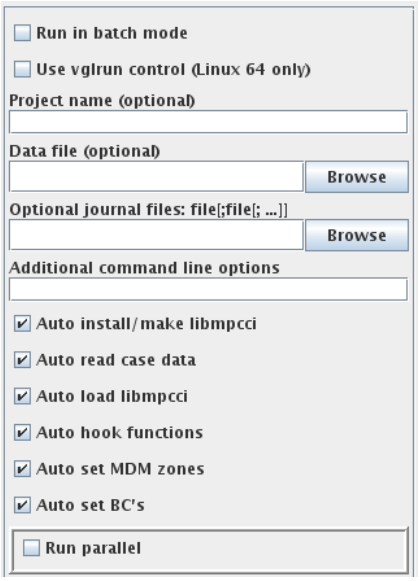


Figure 3: FLUENT options in the Go Step

FLUENT offers a number of options in the Go panel, see Figure 3.

Run in batch mode If this option is selected, FLUENT will not start the graphical user interface, i. e. no user interaction is possible. For batch mode a journal file, which contains the FLUENT commands for analysis execution, is required. See ▷ 9.2.6.4 Batch Execution ◁ for details.

Data file For the analysis a data file can be read. Same as loading a data file in the FLUENT GUI.

Optional journal files A semicolon-separated list of journal files can be given, which will be read by FLUENT when it is started. A journal file must be given for batch execution.

Additional command line options Additional command line options for FLUENT can be given here, they will directly be used when FLUENT is started.

Auto install/make libmpcci Automatically copy the user-defined library which contains the MpCCI interface to the working directory. If this button is not selected, the library must be copied by hand. Therefore it should always be used in a standard analysis.

Auto read case data Read the case file which was selected in the Models step when FLUENT is started. If a dat file with the same filename is available, it will be automatically selected at start.

Auto load libmpcci Load the code adapter library. This options should only be unselected for special purposes.

Auto hook functions Hooks the user-defined functions of the MpCCI code adapter library automatically. If not set, the functions must be hooked manually as described in ▷ 9.2.1.1 Setting UDF-Hooks ◁.

Auto set MDM zones Sets the interface zones for the Moving Deforming Mesh automatically. If nodal displacements are transferred from a structural code, this option should be selected to allow deformations of the FLUENT mesh.

Auto set BC's Automatically set the boundary conditions for the coupling regions, which is necessary to enable data transfer on these boundaries.

Run parallel Select this, if you want to run FLUENT in parallel mode. See ▷ 9.2.6.3 Parallel Execution ◁.

9.2.6 Running the Computation

Coupled simulations can be run using the FLUENT window. For running a simulation without a graphical interface, see ▷ 9.2.6.4 Batch Execution ◁.

Before FLUENT is started by pressing the Start button in the Go Step of the MpCCI GUI, MpCCI creates a journal file `"mpcci_<problem name>.jou"`, which performs the tasks selected in the MpCCI GUI Go Step. These steps are also reflected in FLUENT's output which partially depend on the settings (e. g. quantities, steady state/transient):

- Load `"cosimtools.scm"` which contains helper functions needed for a coupled simulation:

```
Loading "/home/user/mpcci/codes/FLUENT/cosimtools.scm"
Done.
```

- Enable coupling with MpCCI,

```
> (rpsetvar 'mpcci/on? #t)mpcci/on?
```

- Read the case file if Auto read case data is selected,

```
> /file/read-case "example.cas"
Reading "example.cas"...
```

- Load the MpCCI adapter library `"libmpcci"` if Auto load libmpcci is checked,

```
> /define/user-defined/compiled-functions/load libmpcci
"/home/user/computations/fluent"

Opening library "libmpcci"...
Library "libmpcci/lnx86/3d/libudf.so" opened
   UDF_List_globals
   UDF_Write_globals
```

  (output is followed by a list of all functions)

- Hook the MpCCI functions if Auto hook functions is set, e. g.

```
> (co-set-udf-hook 'init       "UDF_Initialize::libmpcci")
> (co-set-udf-hook 'adjust "UDF_Adjust::libmpcci")
```

```
> (register-dynamic-function "exchange-mpcci-quantities" #t #f \%udf-on-demand
"UDF_Dynamic_exchange::libmpcci")
```

- Set dynamic mesh zones if Auto set MDM zones is selected,

```
> /define/models/dynamic-mesh? yes
> /define/dynamic-zones/create 6 motion type: (stationary rigid-body deforming
                                                user-defined)
user-defined UDF_Grid_position::libmpcci
adjacent cell zone name/id [2]
cell height (air-remesh) (m) [0]
```

- Set boundary conditions if Auto set BC's is enabled,

```
(co-set-zone-profile "wall" "wall-temperature" "UDM00_Profile::libmpcci")Fluent
MpCCI_UDMprofile: Set default zero before MpCCI init.
```

- Load the MpCCI Control Panel.

```
load "/home/user/mpcci/codes/FLUENT/mpccipanel.scm")
Loading "/home/user/mpcci/codes/FLUENT/mpccipanel.scm"
Done.
```

If all coupling functions are hooked - either automatically or as described in ▷ 9.2.1.1 Setting UDF-Hooks ◁ - no special steps need to be carried through to start the simulation:

- Initialize the solution, this will also trigger MpCCI initialization.
- Start the iteration, MpCCI data transfer routines will be called automatically.

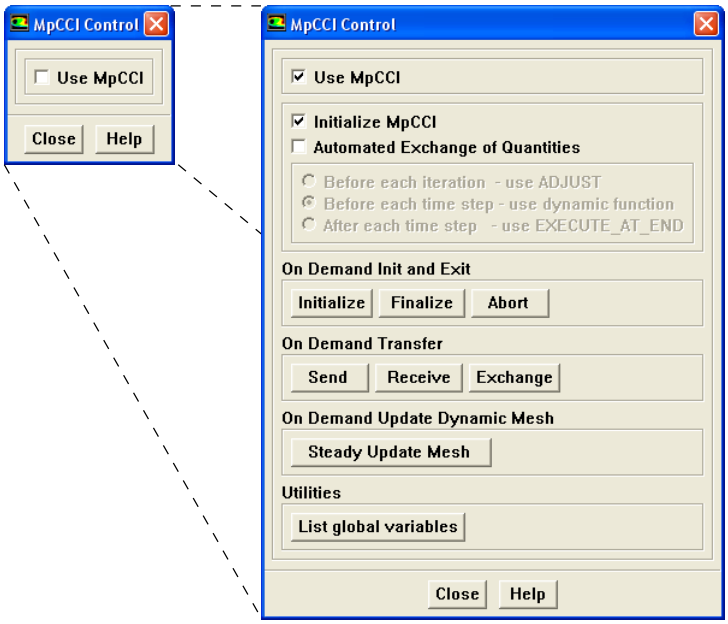


Figure 4: MpCCI Control Panel in FLUENT

9.2.6.1 The MpCCI Control Panel

The MpCCI Control Panel (Figure 4) is an extra panel in the FLUENT GUI, which is available if FLUENT is started during a coupled simulation. It allows to perform some coupling actions manually. Select MpCCI→MpCCI Control... from the FLUENT menu to open the panel.

Select Use MpCCI to enable coupling with MpCCI.

The second box of options hooks or unhooks MpCCI functions. If Initialize MpCCI is checked, the MpCCI initialization will be carried through automatically with FLUENT initialization. If you select the box next to Automated Exchange of Quantities you can decide at which points in the simulation data transfers should take place. Choose one of Before each iteration (recommended for steady-state problems), Before each time step (i. e. exchange before iteration) or After each time step (exchange after iteration). For each selection a specific MpCCI function is hooked.

The further buttons allow to perform coupling tasks on demand. Initialize initialized coupling with MpCCI, Finalize ends the coupling process gracefully, and Abort directly aborts the coupling process.

The transfer buttons trigger a transfer of quantities, Send will yield sending of all quantities which were selected in the Regions step of the MpCCI GUI. Receive yields receiving all quantities selected to receive and Exchange will yield a complete transfer of all selected quantities.

Steady Update Mesh yields an update of the mesh, which makes sense after receiving node positions.

9.2.6.2 The MpCCI Run FSI

The MpCCI Run FSI panel is an extra panel in the FLUENT GUI, which is available from the FLUENT menu MpCCI→MpCCI Run FSI... if FLUENT is starting for

- an implicit coupled simulation (Figure 5):
  It allows to perform some time steps with the time step size defined from the MpCCI GUI, to set the Reporting Interval, Profile Update Interval.
  If the adaptive convergence control is used, the FLUENT monitor convergence settings will be used to terminate the time step once the coupled inner iterations have reached the defined convergence. This will lead to an earlier progression to the next time step when the original FLUENT .cas file contained a convergence check for the residual monitors. When the coupled quantities are converged, the settings of the FLUENT convergence check are activated. If the residuals are converged, the next time step is started.
- a steady state FSI simulation (Figure 6):
  The MpCCI Run FSI panel is activated if the model has been started in interactive mode and with the Auto hook functions. It allows to perform some iterations and to set the Reporting Interval, Profile Update Interval.
  If the subcycling has been activated from MpCCI GUI, the MpCCI Run FSI panel will automatically take it in consideration.

In the text interface or journal file the simulation can be started with the command:

```
> (mpcci-solve n)
```

where n represents the number of time steps or iterations to be calculated.

9.2.6.3 Parallel Execution

For a parallel run of FLUENT (i. e. FLUENT itself uses several parallel processes) additional options can be selected in the Go Step as shown in Figure 7.

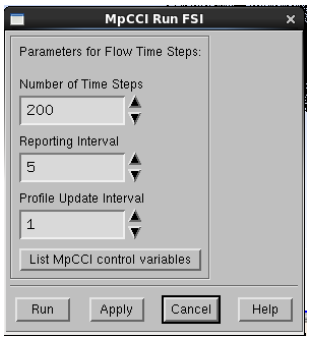


Figure 5: MpCCI Run FSI panel in FLUENT for transient implicit solution

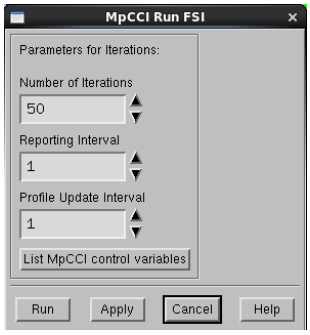


Figure 6: MpCCI Run FSI panel in FLUENT for steady state solution

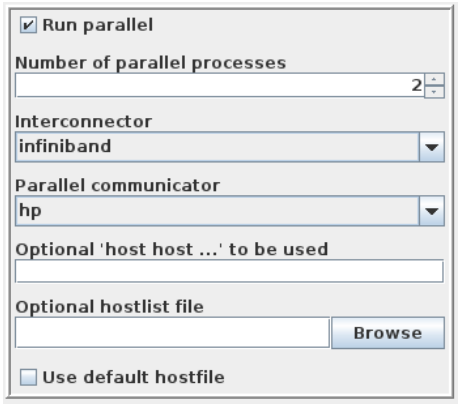


Figure 7: FLUENT options for a parallel run

Please read also chapter "31. Parallel Processing" of the FLUENT 6.3 User's Guide.

Number of parallel processes Select how many FLUENT processes you wish to start.

Interconnector Select the interconnector type as given in the FLUENT manual, this is passed as option `-p` to FLUENT.

Parallel communicator Select the parallel communicator as given in the FLUENT manual, this is passed

as option `-mpi=` to FLUENT.

Optional 'host host ...' to be used Enter host names for parallel execution of FLUENT.

Optional hostlist file Specify a hostfile, from which host names are extracted.

Use default hostfile A default hostfile can be configured by setting `MPCCI_HOSTLIST_FILE`, see ▷ V-3.6.2 Hostlist File ◁.

9.2.6.4 Batch Execution

FLUENT can be started without the graphical user interface. This is important if you run a simulation on a remote computer with text access only. For batch mode in a coupled simulation you must check the Run in batch mode button in the Go Step and provide a journal file which must be given under Optional journal files:.

As no graphical interface is available in batch mode you should perform all steps needed for the simulation in the journal file. A simple journal file for a transient analysis would contain:

```
;; Initialize flow and connect to MpCCI
/solve initialize initialize-flow
;; Perform unsteady iterations for a specified number of time steps
/solve dual-time-iterate 5 20
;; Exit simulation
/exit
```

If you want to do subcycling (iterations without exchange), you should provide the number of steps without coupling as coupling step size in the Coupling steps area of the Algorithm step.
The journal file might contain the usual commands to start the iterations:

```
;; Define autosave of case and data files
/file/autosave/case-frequency 10
/file/autosave/data-frequency 10
/file/autosave/overwrite-existing-files yes
;; Initialize flow
/solve/initialize initialize
;; Iterate
/solve/iterate 1000
;; Write case and data file
wcd file
;; Exit simulation
/exit yes
```

It is required that the MpCCI libmpcci is loaded and the necessary functions are hooked. This can be achieved by selecting the required Auto-options in the Go Step (select all if in doubt) or including the corresponding commands in the journal file. The commands for loading and functions hooking can be found in the journal file which is written by MpCCI at start-up of a FLUENT simulation, they are also described in ▷ 9.2.1.1 Setting UDF-Hooks ◁.

9.2.6.5 MpCCI Scheme Commands and Variables

List of available variables to control the calculation flow:

- `mpcci/mpcci_used` provides the MpCCI connection status. If the value is negative, FLUENT is not anymore connected to MpCCI.

- `mpcci/mpcci_init` provides the MpCCI initialisation status. If the value is equal 0, FLUENT has not been initialized with MpCCI. A value equals to 1 indicated that the initialisation with MpCCI has been done.
- `mpcci/convergence` contains the status of the coupled job after the data transfer occurs.
  The convergence status may have the following value defined as constant:
  - `mpcci/conv_state_error` indicates an error.
  - `mpcci/conv_state_invalid` indicates an invalid status.
  - `mpcci/conv_state_diverged` indicates a divergence status.
  - `mpcci/conv_state_stop` indicates a stop request.
  - `mpcci/conv_state_converged` indicates a convergence status.
  - `mpcci/conv_state_continue` indicates a continue request.
- `mpcci/coupling-inittact` contains the value of the quantities initial transfer action selected in the MpCCI GUI.
  It may have the following values:
  - `mpcci/init_send` indicates the send action.
  - `mpcci/init_recv` indicates the receive action.
  - `mpcci/init_xchg` indicates the exchange action.
  - `mpcci/init_skip` indicates the skip action.
- `mpcci/coupling-substep` contains the number of substeps defined in MpCCI GUI.
- `mpcci/coupling-type` provides the coupling mode selected from the MpCCI GUI.
  It may have the following value:
  - `mpcci/explicit-coupling`
  - `mpcci/implicit-coupling`

You can use the `ON_DEMAND` functions listed in ▷ 9.4.2 UDF-Hooks ◁ as function from the journal file. You need to use the following declaration in your journal file to name the functions:

```
(define udf-eod-init     (co-get-udf-lib-name "UDF_Init_MpCCI"        ))
(define udf-eod-exit     (co-get-udf-lib-name "UDF_Exit_MpCCI"        ))
(define udf-eod-abort    (co-get-udf-lib-name "UDF_Abort_MpCCI"       ))
(define udf-eod-send     (co-get-udf-lib-name "UDF_Send_on_demand"    ))
(define udf-eod-recv     (co-get-udf-lib-name "UDF_Recv_on_demand"    ))
(define udf-eod-xchg     (co-get-udf-lib-name "UDF_Xchg_on_demand"    ))
```

Then the defined function can be used by using this syntax: `(%udf-on-demand udf-eod-xchg)`

9.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for FLUENT are:

```
Usage:
   mpcci FLUENT [-]option


Synopsis:
   Use 'mpcci FLUENT' to get information about FLUENT and to
   build/install your private adapter ...


Options:
```

```
-diff  <cas1> <cas2>
         Run the scanner on two case files and print the differences.

-help
         This screen.

-info
         List verbose information about all FLUENT releases.

-libmpcci  <RELEASE> [-64] <VERSION>
         Install the FLUENT

            "libmpcci/ARCH/VERSION/libudf.so"

         in your current working directory - where the .cas and
         .dat files are located - by either just copying the MpCCI
         libudf's or remaking the libudf from MpCCI and your own
         sources located in "libmpcci/src".
         You do NOT need to have a "libmpcci/Makefile" and/or
         "libmpcci/src/makefile" prepared since the makefiles are
         generated automatically from your FLUENT installation.

         RELEASE: The FLUENT release.
         ARCH   : The FLUENT architecture token
                  (automatically determined by MpCCI)
         VERSION: The version 2d, 3d_node etc.

         Please specify the FLUENT release (e.g. 13.0.0) you
         would like to use and a list of versions (2d, 3d_node etc.).

         For more information type "mpcci FLUENT libmpcci".

-libudf  <RELEASE> [-64] <VERSION> [MSVC_VERSION]
         Compile the FLUENT

            "libudf/ARCH/VERSION/libudf.so"

         from your current working directory - where the .cas and
         .dat files are located - by making the libudf with your own
         sources located in "libudf/src".

         RELEASE     : The FLUENT release.
         ARCH        : The FLUENT architecture token
                       (automatically determined by MpCCI)
         VERSION     : The version 2d, 3d_node etc.
         MSVC_VERSION: The version of MSVC compiler to use
                       (MSVC_100, MSVC_110, MSVC_120, MSVC_140, MSVC).

         Please specify the FLUENT release (e.g. 13.0.0) you
         would like to use and a list of versions (2d, 3d_node etc.).

         For more information type "mpcci FLUENT libudf".
```

```
-releases
         List all FLUENT releases which MpCCI can find.

-scan  <casfile>
         Run the scanner and create a scanner output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci fluent -libmpcci <release#|latest> [-64] version version`

The `libmpcci` subcommand installs and compiled if needed a version of the MpCCI udf library as described above.

```
Usage:
   mpcci FLUENT libmpcci <release#|latest> [-64] version version version ...

Examples:
   mpcci FLUENT libmpcci   12.0.16  3d 3ddp 2d 2ddp
   mpcci FLUENT libmpcci   latest   3ddp 3ddp_host
```

`mpcci fluent -libudf <release#|latest> [-64] version version [MSVC_VERSION]`

The `libudf` subcommand compiles a version of the user FLUENT udf library as described above.

```
Usage:
   mpcci FLUENT libudf <release#|latest> [-64] version version version ...

Examples:
   mpcci FLUENT libudf   6.2.18   3d_host 3d_node
   mpcci FLUENT libudf   6.3.26   3d 3ddp 2d 2ddp
   mpcci FLUENT libudf   latest   3ddp 3ddp_host
```

9.4 Code Adapter Reference

9.4.1 The MpCCI UDF Library

The MpCCI code adapter for FLUENT uses user-defined functions ("UDF") and user-defined memory ("UDM") to manage the data transfer. The code adapter is distributed as a dynamic library, which is located in
"<*MpCCI_home*>`/codes/FLUENT/adapters/`<*FLUENT release*>`/`<*platform*>`/`<*FLUENT code*>".

Before running the analysis, the code adapter must be copied to a subdirectory `"libmpcci"` of the working directory. This task is performed automatically by MpCCI if the option Auto install/make libmpcci is selected in the Go Step. Otherwise the command `mpcci FLUENT libmpcci` can be used. The working directory is the directory where the case file `"*.cas"` is located and where FLUENT is executed.

The adapter functions must be hooked at different places in FLUENT, see ▷ 9.2.1.1 Setting UDF-Hooks ◁. A list of all adapter functions is given in Table 2 on page 105.

More information on user-defined functions (UDFs) can be found in the "FLUENT UDF Manual" which is part of the FLUENT documentation.

9.4.2 UDF-Hooks

The data transfer with MpCCI is realized with user-defined functions ("UDF"), which are included in the MpCCI distribution. A list of all UDFs of the MpCCI adapter is given in Table 2 on page 105.

In some cases it is preferable to set or check the necessary functions hooks manually.

Most UDF functions can be hooked using the User-Defined Function Hooks panel, which opens when selecting Define→User-Defined→Function Hooks... from the FLUENT menu.

For a coupled simulation the following steps must be carried through by user-defined functions:

MpCCI Initialization is realized in `UDF_Initialize`, which can be hooked in the UDF-hooks panel or by pressing the Initialize button of the MpCCI Control panel.

Data exchange for transient problems with dynamic mesh is carried before the iteration.
For explicit coupling this is carried through by one of these functions `UDF_Dynamic_exchange`, `UDF_Grid_Motion_All` or `UDF_Adjust_Once` depending of the configuration (the time step is sent, not exchanged, received).
For iterative coupling this is carried through by one of these functions `UDF_Dynamic_exchange_implicit`, `UDF_Grid_Motion_All_implicit` or `UDF_Adjust_implicit` depending of the configuration (the time step is sent, not exchanged, received).
For steady state problems `UDF_Adjust` should be used to achieve an exchange for each iteration.

`UDF_Adjust` and `UDF_At_end` can be hooked over the FLUENT function hook panel, whereas `UDF_Dynamic_exchange` can be hooked over the MpCCI Control panel or by the Auto hook functions in MpCCI Go Step.

Data storage For some quantities the data is stored in user defined memory (UDM). To distinguish the quantities, a storage index is set for each quantity in the Regions step, as shown in Figure 8. If you do not change it, the index is increased automatically. In addition the corresponding `UDM...` functions must be hooked at appropriate places.

There are three types of such quantities:

- Profiles for various boundary conditions like inlet or outlet boundaries use the boundary functions `UDM00_Profile` to `UDM10_Profile` to set the received quantities on the boundaries. Hook the function in the Boundary Conditions panel of FLUENT (Define→Boundary Conditions... in the menu).
- Source terms are also set in the Boundary Conditions panel but not for inlet or outlet surfaces but for fluid type boundaries: Check Source Terms in the Fluid window and select the `UDM.._Source` function for the appropriate source.
- Material property quantities can be set in the Materials panel (Define→Materials). Select user-defined and the appropriate `UDM..Property` function in the User-Defined Functions panel.

In addition to this minimal subset of user-function calls, certain situation require additional functions:

Analysis with Deforming Mesh: If the quantity NPosition or rigid body motions are received by FLUENT, the mesh must be updated by a user-defined function. The appropriate functions can be hooked automatically by activating the option Auto set MDM zones, Otherwise it must be manually hooked by selecting Define→Dynamic Mesh→Zones... from the FLUENT window. Select the coupled zones from the list of Zone Names, choose User-Defined as type and select on the selected zone:

- For explicit coupling:
  - UDF_Grid_position::libmpcci if time step is received or for steady state model.
  - UDF_Grid_Motion_All::libmpcci if time step is sent or not exchanged.
- For iterative coupling:
  - UDF_Grid_position_implicit::libmpcci if time step is received.
  - UDF_Grid_Motion_All_implicit::libmpcci if time step is sent or not exchanged.

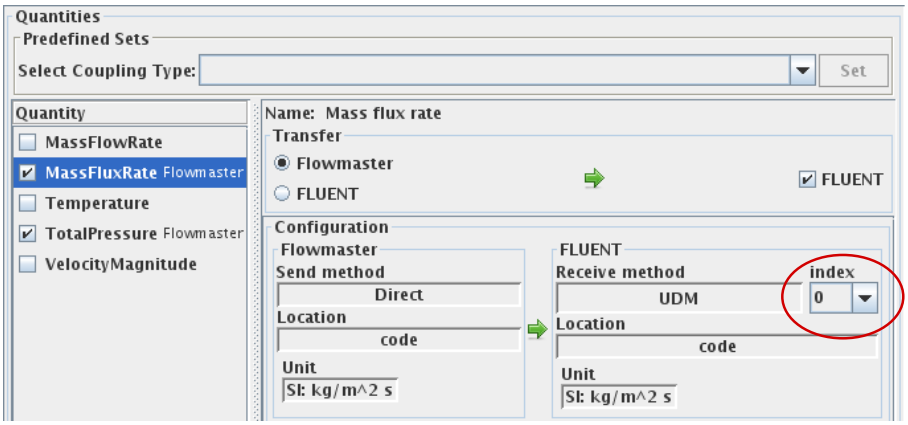


Figure 8: UDM storage index for quantities received by FLUENT.

For the rigid body quantities CGAngle, CGOmega, CGPosition or CGVelocity the type Rigid Body must be selected together with UDF_Grid_position::libmpcci.
An alternative for the rigid body quantities AngularVelocity, Velocity the type Rigid Body must be selected together with UDF_CG_motion::libmpcci.

Restart Analysis: To store global values in the `"*.dat"` file after the first analysis and reread it from there in a restart you should hook UDF_Read_globals and UDF_Write_globals in the UDF-hooks panel as Read Data and Write Data functions.

Exchange of time step size: If the time step size is received by FLUENT it is required to hook a function in the Run Calculation panel of FLUENT ((Solve|Solution|Solving)→Run Calculation...). MpCCI will set the Time Stepping Method to Adaptive and select UDF_Deltat::libmpcci as user-defined time step.

UDF Hook	MpCCI Function	Purpose / Description
INIT	UDF_Initialize	Initialize the connection to MpCCI.
EXECUTE_AT_EXIT	UDF_At_exit	Shutdown the MpCCI connection.
ADJUST	UDF_Adjust	MpCCI data transfer.
	UDF_Adjust_Once	MpCCI data transfer.
	UDF_Adjust_implicit	MpCCI data transfer.
	UDF_Adjust_Empty	Empty call for the FLUENT FSI panel.
DELTAT	UDF_Deltat	Set the time step size if it is received by FLUENT.
ON_DEMAND	UDF_List_globals	List global variables.
	UDF_Dynamic_exchange	MpCCI data transfer in explicit coupling.
	UDF_Dynamic_Set_Adjust_Once	MpCCI updates control flags in explicit coupling.
	UDF_Dynamic_Explicit_Step_begin	MpCCI updates control flags in explicit coupling.
	UDF_Dynamic_Implicit_Step_begin	MpCCI updates control flags in iterative coupling.
	UDF_Dynamic_Implicit_Exchange_Step_begin	MpCCI data transfer in iterative coupling.
	UDF_Exit_MpCCI	Shutdown the MpCCI connection.
	UDF_Abort_MpCCI	Abort the MpCCI connection.
	UDF_Init_MpCCI	Initialize the connection to MpCCI.
	UDF_Send_on_demand	MpCCI data transfer: Send only.
	UDF_Recv_on_demand	MpCCI data transfer: Receive only.
	UDF_Xchg_on_demand	MpCCI data transfer.
	UDF_Remesh_total_on_demand	MpCCI receives a full remeshing information.
	UDF_Remesh_move_on_demand	MpCCI receives a deformation information.
RW_FILE	UDF_Read_globals	Read global data from "*.dat" file.
	UDF_Write_globals	Write global data into "*.dat" file.
CG_MOTION	UDF_CG_motion	Set the rigid body motion.
	UDF_CG_motion_All	MpCCI data transfer and set the rigid body motion.
GRID_MOTION	UDF_Grid_position	Set nodal coordinates to the received position.
	UDF_Grid_Motion_All_implicit	MpCCI data transfer and set nodal coordinates to the received position in iterative coupling.
	UDF_Grid_position_exchange	MpCCI data transfer and set nodal coordinates to the received position in explicit coupling.
	UDF_Grid_steadyMDM	MpCCI data transfer and set nodal coordinates to the received position in iterative coupling.
	UDF_Grid_Motion_implicit	MpCCI data transfer and set nodal coordinates to the received position in iterative coupling.
PROFILE	UDM00_Profile ⋮ UDM10_Profile	Set boundary profile values stored in UDM 0 - 10.
SOURCE	UDM00_Source ⋮ UDM10_Source	Set a cell source value stored in UDM 0 - 10.
PROPERTY	UDM00_Property ⋮ UDM10_Property	Set a cell property value stored in UDM 0 - 10.

Table 2: User-defined functions (UDFs) of the MpCCI FLUENT adapter

9.5 Trouble Shooting, Open Issues and Known Bugs

Feature:
FLUENT parallel under Microsoft Windows
Version:
12.x, 13
Problem:
FLUENT calculation hangs during the initialization stage in parallel on a Microsoft Windows workstation if FLUENT graphical interface is used. The Interconnector and Parallel communicator are set to default.
Workaround:
First delete the directory `"libmpcci"` located under the FLUENT `".cas"` model directory. Then in the MpCCI GUI, select the option net from Parallel communicator list.
Using FLUENT interactively requires the net parallel communicator contrary to a batch calculation which may use the default parallel communicator.

By switching the Parallel communicator requires to delete the `"libmpcci"` each time before the start.

9.6 Frequently Asked Questions

Question:
FEM model's structure is using shell element. In FLUENT since the structure has no thickness hence no volume, the FSI interface is defined as wall type. Can MpCCI get correct pressure loading from two sides of the shell?
Answer:
For such thin wall, FLUENT model will create a shadow wall. For the coupling if one side is selected MpCCI will additionally get the forces on the shadow wall and provide the forces on two sides of the shell.
This is not applied to pressure quantity.

Question:
I do a steady state FSI simulation and FLUENT could not get the nodal position from the FE code.
Answer:
After FLUENT has done one data exchange you should call the "steady update mesh" function manually from the MpCCI Control panel. If you are using a journal file you need to call that command:

```
(steady-update-dynamic-mesh)
```

after the data exchange occurs in order to get the new nodal position.
Update:
This setting is now automatically set by MpCCI from release MpCCI 4.4

Question:
I have installed FLUENT on Microsoft Windows and can run it. But when I command "mpcci FLUENT " or select the FLUENT version in the MpCCI GUI I receive the message:

"mpcci FLUENT: Can't find any FLUENT installation for this architecture".
Answer:
Please add the path of your FLUENT installation to your PATH environment variable.

Question:
I want to receive WallTemp in FLUENT but apparently FLUENT does not account for the received temperature.
Answer:
Check if for the coupled boundaries in FLUENT the thermal conditions are set to "temperature" and the MpCCI lib is hooked for temperature value (▷ 9.2.1.1 Setting UDF-Hooks ◁).

Question:
How to autosave FLUENT data in compressed format?
Answer: You should add the file suffix `".gz"` to the file name you want to save.

- In the journal file you can provide the root name of the file to save with the following command: `/file/autosave/root-name mpcci_job_%t.gz`
- From the FLUENT UI you can set this from the menu Solve →Calculation Activities →Edit from the Autosave Every option. Add the suffix `".gz"` to the file name.

10 JMAG

10.1 Quick Information

Company name	JSOL Corporation
Company homepage	www.jmag-international.com
Support	jmag-support@sci.jsol.co.jp
Tutorials	▷ VII-10 Busbar System ◁ ▷ VII-11 Three Phase Transformer ◁

10.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		–	
		X	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: <CodeInfo> ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	SolidStructure	X	▷ V-3.1.1 Physical Domains ◁
	SolidThermal	X	
	Electromagnetism	X	

10.1.2 Supported Platforms and Versions

The following versions of JMAG are supported by MpCCI:

	Supported versions													
MPCCI_ARCH: Code platform	15.0	15.1	16.0	16.1	17.0	17.1	18.0	18.1	19.0	20.0	20.1	21.0	22.0	22.1
lnx4_x64: linux64	X	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: x64	X	X	X	X	X	X	X	X	X	X	X	X	X	X

10.1.3 References

JMAG Documentation is part of the JMAG distribution.

10.1.4 Adapter Description

The JMAG-MpCCI multiphysics coupling is enabled via the JCoupled module. The JMAG-MpCCI code adapter is developed by Fraunhofer SCAI in cooperation with JSOL Corporation. It is delivered as shared library implementing the JMAG Co-Simulation API.

10.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary JMAG installation.
- `JW_MPCCI` token license for JMAG-MpCCI multiphysics capability.
- A JMAG code adapter license token for MpCCI.

10.1.6 Supported JMAG Modules

The following modules are supported for a co-simulation:

- FQ - Time Harmonic Magnetic (3D)
- TR - Transient Magnetic (3D)

10.2 Coupling Process

10.2.1 Model Preparation

There are some issues which you should consider while creating a JMAG model for a co-simulation study with JMAG-Designer:

Enabling a coupled analysis You have to activate the Two way coupled analysis option from the Coupling study properties window (Figure 1).

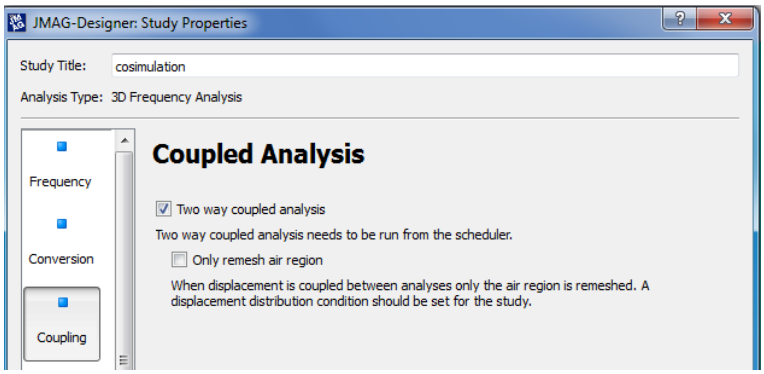


Figure 1: JMAG coupled analysis

Enabling the output of quantities For the current list of supported quantities (▷ 10.2.4 Regions Step ◁) sent by JMAG you should activate the following output from the Output control in the Show Advanced Settings (Figure 2):

- Current Density

- Joule Loss Density
- Lorentz Force Density

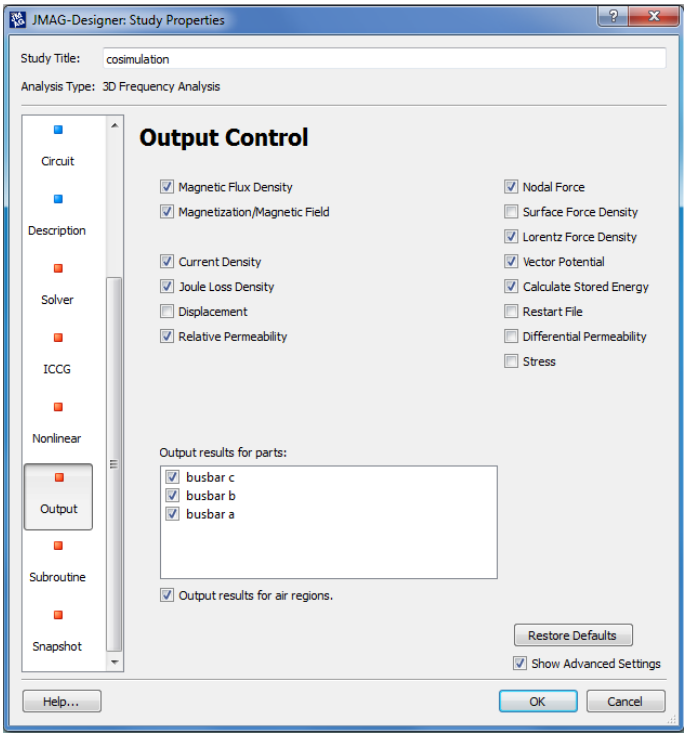


Figure 2: JMAG output control

Export the JCF For performing a JMAG calculation, the JCF file has to be exported.

To run the solver in parallel you have to select the solver option (Figure 3) by activating the Show Advanced Settings option and activate the appropriate parallel method: shared memory or distributed memory.

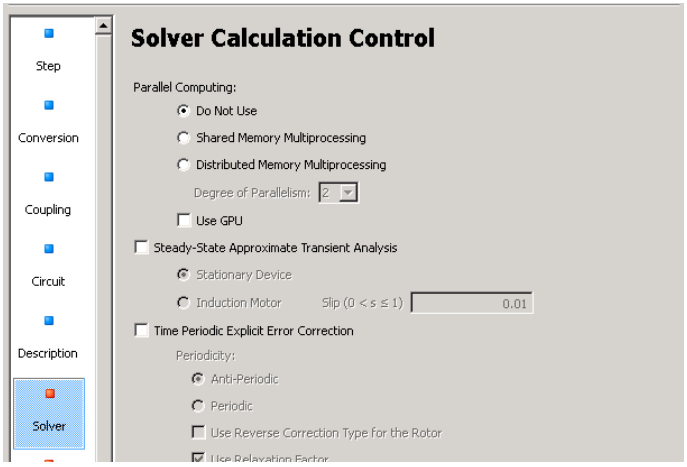


Figure 3: JMAG solver option

Modeling temperature dependent material In order to use the temperature or electrical conductivity quantities provided by MpCCI, the electric properties should be modified to Temperature Dependent (Fig-

ure 4) and graph of type Conductivity vs Temperature should be created.

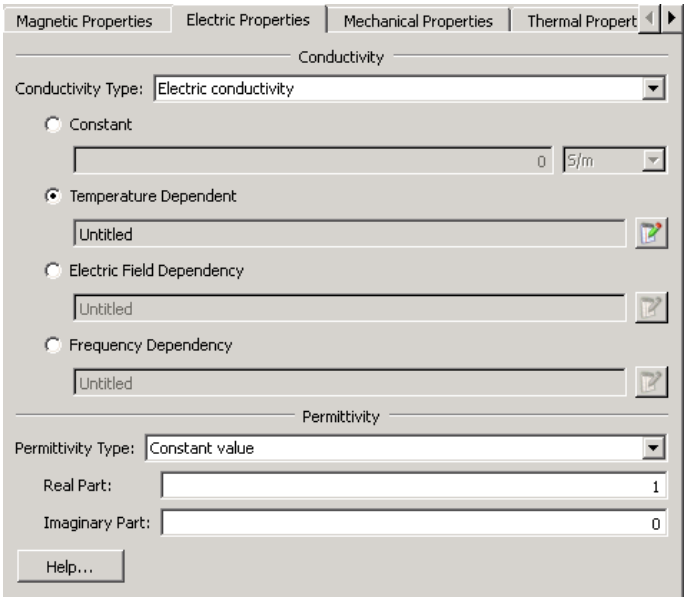


Figure 4: JMAG material properties

10.2.2 Models Step

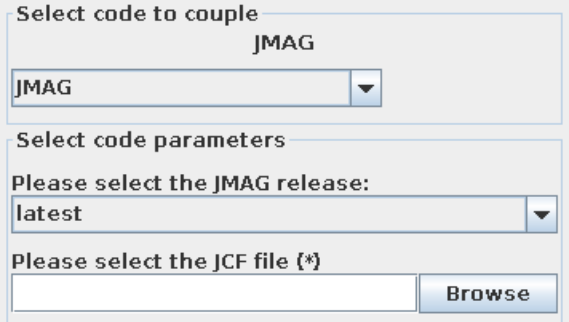


Figure 5: JMAG options in the Models step

In the Models step, the following options must be chosen:

JMAG release Select the release of JMAG you want to use. latest (default) will select the latest version which is installed on your system.

JCF file Select the JCF file of your JMAG project.
The MpCCI scanner uses the JMAG JCF file to extract model information.

10.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

In the Algorithm step, following additional option is available:

Solver settings

JMAG analysis type This shows the current solver used for the model. You will see the following possible solver types:

- 3D_transient_(TR)
- 3D_frequency_(FQ)

In case of a 3D_transient_(TR) application, JMAG will use the time step and number of steps provided in the Step Control properties of the JCF file.

In case of a 3D_frequency_(FQ) you should provide the number of steps you want JMAG to perform in the Coupling duration panel in the Common Basics settings. For each step a co-simulation will happen.

10.2.4 Regions Step

The JMAG adapter stores the quantities using a direct memory access to the JMAG solver ("Direct"). JMAG supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
CurrentDensity	Vector	0.0 A/m^2	flux dens.	Volume	Element	Direct	
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	
ElectrCond1	Scalar	0.0 S/m	field	Volume	Node		Direct
ElectrCond3	Vector	0.0 S/m	field	Volume	Node		Direct

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
Force	Vector	0.0 N	flux integral	Volume	Node	Direct	
JouleHeat	Scalar	0.0 W/m^3	flux dens.	Volume	Element	Direct	
LorentzForce	Vector	0.0 N/m^3	flux dens.	Volume	Element	Direct	
NPosition	Vector	0.0 m	mesh coordinate	Volume	Node	Direct	Direct
Temperature	Scalar	300.0 K	field	Volume	Node		Direct

ElectrCond1 provides a direction independent scalar electric conductivity distribution for the material. This is appropriate for an isotropic material.

ElectrCond3 provides the electric conductivity for an orthotropic material. The electric conductivity is distributed in X, Y, Z direction for the material according to the electric conductivity vector value.

10.2.5 Go Step

There is no special specified setting for JMAG in Go step.

10.2.5.1 Running the Computation

When the Start button is pressed, JMAG is started with the options given in the Go step. If the Stop button is pressed, a stop-file `"STOP"` is created and JMAG will stop the next time it checks the presence of a stop file.

On the JMAG application side the file `"mpcci_<jcf_filename>.log"` contains the log of the co-simulation. The log file reflects the actions and state of the solver and the MpCCI adapter.

10.2.5.2 Post-Processing

After having solved a coupled simulation the results computed on the JMAG side (`".jplot"`) may be opened with JMAG-Designer tool. You may visualize the coupled quantities sent to the third party code.

10.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for JMAG are:

```
Usage:
   mpcci JMAG [-]option


Synopsis:
   'mpcci JMAG' is used to get information about JMAG.


Options:
   -bgcolor                  Display the JMAG Designer background color.

   -diff     <JCF1> <JCF2>   Run the scanner on two .jcf files and print the
                             differences.

   -help                     This screen.
```

```
-info                    List verbose information about all JMAG releases.

-releases                List all JMAG releases which MpCCI can find.

-scan     <JCF file>     Run the scanner and create a scanner output file.

-solver   <JCF file>     Display the JMAG solver used from the JCF file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci jmag -bgcolor`

The `bgcolor` subcommand gets the JMAG Designer background color and prints it to stdout.

`mpcci jmag -solver <JCF file>`

The `solver` subcommand gets the used solver from the specified JCF file and prints it to stdout.

10.4 Code Adapter Reference

Within the MpCCI distribution the `"adapters"` directory contains the necessary software to connect the simulation programs to MpCCI depending on your license. The files are located within the subdirectory "<*MpCCI_home*>`/codes/JMAG/adapters`".

This subdirectory is further divided by several release subdirectories, e. g. `"11.0"`. The version directories are further divided by several architectures (e. g. `"linux32"`, `"linux64"`, `"win32"`, `"x64"`). There you find the library files of the JMAG adapter (e. g. `"libjmagmpcci.[so|dll]"`). The connection to MpCCI is established using these shared libraries which are loaded by the JCoupled application automatically.

11 Marc

11.1 Quick Information

Company name	HEXAGON
Company homepage	hexagon.com/products/marc
Support	simcompanion.hexagon.com
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁ ▷ VII-8 Exhaust Manifold ◁

11.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		X	
		X	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	SolidStructure	X	▷ V-3.1.1 Physical Domains ◁
	SolidThermal	X	
	SolidAcoustics	X	

11.1.2 Supported Platforms and Versions

Marc is supported on the following platforms:

	Supported versions														
MPCCI_ARCH: Code platform	2016	2017	2017.1	2018	2018.1	2019	2020	2021.2	2021.4	2022.1	2022.2	2022.3	2022.4	2023.1	2023.2
lnx4_x64: linux64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: win64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

For more information on supported platforms and compilers see also the Marc Release Guide.

11.1.3 References

Marc, Volume A: Theory and User Information by MSC.Software Corporation. This part of the Marc documentation contains general information on performing a simulation with Marc.

Marc, Volume D: User Subroutines and Special Routines This part of the Marc documentation contains information on the user subroutines which are also used by the code adapter. See especially chapter 12.

Marc, Volume C: Program Input for information on the COUPLING REGION option, which is used by MpCCI to define the coupling region.

11.1.4 Adapter Description

The code adapter is provided in an object file. Similar to object files of user-defined functions these files are linked with Marc before starting the computation. Therefore the appropriate compiler is needed to run a coupled simulation (see ▷ 11.1.5 Prerequisites for a Coupled Simulation ◁).

11.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary Marc installation.
- Appropriate compiler release in the user environment. As the MpCCI code adapter is based on user-defined methods which must be linked statically to the Marc executable, the proper compiler is required for coupled simulations. The path to the compiler must be given in an appropriate shell variable, e. g. `INTEL` for the Intel compiler. MpCCI will complain if the variable is not set correctly.

  It is recommended to first try to run an example which uses user subroutines to check whether the compiler is installed correctly.

  For more information on compiler requirements see the list of supported platforms in the Marc release guide, chapter 6.

11.2 Coupling Process

Please read also the corresponding ▷ IV-2 Setting up a Coupled Simulation ◁.

11.2.1 Model Preparation

Marc does not use a fixed unit system, so any consistent unit system may be used to define the Marc model.

The Marc model can be defined like a normal model. For the coupled analysis, the surfaces which form the coupling region must be defined as user sets:

- sets of finite element edges or geometric curves, for 2-D surface coupling;
- sets of finite element faces or geometric surfaces, for 3-D surface coupling;
- sets of finite elements or contact bodies, for volume-based coupling in any dimension.

The sets will then be listed in the Regions step of the MpCCI GUI.

Coupling is only supported for the new input file format, so the option NEW-STYLE TABLE must be selected in the RUN JOB menu of Mentat (option tables in the input file). MpCCI has to insert boundary conditions into the input file and only supports the new format.

Instead of directly submitting the file from Mentat, simply write an input file. The analysis is started from the MpCCI GUI.

It is recommended to first start a stand-alone Marc computation to check if the model is set up correctly.

.

11.2.2 Models Step

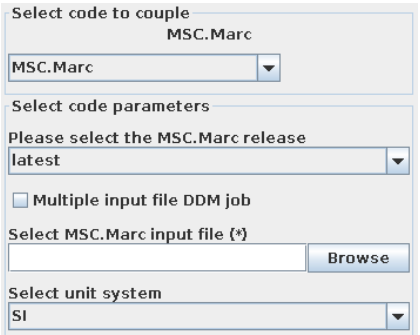


Figure 1: Marc options in the Models step

In the Models step the following options must be chosen:

MSC.Marc release Select the Marc release you want to use. latest (default) selects the latest release which is installed on your system.

Multiple input file DDM job This option is needed for parallel runs of Marc in which the domain decomposition is done in the GUI and multiple input files have been written. For single file DDM, the button must not be selected.

MSC.Marc input file Select the Marc input file for the analysis.

Unit system Select the unit system which was used to define the Marc model. Marc has no units built into it, a self-consistent set of units should be used. In the Models step you can select from British, SI, cgs and variable (see ▷ 1.2 Unit Systems ◁).

11.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁. There is no special specified setting for Marc.

11.2.4 Regions Step

The following quantities are supported:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Line, Face, Volume	Element		Direct
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	Direct
FilmTemp	Scalar	300.0 K	field	Line, Face	Element		Direct
NPosition	Vector	0.0 m	mesh coordinate	Line, Face, Volume	Node	Direct	
OverPressure	Scalar	0.0 N/m^2	flux dens.	Line, Face, Volume	Element		Direct
RelWallForce	Vector	0.0 N	flux integral	Line, Face	Node		Direct
WallForce	Vector	0.0 N	flux integral	Line, Face	Node		Direct
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Line, Face	Element		Direct
WallHTCoeff	Scalar	0.0 W/m^2 K	field	Line, Face	Element		Direct
WallTemp	Scalar	300.0 K	field	Line, Face	Node	Direct	

If the time step size is received by Marc, the option AUTO STEP must be selected in Mentat to enable time step adaptation in Marc.

11.2.5 Go Step

In the Go step the following options can be chosen:

Enter a job name This is the name of the Marc job, which is also used as base for the Marc output files.

Select integer mode Select an integer mode to use which can be one of default, i4 and i8.

Optional restart file If you want to restart a previous computation, select the restart file here.

Optional post file If you want to restart a previous computation from a post file, select it here.

Optional view factor file Select a view factor file.

User Subroutine Select a file with the user subroutines.

Additional command line options If you need any further command line options for starting Marc, enter them here. See also Volume C, Appendix B of the Marc manual. Do not set command line options which are already set by the MpCCI GUI (e. g. `-jid` for the job name).

Run parallel Select this option for a parallel run. See ▷ 11.2.6.1 Parallel Execution ◁ below.

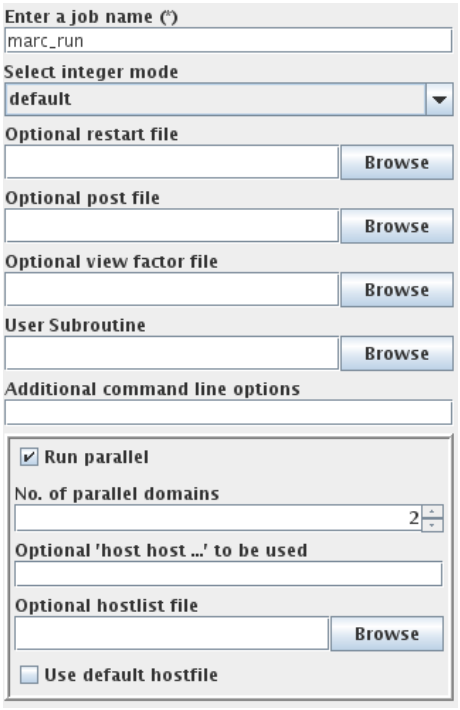


Figure 2: Marc options in the Go step

11.2.6 Running the Computation

Instead of directly submitting the file from Mentat, simply write an input file. The analysis is started from the MpCCI GUI.

11.2.6.1 Parallel Execution

There is no limitation regarding parallel execution of Marc in a coupled simulation. Both, automatic domain decomposition and manual decomposition are supported. The coupling region information is automatically passed to all subprocesses.

If you use multiple input files, the option Multiple input file DDM job must be selected in the Models step.

If Run parallel is selected in the Go step of the MpCCI GUI, the following options can be selected for a parallel run of Marc (cf. Figure 2):

No. of parallel domains Enter the number of parallel domains here. The number must correspond to the number of domain input files if multiple input files are used.

Optional 'host host ...' to be used Enter a list of host names for a simulation distributed on different computers.

Optional hostlist file Specify a hostfile, from which host names are extracted ▷ V-3.6.2 Hostlist File ◁.

Use default hostfile A default hostfile can be configured by setting MPCCI_HOSTLIST_FILE ▷ V-3.6.2 Hostlist File ◁.

11.2.7 Post-Processing

Pressures or forces received by Marc in a coupled simulation can be visualized in Mentat: Select External Force in the post-processing menu.

11.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for Marc are:

```
Usage:
   mpcci MSC.Marc [-]option


Synopsis:
   'mpcci MSC.Marc' is used to get information about MSC.Marc.


Options:
   -align    <ARGS>   Do a coordinate transformation on all nodes of a .dat
                      file based on a plane definition file and align the
                      nodal coordinates for the coupling partner.

   -help              This screen.

   -info              List verbose information about all MSC.Marc releases.

   -releases          List all MSC.Marc releases which MpCCI can find.

   -scan     [-ddm]    <input-file>
                      Run the scanner and create a scanner output file.
                      Specify -ddm if you have multiple input files.
```

The subcommands `align`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

11.4 Trouble Shooting, Open Issues and Known Bugs

Version:
From Marc 2014.2 and later
Problem:
At start Marc launch the compilation and link process to run the co-simulation. The linking process may fail with such error message:

```
ld: ACSI_MarcLib.a(Build_MarcLib.o): undefined reference to symbol '__cxa_pure_virtual@@CXXABI_1.3'
/usr/lib64/libstdc++.so.6: error adding symbols: DSO missing from command line
```

This issue usually appears when running Marc on unsupported MSC Linux OS.
Workaround:
Modify the following file "include_linux64" located in MARC "install_directory/tools" directory. You will need to add the option -cxxlib to the variable SYSLIB like below:

```
SYSLIBS="-L${MPI_ROOT}/lib64 -lmpi_mt -lmpifort -lrt $OPENMP -threads -lpthread -shared-intel"

to

SYSLIBS="-L${MPI_ROOT}/lib64 -lmpi_mt -lmpifort -lrt $OPENMP -threads -lpthread -shared-intel
-cxxlib"
```

Please check that you have set the right Intel compiler version for Marc.

12 MATLAB

12.1 Quick Information

Company name	MathWorks
Company homepage	www.mathworks.com
Support	www.mathworks.com/support/
Tutorials	▷ VII-12 Spring Mass System ◁

12.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	X	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		X	
		–	
		X	
		X	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	X	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	Fluid	X	▷ V-3.1.1 Physical Domains ◁
	System	X	

12.1.2 Supported Platforms and Versions

The following versions of MATLAB are supported by MpCCI:

	Supported versions			
MPCCI_ARCH: Code platform	R2018a	R2019a	R2019b	R2021a
lnx4_x64: glnxa64	X	X		X
windows_x64: win64	X		X	X

12.1.3 References

MATLAB Documentation is part of the MATLAB distribution or available online at www.mathworks.com/help.

12.1.4 Adapter Description

The MATLAB-MpCCI coupling is enabled by using the mex-function and is delivered as shared library. The MEX functions are called from a MATLAB script.
The MATLAB-MpCCI code adapter is developed by Fraunhofer SCAI.

12.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary MATLAB installation.
- A MATLAB code adapter license token for MpCCI.

12.1.6 Supported MATLAB Modules

For now just the coupling with `"*.m"`-scripts is supported. However it is possible to use different MATLAB Toolboxes, which can be called from the `"*.m"`-Script.

12.2 Coupling Process

12.2.1 Model Preparation

As the user can create his own algorithms for the solution process, the user has to implement the MpCCI MEX function calls in the MATLAB script.
It is recommended to steer the simulation from a master `"*.m"`-script where all the different aspects of the simulation are managed. Let's call it `"model.m"`.
Using this approach the simulation stages are easier to be identified by the user. The solution process respectively the simulation must be implemented in a way which allows to exchange data with the MpCCI server at desired stages.
For a steady state simulation a stage reflects an iteration step for example. For a transient simulation a stage may be a time step or an inner iteration step from time step advancement in case of an implicit solver for example.
The user needs to create in the master `"*.m"`-script the solver structure to reflect the different stages according to the simulation type. For example a `for`-loop can be employed to divide a time interval in multiple steps and call an integration and an MpCCI data synchronization in each step.
Before starting a coupled simulation using MATLAB, the `"model.m"` script has to be prepared for MpCCI based on the assumption that the `"model.m"` has been prepared to integrate the MpCCI mex-function at the different stages.
The integration of the MpCCI mex-function is realized by inserting in the MATLAB script a comment line with the keyword `$mpcci` followed by a function name or variable type, for example:

```
%$mpcci sync
```

Here are the different steps to follow in order to make the `"model.m"` script compatible for a co-simulation:

1. Declare the variables used for the coupling.
2. Insert the MpCCI co-simulation call.

12.2.1.1 MATLAB Variables Declaration

In order to let MpCCI recognize which variables should be used for the co-simulation, the user needs to declare in the master `"model.m"` script all the variables involved in the coupling.
The user should specify the type of each coupled variable. MpCCI provides the following supported types:

- `global`: Global variables represent information related to the code like physical time, time step size. (See ▷ 12.2.5 Regions Step ◁ for the list of supported global quantities)
- `ipoint`: Ipoint variables represent an integration point information. Theses variables are usually connected with a mesh interface.
- `cpoint`: Cpoint variables comprise point information which can be located in the space and basically interact with other point variables of the same dimension.
- `surface`: Surface variables represent mesh entities which contain values per elements, nodes.
- `volume`: Volume variables represent mesh entities which contain values per elements, nodes. Supports actually 2D surface volume.

Beside the declaration of the coupled variables, the user should declare the variable name used for

- the iteration counter in case of a steady state solver: use the `iter` as type.
- the physical time, time step size, iteration counter in case of transient solver (explicit and implicit method): with resp. use the `time`, `dt`, `iter` as type.
- the current solution state to MpCCI. This state is used to get the convergence status of the solver and should be declared by using the `conv` type.
- the coupled job convergence status in case of an implicit coupling: use the `jobconv` as type. The user can control the status of the coupled job. A returned value greater than zero indicated that the current iteration should stop. All partners have stopped their iterations and are processing the next time step.

The variables declaration may be done at the begin of the `"model.m"` script for example. There is no restriction about the location of the co-simulation variables. It is recommended to group the declaration in order to better track them. Each MpCCI mex-function is explained in details in this section ▷ 12.2.2.1 Available Commands ◁.

```
%$mpcci  cpoint displacement,force
%$mpcci  time  cTime
%$mpcci  dt    GLOBALsyncTimeStep
%$mpcci  iter  cIter
%$mpcci  conv  cConv
%$mpcci  jobconv  coupledConv

c = [1.0, 1.0, 1.0]'*1.0e1;
displacement = [0.0, 0.0, 0.0]';
cTime = 0;
GLOBALsyncTimeStep = 3.1623e-02;
endTime = 1.0;
m = 10;
g = 9.81274;
```

The MATLAB-variables have to be column vectors.

MpCCI checks that

- all co-simulation variables are properly declared in the MATLAB script. Otherwise the variable is marked as *UNDECLARED* by the MpCCI scanner.
- all co-simulation variables are uniquely declared. During the scanner process the user will be informed if the variables are not unique. The user should fix the issue.

12.2.1.2 MATLAB Co-Simulation Declaration

The user has to place at the different stages an MpCCI call:

- At the end of the initialization phase of all the data, prior to the begin of the solving process the user should use the command `$mpcci init`. This call is therefore optional. This call requires that the iteration counter, time are correctly initialized too.
- During the iteration step or time stepping the user should choose where the MpCCI call should be placed: at the begin or at the end of the solving step (see ▷ V-3.4 Coupling Process ◁ for the difference in the coupling algorithm). Use the command `$mpcci sync`, or `$mpcci send`, `$mpcci recv`.
- At the end of the solution process, the user should disconnect the MpCCI server by inserting the call `$mpcci exit`.

You can check Figure 1 (part VIII) to visualize the possible stages for exchanging the data.
A sample of the MATLAB script can be found at the next section ▷ 12.2.2.2 Sample M Script ◁.

12.2.2 MpCCI MEX Function

In MATLAB, the coupling process is controlled via an `"m"` file which calls functions provided by MpCCI.

12.2.2.1 Available Commands

Each command is inserted as a comment % in the MATLAB script. This lets the user use the MATLAB script without co-simulation activation and test the proper run of the script.
Co-simulation variables declaration statement:

`%$mpcci global globvar1 ...`
Declare list of variables of type global.
globvar1 is the name of the variable used in MATLAB script.
The variables can be separated by a space or a comma if you have several variables to declare, e.g.: `%$mpcci global globvar1 globavar2 globvar3`

`%$mpcci ipoint ipointvar1 ...`
Declare a list of variables of type ipoint.
ipointvar1 is the name of the variable used in MATLAB script.
The variables can be separated by a space or a comma if you have several variables to declare, e.g.: `%$mpcci ipoint ipointvar1 ipointvar2`

`%$mpcci cpoint cpointvar1 ...`
Declare a list of variables of type cpoint.
cpointvar1 is the name of the variable referenced in MATLAB script.
The variables can be separated by a space or a comma if you have several variables to declare, e.g.: `%$mpcci cpoint cpointvar1 cpointvar2 cpointvar3`
If a cpoint is used as a moving sensor, the corresponding local coordinate of the sensor parameter can be provided to MpCCI as a pair value declaration for example (cpointvar1 cpointvar1_coord). The array named cpointvar1_coord contains the coordinates of this moving point.

In that case the full declaration of cpointvar1 would look like:
`%$mpcci cpoint (cpointvar1 cpointvar1_coord)`
Basically you should pair the cpoint variable with its coordinates variable with parentheses.

%$mpcci surface (mesh1 mesh1_elem) ...

Declare a list of variables of type surface.
The parameters (mesh1 mesh1_elem) define a pair of variables representing a mesh of dimension surface where the name is associated with mesh1.

- The variable mesh1 is a list of nodal ids and coordinates per row by respecting this syntax. This variable is also used as prefix to defined the quantities.
  `mesh1 = [id0,x0,y0,z0; id1,x1,y1,z1; id3,x3,y3,z3;...]`

- mesh1_elem is the variable defining the element topology of the mesh mesh1. The variable is a matrix of size (number of elements * 9). Each row begins with the element id followed by the list of 8 node ids defining this element.
  MATLAB supports the following element types with MpCCI:
  - linear, quadratic triangles (MPCCI_ETYP_TRIA3, MPCCI_ETYP_TRIA6) and
  - linear and quadractic quadrilaterals (MPCCI_ETYP_QUAD4, MPCCI_ETYP_QUAD8).

  As the mesh may be composed of mixed elements, elements which don't have 8 nodes should fill the rest of the row with the value -1. In that way MpCCI mex-function can recognize the element type.
  `mesh1_elem = [id0,n0,n1,n2,-1,-1,-1,-1;id1,n1,n4,n6,n8,-1,-1,-1;...]`
  The first element with id0 is a triangle element, the second element id1 is a quad element.
  To store the quantities exchanged by the co-simulation based on this mesh, MpCCI mex-function is using and expecting the declaration of following variable respecting this syntax:
  `<mesh_prefix>_<quantityname>`

  - The variable name is composed of the name of the mesh (mesh1 in the current example) concatenated with an underscore and the name of the MpCCI quantity quantityname: for example `mesh1_relwallforce`
  - The variable name must be in lower case.
  - The size of the variable is for example equal to (number of nodes * 3) for a nodal vector quantity.
  - Each mesh quantity variable must be correctly initialized.

For the following quantities WallForce and RelWallForce the force vector field may be computed automatically by MpCCI if MATLAB provides the pressure variable value using the naming convention: `<mesh_prefix>_pressure`. Otherwise MpCCI expects to find the variable `<mesh_prefix>_wallforce` or `<mesh_prefix>_relwallforce`.

%$mpcci time var1

Declare var1 as time variable.
This corresponds to current simulation time. The value can not decrease. By a static simulation the value has to be equal -1 or not declared. If the variable is not declared MpCCI will set the value -1 for the data exchange call.

%$mpcci dt var1

Declare var1 as time step size variable of the simulation.
The value can be set to -1 if not used, for e. g. a steady state simulation, or not declared. If the variable is not declared MpCCI will set the value 0 for the data exchange call.

%$mpcci iter var1

Declare var1 as the iteration variable.
This defines the iteration number for a transient implicit simulation or for a steady state simulation. The value must be -1 for a transient explicit co-simulation or not declared. If the variable is not

declared MpCCI will set the value -1 for the data exchange call.
Depending of the coupling scheme selected in the MpCCI GUI (Go step), this value will be automatically ignored if Explicit-Transient is selected.

%$mpcci conv var1
Declare var1 as the convergence variable.
This variable can be assigned with the following value:

- 1: notify a divergence status.
- 2: notify a stop status. The code can not continue the next iteration for the implicit coupling. This will force the partner code to proceed to the next time step.
- 3: notify a convergence status. The MATLAB solution has converged.
- 4: notify the continue status. MATLAB wants to continue the iteration.

If the variable is not declared MpCCI will set the value 0 (invalid state) for the data exchange call.

Co-simulation control statement:

%$mpcci init
Declare MATLAB connection with MpCCI.

%$mpcci sync
Declare a data exchange (send and receive) at this point.

%$mpcci send
Declare a data exchange (send only) at this point.

%$mpcci recv
Declare a data exchange (receive only) at this point.

%$mpcci exit
Disconnect from the MpCCI server and stop MATLAB.

%$mpcci quit
Disconnect from the MpCCI server and allow MATLAB to run.

%$mpcci error msg
Disconnect from the MpCCI server with an error message msg and stop MATLAB. This will terminate the complete co-simulation partners.

12.2.2.2 Sample M Script

The following example of the "*.m"-file is used to illustrate the definition of the requested information:

```
c=[1.0, 1.0, 1.0]'*1.0e1;
displacement=[0.0, 0.0, 0.0]';
GLOBALsyncTimeStep =  3.1623e-02;
endTime = 1.0;
m = 10; g = 9.81274;

% Setting control the solver type
iterative_solver = 0;
% Variable to evaluate the coupled job status
coupledConv = 0;

%$mpcci  cpoint displacement,force
%$mpcci  time  cTime
%$mpcci  dt    GLOBALsyncTimeStep
%$mpcci  iter  cIter
```

```
%$mpcci  conv  cConv
%$mpcci  jobconv coupledConv

if(iterative_solver == 1)
   iter_max = 10;
else
   iter_max = 0;
end

for i=0:endTime/GLOBALsyncTimeStep
   cTime = i*GLOBALsyncTimeStep;
   cConv = 2;

   %iterative coupling
   for cIter=0:iter_max
      if (iterative_solver == 1)
         if cIter == iter_max
            cConv = 2; % conv = stop signal
         else
            cConv = 4; % conv = continue signal
         end
      else
         cConv = 3;    % state converged
      end
      %$mpcci sync

      force = -c.*displacement;

      if (coupledConv > 0)
        disp('Receive stop signal: exit the iterative loop!');
        break;
      end
   end
end

%$mpcci exit
```

In the first comment we can see the definition of the coupling variables `displacement` and `force` as `cpoint`. The next four lines specify the auxiliary variables for the MpCCI server. This `"*.m"`-script demonstrates the iterative transient coupling. Therefore we can see two `for`-loops. The first loop increments the time variable and the second one implements the corrector iterations. There are two synchronization calls in the script. The first one communicates with the MpCCI server from the corrector iteration. The second synchronization call sets the convergence flag to 3, which means that the iterative calculation in MATLAB is finished and the last communication for the current time is requested. The comment in the last line stops the communication with the MpCCI server.
Before MATLAB starts MpCCI will create a new MATLAB script file and replace each MpCCI control statement with the real mex function call. Below is an example of the patched MATLAB script.

```
addpath('/home/software/mpcci/codes/MATLAB/adapters/R2010b/glnxa64');

c=[1.0, 1.0, 1.0]'*1.0e1;
displacement=[0.0, 0.0, 0.0]';
GLOBALsyncTimeStep =  3.1623e-02;
```

```
endTime = 1.0;
m = 10; g = 9.81274;

% Setting control the solver type
iterative_solver = 0;
% Variable to evaluate the coupled job status
coupledConv = 0;

%$mpcci  cpoint displacement,force
%$mpcci  time  cTime
%$mpcci  dt    GLOBALsyncTimeStep
%$mpcci  iter  cIter
%$mpcci  conv  cConv
%$mpcci  jobconv coupledConv

if(iterative_solver == 1)
   iter_max = 10;
else
   iter_max = 0;
end

for i=0:endTime/GLOBALsyncTimeStep
   cTime = i*GLOBALsyncTimeStep;
   cConv = 2;

   %iterative coupling
   for cIter=0:iter_max
      if (iterative_solver == 1)
         if cIter == iter_max
            cConv = 2; % conv = stop signal
         else
            cConv = 4; % conv = continue signal
         end
      else
         cConv = 3;    % state converged
      end
      mpcci('SYNC',cTime,GLOBALsyncTimeStep,cIter,cConv,'coupledConv');

      force = -c.*displacement;

      if (coupledConv > 0)
        disp('Receive stop signal: exit the iterative loop!');
        break;
      end
   end
end

mpcci('EXIT');
```

12.2.3 Models Step

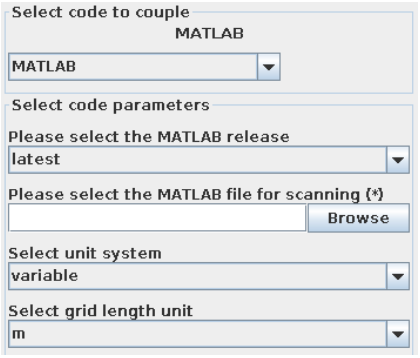


Figure 1: MATLAB options in the Models step

In the Models step, the following options must be chosen:

MATLAB release Select the release of MATLAB you want to use. latest (default) will select the latest version which is installed on your system.

MATLAB file Select the MATLAB m file of your MATLAB project.
The MpCCI scanner uses the MATLAB m file to extract model information.

Unit system Select the unit system which was used in MATLAB (see ▷ 1.2 Unit Systems ◁).

12.2.4 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁. There is no special specified setting for MATLAB.

12.2.5 Regions Step

The MATLAB adapter stores the quantities using a direct memory access to the MATLAB solver ("Direct"). The user has to use MATLAB-array with appropriate dimension for the coupling. If e. g. a force is received in MATLAB, the adapter expects a vector of dimension 3. All the vectors must be column vectors. MATLAB supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code, Element	Direct	Direct
Acceleration	Vector	0.0 m/s^2	field	Point	Code	Direct	Direct
AngularAcceleration	Vector	0.0 rad/s^2	field	Point	Code	Direct	Direct
AngularCoordinate	Quaternion	0.0	mesh coordinate	Point	Code	Direct	Direct
AngularVelocity	Vector	0.0 rad/s	field	Point	Code	Direct	Direct
BodyForce	Vector	0.0 N/m^3	flux dens.	Volume	Node, Element	Direct	Direct
CurrentDensity	Vector	0.0 A/m^2	flux dens.	Volume	Node, Element	Direct	Direct
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	Direct
ElectrCond1	Scalar	0.0 S/m	field	Volume	Node, Element	Direct	Direct
ElectrCond3	Vector	0.0 S/m	field	Volume	Node, Element	Direct	Direct
ElectrCondX	Scalar	0.0 S/m	field	Volume	Node, Element	Direct	Direct
ElectrCondY	Scalar	0.0 S/m	field	Volume	Node, Element	Direct	Direct
ElectrCondZ	Scalar	0.0 S/m	field	Volume	Node, Element	Direct	Direct
ElectricPot	Scalar	0.0 V	field	Volume	Node, Element	Direct	Direct
ElectrRes1	Scalar	0.0 ohm m	field	Volume	Node, Element	Direct	Direct
ElectrRes3	Vector	0.0 ohm m	field	Volume	Node, Element	Direct	Direct
ElectrResX	Scalar	0.0 ohm m	field	Volume	Node, Element	Direct	Direct
ElectrResY	Scalar	0.0 ohm m	field	Volume	Node, Element	Direct	Direct
ElectrResZ	Scalar	0.0 ohm m	field	Volume	Node, Element	Direct	Direct
FilmTemp	Scalar	300.0 K	field	Face	Code, Element	Direct	Direct
Force	Vector	0.0 N	flux integral	Point	Code	Direct	Direct
JouleHeat	Scalar	0.0 W/m^3	flux dens.	Volume	Node, Element	Direct	Direct
LorentzForce	Vector	0.0 N/m^3	flux dens.	Volume	Node, Element	Direct	Direct
MagneticFlux	Vector	0.0 T	flux dens.	Volume	Node, Element	Direct	Direct
MassFlowRate	Scalar	0.0 kg/s	flux integral	Point	Code	Direct	Direct

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
MassFluxRate	Scalar	0.0 $kg/m^2 s$	flux dens.	Point	Code	Direct	Direct
NPosition	Vector	0.0 m	mesh coordinate	Face, Volume	Code	Direct	Direct
PointPosition	Vector	0.0 m	mesh coordinate	Point	Code	Direct	Direct
RealFlag	Scalar	0.0	g-max	Global	global	Direct	Direct
SpecificHeat	Scalar	1.0 J/kg K	field	Volume	Node, Element	Direct	Direct
Temperature	Scalar	300.0 K	field	Point, Volume	Code, Element	Direct	Direct
ThermCond1	Scalar	0.0 W/m K	field	Volume	Node, Element	Direct	Direct
ThermCond3	Vector	0.0 W/m K	field	Volume	Node, Element	Direct	Direct
ThermCondX	Scalar	0.0 W/m K	field	Volume	Node, Element	Direct	Direct
ThermCondY	Scalar	0.0 W/m K	field	Volume	Node, Element	Direct	Direct
ThermCondZ	Scalar	0.0 W/m K	field	Volume	Node, Element	Direct	Direct
Torque	Vector	0.0 N m	flux integral	Point	Code	Direct	Direct
TotalPressure	Scalar	0.0 N/m^2	flux dens.	Point	Code	Direct	Direct
Velocity	Vector	0.0 m/s	field	Point	Code	Direct	Direct
VelocityMagnitude	Scalar	0.0 m/s	field	Point	Code	Direct	Direct
WallForce	Vector	0.0 N	flux integral	Face	Code, Element	Direct	Direct
WallHTCoeff	Scalar	0.0 $W/m^2 K$	field	Face	Code, Element	Direct	Direct
WallTemp	Scalar	300.0 K	field	Face	Code, Element	Direct	Direct

12.2.6 Go Step

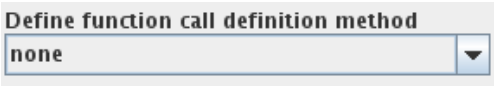


Figure 2: MATLAB options in the Go step

MATLAB offers nothing but the common coupling configuration in the Go step (see Figure 2).

Define function call definition method

- none: MpCCI is just processing the master script and the MpCCI instructions in the m-file.
- nested: MpCCI uses the master script as the main and parent function. All other functions referenced from the master script will be included as nested function in a single MATLAB script.
- local: MpCCI uses the master script as function. All other functions referenced from the master script will be included as a local functions in a single MATLAB script.

12.2.6.1 Running the Computation

When the Start button is pressed, MATLAB is started with the options given in the Go step. The master script is patched for the co-simulation in a new file beginning with the mpcci_ prefix followed by the master script name.
If the Stop button is pressed, a stop-file `"job.stop"` is created and MATLAB will stop the next time it checks the presence of a stop file.

12.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for MATLAB are:

```
Usage:
   mpcci MATLAB [-]option


Synopsis:
   'mpcci MATLAB' is used to get information about MATLAB.


Options:
   -files  <main.m>
            List all files involved starting with the main.m file.

   -help
            This screen.

   -info
            List verbose information about all MATLAB releases.

   -join  <main.m>
```

```
          Join all files involved starting with the main.m file
          into a single .m file.

-releases
          List all MATLAB releases which MpCCI can find.

-scan  <main.m>
          Run the scanner on the MATLAB script file and create
          a scanner output file.
```

The subcommands `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci matlab -join <main.m>`

The `join` subcommand joins all files involved in the MATLAB run into a single `".m"` file. It starts with the given main `".m"` file.

12.4 Code Adapter Description

Within the MpCCI distribution the `"adapters"` directory contains the necessary software to connect the simulation programs to MpCCI depending on your license. The files are located within the subdirectory "<*MpCCI_home*>`/codes/MATLAB/adapters`".

This subdirectory is further divided by several release subdirectories, e. g. `"R2010b"`. The version directories are further divided by several architectures (e. g. `"glnxa64"`). There you find the library files of the MATLAB adapter (e. g. `"mpcci.[mexa64]"`).

With MATLAB the user can create his own algorithms for the solution process via an m-file script, therefore all coupling algorithms are possible.

13 MSC NASTRAN

13.1 Quick Information

Company name	HEXAGON
Company homepage	hexagon.com/products/product-groups/computer-aided-engineering-software/msc-nastran
Support	simcompanion.hexagon.com
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁ ▷ VII-4 Driven Cavity ◁ ▷ VII-5 Pipe Nozzle ◁

13.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		X	
		–	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	SolidStructure	X	▷ V-3.1.1 Physical Domains ◁
	SolidAcoustics	X	

13.1.2 Supported Platforms and Versions

MSC NASTRAN is supported on the following platforms:

	Supported versions																	
MPCCI_ARCH: Code platform	2017.0	2017.1	2018.0	2018.1	2018.2	2019.0	2020.0	2021.0	2021.1	2021.2	2021.3	2021.4	2022.1	2022.2	2022.3	2022.4	2023.1	2023.2
lnx4_x64: lx8664			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: win8664	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

For details on the platforms supported by MSC NASTRAN see also the Platform Support page at www.mscsoftware.com/support/platform-support.

13.1.3 Adapter Description

The code adapter is provided as an dynamic library implementing the OpenFSI service.

13.1.4 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- MSC NASTRAN installation including SOL400 and the necessary license token ('MD_Nonlinear', or 'NA_Nonlinear').
- Iterative coupling requires the usage of NLSTEP definition in the bulk data entries.

13.2 Coupling Process

Please read also the corresponding ▷IV-2 Setting up a Coupled Simulation◁.

13.2.1 Model Preparation

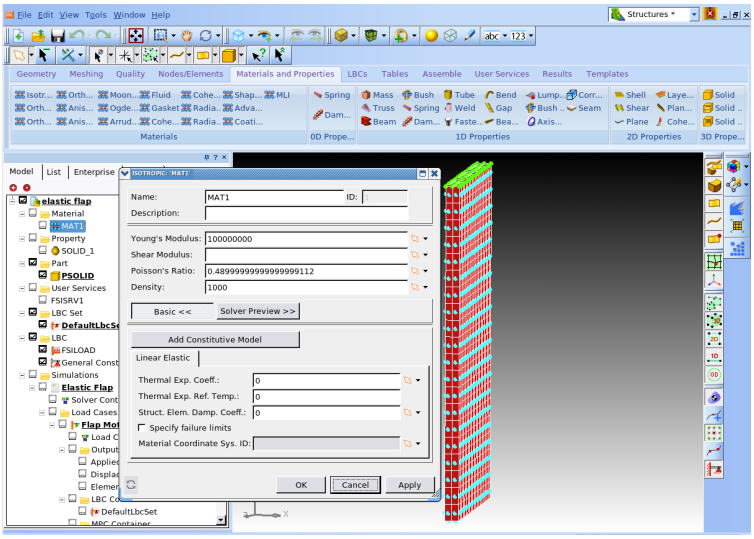


Figure 1: Model preparation under SimXpert.

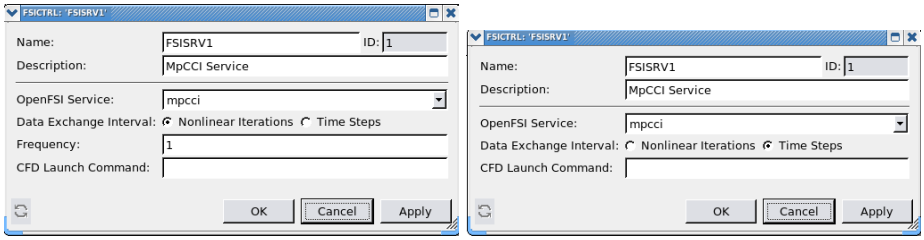


Figure 2: OpenFSI Data Exchange Interval under SimXpert: on the left implicit and on the right explicit setting

1. Create Structural model using SimXpert (Figure 1).
   - Define appropriate properties for the structure.
2. Define Service for OpenFSI.
   - Define CFD service under User Services OpenFSI.
   - Provide a dummy name. This will be updated by MpCCI before starting the computation.
   - Choose whether coupling should occur at each (Data Exchange Interval Figure 2):
     – solution time step (explicit): Time Steps.
     – within the iteration loop (implicit): Nonlinear Iterations.
     You can define the Frequency of the data exchange within the time step.
3. Define OpenFSI Boundary conditions (Figure 3).

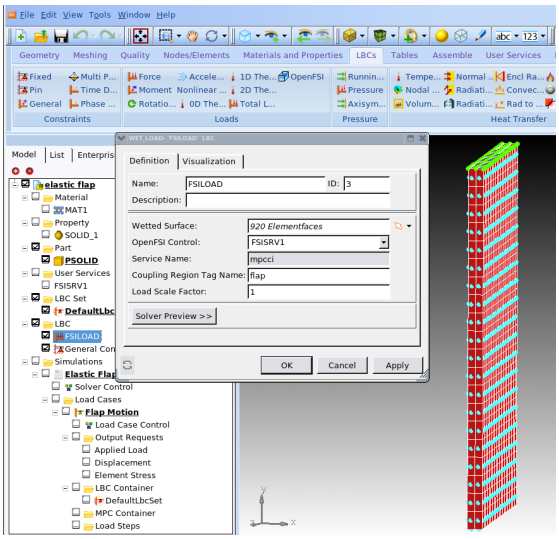


Figure 3: OpenFSI Loads Definition under SimXpert.

- Applied loads to wetted surfaces under Loads OpenFSI .
- Select surfaces or element faces.
- Pick OpenFSI Service alias name.
- Wetted surfaces can point to more than one service.
- Enter Coupling Region tag name to identify the region.
- Scale factor "1" should be used.

4. Define MSC NASTRAN Job: Solution type must be "General Nonlinear Analysis (SOL400)".
   - Define the Load Case:"Nonlinear Transient","Linear Static","Nonlinear Static".
   - Define Load output Request for post processing of OpenFSI loads (forces).

13.2.2 Models Step

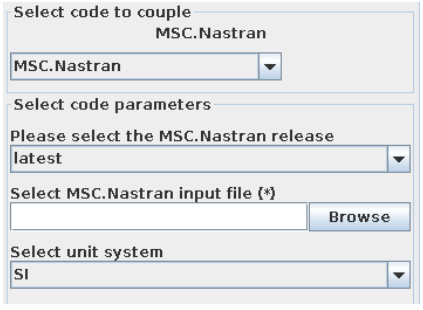


Figure 4: MSC NASTRAN options in the Models step

In the Models step the following options must be chosen:

MSC NASTRAN release Select the MSC NASTRAN release you want to use. latest (default) selects the latest release which is installed on your system.

MSC NASTRAN input file Select the MSC NASTRAN input file for the analysis (`".bdf"` or `".dat"` file)

Unit system Select the unit system which was used to define the MSC NASTRAN model (see ▷1.2 Unit Systems◁).

13.2.3 Algorithm Step

For general options please refer to ▷V-4.7.2 Code Specific Algorithm Settings◁. In the Algorithm step, following option is available in the code specific section in Coupling steps:

Number of inner iterations This options appears only for Implicit coupling scheme. Set up this option in order to configure the FSICTRL command. If the MSC NASTRAN .bdf file contains the keyword NLSTEP followed either by GENERAL, ADAPT or FIXED, the number of inner iterations and the time step size will be adjusted to match the settings here.

13.2.4 Regions Step

The following quantities are supported:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	Direct
NPosition	Vector	0.0 m	mesh coordinate	Line, Face	Code	Direct	
RelWallForce	Vector	0.0 N	flux integral	Line, Face	Code		Direct
Velocity	Vector	0.0 m/s	field	Line, Face	Code	Direct	
WallForce	Vector	0.0 N	flux integral	Line, Face	Code		Direct

13.2.5 Go Step

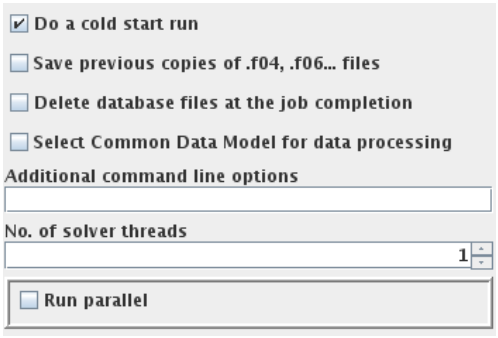


Figure 5: MSC NASTRAN options in the Go step

In the Go step the following options can be chosen:

Do a cold start run All ".IFPDAT", ".DBALL", ".MASTER" files will be deleted. Otherwise this will be considered as a restart job.

Save previous copies of .f04, .f06... files Save a previous copy of .f04, .f06... files using the MSC NASTRAN option -old=[yes|no].

Delete database files at the job completion Delete the database files at the job completion src=yes. The job could not be restarted if this is activated.

Select Common Data Model for data processing Activate the common data model processing sys444=1 for MSC NASTRAN.

Additional command line options Additional command line options for MSC NASTRAN can be given here, they will directly be used when MSC NASTRAN is started.

No. of solver threads The number of solver threads MSC NASTRAN should use for this run can be given here.

Run parallel Select this option for a parallel run. See ▷ 13.2.6.1 Parallel Execution ◁ below.

13.2.6 Running the Computation

When the Start button is pressed, MSC NASTRAN is started with the options given in the Go step in batch.
If the coupling scheme Implicit is selected, the FSICTRL from the ".bdf" file will be automatically set to IMPLICIT.
If the coupling scheme Explicit is selected, the FSICTRL from the ".bdf" file will be automatically set to EXPLICIT.

13.2.6.1 Parallel Execution

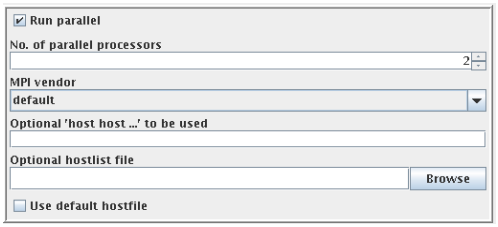


Figure 6: MSC NASTRAN options for parallel execution

If Run parallel is selected in the Go step of the MpCCI GUI, the following options can be selected for a parallel run of MSC NASTRAN (cf. Figure 6):

No. of parallel processors Enter the number of parallel processors here.

MPI vendor Select the MPI vendor to use. If default is selected it will start MSC NASTRAN with your default installation setting.

Optional 'host host ...' to be used Enter a list of host names for a simulation distributed on different computers.

Optional hostlist file Specify a hostfile, from which host names are extracted.

Use default hostfile A default hostfile can be configured by setting MPCCI_HOSTLIST_FILE ▷ V-3.6.2 Hostlist File ◁.

13.2.6.2 Batch Execution

MSC NASTRAN is always run as a batch process, therefore no special settings are necessary for batch execution.

13.2.7 Post-Processing

Use SimXpert to post-process the results saved in a ".xdb" file.

13.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for MSC NASTRAN are:

```
Usage:
   mpcci MSC.Nastran [-]option


Synopsis:
   'mpcci MSC.Nastran' is used to get information about MSC.Nastran.


Options:
   -align  <ARGS>
            Do a coordinate transformation on all nodes of a .bdf/.dat
            file based on a plane definition file and align the
            nodal coordinates for the coupling partner.

   -bdfinfo  [file file ..]
            Extract and display coupling information on BDF files.

   -help
            This screen.

   -info
            List verbose information about all MSC.Nastran releases.

   -releases
            List all MSC.Nastran releases which MpCCI can find.

   -scan  <input-file>
            Run the scanner and create a scanner output file.
```

The subcommands `align`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci msc.nastran -bdinfo [file file ...]`

The `bdinfo` subcommand extracts the coupling information on the given BDF files and prints them to stdout.

13.4 Code Adapter Reference

The MpCCI code adapter for MSC NASTRAN uses the OpenFSI Service definition to manage the data transfer. The code adapter is distributed as a dynamic library, which is located in "<*MpCCI_home*>/codes/MSC.Nastran/adapters/<*MSCNastran release*>/<*platform*>/Apps".

MpCCI will set all necessary environment variable to locate the MpCCI- OpenFSI service.

MSC NASTRAN exchanges data during the time step initialization for the explicit scheme.
For implicit scheme MSC NASTRAN exchanges data during the time step initialization and during the iterative loop.

13.5 Trouble Shooting, Open Issues and Known Bugs

Feature:
Face Coupling
Version:
2010.1
Problem:
MSC NASTRAN could not load a model with QUAD8 elements for the wetted surface.
Workaround:
Replace the hexahedral element CHEXA20 to CHEXA8 which will create QUAD4 elements for the coupling.

14 OpenFOAM

14.1 Quick Information

Company name	OpenCFD Limited
Company homepage	www.openfoam.com
Support	www.openfoam.com/support/
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-4 Driven Cavity ◁ ▷ VII-6 Blood Vessel ◁ ▷ VII-8 Exhaust Manifold ◁ ▷ VII-9 Cube in a Duct Heater ◁ ▷ VII-13 Y-Junction ◁

14.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	X	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		X	
		X	
Feature	MpCCI Configurator	X	▷ V-3.5 Smart Configuration ◁
	Negotiation	X	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	X	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	Fluid	X	▷ V-3.1.1 Physical Domains ◁
	FluidThermal	X	
	FluidPlasma	X	

14.1.2 Supported Platforms and Versions

	Supported versions														
MPCCI_ARCH: Code platform	v1606+	v1612+	v1706	v1712	v1806	v1812	v1906	v1912	v2006	v2012	v2106	v2112	v2206	v2212	v2306
lnx4_x64: linux64	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

14.1.3 References

OpenFOAM User Guide is part of the OpenFOAM distribution.

OpenFOAM Programmer's Guide is part of the OpenFOAM distribution.

OpenFOAM C++ Source Guide This is the source code documentation generated by Doxygen. It is available at www.openfoam.com/docs/.

14.1.4 Adapter Description

MpCCI uses the function object interface of OpenFOAM. This interface provides the opportunity to have the adapter library loaded by the solver and the data transfer triggered in each time step. Since MpCCI uses only OpenFOAM-intrinsic mechanisms, code-coupling works without any modification to the OpenFOAM solver.

For transient simulations with implicit coupling scheme, if constant time-stepping is chosen but the end time is not dividable by the time step size, the end time will not be reached in OpenFOAM's calculations and it will stop calculating earlier than the given value. This might lead to co-simulation errors at the end of the coupling.

14.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary OpenFOAM installation.
- Before using MpCCI make sure the environment variable `FOAM_INST_DIR` is set properly. This means that `FOAM_INST_DIR` is the parent directory of any installed OpenFOAM version. e. g.
  - "<*$FOAM_INST_DIR* >/OpenFOAM-v2006"
- An MpCCI Grid Morpher license token if it will be used.
- Make sure that the appropriate environment of your OpenFOAM version is sourced.
- Make sure that the MpCCI code adapters for OpenFOAM are built as described in ▷ 14.5 Code Adapter Reference ◁.

14.2 Coupling Process

14.2.1 Model Preparation

Models can be prepared as usually.
The coupling components must be defined as separate surfaces or volumes. Table 1 shows the list of surfaces defined in an OpenFOAM model, which then appear in the Coupling Step of the MpCCI GUI.
MpCCI will detect the model to have a transient solution type if the OpenFOAM application contains one or more of the words pimple, piso, ico or DyM (e. g. icoFoam or pimpleDyMFoam); if the application name contains simple (e. g. simpleFoam) MpCCI assumes the solution type to be steady-state. If the OpenFOAM application name contains none of these keywords, the user has to set the coupling scheme – steady or transient – in the Go step.

If you exchange a relative pressure (e. g. RelWallForce or Overpressure), you must set the reference pressure to an appropriate value, which usually corresponds to the atmospheric pressure. (▷ 14.2.5 Go Step ◁)
For more information on relative and absolute pressures see ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁.

When receiving the wall temperature (**WallTemp**) in OpenFOAM set the boundary condition type of coupled walls from the file "0/T" to "fixedValue", otherwise the received wall temperature and heat flux are not taken into account, resp. not calculated for the computation.

When receiving mesh deformation (**NPosition**) in OpenFOAM set the boundary condition type of coupled walls from the file "0/U" to "movingWallVelocity" with value (0,0,0), otherwise the wall velocity is not taken into account, resp. not calculated for the computation.

Sample from the "0/T":

```
internalField   uniform $temperature;

boundaryField
{
    couple-flap
    {
       type            fixedValue;
       value           uniform $temperature;
    }
    ....
}
```

All further options required for coupling can be set in the MpCCI GUI.

14.2.1.1 Setting function object

In order to have the function object loaded, MpCCI adds some lines to "<*case directory*>/system/controlDict" which instruct the solver to load the adapter library and to call the appropriate init- and transfer-functions.

```
libs ("libfoammpcci.so");

functions
(
   MpCCI_functionObject_adapter_for_OpenFOAM
   {
      type mpcci; // Type of functionObject
   }
);
```

See ▷ 14.2.5 Go Step ◁ for a complete description of the Go step options.

14.2.1.2 Deforming Meshes

In typical FSI problems, deformations are computed by the solid mechanics code and sent to OpenFOAM, i. e. OpenFOAM has to move boundaries and deform the mesh.

To make coupled simulations with deforming meshes you have to choose an OpenFOAM solver that is capable of handling dynamic meshes. Solvers which can handle deforming meshes are usually those that have a ... DyMFoam in its name. Alternatively you may write your own custom solver. Further you have to provide the file "<*case directory*>/constant/dynamicMeshDict" controlling how OpenFOAM performs mesh motion. Make sure to employ a motion solver operating with displacements e.g. displacementLaplacian or velocities velocityLaplacian.

velocityLaplacian is not available for OpenFOAM versions below 2.4.

```
FoamFile
{
    version     2.0;
    format      ascii;
    class       dictionary;
    object      motionProperties;
}
// * * * * * * * * * * * * * * * * * //
5
(
    wall
    {
        type            wall;
        nFaces          18640;
        startFace       296814;
    }
    outlet
    {
        type            patch;
        nFaces          256;
        startFace       315454;
    }
    i3
    {
        type            patch;
        nFaces          283;
        startFace       315710;
    }
    i2
    {
        type            patch;
        nFaces          318;
        startFace       315993;
    }
    i1
    {
        type            patch;
        nFaces          291;
        startFace       316311;
    }
)
// ****************************** //
```

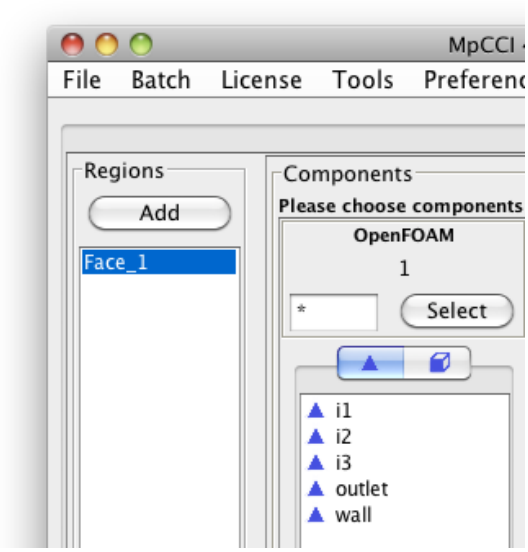


Table 1: List of surfaces in the Regions step of the MpCCI GUI (right) and in OpenFOAM (left) defined in "<*case directory*>/constant/polymesh/boundary".

Here's an example of a dynamicMeshDict:

```
FoamFile
{
    version     2.0;
    format      ascii;
    class       dictionary;
    object      motionProperties;
}
// * * * * * * * * * * * * * * * * * * * * * * * * //

dynamicFvMesh      dynamicMotionSolverFvMesh;

motionSolverLibs ("libfvMotionSolvers.so");

solver            displacementLaplacian;

diffusivity       inverseDistance (couple-flap);
```

```
// ****************************************** //
```

Currently it is not possible to remesh a coupling component itself during a computation.

14.2.2 Models Step

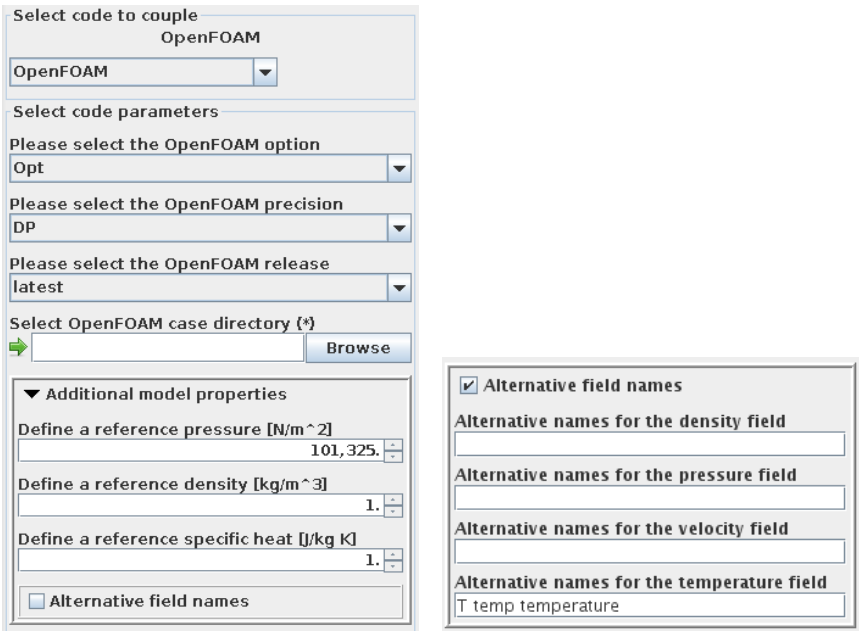


Figure 1: OpenFOAM options in the Models step

In the Models step, the following options must be chosen:

OpenFOAM option Select the OpenFOAM option from Opt, Debug.

OpenFOAM precision Select the OpenFOAM precision from DP for double precision or SP for single precision.

OpenFOAM release Select the release of OpenFOAM you want to use. The version must match your case. latest (default) will select the latest version which is installed on your system.

OpenFOAM case directory Select the case directory of your OpenFOAM model.

Additional model properties

Define a reference pressure [N/m^2] If you exchange a relative pressure (e. g. RelWallForce or Overpressure), you must set the reference pressure to an appropriate value, which usually corresponds to the atmospheric pressure. For more information on relative and absolute pressures see ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁.

Define a reference density [kg/m^3] This value is only relevant in incompressible fluid flow. The calculation of forces and heat flux involve the density, thus a reference density has to be specified. Beyond that some incompressible solvers' pressure field does not contain the plain pressure p itself but $\frac{p}{\varrho}$ which is actually the pressure divided by the density. Therefore the adapter needs a reference density to translate between the bare pressure p handled by MpCCI and $\frac{p}{\varrho}$ occurring in some OpenFOAM solvers.

Define a reference specific heat [J/kg K] This value is only relevant in incompressible fluid flow. The calculation of heat flux involves the specific heat, thus a reference value has to be specified.

Alternative field names If your (customized) solver does not use the usual names for the quantities e. g. temperature instead of T, you may select this option to define alternative names for the density, pressure, velocity and temperature fields. If you are unsure about the names used by your solver you may define (whitespace separated) lists of names e. g. T temp temperature.

When using the MpCCI Configurator, the reference values for pressure and density are taken into account. A change of these reference values currently does not automatically lead to the start of the MpCCI Configurator to calculate new coupling settings. Workaround: The user has to trigger a rescan of the model file which leads to a new MpCCI Configurator run.

14.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

In the Algorithm step, following additional option is available:

Solver settings

Use alpha Courant interface *(Only for Implicit coupling scheme with an adaptive time step size negotiated with all codes (cf. ▷ V-4.7.1 Common Basic Algorithm Settings ◁.))* Check this option if the alpha Courant interface shall be used.

14.2.4 Regions Step

OpenFOAM supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Line, Face, Volume	Code	Dir	
DeltaTime	Scalar	1.0 s	g-min	Global	global	Dir	Dir
FilmTemp	Scalar	300.0 K	field	Line, Face	Code	Dir	
HeatRate	Scalar	0.0 W	flux dens.	Face	Code	Dir	
MassFlowRate	Scalar	0.0 kg/s	flux integral	Face	Code	Dir	Dir
MassFluxRate	Scalar	0.0 $kg/m^2\,s$	flux dens.	Face	Code	Dir	Dir
NPosition	Vector	0.0 m	mesh coordinate	Line, Face, Volume	Code		Dir
OverPressure	Scalar	0.0 N/m^2	flux dens.	Line, Face, Volume	Code	Dir	
RelWallForce	Vector	0.0 N	flux integral	Line, Face	Code	Dir	
Temperature	Scalar	300.0 K	field	Line, Face, Volume	Code	Dir	Dir
TotalPressure	Scalar	0.0 N/m^2	flux dens.	Line, Face, Volume	Code	Dir	Dir
Velocity	Vector	0.0 m/s	field	Line, Face, Volume	Code	Dir	Dir
WallForce	Vector	0.0 N	flux integral	Line, Face	Code	Dir	
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Line, Face	Code	Dir	
WallHTCoeff	Scalar	0.0 $W/m^2\,K$	field	Line, Face	Code	Dir	
WallTemp	Scalar	300.0 K	field	Line, Face	Code	Dir	Dir

14.2.5 Go Step

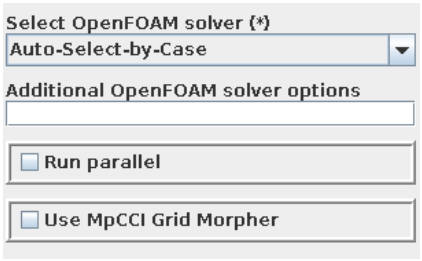


Figure 2: OpenFOAM options in the Go step

OpenFOAM offers a number of options in the Go panel, see Figure 2.

OpenFOAM solver Choose the OpenFOAM solver from the list of installed solvers. Select Auto-Select-by-Case to leave the decision to MpCCI. In the latter case MpCCI reads the solver name from the application entry in the "<*case directory*>`/system/controlDict`" file.

Additional OpenFOAM solver options Everything added here will be appended to the arguments of the starter command.

Run parallel Activate OpenFOAM in parallel mode. See ▷ 14.2.6.1 Parallel Execution ◁.

Use MpCCI Grid Morpher Activate the MpCCI Grid Morpher and access to the MpCCI Grid Morpher configuration, see ▷ 14.3 Grid Morphing ◁.

14.2.6 Running the Computation

Coupled simulations can be run using the Start button in the Go panel. No special steps need to be carried through to start the simulation.

14.2.6.1 Parallel Execution

For a parallel run of OpenFOAM (i. e. OpenFOAM itself uses several parallel processes) additional options can be selected in the Go step as shown in Figure 3.

Use external 3rd party MPI Check this box if you want to use an MPI runtime environment (e.g. mpirun) that is not part of your OpenFOAM distribution, see ▷ 14.2.6.2 External 3rd party MPI ◁.

No. of parallel processes Select how many OpenFOAM processes you wish to start.

Select decomposition method Choose one out of three methods: simple, scotch or metis.

Splits by direction In case of the simple decomposition method you have to define a list of three positive integer values whose product must equal the value specified in No. of parallel processes.

Optional processor weights In case of the scotch or metis decomposition method you may enter a list of processor weights to specify a load balancing. Leave blank for default.

Decompose case MpCCI will automatically run the decomposer of OpenFOAM if the number of parallel processes changed since the last decomposition. Press this button to start the decomposer explicitly.

Reconstruct case Press this button to reconstruct the decomposed case.

Optional hostlist file Specify a hostfile, from which host names are extracted.

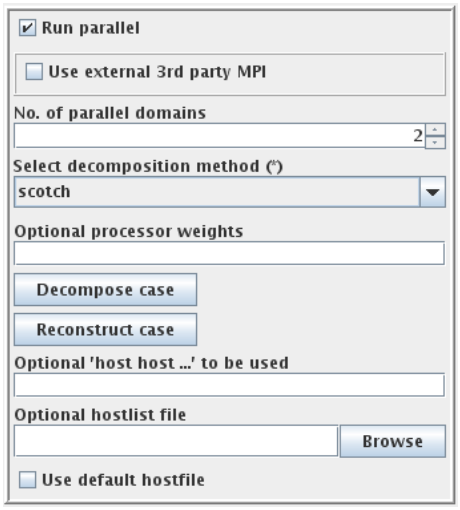


Figure 3: OpenFOAM options for a parallel run

Use default hostfile A default hostfile can be configured by setting `MPCCI_HOSTLIST_FILE`, see ▷ V-3.6.2 Hostlist File ◁.

14.2.6.2 External 3rd party MPI

By checking the Use external 3rd party MPI box you can use an MPI runtime environment that is not part of the OpenFOAM distribution.
The MPI runtime environment should be already set up for OpenFOAM. Some following options will help to define a proper environment for starting the OpenFOAM application in parallel for third party MPI vendor.

MPI vendor Select the MPI vendor type to use.
There are two options:

- default: Start the default MPI executable command to launch the parallel execution. MpCCI searches in this sequence for the following program to use: mpirun, mpiexec. The standard MPI parallel options are passed to this executable.
- sgi: Start the SGI MPI executable command mpiexec_mpt with its specific options.
- intelmpi: Start the Intel MPI executable command mpiexec with its specific options.

Use external foamExecMpcci launcher Running OpenFOAM in parallel requires to export some environment variables defining the location of the co-simulation server for example. Some MPI vendors do not implement the export of environment variables by argument option. MpCCI provides the option to use a wrapper script `"foamExecMpcci"` to start the simulation. This script can be provided by the user or generated by MpCCI at runtime.

Generate foamExecMpcci MpCCI generates the script `"foamExecMpcci"` in the project directory to launch the application.

If the script is provided by the user, the script should ensure to load the environment definition file `"envMpcci"` under Linux, `"envMpcci.bat"` under Microsoft Windows. The environment file definition is saved under the project directory.

Define shell type for environment source Set the shell type to define the list of environment to export. Under Microsoft Windows the syntax is automatically set to batch like syntax independent of the set

value.

- default Default syntax option is bash like under Linux.
- bash Use the bash syntax to export the environment variable.
- csh Use the csh syntax to export the environment variable.

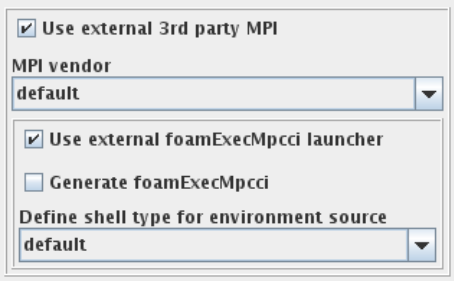


Figure 4: OpenFOAM options for third party MPI

14.2.6.3 Batch Execution

OpenFOAM is always run as a batch process, therefore no special settings are necessary for batch execution.

14.2.6.4 Running on a Remote Machine

In case the required environment to start the simulation is not correctly set/exported on a remote machine one can help MpCCI to set the environment (see ▷ V-3.7.1.2 Configure a Simulation Code for Running on a Remote Machine ◁). Example:

```
FOAM_INST_DIR=~/OpenFOAM/OpenFOAM-v1712
PATH+=~/OpenFOAM/OpenFOAM-v1712/platforms/linux64GccDPInt32Opt/bin
LD_LIBRARY_PATH+=/cluster/lib64
```

14.2.7 Post-Processing

Post-processing for the OpenFOAM part of the results can be performed as in ordinary computations, e. g. with paraFoam.

14.3 Grid Morphing

The grid morpher will smooth a grid based on the displacements of some boundary or interior vertices. A moving or morphing grid capability is always required with fluid-structure interactions. The user has the choice between the MpCCI Grid Morpher (▷ 14.3.1 MpCCI Grid Morpher ◁) and the OpenFOAM Grid Morpher (▷ 14.3.2 OpenFOAM Grid Morpher ◁).

14.3.1 MpCCI Grid Morpher

MpCCI offers a morphing method which allows vertices to float along semi-planar boundaries, e.g. symmetry planes. The morpher process may be monitored within an additional output terminal and a morpher

log file in the OpenFOAM working directory (`"mpcci_morpher_<case directory>.log"`).

The morpher controls the results of the morphing step, it may control the length of the edges, the shape and size of faces and also checks the quality of cells. There are options available to limit the compression and elongation of edges.

The following options (Figure 5) may be adjusted, whereas the default values are in many cases appropriate. The description of the MpCCI Grid Morpher is provided at ▷ V-8 MpCCI Grid Morpher ◁.

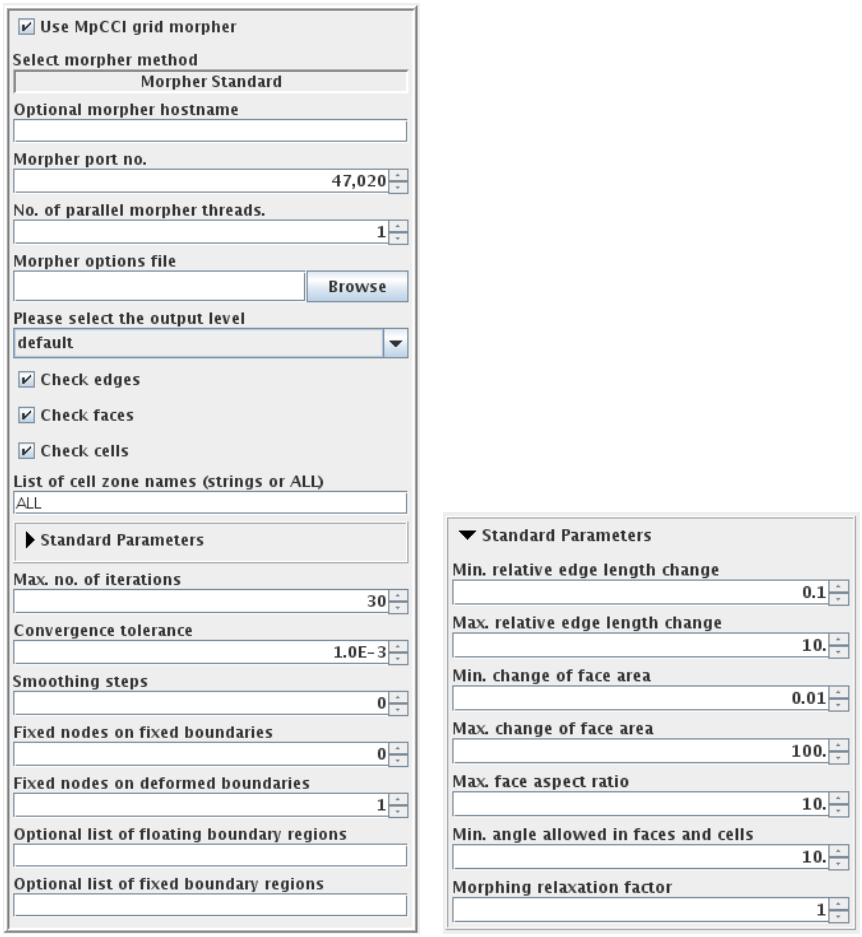


Figure 5: OpenFOAM Options for MpCCI Grid Morpher

14.3.2 OpenFOAM Grid Morpher

If the MpCCI Grid Morpher is not selected, OpenFOAM will use the solver type defined in the `"dynamicMeshDict"`.
In the case of the ▷ VII-2 Elastic Flap in a Duct ◁ tutorial,
the displacementLaplacian has been used.
You can observe the log output of OpenFOAM in Figure 6. See also ▷ 14.2.1.2 Deforming Meshes ◁

```
/*---------------------------------------------------------------------------*\
| =========                 |                                                 |
| \\      /  F ield         | OpenFOAM: The Open Source CFD Toolbox           |
|  \\    /   O peration     | Version:  1.7.1                                 |
|   \\  /    A nd           | Web:      www.OpenFOAM.com                      |
|    \\/     M anipulation  |                                                 |
\*---------------------------------------------------------------------------*/
Build : 1.7.1-03e7e056c215
Exec  : /home/test/OpenFOAM/test-1.7.1/applications/bin/linux64GccDPOpt/rhoPimple-
DyMFoamMpcci
Date  : Mar 05 2012
Time  : 19:45:10
Host  : zeus
PID   : 21311
Case  : /home/test/coupling/ElasticFlap/OpenFoam/1.7
nProcs: 1
SigFpe: Enabling floating point exception trapping (FOAM_SIGFPE).

// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //
Create time

Create mesh for time = 0


Selecting dynamicFvMesh dynamicMotionSolverFvMesh
Selecting motion solver: displacementLaplacian
Selecting motion diffusion: inverseDistance

.....
```

Figure 6: OpenFOAM output for displacement laplacian solver

14.4 Code-Specific MpCCI Commands

The MpCCI subcommands available for OpenFOAM are:

```
Usage:
   mpcci OpenFOAM [-]option


Synopsis:
   'mpcci OpenFOAM' is used to get information about OpenFOAM.


Options:
   -allapps  [CASEDIR] [SP|DP] [VOpt|VDebug] [RELEASE]
               List the solver used by this case and all OpenFOAM applications.

   -caseapp  [CASEDIR]
               Show the solver used by this case.
```

```
-cleanTimeDir
             Mark time directories (serial and parallel) of an OpenFOAM
             case containing only empty functionObjectProperties files
             with <time>_DELETE.

-decompose  [OPTIONS]
             Decompose the serial OpenFOAM case into a parallel case.
             Use -f option to overwrite existing decomposition.

-diff  <CASEDIR1> <CASEDIR2>
             Run the scanner on two cases and print the differences.

-env  [RELEASE]
             Print the OpenFOAM specific environment.

-envmpcci  [RELEASE]
             Print the OpenFOAM MpCCI specific environment.

-gmdmake  [CASEDIR]
             Make an MpCCI grid morpher data file from the OpenFOAM case.

-help
             This screen.

-info  [SP|DP] [VOpt|VDebug]
             List verbose information about all OpenFOAM releases.

-magic  [CASEDIR]
             Print the magic tokens of the MpCCI grid morpher data .gmd file
             or all gmd files in the current directory.

-reconstruct  [CASEDIR] [RELEASE]
             Reconstruct a serial OpenFOAM case from the decomposed case.

-releases  [SP|DP] [VOpt|VDebug]
             List all OpenFOAM releases which MpCCI can find.

-scan  <CASEDIR>
             Run the scanner on the case and create a scanner output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci openfoam -allapps [CASEDIR] [SP|DP] [VOpt|VDebug] [RELEASE]`

The `allapps` subcommand gets the solver used by the given case as well as all OpenFOAM basic and user local applications and prints them to stdout line by line.

`mpcci openfoam -caseapp [CASEDIR]`

The `caseapp` subcommand gets the solver used by the given case and prints it to stdout.

mpcci openfoam -cleanTimeDir

The `cleanTimeDir` subcommand marks time directories (serial and parallel) of an OpenFOAM case containing only empty functionObjectProperties as `"<time>_DELETE"`.

mpcci openfoam -decompose [OPTIONS]

The `decompose` subcommand decomposes the serial OpenFOAM case into a parallel case. It offers following options:

```
Usage:
   mpcci OpenFOAM decompose [-]options


Synopsis:
   'mpcci OpenFOAM decompose' is used to decompose an OpenFOAM case.


Options:
   -case     <casedir>         Defines the case direcory.
   -force                      Force a new decomposition.
   -help                       This screen.
   -method   <simple|scotch>   Defines the decomposition method.
   -nprocs   <nprocesses>      Defines the no. of processes.
   -pweights <weights>         Defines the processor weights.
   -release  <release>         Define the release to be used.
   -splits   <x y z>           Defines the split in each direction.
```

Use -force option to overwrite an existing decomposition.

mpcci openfoam -env [RELEASE]

The `env` subcommand gets the OpenFOAM specific environment variables for the specified release and prints them to stdout. If no release is specified the latest installed release will be taken.

mpcci openfoam -envmpcci [RELEASE]

The `envmpcci` subcommand gets the OpenFOAM MpCCI specific environment variables for the specified release and prints them to stdout. If no release is specified the latest installed release will be taken.

mpcci openfoam -gmdmake [CASEDIR]

The `gmdmake` subcommand makes an MpCCI grid morpher data file from the OpenFOAM case. CASEDIR specifies the OpenFOAM case directory. Default is the current directory.

mpcci openfoam -magic [CASEDIR]

The `magic` subcommand gets the magic tokens of the MpCCI grid morpher data gmd file in the specified case directory i. e. `"<CASEDIR>/mpcci_morpher.gmd"` or of all gmd files in the current directory if CASEDIR is not specified and prints them to stdout.

mpcci openfoam -reconstruct [CASEDIR] [RELEASE]

The `reconstruct` subcommand reconstructs a serial OpenFOAM case from the decomposed case in the given CASEDIR and for the given RELEASE. The current directory and latest installed release will be taken as default.

14.5 Code Adapter Reference

- Volumetric data can only be transferred unidirectional–namely from OpenFOAM to another code.
- The MpCCI code adapter for OpenFOAM uses so called function objects to manage the data transfer. Whether exchange is done before or after the solution depends on the solver employed to solve your problem. The standard solvers of OpenFOAM usually perform an exchange before solution.
  The code adapter is distributed as dynamic libraries, which are located below "<*MpCCI_home*>/codes/OpenFOAM/adapters/".

  Depending on version and platform the binaries are placed in further subdirectories:
  "./<*$WM_PROJECT_VERSION*>/<*$WM_OPTIONS*>/libfoammpcci.so".

  There's also an auxiliary library used in case of dynamic mesh motion; this is
  "./<*$WM_PROJECT_VERSION*>/<*$WM_OPTIONS*>/libmpccimotionsolver.so".

  If there's no adapter available for your particular version and platform, you can simply build the desired libraries on your own. Just call `./Allwmake` located in
  "<*MpCCI_home*>/codes/OpenFOAM/adapters/src/<*MPCCI_FOAM_VERSION*>".

  <*MPCCI_FOAM_VERSION*> corresponds to the following folder name:
  - "v1.7-2.1" Adapter code compatible with OpenFOAM 1.7 to 2.1
  - "v2.2.-2.3" Adapter code compatible with OpenFOAM 2.2 to 2.4
  - "v3.0.1" Adapter code compatible with OpenFOAM 3.0.1
  - "v1606+" Adapter code compatible with OpenFOAM v1606+
  - "v1612+-v1712" Adapter code compatible with OpenFOAM v1612+,v1706,v1712.
- If the MpCCI Grid Morpher is used you will require an auxiliary tool "mpcci_foam2gmd.exe" which is located below "<*MpCCI_home*>/codes/OpenFOAM/bin/".

  Depending on version and platform the binaries are placed in further subdirectories:
  "./<*$WM_PROJECT_VERSION*>/<*$WM_OPTIONS*>/mpcci_foam2gmd.exe".

  This tool is used to convert the OpenFOAM mesh to the MpCCI Grid Morpher format.
  To build the tool you should:
  1. Go to the directory "<*MpCCI_home*>/codes/OpenFOAM/foam2gmd"
  2. Call `./Allwmake`

  The tool "mpcci_foam2gmd.exe" executable will be automatically placed under the "bin" directory.

Please make sure that the appropriate environment of your OpenFOAM version is sourced.

15 SIMPACK

15.1 Quick Information

Company name	SIMULIA
Company homepage	www.simpack.com
Support	www.3ds.com/support/
Tutorials	▷ VII-12 Spring Mass System ◁

15.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		X	
		–	
		–	
		–	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	X	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	X	▷ V-4.8.2.1 Copying Components ◁
Domains	System	X	▷ V-3.1.1 Physical Domains ◁

15.1.2 Supported Platforms and Versions

SIMPACK is supported on the following platforms:

	Supported versions	
`MPCCI_ARCH`: Code platform	9.7	9.8.1
`lnx4_x64`: `linux64`	X	X
`windows_x64`: `win64`	X	X

15.1.3 References

SIMPACK Documentation Your SIMPACK installation contains the SIMPACK Assistant.

15.1.4 Adapter Description

The code adapter for SIMPACK is developed and distributed by the Fraunhofer SCAI.

15.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary SIMPACK installation.
- Enough license tokens.

15.2 Coupling Process

Please read also ▷ IV-2 Setting up a Coupled Simulation ◁.

15.2.1 Model Preparation

The SIMPACK model can be prepared with SIMPACK GUI. Please consider the following advices:

- The model can be defined in any of the consistent systems of units supported by MpCCI (see ▷ 1.2 Unit Systems ◁). The basic unit system must be given in the Models step of the MpCCI GUI. Units of single quantities can be set in the Regions step.
- The SIMPACK model must contain a definition of a force element of type user force 20 as a coupling component. Also multiple elements of this type can be included, to introduce different coupling points. The element which serves as coupling component can be selected in the Regions step of the MpCCI GUI. Also multiple elements can be selected.


It is recommended to create a complete SIMPACK model first and test it separately without co-simulation. The quantities which will be transferred by the partner code can be simulated by appropriate loads or boundary conditions.

15.2.2 Simulation

The only SIMPACK simulation mode, supported by MpCCI for now is a dynamic simulation. The step sizes or any other options of the SIMPACK solver are not changed by MpCCI. The data from the co-simulation will be provided to SIMPACK/Solver as it is requested by the calls of the corresponding uforce subroutine. The communication time points are not controlled by MpCCI. However it is possible to restrict the communication to a fixed time steps scheme. Please be sure, that the co-simulation partner also uses a dynamic simulation or at least provide time values for the sent data.

The time steps of the co-simulation partners differ in general. To match the data values between requested and provided time points the server interpolates the quantities in time. Therefore multiple buffers are used per default with a history size of 4. If the time step size is much smaller than that from the partner code you may need to increase the history size (See ▷ V-4.10.2 Job ◁ and ▷ V-3.4.5.3 Coupling with Non-Matching Time Steps ◁).

15.2.3 Models Step

In the Models step, the following options must be chosen:

SIMPACK release Select the SIMPACK release you wish to use. Only supported releases installed on your system are listed. The selection latest always refers to the latest supported version (default). The release should match the input file.

SIMPACK file for scanning Select the SIMPACK input file `"*.spck"` to provide the simpack model definition to MpCCI.

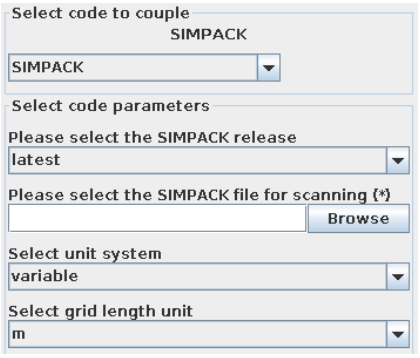


Figure 1: SIMPACK options in the Models step

Unit system Select the unit system which was used in SIMPACK (see ▷ 1.2 Unit Systems ◁). Default is set to variable for the unit system with m for the grid length unit.

15.2.4 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

In the Algorithm step, following additional options are available:

Solver settings

Provide partials If this option is checked, SIMPACK will provide the partial derivatives of the received quantities with respect to the sent quantities. This helps the process of solving the non-linear equations in the corrector iterations. See ▷ 15.2.5.1 Semi-implicit Mode and Partial Derivatives ◁ for more details.

Communication delay of the co-simulation This parameter is used for the approximation of the semi-implicit mode or partial derivatives. This is the communication offset, introduced by the co-simulation. The reaction on the data, sent at some time points is received by the next communication. This is the general case for the parallel explicit co-simulation. Due to technical reasons, the offset by the co-simulation is to be set to 1. Those are the communication scenarios which are for now supported by MpCCI. Wrong setting of this parameter results in errors by the calculation of approximation for the semi-implicit and partial derivatives modes.

Synchronized history buffer update Check this parameter for the SIMPACK adapter to update the saved states only at certain time points. This can be used e. g. if the co-simulation partner takes different time step sizes for the simulation. In this case, data provided as reaction and saved outgoing quantities have to be adjusted. With the option Time step for approximation update a constant step size for the updates can be set. As well a Time-Step-Size control variable can be used (see ▷ 15.2.5 Regions Step ◁).

Time step for approximation update Sets a constant step size for the synchronized history buffer updates. If this value is negative, the adapter tries to use the Time-Step-Size control variable.

15.2.5 Regions Step

SIMPACK supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AngularCoordinate	Quaternion	0.0	mesh coordinate	Point	Node	Direct	
AngularVelocity	Vector	0.0 rad/s	field	Point	Node	Direct	
DeltaTime	Scalar	1.0 s	g-min	Global	global		Direct
Force	Vector	0.0 N	flux integral	Point	Node	Direct	Direct
PointPosition	Vector	0.0 m	mesh coordinate	Point	Node	Direct	
RealFlag	Scalar	0.0	g-max	Global	global		Direct
Torque	Vector	0.0 N m	flux integral	Point	Node	Direct	Direct
Velocity	Vector	0.0 m/s	field	Point	Node	Direct	

In this step the user can select the elements of the SIMPACK-model and set the quantities to be exchanged by the co-simulation.

The outgoing quantities are requested from the `From Marker`.

Furthermore the time step size to control the approximation process can be received by SIMPACK. For this purpose an additional element `Time-Step-Size` is provided in the global variables list, which can only receive the time step size. MpCCI uses this value to control the calculation of partial derivatives (see ▷ 15.2.6 Go Step ◁). If the user requires time step size to be sent by SIMPACK, the operation is ignored.

15.2.5.1 Semi-implicit Mode and Partial Derivatives

In SIMPACK the predictor-corrector-approach (see SIMPACK documentation) is implemented to solve the equation of motion. In corrector iterations a system of non-linear equations is considered. For this purpose SIMPACK uses e. g. the Newton approach. This algorithm utilizes partial derivatives with respect to generalized coordinates for solving non linear equations.

The SIMPACK adapter can provide the partial derivatives of the incoming quantities with respect to the outgoing quantities. To allow this the user must check the option Provide partials (see ▷ 15.2.6 Go Step ◁).

To provide the partial derivatives the SIMPACK adapter will store the incoming and outgoing quantities. Those saved values are then used to calculate a numerical approximation of the partial derivatives. Different parameters can be adjusted to control the calculation (see ▷ 15.2.6 Go Step ◁).

Normally, the data exchange between SIMPACK and MpCCI server is done for every single time step. However, the internal solution algorithms are in general iterative. As consequence, there are variations of local state for each iteration at single time point. With the partial derivatives we use the semi-implicit approach in SIMPACK, to improve the local accuracy of solution and provide an approximation of the received quantities (e. g. force) with respect to the outgoing quantities (e. g. position) between the communication points. The semi-implicit mode is automatically activated with the Provide partials.

The relations between outgoing and incoming quantities are adjusted automatically. MpCCI defines dependencies between appropriate kinematic and dynamic quantities. The force quantity is linked to the position, velocity or acceleration. The torque quantity is linked to the angular position, angular velocity or angular acceleration.

15.2.6 Go Step

In the Go step, the following options can be selected:

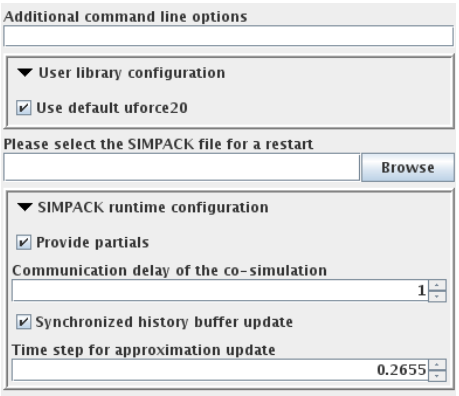


Figure 2: SIMPACK options in the Go step

Additional command line options Additional command line options for SIMPACK can be given here, they will directly be used when SIMPACK is started.

User library configuration Expand this section to access the additional user subroutine configuration.

Use default uforce20 Check this option if you want to use the provided user library based on uforce20 force type element. If this option is unchecked, MpCCI supposes that the user provides an MpCCI-compatible user library for SIMPACK, which already includes MpCCI calls.

Please select the SIMPACK file for a restart If you want to restart a previous computation, select a restart file here.

15.2.7 Running the Computation

With the Start button SIMPACK is started with the options given in the Go step.

In the explicit mode SIMPACK sends and receives data for each time step.

If the Stop button is pressed SIMPACK receives a `STOP` command from the adapter and terminates the simulation.

You can check during the SIMPACK run for the SIMPACK log file. The messages of the co-simulation progress and of the SIMPACK simulation can be found there. In case of any issue with SIMPACK, please first check the SIMPACK log file for further information.

15.2.7.1 Batch Execution

SIMPACK always runs as a batch process, therefore no special settings are necessary for batch execution.

15.2.8 Post-Processing

Post-processing for the SIMPACK part of the results can be performed as in ordinary computations, e. g. with SIMPACK-post. The "<*job name*>`.sbr`" file can be found in the SIMPACK model directory.

15.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for SIMPACK are:

```
Usage:
   mpcci SIMPACK [-]option


Synopsis:
   'mpcci SIMPACK' is used to get information about SIMPACK.


Options:
   -help
            This screen.

   -info
            List verbose information about all SIMPACK releases.

   -releases
            List all SIMPACK releases which MpCCI can find.

   -scan  [-r release] <spck file>
            Run the scanner and create a scanner output file.
```

The subcommands `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

16 STAR-CCM+

16.1 Quick Information

Company name	Siemens PLM
Company homepage	www.plm.automation.siemens.com
Support	www.plm.automation.siemens.com/global/de/support/
Tutorials	▷ VII-2 Elastic Flap in a Duct ◁ ▷ VII-3 Vortex-Induced Vibration of a Thin-Walled Structure ◁ ▷ VII-5 Pipe Nozzle ◁ ▷ VII-8 Exhaust Manifold ◁ ▷ VII-9 Cube in a Duct Heater ◁ ▷ VII-13 Y-Junction ◁

16.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		X	
		–	
		X	
		X	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	X	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	Fluid	X	▷ V-3.1.1 Physical Domains ◁
	FluidThermal	X	

16.1.2 Supported Platforms and Versions

	Supported versions											
MPCCI_ARCH: Code platform	2019.1	2019.2	2019.3	2020.1	2020.2	2020.3	2021.2	2022.1	2206	2210.0001	2302	2306
(windows|lnx4)_x64: lib	X	X	X	X	X	X	X	X	X	X	X	X

16.1.3 References

STAR-CCM+ Documentation is part of the STAR-CCM+ distribution (e. g. STAR-CCM+ User Guide).

16.1.4 Adapter Description

For STAR-CCM+ the MpCCI plugin library `"libstarccmmpcci.jar"` is retrieved from MpCCI installation and dynamically loaded by STAR-CCM+ at runtime and all data transfer and management is carried out over MpCCI Java macro routines (▷ 16.5 Code Adapter Reference ◁).

The viscous and viscoelastic solvers in STAR-CCM+ are supported for the co-simulation.

16.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary STAR-CCM+ installation.
- The command `starccm+` should be set in the `PATH` under Linux.

16.2 Coupling Process

Please read also ▷ IV-2 Setting up a Coupled Simulation ◁.

16.2.1 Model Preparation

The STAR-CCM+ model can be prepared with STAR-CCM+ GUI. Please consider the following approach for model preparation:

- The STAR-CCM+ solver internally operates only in SI units. The geometrical dimensions should best be defined in meters. However the user can use in STAR-CCM+ GUI a preferred unit system. In that case you should remember the unit setting in order to provide it at the Models step in MpCCI GUI.
- The STAR-CCM+ model must contain a definition of the coupling domains and boundary regions (e. g. couple-wall).
- To enable a coupled simulation with an unprepared model several modifications of the model are required. For popular coupling types (▷ V-3.1.2 Coupling Types ◁) the modifications will be carried out by MpCCI automatically.
- MpCCI supports following STAR-CCM+ Motion Specification for FSI (▷ 16.4 Grid Morphing ◁):
  - Morphing: The Morpher method Displacement is used in this case.
  - DFBI Morphing: The Six DOF morphing method Six DOF body plus Displacement is used.

  The Motion Specification should be defined in the model and set to the value fixed. Selected boundary walls from MpCCI GUI will be configured by MpCCI with the value Displacement.
- Model using Overset Mesh method is also supported for FSI application.
- MpCCI supports the different heat transfer coefficient type of STAR-CCM+ for the thermal co-simulation model. Therefore if the convection surface load is defined as
  - heat transfer coefficient (WallHTCoeff), ambient temperature (FilmTemp) or,
  - heat rate (HeatRate), ambient temperature (FilmTemp)

the heat transfer coefficient properties of STAR-CCM+ should be configured according to your application. Following heat coefficient type of STAR-CCM+ are available to select in the MpCCI GUI (see ▷ 16.2.5 Go Step ◁):

- HeatTransferCoefficientUserYPlus (default) is the specified y+ heat transfer coefficient and will be combined with specified y+ heat transfer reference temperature for FilmTemp.
- LocalHeatTransferCoefficient is the local heat transfer coefficient and will be combined with the local heat transfer reference temperature for FilmTemp.
- HeatTransferCoefficient is the heat transfer coefficient and will be combined with the constant reference temperature defined in this field function for FilmTemp. For this purpose a user field function HeatTransferReferenceTemperature will be built and filled with the reference value.

It is recommended to create a complete STAR-CCM+ model first and test it separately without co-simulation. The quantities, which will be later on transferred by the partner code, can be simulated by appropriate loads or boundary conditions if desired.

16.2.2 Models Step

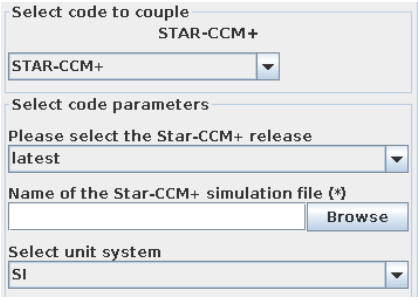


Figure 1: STAR-CCM+ options in the Models step

In the Models step, the following options must be selected: (Figure 1):

STAR-CCM+ release Select the release of STAR-CCM+ you would like to use, latest (default) will select the latest installed STAR-CCM+ version for which an MpCCI adapter is also installed. Please make sure that the model file was not created with a STAR-CCM+ version newer than the STAR-CCM+ version used with MpCCI.

STAR-CCM+ simulation file Select the model file (`".sim"`) of your STAR-CCM+ model.

Unit system Select the unit system which was used in STAR-CCM+ (see ▷ 1.2 Unit Systems ◁).

16.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

In the Algorithm step, following additional options are available:

Solver settings

Type of solver step size *(Only available for the STAR-CCM+ implicit unsteady solver)*

- Defined by model Select this option in order to used the time step from the model file.
- Constant Select this option in order to overwrite the setting from the model file by providing a new constant time step size value.

Solver time step size *(Only available with Constant Type of solver step size)* Provide the solver time step size to use.

Maximum number of inner iterations Provide the maximum number of inner iterations to perform for a solver time step.

Select type of heat transfer coefficient If WallHTCoeff, HeatRate, FilmTemp are coupled, define here the heat coefficient type of STAR-CCM+, available are:

- HeatTransferCoefficientUserYPlus (default) is the specified y+ heat transfer coefficient and will be combined with specified y+ heat transfer reference temperature for FilmTemp.
- LocalHeatTransferCoefficient is the local heat transfer coefficient and will be combined with the local heat transfer reference temperature for FilmTemp.
- HeatTransferCoefficient is the heat transfer coefficient and will be combined with the constant reference temperature defined in this field function for FilmTemp. For this purpose a user field function HeatTransferReferenceTemperature will be built and filled with the reference value.

For STAR-CCM+, the coupling period should be limited via Coupling duration panel in the Common Basics settings.

16.2.4 Regions Step

STAR-CCM+ supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
AbsPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Direct	
AngularVelocity	Vector	0.0 rad/s	field	Point	Code		Direct
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	Direct
FilmTemp	Scalar	300.0 K	field	Face	Code	Direct	
Force	Vector	0.0 N	flux integral	Face	Code	Direct	
HeatRate	Scalar	0.0 W	flux dens.	Face	Code	Direct	
IterationNo	Scalar	0	g-max	Global	global	Direct	Direct
MassFlowRate	Scalar	0.0 kg/s	flux integral	Face	Code	Direct	Direct
MassFluxRate	Scalar	0.0 $kg/m^2\,s$	flux dens.	Face	Code	Direct	Direct
NPosition	Vector	0.0 m	mesh coordinate	Face	Code		Direct
OverPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Direct	
PhysicalTime	Scalar	0.0 s	g-min	Global	global	Direct	Direct
RefPressure	Scalar	1.12e5 N/m^2	g-max	Global	global	Direct	Direct
RelWallForce	Vector	0.0 N	flux integral	Face	Code	Direct	Direct
StaticPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Direct	Direct
Temperature	Scalar	300.0 K	field	Face	Code	Direct	Direct
TimeStepNo	Scalar	0	g-max	Global	global	Direct	Direct
Torque	Vector	0.0 N m	flux integral	Face	Code	Direct	
TotalPressure	Scalar	0.0 N/m^2	flux dens.	Face	Code	Direct	Direct
Velocity	Vector	0.0 m/s	field	Point, Face	Code	Direct	Direct
WallForce	Vector	0.0 N	flux integral	Face	Code	Direct	Direct
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Code	Direct	Direct
WallHTCoeff	Scalar	0.0 $W/m^2\,K$	field	Face	Code	Direct	
WallTemp	Scalar	300.0 K	field	Face	Code	Direct	Direct

16.2.5 Go Step

In the Go step, the following options can be selected:

Run in batch STAR-CCM+ runs in batch mode.

Auto start with the default template macro Select this option to use the MpCCI provided Java macro template. Depending on the selected coupling scheme one of the following template files will be copied into the working directory containing the `".sim"` file:
`"mpcci_runjob_steady.java"` or `"mpcci_runjob_unsteady.java"`.
Following option is available if the default Java macro template shall be used (see Figure 3):

Do a cold start run Delete the current solution from the `".sim"` file before starting the simulation.

STAR-CCM+ Java macro file STAR-CCM+ macro file to steer the computation. This option is displayed and required if the Auto start with the default template macro is not activated (see Figure 2 on the left).

Do not shut down server after batch file execution STAR-CCM+ won't shut down after batch file has been executed.

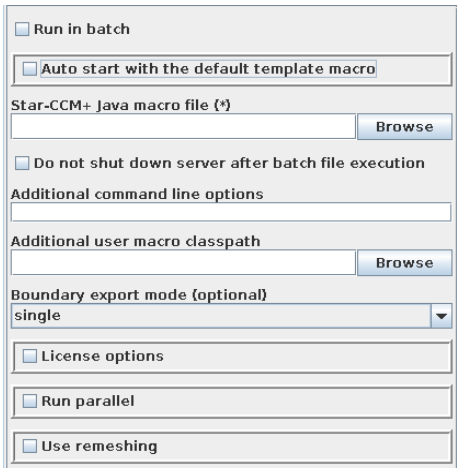


Figure 2: STAR-CCM+ options in the Go step

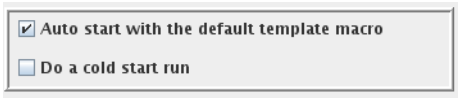


Figure 3: STAR-CCM+ options using default template macro

Additional command line options It is possible to invoke STAR-CCM+ with additional command line options (STAR-CCM+ Run Options). Please refer to the STAR-CCM+ User Guide for possible options.

Additional user macro classpath It is possible to provide to STAR-CCM+ an additional path containing a user library. This classpath is appended to the MpCCI path.

Boundary export mode (optional) Define how the boundary information is exported.

- single (default) The code adapter will use a single file for exporting all the coupled regions.
- individual The code adapter will use an individual file for exporting each coupled region.

License options See ▷ 16.2.5.1 License Setting Details ◁.

Run parallel Run STAR-CCM+ in parallel mode, see ▷ 16.2.6.1 Parallel Execution ◁

Use remeshing Activate the MpCCI remeshing module, see ▷ 16.2.6.2 MpCCI Remeshing Module ◁

16.2.5.1 License Setting Details

License options Define the STAR-CCM+ license options (see Figure 4).

- Power session: use power session license model.
- Lite session: use lite session license model.
- PoD session: for this license option you should additionally provide the Server name in the form portnumber@host and the PoD key.

If no additional license option is provided the standard default method to check out a license is used by STAR-CCM+.

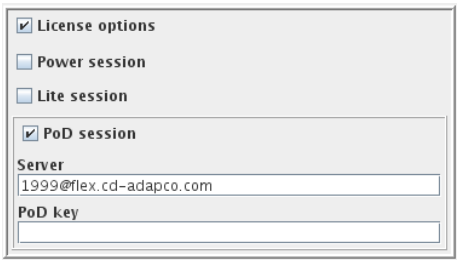


Figure 4: STAR-CCM+ options for license settings

16.2.6 Running the Computation

When the Start button is pressed, STAR-CCM+ is started with the options given in the Go step.
If the Stop button is pressed, an ABORT-file is created and STAR-CCM+ will stop the next time it checks the presence of a stop file. This requires that the stop criterion for the `"ABORT"` file is activated and that the user Java macro script exits if the computation is aborted.
The provided MpCCI Java macro script implements such exit on `"ABORT"` file.
When STAR-CCM+ is started, MpCCI will update the classpath in the STAR-CCM+ setting file if STAR-CCM+ is running with GUI otherwise the new classpath is passed via a command line option to STAR-CCM+.

16.2.6.1 Parallel Execution

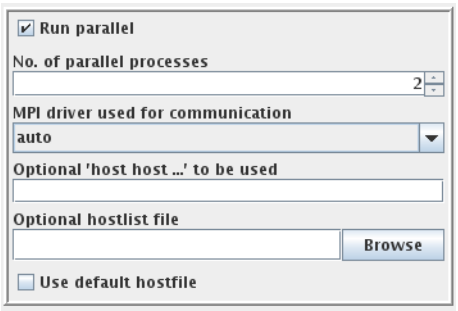


Figure 5: STAR-CCM+ options for a parallel run

If the Run parallel check button is activated the following options are raised (Figure 5):

No. of parallel processes Select the number of parallel STAR-CCM+ processes to be launched.

MPI driver used for communication Select the MPI implementation.

Optional 'host host...' to be used Enter host names for parallel execution of STAR-CCM+.

Optional hostlist file Specify a hostfile from which host names are extracted.

Use default hostfile A default hostfile can be configured by setting MPCCI_HOSTLIST_FILE ▷ V-3.6.2 Hostlist File ◁.

In case that a hostlist and a hostfile are defined, MpCCI adds up the hosts and passes as much hosts as defined processes to STAR-CCM+. The order of the host definitions in the MpCCI GUI defines the priority of the employed hosts (1st hostlist, 2nd hostfile and 3rd default hostfile).

16.2.6.2 MpCCI Remeshing Module

Prerequisites for MpCCI remeshing module:

- The model must have a valid meshing module.
- The remeshing module only works for 3D models because based on the STAR-CCM+ meshing tools.
- The model must contain unique boundary names.
- The model must contain unique feature curve names.

The MpCCI remeshing module will basically create a new mesh based by considering the meshing option values from the mesh continua and from the boundaries if available.
The user may activate the module by checking the Use remeshing option (see Figure 6). Once the remeshing module is activated this one is only applied on regions with morphing motion and if the region will be deformed by MpCCI.

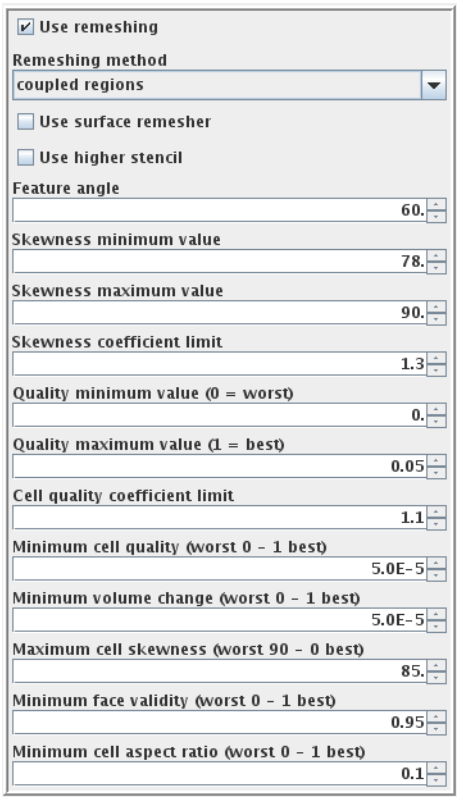


Figure 6: STAR-CCM+ options for remeshing

Remeshing setting description:

Use remeshing Activate the remeshing module.

Remeshing method The user can choose to apply a global remeshing on the model (option: all regions) or to limit the remeshing on the coupled regions (option: coupled regions).

Use surface remesher Turn on surface mesh refinement.

Use higher stencil Turn on higher-order stencil for interpolation for the mesh replacement instead of closest point. The option is only available if the remeshing is applied on coupled regions only.

The usage of higher-order may consume more CPU time on large regions.

Feature angle Set the sharp edge angle value for the creation of feature curves.

Skewness minimum value Set the minimum value of the skewness angle function.

Skewness maximum value Set the maximum value of the skewness angle function.

Skewness coefficient limit Set the skewness coefficient limit.
The skewness coefficient is defined as the ratio between the current number of cells in the threshold skewness and the last number of cells in the threshold skewness from the last remeshing. If this value is larger than the specified limit the remeshing condition is satisfied.

Quality minimum value (0 = worst) Set the minimum value for the cell quality function.

Quality maximum value (1 = best) Set the maximum value for the cell quality function.

Cell quality coefficient limit Set the cell quality coefficient limit.
The cell quality coefficient is defined as the ratio between the current number of cells in the threshold cell quality and the last number of cells in the threshold from the last remeshing. If this value is larger than the specified limit the remeshing condition is satisfied.

Minimum cell quality (worst 0 - 1 best) Set the minimum cell quality value with 0 being the worst and 1 being perfect.
If the current minimum cell quality is smaller than the specified value, the remeshing condition is satisfied.

Minimum volume change (worst 0 - 1 best) Set the minimum volume change value with 0 being the worst and 1 being perfect.
If the current minimum volume change is smaller than the specified value, the remeshing condition is satisfied.

Maximum cell skewness (worst 90 - 0 best) Set the maximum cell skewness value with 90 being the worst and 0 being perfect.
If the current maximum cell skewness is larger than the specified value, the remeshing condition is satisfied.

Minimum face validity (worst 0 - 1 best) Set the minimum face validity value with 0 being the worst and 1 being perfect.
If the current minimum face validity is smaller than the specified value, the remeshing condition is satisfied.

Minimum cell aspect ratio (worst 0 - 1 best) Set the minimum cell aspect ration value with 0 being the worst and 1 being perfect.
If the current cell aspect ratio is smaller than the specified value, the remeshing condition is satisfied.

If the remeshing module is activated, it will be checked before every MpCCI data exchange.

16.2.6.3 Batch Execution

Activate the option Run in batch (see Figure 2 on the left) to run STAR-CCM+ as a batch process.

16.2.7 Post-Processing

Post-processing for the STAR-CCM+ part of the results can be performed as in ordinary computations, e. g. with STAR-CCM+ GUI. The results "<*job name*>`.sim`" file can be found in the same directory as the input file.

16.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for STAR-CCM+ are:

```
Usage:
   mpcci STAR-CCM+ [-]option


Synopsis:
   Use 'mpcci STAR-CCM+' to get information about STAR-CCM+, and more...

   Most of the required steps are automatically done within
   the MpCCI GUI. The commandline version may be helpful in
   case of problems and for debugging.


Options:
   -diff  <sim1> <sim2>
            Run the scanner on two sim files and print the differences.

   -getmacro  <steady|unsteady>
            Copy the MpCCI Java macro template to the current directory.

   -help
            This screen.

   -info
            List verbose information about all STAR-CCM+ releases.

   -releases
            List all STAR-CCM+ releases which MpCCI can find.

   -scan  <sim>
            Run the scanner and create a scanner output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci star-ccm+ -getmacro <steady|unsteady>`

The `getmacro` subcommand provides a local copy of the MpCCI Java macro template. This allows the user to append own additional functions to the template.

16.4 Grid Morphing

The grid morpher will smooth a grid based on the displacements of some boundary or interior vertices. A moving or morphing grid capability is always required with fluid-structure interactions. The user should activate the morpher model for the simulation and configure the boundaries that should be morphed. MpCCI supports the following STAR-CCM+ moving mesh models:

- Mesh morphing
- Dynamic fluid body interaction 6DOF

The boundary conditions properties for these morpher models will be automatically updated resp. to

- total displacement method
- 6 DOF body plus displacement

16.5 Code Adapter Reference

The necessary plug-ins can be found in
"<*MpCCI_home*>/codes/STAR-CCM+/adapters/<*starccmrelease*>/lib"

The data transfer and management is handled over Java macros plug-ins, which are implemented in the MpCCI-STAR-CCM+ adapter library.

MpCCI has a limited ability to analyze the input in the MpCCI GUI and then decide what modifications have to be done to enable the model for a coupled simulation. These will be carried out when starting the simulation in the Go step (▷ 16.2.5 Go Step ◁) and when STAR-CCM+ connects to the MpCCI server.

16.5.1 Java Macro Script

In STAR-CCM+, the coupling process is controlled via a Java macro script, which calls functions provided by MpCCI.
MpCCI provides a set of Java macro scripts ready for the coupling under the directory:
"<*MpCCI_home*>/codes/STAR-CCM+/adapters/macro"

- "mpcci_runjob_steady.java": for steady state analysis.
- "mpcci_runjob_unsteady.java": for transient analysis.

One of the macro scripts is automatically used if the Auto start with the default template macro is activated. If the user provides its own Java macro script file, this one should contain an import statement to use the MpCCI-STAR-CCM+ adapter library.

```
import mpcci.starccm.*;
import mpcci.client.*;
```

The user has the possibility to get a copy of the MpCCI Java macro template in order to update it to his convenience. Therefor use the command `mpcci star-ccm+ -getmacro [steady|unsteady]`.

The `execute()` function could be implemented to start the simulation computation with some MpCCI commands to enable the data exchange.

16.5.1.1 Available Commands

The command for MpCCI calls within STAR-CCM+ is available after having instantiated the MpCCI adapter `new Adapter(simulation)`.

```
Adapter mpcci = new Adapter(simulation);
mpcci.initCouplingInfo();
JMpCCIClient.MPCCI_TINFO tinfo = mpcci.getTinfo();
mpcci.mpcciTinfoHasDuration();
mpcci.mpcciTinfoRemoveDurationCtl();
mpcci.mpcciTinfoHasSubcycle();
mpcci.mpcciTinfoRemoveSubcycleCtl();
mpcci.init()
```

```
mpcci.exchange()
mpcci.exit();
```

The available routines have the following functionality:

Adapter mpcci = new Adapter(simulation);
Instantiates the MpCCI adapter.
The adapter functions are accessible by the variable mpcci.

mpcci.initCouplingInfo()
Read MPCCI_TINFO environment variable containing the coupling setting information.
Part of these settings contain information settings from the duration control, subcycle.

JMpCCIClient.MPCCI_TINFO tinfo = mpcci.getTinfo()
Get the variable tinfo to access the information from MPCCI_TINFO.

mpcci.mpcciTinfoHasDuration()
Query if the Use duration control has been activated.
For a steady state simulation you can access through tinfo variable from above the following information:

- tinfo.iter_cbeg: Iteration No. for starting the coupling.
- tinfo.iter_cend: Iteration No. for ending the coupling.
- tinfo.iter_pend: No. of iterations after the coupling.

After reading these information you must remove the iteration control from the MpCCI coupling manager by calling mpcci.mpcciTinfoRemoveDurationCtl().
For a transient simulation you can access through tinfo variable from above the following information:

- timeCplStart: Time of coupling start.
- timeCplPost: Time after the coupling.
- timeStepSize: Solver time step size if provided from MpCCI GUI.
- maxInnerIterations: Maximum number of iterations per time step.

mpcci.mpcciTinfoRemoveDurationCtl()
Remove the control duration from the MpCCI coupling manager as this is implemented in the Java macro script.

mpcci.mpcciTinfoHasSubcycle()
Query if the Use subcycling has been activated.
The number of subcycle steps can be read from tinfo.sub_step. After reading this information you must remove the iteration control from the MpCCI coupling manager by calling mpcci.mpcciTinfoRemoveSubcycleCtl().

mpcci.mpcciTinfoRemoveSubcycleCtl()
Remove the subcycle control from the MpCCI coupling manager as this is implemented in the Java macro script. It avoids to subcycle twice.

String coldStart = System.getenv("_MPCCI_STARCCM_COLDSTART")
Get information if a cold start should be done. In that case the solution should be cleared before starting the computation.

mpcci.init()
Initializes the MpCCI process.
During that process the STAR-CCM+ model will be modified automatically for the coupling.

mpcci.exchange()
Performs a transfer operation, first SEND followed by RECEIVE.


In case of a transient simulation using a grid morpher, the data exchange should be performed prior to the time step in order to provide updated values for the grid morpher.

mpcci.exit()
Performs an MpCCI quit and quits the MpCCI process within STAR-CCM+.

16.5.1.2 MpCCI Template Java Script: Steady State Simulation

This sample is extracted from the
"<*MpCCI_home*>/codes/STAR-CCM+/adapters/macro/mpcci_runjob_steady.java" file.
This sample script is divided into 5 sections:

1. There are some steering variables for running the simulation:
   - nbCoupling: defines the number of data exchanges.
   - initIteration: defines the number of iterations before the coupling begins.
   - nbIteration: defines the number of iterations to be done between each coupling step.
   - postIteration: defines the number of iterations after the coupling.
   - lastIteration: defines the iteration number of the final coupling.

   These variables are initialized by the values set from the tinfo.
2. The setup of the simulation stop criteria is adjusted according to the steering variables.
3. The simulation will be initialized and the pre iterations executed.
4. The co-simulation phase begins:
   - The connection to the MpCCI server is established.
   - The solution will exchange data then iterate. This will loop for nbCoupling times.
   - The connection to the MpCCI server is closed.
5. The simulation will terminate with some post iterations.

```
package macro;

import java.util.*;
import java.io.File;
import star.common.*;
import star.base.neo.*;
import star.vis.*;

import mpcci.starccm.*;
import mpcci.client.*;

public class mpcci_runjob_steady extends StarMacro {
   public boolean isImplicitUnsteadyModel(Simulation simulation) {
      try {
         simulation.getSolverManager().getSolver(ImplicitUnsteadySolver.class);
         return true;
      } catch (Exception e) {
         return false;
      }
   }
   public boolean isExplicitUnsteadyModel(Simulation simulation) {
      try {
         simulation.getSolverManager().getSolver(ExplicitUnsteadySolver.class);
         return true;
      } catch (Exception e) {
```

```
      return false;
   }
}
public boolean isSteadyModel(Simulation simulation) {
    return (!isImplicitUnsteadyModel(simulation)
         && !isExplicitUnsteadyModel(simulation));
}

public void execute() {
   // number of data exchanges
   int nbCoupling = 1;
   // number of initial iterations before the coupling begins
   int initIteration = 0;
   // number of iterations between coupling steps
   int nbIteration = 1;
   // number of iterations after the coupling
   int postIteration = 0;
   // last of iterations ending the coupling
   int lastIteration = 0;

   boolean abort = false;
   boolean removeInitialSolution = false;

   Simulation simulation = getActiveSimulation();
   if(!isSteadyModel(simulation))
   {
      simulation.println("** ERROR ** The solution is not a steady state model:");
      simulation.println("   The MpCCI Java macro is only valid for a steady
                          state model!");
      simulation.kill();
   }

   // instantiate MpCCI Co-simulation for CCM+
   Adapter mpcci = new Adapter(simulation);
   mpcci.initCouplingInfo();
   JMpCCIClient.MPCCI_TINFO tinfo = mpcci.getTinfo();

   String coldStart    = System.getenv("_MPCCI_STARCCM_COLDSTART");

   if (mpcci.mpcciTinfoHasDuration())
   {
      if (tinfo.iter_cbeg > 0) initIteration = tinfo.iter_cbeg;
      if (tinfo.iter_cend > 0) lastIteration = tinfo.iter_cend;
      if (tinfo.iter_pend > 0) postIteration = tinfo.iter_pend;
      mpcci.mpcciTinfoRemoveDurationCtl();
   }

   if (mpcci.mpcciTinfoHasSubcycle())
   {
      if (mpcci.mpcciTinfoSubcycleType() == JMpCCIClient.MPCCI_TMODE_SUBCYCLE_CONST
          && tinfo.sub_step > 0)
      {
```

```
      nbIteration  = tinfo.sub_step;
   }
   mpcci.mpcciTinfoRemoveSubcycleCtl();
}

if (coldStart != null && coldStart.length() > 0)
{
    removeInitialSolution = Boolean.parseBoolean(coldStart);
}

if (!mpcci.mpcciTinfoHasSubcycle()
|| mpcci.mpcciTinfoSubcycleType() == JMpCCIClient.MPCCI_TMODE_SUBCYCLE_CONST)
{
   int iterCount = 0;
   nbCoupling = (lastIteration - initIteration) / nbIteration;
   iterCount = (initIteration +(nbIteration * nbCoupling));
   if (iterCount < lastIteration)
   {
      postIteration = postIteration + (lastIteration -iterCount);
      lastIteration = iterCount;
   }
}

int currentIteration = simulation.getSimulationIterator().getCurrentIteration();

// total number of iterations for the solver
int totalIteration = lastIteration + postIteration;
if (!removeInitialSolution)
{
   totalIteration += currentIteration;
   lastIteration += currentIteration;
}

simulation.println("*** MpCCI Co-simulation setup for steady state analysis:");
if (mpcci.mpcciTinfoSubcycleType() == JMpCCIClient.MPCCI_TMODE_SUBCYCLE_CONST)
{
   simulation.println("*** Number of data exchange     : " + nbCoupling);
   simulation.println("*** Number of sub-iteration     : " + nbIteration);
}
else
{
   simulation.println("*** Number of sub-iteration     : VARIABLE");
}
simulation.println("*** Number of pre-iteration     : " + initIteration);
simulation.println("*** Number of post-iteration    : " + postIteration);
simulation.println("*** Number of existing iteration: " + currentIteration);
simulation.println("*** Total number of iteration   : " + totalIteration);
simulation.println("*** Clear initial solution      : " + removeInitialSolution);


// Get the maximum steps set from the sim project file and modify it
StepStoppingCriterion stepStoppingCriterion = null;
```

```
AbortFileStoppingCriterion abortFileStoppingCriterion = null;
Collection<Object> v = simulation.getSolverStoppingCriterionManager().getChildren();
Iterator<Object> it = v.iterator();
while(it.hasNext())
{
   Object stopingCriterion = it.next();
   if (stopingCriterion instanceof AbortFileStoppingCriterion)
   {
      abortFileStoppingCriterion = (AbortFileStoppingCriterion) stopingCriterion;
   } else
   if (stopingCriterion instanceof StepStoppingCriterion)
   {
      stepStoppingCriterion = (StepStoppingCriterion)stopingCriterion;
   }
}
if (stepStoppingCriterion != null) // reset the maximun steps for the model
{
   stepStoppingCriterion.setMaximumNumberSteps(totalIteration);
}
else
{
   simulation.println("*** No Maximum number of step criterion has been found!");
}
if (abortFileStoppingCriterion != null) // activate stop file
{
   abortFileStoppingCriterion.setFilePath("ABORT");
   abortFileStoppingCriterion.setIsUsed(true);
   abortFileStoppingCriterion.setInnerIterationCriterion(true);
}
else
{
   simulation.println("*** No stop file criterion has been found!
   An ABORT will not be possible");
}

File abortFile = new File(simulation.getSessionDir()+File.separator +"ABORT");


Solution solution = simulation.getSolution();

if (removeInitialSolution)
   solution.clearSolution();
// initialize the solver
if (!solution.isInitialized())
   solution.initializeSolution();
abort = abortFile.exists();

if (!abort && initIteration > 0)
{
   // Start a pre-computation without coupling
   simulation.println("Starting pre iterations...");
   simulation.getSimulationIterator().step(initIteration);
```

```
   abort = abortFile.exists();
}

// Initialize MpCCI co-simulation
if (!abort && mpcci.init())
{
   currentIteration = simulation.getSimulationIterator().getCurrentIteration();
   int couplingStepNo = 0;
   while(currentIteration < lastIteration)
   {
      // Exchange the data to MpCCI
      mpcci.exchange();
      if (mpcci.mpcciTinfoSubcycleType() ==
                                 JMpCCIClient.MPCCI_TMODE_SUBCYCLE_TABLE)
      {
         nbIteration = mpcci.mpcciTinfoGetSubcycleSizeAt(couplingStepNo);
         if ((nbIteration + currentIteration) >= lastIteration)
         {
            nbIteration = lastIteration - currentIteration;
            simulation.println("Reducing the number of sub-iterations to meet
                               the maximum iterations criterion...");
         }
         simulation.println("Starting sub-iterations cycle #"
         + (couplingStepNo+1) + " with " + nbIteration + " iterations...");
      }
      else
      {
         simulation.println("Starting sub-iterations cycle "
         + (couplingStepNo+1) + "/" + nbCoupling + "...");
      }
      // iterate nbIteration before exchange
      simulation.getSimulationIterator().step(nbIteration);
      currentIteration = simulation.getSimulationIterator().getCurrentIteration();
      couplingStepNo++;

      abort = abortFile.exists();
      if (abort)
      {
         simulation.println("Aborting sub-iterations...");
         break;
      }
   }
   // Try last data exchange to MpCCI
   mpcci.exchange();
   // Finalize the co-simulation: close the communication with the server
   mpcci.exit();
}

// Terminate the CFD solution by performing some iterations: endIterations
// sim is automatically saved
if (!abort)
{
```

```
         if (postIteration > 0)
         {
            simulation.println("Starting post iterations");
            simulation.getSimulationIterator().step(postIteration);
         }
      }
      else
      {
         simulation.println("Solution has been aborted.");
         abortFile.delete();
      }
   }
}
```

16.5.1.3 MpCCI Template Java Script: Transient Simulation

This sample is extracted from the
"<*MpCCI_home*>/codes/STAR-CCM+/adapters/macro/mpcci_runjob_unsteady.java" file.
This sample script is divided into 5 sections:

1. There are some steering variables for running the simulation:
   - timeCplStart: defines time before starting the coupling.
   - timeCplEnd: defines time for ending the coupling.
   - maxInnerIterations: defines the number of iterations for a time step.
   - timeCplPost: defines time after the coupling.
   - changeTimeStepSizeSetting: possibility to change the initial time step size.
   - timeStepSize: time step size to use.
   - nbStep: defines the number of time steps without coupling (subcycle).
   - maxTotalTime: defines the total simulation time.

   These variables are initialized by the values set from the tinfo and the list of getenv calls.
2. The setup of the simulation stop criteria is adjusted according to the steering variables.
3. The co-simulation phase begins:
   - The connection to the MpCCI server is established.
   - The solution will exchange data then performs nbStep time steps. This will loop for the duration of maxTotalTime. This section takes in account the time before starting the coupling and the time after the coupling.
   - The connection to the MpCCI server is closed.

```
package macro;

import java.util.*;
import java.beans.*;
import java.io.File;

import star.common.*;
import star.base.neo.*;
import star.vis.*;

import mpcci.starccm.*;
```

```
import mpcci.client.*;

/**
* NOTE:
* Java Macro file valid for an implicit unsteady solver.
*/
public class mpcci_runjob_unsteady extends StarMacro{
   public boolean isImplicitUnsteadyModel(Simulation simulation) {
      try {
         simulation.getSolverManager().getSolver(ImplicitUnsteadySolver.class);
         return true;
      } catch (Exception e) {
      }
      return false;
   }
   public boolean isExplicitUnsteadyModel(Simulation simulation) {
      try {
         simulation.getSolverManager().getSolver(ExplicitUnsteadySolver.class);
         return true;
      } catch (Exception e) {
      }
      return false;
   }
   public boolean isSteadyModel(Simulation simulation) {
       return (!isImplicitUnsteadyModel(simulation)
            && !isExplicitUnsteadyModel(simulation));
   }
public void execute() {
      // Time before starting the coupling
      double timeCplStart = 0.0;
      // Time for ending the coupling
      double timeCplEnd = 0.0;
      // Time after the coupling
      double timeCplPost  = 0.0;
      // Number of time steps between coupling steps
      int nbStep = 1;

      // Parameter for the Stopping Criteria of the implicit unsteady solver:
      // flag to modify the setting in the sim file,
      // if false the setting from the sim file is used.
      boolean changeTimeStepSizeSetting = false;
      // time step size in seconds
      double timeStepSize = 0.00025;
      // number of maximum inner iterations for a time step
      int maxInnerIterations = 30;

      double currentTimeStepSize = 0.0;
      boolean abort = false;
      boolean removeInitialSolution = false;

      Simulation simulation = getActiveSimulation();
      if(isSteadyModel(simulation))
```

```
{
   simulation.println("** ERROR ** The solution is not a unsteady model:");
   simulation.println("The MpCCI Java macro is only valid for a unsteady model!");
   simulation.kill();
}

// instantiate MpCCI Co-simulation for CCM+
Adapter mpcci = new Adapter(simulation);
mpcci.initCouplingInfo();
JMpCCIClient.MPCCI_TINFO tinfo = mpcci.getTinfo();

String timePend  = System.getenv("_MPCCI_STARCCM_TIMEPEND");
String dt        = System.getenv("_MPCCI_STARCCM_TIMEDT");
String maxIter   = System.getenv("_MPCCI_STARCCM_TIMEITER");
String coldStart = System.getenv("_MPCCI_STARCCM_COLDSTART");

if (mpcci.mpcciTinfoHasDuration())
{
    if (tinfo.time_cbeg > 0.0)
    {
        timeCplStart = tinfo.time_cbeg;
    }
    if (tinfo.time_cend > 0.0)
    {
        timeCplEnd = tinfo.time_cend;
    }
}
// Check coupling time.
if (!(timeCplEnd - timeCplStart > 0))
{
    simulation.println("*** No coupling time has been specified in the
                        MpCCI coupling configuration.");
    simulation.println("*** Simulation will exit after one coupled time step.");
}

if (timePend != null && timePend.length() > 0 )
{
    timeCplPost = Double.parseDouble(timePend);
}

// Set number of substeps.
if (mpcci.mpcciTinfoHasSubcycle())
{
   if (mpcci.mpcciTinfoSubcycleType() == JMpCCIClient.MPCCI_TMODE_SUBCYCLE_CONST
   && tinfo.sub_step > 0)
   {
      nbStep = tinfo.sub_step;
   }
}

// Set maximum inner iterations.
if (maxIter != null && maxIter.length() > 0)
```

```
{
   maxInnerIterations = Integer.parseInt(maxIter);
}

// Set time step size.
if (dt != null && dt.length() > 0 && Double.parseDouble(dt) > 0)
{
   changeTimeStepSizeSetting = true;
   timeStepSize = Double.parseDouble(dt);
}

// Set whether to remove the initial solution.
if (coldStart != null && coldStart.length() > 0)
{
   removeInitialSolution = Boolean.parseBoolean(coldStart);
}

// Set current simulation time.
double currentTime = simulation.getSimulationIterator().getElapsedTime();

// Set total maximum time.
double maxTotalTime = timeCplEnd + timeCplPost;
if (!removeInitialSolution)
{
    maxTotalTime += currentTime;
}

simulation.println("*** MpCCI Co-simulation setup for transient analysis:");
simulation.println("*** Coupling time : " + (timeCplEnd - timeCplStart));
simulation.println("*** Time before coupling : " + timeCplStart);
if (mpcci.mpcciTinfoSubcycleType() == JMpCCIClient.MPCCI_TMODE_SUBCYCLE_CONST)
{
   simulation.println("*** Number of time steps without coupling: " + nbStep);
}
else
{
   simulation.println("*** Number of time steps without coupling: VARIABLE");
}
simulation.println("*** Number of inner iteration/time step  : "
                                                    + maxInnerIterations);
simulation.println("*** Time post coupling : " + timeCplPost);
simulation.println("*** Existing time : " + currentTime);
simulation.println("*** Total time : " + maxTotalTime);
if (isImplicitUnsteadyModel(simulation))
{
   ImplicitUnsteadySolver implicitUnsteadySolver = ((ImplicitUnsteadySolver)
      simulation.getSolverManager().getSolver(ImplicitUnsteadySolver.class));

   if (changeTimeStepSizeSetting) // Set the initial time step size
   {
      implicitUnsteadySolver.getTimeStep().setValue(timeStepSize);
      simulation.println("*** New time step size value : "+ timeStepSize); }
```

```
      currentTimeStepSize = implicitUnsteadySolver.getTimeStep().getSIValue();
      simulation.println("*** Current time step size value : "
                                                  + currentTimeStepSize);
      simulation.println("*** Unsteady model : implicit");
   }
   else
   {
      simulation.println("*** Unsteady model : explicit");
   }
   simulation.println("*** Clear initial solution : " + removeInitialSolution);

   // Get the maximum time set from the sim project file and modify it
   StepStoppingCriterion stepStoppingCriterion = null;
   AbortFileStoppingCriterion abortFileStoppingCriterion = null;
   InnerIterationStoppingCriterion innerIterationStoppingCriterion = null;
   PhysicalTimeStoppingCriterion physicalTimeStoppingCriterion = null;
   Collection<Object> v = simulation.getSolverStoppingCriterionManager().getChildren();
   Iterator<Object> it = v.iterator();
   while(it.hasNext())
   {
      Object stoppingCriterion = it.next();
      if (stoppingCriterion instanceof AbortFileStoppingCriterion)
      {
         abortFileStoppingCriterion = (AbortFileStoppingCriterion) stoppingCriterion;
      } else
      if (stoppingCriterion instanceof StepStoppingCriterion)
      {
         stepStoppingCriterion = (StepStoppingCriterion)stoppingCriterion;
      } else
      if (stoppingCriterion instanceof InnerIterationStoppingCriterion)
      {
         innerIterationStoppingCriterion = (InnerIterationStoppingCriterion)
                                                        stoppingCriterion;
      } else
      if (stoppingCriterion instanceof PhysicalTimeStoppingCriterion)
      {
         physicalTimeStoppingCriterion = (PhysicalTimeStoppingCriterion)
                                                      stoppingCriterion;
      }
   }

   // Reset maximum physical time stop criteria.
   if (physicalTimeStoppingCriterion == null)
   {
      simulation.println("*** No maximum time criterion has been found, set own.");
      // Need a name for the stopping criterion
      physicalTimeStoppingCriterion = simulation.getSolverStoppingCriterionManager()
      .createSolverStoppingCriterion(PhysicalTimeStoppingCriterion.class,
                                     "maxTotalTime");
   }
   physicalTimeStoppingCriterion.setMaximumTime(maxTotalTime);
   physicalTimeStoppingCriterion.setIsUsed(true);
```

```
if (stepStoppingCriterion != null) // Deactivate the maximum steps for the model.
{
   stepStoppingCriterion.setIsUsed(false);
}

if (abortFileStoppingCriterion != null) // activate stop file
{
   abortFileStoppingCriterion.setFilePath("ABORT");
   abortFileStoppingCriterion.setIsUsed(true);
   abortFileStoppingCriterion.setInnerIterationCriterion(true);
}
else
{
   simulation.println("*** No stop file criterion has been found!
                                  An ABORT will not be possible");
}

if (innerIterationStoppingCriterion != null)
// set the maximum number of inner iterations for the time step
{
   innerIterationStoppingCriterion.setIsUsed(true);
   innerIterationStoppingCriterion.setMaximumNumberInnerIterations
                                                        (maxInnerIterations);
}
else
{
   simulation.println("*** No inner iteration criterion has been found!");
}

File abortFile = new File(simulation.getSessionDir()+File.separator +"ABORT");

Solution solution = simulation.getSolution();

if (removeInitialSolution)
   solution.clearSolution();
// initialize the solver
if (!solution.isInitialized())
   solution.initializeSolution();

abort = abortFile.exists();

SimulationIterator simulationIterator = simulation.getSimulationIterator();

// Initialize MpCCI co-simulation
if (!abort && mpcci.init())
{
   // Count number of coupling steps for info output and getting
   // number of substeps in case of subcycle table.
   int cstep = 0;
   boolean subcycleTable = mpcci.mpcciTinfoSubcycleType()
                           == JMpCCIClient.MPCCI_TMODE_SUBCYCLE_TABLE;
```

```
         // Perform data exchanges until stopping criterion is satisfied.
         while (!physicalTimeStoppingCriterion.getIsSatisfied())
         {
            // Exchange the data to MpCCI
            mpcci.exchange();
            simulation.println("Starting coupling cycle "+ (cstep + 1)
            + " at " + solution.getPhysicalTime() + "s/" + maxTotalTime + "s ...");
            if (subcycleTable)
            {
               nbStep = mpcci.mpcciTinfoGetSubcycleSizeAt(cstep);
            }
            simulation.println("Running " + nbStep + " time step(s)...");
            simulationIterator.run(nbStep);

            // Check abort.
            abort = abortFile.exists();
            if (abort)
            {
               simulation.println("Aborting time step cycle...");
               break;
            }
            // Next coupling step.
            cstep++;
         }
         // Finalize the co-simulation: close the communication with the server.
         mpcci.exit();
      }

      if (abort)
      {
         simulation.println("Solution has been aborted.");
         abortFile.delete();
      }
   }
}
```

16.6 Trouble Shooting, Open Issues and Known Bugs

- Under Microsoft Windows please avoid the usage of white space in your working directory containing the STAR-CCM+ model file. The loading of the adapter library would fail.

17 TAITherm

17.1 Quick Information

Company name	ThermoAnalytics
Company homepage	www.thermoanalytics.com
Support	www.thermoanalytics.com/support
Tutorials	▷ VII-9 Cube in a Duct Heater ◁

17.1.1 Supported Coupling Features

		Supported	
Scheme	Explicit	X	▷ V-3.4.2 Coupling Schemes ◁
	Implicit	–	
Dimension		–	▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁
		–	
		–	
		X	
		–	
Feature	MpCCI Configurator	–	▷ V-3.5 Smart Configuration ◁
	Negotiation	–	▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁
	Self-Coupler	–	▷ VIII-2.4.1 Code Information: `<CodeInfo>` ◁
	CopyComponents	–	▷ V-4.8.2.1 Copying Components ◁
Domains	Radiation	X	▷ V-3.1.1 Physical Domains ◁

17.1.2 Supported Platforms and Versions

The following versions of TAITherm are supported by MpCCI:

	Supported versions												
MPCCI_ARCH: Code platform	12.5.1	12.5.2	12.6.0	12.7.0	13.0.0	13.1.0	2020.1.0	2020.2.0	2021.1.2	2021.2.1	2021.2.5	2022.1.0	2022.2.0
lnx4_x64: x86_64	X	X	X	X	X	X	X	X	X	X	X	X	X
windows_x64: win64	X	X	X	X	X	X	X	X	X	X	X	X	X

17.1.3 References

TAITherm Documentation is part of the TAITherm distribution.

17.1.4 Adapter Description

The code adapter for TAITherm is based on a shared library `"libradthermmpcci.so|dll"` which is loaded by TAITherm and it includes the necessary interface functions.

17.1.5 Prerequisites for a Coupled Simulation

To run a coupled simulation you need the following:

- Ordinary TAITherm installation.

17.2 Coupling Process

Please read also ▷ IV-2 Setting up a Coupled Simulation ◁.

17.2.1 Model Preparation

Models can be prepared as usually.
The view factors file may be already computed by TAITherm before starting the coupled simulation because it may take some time until the view factors file is created.
You can execute the following TAITherm command to run the view factors computation separately:
`taitherm -runviewfactors <file.tdf>`
If the view factors have not been pre-computed before the coupled simulation start, TAITherm will perform this calculation as first step before solving the thermal problem.
The coupling components must be defined as separate parts.

17.2.2 Models Step

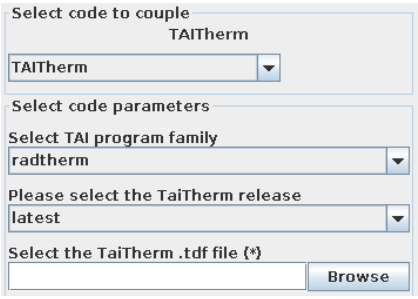


Figure 1: TAITherm options in the Models step

In the Models step, the following options must be chosen:

TAITherm program family Select The TAITherm program family from

- muses,
- taitherm, (default)
- powertherm.

TAITherm release Select the release of TAITherm you want to use. latest (default) will select the latest version which is installed on your system.

.tdf file Select the "TAITherm *.tdf" file of your TAITherm model.

The MpCCI TAITherm scanner reads the ".tdf" file and extracts all the parts by checking the following rules:

- the TAITherm part must not be empty. Parts having no elements are not scanned. For example Fluid part is not listed, because it has a single node and no geometry. This is not actually supported.
- TAITherm part having a rear side is automatically suffixed with "-backside" in the part name.
- The following part types are accepted for the coupling:
  - STANDARD: standard two sided part, standard (1-Layer) insulated part.
  - STANDARD_ASSIGNED: standard part with assigned temperature part.
  - MULTILAYER: multilayer part.
  - HIGH_CONDUCTIVE: high conductive part.
  - ENGINE: engine part.
  - face: for backward compatibility reason.
- Duplicated part names will be automatically suffixed with the part ID.

17.2.3 Algorithm Step

For general options please refer to ▷ V-4.7.2 Code Specific Algorithm Settings ◁.

In the Algorithm step, following additional options are available partly depending on the analysis type:

Solver settings

Convergence criteria The convergence criteria define the stopping criteria to apply.
Two options are available:

- Fixed number of loops
  This option sets a maximum number of iterations within a subcycling step (cf. coupling steps setting) in case of a Steady state analysis type or the maximum number of iterations per time step for an Transient analysis type.
- Tolerance slope
  This option complements the Fixed number of loops by considering a tolerance slope value within the subcycling step in case of a Steady state analysis type or within the iterations per time step for an Transient analysis type.

According to the selected Convergence criteria, different options will be proposed in the different setting sections. This allows to configure the solver behaviour when coupling with subcycling is activated (Figure 2) or for the transient analysis type.

17.2.3.1 Steady State Analysis Type

Solver settings

Tolerance slope (K) *(only with Tolerance slope option)* Set the tolerance slope to be used.
Tolerance slope refers to the rate at which the tolerance is changing. The tolerance refers to the maximum change in temperature for any one element in K (SI units) between the current and previous iteration.
The Tolerance slope is evaluated at each solver iteration step within the coupling step.

Current values Shows the current information from the TAITherm model:

Solver tolerance slope (K) Displays the current solver setting used by the current model file for the tolerance slope.

Maximum number of solver iterations Displays the current solver setting used by the current model file for the maximum value of iterations.

Solver total runtime (s) Displays the current solver setting used by the current model file for the duration.

Coupling steps

Constant maximum coupling step size (solver steps) *(only with Tolerance slope option)* Defines the maximum number of iterations without coupling to perform.

Minimum coupling step size (solver steps) *(only with Tolerance slope option)* Defines the minimum number of iterations without coupling to perform at least before activating the selected Tolerance slope convergence criterion.

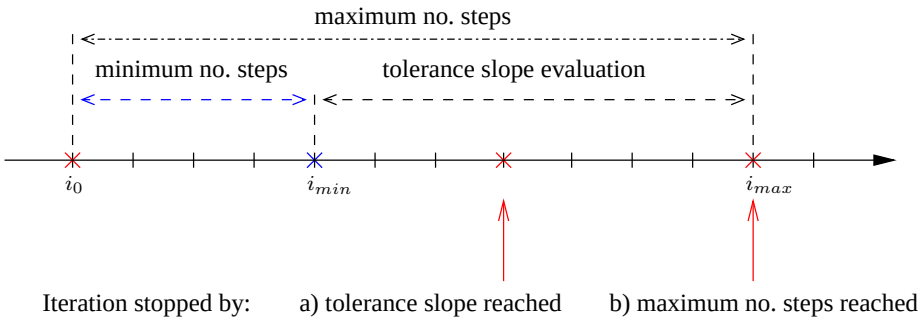


Figure 2: Subcycling behaviour with tolerance slope.

17.2.3.2 Transient Analysis Type

Solver settings

Tolerance slope (K) *(only with Tolerance slope option)* Set the tolerance slope to be used.
Tolerance slope refers to the rate at which the tolerance is changing. The tolerance refers to the maximum change in temperature for any one element in K (SI units) between the current and previous iteration.
The Tolerance slope is evaluated at each solver inner iteration step within the time step.

Type of solver step size Define the solver time step type to use:

- Defined by model Use the time step size defined in the input file. This allows you to use a curve definition for the time step size.
- Constant Overwrite the time step size setting with a new constant time step size value provided in the MpCCI GUI.

Solver step size (s) *only with Constant option* Define the solver time step size to use.

Number of inner iterations *(only with Fixed number of loops option)* Specifies the value for a fixed number of inner iterations during a solver step.

Maximum number of inner iterations *(only with Tolerance slope option)* Specifies the value for a maximum number of inner iterations during a solver step.

Current values Groups the options for starting and ending the coupling. The additional information for TAITherm solver settings are:

Solver tolerance slope (K) Displays the current solver setting used by the current model file for the tolerance slope.

Solver step size (s) Displays the current solver setting used by the current model file for the time step size.

Maximum number of solver iterations Displays the current solver setting used by the current model file for the maximum number of solver iterations.

Solver total runtime (s) Displays the current solver setting used by the current model file for the duration.

17.2.4 Regions Step

The TAITherm adapter only stores quantities directly ("Direct").

TAITherm supports the following quantities for coupling:

Quantity	Dim.	Default Value	Integration Type	Coupling Dimension	Location	Send Option	Receive Option
DeltaTime	Scalar	1.0 s	g-min	Global	global	Direct	
FilmTemp	Scalar	300.0 K	field	Face	Code		Direct
IterationNo	Scalar	0	g-max	Global	global	Direct	
PhysicalTime	Scalar	0.0 s	g-min	Global	global	Direct	
Residual	Scalar	0.0	g-max	Global	global	Direct	
TimeStepNo	Scalar	0	g-max	Global	global	Direct	
WallHeatFlux	Scalar	0.0 W/m^2	flux dens.	Face	Code		Direct
WallHTCoeff	Scalar	0.0 $W/m^2 K$	field	Face	Code		Direct
WallTemp	Scalar	300.0 K	field	Face	Code	Direct	

17.2.5 Go Step

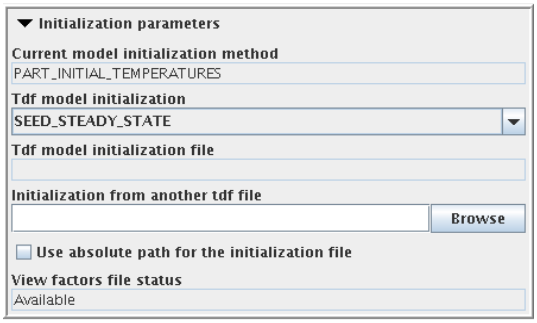


Figure 3: TAITherm options for Initialization parameters in the Go step.

In the Go step the following options can be chosen:

Initialization parameters Groups the options which can be set for initialization (cf. Figure 3).

Current model initialization method The initialization method used by the current model file. This value is delivered by the scanner.

Tdf model initialization
Choosable initialization types for the tdf model are (additional information about these options can be found in TAITherm manual):

PART_INITIAL_TEMPERATURES This option will use the initial temperature that was set for each part to start the steady state solution.

SEED_STEADY_STATE This option allows you to specify the initial temperature used by the solution to come from the results of a previously computed solution. This feature can provide faster steady state convergence in new models.

- If you choose SEED_STEADY_STATE and do not browse to a file, it will automatically try to seed from the current file (self-seed).
- If the seed model does not have results, the initialization method falls back to PART_INITIAL_TEMPERATURES.

TRANSIENT_RESTART This option allows you to continue a transient thermal solution with a new file.

TRANSIENT_INITIALIZATION Similar to TRANSIENT_RESTART, TRANSIENT_INITIALIZATION allows you to continue a transient thermal solution with a new file. The only difference between the two options is that the tdf file with the transient results does not have to exist when selecting TRANSIENT_INITIALIZATION.

Tdf model initialization file The initialization file used for the tdf model. Not available for tdf model initialization type PART_INITIAL_TEMPERATURES. This value is delivered by the scanner.

Initialization from another tdf file Choose another tdf file for initialization. Not available for tdf model initialization type PART_INITIAL_TEMPERATURES.

Use absolute path for the initialization file The selected initialization file will be saved in the current tdf file with the absolute path reference.
Not available for tdf model initialization type PART_INITIAL_TEMPERATURES.

View factors file status Indicates the status of the view factors file which is delivered by the scanner. Default is Missing meaning it is not delivered by the scanner.

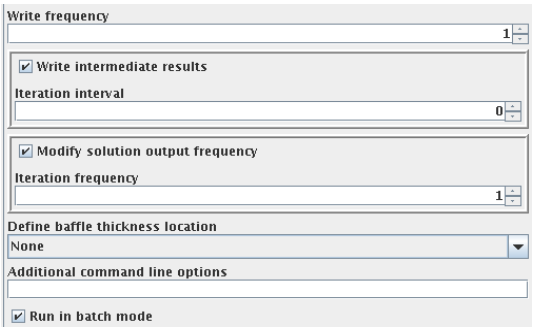


Figure 4: Output and start settings.

Write frequency Defines the frequency (in time step) to store the results (cf. Figure 4). For steady state simulation the results are saved at the end of the calculation.
For Explicit-SteadyState coupling this value is set to 1.

Write intermediate results If this option is enabled, an additional tdf file will be written at each iteration interval during the thermal solution. Each tdf file will contain the model data and the thermal results from that point in the simulation.

Iteration interval Defines the iteration interval at which the tdf file will be saved.

Modify solution output frequency If this option is enabled, you can define the output frequency of the solver residual.

Iteration frequency Defines the iteration frequency to output the solver residual.

Define baffle thickness location If the option BaffleShift from ▷ V-4.10.2 Job ◁ is activated, this option Define baffle thickness location will be displayed. The user should provide the thickness information about how the TAITherm part having layer properties has been defined. This defines the reference layer used for the thickness definition.
The user has the following options:

None The front and rear side will not be shifted. (default)

Backplane The rear side is used as reference location to shift the front side.

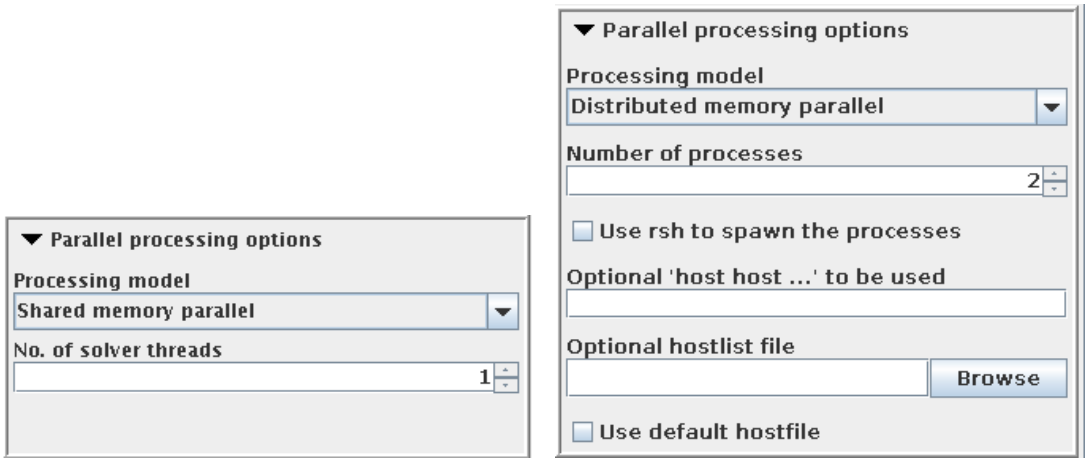
Frontplane The front side is used as reference location to shift the rear side.

Middle Both sides are shifted from the middle of the thickness value.

The front and rear sides are virtually separated in the MpCCI server in the geometric space if one of the options Backplane, Frontplane or Middle is selected.

Additional command line options Additional command line options for TAITherm can be given here, they will directly be used when TAITherm is started.

Run in batch mode If you want to run TAITherm in batch mode, select this option.



(a) Shared memory parallel settings (b) Distributed memory parallel settings

Figure 5: TAITherm Parallel processing options.

Parallel processing options Display configuration for the parallel processing (Figure 5):

Processing model List of available parallel processing model

Serial Run the thermal solution using one processor.

Shared memory parallel This option is applicable to a single system. ▷ 17.2.7.2 Parallel Execution ◁

No. of solver threads Set the number of threads to use on a multi-threaded system based.

Distributed memory parallel This option is useful for a single system or a series of connected machines.

No. of processes Set the number of processes that the solver will use. Each process will be configured with one thread.

Use rsh to spawn the processes Specify RSH method for spawning the processes over the list of machines. Default is SSH.

Option 'host host...' to be used Enter host names for the parallel execution.

Optional hostlist file Specify a hostfile from which the host names are extracted.

Use default hostfile A default hostfile can be configured by setting MPCCI_HOSTLIST_FILE ▷ V-3.6.2 Hostlist File ◁.

17.2.6 Checking the Computation

TAITherm provides a configuration checker as described in ▷ V-4.11.2 Checking the Configuration ◁ which

- checks if the initialization file is not omitted in case of transient restart or initialization method.
- checks the convergence criteria and solution parameters settings. For example:
  - checks if the duration value is greater or equal the time for ending the coupling.
  - checks if the maximum value of iterations is large enough according to the settings made in convergence criteria.
  - checks if the Minimum no. of steps without coupling does not exceed the Maximum no. of steps without coupling.
  - checks the variable subcycling table definition.
- checks that there is no mixing part in the coupled regions: front side and rear side parts are not allowed to be selected in the same coupled region.
- provides a coupling configuration summary.

17.2.7 Running the Computation

By clicking on the Start button from MpCCI GUI, MpCCI

- checks that there is no mixing part in the coupled regions: front side and rear side parts are not allowed to be selected in the same coupled region.
- starts a tool to prepare the `"tdf"` file for co-simulation (see ▷ 17.2.7.1 Hook Functions ◁).
- does a local copy of the MpCCI TAITherm adapter library before the code starts. It facilitates the port of the TAITherm `"tdf"` file.

The TAITherm computation is started, when using the GUI mode (non-batch mode), by clicking the Run button in section Analyse of the TAITherm GUI, otherwise TAITherm runs in batch mode.

When running a steady state simulation, TAITherm will save the results when either the total number of Maximum # iterations or the Tolerance Slope (K) criterion is satisfied. The Maximum # iterations is adjusted in the tdf file by MpCCI before the simulation starts. In MpCCI GUI the fields Iteration no. for ending the coupling and No. of iterations after the coupling are used to calculate this criterion. The Tolerance slope(K) is also adjusted in the tdf with the defined value from MpCCI GUI if the Convergence criteria is selected to Tolerance slope.
If TAITherm gets disconnected from the coupling server, the TAITherm solution will continue until the defined convergence criterion is reached.
When running a transient simulation, TAITherm saves the data at specified Write frequency value.
If TAITherm gets disconnected from the coupling server, the TAITherm solution will abort the current time step where the incident occurred and the results should be saved by TAITherm.

Using the MpCCI GUI Stop button executes a stopper script which sends a stop signal to TAITherm. Receiving this signal, TAITherm is able to terminate and save the tdf results.

17.2.7.1 Hook Functions

By starting the TAITherm computation the model will be automatically set up by MpCCI.

- MpCCI automatically hooks the Solution Start, Time Step Start, Iteration Start, Iteration End and Solution End TAITherm hook functions. The MpCCI TAITherm adapter decides which hook function to use according to the analysis type (Steady state or Transient).
- TAITherm model is automatically checked: the part convection type will be adjusted to TAITherm HandTfluid property for the co-simulation with the following default values:
  - $0 \frac{W}{m^2 * K}$ for heat transfer coefficient.
  - 273 K for the film temperature.

Running TAITherm with GUI allows you to see the changes applied to the model.

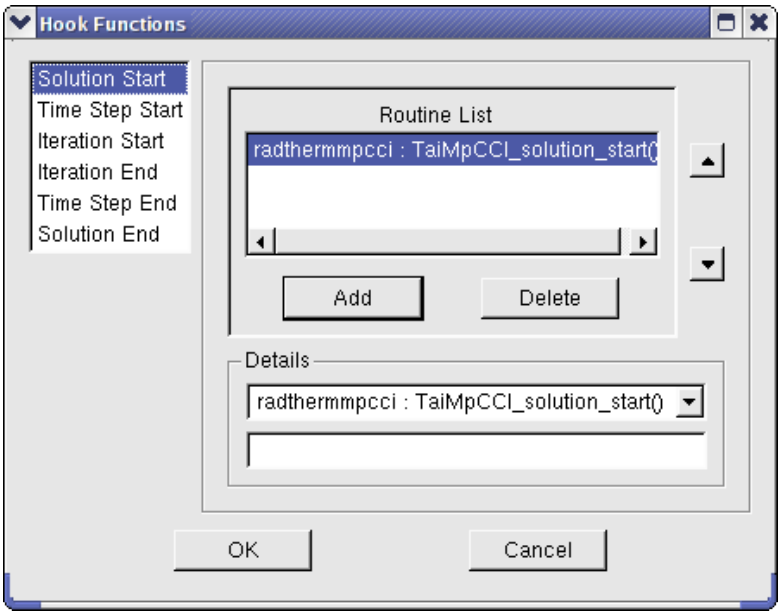


Figure 6: TAITherm Hook Functions Setup.

You can check the hooks setting by selecting the Analyse→Params section in the TAITherm GUI in order to access the hook functions setup Figure 6. By clicking on the button HookFunctions... the setup window will appear. You have to set up these functions for the following available TAITherm hooks:

Solution Start The routine radthermmpcci::TaiMpCCI_solution_start() has been automatically added. This is the function to initialize TAITherm with MpCCI.

Time Step Start The routine radthermmpcci::TaiMpCCI_timestep_start() has been automatically added. This is the function to exchange data before a new computation for transient simulation.

Iteration Start The routine radthermmpcci::TaiMpCCI_iteration_start() has been automatically added. This is the function to exchange data before a new computation for steady state simulation.

IterationEnd The routine radthermmpcci::TaiMpCCI_iteration_end() has been automatically added. This is the function to check the solution for the steady state simulation.

Solution End The routine radthermmpcci::TaiMpCCI_solution_end() has been automatically added. This is the function to terminate the coupled simulation.

17.2.7.2 Parallel Execution

There are two ways to launch TAITherm in parallel:

In batch mode By activating the batch mode you may specify the number of parallel solver threads.

In TAITherm GUI Before starting the TAITherm computation you need to check the number of processors to use set by MpCCI GUI, see

- Edit → Preferences → Application for older release than TAITherm 11.2 Figure 7
- Edit → Preferences → Parallel Processing Figure 8.

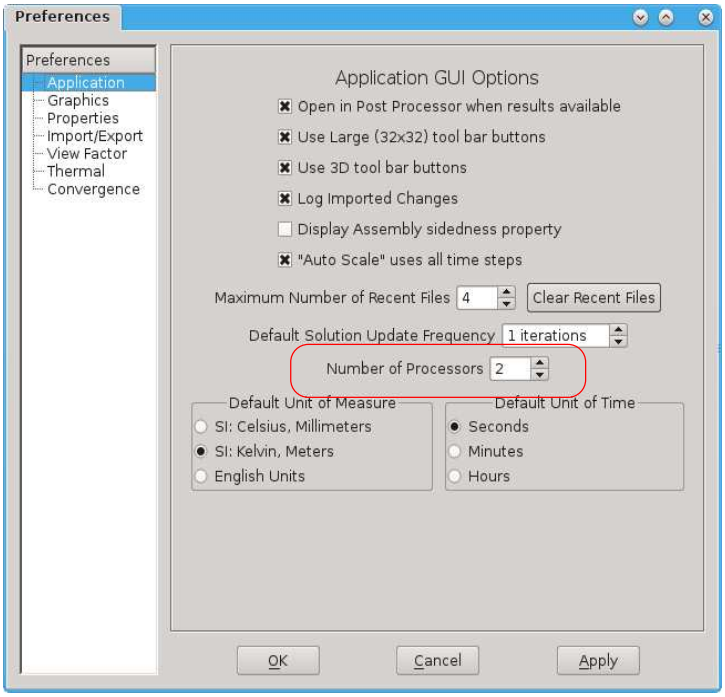


Figure 7: Number of processors setting in TAITherm GUI v11.0.

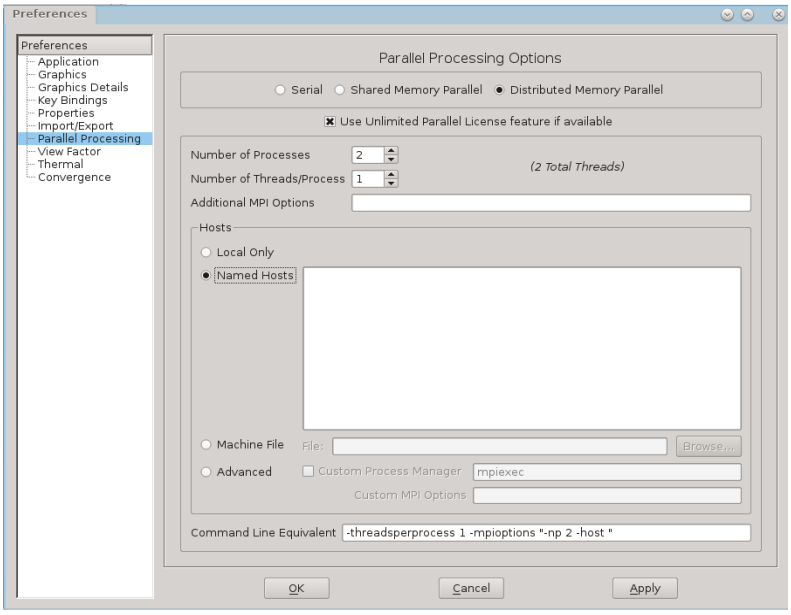


Figure 8: Parallel processing setting in TAITherm GUI v12.0.

17.2.8 Post-Processing

After a coupled simulation has finished the results computed on the TAITherm side may be visualized by using the TAITherm post-processing tool.

17.3 Code-Specific MpCCI Commands

The MpCCI subcommands available for TAITherm are:

```
Usage:
   mpcci TAITherm [-]option


Synopsis:
   'mpcci TAITherm' is used to get information about TAITherm.


Options:
   -clean [-r release] <tdf file>

      Clean up MpCCI hooks from tdf file.


   -diff <tdf1> <tdf2>

      Run the scanner on two tdf files and print the differences.


   -help
```

```
   This screen.

-importCFD [-r release] [-tcd tcd_filename] <-csp project> <-out tdf_output>

   Generate the file setting and execute the command for the importCFD option.

-info

   List verbose information about all TAITherm releases.

-releases

   List all TAITherm releases which MpCCI can find.

-scan [-r release] <tdf file>

   Run the scanner and create a scanner output file.
```

The subcommands `diff`, `info`, `releases` and `scan` are described in ▷ 1.1 Common MpCCI Subcommands for Simulation Codes ◁.

`mpcci taitherm -clean [-r release] <tdf file>`

The `clean` subcommand cleans up the MpCCI hooks from the given tdf file. All parts of type assigned temperature with a convection type HandTfluid will be set back without convection (value none for the convection type). If no release is specified, the latest one will be taken.

`mpcci taitherm -importCFD [-r release] [-tcd tcd_file] -csp <project> -out <tdf ouput>`

This option allows the user to import convection boundary conditions from an external CFD program using a transient convection data file (-tcd). The file to be used may be passed to the option -tcd. The .tcd file is a free-formatted file that holds fluid temperatures and convection coefficients from CFD analysis (see TAITherm User Manual for Transient Convection Data for details of the TCD format).
The `importCFD` subcommand generates a file setting and executes the command for the importCFD option from TAITherm. The file setting contains following options:

- the mesh mapping option is set to Off.
- The append option is to
  - Off for a steady state calculation or the first import of a transient calculation.
  - On for a transient calculation.

  The option value depends on the analysis type (Steady state or Transient) set during the co-simulation.
- the imported values are set on convection coefficients and film temperature.
- The list of parts is generated according to the list of coupled components defined in the MpCCI project file -csp. The option for Front, Back, Both is automatically set.
- The CFD results to import is provided by the option -tcd to add only one results file or by omitting this option the selection of the tcd files is automatically done based on the analysis type performed during the co-simulation:

– select the latest tcd file for a steady state from the model directory.
– select all tcd files for a transient calculation from the model directory.

The TAITherm setup with imported CFD data is saved in an new tdf file by the option -out. The tdf file to setup is automatically extracted from the MpCCI csp file. The directory containing the tdf file is used as model directory and will contain the file setting "mpcci_cfdimport_setting_INDEX.txt" and the new tdf file. INDEX corresponds to the import step number. The import step number zero has will always remove all existing records from the tdf file. You may keep track of the import process executed by MpCCI by executing by yourself the command: `taitherm -importCFD "mpcci_cfdimport_setting_INDEX.txt" -save new.tdf`

The parts of type assigned will not be included in the import setting file if they have been used during the co-simulation.

17.4 Code Adapter Reference

- Within the MpCCI distribution the "adapters" directory contains the necessary software to connect the simulation programs to MpCCI. The files are located within the subdirectory "<*MpCCI_home*>/codes/TAITherm/adapters".

  This subdirectory is further divided by several release subdirectories, e. g. "10.5.0" and "11.0.0". The version directories are further divided by several architectures (e. g. "x86_64", "win64"). There you find the library files of the TAITherm adapter (e. g. "libradthermmpcci.so"). The connection to MpCCI is established using these shared libraries.

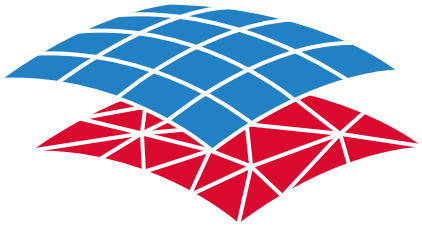
  MpCCI adapter recognizes parts with layer definition and automatically defines the method to shift the front and rear side part to the MpCCI server.
  Only constant thickness over the part is defined and supported.
- To prepare and check the "TDF" model file MpCCI provides a tool based on the TAITherm TDFIO library to process the model file. The files are located within the subdirectory "<*MpCCI_home*>/codes/TAITherm/bin".

  This subdirectory is further divided by several release subdirectories, e. g. "10.5.0" and "11.0.0". The version directories are further divided by several architectures (e. g. "x86_64", "win64"). There you find the executable of the MpCCI TAITherm utility tool "mpcci_radthermutil.exe".

17.4.1 Quantity Handling

Following paragraph describes the default rules applied by the code adapter for the following quantities prescribed to TAITherm:

- Negative wall temperature values are reset to zero.
- Negative wall heat transfer coefficient values are reset to zero.
- Negative film temperature values are reset to zero.
- Negative wall heat flux values are inverted.



MpCCI
CouplingEnvironment

Part VII

—

Tutorial

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part VII Tutorial
PDF version
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VII Tutorial – Contents

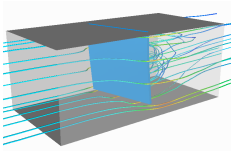
1 Introduction

The tutorial is a collection of examples. The files needed to run these examples are included in the MpCCI distribution in the directory "<*MpCCI_home*>/tutorial". All analysis steps are explained in detail. Please keep in mind that the descriptions are written to demonstrate the usage of MpCCI, they are not very useful if you want to learn how to use the simulation codes.

1.1 Overview of the Tutorials Grouped by Coupling Type

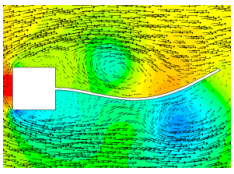
1.1.1 Fluid-Structure Interaction

▷ 2 Elastic Flap in a Duct ◁



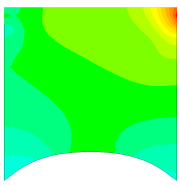
Analysis type:	Transient
Special topics:	Exchange of time step size, grid morphing, 3D-model,
Codes:	Fluid mechanics: FINE/Open, FINE/Turbo, FLUENT, Solid mechanics: Abaqus, ANSYS, Marc, MSC NASTRAN OpenFOAM, STAR-CCM+
Quantities:	DeltaTime, NPosition, RelWallForce

▷ 3 Vortex-Induced Vibration of a Thin-Walled Structure ◁



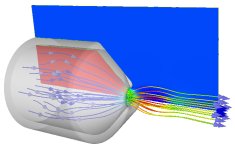
Analysis type:	Transient with pre-computed flow field
Special topics:	Different unit systems, 2D-model
Codes:	Fluid mechanics: FINE/Open, FINE/Turbo, FLUENT, STAR-CCM+ Solid mechanics: Abaqus, ANSYS, Marc, MSC NASTRAN
Quantities:	NPosition, RelWallForce

▷ 4 Driven Cavity ◁



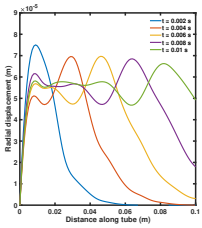
Analysis type:	Implicit transient
Special topics:	Quasi-Newton relaxation, adaptive time step size
Codes:	Fluid mechanics: FLUENT, OpenFOAM Solid mechanics: Abaqus, MSC NASTRAN
Quantities:	NPosition, WallForce

▷ 5 Pipe Nozzle ◁



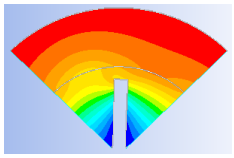
Analysis type:	Steady state unidirectional exchange
Special topics:	Axisymmetry, different unit systems, use of UDF (FLUENT) and field (STAR-CCM+) functions
Codes:	Fluid mechanics: FLUENT, STAR-CCM+ Solid mechanics: ANSYS, MSC NASTRAN
Quantities:	RelWallForce

▷ 6 Blood Vessel ◁



Analysis type:	Transient
Special topics:	Smart configuration of MpCCI, 3D-model
Codes:	Fluid mechanics: OpenFOAM Solid mechanics: Abaqus
Quantities:	Selected by smart configuration of MpCCI

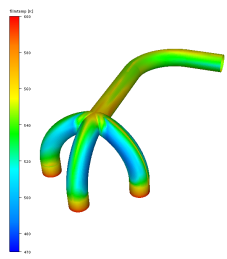
▷ 7 Periodic Rotating Fan Model ◁



Analysis type:	Steady state
Special topics:	Periodic models with different section shapes, ramping, 2D-model
Codes:	Fluid mechanics: FLUENT Solid mechanics: Abaqus
Quantities:	NPosition, RelWallForce

1.1.2 Thermal Surface Coupling

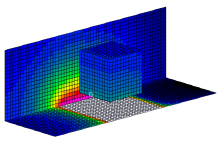
▷ 8 Exhaust Manifold ◁



Analysis type:	Steady state with pre-computed flow field
Special topics:	Subcycling of fluid solver, incompressible fluid, 3D-model
Codes:	Solid heat transfer: Abaqus, ANSYS, Marc Fluid heat transfer: FLUENT, OpenFOAM, STAR-CCM+
Quantities:	FilmTemp, WallHTCoeff, WallTemp

1.1.3 Thermal Radiation Coupling

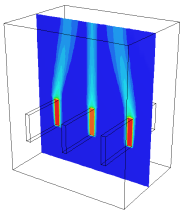
▷ 9 Cube in a Duct Heater ◁



Analysis type:	Steady state radiative heat transfer
Special topics:	Subcycling, forced convection, 3D-model
Codes:	Heat radiation: TAITherm Fluid heat transfer: FLUENT, OpenFOAM, STAR-CCM+
Quantities:	FilmTemp, WallHTCoeff, WallTemp

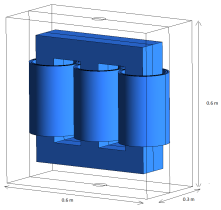
1.1.4 Electrothermal Analysis

▷ 10 Busbar System ◁



Analysis type:	Steady state flow field calculation and magnetic calculation in frequency domain
Special topics:	Volume coupling, several coupling regions, subcycling, 3D-model
Codes:	Electromagnetism: ANSYS, JMAG Fluid mechanics: FLUENT
Quantities:	JouleHeat, Temperature

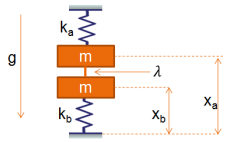
▷ 11 Three Phase Transformer ◁



Analysis type:	Steady state flow field calculation and magnetic calculation in frequency domain
Special topics:	Volume coupling, several coupling regions, subcycling, 3D-model
Codes:	Electromagnetism: JMAG Fluid mechanics: FLUENT
Quantities:	JouleHeat, Temperature

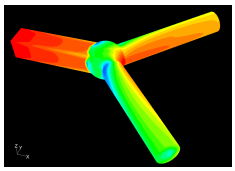
1.1.5 System Coupling

▷ 12 Spring Mass System ◁



Analysis type:	Transient
Special topics:	Spring-Mass-System with a split mass (analytical solution is known), implicit coupling, explicit with non-matching time step sizes, comparison of implicit to explicit coupling
Codes:	System for model A: SimulatorA (simple C executable), MATLAB System for model B: Abaqus, Adams, MATLAB, SIMPACK, SimulatorB (simple C executable).
Quantities:	Force, PointPosition, additionally Acceleration for coupling with Adams

▷ 13 Y-Junction ◁



Analysis type:	Steady state
Special topics:	1D - 3D coupling, remote file browser
Codes:	System: FloMASTER Fluid mechanics: FLUENT, OpenFOAM, STAR-CCM+
Quantities:	MassFluxRate, TotalPressure, MassFlowRate

2 Elastic Flap in a Duct

2.1 Problem Description

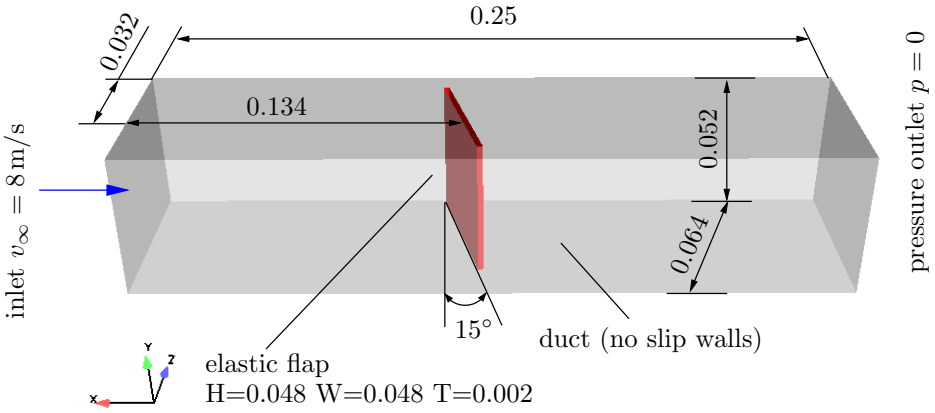


Figure 1: Elastic flap: Geometry [m] and boundary conditions

Topics of this Tutorial

- Fluid-Structure Interaction (cf. ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁)
- Coupling of time step (sent by computational fluid dynamics code)
- Usage of the MpCCI Grid Morpher for OpenFOAM
- 3D-model

Simulation Codes

- Fluid mechanics: FINE/Open, FINE/Turbo, FLUENT, OpenFOAM, STAR-CCM+
- Solid mechanics: Abaqus, ANSYS, Marc, MSC NASTRAN

2.2 Model Preparation

The simulation couples a solid mechanics model with a fluid mechanics model. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the subdirectories from "<*MpCCI_home*>`/tutorial/ElasticFlap`" which correspond to the simulation codes you want to use.

2.2.1 Solid Model

The solid part corresponds to a rectangle (Figure 2):

The material is linear elastic with density $\varrho = 1000\,\mathrm{kg/m^3}$, elastic modulus $E = 1.0 \times 10^8\,\mathrm{Pa}$ and Poisson's ratio $\nu = 0.49$.

The mesh consists of $20 \times 20 \times 2$ brick elements with 20 nodes each. All nodes at the top are fixed, i. e. they cannot move in any direction.

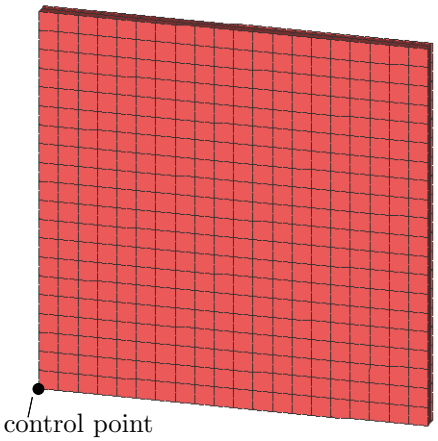


Figure 2: Elastic flap: Mesh of the structural domain

The solid mechanics code is set up with an adaptive time step setting with an initial time step size $\Delta t = 0.25\,\text{ms}$ and a total time $t = 0.2\,\text{s}$.

A control-point/node is selected in each solid model for evaluation of the results, see ▷ 2.5 Discussion of Results ◁.

Abaqus

C3D20R elements are used. The whole surface except for the fixed end is defined as an element set, which can be selected as coupling component.

ANSYS

The standard 20-node brick element type SOLID95 - 3D 20-Node Structural Solid is used. In ANSYS, the time stepping scheme is set up in the APDL script by:

```
ptime = ptime0 + DeltaTime
ptime0= ptime
time, ptime
solve
```

ANSYS receives the time step size from the component DeltaTime and the total simulation time is set with the `time, ptime`.

Marc

The fully integrated 20-node brick elements 21 are used. The solver has been set up with an adaptive time step.

MSC NASTRAN

The standard CHEXA8 elements are used. The whole surface except for the fixed end is defined as an wetted surface, which can be selected as coupling component. The wetted surface has QUAD4 elements defined for applying the FSI load.
The control node in MSC NASTRAN is the node number 1. The solver has been set up with an adaptive time step.

...

2.2.2 Fluid Model

The fluid domain comprises the whole rectangular area in Figure 3 except for the flexible elastic flap structure.

The computational fluid dynamics code is set up with a fixed time step configuration $\Delta t = 0.25\,\text{ms}$.

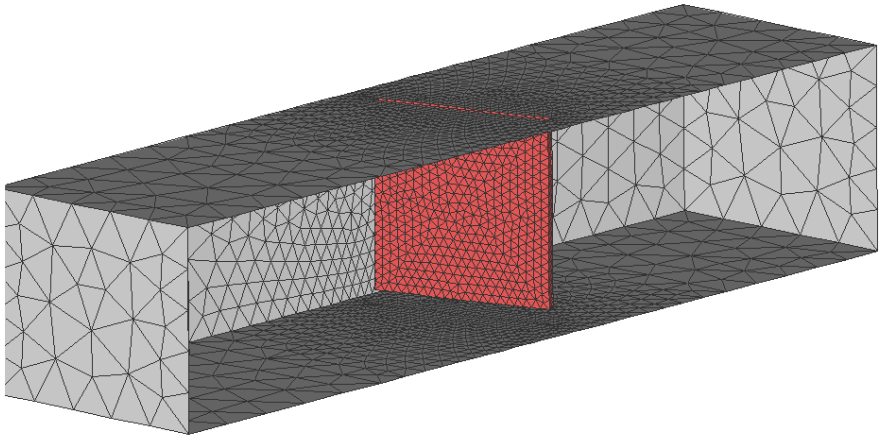


Figure 3: Elastic flap: Partial mesh of the fluid domain

FINE/Open

The mesh was generated with HEXPRESS and consists of hexahedral elements. The surface of the flexible structure is defined as separate solid boundaries.

FINE/Turbo

The mesh was generated with IGG and consists of hexahedral elements. The surface of the flexible structure is defined as separate solid boundaries.

The FINE/Turbo project file `"flap.iec"` must be opened and resaved with the target FINE/Turbo release you want to use in order to avoid any project file incompatibilities with the used FINE/Turbo release at runtime.

FLUENT

The mesh was generated with Gambit and consists of tetrahedral elements. The surface of the flexible structure is defined as a separate boundary named “couple-flap”.

OpenFOAM

The mesh corresponds to the mesh which is used in FLUENT. The surface of the flexible structure is defined as a separate boundary named “couple-flap”.

STAR-CCM+

The mesh corresponds to the mesh which is used in FLUENT. The boundary regions in the middle (named air-remesh) are subdivided, because they will later be addressed by the STAR-CCM+ grid morpher as sliding boundaries.

...

2.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

2.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.
2. Select the FSI coupling specification Gauge Pressure Based Fluid-Structure Interaction because this problem is a fluid-structure interaction with consideration of a reference pressure (cf. ▷ V-4.5.2 Category: Fluid-Structure Interaction (FSI) ◁).

2.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the fluid mechanics domain, choose your code to couple:

FINE/Open

Option	Action
Code to couple	Select FINE/Open.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-6 FINE/Open ◁).
Model file	Select `"elasticFlap_serial.run"` in the subdirectory `"FINEOpen/elasticFlap_serial/"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
▼ Additional model properties	
Reference pressure	Set pressure to 101325 $\mathrm{N/m^2}$.

FINE/Turbo

Option	Action
Code to couple	Select FINE/Turbo.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-7 FINE/Turbo ◁).
Run file	Select the run file `"flap_model.run"` in the subdirectory `"FINETurbo/flap_model"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is three-dimensional, thus select the FLUENT version 3ddp.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/elastic_flap.cas"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

OpenFOAM

Option	Action
Code to couple	Select OpenFOAM.
Option	Select the OpenFOAM option Opt or Debug.
Precision	Select the OpenFOAM precision: DP for double or SP for single precision.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-14 OpenFOAM ◁).
Case directory	Select the case directory `"OpenFOAM/`<*version*>`"` fitting your OpenFOAM version (e. g. `"OpenFOAM/v1806-v2306"` for use with OpenFOAM v1806 to v2306). The files will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
▼ Additional model properties	
Reference pressure	Set pressure to 101325 N/m^2.

STAR-CCM+

Option	Action
Code to couple	Select STAR-CCM+.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-16 STAR-CCM+ ◁).
Simulation file	Select the simulation file `"STAR-CCM+/elasticflap.sim"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

...

2. For the solid mechanics domain, choose your code to couple:

Abaqus

Option	Action
Code to couple	Select Abaqus.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-2 Abaqus ◁).
Input file	Select input file `"Abaqus/elastic_flap.inp"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

ANSYS

Option	Action
Code to couple	Select ANSYS.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-4 ANSYS ◁).
Product	You can select any ANSYS product which can be used for structural analysis, e. g. ansys.
Database file	Select database file `"ANSYS/elastic_flap.db"`. The file will be scanned immediately.
Solution type	Undefined is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

Marc

Option	Action
Code to couple	Select Marc.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-11 Marc ◁).
Input file	Select input file `"MSC.MARC/elastic_flap_job1.dat"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

MSC NASTRAN

Option	Action
Code to couple	Select MSC NASTRAN.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-13 MSC NASTRAN ◁).
Input file	Select input file `"MSC.Nastran/elastic_flap.bdf"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

...

Proceed to the Algorithm step by pressing Algorithm.

2.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	Set to Explicit.
▼ Coupling steps	
Type of coupling step size	Set to Sent by code because the time step is coupled.
▼ Coupling algorithm	
Algorithm type	Set to Serial.
Leading code	Set to solid mechanics code.
▼ Coupling duration	
Set total coupling time	Check this option.
Total coupling time	Set to 0.2 s.

2. For your fluid mechanics code:

FINE/Open

No code specific options need to be set.

FINE/Turbo

No code specific options need to be set.

FLUENT

No code specific options need to be set.

OpenFOAM

No code specific options need to be set.

STAR-CCM+

Option	Action
▼ Solver settings	
Type of solver step size	Set to Defined by model.
Maximum number of inner iterations	Set to 30.

...

3. For your solid mechanics code:

Abaqus

No code specific options need to be set.

ANSYS

Option	Action
▼ Analysis	
Analysis type	Select Transient.

MSC NASTRAN

No code specific options need to be set.

Marc

No code specific options need to be set.

...

Press the Regions button at the bottom of the window to get to the Regions step.

2.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷IV-2.6 Regions Step – Defining Coupling Regions and Quantities◁).

The time steps of the two solvers are coupled, whereas the fluid mechanics code will send the time step to the solid mechanics code.

1. At first select the Global tab to get access to the global variables.
2. Choose the variables to be coupled by dragging them into the Coupled boxes.:

   Lookup your codes in the following table and select the components to be coupled:

For region Global_1	
For fluid mechanics codes	**Select global variable**
FINE/Open	Var Time-Step-Size
FINE/Turbo	
FLUENT	
OpenFOAM	
STAR-CCM+	
For solid mechanics codes	**Select global variable**
Abaqus	Var Time-Step-Size
Marc	
MSC NASTRAN	
ANSYS	Var DELTATIME

3. Select DeltaTime as quantity to be transferred and configure as follows:

For quantity DeltaTime	
Option	**Action**
Sender	Select fluid mechanics code.
Default value which is set on sender site	Set to 2.5E-4.

The coupling region has to be defined.

1. Select the Mesh tab to get access to the mesh based element components.

2. Select Build Regions tab and here the Setup tab.
   In this example the coupling region corresponds to the surface of the flexible structure. MpCCI treats this region as a "Face" because it represents a 2D structure. The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.
   Now choose the components which characterize the surface of the flap. Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For fluid mechanics codes	**Select coupling component(s)**
FINE/Open	▲ Elastic_Flap_group_0 ▲ Elastic_Flap_group_1 ▲ Elastic_Flap_group_2 ▲ Elastic_Flap_group_3 ▲ Elastic_Flap_group_4
FINE/Turbo	▲ flap_front ▲ flap_back ▲ flap_bottom ▲ flap_right ▲ flap_left
FLUENT	▲ couple-flap
OpenFOAM	
STAR-CCM+	

For solid mechanics codes	**Select coupling component**
Abaqus	▲ ASSEMBLY_WALL_WALL-SURFACE
ANSYS	▲ WALLSURFACE
Marc	▲ wallsurface
MSC NASTRAN	▲ flap

3. Select Define Quantity Sets tab.
   The quantity NPosition has already been selected based on the chosen coupling specification. Now choose the force quantity to be exchanged.

For quantity set	**Select quantities**	**Set sender**
NPosition<–*Solid mechanics code*	RelWallForce	Fluid mechanics code

   The resulting name for the quantity set will be NPosition<–*Solid mechanics code* | RelWallForce<–*Fluid mechanics code*.

4. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	**Check quantity set**
Region_1	NPosition<–*Solid mechanics code* | RelWallForce<–*Fluid mechanics code*

No changes are required in the Monitors and Settings steps. You may proceed to the Go step by pressing Go.

2.3.5 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷ IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation ◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your fluid mechanics code:

FINE/Open

Option	Action
Expert mode	Check and access further options.
Mesh deformation	Select Radial basis functions.

FINE/Turbo

Option	Action
Set the requested memory	Check this option because for the coupling the memory has to be increased.
Number of reals (Mb)	Set to 100.
Number of ints (Mb)	Set to 10.
Expert mode	Check and access further options.
Mesh deformation	Select Radial basis functions.
Save inverse matrix of radial basis functions	Select Compute and use inverse matrix.

FLUENT

No code specific options need to be set.

OpenFOAM

Option	Action
Select OpenFOAM solver	Leave the default Auto-Select-by-Case. The setting from the `"controlDict"` file will be used.
Use MpCCI grid morpher	Check to use the grid morpher. Additional options become visible.
Optional list of floating boundary regions	Enter 3 to allow sliding of nodes on boundary region channel-middle close to the flap.

Refer to ▷ VI-14.3 Grid Morphing ◁ for more information on the MpCCI Grid Morpher options.

The numbering of boundary regions corresponds to the numbering in the OpenFOAM `"constant/polymesh"` subdirectory of your case.

STAR-CCM+

Option	Action
Run in batch	Check this option.
Auto start with the default template macro	Check this option.
License options	Set according to your license type (cf. ▷ VI-16.2.5.1 License Setting Details ◁).

...

2. For your solid mechanics code:

Abaqus

No code specific options need to be set.

ANSYS

Option	Action
Gui option	Keep -b to start ANSYS in batch mode.
APDL input script	Select the input script `"ANSYS/runflap.ans"`.

MSC NASTRAN

No code specific options need to be set.

Marc

No code specific options need to be set.

...

Now you may run the computation.

2.4 Running the Computation

2.4.1 Starting the Simulation

Save the MpCCI project file with name `"elastic_flap.csp"` over the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

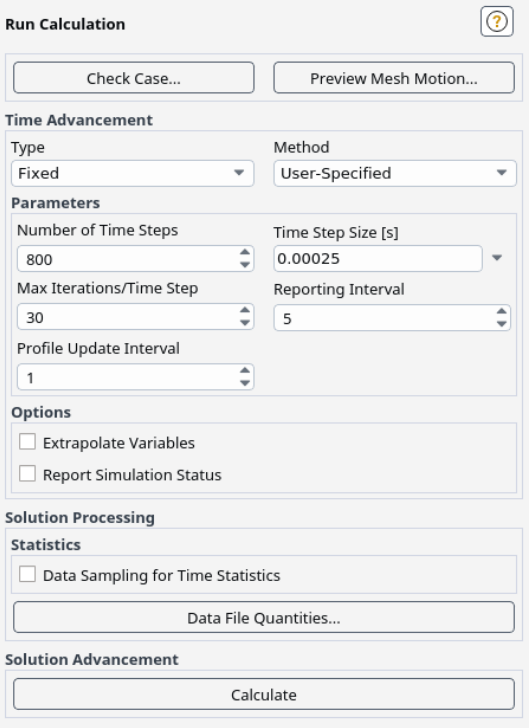
FINE/Open

FINE/Open will perform 800 time steps and will run in batch mode.

FINE/Turbo

FINE/Turbo will perform 800 time steps and will run in batch mode.

FLUENT



The FLUENT GUI is started, in which the calculation must be initialized and started as follows:

1. Select Solution→Initialization to open the initialization panel. Press the button Initialize.
2. Select Solution→Run Calculation to open the Run Calculation panel as shown on the left.
3. As the time step size is fixed to 0.00025 s, you should select a large Number of Time Steps, e. g. 800 to cover a simulation time of 0.2 s at least.
4. Finally, press Calculate to start the simulation.

During the simulation, FLUENT will display the residuals and a plane section through the flap to visualize the deformation.

OpenFOAM

The total coupling time of 0.2 seconds and the time step of $2.5e-4$ s have been set in the `"controlDict"` file. OpenFOAM will run in batch mode.

STAR-CCM+

STAR-CCM+ will perform 800 time steps to cover a total coupling time of 0.2 seconds. The time step of 0.00025 s will be set in the java macro file `"mpcci_runjob_unsteady.java"` which will be automatically copied to the working directory. STAR-CCM+ will run in batch mode.

...

2.4.2 End of the Simulation

The fluid mechanics codes determine the time step size which is constant $\Delta t = 0.00025$ s. Therefore only they have the information when to finish the simulation. In this case it is almost impossible to obtain a "clean exit" of both codes.

If the simulation has reached the end time of $t = 0.2$ s you can kill the remaining codes with the Kill button. All of the codes used in this example still write complete result files, therefore no data loss should be expected and it is possible to obtain the results described below.

Marc

Marc terminates a successful simulation with exit code 256, which looks like a failed run to the MpCCI GUI and is displayed accordingly by a Failed button. Do not be confused. With a click on this button the termination message of Marc can be controlled.

...

2.5 Discussion of Results

To compare the results of the different simulations, a control point was selected in the solid mechanics codes, see Figure 2. To display the motion of this point in x-direction similar to Figure 4 proceed as follows:

Abaqus

Open the output database `"abaqus_run.odb"` in Abaqus/CAE to plot the displacement of the control point:

Select Result→History Output from the menu bar to open the History Output panel.
Select U1 at Node 1 in NSET CONTROL-NODE and press Plot to plot the displacement in x-direction.

ANSYS

Start ANSYS and select TimeHist PostPro, open the file `"file.rst"`. In the Time History Variables panel, press the ⊞ button and select Nodal Solution →DOF Solution →X-Component of displacement and select node 366. Press the Graph Data button to plot the graph.

Marc

In Mentat select RESULTS and open the `"marc_run_[i4|i8].t16"` file. Switch to HISTORY PLOT, create a plot for the node-set "control-node" over all increments. Select the following data variables "Time" (x-axis) and "Displacement X" (y-axis) to plot the curve. Finally press FIT to fit the plot limits, otherwise the curve is displayed very small.

MSC NASTRAN

In SimXpert or PATRAN attach the results file `"mpcci_elastic_flap.xdb"`. You can create a chart for plotting the displacement in x direction for the node 1 for example.

...

...

Coupling specification The selected FSI coupling specification Gauge Pressure Based Fluid-Structure Interaction may display the pressure quantity OverPressure in the Define Quantity Sets tab from the Regions step if the solid mechanics code supports this quantity. Similar results can be achieved with this quantity which ignores any shear force effects of the fluid model, which is valid in case of the air material. The OverPressure quantity is considered as a normal force vector to the element surface.

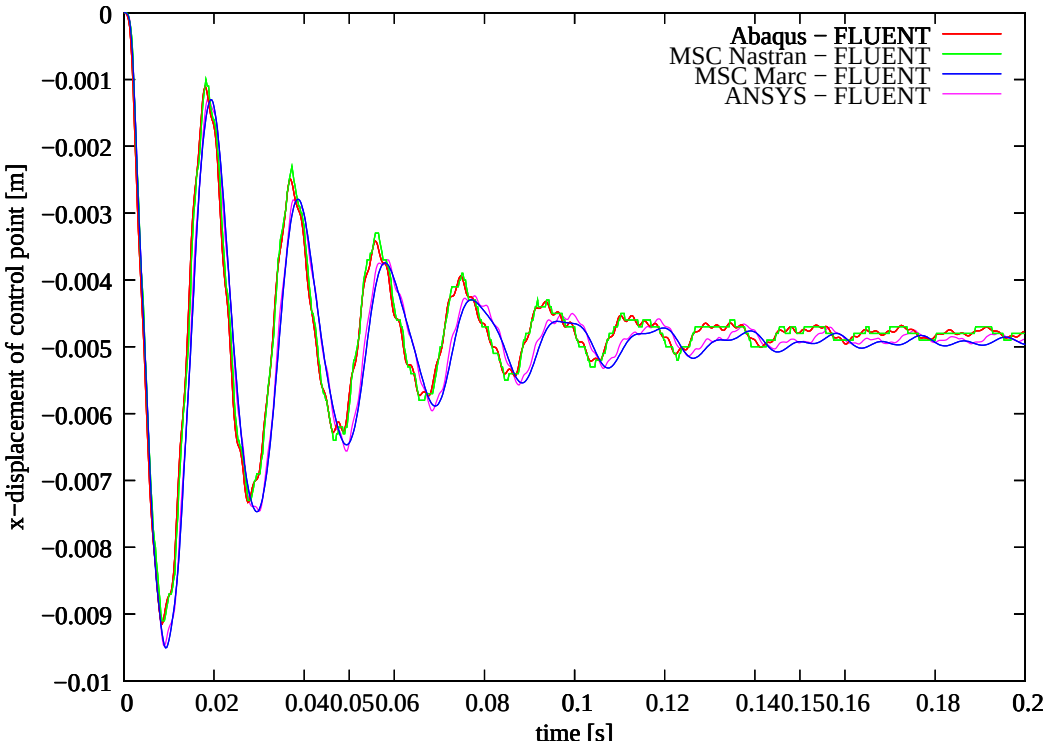


Figure 4: Elastic flap: Displacement of the control point for Abaqus, ANSYS, Marc and MSC NASTRAN coupled with FLUENT.

3 Vortex-Induced Vibration of a Thin-Walled Structure

3.1 Problem Description

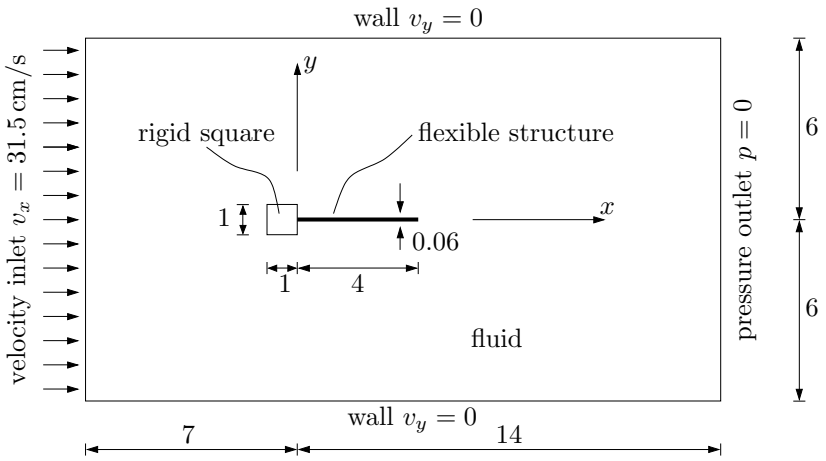


Figure 1: Vortex-induced vibration: Geometry and boundary conditions, the dimensions are given in cm.

Topics of this Tutorial

- Fluid-Structure Interaction (cf. ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁)
- Transient with pre-computed flow field
- Models with different unit systems (structural model: cgs units, fluid model: SI units).
- 2D-model

Simulation Codes

- Fluid mechanics: FINE/Open, FINE/Turbo, FLUENT, STAR-CCM+
- Solid mechanics: Abaqus, ANSYS, Marc, MSC NASTRAN

Description

The example is taken from an article by Walhorn et al. [2002] and is originally based on a computation by Wall [1999].

The computation consists of two parts. First, only the flow field is computed until a Von Kármán vortex street develops behind the square. This first step is computed without coupling, the flexible structure remains rigid. After this initial calculation, a coupled analysis is carried through, the structure is now flexible. This yields vibration of the structure with increasing amplitude.

3.2 Model Preparation

The simulation couples a solid mechanics model with a fluid mechanics model. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the particular subdirectories from "<*MpCCI_home*>`/tutorial/VortexVibration`" which correspond to the simulation codes you want to use.

3.2.1 Fluid Model

The fluid domain comprises the whole rectangular area in Figure 1 except for the rigid square and the flexible structure.

The fluid has a constant density of $\varrho = 1.18 \cdot 10^{-3} \frac{\mathrm{g}}{\mathrm{cm}^3}$ and a viscosity $\mu = 1.82 \cdot 10^{-4} \frac{\mathrm{g}}{\mathrm{cm\,s}}$.

The information about mesh properties and the steps to provide the initial solution can be found below, depending on your chosen CFD code:

FINE/Open

The mesh has been created by HEXPRESS and is built as non conformal mesh. The surface of the flexible structure is defined by the components "VortexVibration_group_6", "VortexVibration_group_7" and "VortexVibration_group_8".

In order to calculate the Von Kármán vortex street serving as initial condition for the coupled simulation perform the following steps:

- Open the FINE/Open GUI and select the project vortexVibration.iec
- Make the computation preComputation active. It will run for 2.16 s.
- Save the run file and start the computation. This computation is used as initial solution for the coupled simulation.
- Select the serial computation name and replace the initial solution file by selecting the `".run"` file from the computation preComputation.
- Save the run file.
- Close the FINE/Open GUI and proceed with the MpCCI GUI.

The computation project name serial has been set for a 2D co-simulation analysis. The parameter iMpCCIzSize is set to 0.002 which is the length of the cell in z-direction. This parameter can be set from the Local parameters in the Advanced menu of the Control Variables in the Computation Control section.

FINE/Turbo

The mesh has been created by IGG and is built as structured mesh. The surface of the flexible structure is defined by the components "Beam_1", "Beam_2" and "Beam_3".

In order to calculate the Von Kármán vortex street serving as initial condition for the coupled simulation perform the following steps:

- Open the FINE/Turbo GUI and select the project vortex.iec
- Make the computation init_ustd active. It will run for 2.16 s.
- Save the run file and start the computation. This computation is used as initial solution for the coupled simulation.
- Select the cpl_ustd computation and reset the initial solution file by selecting the `".run"` file from the computation init_ustd.
- Save the run file.
- Close the FINE/Turbo GUI and proceed with the MpCCI GUI.

FLUENT

The mesh was generated with Gambit. Around the flexible structure, the elements are smaller than those at the outer boundaries. The surface of the flexible structure is defined as a separate boundary named "flexible-struct".

The Von Kármán vortex street serving as initial condition for the coupled simulation is pre-computed and is provided in terms of the file `"FLUENT/plate-2160.dat"`.

STAR-CCM+

The mesh corresponds to the mesh which is used in FLUENT. The surface of the flexible structure is defined as a separate boundary named "fluid:flexible-struct". This boundary region will later be addressed by the STAR-CCM+ grid morpher.

The Von Kármán vortex street serving as initial condition for the coupled simulation is pre-computed and is included in the simulation setup file `"STAR-CCM+/plate2160.sim"`.

...

3.2.2 Solid Model

The solid part corresponds to a cantilevered transverse beam as shown in Figure 2.

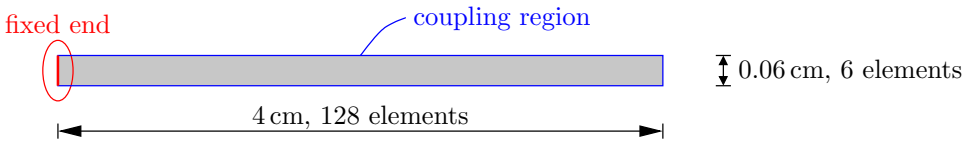


Figure 2: Vortex-induced vibration: flexible solid model and meshing parameters.

The material is linear elastic with density $\varrho = 2.0\,\mathrm{g/cm^3}$, elastic modulus $E = 2.0 \cdot 10^6\,\frac{\mathrm{g}}{\mathrm{cm\,s^2}}$ and Poisson's ratio $\nu = 0.35$.

The mesh consists of 128×6 linear 4-node plane-strain elements. All nodes at the left end are fixed, i. e. they cannot move in x and y-direction. The whole surface except for the fixed end is defined as an element set, which can be selected as coupling component.

All solid models are created using the cgs unit system, i. e. the units given above.

The solid model receives forces from the fluid model, which are computed with an out-of-plane thickness $t = 1\,\mathrm{m}$. Therefore the solid models must have the same thickness $t = 100\,\mathrm{cm}$.

Abaqus

In Abaqus, CPE4 elements are used. The meshing and modeling was performed in Abaqus/CAE.

ANSYS

In ANSYS, element `PLANE42` is used, the coupling surface is covered with `BEAM3` elements, which are deselected for the solution.

ANSYS does not provide the possibility to use a plane strain model with a given thickness. Therefore a plane stress model is used instead, which yields a softer structure.

MSC NASTRAN

In MSC NASTRAN CQUAD4 elements are used with shell property. The meshing and modeling was performed in SimXpert.

Marc

In Marc the element type 11 is used, i. e. plane-strain full integration quadrilateral elements. The meshing and modeling was performed in Mentat.

...

3.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

3.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.
2. Select the FSI coupling specification Gauge Pressure Based Fluid-Structure Interaction because this problem is a fluid-structure interaction with consideration of a reference pressure (cf. ▷ V-4.5.2 Category: Fluid-Structure Interaction (FSI) ◁).

3.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the fluid mechanics domain, choose your code to couple:

FINE/Open

Option	Action
Code to couple	Select FINE/Open.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-6 FINE/Open ◁).
Model file	Select `"vortexVibration_serial.run"` in the subdirectory `"FINEOpen/vortexVibration_serial/"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
▼ Additional model properties	
Reference pressure	Set pressure to 101325 N/m^2.

FINE/Turbo

Option	Action
Code to couple	Select FINE/Turbo.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-7 FINE/Turbo ◁).
Run file	Select the run file `"vortex_cpl_ustd.run"` in the subdirectory `"FINETurbo/vortex_cpl_ustd"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is two-dimensional, thus select the FLUENT version 2ddp.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/plate.cas"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

STAR-CCM+

Option	Action
Code to couple	Select STAR-CCM+.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-16 STAR-CCM+ ◁).
Simulation file	Select the simulation file `"STAR-CCM+/plate2160.sim"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

...

2. For the solid mechanics domain, choose your code to couple:

Abaqus

Option	Action
Code to couple	Select Abaqus.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-2 Abaqus ◁).
Input file	Select input file `"Abaqus/plate.inp"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select cgs to ensure that dimensions and quantities are transferred correctly. The Abaqus model was created using the cgs unit system, i. e. the values given in Figure 1 were directly entered in Abaqus/CAE and the geometry was created in cm.

ANSYS

Option	Action
Code to couple	Select ANSYS.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-4 ANSYS ◁).
Product	You can select any ANSYS product which can be used for structural analysis, e. g. ansys.
Database file	Select database file `"ANSYS/plate.db"`. The file will be scanned immediately.
Solution type	Undefined is displayed as a result of the scan process.
Unit system	Select cgs to ensure that dimensions and quantities are transferred correctly. The ANSYS model was created using the cgs unit system, i. e. the values given in Figure 1 were directly entered in ANSYS and the geometry was created in cm.

MSC NASTRAN

Option	Action
Code to couple	Select MSC NASTRAN.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-13 MSC NASTRAN ◁).
Input file	Select input file `"MSC.Nastran/vortexvibration.bdf"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select cgs to ensure that dimensions and quantities are transferred correctly. The MSC NASTRAN model was created using the cgs unit system, i. e. the values given in Figure 1 were directly entered in SimXpert and the geometry was created in cm.

Marc

Option	Action
Code to couple	Select Marc.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-11 Marc ◁).
Input file	Select input file `"MSC.Marc/plate.dat"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select cgs to ensure that dimensions and quantities are transferred correctly. The Marc model was created using the cgs unit system, i. e. the values given in Figure 1 were directly entered in Mentat and the geometry was created in cm.

...

Proceed to the Algorithm step by pressing Algorithm.

3.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	Set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Serial.
Leading code	Set to solid mechanics code.
▼ Coupling duration	
Set total coupling time	Check this option.
Total coupling time	Set to 10 s.

2. For the fluid mechanics code:

FINE/Open

No code specific options need to be set.

FINE/Turbo

No code specific options need to be set.

FLUENT

No code specific options need to be set.

STAR-CCM+

Option	Action
▼ Solver settings	
Type of solver step size	Set to Constant.
Solver time step size	Set to 0.001.
Maximum number of iterations per time step	Set to 30.

...

3. For your solid mechanics code:

Abaqus

Option	Action
▼ Solver settings	
Use subcycling	Deselect this option.
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 0.001, which equals the time step size in the Abaqus input file.

ANSYS

Option	Action
▼ Analysis	
Analysis type	Select Transient.

MSC NASTRAN

No code specific options need to be set.

Marc

No code specific options need to be set.

...

Press the Regions button at the bottom of the window to get to the Regions step.

3.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▹ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◃).

1. At first select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example the coupling region corresponds to the surface of the flexible structure. MpCCI treats this region as a "Face" because it represents a 2D structure. The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.
   Now choose the components to be coupled. Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For fluid mechanics codes	**Select coupling component(s)**
FINE/Open	▲ VortexVibration_group_6 ▲ VortexVibration_group_7 ▲ VortexVibration_group_8
FINE/Turbo	▲ Beam_1 ▲ Beam_2 ▲ Beam_3
FLUENT	▲ flexible-struct
STAR-CCM+	▲ flexible-struct
For solid mechanics codes	**Select coupling component**
Abaqus	▲ ASSEMBLY_OUTSIDE
ANSYS	▲ OUTSIDE
MSC NASTRAN	▲ struct
Marc	▲ outside

3. Select Define Quantity Sets tab.
   The quantity NPosition has already been selected based on the chosen coupling specification. Now choose the force quantity to be exchanged.

For quantity set	Select quantities	Set sender
NPosition<–*Solid mechanics code*	RelWallForce	Fluid mechanics code

   The resulting name for the quantity set will be NPosition<–*Solid mechanics code* | RelWallForce <–*Fluid mechanics code*.

4. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	Check quantity set
Region_1	NPosition<–*Solid mechanics code* | RelWallForce <–*Fluid mechanics code*

No changes are required in the Monitors and Settings steps. You may proceed to the Go step by pressing Go.

3.3.5 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your fluid mechanics code:

FINE/Open

Option	Action
Expert mode	Check to access further options.
Mesh deformation	Select Radial basis functions.

FINE/Turbo

Option	Action
Expert mode	Check to access further options.
Mesh deformation	Select Radial basis functions.
Save inverse matrix of radial basis functions	Select Compute and use inverse matrix.

FLUENT

Option	Action
Data file (optional)	Choose the data file `"FLUENT/plate-2160.dat"` because FLUENT does a restart from pre-computed flow field.

STAR-CCM+

Option	Action
Run in batch	Check this option.
Auto start with the default template macro	Check this option.
License options	Set according to your license type (cf. ▷ VI-16.2.5 Go Step ◁).

...

2. For your solid mechanics code:

Abaqus

No code specific options need to be set.

ANSYS

Option	Action
Gui option	Keep -b to start ANSYS in batch mode.
APDL input script	Select the input script `"ANSYS/runplate.ans"`.

MSC NASTRAN

No code specific options need to be set.

Marc

No code specific options need to be set.

...

Now you may run the computation.

3.4 Running the Computation

Save the MpCCI project file with name `"plate.csp"` via the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step.

Firstly a warning message from the application checker is displayed. It should be noted that no extrapolation in time is supported by MpCCI. However, the coupling step size is set to the same value for both codes, so that no extrapolation is required. This warning can therefore be acknowledged.

Then the simulation codes are started and their GUI or additional terminal windows open.

FINE/Open

Because a flow field is loaded from `"FINEOpen/vortexVibration_preComputation/vortexVibration_preComputation.run"`, the computation does not need to be initialized. The time step has been set to 0.001 seconds and the maximum number of time steps has been set to 10000 in the project file.

FINE/Turbo

Because a flow field is loaded from `"FINETurbo/vortex_init_ustd/vortex_init_ustd.run"`, the computation does not need to be initialized. The time step has been set to 0.001 seconds and the maximum number of time steps has been set to 10000 in the project file.

FLUENT

The FLUENT GUI is started. The computation does not need to be initialized as a flow field is loaded from `"FLUENT/plate-2160.dat"`. The calculation must be started as follows:

1. Select Solution→Run Calculation to open the Run Calculation panel.
2. Set the Number of Time Steps to 10000.
3. Finally, press Calculate to start the simulation.

During the simulation, FLUENT will display the residual, the resulting moment of the forces on the coupling surface and the pressure distribution in the fluid domain. You can also see the deformation of the flexible structure in the pressure distribution window.

STAR-CCM+

The computation does not need to be initialized as a flow field is loaded from `"STAR-CCM+/plate2160.sim"`. In the java macro file `"mpcci_runjob_unsteady.java"`, the initialize() function for the solution is not executed because the Do a cold start run option is not activated. The time step has been initialized to 0.001 seconds and the Total coupling time is read from the MpCCI GUI setting which was defined to 10 s.

...

3.4.1 End of the Simulation

Marc

Marc terminates a successful simulation with exit code 256, which looks like a failed run to the MpCCI GUI and is displayed accordingly by a Failed button. Do not be confused. With a click on this button the termination message of Marc can be controlled.

...

3.5 Discussion of Results

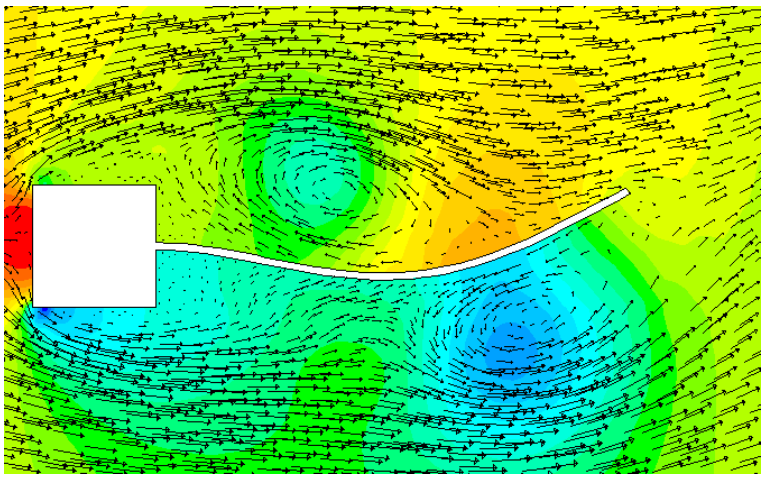
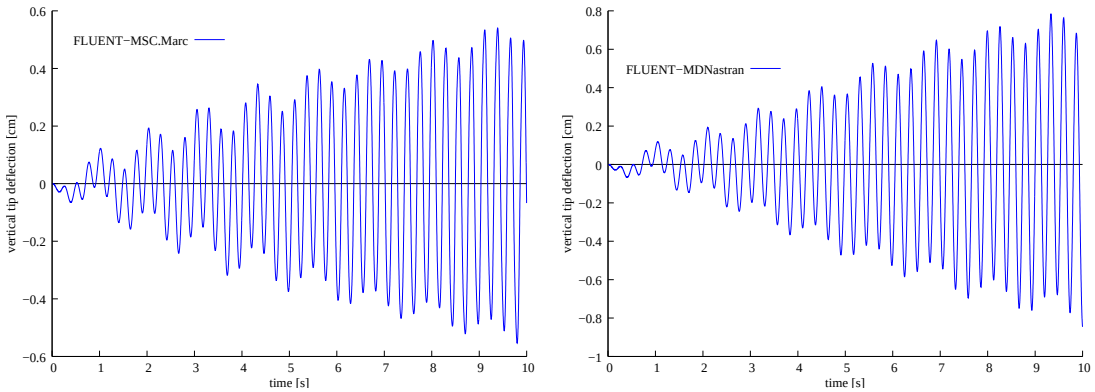


Figure 3: Vortex-induced vibration: Part of the flow field in FLUENT with velocity vectors and pressure distribution (red=high pressure, blue=low pressure).

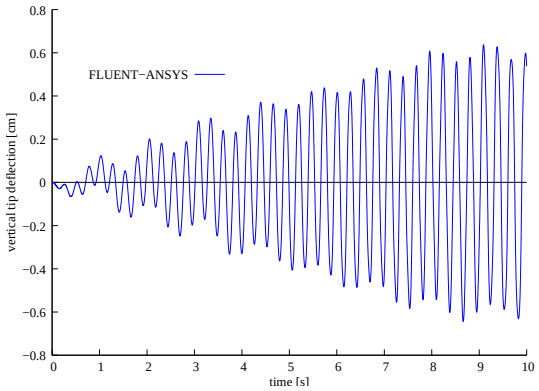
The vortex street yields pressure changes at the surface of the flexible structure, a typical pressure distribution is shown in Figure 3. The resulting forces accelerate the structure and cause a vibration with increasing amplitude.

However, as the structural models are not perfectly identical – the Abaqus model is a little stiffer than the Marc model. The ANSYS model is much weaker as the other two, because the ANSYS model is based on a plane stress assumption while the others use plane strain. Therefore the natural frequencies of the models differ, which yields different responses as shown in Figure 4.

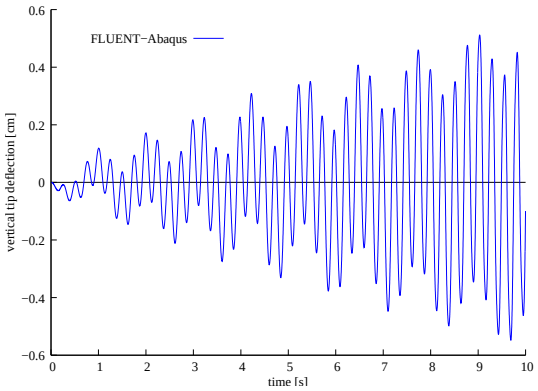


(a) FLUENT-Marc

(b) FLUENT-MSC NASTRAN



(c) FLUENT-ANSYS



(d) FLUENT-Abaqus

Figure 4: Vortex-induced vibration: Vertical deflection of the tip.

4 Driven Cavity

4.1 Problem Description

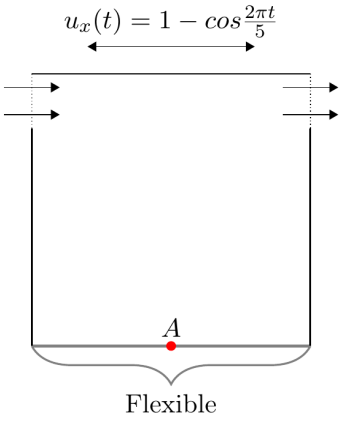


Figure 1: Driven cavity: Geometry of the two-dimensional flowed through cavity with moving top face and flexible bottom.

Topics of this Tutorial

- Fluid-Structure Interaction (cf. ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁)
- Implicit transient coupling (cf. ▷ V-3.4.5.1 Implicit Coupling ◁) with
- Quasi-Newton Method (cf. ▷ V-3.3.3.4 Quasi-Newton Method ◁)
- Adaptive time step size (cf. ▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁)

Simulation Codes

- Fluid mechanics: FLUENT, OpenFOAM
- Solid mechanics: Abaqus, MSC NASTRAN

Description

The example is taken from Koch [2016], which was originally set up by Mok [2001]. The low structural stiffness leads to a strong added mass effect. Only iterative coupling leads to a stable simulation. The Quasi-Newton relaxation is used in order to accelerate the convergence in each time step. In this tutorial, both two- and three-dimensional simulations can be performed, except for OpenFOAM, as it is only capable of simulating 3D models. 2D simulations are generally simpler and faster. However, simulations are more realistic for three-dimensional cases. At the end in ▷ 4.5.1 Coupling with Adaptive Time Step ◁, it is shown how to perform this tutorial with adaptive time step size.

4.2 Model Preparation

The simulation couples a solid mechanics model with a fluid mechanics model. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the particular subdirectories from "<*MpCCI_home*>/tutorial/DrivenCavity".

4.2.1 Fluid Model

The fluid domain comprises the quadratic area ($1\,\mathrm{m} \times 1\,\mathrm{m}$) and the cube ($1\,\mathrm{m} \times 1\,\mathrm{m} \times 1\,\mathrm{m}$) for the two- and three-dimensional models, respectively. The two-dimensional model is shown in Figure 1, which is also the 2D projection of the three-dimensional model. The top face is oscillating with a frequency of 0.2 Hz. The flow inlet and outlet are situated left and right near the top of the domain and are 0.2 m wide. The bottom of the cavity is flexible, which is modelled in the structural simulation.

The fluid is incompressible with density $\varrho_F = 1\,\frac{\mathrm{kg}}{\mathrm{m}^3}$ and a viscosity of $\nu_F = 0.001\,\frac{\mathrm{m}^2}{\mathrm{s}}$.

The time steps in the solid and fluid code are set to the same fixed values. This is necessary for iterative transient coupling schemes. The time step size for this example is $\Delta t = 0.1\,\mathrm{s}$ and the total time is $t = 40.0\,\mathrm{s}$.

FLUENT

For FLUENT both the two- and three-dimensional cases are provided. An adaptive mesh is used. Overall, the 2D and 3D meshes consist of 24×24 quadrilateral cells and $24 \times 26 \times 24$ Hexahedron cells, respectively. The wetted surface of the flexible wall is defined as a boundary named “bottom”.

The oscillation of the top face is defined by a user-defined function. The FLUENT model has been saved with the auto-recompile flag option which will automatically copy the provided `"velocity.c"` file and compile the function if the folder `"libudf"` is not available.
Please check and load you compiler settings before opening FLUENT for the first time in order to compile the user-defined attached function.
Start fluent 2ddp or fluent 3ddp, then read the corresponding casefile `"cavity2d.cas"` or `"cavity3d.cas"` in order to compile in advance the user-defined function. This step can be done during the co-simulation start before running the calculation for FLUENT if all compiler settings are correctly set.

OpenFOAM

For OpenFOAM only the three-dimensional case is provided. An adaptive mesh is used. Overall, the mesh consists of $24 \times 26 \times 24$ Hexahedron cells. The wetted surface of the flexible wall is defined as a boundary named “bottom”.

...

4.2.2 Solid Model

The solid part corresponds to the flexible wall at the bottom. Its thickness is 0.002 m and it is fixed at the left and the right side. A control node A in the middle is selected for evaluation of the results.

The material is linear elastic with density $\varrho_S = 250\,\mathrm{kg/m^3}$, elastic modulus $E = 250\,\frac{\mathrm{kg}}{\mathrm{m\,s^2}}$ and Poisson’s ratio $\nu_S = 0$.

The time step size is set to $\Delta t = 0.1\,\mathrm{s}$ to match the step size of the computational fluid dynamics code.

Abaqus

For Abaqus both the two- and three-dimensional cases are provided. In the 2D-model, the flexible wall is meshed by three layers of 80 CPS4 elements. Whereas in 3D-model, it is meshed by 1200 C3D8 elements. In order to define the region, where quantities are exchanged, a surface named “COUPLINGSURF” is built from the top of the flexible wall.

MSC NASTRAN

Both the two- and three-dimensional cases are provided for MSC NASTRAN as well. In the 2D-model, the flexible wall is meshed by three layers of 80 CQUAD4 elements. For the 3D case, a shell model with

thickness 0.002 m in y-direction is discretized by a 30×30 mesh, resulting in 900 CQUAD4 elements. The coupled surface is called "surf" for both models.

...

4.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

4.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.

2. Select the FSI coupling specification Absolute Pressure Based Fluid-Structure Interaction because this problem is a fluid-structure interaction without consideration of a reference pressure (cf. ▷ V-4.5.2 Category: Fluid-Structure Interaction (FSI) ◁).

4.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the fluid mechanics domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	For a 2D simulation select the FLUENT version 2ddp. For a 3D simulation select the FLUENT version 3ddp.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	For a 2D simulation select input file `"FLUENT/cavity2d.cas"`. For a 3D simulation select input file `"FLUENT/cavity3d.cas"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

OpenFOAM

Option	Action
Code to couple	Select OpenFOAM.
Option	Select the OpenFOAM option Opt or Debug.
Precision	Select the OpenFOAM precision: DP for double or SP for single precision.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-14 OpenFOAM ◁).
Case directory	Select the case directory "OpenFOAM/<*version*>" fitting your OpenFOAM version (e. g. "OpenFOAM/v1806-v2306" for use with OpenFOAM v1806 to v2306). Please note that the provided files are only for 3D simulation. The files will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
▼ Additional model properties	
Reference pressure	Set pressure to 0 N/m^2 because the analysis is absolute pressure based.

...

2. For the solid mechanics domain, choose your code to couple:

Abaqus

Option	Action
Code to couple	Select Abaqus
Release	Set to latest or a version supported by MpCCI (see ▷ VI-2 Abaqus ◁).
Input file	For a 2D simulation select input file "ABAQUS/body2d.inp". For a 3D simulation select input file "ABAQUS/body3d.inp". The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

MSC NASTRAN

Option	Action
Code to couple	Select MSC NASTRAN.
Release	Set to latest or a version supported by MpCCI (see ▷ VI-13 MSC NASTRAN ◁).
Input file	For a 2D simulation select input file "MSC.Nastran/body2d.bdf". For a 3D simulation select input file "MSC.Nastran/shell3d.bdf". The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

...

Please make sure to select the model files with matching dimensions.

Proceed to the Algorithm step by pressing Algorithm.

4.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	Set to Implicit.
▼ Solver settings	
Type of solver step size	Set to Constant.
Constant solver step size	Set to 0.1 s.
▼ Coupling algorithm	
Algorithm type	Set to Serial.
Leading code	Set to solid mechanics code.
▼ Coupling duration	
Maximum number of coupling step iterations	Set to 20.
Set total coupling time	Check this option.
Total coupling time	Set to 40 s.

2. For the fluid mechanics code:

FLUENT

Option	Action
▼ Coupling steps	
Number of inner iterations	Set to 25.

OpenFOAM

No code specific options need to be set.

...

3. For your solid mechanics code:

Abaqus

No code specific options need to be set.

MSC NASTRAN

Option	Action
▼ Coupling steps	
Number of inner iterations	Set to 1, as the residuum in MSC NASTRAN after 1 inner iteration is much smaller than the coupling residuum.

...

Press the Regions button at the bottom of the window to get to the Regions step.

4.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷IV-2.6 Regions Step – Defining Coupling Regions and Quantities◁).

1. At first select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example, the coupling region corresponds to the wetted surface of the flexible wall. MpCCI treats this region as a "Face" because it represents the surface of a 2D structure. The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.
   Now choose the components which characterize the wetted surface of the flexible wall at the bottom. Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For fluid mechanics code	**Select coupling component**
FLUENT	▲ bottom
OpenFOAM	
For solid mechanics code	**Select coupling component**
Abaqus	▲ COUPLINGSURF
MSC NASTRAN	▲ surf

3. Select Define Quantity Sets tab.
   The quantity NPosition has already been selected based on the chosen coupling specification. Now choose the force quantity to be exchanged.

For quantity set	Select quantities	Set sender
NPosition<–*Solid mechanics code*	WallForce	Fluid mechanics code

   The resulting name for the quantity set will be NPosition<–*Solid mechanics code* | WallForce<–*Fluid mechanics code*.

4. Add a relaxation operator to quantity WallForce (cf. ▷V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components◁).
   For a stable and accelerated computation, the Quasi-Newton relaxation is used in conjunction with transient iterative coupling. A more detailed description of Quasi-Newton methods is given in ▷V-3.3.3.4 Quasi-Newton Method◁.

   Apply the relaxation operator to the WallForce quantity in quantity set NPosition<–*Solid mechanics code* | WallForce<–*Fluid mechanics code* as follows:

Option	Action
Quantity	Mark the already selected quantity WallForce by clicking on its name.
Operator	Select Relaxation.

   The relaxation operator is a post processor which will be applied to the receiver of the quantity (here the solid mechanics code). Configure the relaxation parameters on the basis of the above description as follows:

Option	Action
Relaxation method	Select Quasi-Newton.
Type of Anderson Mixing method	Select Inverse.
Omega(ω)	Set to 0.1 which is the default.
Number of reused levels	Set to 1 which is the default.

5. Add a convergence check operator to quantity WallForce (cf. ▷ V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).
   To terminate the coupling process a convergence tolerance for the inner iterations can be entered.

   Apply the convergence check operator to the WallForce quantity in quantity set NPosition<–*Solid mechanics code* | WallForce<–*Fluid mechanics code* as follows:

Option	Action
Quantity	Mark the already selected quantity WallForce by clicking on its name.
Operator	Select ConvergenceCheck.

   This is a pre processor and will be applied to the sender of the quantity (here the fluid mechanics code). Configure the convergence parameters as follows:

Option	Action
Tolerance value	Set to $1e-4$ which is appropriate for this simulation.

6. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	Check quantity set
Region_1	NPosition<–*Solid mechanics code* | WallForce<–*Fluid mechanics code*

No changes are required in the Monitors step. You may proceed to the Settings step by pressing Settings.

4.3.5 Settings Step

In the Settings step the plots of the peak (min and max) and mean values for the inner iterations – which are used to check the convergence – have to be activated. To achieve this:

Parameter	Value
Monitor.Peaks	Set selected.

Proceed to the Go step by pressing Go.

4.3.6 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷ IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation ◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your fluid mechanics code:

FLUENT

No code specific options need to be set.

OpenFOAM

Option	Action
Select OpenFOAM solver	Leave the default Auto-Select-by-Case. The setting from the `"controlDict"` file will be used.

...

2. For your solid mechanics code:

Abaqus

No code specific options need to be set.

MSC NASTRAN

No code specific options need to be set.

...

Now you may run the computation.

4.4 Running the Computation

Save the MpCCI project file with name `"cavity.csp"` via the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

FLUENT

The FLUENT GUI is started.

The iterative coupling settings done in the MpCCI GUI will be automatically reported in the Max Iterations/Time Step to fit the maximum number of iterations. For this example maximum 500 iterations per time step are needed – for 25 iterations between the data exchanges and at most 20 coupling steps per time step defined in MpCCI GUI.

In the FLUENT GUI the calculation must be initialized and started as follows:

1. Select (Solve|Solution|Solving)→Run Calculation to open the Run Calculation panel. Check that the time step size is fixed to 0.1 s.
2. Initialize the computation by selecting Solve→Initialization and pressing the Initialize button.
3. Select MpCCI→MpCCI Run FSI. You should select 400 Number of Time Steps to cover a simulation time of at least 40.0 s and press Run to start the simulation.

During the simulation, FLUENT will display the residuals.

OpenFOAM

The total coupling time of 40 seconds and the time step of 0.1 s have been set in the `"controlDict"` file. OpenFOAM will run in batch mode.

...

4.5 Discussion of Results

The results of the different simulations can be compared using the displacement of the central node in the solid mechanics code. To display the motion of the central node in y-direction proceed as follows:

Abaqus

Open the output database `"abaqus_run.odb"` in Abaqus/CAE to plot the displacement of the control point:

Select Result→History Output from the menu bar to open the History Output panel.
Select U2 at Node 41 in NSET CONTROL-NODE and U2 at Node 26938 in NSET CONTROL-NODE for 2D and 3D models, respectively. Then press Plot to plot the displacement in y-direction.

MSC NASTRAN

In SimXpert or PATRAN attach the results file `"mpcci_body2d.xdb"` or `"mpcci_shell3d.xdb"` for 2D and 3D models, respectively. You can create a chart for plotting the displacement in y direction for the node 248 for the 2D and 481 for the 3D model.

...

It should be noted that an explicit transient coupling scheme leads to divergence, as shown in Figure 2. This is due to a known instability problem named the strong added mass effect. However, a robust co-simulation can be performed by an iterative coupling. The complete oscillation of control node A is plotted in Figure 3. For these results, implicit coupling scheme with Quasi-Newton relaxation is used. It should be noted that the different response between two- and three-dimensional models is due to the slight difference in the nature of 2D and 3D simulations, as it is assumed for 2D models there is no gradient in the z-direction.

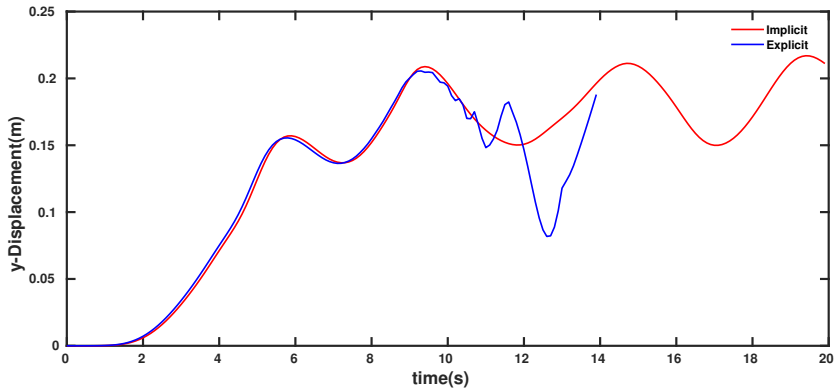


Figure 2: 2D driven cavity: Computed y-displacement of control node A with an explicit (divergent) and an implicit (convergent) transient coupling scheme.

If the implicit coupling is used without any relaxation, the number of necessary coupling step iterations until convergence ($tol = 1e-4$) is roughly 30 per time step on average. The Quasi-Newton relaxation, which is chosen in this tutorial, leads to a computational cost saving by a factor of 7, while the results of both iterative methods coincide. This reduction is attributed to the small number of necessary coupling step iterations (average 5), cf. Figure 4a. The oscillation of the iterations is completely eliminated by the Quasi-Newton relaxation, cf. Figure 4b. A comparison between performance of Quasi-Newton with different Number of reused levels values is tabulated in Table 1, where 4 is the best found value and 0 is the worst one for this configuration. However, it should be noted that the value of Number of reused levels is very problem dependent. These results are obtained from the 2D coupling between FLUENT and Abaqus.

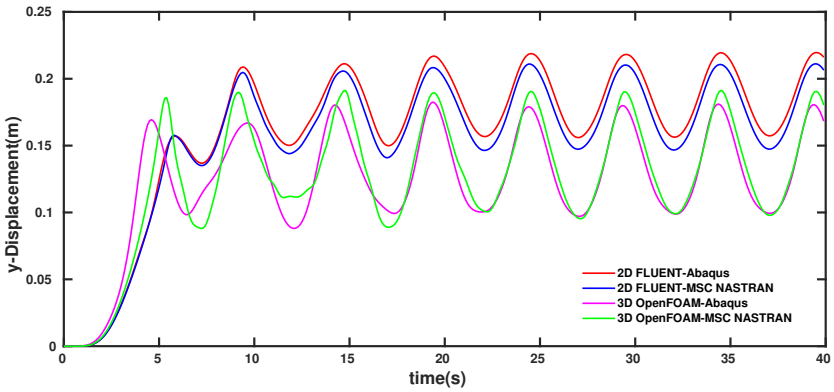
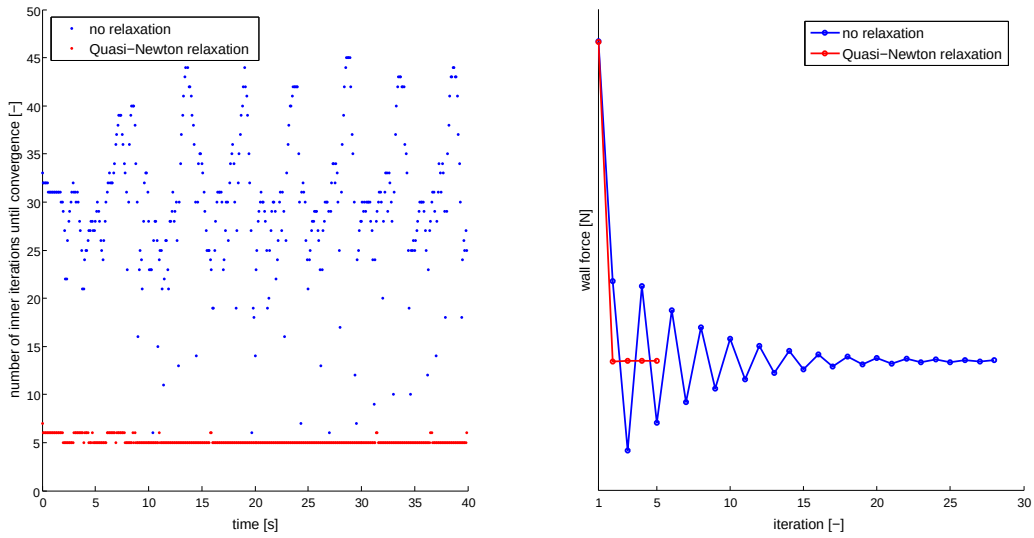


Figure 3: Oscillation of control node A for two- and three-dimensional models.

Number of reused levels	0	1	4	8
Average number of iterations	6.9	5.9	5.4	5.6

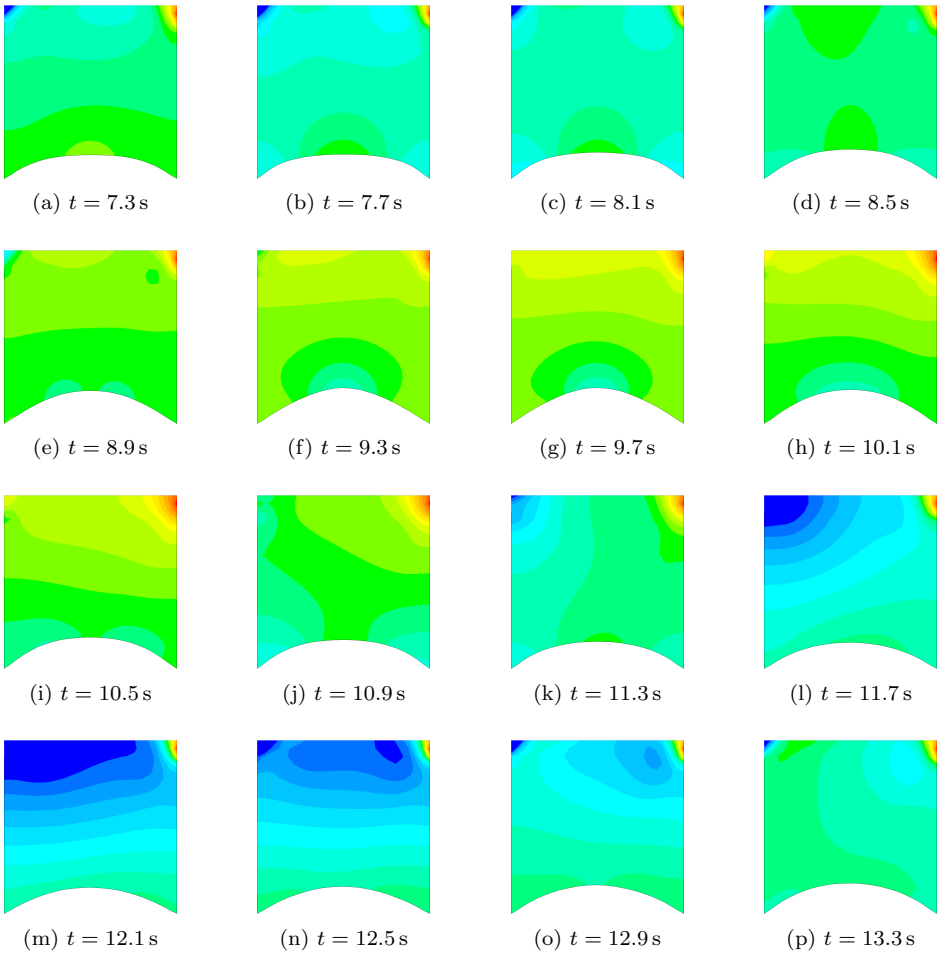
Table 1: Performance of Quasi-Newton with different Number of reused levels for two-dimensional driven cavity.



(a) Number of coupling step iterations per time step (b) Illustrative iteration progression of one time step

Figure 4: 2D driven cavity: Comparison of implicit coupling schemes with respect to the number of necessary coupling step iterations to converge the time steps.

The oscillation of the flexible wall at the bottom of the cavity is shown in Figure 5 for the two-dimensional model.



(a) $t = 7.3\,\mathrm{s}$ (b) $t = 7.7\,\mathrm{s}$ (c) $t = 8.1\,\mathrm{s}$ (d) $t = 8.5\,\mathrm{s}$

(e) $t = 8.9\,\mathrm{s}$ (f) $t = 9.3\,\mathrm{s}$ (g) $t = 9.7\,\mathrm{s}$ (h) $t = 10.1\,\mathrm{s}$

(i) $t = 10.5\,\mathrm{s}$ (j) $t = 10.9\,\mathrm{s}$ (k) $t = 11.3\,\mathrm{s}$ (l) $t = 11.7\,\mathrm{s}$

(m) $t = 12.1\,\mathrm{s}$ (n) $t = 12.5\,\mathrm{s}$ (o) $t = 12.9\,\mathrm{s}$ (p) $t = 13.3\,\mathrm{s}$

Figure 5: 2D driven cavity: Simulation results.

4.5.1 Coupling with Adaptive Time Step

In order to reduce the taken time for the whole simulation, one may increase the time step. However, this might lead to instability in the solvers as well as the coupling. This problem can be solved by consideration of solver limits for choosing an appropriate time step, e.g. CFL condition. MpCCI is capable of performing co-simulations with time step negotiation between the codes (cf. ▷ V-3.4.5.2 Coupling with Exchange of Time Step Size ◁).

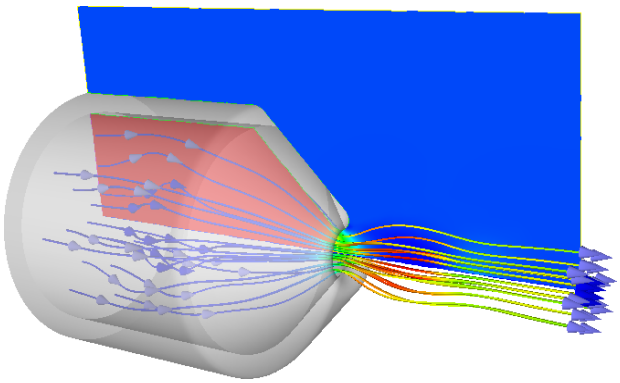
In Algorithm step, adaptive time step can be enabled from the Solver settings panel of Common Basics. In this panel, Type of solver step size should be set to Negotiation with 0.1 s for both Initial solver step size and Minimum solver step size. This reduces the number of performed time steps, while the final results still match.

In order to perform coupling with time step negotiation, the models must be able to vary the time step size.

MpCCI does not support adaptive time step for FLUENT and MSC NASTRAN.

5 Pipe Nozzle

5.1 Problem Description



Topics of this Tutorial

- Fluid-Structure Interaction (cf. ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁)
- Axisymmetric model
- Steady state one-way force mapping
- Use of UDF-functions in FLUENT
- Use of field functions in STAR-CCM+
- Models with different unit systems (MSC NASTRAN)

Simulation Codes

- Fluid mechanics: FLUENT, STAR-CCM+
- Solid mechanics: ANSYS, MSC NASTRAN

5.2 Model Preparation

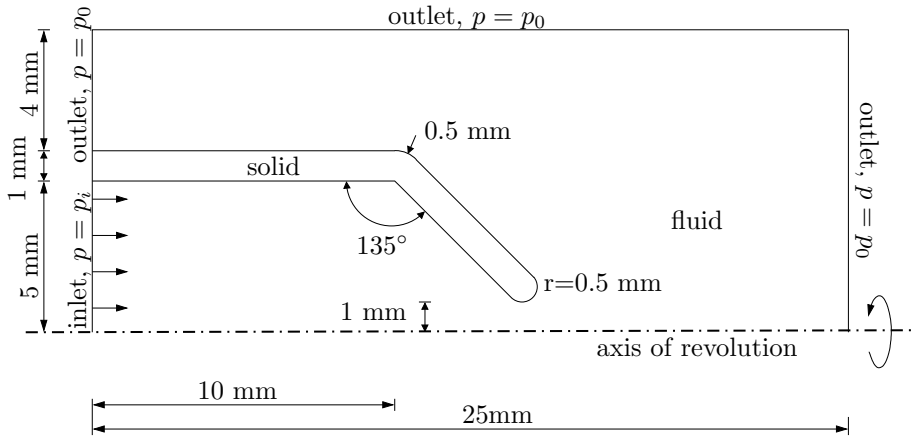


Figure 1: Pipe Nozzle: Section sketch of the axisymmetric model.

The model is axisymmetric, thus only a section of the model is created and meshed. The axis of revolution is different for different simulation codes. MpCCI uses the vertical y-axis. For simulation codes which use different axes, the data is converted in the code adapter.

The solid material is a simple linear elastic material with elastic modulus $E = 2000\,\text{MPa}$ and $\nu = 0.3$. The fluid is modeled as an ideal gas with properties of air.

The fluid is streaming into the nozzle at the pressure inlet as shown in Figure 1. During the simulation the pressure is slowly increased with a user-defined function up to a value of $p_i = 0.04\,\text{MPa}$.

The simulation is a steady state simulation, the surface forces are only transferred once from the fluid model to the solid model, where they are applied as boundary conditions to compute the stress distribution.

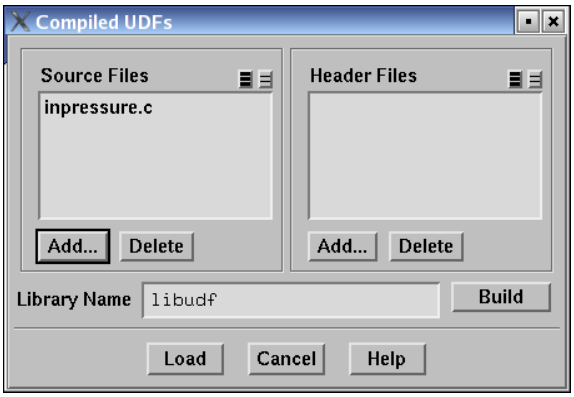
5.2.1 Fluid Model

FLUENT

FLUENT uses the horizontal x-axis as axis of revolution, thus the model is created as shown in Figure 1.

A user-defined function is used to slowly increase the inlet pressure in order to ensure convergence of the FLUENT solver.

Before starting the computation, the `"libudf"` library for FLUENT must be built:



- Change to the `"FLUENT"` directory, start fluent 2ddp and read the case-file `"nozzle.cas"`. FLUENT will print an error message `open_udf_library: No such file or directory`, which indicates that the UDF library is still missing. The error message should not appear if the library was built and is present in the corresponding `"libudf"` directory.
- Select Define→User-Defined→Functions→Compiled... to open the Compiled UDFs panel shown on the left.
- Press the left Add... button and select the file `"inpressure.c"`.
- Press Build to compile the `"libudf"` library.
- Finally exit the panel with Load to load the library.
- Quit FLUENT, you do not need to save changes.

STAR-CCM+

STAR-CCM+ uses the horizontal x-axis as axis of revolution, thus the model is created as shown in Figure 1.

A user field function is used to slowly increase the inlet pressure in order to ensure convergence of the STAR-CCM+ solver.

Before starting the computation, the user field function p_inlet has been created. This function is hooked to the boundary fluid:inlet as Total Pressure.

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5.2.2 Solid Model

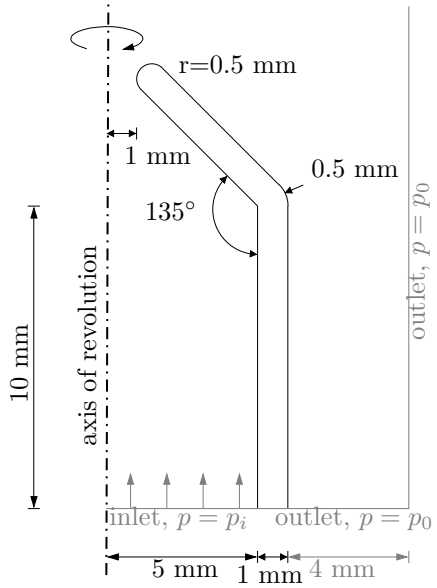


Figure 2: Pipe Nozzle: Section sketch of the axisymmetric model.

ANSYS

ANSYS uses the vertical y-axis as axis of revolution in axisymmetric models. Therefore the geometry must be flipped by swapping x- and y-coordinates, which yields the configuration shown in Figure 2. In ANSYS, PLANE183 elements are used.

MSC NASTRAN

MSC NASTRAN uses the vertical y-axis as axis of revolution in axisymmetric models. Therefore the geometry must be flipped by swapping x- and y-coordinates, which yields the configuration shown in Figure 2. In MSC NASTRAN, CTRIA3X elements are used.

...

Only one iteration step is carried out.

5.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

Before starting the coupled simulation, ensure that you have built the udf library for FLUENT as described above.

5.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.

2. Select the FSI coupling specification One-way force mapping – gauge pressure based because this problem is a one-way fluid-structure interaction where the force is derived from gauge pressure including shear force effects (cf. ▷ V-4.5.2 Category: Fluid-Structure Interaction (FSI) ◁).

5.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the fluid mechanics domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is axisymmetric, i. e. a 2d model. Thus select the FLUENT version 2ddp.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/nozzle.cas"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

STAR-CCM+

Option	Action
Code to couple	Select STAR-CCM+.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-16 STAR-CCM+ ◁).
Simulation file	Select the simulation file `"STAR-CCM+/nozzle.sim"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

2. For the solid mechanics domain, choose your code to couple:

ANSYS

Option	Action
Code to couple	Select ANSYS.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-4 ANSYS ◁).
Product	You can select any ANSYS product which can be used for structural analysis, e. g. ansys.
Database file	Select database file `"ANSYS/nozzle.db"`. The file will be scanned immediately.
Solution type	Undefined is displayed as a result of the scan process.
Unit system	Select the SI unit system, because the ANSYS model file was created using these units.

MSC NASTRAN

Option	Action
Code to couple	Select MSC NASTRAN.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-13 MSC NASTRAN ◁).
Input file	Select input file `"MSC.Nastran/nozzle.bdf"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.
Unit system	Select the mm-t-s unit system, because the MSC NASTRAN model was created using these units.

...

Proceed to the Algorithm step by pressing Algorithm.

5.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	This option is automatically set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Parallel.
Use initialization	Check this option.
Initializing code	Set to Fluid mechanics code.
▼ Coupling duration	
Set maximum number of coupling steps	Check this option.
Maximum number of coupling steps	Set to 1.

2. For the fluid mechanics code:

FLUENT

No code specific options need to be set.

STAR-CCM+

Option	Action
▼ Runtime control	
Define coupling start	Set to Specify iteration to enable a pre-calculation.
Iteration number for coupling start	Set to 400 to activate a pre-calculation of 400 iterations.

...

3. For the solid mechanics code:

ANSYS

Option	Action
▼ Analysis	
Analysis type	Select Steady state.

MSC NASTRAN

No code specific options need to be set.

...

Press the Regions button at the bottom of the window to get to the Regions step.

5.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷IV-2.6 Regions Step – Defining Coupling Regions and Quantities◁).

1. First, select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example MpCCI treats the coupling region as a "Face" because it represents a 2D structure. The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.
   Now choose the components which characterize the coupling region. Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For fluid mechanics code	**Select coupling component**
FLUENT	▲ pipesurface
STAR-CCM+	
For solid mechanics code	**Select coupling component**
ANSYS	▲ PIPESURFACE
MSC NASTRAN	▲ nozzle

3. Select Define Quantity Sets tab.
   The quantity RelWallForce has already been selected based on the chosen coupling specification. No further quantities will be exchanged.
   The resulting name for the quantity set will be RelWallForce<–*Fluid mechanics code*.
4. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	Check quantity set
Region_1	RelWallForce<–*Fluid mechanics code*

No changes are required in the Monitors step. You may proceed to the Settings step by pressing Settings.

5.3.5 Settings Step

The stress results in the solid mechanics code are of interest in our example. These are looked up in the solid mechanics codes. They cannot be visualized in the MpCCI Monitor which only could display the forces. So disable the MpCCI Monitor by setting the following parameter:

Parameter	Value
Monitor.Enable	Set deselected.

No further changes are required in the Settings step. Proceed to the Go step by pressing Go.

5.3.6 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your fluid mechanics code:

FLUENT

Option	Action
Auto hook functions	Deselect to keep FLUENT from sending data in each iteration.

STAR-CCM+

Option	Action
Run in batch	Check this option.
Auto start with the default template macro	Check this option.
License options	Set according to your license type (cf. ▷VI-16.2.5 Go Step◁).

...

2. For your solid mechanics code:

ANSYS

Option	Action
Gui option	Keep -b to start ANSYS in batch mode.
APDL input script	Select the input script `"ANSYS/nozzle.ans"`.

MSC NASTRAN

No code specific options need to be set.

...

Now you may run the computation.

5.4 Running the Computation

Save the MpCCI project file with name "nozzle.csp" over the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

FLUENT

The FLUENT GUI is started, in which the calculation must be initialized and started as follows:

1. In the FLUENT window, select (Solve|Solution|Solving)→Initialization and press the Initialize button to initialize the FLUENT solution.
2. Open the FLUENT Run Calculation panel by selecting (Solve|Solution|Solving)→Run Calculation.... Set the number of iterations to 400 and press the Calculate button. You should see a plot of the FLUENT results during the iterations.
3. Open the MpCCI panel which you find under FLUENT menubar MpCCI→MpCCI Control....
4. In the MpCCI panel, press the Initialize button in the On Demand Init and Exit panel, which will start the neighborhood search in both codes – you should notice according output in the code windows.
5. To send the surface forces from FLUENT to the partner code, press the Send button once. The partner code will now compute the stresses and quit. Close any appearing message windows.
6. Press the Finalize button in the MpCCI panel of FLUENT, which disconnects FLUENT from MpCCI.
7. At last exit FLUENT.

STAR-CCM+

The java macro file "mpcci_runjob_steady.java" will carry the following steps automatically:

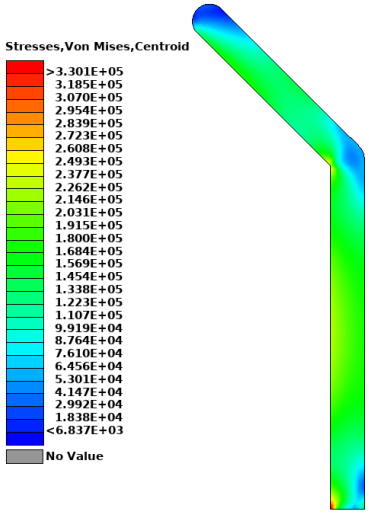
- Initializing the solution.
- Run 400 iterations.
- Connecting STAR-CCM+ to MpCCI server.
- Perform the data exchange, which is only a SEND operation.
- Run 1 iteration.
- Finalize the coupled simulation.
- Results are saved in "nozzle@00401.sim".

...

5.5 Discussion of Results

Have a look at the stress results in the solid mechanics code and compare them to those shown below.

Stresses in the picture are in Pa like in ANSYS. In MSC NASTRAN due to the unit system, stresses are in MPa.



6 Blood Vessel

6.1 Problem Description

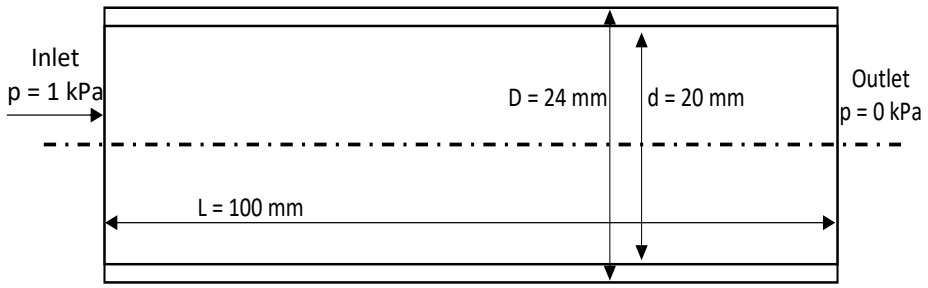


Figure 1: Blood vessel: Geometry and boundary conditions

Topics of this Tutorial

- Fluid-Structure Interaction (cf. ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁)
- Smart configuration of MpCCI (cf. ▷ V-3.5 Smart Configuration ◁)
- 3D-model

Simulation Codes

- Fluid mechanics: OpenFOAM
- Solid mechanics: Abaqus

Description

This tutorial covers the propagation of a pressure pulse through an incompressible fluid medium in a straight flexible blood vessel, which is taken from Ha et al. [2017]. The pressure propagation of the fluid also leads to propagation in the cross-sectional area of the blood vessel.

6.2 Model Preparation

The simulation couples a solid mechanics model with a fluid mechanics model. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the subdirectories from "<*MpCCI_home*>`/tutorial/BloodVessel`" which correspond to the simulation codes you want to use.

6.2.1 Fluid Model

The density of the material is $\varrho = 1000\,\mathrm{kg/m^3}$ with viscosity of $\mu = 0.004\,\mathrm{N.s.m^{-2}}$.

A hexahedral mesh with 40095 nodes is used for the fluid mechanics simulation.

6.2.2 Solid Model

The material is linear elastic with density $\varrho = 1000\,\mathrm{kg/m^3}$, elastic modulus $E = 1.0 \times 10^6\,\mathrm{Pa}$ and Poisson's ratio $\nu = 0.3$.

A hexahedral mesh with 16000 nodes is used for discretization of the solid mechanics domain.

6.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

6.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.

2. Select the FSI coupling specification Fluid-structure interaction with smart configuration because this problem is a fluid-structure interaction and we want to use the smart configuration of MpCCI (cf. ▷ V-4.5.2 Category: Fluid-Structure Interaction (FSI) ◁, ▷ V-3.5 Smart Configuration ◁).

6.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the fluid mechanics domain, choose your code to couple:

OpenFOAM

Option	Action
Code to couple	Select OpenFOAM.
Option	Select the OpenFOAM option Opt or Debug.
Precision	Select the OpenFOAM precision: DP for double or SP for single precision.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-14 OpenFOAM ◁).
Case directory	Select the case directory `"OpenFOAM/<version>"` fitting your OpenFOAM version (e. g. `"OpenFOAM/v1806-v2306"` for use with OpenFOAM v1806 to v2306). The files will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
▼ Additional model properties	
Define a reference pressure	Set pressure to 0 N/m^2 because the analysis is absolute pressure based.
Define a reference density	Set density to 1000 kg/m^3 according to the fluid properties from ▷ 6.2.1 Fluid Model ◁.

. . .

2. For the solid mechanics domain, choose your code to couple:

Abaqus

Option	Action
Code to couple	Select Abaqus.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-2 Abaqus ◁).
Input file	Select input file `"Abaqus/3dTube.inp"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

. . .

Proceed to the Algorithm step by pressing Algorithm.

Leaving the Models step will initiate the smart configuration process. Therefore a project file needs to be assigned and you will be asked to save the project. Save the MpCCI project file with name `"blood_vessel.csp"`.

After MpCCI configuration (cf. ▷ V-3.5 Smart Configuration ◁) is finished, the result is displayed and if everything is ok, the Algorithm step is entered.

6.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

Since we used the smart configuration, where the coupling algorithm is already defined, only the duration of the coupling and maybe some code specific settings have to be set.

The settings should be as follows. If no action is mentioned, keep the default resp. already defined option.

1. For the Common Basics panel:

Option	Action
▼ Coupling duration	
Maximum number of coupling step iterations	Set to 20.

2. For your fluid mechanics code:

OpenFOAM

No code specific options need to be set.

...

3. For your solid mechanics code:

Abaqus

No code specific options need to be set.

...

Press the Regions button at the bottom of the window to get to the Regions step.

6.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▹IV-2.6 Regions Step – Defining Coupling Regions and Quantities◃).

1. At first select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example, the coupling region corresponds to the wetted surface of the flexible structure. MpCCI treats this region as a "Face" because it represents the surface of a 2D structure. The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.
   Now choose the components which characterize the wetted surface of the flexible structure. Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For fluid mechanics code	**Select coupling component**
OpenFOAM	▲ WALL
For solid mechanics code	**Select coupling component**
Abaqus	▲ ASSEMBLY_SURF_INTERNAL_WALL

3. Select Define Quantity Sets tab.
   The quantities have already been selected by the smart configuration of MpCCI. No further quantities will be exchanged.
   The resulting name for the quantity set depends on the selected quantities and will be NPosition<–*Solid mechanics code* | *force/pressure*<–*Fluid mechanics code*.

4. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	Check quantity set
Region_1	NPosition<–*Solid mechanics code* | *force/pressure*<–*Fluid mechanics code*

No changes are required in the Monitors and Settings steps. You may proceed to the Go step by pressing Go.

6.3.5 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation◁). However, in the tutorial no changes are necessary. Now you may run the computation.

6.4 Running the Computation

Press the Start button in the Go step. The project will be saved automatically (a project has already been assigned for the smart configuration) and the simulation codes will be started.

6.5 Discussion of Results

The sixteen control nodes are located at the top of the tube. The displacement over time in the y-direction, which corresponds to the radial displacement, is written to an output file. The radial displacement of the blood vessel is visualized in Figure 2. Each curve demonstrates the radial displacement of the blood vessel at a certain time. As shown, the cross-sectional area of the blood vessel increases due to the higher pressure and propagates forward, as the pressure propagates.

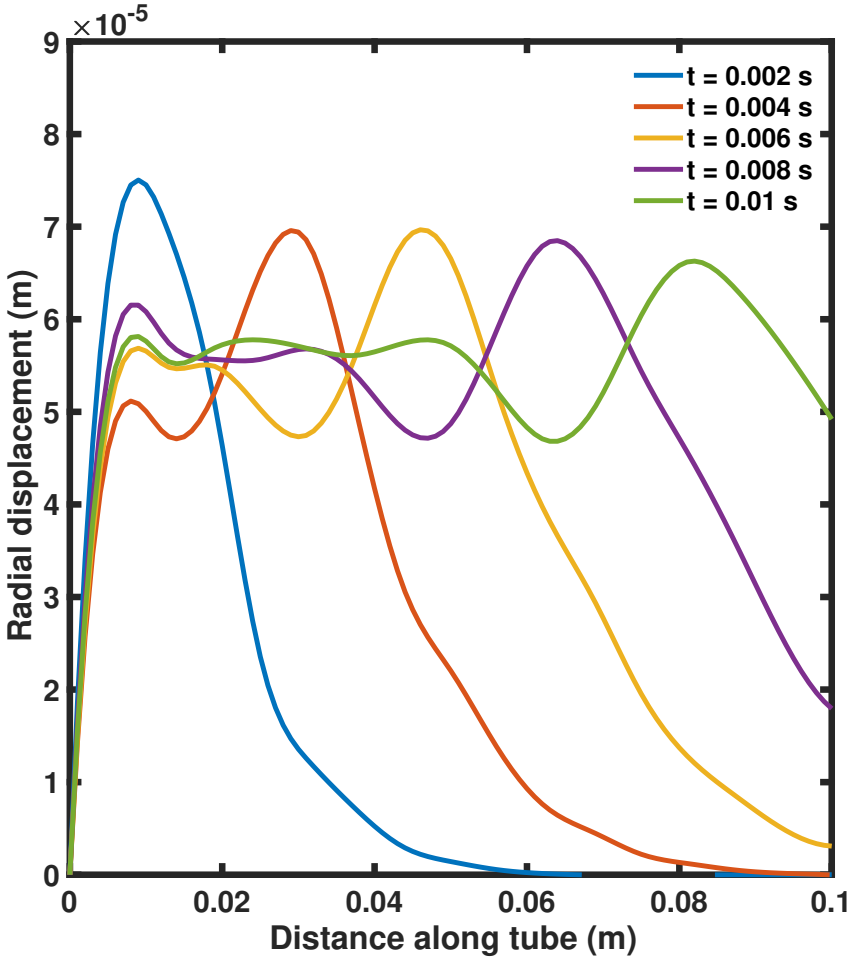


Figure 2: Blood Vessel: Radial displacement of the blood vessel at different times.

7 Periodic Rotating Fan Model

7.1 Problem Description

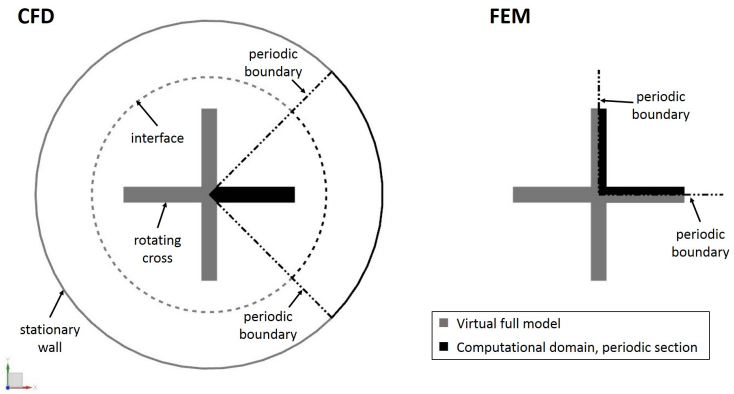


Figure 1: Rotating cross as periodic model

Topics of this Tutorial

- Coupling of periodic models
- Ramping
- Fluid-Structure Interaction (cf. ▷ V-3.1.2.1 Fluid-Structure Interaction (FSI) ◁) for steady state analysis
- 2D-model

Simulation Codes

- Fluid mechanics: FLUENT
- Solid mechanics: Abaqus

Description

In this tutorial we show the concept of periodic models in MpCCI through the example of a steady fluid structure interaction of a two dimensional rotating fan model in a circular channel. Here the periodic section in the CFD computation is geometrically different to the periodic section in the structural mechanics simulation, cf. Figure 1.

The example demonstrates how to use periodic models in an MpCCI coupling. The user can define different section shapes of the coupled models, even use a full model. The only limitation is that the virtual full models coincide (without respect to units and slight geometrical differences), cf. Figure 2. This feature is available for all codes supported by MpCCI.

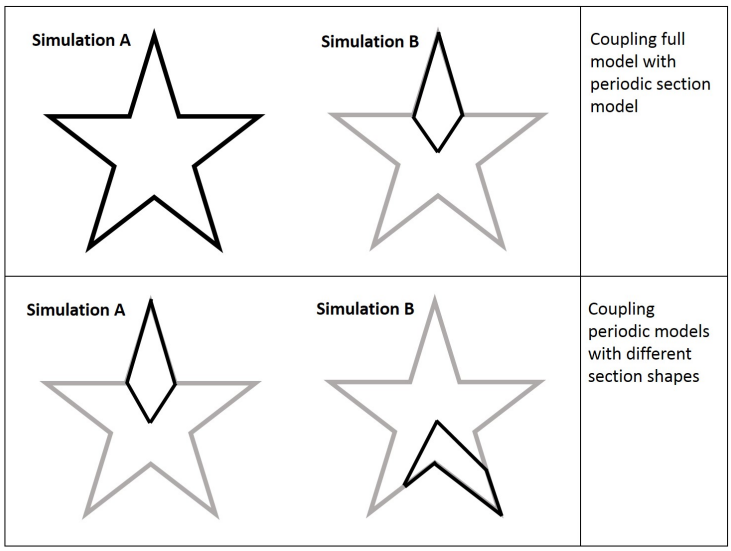


Figure 2: Geometrical coupling schemes for periodic models

7.2 Model Preparation

This simulation couples a structural mechanics model with a fluid mechanics model, both considered as 2D. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the subdirectories from "<*MpCCI_home*>/tutorial/Periodic".

The following model files provide enough simulation period in order to cover the configured coupled simulation. In that case the Set maximum number of coupling steps option is not needed to limit the coupling period as it will end at the end of the total simulation period set in the model files or provided in the user interface.

7.2.1 Fluid Model

The fluid domain is a periodic section of a 2D circular channel, where the outer circle is a stationary wall (radius 2 m). In the center lies a 1/4 cross which rotates (as a moving reference frame) with speed 100 rad/s around the z-axis lying in zero. The rotating and stationary fluid parts are connected using an interface (at radius 1.2 m), see Figure 3.

The fluid is considered as an ideal gas with a viscosity of $\mu = 1.7894 \cdot 10^{-5} \frac{\text{kg}}{\text{m s}}$.
A steady state solution is to be computed.

FLUENT

The mesh was created by ANSA and consists of first order tria elements. The surface of the flexible structure is defined as a separate boundary named "turbo".
The periodic boundary conditions were defined at the section's boundaries. Since the mesh will deform during the coupling "Dynamic Mesh" is activated where the periodic boundaries are kept stationary. FLUENT total number of iterations will be set to 5000.

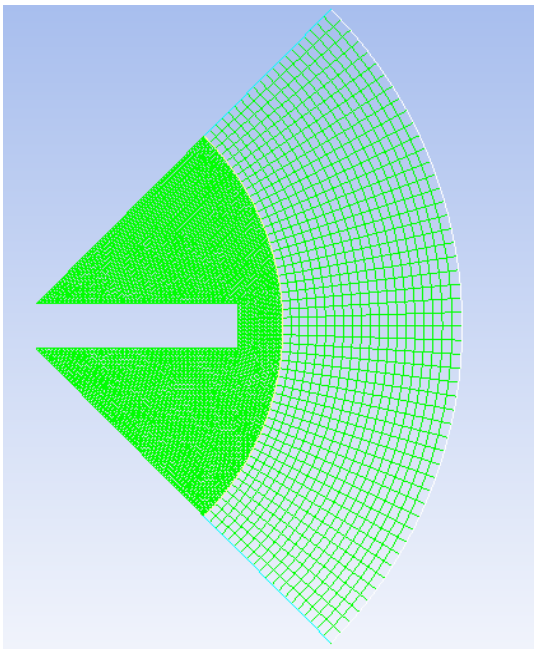


Figure 3: Periodic fluid mesh

7.2.2 Solid Model

The solid part corresponds to a quarter of the cross, where the position of the periodic boundaries are selected in a different way than those chosen in the fluid model, see Figure 4. The thickness of the cross arms is 0.1 m, their length is 0.5 m. The model is fixed in the center of the cross and a centrifugal load of 100 rad/s is applied.
Here an artificial linear elastic material has been used with density $\rho = 78\,\mathrm{kg/m^3}$, elastic modulus 0.5 MPa and Poisson's ratio $\nu = 0.3$.

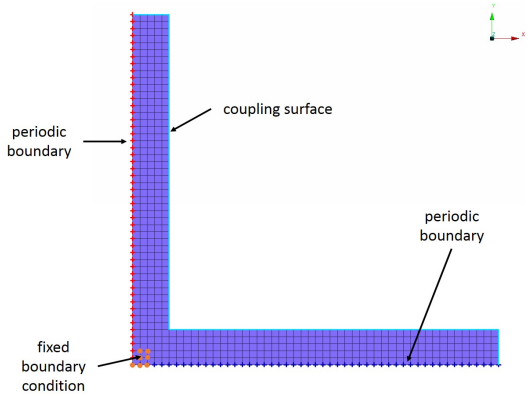


Figure 4: Periodic solid mesh

Abaqus

The mesh was created by ANSA and consists of first order quadrilateral elements (CPE4 element type). The surface of the flexible structure is defined as a 2D-SURFACE named "blade-wall".
The periodic boundary conditions were defined at the section's boundaries using a cyclic symmetry TIE contact.
The total simulation time has been set to 0.05 s.

7.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

7.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.

2. Select the FSI coupling specification Gauge Pressure Based Fluid-Structure Interaction because this problem is a fluid-structure interaction with consideration of a reference pressure (cf. ▷ V-4.5.2 Category: Fluid-Structure Interaction (FSI) ◁).

7.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the fluid mechanics domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is two-dimensional, thus select the FLUENT version 2ddp.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/fan_period1Arm.cas"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

2. For the solid mechanics domain, choose your code to couple:

Abaqus

Option	Action
Code to couple	Select Abaqus.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-2 Abaqus ◁).
Input file	Select input file `"ABAQUS/fan_period2halfArms.inp"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

...

Proceed to the Algorithm step by pressing Algorithm.

7.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	This option is automatically set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Serial.
Leading code	Set to solid mechanics code.

2. For the fluid mechanics code:

FLUENT

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 100 for number of steps without coupling.

...

3. For your solid mechanics code:

Abaqus

Option	Action
▼ Coupling steps	
Constant coupling step size	Set to 0.001 for one increment size for the steady state analysis.

...

Press the Regions button at the bottom of the window to get to the Regions step.

7.3.4 Regions Step

In the Regions step edit the components to define the periodic information, build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷IV-2.6 Regions Step – Defining Coupling Regions and Quantities◁).

1. Select the Mesh tab to get access to the mesh based element components.
2. Select the Edit Components tab in order to define the periodicity of the components (cf. ▷V-4.8.2.3 Periodic Components◁). A default periodicity object "Periodicity_1" is present on the right hand side. Rename it as "quarter" by right clicking on it. Configure the periodicity as follows:

Option	**Action**
Number of periodicity	Set to 4 which is the number of periodic passages which build the virtual full model.
Define the cyclic symmetry axis by the two following specifications.	
Rotation-axis origin	Set to X=0., Y=0., Z=0..
Rotation-axis direction	Set to X=0., Y=0., Z=1..

Now the periodicity "quarter" can be assigned to the components on the left. In this example the coupling region corresponds to the surface of the flexible 2D structure. MpCCI treats this 1D region as a "Face". The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.
Select the periodic components and apply the periodicity.

For fluid mechanics code	**Select component**
FLUENT	▲ turbo

For solid mechanics code	**Select component**
Abaqus	▲ BLADE-WALL

For selected components	
Option	**Action**
Apply periodicity to selected components	Press the button to apply the selected periodicity quarter to the selected components.

Note the change of the symbol in front of the selected component names to .

3. Now select Build Regions tab and here the Setup tab.
Now choose the components which characterize the coupling region. Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For fluid mechanics code	**Select coupling component**
FLUENT	turbo

For solid mechanics code	**Select coupling component**
Abaqus	BLADE-WALL

4. Select Define Quantity Sets tab.
The quantity NPosition has already been selected based on the chosen coupling specification. Now choose the force quantity to be exchanged.

For quantity set	Select quantities	Set sender
NPosition<–*Solid mechanics code*	RelWallForce	Fluid mechanics code

The resulting name for the quantity set will be NPosition<–*Solid mechanics code* | RelWallForce<–*Fluid mechanics code*.

5. Add the Ramping operator to the quantity NPosition (cf. ▷ V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁) to get an accelerated convergence.
Thus mark NPosition by clicking on its name and configuring the listed operator as follows:

Quantity	Operator	Operator option	Operator action
NPosition	Select Relaxation.	Relaxation method	Select Ramping.
		Initial ramp value	Set to 0.1 (default).
		Ramp delta	Set to 0.1 (default).

The relaxation operator is a post processor which will be applied to the receiver of the quantity.

6. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	Check quantity set
Region_1	NPosition<–*Solid mechanics code* | RelWallForce<–*Fluid mechanics code*

No changes are required in the Monitors step. You may proceed to the Settings step by pressing Settings.

7.3.5 Settings Step

The monitor is configured to replicate the periodic coupled components such that a full model can be visualized with its quantities. Moreover the full model is saved in the ccvx file to be reviewed in MpCCI Visualizer.

Parameter	Value
Monitor.Periodic	Set selected to display the replicated periodic parts and quantities.
Output.Tracefile.Writers.CCVX.Periodic	Set selected to include the replicated periodic parts and quantities.

Proceed to the Go step by pressing Go.

7.3.6 Go Step

No changes are required in the Go step. Now you may run the computation.

7.4 Running the Computation

Save the MpCCI project file with name `"periodic.csp"` over the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

FLUENT

The FLUENT GUI is started.

During the simulation, FLUENT will display the residual, the pressure and the velocity distribution in the fluid domain. You can also see the deformation of the flexible structure. Here you need to change the window layout to three windows (as shown in Figure 7).

The computation needs to be initialized and started as follows:

1. Select Solution→Initialization to open the initialization panel. Press the button Initialize.
2. Select MpCCI→MpCCI Run FSI. Set the Number of Iterations to 5000 and press Run to start the simulation. With 100 subiterations there will be 50 couplings.

...

7.5 Discussion of Results

Since the parameter Periodic was enabled for the monitor in Settings step, the periodic parts are shown with their virtual replicates, cf. Figure 5.

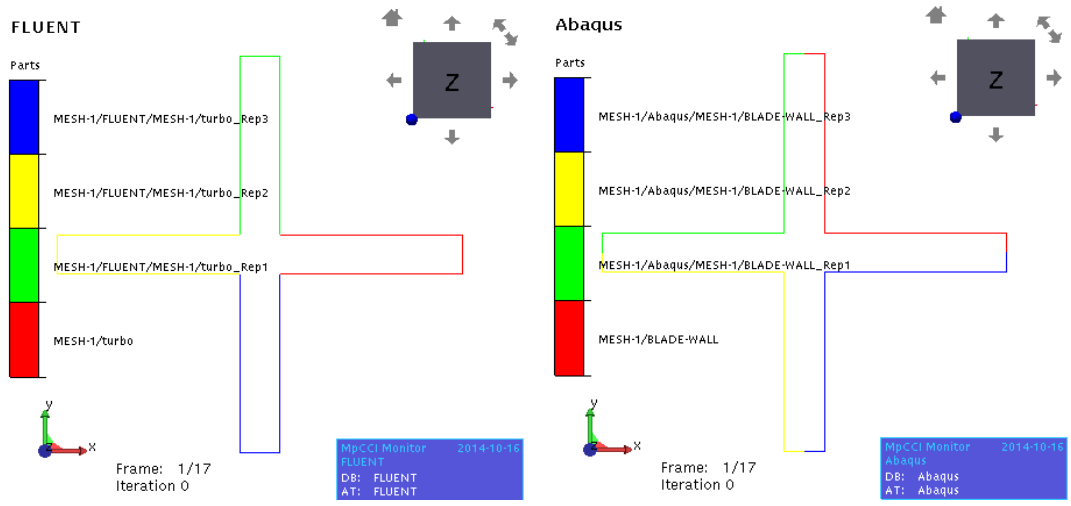


Figure 5: Visualizing the virtual full coupling surfaces in monitor

In the following a comparison of the results of this coupling is presented and is compared to the corresponding coupling of the full models. The full meshes were created out of the periodic meshes, i. e. the number of nodes and elements is four times higher.

The coupling of the periodic models took, as expected, four times less computation time. The relative difference of the computed displacement of a node at the outer corner of the cross compared to the mean displacement of the corresponding nodes of the full model is 0.61 %. The displacement results of both periodic and full models are shown in Figure 6.

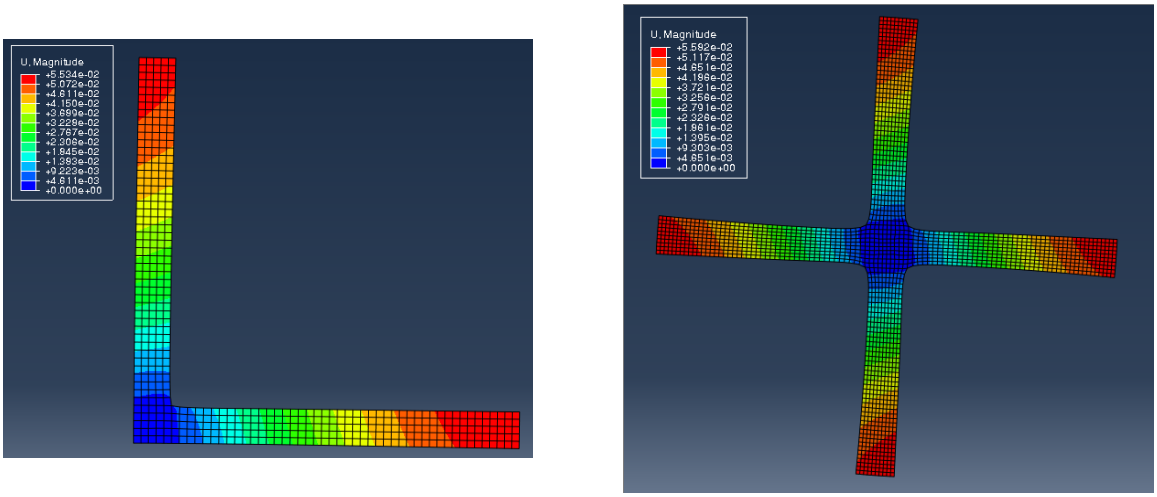


Figure 6: Comparison of coupled deformations on periodic and full Abaqus models

Figure 7 and Figure 8 show the pressure and velocity magnitude in the fluid domain, computed on the periodic and the full coupled model. The differences in the results of the two approaches is founded in the not completely periodic behaviour of the solver on the full computational domain.

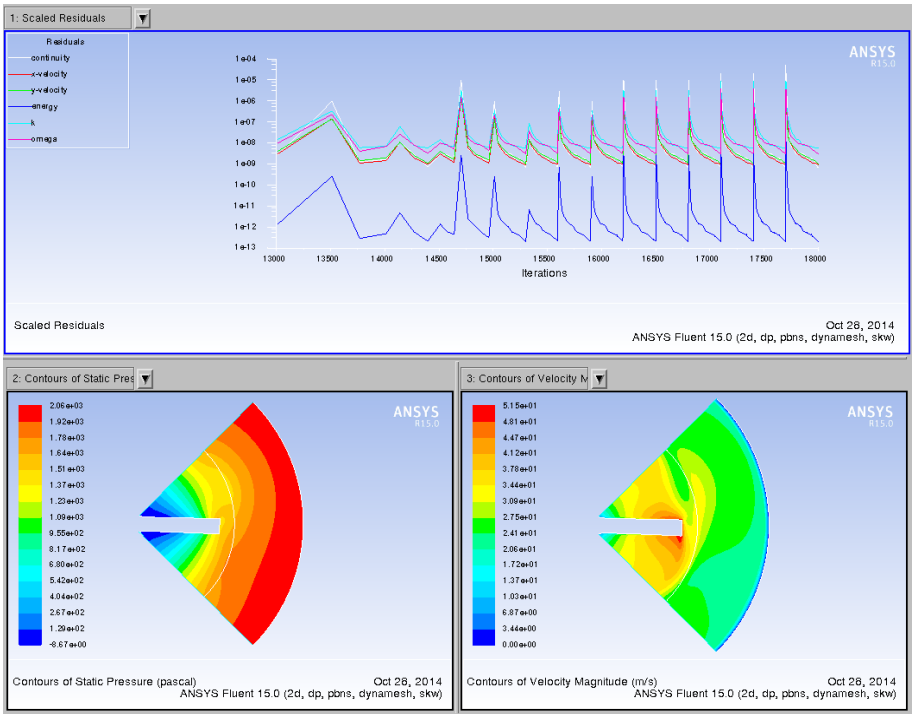


Figure 7: Pressure and velocity as coupling results on periodic FLUENT model with convergence history

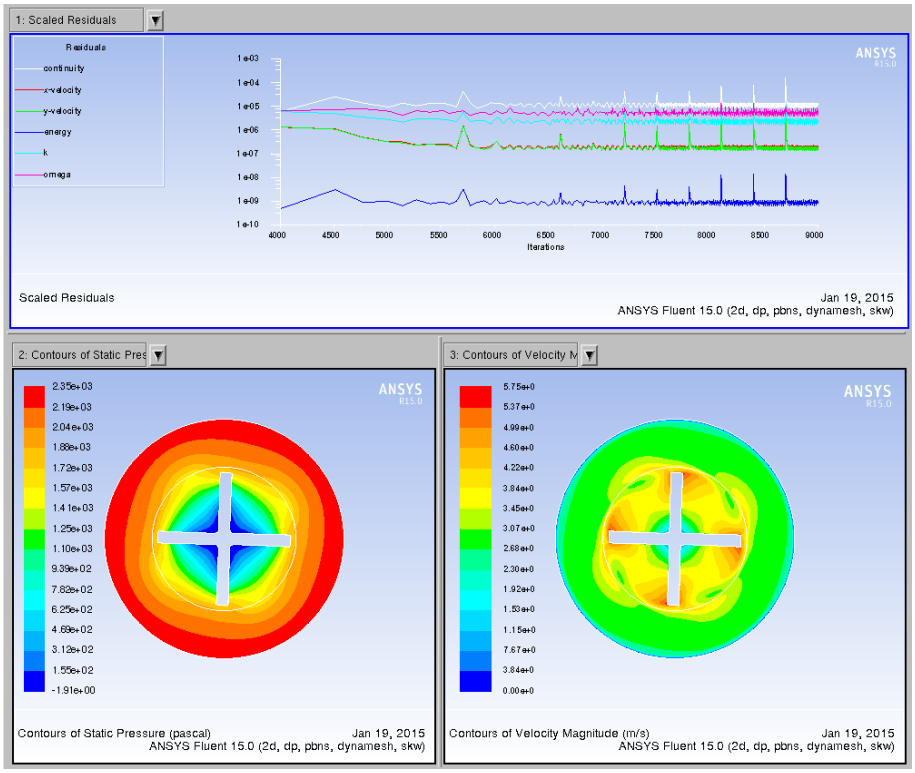


Figure 8: Pressure and velocity as coupling results on full FLUENT model with convergence history

Use the following files for the evaluation of the results:

MpCCI

The MpCCI tracefile `"mpccirun-0000.ccvx"` from the tracefile folder `"mpccirun_<TIMESTAMP>_ccvx"` can be opened by the command `mpcci visualize` which one can trace the exchange process of the coupled surface.

Abaqus

The Abaqus result file name is equal to the defined Abaqus job name parameter followed by the suffix `".odb"`, e.g. `"abaqus_run.odb"`.

FLUENT

The FLUENT result file is `"fan_period1Arm.dat"` after saving the data in FLUENT.

8 Exhaust Manifold

8.1 Problem Description

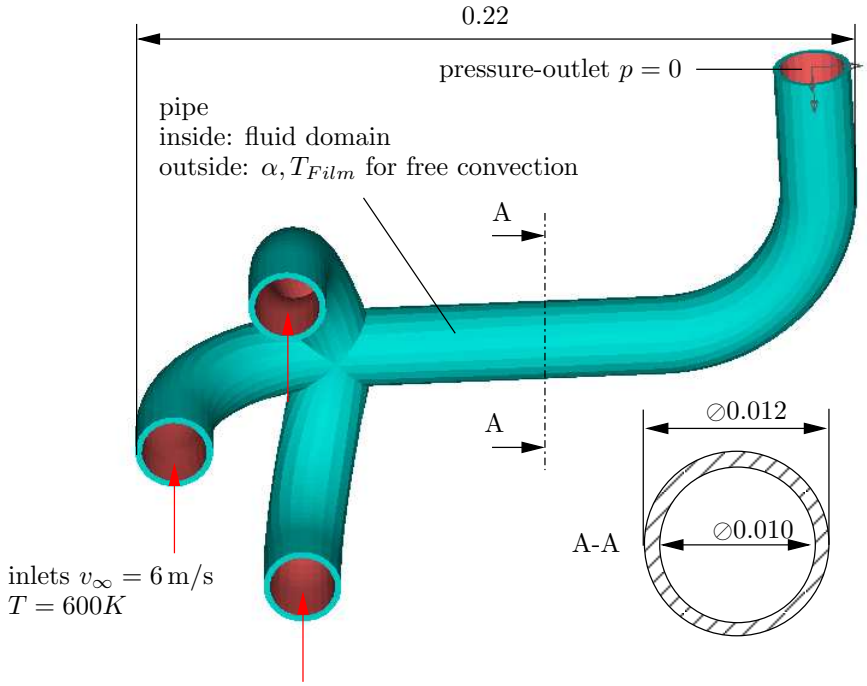


Figure 1: Manifold: Geometry [m] and boundary conditions

Topics of this Tutorial

- Thermal coupling fluid and solid (cf. ▷ V-3.1.2.2 Thermal Coupling ◁)
- Steady state with pre-computed flow field
- Incompressible fluid
- Fluid solver subcycling (cf. ▷ V-3.4.3 Coupling with Subcycling ◁)
- 3D-model

Simulation Codes

- Solid heat transfer: Abaqus, ANSYS , Marc
- Fluid heat transfer: FLUENT, OpenFOAM, STAR-CCM+

8.2 Model Preparation

The simulation couples a solid heat transfer model with a fluid heat transfer model. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory `"ExhaustManifold"` and copy the subdirectories from `"<`*MpCCI_home*`>/tutorial/ExhaustManifold"` which correspond to the simulation codes you want to use.

8.2.1 Solid Model

The solid part of the manifold has the following properties (Figure 2):

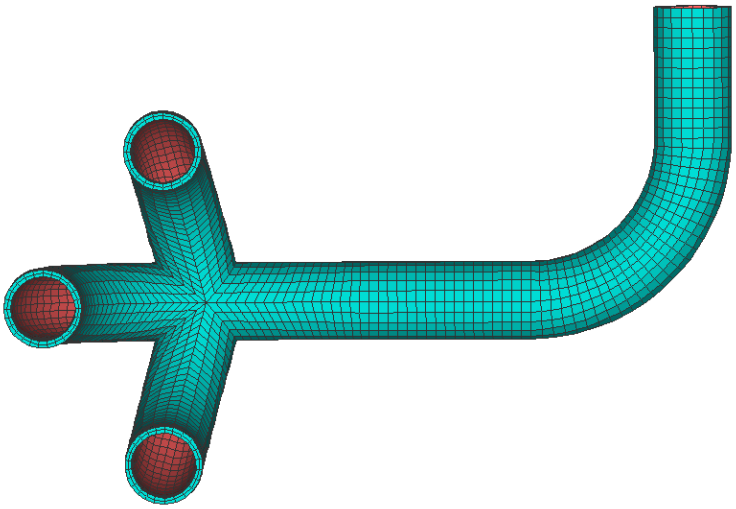


Figure 2: Manifold: Mesh of the solid domain

Conductivity	55.0 $\frac{W}{m \cdot K}$
Film temperature (outside)	300.0 K
Heat coefficient (outside)	50.0 $\frac{W}{m^2 \cdot K}$

Table 1: Manifold: Boundary conditions for solid model

Abaqus

In Abaqus, the mesh consists of 15244 DC3D8 eight-node brick elements.

ANSYS

In ANSYS, the mesh consists of 15244 D3-SOLID70 eight-node brick elements.
Additional D3-SHELL57 dummy surface elements are defined for quantity exchange as described in ▷ VI-4.2.1 Model Preparation ◁.

Marc

In Marc, the mesh consists of 3764 shell elements with 2 mm thickness.
Two surfaces are defined on each side of the shell.

...

8.2.2 Fluid Model

The fluid domain comprises the inner part of the pipe (Figure 3).

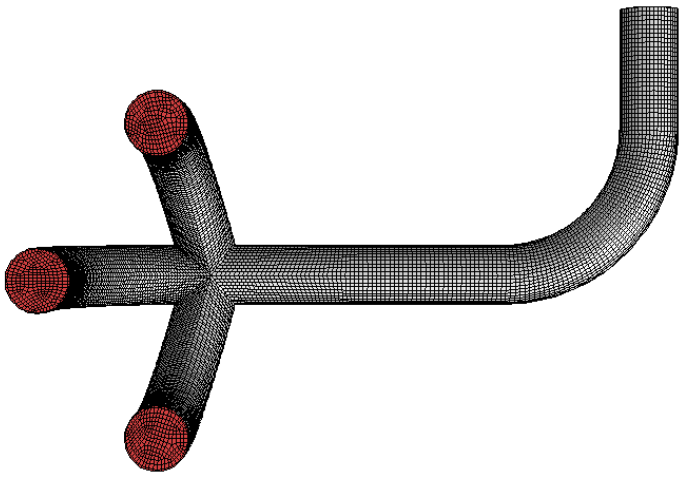


Figure 3: Manifold: Mesh of the fluid domain

Density	1.225 $\frac{kg}{m^3}$
Viscosity	$1.7894E-05$ $\frac{kg}{m \cdot s}$
Conductivity	0.0242 $\frac{W}{m \cdot K}$
Specific heat	1006.43 $\frac{J}{kg \cdot K}$
Inlet	
Velocity	6.0 $\frac{m}{s}$
Temperature	600.0 K
Turbulent Intensity	0.03
Turbulent Length	0.003 m
Outlet	
Relative pressure	0 Pa
Turbulent Intensity	0.03
Turbulent Length	0.003 m

Table 2: Manifold: Boundary conditions for fluid model

The fluid mesh consists of 102236 hexahedral elements.

FLUENT

A standard $k-\epsilon$ model with enhanced wall treatment is applied.

OpenFOAM

A standard $k - \epsilon$ model with standard wall treatment is applied.

STAR-CCM+

A standard $k - \epsilon$ model with enhanced wall treatment is applied.

...

8.2.3 Uncoupled Flow Simulation

Prior to a coupled simulation, it is advisable to carry out an uncoupled flow simulation with simplified boundary conditions. The temperature of the later coupled interface of fluid and solid is set to constant 600 K.

FLUENT

Start FLUENT in double precision and read the case file `"FLUENT/exhaust_manifold.cas"`. Carry out a flow simulation with 200 iterations and save the result in `"FLUENT/exhaust_manifold.dat"`.

OpenFOAM

The pre-calculation is controlled by the Runtime control option Define coupling start in the Algorithm step.

STAR-CCM+

Start STAR-CCM+ and read the model file `"STAR-CCM+/exhaust_manifold.sim"`. Carry out a flow simulation with 200 iterations. The result is saved in `"STAR-CCM+/exhaust_manifold.sim"`.

...

8.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

8.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.
2. Select the Thermal Surface coupling specification Steady state surface heat transfer because this is a heat transfer analysis governed by conduction and convection effects where the convective heat transfer is described by the heat transfer coefficient and film temperature (cf. ▷ V-4.5.4 Category: Thermal Surface ◁).

   Coupling with Abaqus 2016 to Abaqus 2017

   Coupling with surface film properties is not supported for Abaqus versions prior to Abaqus 2018. Therefore select Steady state concentrated heat transfer for coupling with Abaqus 2016 to Abaqus 2017 where the convective heat transfer is described by the heat rate and film temperature.

   ...

8.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the solid heat transfer domain, choose your code to couple:

Abaqus

Option	Action
Code to couple	Select Abaqus.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-2 Abaqus ◁).
Input file	Select input file `"Abaqus/exhaust_manifold.inp"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

ANSYS

Option	Action
Code to couple	Select ANSYS.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-4 ANSYS ◁).
Product	You can select any ANSYS product which can be used for structural analysis, e. g. ansys.
Database file	Select database file `"ANSYS/manifold.db"`. The file will be scanned immediately.
Solution type	Steady state is displayed. The result of the scan process is Undefined (observable after a click on the Done button) but due to the selected coupling specification Steady state surface heat transfer a steady state solution is set automatically.
Unit system	Select the SI unit system (which is the standard).

Marc

Option	Action
Code to couple	Select Marc.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-11 Marc ◁).
Input file	Select input file `"MSC.Marc/exhaust_manifold.dat"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

...

2. For the fluid heat transfer domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is three-dimensional, thus select the FLUENT version 3ddp.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/exhaust_manifold.cas"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

OpenFOAM

Option	Action
Code to couple	Select OpenFOAM.
Option	Select the OpenFOAM option Opt or Debug.
Precision	Select the OpenFOAM precision: DP for double or SP for single precision.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-14 OpenFOAM ◁).
Case directory	Select the case directory `"OpenFOAM/<version>"` fitting your OpenFOAM version (e. g. `"OpenFOAM/v1606-v2306"` for use with OpenFOAM v1606 to v2306). The files will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.
▼ Additional model properties	
	Set reference values according to the fluid properties from Table 2.
Reference density	Set density to 1.225 kg/m^3.
Reference specific heat	Set specific heat to 1006.43 J/kgK.

STAR-CCM+

Option	Action
Code to couple	Select STAR-CCM+.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-16 STAR-CCM+ ◁).
Simulation file	Select the simulation file `"STAR-CCM+/exhaust_manifold.sim"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

Proceed to the Algorithm step by pressing Algorithm.

8.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	This option is automatically set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Parallel.
Use initialization	Check this option.
Initializing code	Set to fluid heat transfer code.
▼ Coupling duration	
Set maximum number of coupling steps	Check this option.
Maximum number of coupling steps	Set to 20.

2. For the solid heat transfer code:

Abaqus

Option	Action
▼ Solver settings	
Use subcycling	Deselect this option as there is no subcycling of Abaqus included.
▼ Coupling steps	
Constant coupling step size	Set to 1 for one increment size for the steady state analysis.

When starting the simulation, Abaqus will receive data from the fluid heat transfer code and accomplish a steady state heat transfer analysis. After this analysis, data is exchanged with the partner code and another analysis is started.

ANSYS

No code specific options need to be set.

The analysis type is automatically set to Steady state as mentioned in the Models step.

Marc

No code specific options need to be set.

...

3. For the fluid heat transfer code:

FLUENT

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 10 solver steps without coupling for subcycling.

OpenFOAM

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 10 solver steps without coupling for subcycling.
▼ Runtime control	
Define coupling start	Set to Specify iteration to enable a pre-calculation.
Iteration number for coupling start	Set to 200 to activate a pre-calculation of 200 iterations.

STAR-CCM+

Option	Action
▼ Solver settings	
Select type of heat transfer coefficient	Set to LocalHeatTransferCoefficient. The setting is selected in order to have comparable results with other CFD simulations codes using the near-wall fluid cell temperature for this tutorial.
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 10 solver steps without coupling for subcycling.

...

Press the Regions button at the bottom of the window to get to the Regions step.

8.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁).

1. At first select the Mesh tab to get access to the mesh based element components.

2. Select Build Regions tab and here the Setup tab.
   In this example the coupling region corresponds to the inner surface of the pipe. MpCCI treats this region as a "Face" because it represents a 2D structure. The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.
   Now choose the components which characterize the inner surface of the pipe. Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For solid heat transfer code	**Select coupling component**
Abaqus	▲ ASSEMBLY_MANIFOLD_INNER_SURFACE
ANSYS	▲ INNER_SURFACE
Marc	

For fluid heat transfer code	**Select coupling component**
FLUENT	▲ wall
OpenFOAM	
STAR-CCM+	

3. Select Define Quantity Sets tab.
   The quantities have already been selected based on the chosen coupling specification: WallTemp<–*Solid heat transfer code*, FilmTemp<–*Fluid heat transfer code*, and WallHTCoeff<–*Fluid heat transfer code* resp. HeatRate<–*Fluid heat transfer code* for coupling with Abaqus 2016 to Abaqus 2017.

4. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	**Check quantity set**
Region_1	WallTemp<–*Solid heat transfer code*, FilmTemp<–*Fluid heat transfer code*, and WallHTCoeff resp. HeatRate<–*Fluid heat transfer code*

No changes are required in the Monitors and Settings steps. You may proceed to the Go step by pressing Go.

8.3.5 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your solid heat transfer code:

Abaqus

No code specific options need to be set.

MpCCI will run the simulation not on the original model file, but rather will use a copy with the prefix `"abaqus_run"`.

ANSYS

Option	Action
Gui option	Keep -b to start ANSYS in batch mode.
APDL input script	Select the input script `"ANSYS/startjob.ans"`.

Marc

No code specific options need to be set.

MpCCI will run the simulation not on the original model file, but rather will use a copy with the prefix `"marc_run_[i4|i8]"`.

...

2. For your fluid heat transfer code:

FLUENT

Option	Action
Auto read case data	Be sure to keep this option selected to automatically read file `"FLUENT/exhaust_manifold.dat"` the result of the uncoupled flow simulation.
Auto set MDM zones	Deselect.

OpenFOAM

No code specific options need to be set.

STAR-CCM+

Option	Action
Run in batch	Check this option.
Auto start with the default template macro	Check this option.
License options	Set according to your license type (cf. ▹ VI-16.2.5 Go Step ◃).

...

Now you may run the computation.

8.4 Running the Computation

Save the MpCCI project file with name `"exhaust_manifold.csp"` via the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

FLUENT

The FLUENT GUI is started.

1. FLUENT automatically loads the data file resulting from the initial computation.
2. Select Solution→Run Calculation to open the Run Calculation panel.

3. As FLUENT will do 10 iterations before each data exchange with MpCCI and the maximum number of data exchanges is set to 20 you should specify 200 Iterations.
4. Finally press Calculate to start the simulation.

In order to survey the convergence of the simulation, FLUENT will display the residual and the integral total surface heat flux on the coupling surface.

OpenFOAM

OpenFOAM will run for 200 iterations. The solution needs not to be initialized as a flow field is loaded from simulation file previously computed. OpenFOAM will run in batch mode.

STAR-CCM+

STAR-CCM+ will run for 200 iterations. The solution needs not to be initialized as a flow field is loaded from simulation file previously computed. STAR-CCM+ will run in batch mode.

...

8.4.1 End of the Simulation

Marc

Marc terminates a successful simulation with exit code 256, which looks like a failed run to the MpCCI GUI and is displayed accordingly by a Failed button. Do not be confused. With a click on this button the termination message of Marc can be controlled.

...

8.5 Post-Processing

Use the following files for the evaluation of the results.

MpCCI

MpCCI tracefile `"mpccirun-0000.ccvx"` from the tracefile folder `"mpccirun_<TIMESTAMP>_ccvx"` can be opened by the command `mpcci visualize` which one can trace the exchange process of the coupled surface.

Abaqus

Abaqus result file name is equal to the defined Abaqus job name parameter ▷ VI-2.2.6 Go Step ◁ followed by the suffix `".odb"`, e.g. `"abaqus_run.odb"` and temperatures for node set nodes_evaluate on `"abaqus_run.dat"`.

ANSYS

ANSYS result file `"thermal.rth"`.

Marc

Marc result file `"marc_run_[i4|i8].t16"`.

FLUENT

FLUENT result file `"exhaust_manifold.dat"`.

OpenFOAM

Start paraFoam from the case directory to visualize the results of the OpenFOAM solver.

STAR-CCM+

STAR-CCM+ result file `"exchaust_manifold@00390.sim"`.

...

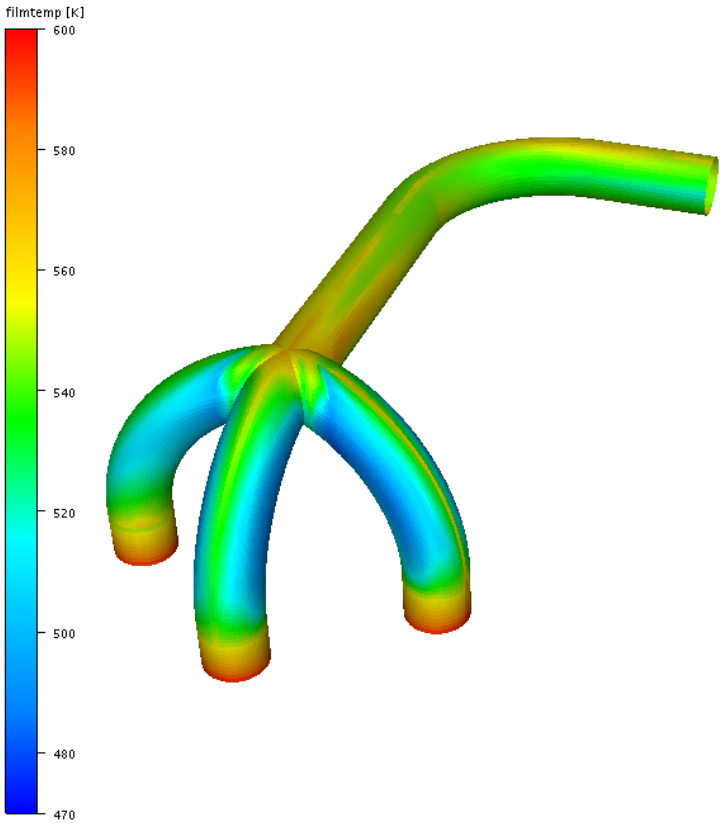


Figure 4: Manifold: Temperature distribution on coupled surface computed with Abaqus and FLUENT from the MpCCI Visualizer. The minimum temperature value is set to 470K.

9 Cube in a Duct Heater

9.1 Problem Description

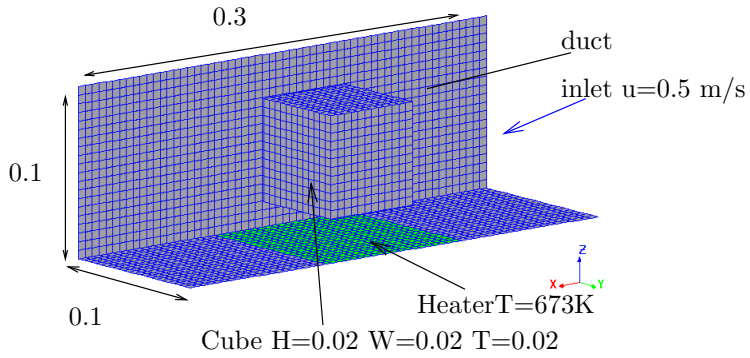


Figure 1: Duct Heater: Geometry [m] and boundary conditions section view

Topics of this Tutorial

- Radiative heat transfer (cf. ▷ V-3.1.2.2 Thermal Coupling ◁)
- Steady state
- Forced convection
- 3D-model
- Subcycling (cf. ▷ V-3.4.3 Coupling with Subcycling ◁)

Simulation Codes

- Heat radiation: TAITherm
- Fluid heat transfer: FLUENT, OpenFOAM, STAR-CCM+

Description

The example case presented in this tutorial describes the forced convection. For this purpose a cube is inserted in an rectangular duct, which is heated up by a heater at the bottom of the duct. Additionally the cube is cooled by air passing through the rectangular duct.

9.2 Model Preparation

The simulation couples a radiation model with a fluid mechanics model. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory `"DuctHeater"` and copy the subdirectories from `"<`*MpCCI_home*`>/tutorial/DuctHeater"` which correspond to the simulation codes you want to use.

9.2.1 Radiation Model

TAITherm

All values at standards settings use temperature calculated except for the heater. The heater is set on a constant surface temperature identical (T=673K) to the CFD settings.

The maximum iterations is set to 499.

...

9.2.2 Fluid Model

The fluid domain comprises the inner part of the duct heater (Table 1.)

Density	1.205 $\frac{kg}{m^3}$
Conductivity	0.0237 $\frac{W}{m \cdot K}$
Specific heat	1006 $\frac{J}{kg \cdot K}$
Inlet	
Velocity	0.5 $\frac{m}{s}$
Temperature	293.0 K
Turbulent Intensity	0.1
Turbulent Length	0.02 m
Outlet	standard setting
Cube	
wall heat	fixed
Temperature	293.0 K
Duct	
wall heat	fixed
Temperature	293.0 K
Heater	
wall heat	fixed
Temperature	673.0 K

Table 1: Duct Heater: Boundary conditions for the fluid model

The settings used for the fluid model are listed in Table 2.

FLUENT

A standard $k-\epsilon$ model with enhanced wall treatment is applied.

OpenFOAM

A standard $k-\epsilon$ turbulence model with wall treatment is applied. The solver buoyantBoussinesqSimpleFoam is used.

Time Domain	Steady state
Gravity	$-9.81\,\frac{m}{s^2}$
Thermal option All settings	 off
Buoyancy for AIR	On

Table 2: Duct Heater: Parameter settings for the fluid model

STAR-CCM+

A standard $k-\epsilon$ turbulence model is applied with wall treatment.
In general, STAR-CCM+ needs an existing solution for the thermal coupling when STAR-CCM+ should send some data first. A cold start would fail in this case. In the Algorithm step STAR-CCM+ will be configured to calculate an initial solution before the coupling begins.

...

9.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

9.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.
2. Select the Thermal Radiation coupling specification Steady state radiative heat transfer because this is a heat transfer analysis governed by radiative and convection effects (cf. ▷ V-4.5.3 Category: Thermal Radiation ◁).

9.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the heat radiation domain, choose your code to couple:

TAITherm

Option	Action
Code to couple	Select TAITherm.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-17 TAITherm ◁).
".tdf" file	Select "radtherm_model.tdf" as input file. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

2. For the fluid heat transfer domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is three-dimensional, thus select the FLUENT version 3ddp.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"fluent_model.cas"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

OpenFOAM

Option	Action
Code to couple	Select OpenFOAM.
Option	Select the OpenFOAM option Opt or Debug.
Precision	Select the OpenFOAM precision: DP for double or SP for single precision.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-14 OpenFOAM ◁).
Case directory	Select the case directory `"OpenFOAM/<`*version*`>"` fitting your OpenFOAM version (e. g. `"OpenFOAM/v1606-v2306"` for use with OpenFOAM v1606 to v2306). The files will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.
▼ Additional model properties	
	Set reference values according to the fluid properties from Table 1.
Reference density	Set density to 1.205 kg/m^3.
Reference specific heat	Set specific heat to 1006 J/kgK.

STAR-CCM+

Option	Action
Code to couple	Select STAR-CCM+.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-16 STAR-CCM+ ◁).
Simulation file	Select the simulation file `"STAR-CCM+/ductheater.sim"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

Proceed to the Algorithm step by pressing Algorithm.

9.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	This option is automatically set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Parallel.
Use initialization	Check this option.
Initializing code	Set to heat radiation code.
▼ Coupling duration	
Set maximum number of coupling steps	Check this option.
Maximum number of coupling steps	Set to 10.

2. For the heat radiation code:

TAITherm

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 50 solver steps without coupling for subcycling.

...

3. For the fluid heat transfer code:

FLUENT

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 50 solver steps without coupling for subcycling.

OpenFOAM

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 50 solver steps without coupling for subcycling.

STAR-CCM+

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 50 solver steps without coupling for subcycling.
▼ Runtime control	
Define coupling start	Set to Specify iteration to enable a pre-calculation.
Iteration number for coupling start	Set to 5 to activate a pre-calculation of 5 iterations. STAR-CCM+ needs a solution before sending the quantities.

...

Press the Regions button at the bottom of the window to get to the Regions step.

9.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁).

1. At first select the Mesh tab to get access to the mesh based element components.

2. Select Build Regions tab and here the Setup tab. Now choose the components to be coupled. In this example the coupling region corresponds to the surface of the duct and the rectangle. The selected coupling specification for this project already set the coupling dimension to Face. So only the lists with Face (▲) components are shown.

   Because in this example the coupling components for all codes are named by a special prefix, you may choose an easier way to select all coupling components by using rules (cf. Figure 21 (part V)). We want to couple all components starting with the strings cube_ or duct_ but not those ending in -backside. The latter ones are automatically generated by the TAITherm scanner and are actually not involved in the coupling. So we will create three rules, one for generating an unused region with the -backside components, a second for the cube_ components, and a third for the duct_ components. The last two rules can be combined in a rules list to generate a joined region. (By the way, you may choose another way e. g. by creating only one rule with a more complex regular expression, but here we won't make a degression on regular expressions but would like to show the power of rules and rules lists.)

To create the rule for the unused backside components press the New button in the Rules tab and set following properties:

Option	Action
Rule name	Type in unusedBackside.
Region criterion	Select Matching pattern and type in .*-backside
Region type	Set Unused.
Region naming	Select Matching pattern.
Press Ok button to save the rule.	

Generate unused region .*-backside with backside components by selecting unusedBackside in the rule list and pressing the Generate button.

To create the rule for the components starting with cube_ press the New button again and set following properties:

Option	Action
Rule name	Type in cube.
Region criterion	Select Matching pattern and type in cube_.*.
Region type	Keep Unused deselected.
Region naming	Select Matching pattern.
Press Ok button to save the rule.	

To create the rule for the components starting with duct_ press the New button again and set following properties:

Option	Action
Rule name	Type in duct.
Region criterion	Select Matching pattern and type in duct_.*.
Region type	Keep Unused deselected.
Region naming	Select Matching pattern.
Press Ok button to save the rule.	

Now select the Rules lists tab and press the New button to create a rules list combining the just created rules. Set following properties:

Option	Action
Rules list name	Type in cubeDuct.
Region criterion	Select Generate one merged region and by join.
Rules list	Add cube from Available rules.
	Add duct from Available rules.
Press Ok button to save the rules list.	

Generate coupling region cubeDuct by selecting cubeDuct in the rules list and pressing the Generate button.

3. Select Define Quantity Sets tab.
The quantities have already been selected based on the chosen coupling specification:
WallTemp<–*Heat radiation code*, FilmTemp<–*Fluid mechanics code*, WallHTCoeff<–*Fluid mechanics code*.

4. Select Assign Quantity Sets tab and assign the defined quantity set to the built region.

For selected region	Check quantity set
cubeDuct	WallTemp<–*Heat radiation code*, FilmTemp<–*Fluid mechanics code*, WallHTCoeff<–*Fluid mechanics code*

No changes are required in the Monitors and Settings steps. You may proceed to the Go step by pressing Go.

9.3.5 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your heat radiation code:

TAITherm

Option	Action
Run in batch	Check this option.

...

2. For your fluid heat transfer code:

FLUENT

Run in batch	Check this option.
Optional journal files	Select the journal file `"run.jou"`.

OpenFOAM

Option	Action
Select OpenFOAM solver	Leave the default Auto-Select-by-Case. The solver setting from the `"controlDict"` file (buoyantBoussinesqSimpleFoam) will be used.

STAR-CCM+

Option	Action
Run in batch	Check this option.
Auto start with the default template macro	Check this option.
License options	Set according to your license type (cf. ▷VI-16.2.5 Go Step◁).

...

9.4 Running the Computation

9.4.1 Starting the Simulation

Save the MpCCI project file with name "duct_heater.csp" over the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and additional terminal windows open.

TAITherm

TAITherm calculation is started in batch mode. The tdf file has been prepared to run 500 iterations.

FLUENT

The FLUENT calculation is started in batch mode. The maximum number of iterations has been set to 500 in the journal file and at the end of the solution the case and dat files are saved.

OpenFOAM

The OpenFOAM calculation is started in batch mode. The maximum number of iterations has been set to 500 in the "controlDict" file.

STAR-CCM+

The STAR-CCM+ calculation is started in batch mode. The maximum number of iterations has been set to 505 by the java macro file as stopping criteria.

...

9.5 Discussion of Results

TAITherm

Temperature results may be visualized in TAITherm GUI. (Figure 2)

FLUENT

FLUENT result file "fluent_model.dat" may be post processed by FLUENT.

OpenFOAM

OpenFOAM results may be post-processed with paraFoam.

STAR-CCM+

STAR-CCM+ result file "ductheater.sim" may be post processed with STAR-CCM+ GUI. At the end of the computation STAR-CCM+ may saved the simulation under the name "ductheater@505.sim"

...

By using the MpCCI Visualizer you may visualize the coupled values from the "mpccirun-0000.ccvx". You may open the tools from the MpCCI GUI Tools→Visualizer. This will open automatically the "mpccirun-0000.ccvx" file.

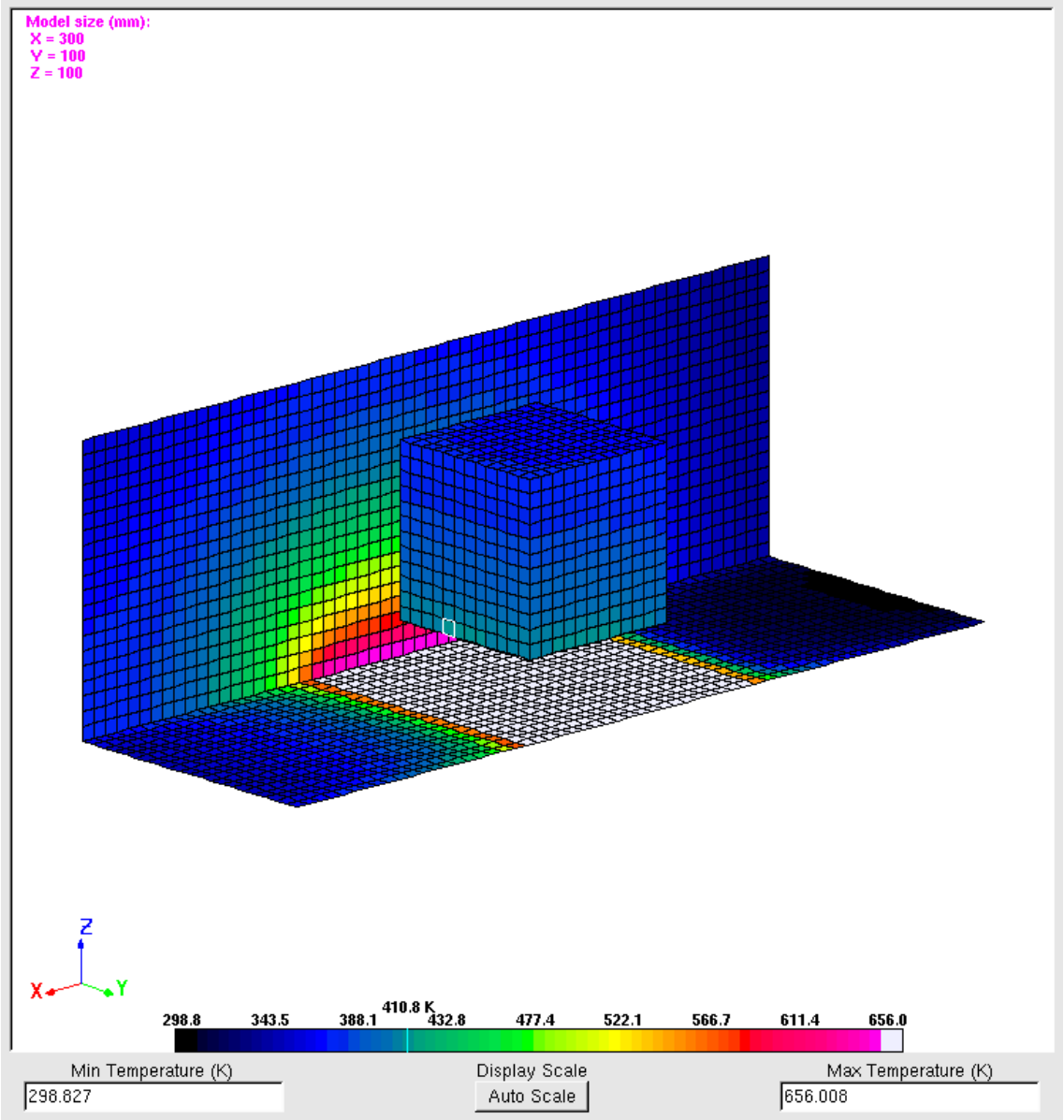


Figure 2: Duct Heater: Temperature section plot

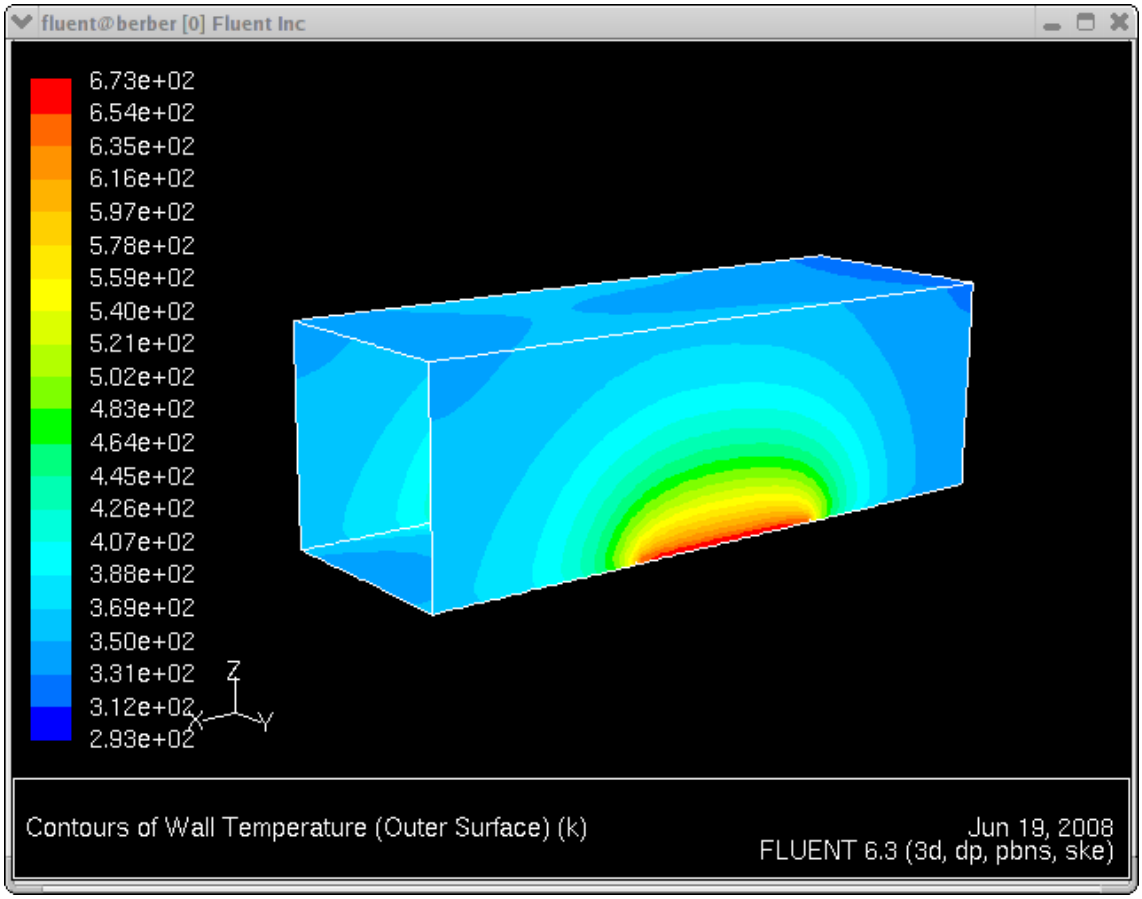


Figure 3: Duct Heater: FLUENT wall temperature contour plot

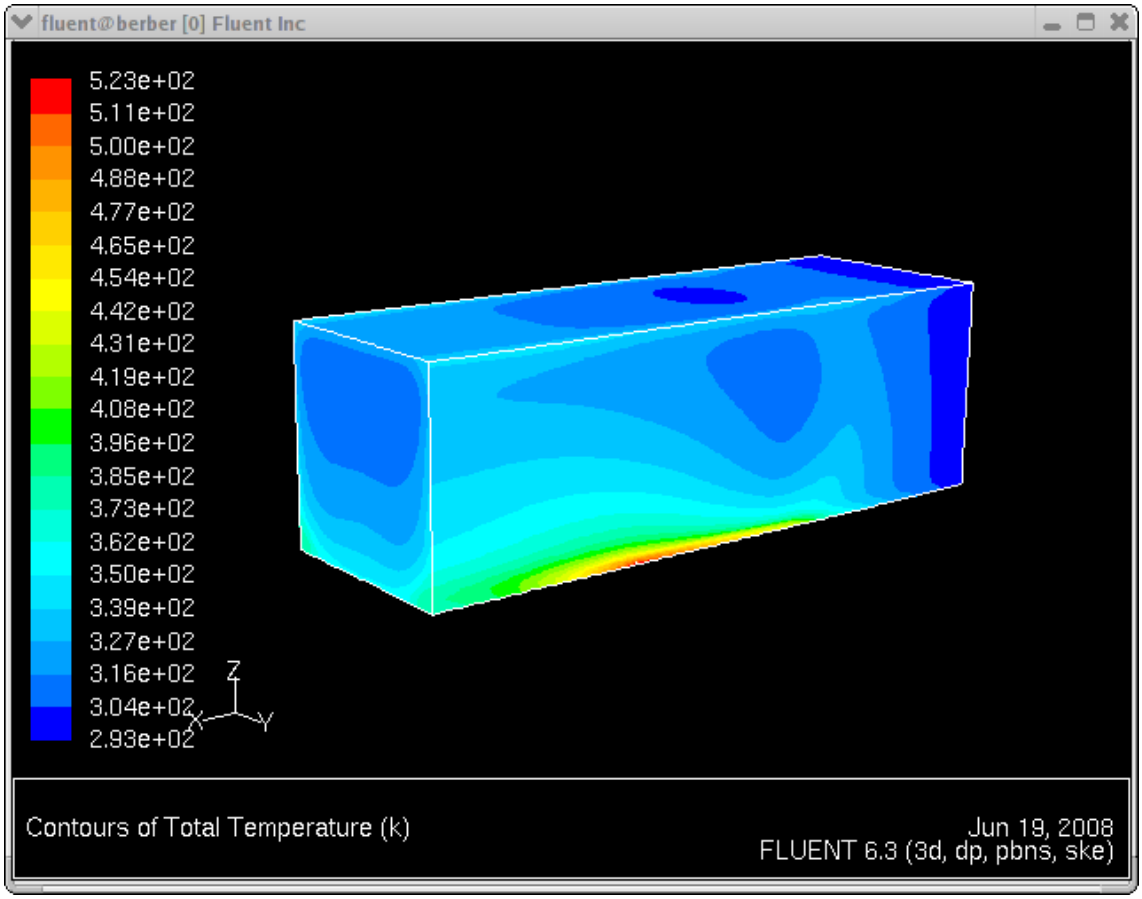


Figure 4: Duct Heater: FLUENT total temperature contour plot

10 Busbar System

10.1 Problem Description

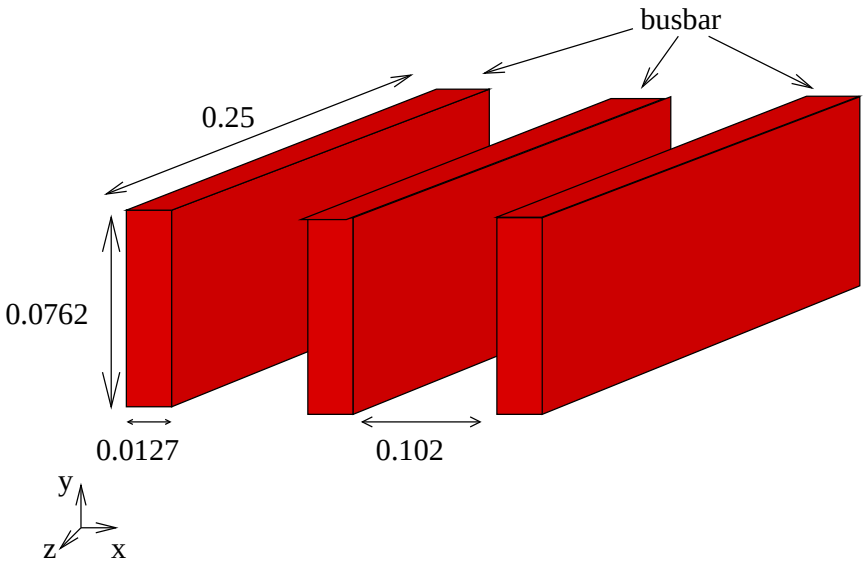


Figure 1: Busbar: Geometry [m].

Topics of this Tutorial

- Magneto-Thermal (cf. ▷ V-3.1.2.3 Electrothermal Analysis ◁)
- 3D-model
- Volume coupling
- Several coupling regions
- Fluid solver subcycling (cf. ▷ V-3.4.3 Coupling with Subcycling ◁)

Simulation Codes

- Electromagnetism: ANSYS, JMAG
- Fluid mechanics: FLUENT

Description

The example is taken from an article by Lyttle et al. [2006]. The task is to solve the electrothermal coupled problem of a busbar system carrying a three-phase current where the current leads to power losses due to the finite resistivity of the conductor. The busbars are made of copper, the RMS current level is 1600 A at a frequency of 60 Hz. Because of the power losses the conductor is heated up as well as the surrounding air leading to free convection around the busbars. To model the convection process the Boussinesq approximation for the density of air is used. A linear rise of resistivity dependent on the temperature of the conductor is also modeled.

The electromagnetic calculation of power-losses is considering:

- eddy currents,
- skin effect,

- proximity effect,
- temperature dependent rise of resistivity.

The thermal calculation is considering:

- heat conduction (fluid and solid),
- heat convection (including buoyancy effects),
- laminar flow.

10.2 Model Preparation

The simulation couples a electromagnetic model with a fluid model. The files you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the subdirectories from "<*MpCCI_home*>`/tutorial/Busbar`" corresponding to the simulation codes you want to use.

10.2.1 Fluid Model

On the front and back side of the fluid cabinet the conductors enter the fluid domain. Here are adiabatic wall boundary conditions set. On the left and right side of the cabinet a wall boundary condition with fixed temperature of 293.15 K is defined. On the bottom and top of the cabinet air can enter and leave the domain on pressure boundary conditions.

FLUENT

No modifications have to be done, as we later carry out a GUI based coupled simulation.

...

10.2.2 Electromagnetic Model

A busbar conductor corresponds to three rectangles each with a dimension of 12.7 mm × 76.2 mm × 250 mm. The magnetic property of copper is linear isotropic with a relative permeability of 1. The temperature dependent electrical resistivity is calculated in this way:

$$\varrho(T) = \varrho_0(1 + \alpha(T - T_{ref}))$$

At reference temperature $T_{ref} = 300$ K the value of resistivity is $\varrho_0 = 1.7241\ 10^{-8}$ Ωm. The temperature coefficient is $\alpha = 0.004$ K^{-1}. The calculation of the current flow and magnetic field is done in frequency domain.

ANSYS

The `"ANSYS/busbar.db"` contains all finite element information. Beside the model file an ANSYS input file `"ANSYS/startjob.ans"` is used to define all boundary conditions, loads and to control the coupling process. At the front and back side of the conductors the voltage degree of freedom will be coupled and on one side for every conductor the voltage degree of freedom is set to 0. At the front side of the conductors a nodal load amps is defined separately for every conductor with real and imaginary part depending on the phasing. The elements are grouped into element components named "phase-a", "phase-b" and "phase-c" to make it possible for the MpCCI ANSYS adapter to detect the elements. For coupling these commands are used:

- `~mpcci, init, 3D`: Initialize the connection to MpCCI.
- `~mpcci, exchange`: Exchange data from the partner code and wait until the data exchange is done.

- `~mpcci, settag, time, iter`: Set the synchronization tag for the current time / iteration.

Furthermore after the frequency domain solution, the effective power loss density is provided via ANSYS command `powerh` which generates an element table named plossd. This element table is just copied to an element table named mpcci_00 using this command: `smult, mpcci_00, plossd,, 1`. Because the MpCCI adapter can read out of element tables with fulfilling the naming convention mpcci_<*index*>. The <*index*> has to be set in the MpCCI GUI.

JMAG

All necessary model information is prepared, no further action is needed. An electric circuit is defined to set the current loads for the finite element solution. The three-phase current source provides an current amplitude of 2262.7 A.

...

10.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

10.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.
2. Select the Electrothermal coupling specification Coupled magnetic field and thermal analysis because this problem analyses the thermal-magnetic behaviour of a busbar system (cf. ▷ V-4.5.6 Category: Electrothermal ◁).

10.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the electromagnetism domain, choose your code to couple:

ANSYS

Option	Action
Code to couple	Select ANSYS.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-4 ANSYS ◁).
Product	You can select any ANSYS product which can be used for electromagnetic analysis, e. g. ane3fl or emag.
Database file	Select database file `"ANSYS/busbar.db"`. The file will be scanned immediately.
Solution type	Steady state is displayed although the result of the scan process is Undefined. However, because the chosen coupling specification presets a stationary analysis, the solution type is updated by MpCCI.

JMAG

Option	Action
Code to couple	Select JMAG.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-10 JMAG ◁).
JCF file	Select file `"JMAG/busbar_system.jcf"` as input file. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

2. For the fluid mechanics domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is three-dimensional, thus select the FLUENT version 3ddp.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/busbar.cas"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

Proceed to the Algorithm step by pressing Algorithm.

10.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	This option is automatically set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Serial.
Leading code	Set to electromagnetism code.
▼ Coupling duration	
Set maximum number of coupling steps	Check this option.
Maximum number of coupling steps	Set to 10 for the frequency response analysis simulation.

2. For the electromagnetism code:

ANSYS

No code specific options need to be set.

JMAG

No code specific options need to be set.

...

3. For the fluid mechanics code:

FLUENT

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 20 solver steps without coupling for subcycling.

...

Press the Regions button at the bottom of the window to get to the Regions step.

10.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁).

1. At first select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example the coupling region corresponds to the solid conductors. MpCCI treats this region as a "Volume" because it represents a 3D structure. The selected coupling specification for this project already set the coupling dimension to Volume. So only the lists with Volume ( ) components are shown.
   There are 3 conductors to couple and for each conductor from the electromagnetism and the fluid mechanics code a coupling region will be created. This will increase the performance of the neighborhood search.
   Now choose the components which characterize the solid conductors. Lookup your codes in the following table and select the coupling components for each region by dragging them into the Added boxes:

   - Build the first region.

For region Region_1	
For electromagnetism code	**Select coupling component**
ANSYS	phase-a
JMAG	busbar a
For fluid mechanics code	**Select coupling component**
FLUENT	phase_a-solid

   - Click on button Add to add new region Region_2.

For region Region_2	
For electromagnetism code	**Select coupling component**
ANSYS	phase-b
JMAG	busbar b
For fluid mechanics code	**Select coupling component**
FLUENT	phase_b-solid

- Click on button Add to add new region Region_3.

For region Region_3	
For electromagnetism code	**Select coupling component**
ANSYS	phase-c
JMAG	busbar c
For fluid mechanics code	**Select coupling component**
FLUENT	phase_c-solid

3. Select Define Quantity Sets tab.
   The quantities have already been selected based on the chosen coupling specification: JouleHeat<–*Electromagnetism code* and Temperature<–*Fluid mechanics code*.
   For some quantities additional code specific settings are necessary:

For quantity	**Code specific settings**	
JouleHeat	Orphans settings	Select Extrapolate to extrapolate values into the orphaned regions where this is possible.
	ANSYS	
	Send method	Select ETAB.
	index	Set to 0 for send method ETAB.
	Location	Select elem.
Temperature	Orphans settings	Select Extrapolate to extrapolate values into the orphaned regions where this is possible.
	ANSYS	
	Location	Select node.

4. Select Assign Quantity Sets tab and assign the defined quantity set to the built regions.

For selected regions	**Check quantity set**
Region_1 Region_2 Region_3	Temperature<–*Fluid mechanics code*, JouleHeat<–*Electromagnetism code*

No changes are required in the Monitors step. You may proceed to the Settings step by pressing Settings.

10.3.5 Settings Step

JMAG

The JMAG model presents some light differences.

For visualizing the orphan information set the following parameter:

Parameter	Value
Monitor.Orphans	Set selected.

...

No further changes are required in the Settings step. Proceed to the Go step by pressing Go.

10.3.6 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your electromagnetism code:

   ANSYS

Option	Action
Gui option	Keep -b to start ANSYS in batch mode.
APDL input script	Select the input script `"ANSYS/startjob.ans"`.

   JMAG

   No code specific options need to be set.

   ...

2. For your fluid mechanics code:

   FLUENT

   No code specific options need to be set.

   ...

Now you may run the computation.

10.4 Running the Computation

Save the MpCCI project file with name `"busbar.csp"` via the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

ANSYS

ANSYS reads the APDL script file `"startjob.ans"` and starts the computation.

JMAG

The JMAG reads the model file `"busbar_system.jcf"` and starts the computation.

FLUENT

The FLUENT GUI is started, in which the calculation must be initialized and started as follows:

1. Select Solution→Initialization to open the initialization panel. Press the button Initialize.
2. Select Solution→Run Calculation to open the Run Calculation panel and enter 200 number of iterations (10 coupling steps with 20 steps each without coupling).
3. Finally, press Calculate to start the simulation.

...

10.5 Discussion of Results

In this busbar simulation it is seen that the coupling takes ten steps to reach a maximum temperature.

Exemplarily the temperature distribution in the middle plane of the cabinet from the FLUENT solution is given in the next picture (Figure 2).

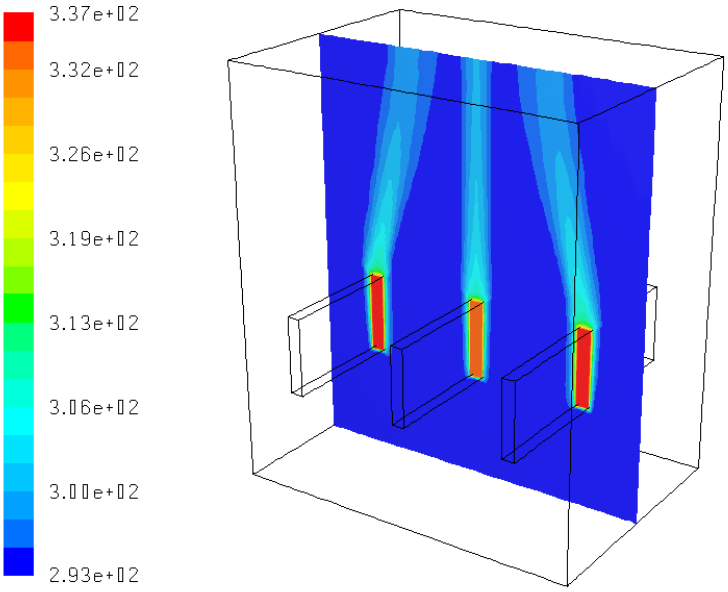


Figure 2: FLUENT results: temperature distribution [K]

Exemplarily the temperature average for each busbar [K] and the summarized power losses [W] from the coupling between JMAG-FLUENT can be plotted. We can observe the correlation between the temperature and joule heat values (Figure 3).

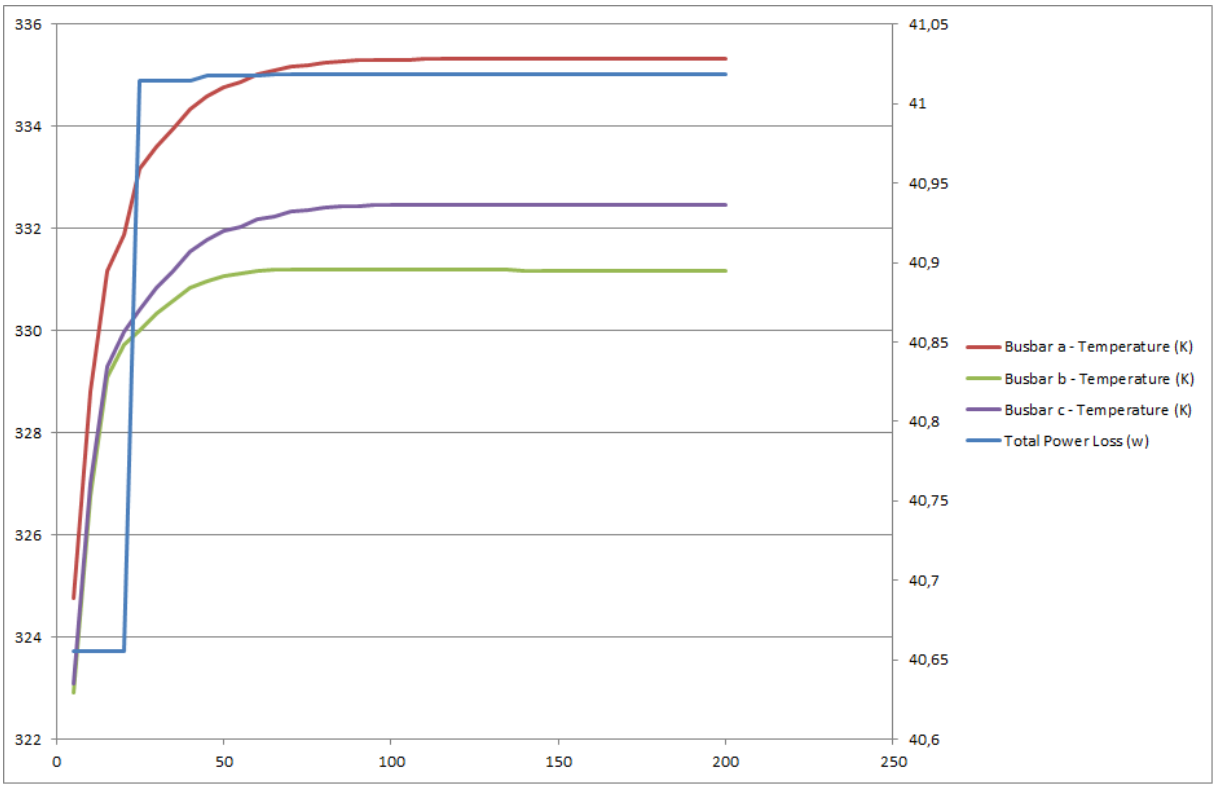


Figure 3: JMAG FLUENT results: temperature average [K] and total power losses [W]

11 Three Phase Transformer

11.1 Problem Description

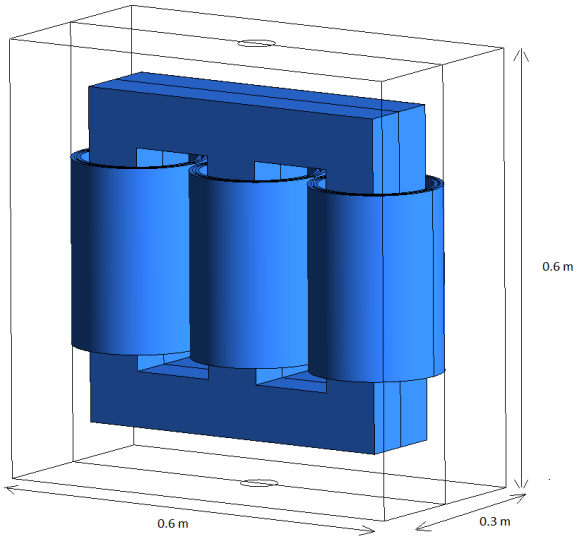


Figure 1: Three phase transformer: Geometry [m].

Topics of this Tutorial

- Magneto-Thermal (cf. ▷ V-3.1.2.3 Electrothermal Analysis ◁)
- 3D-model
- Volume coupling
- Several coupling regions
- Fluid solver subcycling (cf. ▷ V-3.4.3 Coupling with Subcycling ◁)

Simulation Codes

- Electromagnetism: JMAG
- Fluid Mechanics: FLUENT

Description

The transformer geometry model is taken from JMAG application notes # 146.
The tutorial covers an electrothermal coupled problem of a transformer carrying a three-phase current. Losses include copper losses in the coils and iron loss in the core. We have used a step down three phase transformer with a turn ratio of 10 to 1 with the following characteristics:

- The primary voltage of 141.42 V is operating at 60 Hz.
- The connection pattern in the transformer and load sides are Delta-Delta and Y connection respectively.
- The coil resistance for primary winding is 0.031 Ω/phase and 0.00156 Ω/phase for secondary winding.
- External load resistance is 0.06 Ω/phase.

- The core material is 50JN270 (manufacturer JFE steel) with laminating factor of 98.
- The dimensions of the tank are 0.6 m * 0.6 m * 0.3 m.
- The cooling liquid is n-heptane.

Magnetic field analysis handles the phenomena that produce magnetic flux and eddy currents in transformer's core, when current flows through the coil. A linear rise of resistivity dependent on the temperature of the conductor is also modeled.

The electromagnetic calculation of power-losses is considering:

- eddy currents,
- temperature dependent rise of resistivity.

The thermal calculation is considering:

- heat conduction (fluid and solid),
- heat convection (including buoyancy effects),
- laminar flow.

11.2 Model Preparation

The simulation couples an electromagnetic model with a fluid model. The files you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the subdirectories from "<*MpCCI_home*>`/tutorial/Transformer`" corresponding to the simulation codes you want to use.

11.2.1 Fluid Model

The fluid model is composed of the tank, the core and coils. The core and coils are immersed in a cooling fluid: the n-heptane liquid. A symmetry condition is considered for the model. The inlet for the cooling liquid is located at the bottom of the tank and the outlet is located at the top of the tank. The inlet velocity of the liquid is set to 0.001 m/s. The liquid leaves the domain on a pressure boundary condition. The coils are modeled as conductors based on copper material and the core uses steel material. The tank wall is set to an adiabatic wall boundary condition.

FLUENT

No modifications have to be done, as we later carry out a GUI based coupled simulation.

...

11.2.2 Electromagnetic Model

The magnetic property of copper is linear isotropic with a relative permeability of 1. The temperature dependent electrical resistivity is calculated in this way:

$$\varrho(T) = \varrho_0(1 + \alpha(T - T_{ref}))$$

At reference temperature $T_{ref} = 300$ K the value of resistivity is $\varrho_0 = 1.7241\ 10^{-8}$ Ωm. The temperature coefficient is $\alpha = 0.004$ K^{-1}. The calculation of the current flow and magnetic field is done in frequency domain.

JMAG

All necessary model information is prepared in the `"transformer.jcf"`, no further action is needed for generating the jcf file:

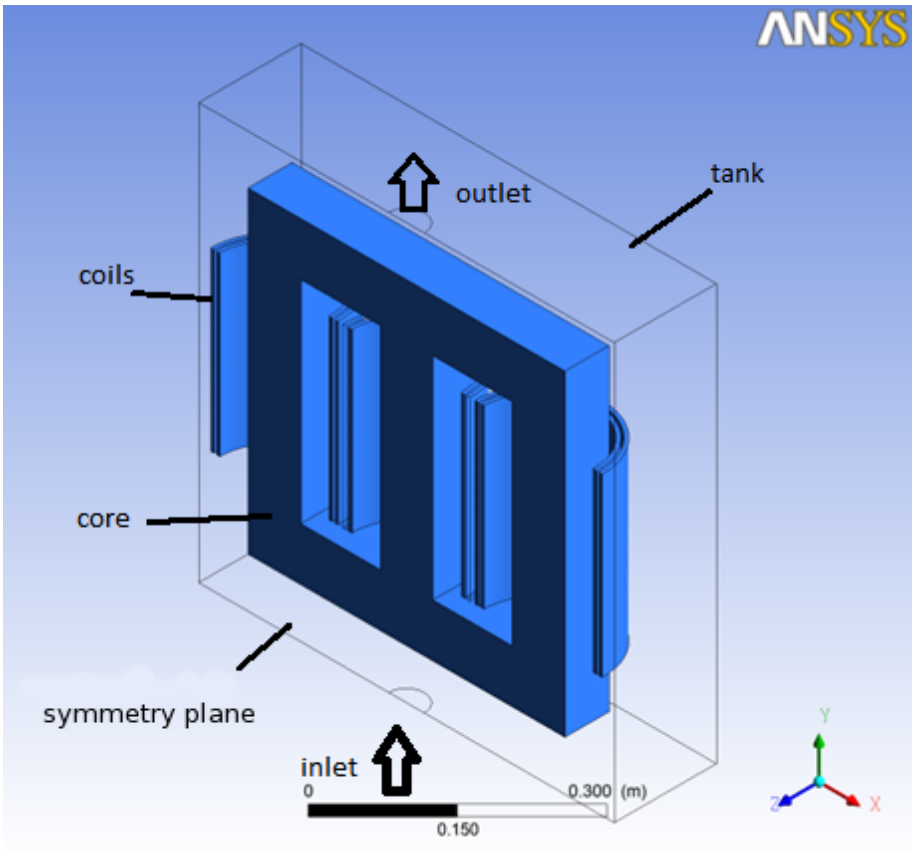


Figure 2: FLUENT boundaries

- The Coupled Analysis is already activated.
- Electric Properties of the material is set up to be temperature dependent.

An electric circuit is defined as shown in Figure 4.
The three-phase voltage source provides an amplitude of 141.42 V. The condition for windings is set to FEM coil which assumes a uniform current distribution in the cross section of the wires. Because of existing symmetry in the structure we construct a half model and analyze this model which has a lower computational cost. This can be done by setting the symmetry boundary condition in JMAG. The tank has not been modeled in JMAG.

In the JMAG directory you have the `"transformer_standalone.jcf"` file which corresponds to the setup for a standalone simulation.

...

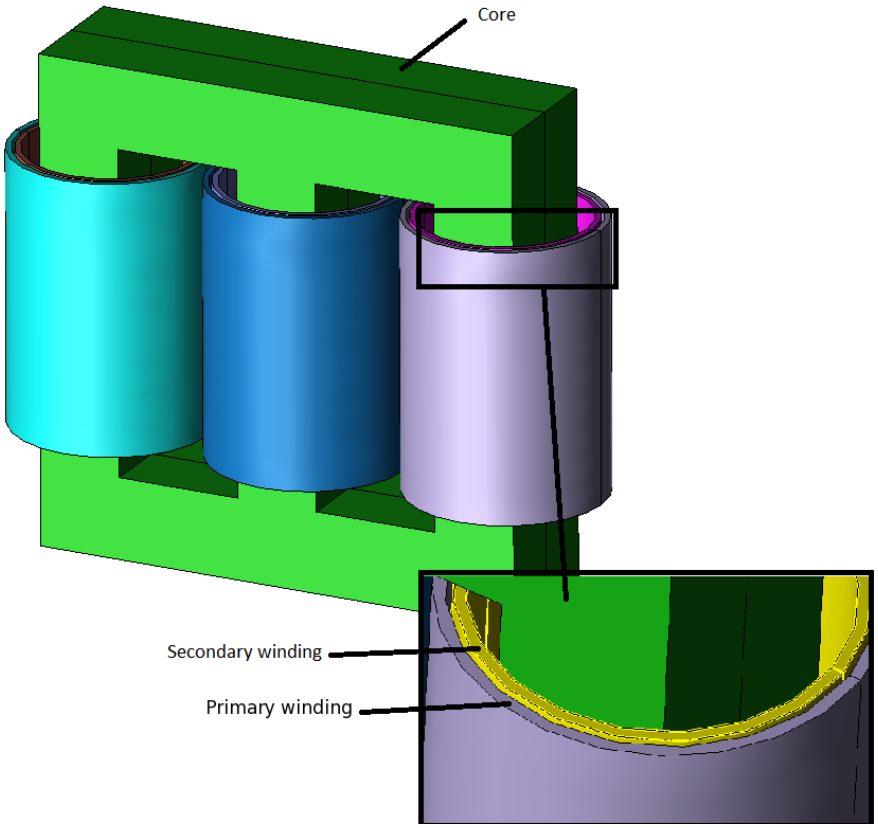


Figure 3: JMAG components

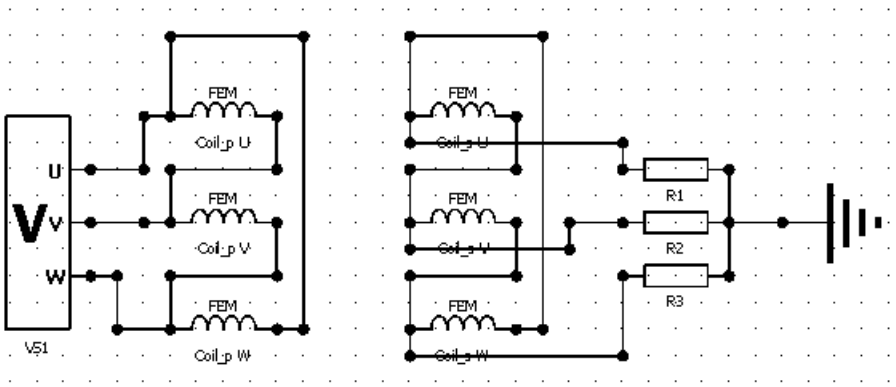


Figure 4: JMAG electric circuit

11.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to

run this tutorial.

11.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.
2. Select the Electrothermal coupling specification Coupled magnetic field and thermal analysis because this prolem analyses the thermal-magnetic behaviour of a transformer carrying a three-phase current (cf. ▷ V-4.5.6 Category: Electrothermal ◁).

11.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the electromagnetism domain, choose your code to couple:

JMAG

Option	Action
Code to couple	Select JMAG.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-10 JMAG ◁).
JCF file	Select file `"JMAG/transformer.jcf"` as input file. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

2. For the fluid mechanics domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is three-dimensional, thus select the FLUENT version 3ddp.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/transformer.cas.gz"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

Proceed to the Algorithm step by pressing Algorithm.

11.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	This option is automatically set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Serial.
Leading code	Set to electromagnetism code.
▼ Coupling duration	
Set maximum number of coupling steps	Check this option.
Maximum number of coupling steps	Set to 20 for the frequency response analysis simulation.

2. For the electromagnetism code:

JMAG

No code specific options need to be set.

...

3. For the fluid mechanics code:

FLUENT

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 20 solver steps without coupling for subcycling.

...

Press the Regions button at the bottom of the window to get to the Regions step.

11.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁).

1. At first select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example the coupling region corresponds to the coils and core. MpCCI treats this region as a "Volume" because it represents a 3D structure. The selected coupling specification for this project already set the coupling dimension to Volume. So only the lists with Volume ( ) components are shown.
   There are 6 conductors (coils) and one core to couple. For each conductor a couple region will be created. This will increase the performance and quality of the neighborhood search.
   Now choose the components which characterize the coils and core. Following table gives an overview of the components to couple for each code in each region:

	JMAG	FLUENT	**Region name**
Primary windings	Coil 1_U	p_u	Region_1
	Coil 1_V	p_v	Region_2
	Coil 1_W	p_w	Region_3
Secondary windings	Coil 2_U	s_u	Region_4
	Coil 2_V	s_v	Region_5
	Coil 2_W	s_w	Region_6
Core	core	core	Region_7

- Lookup your codes in the table and select the coupling components for each region by dragging them into the Added boxes.
- After building one region, click on button Add to add a new region and fill it in the same way as the one before.
- After all regions have been built, assign them a more understandable name as follows:
  - Select all regions.
  - Point with the mouse on the regions and do a right click.
  - From the popup menu choose Rename automatically and select a code from the list. The components from this code are used to rename the regions.
    Selecting e. g. FLUENT for renaming would lead to regions p_u, p_v, p_w, s_u, s_v, s_w and core.

3. Select Define Quantity Sets tab.
   The quantities have already been selected based on the chosen coupling specification:
   JouleHeat<–*Electromagnetism code* and Temperature<–*Fluid mechanics code*.

4. Select Assign Quantity Sets tab and assign the defined quantity set to the built regions.

For selected regions	**Check quantity set**
<*all regions*> e. g. p_u p_v p_w s_u s_v s_w core	JouleHeat<–*Electromagnetism code*, Temperature<–*Fluid mechanics code*

No changes are required in the Monitors and Settings steps. You may proceed to the Go step by pressing Go.

11.3.5 Go Step

No changes are required in the Go step. Now you may run the computation.

11.4 Running the Computation

Save the MpCCI project file with name `"transformer.csp"` over the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

JMAG

JMAG reads the model file `"transformer.jcf"` and starts the computation automatically.

FLUENT

The FLUENT GUI is started, in which the calculation must be initialized and started as follows:

1. Select Solution→Initialization to open the initialization panel. Press the button Initialize.
2. Select Solution→Run Calculation to open the Run Calculation panel and enter 400 number of iterations (20 coupling steps with 20 steps each without coupling).
3. Finally press Calculate to start the simulation.

...

11.5 Discussion of Results

In this transformer simulation it is seen that the coupling takes 20 steps to reach a minimum temperature of 306 K and a maximum temperature of 320 K.

Exemplarily the temperature distribution in the transformer from the FLUENT solution is given in the next picture (Figure 5).

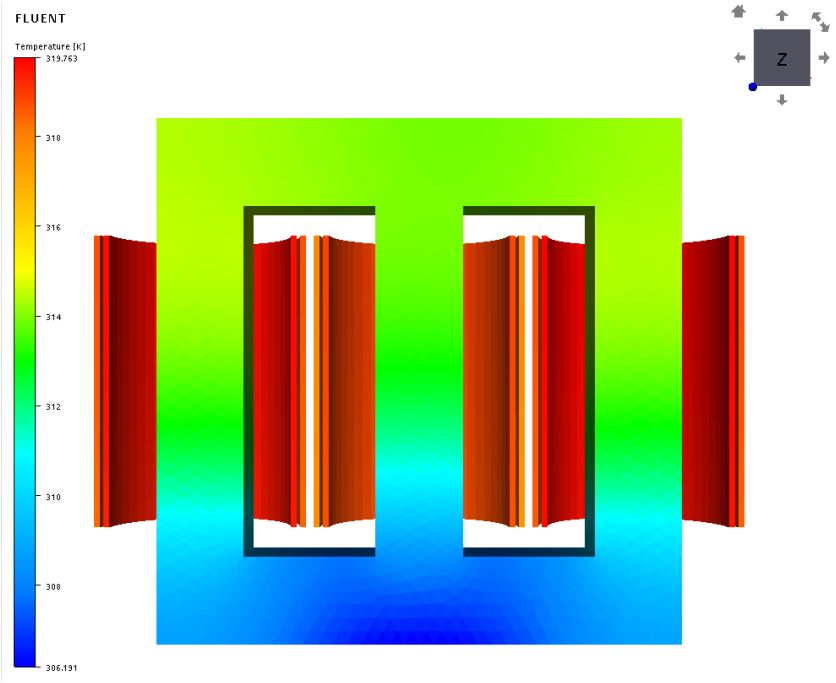


Figure 5: FLUENT results: temperature distribution [K]]

The MpCCI co-simulation thermal analysis will be compared with a standalone JMAG magneto-thermal analysis. The same JMAG magnetic model set up in the file `"transformer_standalone_MG.jcf"` is used for coupling with a JMAG thermal analysis set up in the file `"transformer_standalone_TH.jcf"`.
The thermal analysis model has following properties:

- Use the losses calculation results from the JMAG magnetic simulation. Each coil has a heat source boundary defined.
- Heat transfer boundary for the transformer faces. A constant heat transfer coefficient of 10 $W/m^2.K$ is used.
- Average temperature condition is set up for each coil.

The JMAG coupled analysis is carried out by JMAG itself.

The Joule loss density distribution $[W/m^3]$ in the transformer from the coupling between JMAG-FLUENT can be plotted (Figure 6). The results on the left side correspond to a standalone simulation without consideration of the cooling effect. The maximum Joule loss density reported is about 3.19e+05 W/m^3. The coupled simulation on the right side reports a maximum Joule loss density value of 2.22e+04 W/m^3.

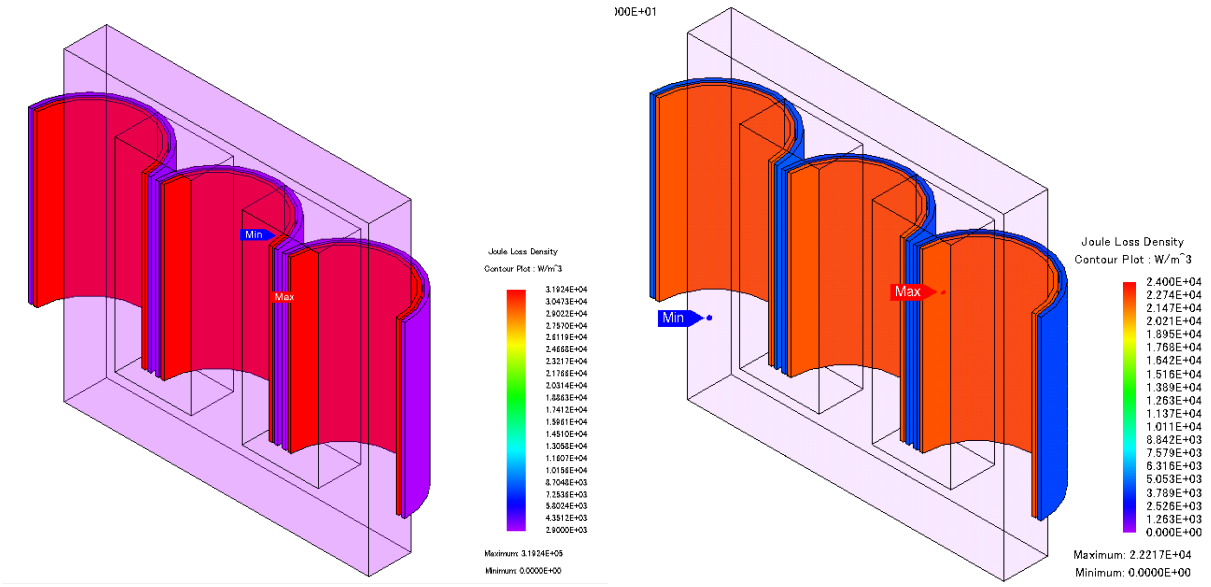


Figure 6: Joule loss density without cooling (left) and with cooling effect (right) $[W/m^3]$ (logarithmic view)

The temperature distribution [K] in the transformer from the coupling between JMAG-FLUENT can be plotted (Figure 7). The results on the left side correspond to a standalone simulation with consideration of the cooling effect assumptions. The standalone analysis shows a minimum temperature of 293.15 K and maximum temperature of 307.15 K.

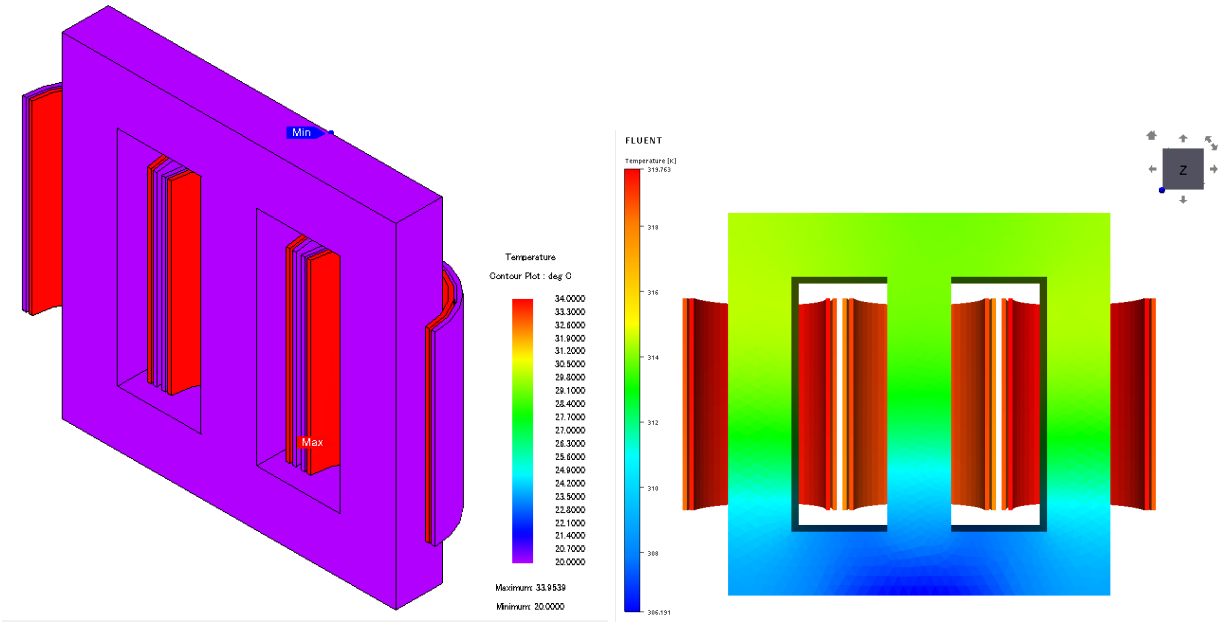


Figure 7: Thermal analysis standalone (left) and with cooling effect (right) [T]

12 Spring Mass System

12.1 Problem Description

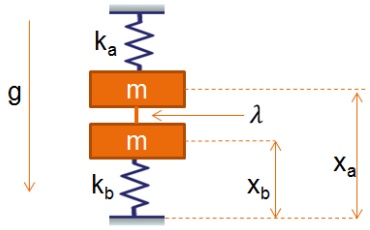


Figure 1: Double mass-spring system

Topics of this Tutorial

- Implicit coupling (cf. ▷ V-3.4.5.1 Implicit Coupling ◁)
- Coupling with non-matching time steps (cf. ▷ V-3.4.5.3 Coupling with Non-Matching Time Steps ◁)
- Verification model
- Comparison of implicit to explicit coupling

Simulation Codes

- System for model A: SimulatorA (simple C executable for spring mass example), MATLAB
- System for model B: Abaqus, Adams, MATLAB, SIMPACK, SimulatorB (simple C executable for spring mass example)

12.2 Model Preparation

This tutorial uses a quite simple example – a dual mass-spring system – to show the possibilities MpCCI offers for implicit coupling and non-matching time step sizes.
The files which you need for the simulation are included in the MpCCI distribution. Create a new directory and copy the subdirectories from "<*MpCCI_home*>/tutorial/Spring" which correspond to the simulation codes you want to use.

12.2.1 Model Description

Initially, a one mass system, with the analytical solution $x(t) = -\frac{gm}{k}(1 - \cos(\sqrt{\frac{k}{m}}t))$ for the position, is partitioned by splitting the mass into two parts. The applied-force coupling in this example is of the type force/displacement coupling, where a subsystem provides kinematic coupling data (position, velocity, acceleration) while the other system provides a force.
The sort of partitioning and the coupling type have an effect on the stability of the simulation. Partitioning by applied-force coupling will guarantee the null stability, i. e. numerical methods applied on these systems converge with infinitesimal coupling step size.

Figure 1 shows two spring-mass systems tied together and initially at rest. A gravity load $g = 10\text{m/s}^2$ is imposed at $t = 0$. The displacements are constrained, resulting in both masses moving together. The

constraint force between the systems is defined as λ. This results in the following equations for the double mass-spring system:

$$\begin{aligned} m_a\ddot{x}_a + k_a x_a &= -m_a g - \lambda \\ m_b\ddot{x}_b + k_b x_b &= -m_b g - \lambda \\ x_a &= x_b \\ \text{at } t = 0: \quad x_a = x_b &= 0 \quad \text{and} \quad \dot{x}_a = \dot{x}_b = 0 \end{aligned}$$

For the mass and the stiffness of the spring-mass systems "stiffness factors" α and β are introduced. These factors define the relative distribution of the single system mass and stiffness values to the total system:

$$\begin{aligned} k_a &= \alpha k \\ k_b &= (1-\alpha)k \\ m_a &= \beta m \\ m_b &= (1-\beta)m \end{aligned}$$

Using these factors the previous equations can be written as:

$$\begin{aligned} \ddot{x}_a + \frac{\alpha}{\beta}\omega^2 x_a &= -g - \frac{\lambda}{\beta m} \\ \ddot{x}_b + \frac{1-\alpha}{1-\beta}\omega^2 x_b &= -g - \frac{\lambda}{(1-\beta)m} \end{aligned}$$

The two equations will be solved separately by a (second order) time integration scheme implemented in a simple C program. The exchange of the quantity information between the two codes will be handled by MpCCI.

SimulatorA – solving the first equation – sends the computed force to SimulatorB, which solves the second equation and then sends the displacement to SimulatorA.

Additionally, MATLAB can be used to solve this simple problem monolithically. Simply execute `"runSimA-SimB.m"` to simulate this example monolithically in MATLAB.
This file can be found in `"mpcci/tutorial/Spring/Matlab/monolithic"`.

A co-simulation setup with MpCCI is described below.

Model A can be realized with SimulatorA or MATLAB while model B besides SimulatorB also can be realized with a simple Abaqus simulation consisting of one mass and a spring or by a MATLAB, Adams or SIMPACK model.

12.2.2 Model A

MATLAB

The MATLAB files for Model A are located in `"MATLAB/SimA/"`. Several files for different coupling types and handling of quantity Acceleration are provided:

- `"runSimA_explicit.m"` for an explicit coupling with computation of acceleration quantity.
- `"runSimA_implicit.m"` for an implicit coupling with computation of acceleration quantity.
- `"runSimA_importAcceleration_explicit.m"` for an explicit coupling with acceleration as coupled quantity which will be exchanged.

- "runSimA_importAcceleration_implicit.m" for an implicit coupling with acceleration as coupled quantity which will be exchanged.

The MATLAB codes for Model A do basically the same as the C source code for the SimulatorA. They compute the acceleration and then solve for the interface force λ_a.

If the acceleration is a coupled quantity, the computation of the acceleration is deactivated by resetting the `calculatedACC` to zero in the m-file:

```
% Flag for using acceleration information from coupled system
% set to 0 to use the coupled value if this one is exchanged
calculatedACC = 0;
```

Please use one of the following m-files with the preset variable value in this case:
"runSimA_importAcceleration_explicit.m" or "runSimA_importAcceleration_implicit.m" depending on the coupling scheme.

At the beginning of the m-files MpCCI tags for the co-simulation setup have to be written as a MATLAB annotation `%` with a leading `$mpcci`-declaration. In this case the coupling point (also called coupling variable) `cpoint` is declared in the definition section of the m-file codes as follows:

```
% Definition of the co-simulation:
%
%$mpcci time t
%$mpcci dt dt
%$mpcci iter i
%$mpcci conv cConv
%
%$mpcci cpoint disp1,lambda,acc1
%
```

In this model three possible coupling variables have been declared: `disp1,lambda,acc1`.

Each coupling variable is associated with a physical quantity. The variable acc1 is declared when the code imports the acceleration quantity.

SimulatorA

The executable for the SimulatorA is part of the MpCCI distribution
("<*MPCCI_HOME*>/codes/SimulatorA/bin/<*version*>/<*MPCCI_ARCH*>/Mpcci_SimulatorA.exe").

SimulatorA receives the displacements x_a (e. g. from SimulatorB), computes the acceleration and then solves for the interface force λ_a:

$$\ddot{x}_a + \frac{\alpha}{\beta}\omega^2 x_a = -g - \frac{\lambda_a}{\beta m}$$

The interface force λ_a is then exported.

...

12.2.3 Model B

Abaqus

The directory "Spring/Abaqus" contains an Abaqus model for the part modeled by SimulatorB: it is a very simple model consisting of a spring and an attached mass.

The coupled point in Abaqus is called NQA.
Additional instances of this point have been created, NQA_DUP and NQA_DUP2, for coupling with a code like MATLAB which defines coupling variables (i. e. signals) for each quantity.

Adams

In Adams the files `"Adams/ModelB.adm"` and `"Adams/sim_command.acf"` represent the part B of the spring mass system. It computes the position of the coupled mass x_b and the acceleration $\ddot{x}_b$. The model has been created using mm as length unit.

No additional preparation steps are required.

The Adams model consists of a mass and a spring with one degree of freedom in the x-direction. The gravity is also defined in the x-direction.

The solver setting uses an adaptive time step model which provides some limitations for a scenario with non-matching time step sizes coupling.

MATLAB

The MATLAB files for Model B are located in `"MATLAB/SimB/"`.

To get the displacements of the submodel B an ODE is solved. This is done by Newmark time integration method (as in the C source code for SimulatorB as described before). Select one of the m-files to choose the solver method and coupling type to use:

- `"runSimB_newmark_explicit.m"` for an integration by Newmark's method and explicit coupling.
- `"runSimB_newmark_implicit.m"` for an integration by Newmark's method and implicit coupling.

SIMPACK

The file `"ModelB.spck"` defines the part B of the spring mass system. SIMPACK computes the position of the mass x_b.

No additional preparation steps are required. The model consists of a mass and a spring with one degree of freedom in the x-direction. The gravity is also defined in the x-direction.

For SIMPACK implicit coupling is not supported.

SimulatorB

The executable for the SimulatorB is part of the MpCCI distribution (`"<`*MPCCI_HOME*`>/codes/SimulatorB/bin/<`*version*`>/<`*MPCCI_ARCH*`>/Mpcci_SimulatorB.exe"`).

SimulatorB receives the interface force λ_a (e. g. from SimulatorA) and then uses the Newmark time integration method to compute the acceleration, velocity and displacements:

$$\ddot{x}_b + \frac{1-\alpha}{1-\beta}\omega^2 x_b = -g - \frac{\lambda_b}{(1-\beta)m}$$

The displacements are exported to its partner code.

...

12.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

12.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.

2. Select a coupling specification.
   For coupling with SIMPACK which does not support the quantity Acceleration select Tutorial →SpringMassSystem (SIMPACK) otherwise select Tutorial →SpringMassSystem. The coupling specification offers a preconfigured setting for this tutorial (see Figure 2).
   Alternatively you can select the General coupling specification General two-domain coupling and do the required settings manually (cf. ▷ V-4.5.1 Category: General ◁).

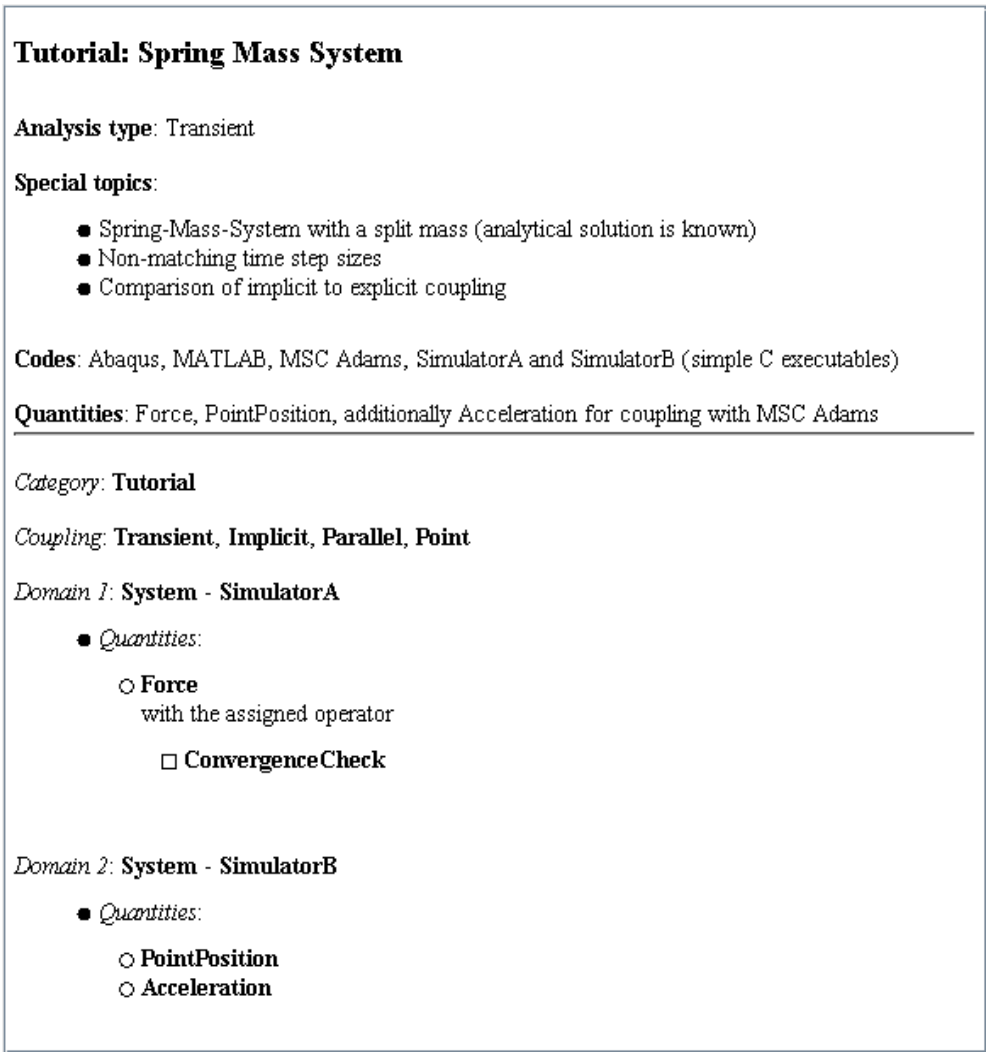


Figure 2: Coupling specification SpringMassSystem

12.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

1. For the first system domain, choose your code for Model A to couple:

MATLAB

Option	Action
Code to couple	Select MATLAB.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-12 MATLAB ◁).
MATLAB file	Select the MATLAB file from directory `"Matlab/SimA/"` depending on the used coupling type and whether the quantity Acceleration will be coupled or computed: `"runSimA_implicit.m"` for implicit coupling and computed acceleration. `"runSimA_explicit.m"` for explicit coupling and computed acceleration. `"runSimA_importAcceleration_implicit.m"` for implicit coupling and coupled acceleration. `"runSimA_importAcceleration_explicit.m"` for explicit coupling and coupled acceleration. If MATLAB is coupled with Adams select the file with the coupled Acceleration quantity. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

SimulatorA

Option	Action
Code to couple	Select SimulatorA.
Release	Set to latest.
SimulatorA file	Select the SimulatorA file `"SimulatorA/model.empty"`. This file is empty. The information is generated from the `"Scanner"` and all settings can be handled in the Go step. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

...

2. For the second system domain, choose your code for Model B to couple:

Abaqus

Option	Action
Code to couple	Select Abaqus
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-2 Abaqus ◁).
Input file	Select input file `"Abaqus/modelB.inp"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the SI unit system (which is the standard).

MATLAB

Option	Action
Code to couple	Select MATLAB.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-12 MATLAB ◁).
MATLAB file	Select the MATLAB file from directory `"Matlab/SimB/"` depending on the used solver and coupling type: For integration by Newmark's method `"runSimB_newmark_implicit.m"` for implicit coupling. `"runSimB_newmark_explicit.m"` for explicit coupling. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

Adams

Option	Action
Code to couple	Select Adams
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-3 Adams ◁).
Adams file	Select Adams file `"Adams/sim_command.acf"`. The file will be scanned immediately.
Solution type	Transient is displayed. The result of the scan process is Undefined (observable after a click on the Done button) but due to the selected coupling specification SpringMassSystem a transient solution is set automatically.
Unit system	Select the variable unit system (which is the default).
Grid length unit	Select mm as unit for the grid length (which is the default).

SIMPACK

Option	Action
Code to couple	Select SIMPACK
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-15 SIMPACK ◁).
SIMPACK file	Select SIMPACK file `"Simpack/ModelB.spck"`. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.
Unit system	Select the variable unit system (which is the default).
Grid length unit	Select m as unit for the grid length (which is the default).

SimulatorB

Option	Action
Code to couple	Select SimulatorB.
Release	Set to latest.
SimulatorB file	Select the SimulatorB file `"SimulatorB/model.empty"`. This file is empty. The information is generated from the `"Scanner"` and all settings can be handled in the Go step. The file will be scanned immediately.
Solution type	Transient is displayed as a result of the scan process.

...

Proceed to the Algorithm step by pressing Algorithm.

12.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The settings are divided into those for implicit and explicit coupling and should be as follows. If no action is mentioned, keep the default option.

Implicit Coupling:

Preset if the SpringMassSystem coupling specification for this tutorial is chosen. In this case only the setting for the coupling duration have to be done. If the General coupling specification has been chosen all settings have to be done.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	Set to Implicit.
▼ Solver settings	
Type of solver step size	Set to Constant.
Constant solver step size	Set to 2.655e-3 s.
▼ Coupling algorithm	
Algorithm type	Set i. e. to Parallel. Depending on this setting a Jacobi or Gauss-Seidel implicit coupling is applied (cf. ▷ V-3.4.5.1 Implicit Coupling ◁).
▼ Coupling duration	
Maximum number of coupling step iterations	Set to 10.
Set total coupling time	Check this option.
Total coupling time	Set to 0.25 s.

2. For your Model A code:

MATLAB

No code specific options need to be set.

The MATLAB file selected in the Models step must fit to implicit coupling and handling of acceleration quantity.

SimulatorA

No code specific options need to be set.

...

3. For your Model B code:

Abaqus

No code specific options need to be set.

MATLAB

No code specific options need to be set.

The MATLAB file selected in the Models step must fit to implicit coupling and handling of acceleration quantity.

Adams

No code specific options need to be set.

The analysis type is automatically set to Transient as mentioned in the Models step.

SIMPACK

No code specific options need to be set.

SimulatorB

No code specific options need to be set.

...

Explicit Coupling:

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	Set to Explicit.
▼ Coupling steps	
Type of coupling step size	Set Defined by each code.
Order of interpolation	Select one of Higher order, First order or Zero order. If coupling with non-matching time step sizes is used, different interpolation methods may lead to different results (cf. ▷ 12.5.2 Non-Matching Time Step Sizes ◁).
▼ Coupling algorithm	
Algorithm type	Set to Parallel. Serial coupling with non-matching time step sizes should be avoided (cf. ▷ V-3.4.5.3 Coupling with Non-Matching Time Steps ◁).
▼ Coupling duration	
Set total coupling time	Check this option.
Total coupling time	Set to 0.25 s.

2. For your Model A code:

MATLAB

No code specific options need to be set.

The MATLAB file selected in the Models step must fit to explicit coupling and handling of acceleration quantity.

SimulatorA

Option	Action
▼ Solver settings	
Solver step size	Set to e. g. 2.655e-3. Different time steps can be used for the simulators (cf. ▷ 12.5.2 Non-Matching Time Step Sizes ◁).

...

3. For your Model B code:

Abaqus

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 2.655e-03. This results in a coupling with matching time steps. Alternatively different time steps can be used for each code (cf. ▷ 12.5.2 Non-Matching Time Step Sizes ◁). You can either enter another fixed coupling time step or let Abaqus use its own adaptive time increment values by deactivating Constant coupling time step box.

MATLAB

No code specific options need to be set.

The MATLAB file selected in the Models step must fit to explicit coupling and handling of acceleration quantity.

Adams

Option	Action
▼ Analysis	
Analysis type	Select Transient.
▼ Solver settings	
Use semi-implicit interpolation	Check and access further options (see ▷ VI-3.2.8.1 Semi-implicit Mode ◁ for details).
Communication delay of the co-simulation	Set to 1 because we have explicit coupling.
Synchronized history buffer update	Check and access further options.
Time step for buffer update	Set to 2.655e-03.
Use constant mass	Check and access further options.
Value of the mass coefficient	Set to 0.25. This value corresponds to the mass of 2.5 kg used for the simulation multiplied by β and is the mass on the Model B side.
Provide partials to Adams	Check and access further options (see ▷ VI-3.2.8.2 Partial Derivatives in Adams ◁ for details).
Minimum value for derivatives	Set to -100e6.

See ▷ VI-3.2.7 Algorithm Step ◁ for details on the settings in the Adams Algorithm step.

SIMPACK

Option	Action
▼ Solver settings	
User library configuration	Check and access further options.
Use default uforce20	Set selected.
SIMPACK runtime configuration	Check and access further options.
Provide partials	Check to provide the partial derivatives of the received quantities with respect to the sent quantities (see ▷ VI-15.2.5.1 Semi-implicit Mode and Partial Derivatives ◁ for details).
Communication delay of the co-simulation	Set to 1 because we have explicit coupling.
Synchronized history buffer update	Check and access further options.
Time step for approximation update	Set to the step size of the co-simulation partner, e. g. 2.655e-3.

SimulatorB

Option	Action
▼ Solver settings	
Solver step size	Set to e. g. 2.655e-3. Different time steps can be used for the simulators (cf. ▷ 12.5.2 Non-Matching Time Step Sizes ◁).

...

Press the Regions button at the bottom of the window to get to the Regions step.

12.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁).

1. At first select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example the coupling region corresponds to points. The selected coupling specification for this project already set the coupling dimension to Point. So only the lists with Point (•) components are shown.

   The setup for building regions differs depending on the used simulation codes. Therefore the setup is split into the parts "Coupling without MATLAB " and "Coupling with MATLAB ". Lookup your setup in the appropriate part.

   Coupling without MATLAB Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

For region Region_1	
For system code	**Select coupling component**
Abaqus	• NQA
Adams	• GFORCE-1::GFORCE_1
SIMPACK	• $F_Spring
SimulatorA	• BearingPoint
SimulatorB	

   Coupling with MATLAB Since MATLAB can only couple one quantity per point, the MATLAB model consists of three separate points, one for each quantity. In order to be able to create a region for each coupled quantity it is necessary to make copies of the partner code component, if the partner code provides only one component for coupling.

   - Copy components for partner code providing only one component for coupling:
     Lookup your partner code in the list below and copy its component twice as described in ▷ V-4.8.2.1 Copying Components ◁.

Partner code	**Select component for copying**	**⇒ Copies**
Adams	• GFORCE-1::GFORCE_1	• GFORCE-1::GFORCE_1::1 • GFORCE-1::GFORCE_1::2
SIMPACK	• $F_Spring	• $F_Spring::1
	ⓘ Because SIMPACK doesn't support to couple quantity Acceleration only one copied component is needed for coupling with MATLAB.	
SimulatorA SimulatorB	• BearingPoint	• BearingPoint::1 • BearingPoint::2

     ⓘ Because the copy function is not available for Abaqus, the Abaqus model already provides the necessary parts (NQA, NQA_DUP, NQA_DUP2).
     MATLAB may be coupled with itself and needs no extra component preparation for this case.

   - Build the coupling regions.
     Lookup your codes in the following table and select the coupling components by dragging

them into the Added boxes:

– Build the first region.

For region Region_1	
For system code	**Select coupling component**
Abaqus	• NQA
MATLAB	• lambda
Adams	• GFORCE-1::GFORCE_1
SIMPACK	• $F_Spring
SimulatorA	• BearingPoint
SimulatorB	

– Click on button Add to add new region Region_2.

For region Region_2	
For system code	**Select coupling component**
Abaqus	• NQA_DUP
MATLAB	• disp1
Adams	• GFORCE-1::GFORCE_1::1
SIMPACK	• $F_Spring::1
SimulatorA	• BearingPoint::1
SimulatorB	

– If MATLAB is coupled with Adams you need to create a third coupled region for exchanging the Acceleration quantity.
For the other codes, except SIMPACK which doesn't support the Acceleration quantity, the exchange of Acceleration is optional. Doing so you may observe an improvement of the force progression on the monitor plot.
For adding a third region Region_3 click on button Add.

For region Region_3	
For code	**Select coupling component**
Abaqus	• NQA_DUP2
MATLAB	• acc1
Adams	• GFORCE-1::GFORCE_1::2
SimulatorA	• BearingPoint::2
SimulatorB	

– After all regions have been built, assign them a more understandable name as follows:
  * Select all regions.
  * Point with the mouse on the regions and do a right click.
  * From the popup menu choose Rename automatically and select MATLAB from the code list. The components from MATLAB will be used to rename the regions which

leads to regions lambda, disp1 and acc1.

3. Select Define Quantity Sets tab.
   The quantities have already been selected based on the chosen coupling specification: Force<–*Model A code*, PointPosition<–*Model B code* and Acceleration<–*Model B code* if Acceleration is supported.

   The exchange of Acceleration is optional except for the coupling with

   - Adams where the acceleration is required and
   - SIMPACK which doesn't support the Acceleration quantity.

   Doing so you may observe an improvement of the force progression on the monitor plot.

Coupling without MATLAB

- If the acceleration is not to be coupled, deselect the quantity Acceleration in the quantity set.
  This results in a quantity set with Force<–*Model A code* and PointPosition<–*Model B code*.
- For some quantities additional code specific settings are necessary:

For quantity	**Code specific settings**	
PointPosition	Adams	
	Unit	Set to mm.
Acceleration	Adams	
	Unit	Set to mm/s^2.

Coupling with MATLAB

As already mentioned, the coupling with MATLAB is limited to only one quantity per region. Therefore, several quantity sets with one quantity each must be created.

- Deselect all quantities but Force from the automatically created quantity set. This results in a quantity set with Force<–*Model A code*.
- Click on button Add to add the new quantity set EmptyQuantitySet.

For quantity set EmptyQuantitySet		
Select quantity	**Option**	**Action**
PointPosition	Set sender	Select code for Model B.
	Code specific settings	
	Adams	
	Unit	Set to mm.

  This results in a quantity set with PointPosition<–*Model B code*.
- If the acceleration is to be coupled, click on button Add to add the new quantity set EmptyQuantitySet.

For quantity set EmptyQuantitySet		
Select quantity	**Option**	**Action**
Acceleration	Set sender	Select code for Model B.
	Code specific settings	
	Adams	
	Unit	Set to mm/s^2.

  This results in a quantity set with Acceleration<–*Model B code*.

For an implicit coupling it is advisable to define a convergence tolerance for the inner iterations. Therefore a convergence check operator (cf. ▷V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components◁) has been added to the Force quantity. For this example a value of 0.01 is small enough to produce an accurate solution.

The operator is configured as follows:

Quantity	Operator	Operator option	Operator action
Force	Select ConvergenceCheck.	Tolerance value	Set to 0.01.

The convergence check operator is a pre processor and will be applied to the sender of the quantity.

For explicit coupling deselect the ConvergenceCheck operator from the Force quantity.

4. Select Assign Quantity Sets tab and assign the defined quantity sets to the built regions.

For coupling without MATLAB

For selected region	Check quantity set
Region_1	Force<–*Model A code*, PointPosition<–*Model B code* and optionally Acceleration<–*Model B code*

For coupling with MATLAB

For selected regions	Check quantity sets
lambda	Force<–*Model A code*
disp1	PointPosition<–*Model B code*
If coupling acceleration	
acc1	Acceleration<–*Model B code*

No changes are required in the Monitors step. You may proceed to the Settings step. by pressing Settings.

12.3.5 Settings Step

If implicit coupling is used and the relative difference between the inner iterations should be monitored during the coupled simulation, the monitor option Inorm has to be selected:

Parameter	Value
Monitor.Inorm	Set selected.

No further changes are required in the Settings step. Proceed to the Go step by pressing Go.

12.3.6 Go Step

No changes are required in the Go step. Now you may run the computation.

12.4 Running the Computation

12.4.1 Starting the Simulation

Save the MpCCI project file with name `"springmass.csp"` over the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and additional terminal windows open.

In case of explicit coupling a warning message is displayed, because the selected coupling specification specifies an implicit scheme with a constant step size of the solver and a convergence check operator for the force quantity. This warning can be ignored and a click on Continue will start the simulation codes.

No additional actions are required.

12.5 Discussion of Results

12.5.1 Implicit Coupling Compared to Explicit Coupling

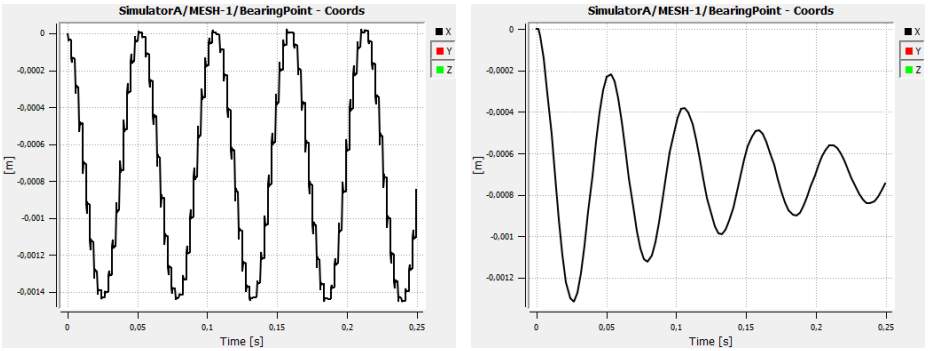


Figure 3: Comparison of implicit (left) and explicit (right) coupling results

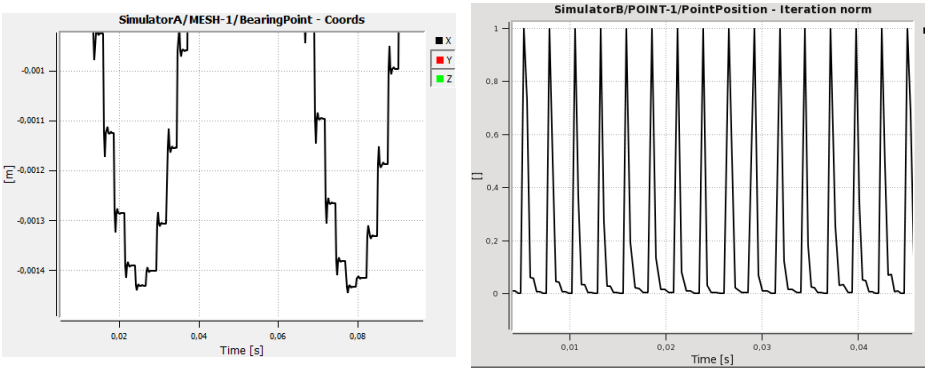


Figure 4: Implicit coupling in more detail: displacement of the bearing point (left) and relative variation of inner iterations (right), used to judge the convergence

Figure 3 shows the different results for an implicit and an explicit coupling algorithm. While the amplitude of the oscillating point displacements remains constant for the implicit coupling scheme, the explicit solution shows a decreasing amplitude.

For other parameter values the explicit coupling algorithm also produces the stable solution with a constant amplitude. Results of explicit coupling for small values β and small time steps are fine. Only for larger values of β and big time step values the instability shown in Figure 3 can be observed.

Implicit coupling results in a stable solution even for large values for β and larger time steps. For the results in Figure 3 a time step value of 2.655E-3 and default values for all other parameters were used.

Figure 4 (left) shows the displacement of the coupled point for the implicit coupling scheme in more detail. At the end of each time step the displacement is plotted for every inner iteration, distributed over the time step. The relatively big changes during the first iterations can be seen; then – depending on the stopping criteria used – the solution remains more or less constant and the next time step is started.

If the adaptive stopping criterion is set to a smaller value the displacement plot will change: the displacement value will reach the correct values earlier in the time step, and then remain more or less constant for the rest of the inner iterations in the time step. The force plots show the same behavior.

On the right hand side of Figure 4 the relative variation for the inner iterations – which is used to judge the convergence of the implicit scheme – is plotted. At the start of each new time step there is a peak, which gets smaller during the following inner iterations. This plot helps to adjust the convergence tolerance to a sensible and problem adapted value.

12.5.2 Non-Matching Time Step Sizes

Using explicit coupling algorithms this example can be used to demonstrate the flexibility of MpCCI when dealing with non-matching time step sizes (cf. ▷ V-3.4.5.3 Coupling with Non-Matching Time Steps ◁). If the codes each use their own time step size, MpCCI automatically interpolates the coupled quantity values to match the respective time steps as closely as possible.

Depending on the available quantity information from previous time steps and the user's interpolation method selection in the Algorithm step, a constant, linear or higher order interpolation (using up to four different time steps for the interpolation) is used.

Because of the oscillatory displacement, this example is very suitable for showing the differences between the interpolation methods.

Using different time step sizes and linear interpolation the oscillatory displacement cannot be recovered resulting in a wrong solution of the coupled simulation. For the plots shown in Figure 5 SimulatorA used a time step of 2.3E-3 and SimulatorB used the default time step value 2.655E-3 setting a parallel algorithm without initialization.

If both time steps are small enough and quite close to each other, a linear interpolation is able to reproduce the oscillations.

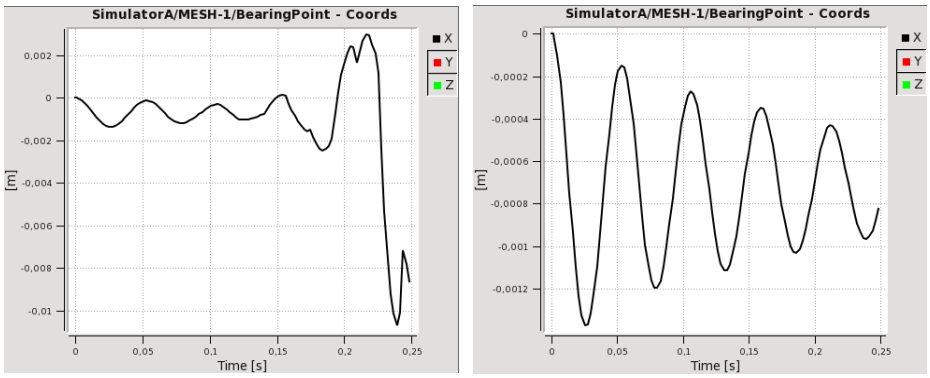


Figure 5: Non-matching time steps (2.3E-3 for SimulatorA and 2.655E-3 for SimulatorB) and different interpolation methods for the spring mass example: displacement for SimulatorA using linear interpolation (left) and higher order interpolation (right).

13 Y-Junction

13.1 Problem Description

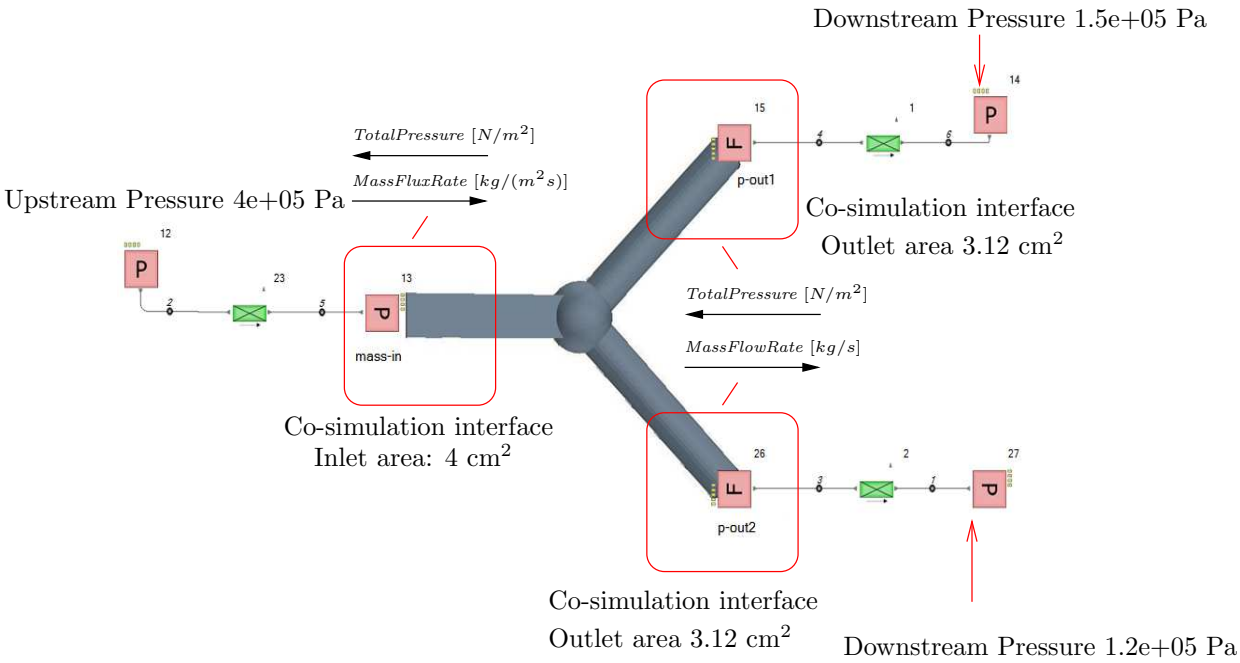


Figure 1: Y-Junction: Fluid geometry and system boundaries

Topics of this Tutorial

- 1D system model
- 3D fluid mechanics model
- Steady state
- Remote file browser

Simulation Codes

- System: FloMASTER
- Fluid mechanics: FLUENT, OpenFOAM, STAR-CCM+

13.2 Model Preparation

The simulation couples a system model with a fluid mechanics model. The files which you need for the simulation are included in the MpCCI distribution. Create a new directory `"Y-Junction"` and copy the subdirectories from `"<`*MpCCI_home*`>/tutorial/Y-Junction"` which correspond to the simulation codes you want to use.

13.2.1 System Model

FloMASTER

The FloMASTER model (Figure 2) is composed of three fluid pipe systems. Each pipe system will prescribe a flow (inlet/outlet) or pressure boundary to the fluid model. The boundaries in a fluid model are represented within a FloMASTER system by a source.

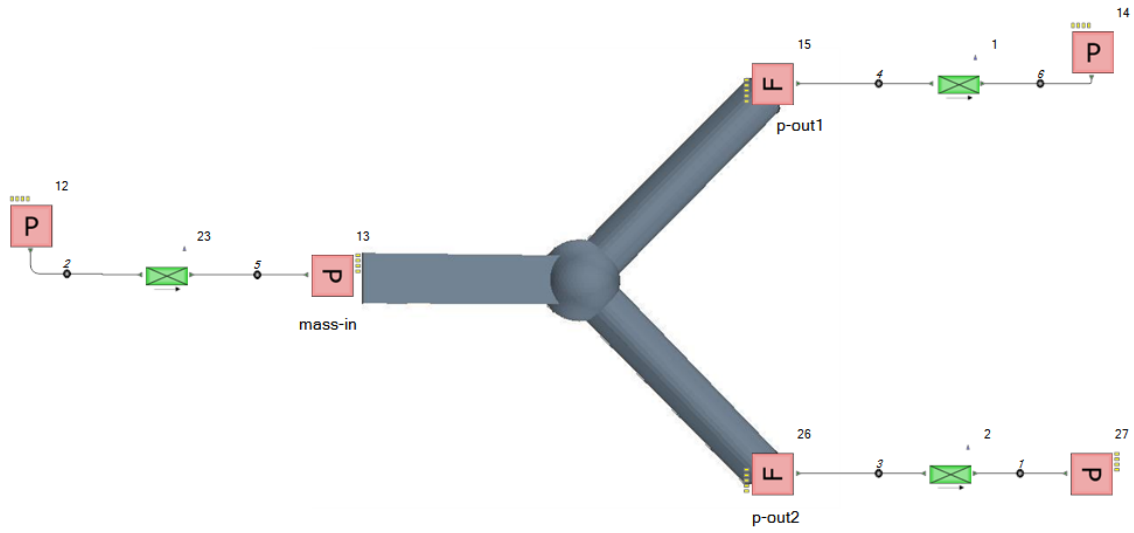
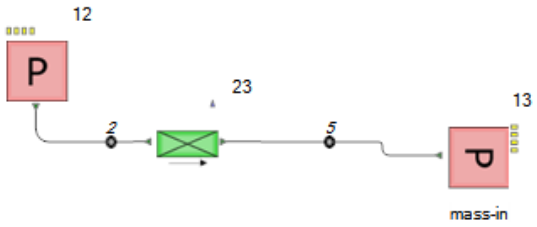


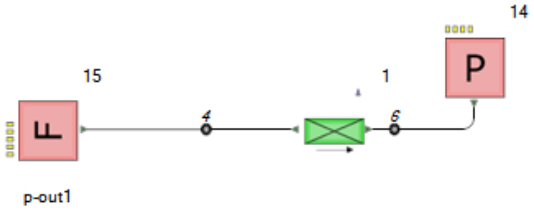
Figure 2: Y-Junction: FloMASTER network

Pipe System Upstream Components Settings



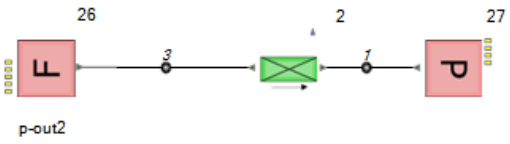
- Liquid type is water.
- The pressure source component "12" has pressure value set to 4e+5 Pa.
- The pressure source component "13" has no specific pressure value set.

Pipe System First Downstream Branch Settings



- Liquid type is water.
- The pressure source component "14" has pressure value set to $1.5e^{+5}$ Pa.
- The flow source component "15" has an initial volumetric flow rate value set to $0.0005 \frac{m^3}{s}$.

Pipe System Second Downstream Branch Settings



- Liquid type is water.
- The pressure source component “27” has pressure value set to $1.2e^{+5}$ Pa.
- The flow source component “26” has an initial volumetric flow rate value set to $0.0004\frac{m^3}{s}$.

Extract the FloMASTER System

1. Start FloMASTER then you need to log on the FloMASTER database.
2. Unpack the appropriate `"Y_Junction.FMpck"` pack file from the `"<`*MpCCI_home*`>/tutorial/Y-Junction/FloMASTER "` folder.

Unpack the file directly under the root of your project tree.

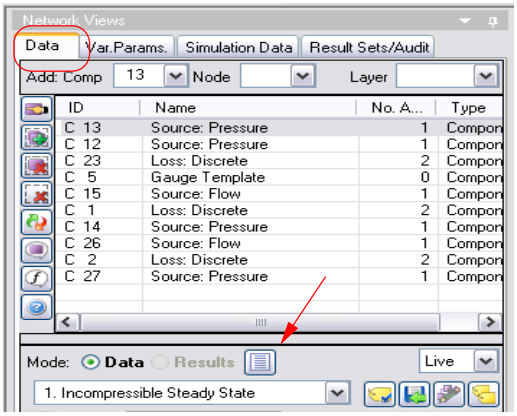
Configure the FloMASTER System for the Co-Simulation

Each source boundary has to activate its External Model Boundary property. For the following boundary IDs “13”, “15”, “26” you have to follow these instructions:

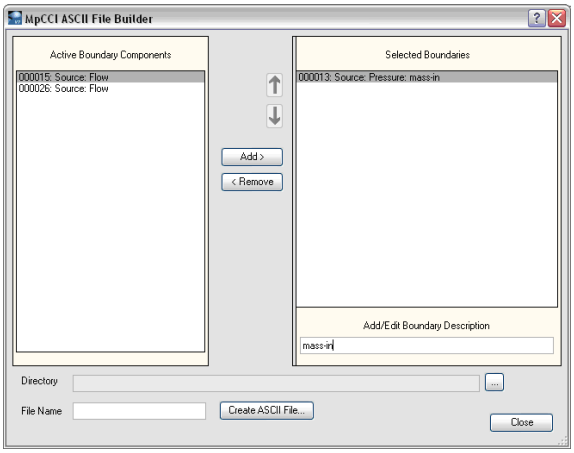
1. Select the boundary component.
2. Edit the boundary with the Edit mouse menu context.
3. Select in the property list the External Model Boundary item.
4. Click on the Sub Form... button.
5. Change the property Boundary Active value to Yes.
6. Click on the button Return.

Run a standalone incompressible steady state (SS) FloMASTER analysis to test the configuration.

Export the FloMASTER System Co-Simulation Information



- In the Network Views select the Data tab option.
- Click on the icon button that Generate a network data or analysis results report.
- Select the MpCCI Link File report type and click on the button OK.



- From the list of Active Boundary Components, select each item and click on the button Add >.
- All active boundary components are in the Selected Boundaries.
- Select a boundary and provide a description by filling the text field Add/Edit Boundary Description.
- For the boundary “13”, enter the name “mass-in”.
- For the boundary “15”, enter the name “p-out1”.
- For the boundary “26”, enter the name “p-out2”.
- Click on the button ... to select an output directory. (e. g. "<*MpCCI_home*>/tutorial/Y-Junction/FloMASTER ")
- In the File Name field provide the name "Y_Junction.fmlink".
- Click on the button [Create ASCII File...
- The file has been created, the dialog can be closed.
- Exit the FloMASTER graphical interface.

Do not renumber any network used for co-simulation as component IDs are used to identify boundaries in MpCCI link file.

13.2.2 Fluid Model

The fluid model is a 3D model using the following settings:

- Turbulence model: k-epsilon RNG
- Time: Steady State
- Fluid: water
- Initial velocity 20 $\frac{m}{s}$
- Mass flow inlet boundary has an initial mass flux rate of 24950 $\frac{kg}{m^2.s^1}$
- Pressure outlet boundary has an initial pressure of $1.5e^{+5}$ Pa and $1.2e^{+5}$ Pa.
- Reference Pressure is 101325 Pa.

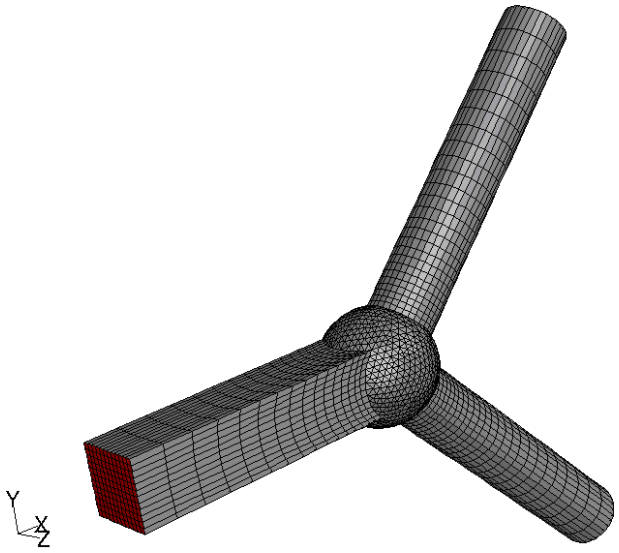


Figure 3: Y-Junction: mesh

13.3 Setting Up the Coupled Simulation with MpCCI GUI

See ▷ IV-2 Setting up a Coupled Simulation ◁ and ▷ V-4 Graphical User Interface ◁ for a detailed description on how to use the MpCCI GUI. Following are the substantive rules to be set in the MpCCI GUI in order to run this tutorial.

13.3.1 Start a New Project

1. At first start the MpCCI GUI by running the command `mpcci gui`.
2. Select the Tutorial coupling specification Y-Junction which offers a preconfigured setting for this tutorial (see Figure 4). Alternatively you can select the General coupling specification General two-domain coupling and do the required settings manually (cf. ▷ V-4.5.1 Category: General ◁).

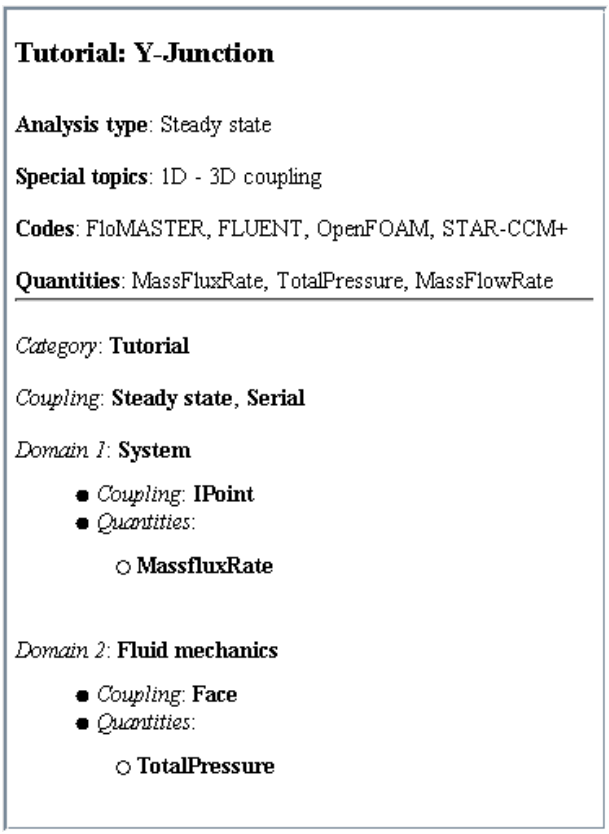


Figure 4: Coupling specification Y-Junction

13.3.2 Models Step

In the Models step select and configure the codes to be coupled (cf. ▷ IV-2.4 Models Step – Choosing Codes and Model Files ◁). Further information on the offered code parameters in the Models step can be looked up in the respective code section of the Codes Manual.

In this tutorial it might be necessary to run MpCCI on different machines with different operating systems

because FloMASTER is only supported for Microsoft Windows and OpenFOAM is only supported for Linux. To select your remote model files see ▷ V-4.12 Remote File Browser ◁.

1. For the system domain, choose your code to couple:

FloMASTER

Option	Action
Code to couple	Select FloMASTER.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-8 FloMASTER ◁).
Data file	Select data file `"FloMASTER/Y_Junction.FMPck"`. The file will be scanned immediately.
Solution type	Steady state is displayed although the result of the scan process is Undefined. However, because the chosen coupling specification presets a stationary analysis, the solution type is updated by MpCCI.

...

2. For the fluid mechanics domain, choose your code to couple:

FLUENT

Option	Action
Code to couple	Select FLUENT.
Version	The model is three-dimensional, thus select the FLUENT version 3ddp.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-9 FLUENT ◁).
Case file	Select the case file `"FLUENT/Y-junction.cas.gz"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

OpenFOAM

Option	Action
Code to couple	Select OpenFOAM.
Option	Select the OpenFOAM option Opt or Debug.
Precision	Select the OpenFOAM precision: DP for double or SP for single precision.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-14 OpenFOAM ◁).
Case directory	Select the case directory `"OpenFOAM/<version>"` fitting your OpenFOAM version (e. g. `"OpenFOAM/v1606-v2306"` for use with OpenFOAM v1606 to v2306). The files will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.
▼ Additional model properties	
	Set reference values according to the fluid properties from ▷ 13.2.2 Fluid Model ◁.
Reference pressure	Set pressure to 101325 N/m^2.
Reference density	Set density to 998 kg/m^3. This corresponds to the material density of water in this model.

STAR-CCM+

Option	Action
Code to couple	Select STAR-CCM+.
Release	Should be set to latest or a version supported by MpCCI (see ▷ VI-16 STAR-CCM+ ◁).
Simulation file	Select the simulation file `"STAR-CCM+/yjunction.sim"`. The file will be scanned immediately.
Solution type	Steady state is displayed as a result of the scan process.

...

A warning window will appear and complains about the model dimensions. You can continue by clicking on Continue.

Proceed to the Algorithm step by pressing Algorithm.

13.3.3 Algorithm Step

In the Algorithm step define the coupling algorithm (cf. ▷ IV-2.5 Algorithm Step – Defining the Coupling Algorithm ◁).

The algorithm option is already preset by the selected coupling specification. Its setting is nevertheless mentioned here for the sake of completeness and in case a general coupling specification was chosen.

The settings should be as follows. If no action is mentioned, keep the default option.

1. For the Common Basics panel:

Option	Action
▼ Coupling analysis	
Define the coupling scheme	This option is automatically set to Explicit.
▼ Coupling algorithm	
Algorithm type	Set to Serial.
Leading code	Set to system code.
▼ Coupling duration	
Set maximum number of coupling steps	Check this option.
Maximum number of coupling steps	Set to 50.

2. For the system code:

FloMASTER

Option	Action
▼ Analysis	
Analysis type	Select Steady state.

...

3. For the fluid mechanics code:

FLUENT

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 20 for number of steps without coupling.
▼ Runtime control	
Define coupling start	Set to Specify iteration to enable a pre-calculation.
Iteration number for coupling start	Set to 200 to activate a pre-calculation of 200 iterations.

OpenFOAM

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 20 for number of steps without coupling.
▼ Runtime control	
Define coupling start	Set to Specify iteration to enable a pre-calculation.
Iteration number for coupling start	Set to 200 to activate a pre-calculation of 200 iterations.

STAR-CCM+

Option	Action
▼ Coupling steps	
Type of coupling step size	Set to Constant.
Constant coupling step size	Set to 20 for number of steps without coupling.
▼ Runtime control	
Define coupling start	Set to Specify iteration to enable a pre-calculation.
Iteration number for coupling start	Set to 200 to activate a pre-calculation of 200 iterations.

...

Press the Regions button at the bottom of the window to get to the Regions step.

13.3.4 Regions Step

In the Regions step build the coupling regions, define quantities to be exchanged and assign the defined quantities to the built regions (cf. ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁).

1. At first select the Mesh tab to get access to the mesh based element components.
2. Select Build Regions tab and here the Setup tab.
   In this example the coupling region corresponds to the surface of the inlet and outlet boundaries. For the system code, MpCCI treats this region as a zero-dimensional "Integration Point". For the fluid mechanics codes, MpCCI treats this region as a "Face" because it represents a 2D structure. The selected coupling specification for this project has already set the coupling dimensions properly. So only the lists with Integration Point (I•) and Face (▲) components are shown.

Lookup your codes in the following table and select the coupling components by dragging them into the Added boxes:

- Build the first region, which represents the flow boundary.

For region Region_1	
For system code	**Select coupling component**
FloMASTER	mass-in
For fluid mechanics code	**Select coupling component**
FLUENT	mass-in
OpenFOAM	
STAR-CCM+	

- Click on button Add to add new region Region_2 for the first pressure boundary.

For region Region_2	
For system code	**Select coupling component**
FloMASTER	p-out1
For fluid mechanics code	**Select coupling component**
FLUENT	p-out1
OpenFOAM	
STAR-CCM+	

- Click on button Add to add new region Region_3 for the second pressure boundary.

For region Region_3	
For system code	**Select coupling component**
FloMASTER	p-out2
For fluid mechanics code	**Select coupling component**
FLUENT	p-out2
OpenFOAM	
STAR-CCM+	

- After all regions have been built, assign them a more understandable name as follows:
  - Select all regions.
  - Point with the mouse on the regions and do a right click.
  - From the popup menu choose Rename automatically and select a code from the list. The components from this code are used to rename the regions. Since the components are named the same in all codes, renaming will lead to regions mass-in, p-out1, and p-out2.

3. Select Define Quantity Sets tab.
Now choose the quantities to be exchanged. We define two quantity sets, one for the flow boundary and one for the pressure boundaries.

- Choose the quantities for the flow boundary. As currently no quantities are assigned to “Emp-

tyQuantitySet" (created by default), a warning symbol is displayed in front of it.

For quantity set EmptyQuantitySet		
Select quantities	**Make quantity settings**	
	Option	**Action**
MassFluxRate	Set sender	Select system code.
	Code specific settings	
	FLUENT	
	index	Set to 0 for receive method UDM.
TotalPressure	Set sender	Select fluid mechanics code.

The resulting name for the quantity set will be MassFluxRate<–*System code* | TotalPressure<–*Fluid mechanics code*.

- Apply an operator to MassFluxRate to get a stable computation (cf. ▷ V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).
  Under-relaxation will be needed. Therefore mark the wanted quantity by clicking on its name and configuring the listed operator as follows:

Quantity	**Operator**	**Operator option**	**Operator action**
MassFluxRate	Select Relaxation.	Relaxation method	Select Fixed.
		Relaxation factor	Set to 0.3 for under-relaxation.

The relaxation operator is a post processor which will be applied to the receiver of the quantity.

- Click on button Add to add new quantity set EmptyQuantitySet and choose the quantities for the pressure boundaries.

For quantity set EmptyQuantitySet		
Select quantities	**Make quantity settings**	
	Option	**Action**
MassFlowRate	Set sender	Select fluid mechanics code.
TotalPressure	Set sender	Select system code.
	Code specific settings	
	FLUENT	
	index	Set to 1 for receive method UDM.

The resulting name for the quantity set will be MassFlowRate<–*Fluid mechanics code* | TotalPressure<–*System code*.

- Apply an operator to TotalPressure to get a stable computation (cf. ▷ V-4.8.7.4 Applying Operators to Quantities of Mesh Based Components ◁).
  Under-relaxation will be needed. Therefore mark the wanted quantity in quantity set MassFlowRate<–*Fluid mechanics code* | TotalPressure<–*System code* by clicking on its name and configuring the listed operator as follows:

Quantity	**Operator**	**Operator option**	**Operator action**
TotalPressure	Select Relaxation.	Relaxation method	Select Fixed.
		Relaxation factor	Set to 0.3 for under-relaxation.

The relaxation operator is a post processor which will be applied to the receiver of the quantity.

4. Select Assign Quantity Sets tab and assign the defined quantity sets to the built regions.

Select regions	Check quantity sets
mass-in	MassFluxRate<–*System code* | TotalPressure<–*Fluid mechanics code*
p-out1 p-out2	MassFlowRate<–*Fluid mechanics code* | TotalPressure<–*System code*

Proceed to the Monitors step by pressing Monitors.

13.3.5 Monitors Step

To monitor the total pressure distribution on the uncoupled pipe surface of the fluid mechanics code an additional component has to be selected.

- Select the Mesh tab to get access to the mesh based element components.
- Lookup your code and configure the component to be monitored.

For fluid mechanics code	Option	Action
FLUENT	Component Dimension	Select Face (▲)
OpenFOAM	Monitored	Select component ▲ wall
STAR-CCM+	Quantity	Check TotalPressure

No changes are required in the Settings step. You may proceed to the Go step by pressing Go.

13.3.6 Go Step

In the Go step configure the application startup and start server and codes (cf. ▷ IV-2.8 Go Step – Configuring the Application Startup and Running the Coupled Simulation ◁).

In the server panel, no changes are necessary.

The code panels are described for each code below. If nothing special is mentioned keep the default settings. Further information on the offered code parameters in the Go step can be looked up in the respective code section of the Codes Manual.

1. For your system code:

FloMASTER

Option	Action
User name	Enter the user name to log in the database.
Working project name	Change the name of the working project corresponding to the root of your project list view in FloMASTER if necessary.
▼ Analysis specification	
System	Select Incompressible for the system.
Analysis type	Select SS for the analysis type.

. . .

2. For your fluid mechanics code:

FLUENT

Option	Action
Optional journal file	Select journal file `"FLUENT/job.jou"`.

OpenFOAM

No code specific options need to be set.

STAR-CCM+

Option	Action
Run in batch	Check this option.
Auto start with the default template macro	Check this option.
License options	Set according to your license type (cf. ▹VI-16.2.5 Go Step◃).

...

Now you may run the computation.

13.4 Running the Computation

13.4.1 Starting the Simulation

Save the MpCCI project file with name `"y_junction.csp"` over the MpCCI GUI menu File→Save Project As.

Press the Start button in the Go step. The simulation codes are started and their GUI or additional terminal windows open.

FloMASTER

The FloMASTER calculation is started in batch mode.

FLUENT

The FLUENT GUI is started and the calculation starts automatically. The FLUENT journal file `"job.jou"` defines the following procedures:

```
;; initialize flow
/solve/initialize initialize-flow

;; do 1000 iterations
/solve iterate 1000
```

FLUENT will perform 1000 iterations (50 coupling steps with 20 iterations each without coupling) until FLUENT converges.

OpenFOAM

The OpenFOAM calculation is started in batch mode. OpenFOAM will perform 1000 iterations (50 coupling steps with 20 iterations each without coupling).

STAR-CCM+

The STAR-CCM+ calculation is started in batch mode. STAR-CCM+ will perform 1000 iterations (50 coupling steps with 20 iterations each without coupling).

...

13.5 Discussion of Results

FloMASTER

You can open the FloMASTER GUI and open the Y_Junction project. You can select some last results and plot a chart of the pressure or mass flow for one boundary component for example.

FLUENT

After FLUENT finished the 1000 iterations, you could save the data and post process the results with FLUENT.

OpenFOAM

OpenFOAM results may be visualized with paraFoam.

STAR-CCM+

STAR-CCM+ result file `"yjunction@01000.sim"` may be post processed.

...

On the fluid model we expect that the pressure at the inlet and outlet is close to the prescribed pressure values imposed by the system model.
At the inlet boundary "mass-in" a pressure of $4e^{+5}$ Pa was prescribed on the system model and on the fluid a total pressure value around $2.3e^{+}5$ Pa is expected.
At the outlet boundary "p-out1" and "p-out2" a total pressure value of $1.5e^{+}5$ Pa respectively $1.2e^{+}5$ Pa is expected.
By using the MpCCI Visualizer you may visualize the coupled values from the
tracefile directory `"mpccirun_<TIMESTAMP>_ccvx"` by executing the command from the tracefile directory:
`mpcci visualize mpccirun-0000.ccvx`

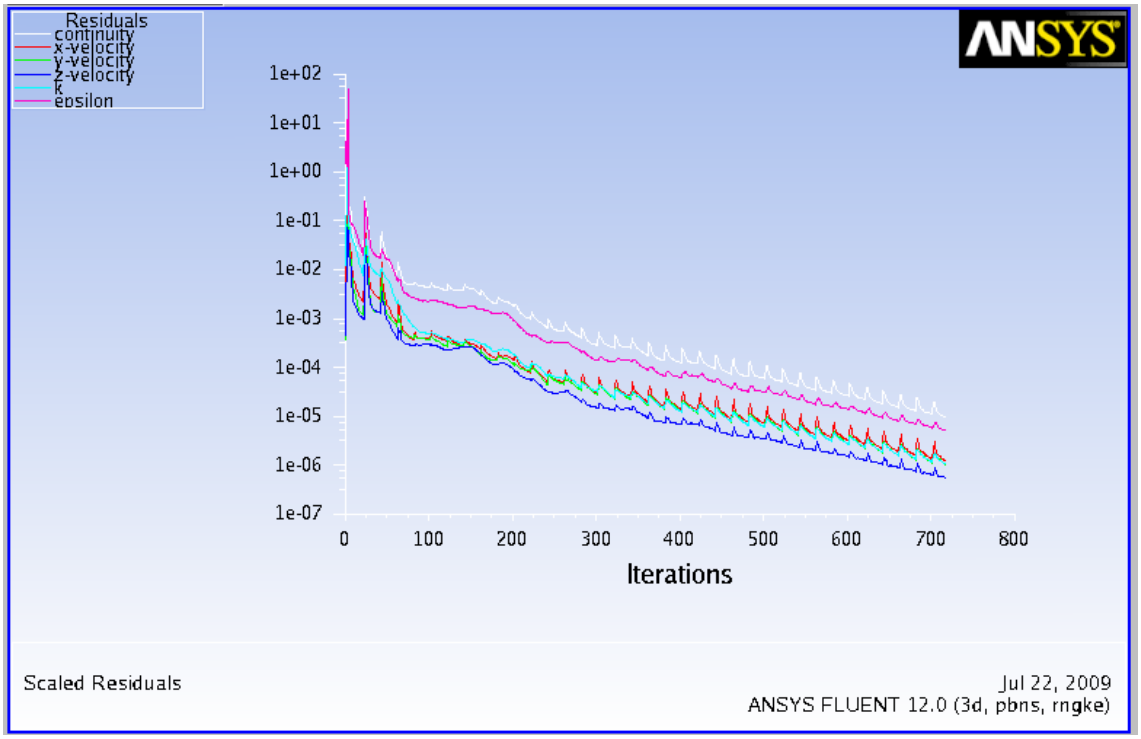


Figure 5: Y-Junction: Fluent Residuals plot

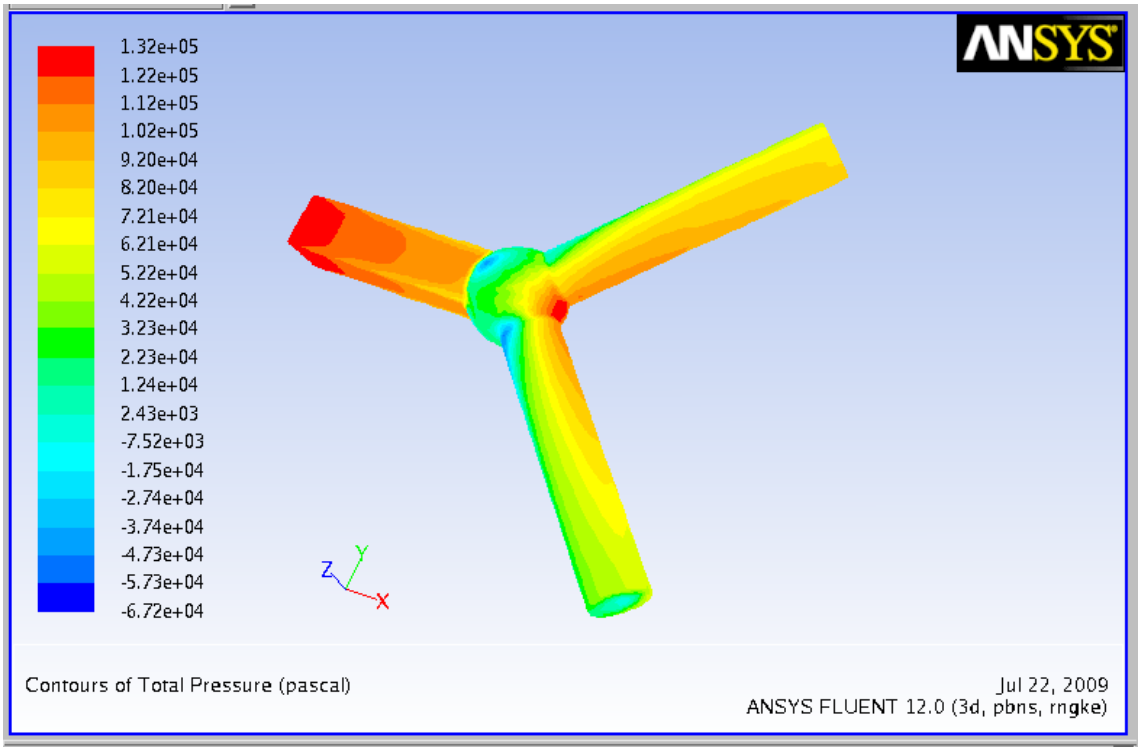


Figure 6: Y-Junction: Fluent Total Pressure plot

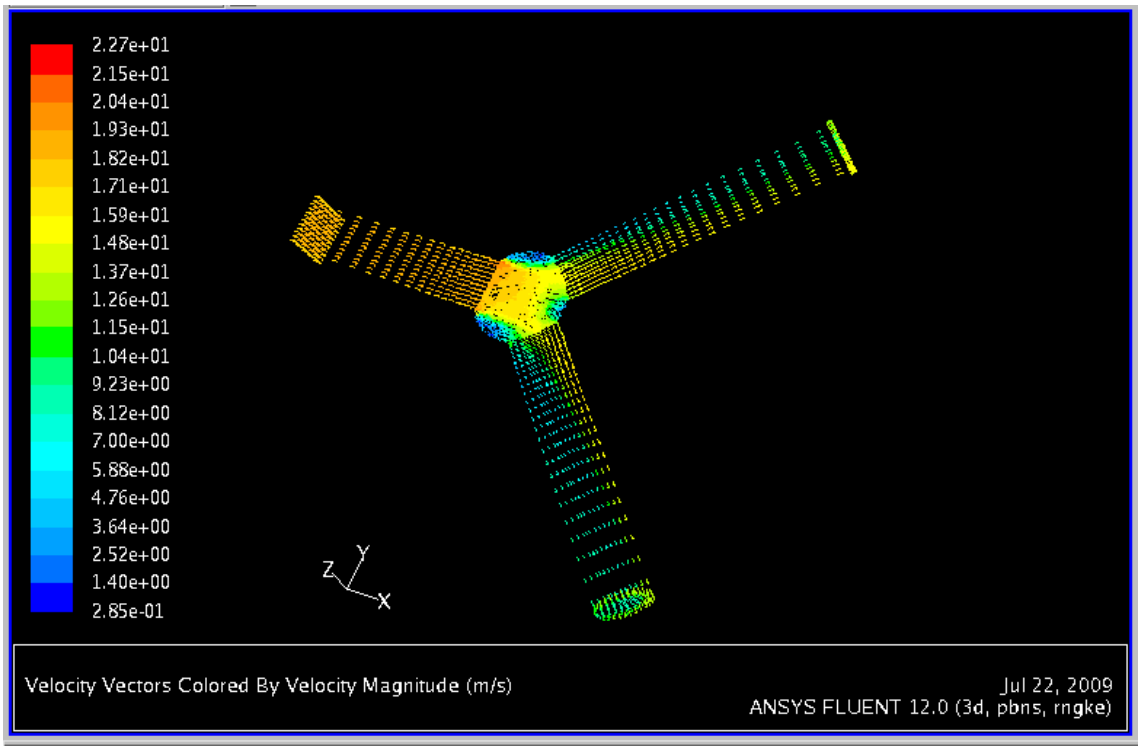


Figure 7: Y-Junction: Fluent Velocity vector section plot

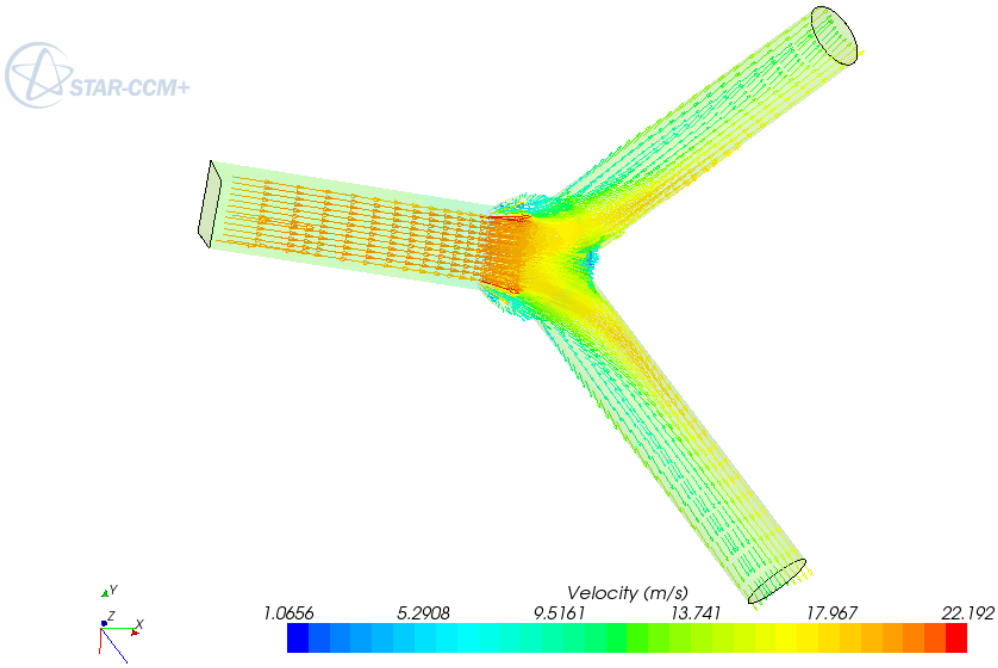


Figure 8: Y-Junction: STAR-CCM+ Velocity vector section plot

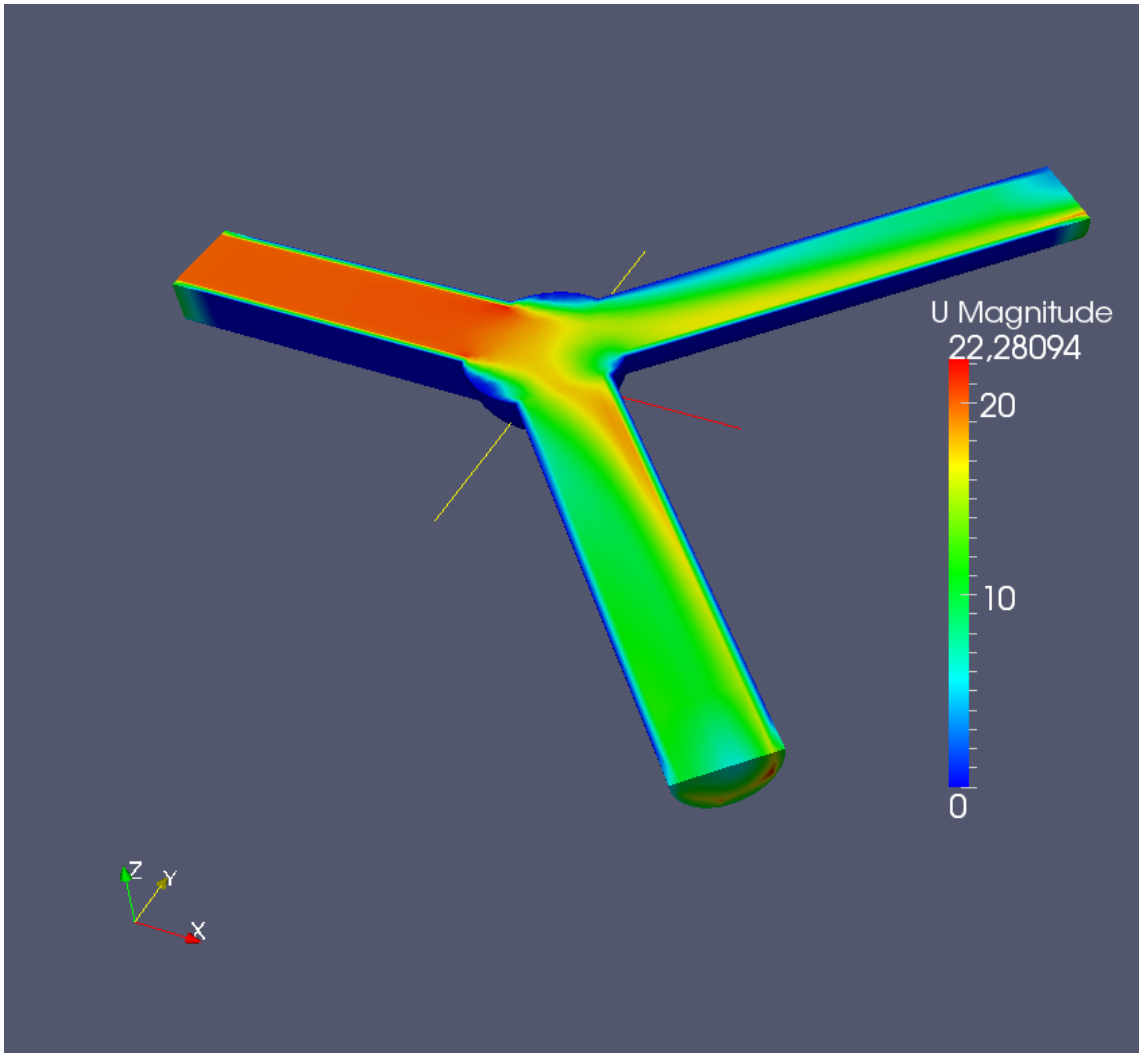
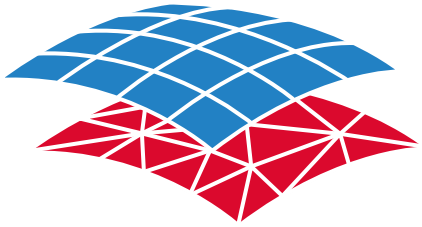


Figure 9: Y-Junction: OpenFOAM Velocity contour section plot



MpCCI
CouplingEnvironment

Part VIII

—

Programmers Guide

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part VIII Programmers Guide
PDF version
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SCAI

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VIII Programmers Guide – Contents

1 Introduction

This "Programmers Guide" addresses to engineers who have developed their own simulation code and plan to use it within the MpCCI coupling environment. The current MpCCI version allows one level of interfacing own codes with the coupling environment:

- the MpCCI Adapter level used since MpCCI 3 for commercial codes.

The MpCCI SDK interface level provides various basic functions to define coupling regions, control communication between the coupled codes and to handle other MpCCI parameters. There is no fixed protocol by using the MpCCI SDK when to communicate which data with which other components. There is no guarantee that the MpCCI SDK integration of a code A has a compatible communication protocol as that of any other code B.

To avoid such protocol incompatibilities between different code integrations MpCCI 3.0 has introduced the concept of code adapters. These adapters have internal mechanisms to control the current coupling state and actions of each integrated code. The `Code Coupling Manager` guarantees a consistent behavior and communication protocol for all adapted codes. Chapter ▷ 2 MpCCI API ◁ describes the integration of new simulation codes using a code adapter.

The current MpCCI 4 supports the code Adapter level integration. In midterm the codes using MpCCI SDK interface of MpCCI 3 should migrate their coupling interface with that standard coupling interface.

2 MpCCI API

MpCCI `API` represents the `Adapter Programming Interface`.
This section describes how to establish MpCCI support for your code, i. e. the code then can be coupled with all other codes, which are already supported by MpCCI.

This section is organized as follows:

- General description of code integration. Read this to get an idea how code integration works.
  ▷ 2.1 Code Integration and Simulation Code Requirements ◁
- Description of the MpCCI API Kit, which contains template files and an example. A step-by-step procedure for code integration is given here.
  ▷ 2.2 Code Integration with the MpCCI API Kit ◁
- Reference for MpCCI GUI integration.
  ▷ 2.3 Code Configuration Directory ◁
  ▷ 2.4 MpCCI GUI Configuration File gui.xcf ◁
  ▷ 2.5 Perl Scripts ◁
- Reference for the code adapter.
  ▷ 2.6 MpCCI Adapter Implementation ◁
  ▷ 2.7 MpCCI Coupling Manager Functions ◁
  ▷ 2.8 MpCCI Driver Functions ◁
  ▷ 2.9 Data Structures and Predefined Macros ◁

Before starting the integration of a new code, you should contact the MpCCI support, `mpcci-support@scai.fraunhofer.de`, to obtain:

- The MpCCI API Kit, a set of template files and an example.
- A license for an adapter to your code.

2.1 Code Integration and Simulation Code Requirements

In order to understand code integration, you should be aware of the general procedure of a coupled simulation with MpCCI, which is described in ▷ IV-1.3 Code Coupling with MpCCI ◁.

2.1.1 Data Exchange and Data Access

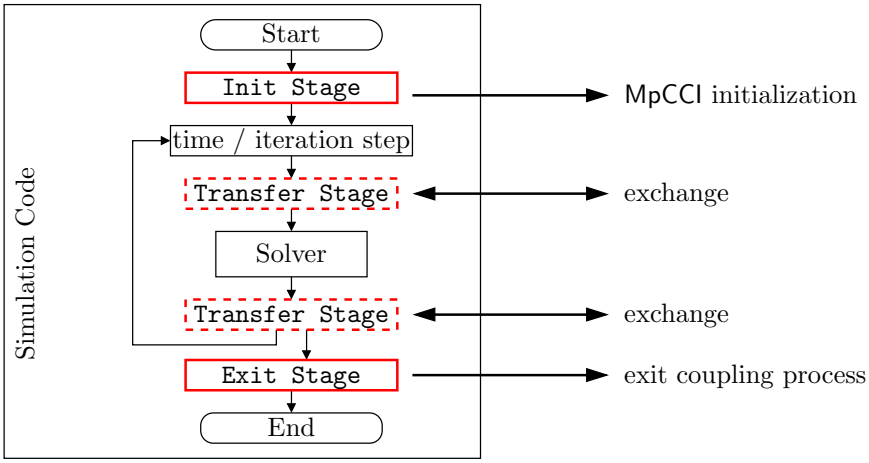


Figure 1: Calls of adapter library routines from the simulation code. The `Transfer Stage` can be inserted before or after the solver.

For the coupling process, the analysis code must be able to send and receive data based on the mesh of a coupling component. This requires access to the following data of a simulation code:

Mesh information MpCCI handles exchanges of data between non-matching grids, thus it needs to know the grids on both sides. Therefore, the mesh data of the coupling component must be transferred to MpCCI. This includes

- Number of nodes, number of elements, type of floating point values
- Nodes: ID, coordinates,
- Elements: ID, type, nodes.

Physical values to be exchanged During the coupling process, data is exchanged, which must be transferred to MpCCI or received from MpCCI. This requires local

- Reading access to values of data to be transferred,
- Allocation of memory for receiving data,
- Method to put received data on local mesh.

Time/Iteration information During the coupling process, data is exchanged, which must be identified by the simulation time or iteration. This allows the MpCCI server to manage the data exchange and to provide the corresponding data requested by a code.

The data is sent or received by "driver functions", which must be implemented as part of the code adapter. In addition coupling manager functions of the adapter library must be called by the interface functions. The simulation calls these functions at certain stages as depicted in Figure 1.

MpCCI provides a C-Interface, which can be used from C, C++ and FORTRAN codes.

In addition to this actual adapter, a number of files can be provided to allow MpCCI to manage the coupled simulation and integrate the code into the MpCCI GUI.

2.1.2 MpCCI Interface for Code Integration

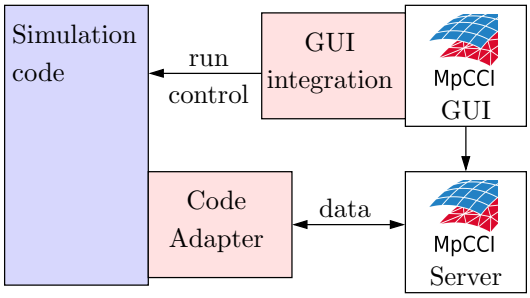


Figure 2: The two basic parts needed for code integration: GUI integration and code adapter

Two basic things are necessary for coupling a simulation code with MpCCI, see also Figure 2.

GUI integration. The integration into the MpCCI GUI is realized with a set of configuration files which describe the properties and capabilities of a code, how to scan input files and start the code. An overview of these files is given in ▷ 2.3 Code Configuration Directory ◁.

Code Adapter. The code adapter is needed to handle the data exchange. The adapter is a plug-in into the simulation code, which can be realized in different ways: It can be included directly into the code or be based on user functions which are provided by the code. MpCCI provides a basic C-interface for the development of code adapters. The structure of the code adapter is sketched in Figure 3. Its main parts are:

Driver functions which perform the basic data exchange with the code. It is the passive part of the adapter, as the driver functions are called by the adapter library.

The Code Coupling Manager is a set of functions for the communication between the code adapter and the MpCCI server. It is part of the MpCCI software package. The functions are defined in the header file `"mpcci.h"`, the object files in `"libmpcci*.a"` must be linked with the simulation code. The coupling manager functions call the provided driver functions. The exact procedure is sketched exemplarily for `mpcci_init` in Figure 22.

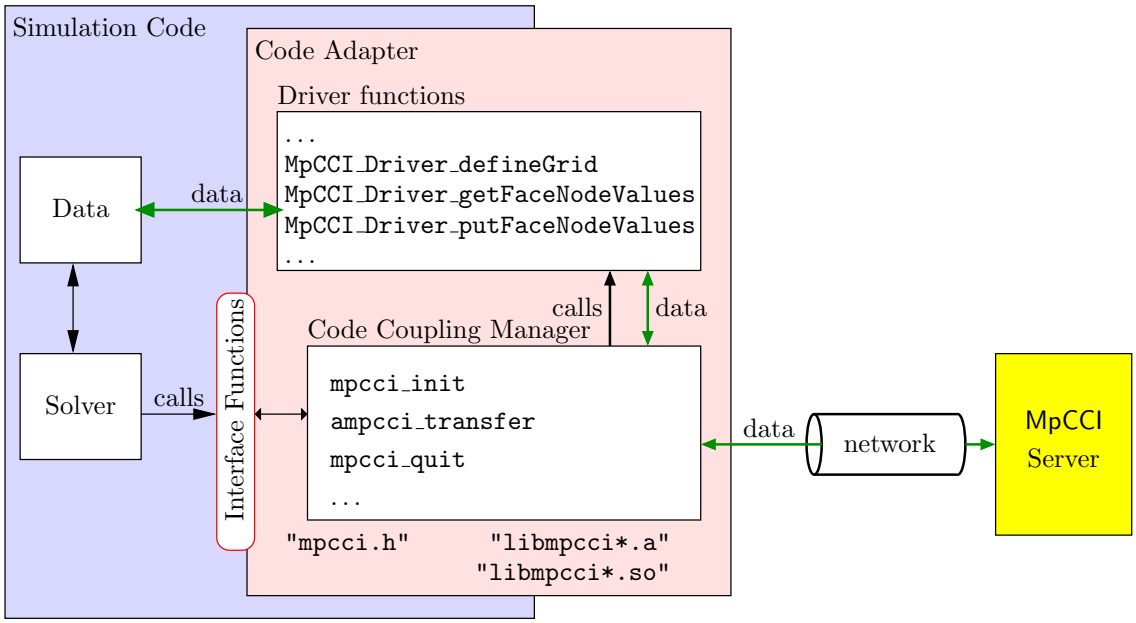


Figure 3: Code adapter structure: The code adapter is a plug-in of the analysis code, which consists of two parts: Driver functions and Code Coupling Manager

2.2 Code Integration with the MpCCI API Kit

The MpCCI API Kit contains templates as well as a simple example to demonstrate the integration of a simulation code into MpCCI.

The MpCCI API Kit contains the following files:

Directory	**Description**
`"adapter"`	Templates for code adapter
`"configuration"`	Templates for configuration directory
`"example/configuration"`	Configuration directory files for the example
`"example/C/src"`	Source code of the example in C
`"example/C/src-nompcci"`	Source code of the example without code adapter in C
`"example/FORTRAN/src"`	Source code of the example in FORTRAN
`"example/FORTRAN/src-nompcci"`	Source code of the example without code adapter in FORTRAN
`"example/test"`	Files for testing the example
`"example/test-nompcci"`	Files for testing the example without code adapter

2.2.1 A Simple Example

As a simple example, the – simplified – simulation of an elastic foundation is included in the MpCCI API Kit. The original source code is included in the directory `"example/C/src-nompcci"`, a FORTRAN version can be found in `"example/FORTRAN/src-nompcci"`. The code can be used for two- and three-dimensional computations. The functionality is implemented in `"main.c"` (`"main.f"`), data structures are defined in `"data.h"` and `"data.c"` (`"data.f"`) together with a simple file input routine. The code is kept simple and thus does not contain any input file checks etc. .

Only two element types are supported: Line elements with two nodes and quadrilateral elements with four

nodes. For each element an example input file is included in `"example/test-nompcci"`.

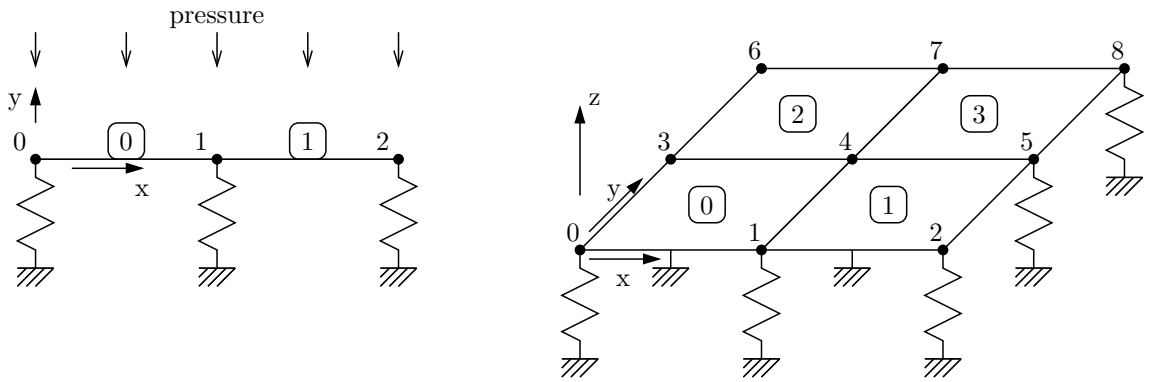


Figure 4: Examples for the simple foundation code.

The structure modeled in `"2dexample.fnd"` is depicted in Figure 4 on the left, its content is:

```
EF bed1 2 1 -0.5
NODES 3
0 0 0
1 1 0
2 2 0
ELEMENTS 2
0 0 1
1 1 2
```

The acronym `EF` in the first line starts the definition of an elastic foundation (one file could contain more than one!). Its name is “bed1”, with space dimension “2” and springs in direction “1”, i. e. the y-direction. The spring constant of all springs is “-0.5”. The minus sign is added because it is loaded from top, i. e. a positive pressure should result in a motion in negative y-direction.

Running “foundation” with this input file yields:

```
> ../bin/foundation-nompcci 2dexample.fnd
Foundation - computation
Reading file >>2dexample.fnd<<...
foundation >bed1<   dim=2  direction=1  stiffness=-0.5
  nodes...
    0 :  0 0
    1 :  1 0
    2 :  2 0
  elements...
    0 : 0 1
    1 : 1 2
  allocating memory...
read 1 foundations.

Step 0 of 3
Please enter pressure: 1.0

results for foundation 'bed1':
  node 0:   force=     0.5      displacement=      -1
```

```
  node 1:   force=       1      displacement=      -2
  node 2:   force=     0.5      displacement=      -1

Step 1 of 3
Please enter pressure: 2

results for foundation 'bed1':
  node 0:   force=       1      displacement=      -2
  node 1:   force=       2      displacement=      -4
  node 2:   force=       1      displacement=      -2
```

In each step, the user is asked for a pressure value which is then applied and the resulting forces and displacements are printed to `stdout`. The number of "steps" can also be given as a second command line argument after the input file name, three steps are made if nothing is specified.

Please have a look at the files of the original code in `"src-nompcci"`. The header file `"data.h"` contains the definition of the data structure `FOUNDATION` and of a list of such structures `fndlist` which is filled by the values from the input file.

In `"main.c"` (`"main.f"`) all actual computations are contained, a number of functions is called from `main`, which controls what is done.

The example was created on a Linux 64 Bit machine but should also run on other Linux systems. The C version was compiled using the GNU compiler `gcc`, the FORTRAN version was tested with GNU, Absoft 9.0, Intel 9.1 and PGI 6.1 compilers, see the `"Makefile"`.

For combining C and FORTRAN sources, as it is done in the FORTRAN example, the naming conventions depend on the compiler. In the sources of the example an underscore is added to the C function names and lowercase names are used. Please consult the documentation of your compiler to find how to combine C and FORTRAN sources.

2.2.2 Step-by-Step Procedure for Code Integration

The MpCCI API Kit provides general files for a new code adapter and an example called foundation code. The code adapter files are:

General	Example
`"configuration/*"`	`"example/configuration/*"`
`"adapter/adapter.h"`	`"example/C/src/adapter.h"`
`"adapter/adapter.c"`	`"example/C/src/adapter.c"`

The example files for the code foundation are provided in an original standalone version and a new version with the MpCCI code adapter:

Standalone	Adapter
`"example/C/src-nompcci/data.h"`	`"example/C/src/data.h"`
`"example/C/src-nompcci/data.c"`	`"example/C/src/data.c"`
`"example/C/src-nompcci/main.c"`	`"example/C/src/main.c"`
`"example/C/src-nompcci/Makefile"`	`"example/C/src/Makefile"`

Each `"Makefile"` for the foundation example generates the executable `"example/bin/foundation"`. In order to switch between the standalone and the adapter version you have to rebuild the executable.

To understand the changes you can compare ("diff") the general code adapter files with the foundation example and the standalone foundation files with the adapter foundation files.
All changes are commented and marked with `CHANGED:`. (For FORTRAN see the corresponding files in `"example/FORTRAN"`.)

The creation of a code adapter can be performed on a step-by-step basis:
Step 1: Preparations.
Step 2: Create the configuration directory.
Step 3: Test the configuration.
Step 4: Create the code adapter.
Step 5: Test the code adapter.

For each step, the corresponding changes in the example are mentioned as well.

STEP 1: Preparations.

Understand the basic concepts of MpCCI. If you have no experience with MpCCI, it is recommended to run some of the Tutorial examples first. Try to understand the way MpCCI works by reading ▷ V-3 Code Coupling ◁.

Decide which quantities shall be exchanged. Just select a basic set of quantities, more can be added later. It is sufficient to select one quantity for receiving and one for sending.

A complete list of quantities is given in the Appendix.

Identify possible coupling components. Decide whether data is exchanged on surfaces or volume and how they can be found in the model files.

The example "foundation" code computes displacements due to an external pressure. Thus the following quantities will be exchanged:

foundation code (elements) ← `OverPressure` ← partner code
foundation code (nodes) → `NPosition` → partner code

STEP 2: Create the configuration directory.

Copy files from MpCCI API Kit The configuration directories for simulation codes are all located in the subdirectory "<*MpCCI_home*>/codes" of the MpCCI home directory, which you can find with the command `mpcci home`.

In the "codes" directory, there is one configuration directory for each code. You should already find some of commercial simulation codes there.

Create a directory with the name of your code there and copy all template files from the MpCCI API Kit, subdirectory "configuration", to your new code configuration directory.

"gui.xcf" Change options to your needs, a detailed description is given in ▷ 2.4 MpCCI GUI Configuration File gui.xcf ◁.

For the "foundation" example, the codename is set to "foundation". The foundation code does not use any units, so as default we select "SI". The code type is set to `SolidStructure`, as deformations of solid structures are computed. A list of available types is given in ▷ V-3.1.1 Physical Domains ◁.
In the section `<ModelsMenuEntries>`, only "1.0" is added as version, the file extension is set to `.fnd` and the unit selection menus are kept as no fixed set of units is used in the code.
The `<ComponentTypeDimensions>` are a list of names for the coupling components. We actually only need Face, but add names `Global`, `Line`, `Face` and `Volume`.
From the supported quantities, `OverPressure` and `NPosition` are kept, the locations are set appropriately and send and receive options are set to `Direct` as all data will be directly written to and read from the code's data structures. Both quantities can be exchanged on faces. In the 2D case, a line also represents a face!
As an additional Go-Menu entry, a selection of the number of steps is added. This is later passed to the code as a command line argument. It should also be checked by the Checker.
The Scanner only needs to know the model file, the Checker and Starter also get the number of steps, the stopper gets the model file name.

Perl scripts: "Checker.pm", "Info.pm","Scanner.pm", "Starter.pm", "Stopper.pm", "Subcmd.pm"

The Perl scripts are needed to get information at run time and interact with your code. See ▷ 2.5 Perl Scripts ◁ for a detailed description, each template file is commented.

Most important are "Scanner.pm" to scan the input file and "Starter.pm" to start the code. It is recommended to also use "Info.pm" to gather basic information and "Stopper.pm" to trigger a graceful exit of your code. The "Checker.pm" is optional and is used to validate the code configuration before the code is executed.

The MpCCI API Kit contains an additional "external_Scanner.pm" if you do not want to use Perl to scan the model file, but e. g. the file reader of your simulation code.

In the information module "Info.pm" for foundation, the only thing which is really done is to find the executable in the path and return the requested information.
The "Scanner.pm" scans the model file "*.fnd" for coupling component definitions, in our case these are all elastic foundations which are defined. These start with the keyword `EF` which is followed by the name. The input file is simply searched for lines containing this information, which is then returned to the calling MpCCI function.
The "Checker.pm" checks whether the number of steps is sufficient and adds them to the summary information of the Checker output.
The "Starter.pm" obtains the model file name and the number of steps from the MpCCI GUI, creates an argument list `@argv` with the corresponding command line arguments and starts "foundation".

STEP 3: Test the configuration.

Testing the Perl scripts. Before testing the GUI integration, you should ensure that the Perl scripts work.

- Start with the scanner.
  The code has a list of available command line option, see `mpcci foundation help`. To run a test, you must provide the model file to scan. The MpCCI API Kit provides a model file in the subdirectory `"example/test/foundation"`.
  ```
  mpcci foundation scan elasticwall.fnd
  ```
  The results of the scanning process are saved in a scan file `"mpcci_<`*original filestem*`>.scan"`, i. e. for the above example the file would be named `"mpcci_elasticwall.scan"`.
  All information your scanner found should be contained in this file. The model info is listed first, followed by the list of components. Please check if all information is present.
- Test the starter using `"test_Starter.pl"`.
  You should edit the `"test_Starter.pl"` and modify the variable $ENV{'_MPCCI_MODEL_FILE'} to point to the model file.
  If all necessary variables are set, you can simply run `"test_Starter.pl"`. The starter should not do more than start your code with the appropriate command line options.
- You can also test the stopper with `"test_Stopper.pl"`.

For "foundation" the testing scripts `"test_Stopper.pl"` and `"test_Starter.pl"` were changed: The stopper only needs the model file, the starter model file and number of steps for testing.

Testing `"gui.xcf"` For testing `"gui.xcf"` you need to have a license for a code adapter, which you usually receive together with the MpCCI API Kit.

For testing, you must prepare a simple input file and one for the partner code and proceed as follows.

1. Go to the testing directory (for the foundation example this is `"example/test"`) and start the MpCCI GUI with `mpcci gui`.
   → If you get an error message right after starting the MpCCI GUI, there is a syntax error in your `"gui.xcf"`. Make sure, that the file is a proper XML-file.
2. Your newly added code should now appear in the list of codes on the left side.
   → If you cannot find your new code, ensure that you have created a new subdirectory in `"<`*MpCCI_home*`>/codes"` with the correct name.
   → If your new code is still not visible, check the settings in the Code→Configure menu in the MpCCI GUI, which lists all the codes available for coupling.
3. Click on your code, and you should see what you defined as elements of the Models step.
   → If some elements are missing or wrong, check the `<ModelsMenuEntries>` section.
4. Fill in the required values in the form.
   → With selection of the model file the scanner is started. When the scanner finished, click on the box which appears next to the code selection and check the return values of the scanner.
5. Select and scan the partner code and proceed with the Regions step.
   → Here, you should be able to select the components scanned from the model files and select the quantities as defined in `"gui.xcf"`. If you cannot select any quantity there are no quantities which are supported on the same geometric entity by both codes. If some quantities are missing check the `<SupportedQuantities>` block. Remember that only quantities will be shown, which are also supported by the partner code!
6. Finally, proceed to the Go step and check the entries in the panel of your code.
   → If entries are wrong check the `<GoMenuEntries>` section of `"gui.xcf"`.
7. You can also start your code – it should simply run as usually. However, no coupling will occur as no code adapter is present. For the foundation example you may use the standalone version, which runs as usually without coupling, or you use the adapter version for a coupled simulation.

STEP 4: Create the code adapter.

- The adapter template files are located in the subdirectory `"adapter"`. Add `"adapter.h"` and `"adapter.c"` to your source code.
- Change the definition of the list of driver functions `MpCCIDriverFunctions` in `"adapter.c"` to fit your needs: Add name of your code and select which data exchange functions you need. Usually the block with functions called before/after some actions can be left empty.
- Look if the interface functions are also useful for your code and make appropriate changes. In most cases they should already be OK.
- Adjust the driver functions. All driver functions which are declared in `MpCCIDriverFunctions` must be defined. See ▷ 2.8 MpCCI Driver Functions ◁ for a description.
- Change `"adapter.h"` to fit `"adapter.c"`
- Insert the calls of the interface functions at appropriate places in your code as described in ▷ 2.1 Code Integration and Simulation Code Requirements ◁.
- Add `"adapter.c"`, the MpCCI include directory `"<`*MpCCI_home*`>/include"` and the MpCCI client library for your platform to your `"Makefile"`.
- If your code is compiled and linked, you can proceed with testing the adapter.

For "foundation" the most important changes are (please see source code files in `"example/[C|FORTRAN]/src"` for details):

Driver Functions Only a small set of driver functions,
`MpCCI_Driver_partUpdate`,
`MpCCI_Driver_definePart`,
`MpCCI_Driver_getFaceNodeValues`
and `MpCCI_Driver_putFaceElemValues`
are used, all other functions were set to `NULL` in the `MpCCIDriverFunctions` structure.

Additional helper functions Additional helper functions are required: `getSurfaceID` to identify coupling components by their names and for `adapterOutput` and `error` for data output. In the C version they are included in `"adapter.c"` in the FORTRAN version they are located in `"helpers.f"`.

Data exchange In the C version the data access is directly written into the driver functions `MpCCI_Driver_getFaceNodeValues` and `MpCCI_Driver_putFaceElemValues`.
The FORTRAN version uses additional subroutines in `"helpers.f"`: `getInfo` to obtain basic information, `getMesh` to obtain mesh information and `getNPosition` and `putPressure` for data exchange. The FORTRAN helper functions are called from the C routines in `"adapter.c"`.

Makefiles The Makefile must be changed to include `"mpcci.h"` and the MpCCI library. For FORTRAN, additionally a C compiler is required to compile `"adapter.c"` which can be linked directly with the FORTRAN objects.

STEP 5: Test the code adapter.

Please ensure first that the files in the configuration directory are correct (Step 3). So we can assume now, that you already have set up a sample problem.

- Install the license for your code - either on a license server or on your local machine, see ▷ III-5 Licensing ◁ for details. You can check the license status with `mpcci license mpcci` or from the MpCCI GUI in License→Check the MpCCI license status.
- Open your project (`"*.csp"`) in the MpCCI GUI.
- In the Settings step, you may set the output level to 3 to obtain maximum output.
- In the Go step, select Run server processes inside xterm.
- Start the MpCCI server and both simulation codes by pressing the Start buttons in the Go step. One window for each code server (and the control process if enabled) and for both codes should pop up.
- Check the output of your code and the corresponding MpCCI server. The output of the servers should help you to find any errors in the code adapter functions.

For the foundation code, the code's minimal output (in the yellow window) should look as follows:

```
Starting: foundation elasticwall.fnd 2 1> mpcci_elasticwall.log 2>&1

Waiting for logfile "mpcci_elasticwall.log"....
```

This means MpCCI is waiting for the code's output. This message should be followed by the usual output of the code, here:

```
Foundation - computation
Reading file >>elasticwall.fnd<<...
foundation >elasticwall<   dim=3  direction=2  stiffness=-5
nodes...
```

and so on. Further below you should find the call of `ampcci_tinfo_init`, with

```
Initializing the coupling process!
MpCCI: Coupling configuration setting:
MpCCI:    Scheme: Explicit
MpCCI:    Algorithm: Serial
MpCCI:    Code behavior: Leading
```

followed by the list of coupled regions after the `ampcci_config` call,

```
MpCCI: Coupling grid definition for component "elasticwall" ...
MpCCI: Server: 47010@berber
MpCCI:    Part  : "elasticwall"
MpCCI:    MeshDim(2), MeshId(1), PartId(0), Nodes(9), Elements(4)
MpCCI:    2 Quantities:
MpCCI:       Direction(RECV), Dimension(1), Location(ELEM), Storage(Direct/0),
Name(OverPressure)
MpCCI:       Direction(SEND), Dimension(3), Location(NODE), Storage(Direct/0),
Name(NPosition)
```

For each exchange you should see an output like

```
MpCCI: entered put_values...
MpCCI: finished put_values...
```

Remember that the first exchange depends on the used coupling algorithm (parallel with or without initialization or serial), thus – depending on your choice – the output `get_values` or `put_values` may

not appear.

The output in the server window provides basic information(because the output level is set to 1). This is followed by the actual server output, starting with

```
[MpCCI License] mpcci_adapter_foundation: feature test...
[MpCCI License] mpcci_adapter_foundation: feature test done.
[MpCCI License] mpcci_clients: feature checkout...
[MpCCI License] mpcci_clients: feature checked out.
```

which is followed by:

```
Loading code specific mesh and quantity settings for code "foundation":

   Code specific quantity properties:

      "NPosition": Location(NODE), Default(0)
         Send    : Method(0), Index(0)
         Receive : Method(0), Index(-1)

      "OverPressure": Location(ELEM), Default(0)
         Send    : Method(0), Index(-1)
         Receive : Method(0), Index(0)

   Code specific parts properties:

      "elasticwall": MeshId(1), PartId(1)
         Send   : "NPosition"
         Receive: "OverPressure"

   Code specific mesh scale: 1

   Code specific mesh transformation:
                  1            0            0            0
                  0            1            0            0
                  0            0            1            0
                  0            0            0            1
      Det: 1
```

which reflects the mesh and quantity settings. This is followed by a block starting with

```
Code: "foundation", ID(0), nice(64), clients(1), type(Finite Element).
   Mesh: "foundation/MESH-1", mid(1)
           Coord system: 3D
           Mesh type   : FACE
           Distances   : [0.5 .. 0.707107]
           Bounding box: [0 .. 1] [0 .. 1] [0 .. 0]
           Domain size : 1

      Send: "NPosition"
              Dimension : 3
              Direction : SEND
              Location  : node
              Default   : 0
              Buffers   : 1
```

```
    Recv: "OverPressure"
            Dimension : 1
            Direction : RECV
            Location  : element
            Default   : 0
            Buffers   : 1
            Source    : "FLUENT/MESH-1" -> rel_ml -> map_ml

    Part: "foundation/MESH-1/elasticwall", pid(0)
            Coord system  : 3D
            Mesh type     : FACE
            NNodes        : 9
            NElements     : 4
                    Type1 : QUAD4
                    Ntypes: 1
            Total nodeids : 16
            Total vertices: 16
            Distances     : [0.5 .. 0.707107]
            Bounding box  : [0 .. 1] [0 .. 1] [0 .. 0]
            Domain size   : 1
```

with the element definitions. Next follows the neighborhood computation, which lists the neighborhood information (see also ▷ V-3 Code Coupling ◁), starting with

```
Neighborhood relationship: "foundation/MESH-1" -> "FLUENT/MESH-1"
rel_ml::create_mapmesh(MESH="foundation/MESH-1"): new mesh representation.
rel_ml::create_mapmesh(MESH="FLUENT/MESH-1"): new mesh representation.
rel_ml::execute(MAPLIB_REL=0x8071158): Configuration:
  nodetolerance=0.0292845
  normaldistance=0.146422
  tangentialdistance=0.146422
  distance=0.146422
  precision=1e-06
  multiplicity=4.82923
  orphaninfo=true
rel_ml::execute(MAPLIB_REL=0x8071158)
   -> 0 seconds CPU.
```

2.2.3 Code Coupling with the Example

For testing the code adapter for the example code, a set of sample problems is provided in `"example/test"` for coupling “foundation” with some commercial codes.

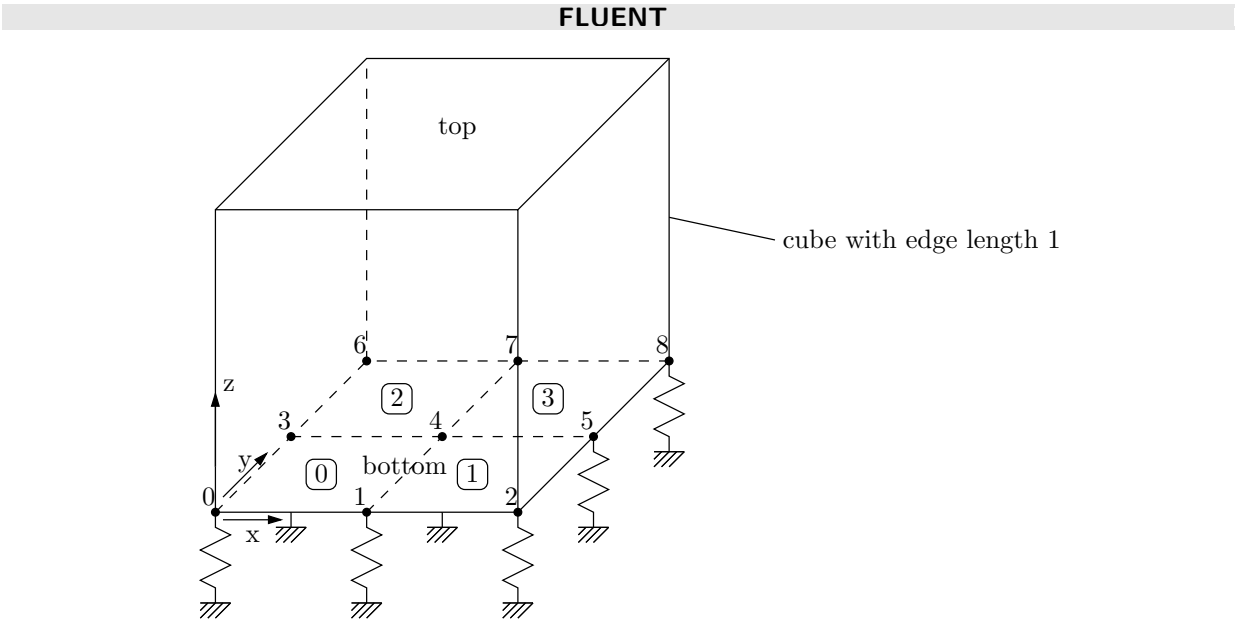


Figure 5: FLUENT– foundation sample problem. A cube filled with an ideal gas is coupled with an elastic foundation which deforms due to the gas pressure.

The sample problem is sketched in Figure 5. Both input files are given, `"foundation/elasticwall.fnd"` for “foundation” and for FLUENT `"FLUENT/cube.cas"`.

To run the sample problem do the following:

- Go to the `"example/test"` directory and start the MpCCI GUI.
- Select “foundation” as the first code (you should first finish creating the configuration and code adapter for the foundation code, see ▷2.2.2 Step-by-Step Procedure for Code Integration◁) and `"foundation/elasticwall.fnd"` as model file. Keep the unit system set to SI.
- Start the Scanner for “foundation”, if you click on the green check mark, you should get

```
# MpCCI relevant information:
#   Model dimensions  : 3D
#   Coordinate system : Cartesian
#   Solution type     : Static
#   Load cases        : ?
#   Unit system       : ?
#   Precision         : Double precision (64 bit)
#
   elasticwall     Face
```

- Select FLUENT as the second code, the FLUENT version 3ddp, and the latest FLUENT release. Finally choose `"FLUENT/cube.cas"` as model file.
- Proceed to the Regions step – the Face (2D)-card should be selected. Select elasticwall and bottom as coupling components and NPosition and OverPressure as quantities.

- Proceed to the Go step. Select Run server processes inside xterm for the server. For "foundation" select 3 as number of steps. For FLUENT do not change further options.
- Save the project and start the processes. One server window should pop up. A yellow window with the output of the foundation code should pop up and the FLUENT graphical interface.
- In the FLUENT window select Solution→Initialization and press the Initialize button to initialize the FLUENT solution.
- Select Solution→Run Calculation and set the Number of Time Steps to 3 and press Calculate.
- The MpCCI Monitor will automatically start.
- Now, FLUENT should perform 20 iterations while "foundation" finishes its computation. The FLUENT result is depicted in Figure 6. You should clearly recognize the deformation of the bottom where the elastic foundation is coupled.
- After the process terminated, the windows closed automatically.

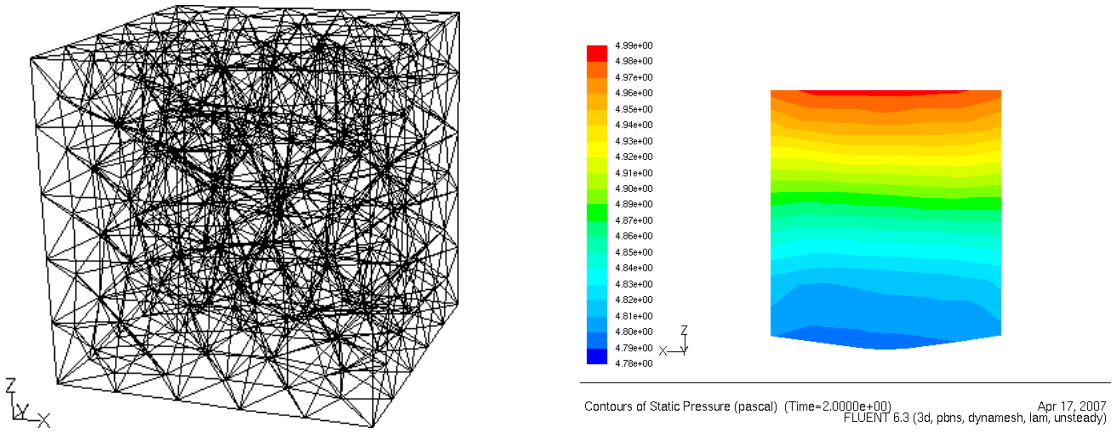


Figure 6: FLUENT mesh and result of the cube example.

2.3 Code Configuration Directory

The files which are required to integrate the code into MpCCI must be located in a specific directory, as already described in ▷ 2.2 Code Integration with the MpCCI API Kit ◁. The directory "<*MpCCI_home*>/codes" has one subdirectory for each code which is supported by MpCCI. At least six files, which always have the same file names, should be inside any code subdirectory:

"gui.xcf" This file contains all definitions which are required to fit the code into the MpCCI GUI, which includes

- code name and version information,
- extension of input files,
- additional code options for the Models and Go steps,
- and a list of supported quantities.

▷ 2.4 MpCCI GUI Configuration File gui.xcf ◁

"Scanner.pm" This Perl script is started to scan the input file of the simulation code for information which is needed for the coupling process, mainly to identify possible coupling components.
▷ 2.5.2 Scanner.pm ◁

"Starter.pm" The starter script starts the simulation code with appropriate command line options, which can be selected in the MpCCI GUI.
▷ 2.5.4 Starter.pm ◁

"Stopper.pm" The stopper script is called if the code shall be stopped, i. e. if the Stop button in the MpCCI GUI is clicked.
▷ 2.5.5 Stopper.pm ◁

"Info.pm" should collect application specific information like code release.
▷ 2.5.7 Info.pm ◁

"Checker.pm" should validate the code configuration before the code starts, i. e. the "Starter.pm" is executed. The Check button in the MpCCI GUI executes this script.
▷ 2.5.3 Checker.pm ◁]

"Subcmd.pm" can be used to define MpCCI code specific subcommands. These subcommands define the command line interface.
▷ 2.5.8 Subcmd.pm ◁

2.4 MpCCI GUI Configuration File "gui.xcf"

The file "gui.xcf" is an XML-file, which contains definitions for the MpCCI GUI. Entries for the Models and Go step and for the Codes menu in the menu bar can be defined, and the selected options can be passed on to the scanner, starter, stopper and killer scripts.

It consists of several sections, which are discussed in the following. A general description of the entries is given in ▷ 2.4.9 General MpCCI GUI Elements ◁.

2.4.1 Code Information: <CodeInfo>

```
<CodeInfo>
   <Units          type="string" default="SI" />
   <Type           type="string" default="Fluid FluidThermal FluidHydrodynamics" />
   <Feature        type="string" default="CopyComponents SelfCoupler
                                          Negotiation iterativeCoupling" />
</CodeInfo>
```

The code information block contains the basic information of a code:

`Units`	Unit system used by the code
`Type`	Type of code
`Feature`	Type of feature

The unit systems supported by MpCCI are listed in ▷ VI-1.2 Unit Systems ◁.

The type of the code defines the physical domains this code supports. Usually one code can support different analysis types. These can be given separated by spaces. The MpCCI tokens associated with the physical domains are listed in ▷ V-3.1.1 Physical Domains ◁, also more information on their meaning.

The type of feature may be needed to determine possible coupling specifications (cf. ▷ V-4.5 Coupling Specifications ◁). Currently accepted values are:

CopyComponents Indicates that a code allows making copies of its components (cf. ▷ V-4.8.2.1 Copying Components ◁).

SelfCoupler Indicates that a code can be coupled with itself.

Negotiation Describes the code capability to negotiate the time step size prior to the next time step.

IterativeCoupling Describes the support of Implicit coupling scheme.

2.4.2 Codes Menu: <CodesMenuEntries>

For each code commands can be defined which are provided in the menu bar beneath the codename item. If more than three codes are offered the code menus are collected under the `Codes` item in the menu bar.

Each provided command is defined as a menu element

```
<Release type="menu"
         text="Releases"
         tooltip="Display all installed releases located by MpCCI."
         command="mpcci Codename releases" />
```

- `Release` is the unique identifier of the selected value.
- the `type` is `"menu"`.
- the provided `text` is displayed as the menu entry.
- the `tooltip` is shown as tooltip for the menu entry.

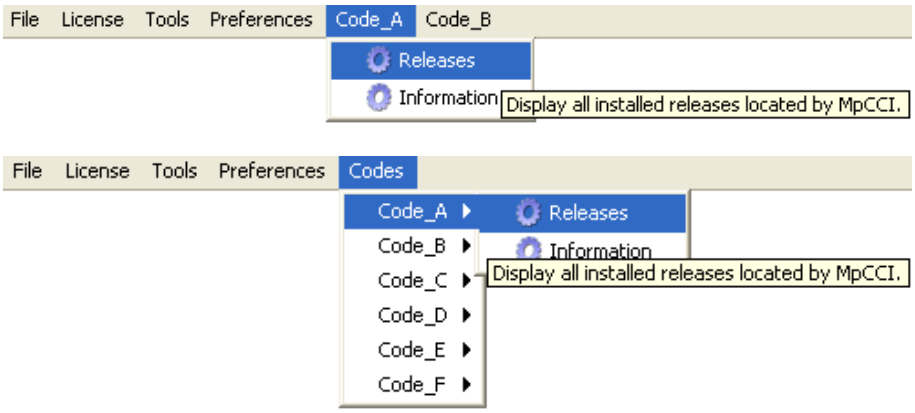


Figure 7: Codes menus for two (Code_A and Code_B) and more than three codes

- the `command` will be passed to the local system to be executed.

The result of the executed command will be shown in a dialog box.

2.4.3 Models Step: `<ModelsMenuEntries>`

For each code additional options can be added to the Models step in the MpCCI GUI. The information given here is only partly evaluated by the MpCCI GUI itself. Most options are for use in the scanner or starter to hand it over to the simulation code. The definitions in the `"gui.xcf"` actually completely determine the appearance in the MpCCI GUI.

The template file from the MpCCI API Kit contains already two examples. An overview of all possible elements is given in ▷ 2.4.9 General MpCCI GUI Elements ◁.

The first element in the example is an enumeration element

```
<Release  type="enum" default="latest" sort="false"
          description="Please select the release:">
  <enum value="latest" />
  <enum value="1.1" />
  <enum value="1.0" />
</Release>
```

`Release` is the unique identifier of the selected value.

The second element is a file selector, which is usually part of every Models Step entry:

```
<ModelFile type="filename" required="true" default=""
           description="Please select the model file:">
  <filename suffix=".mod" />
</ModelFile>
```

Further `<filename>` lines can be added to allow a selection of different suffixes.

An example of a configuration is shown in Figure 8.

```
<ModelsMenuEntries>
   <Release  type="enum" default="latest"
     sort="false" description="Select release">
       <enum value="latest" />
       <enum value="1.1" />
       <enum value="1.0" />
   </Release>

   <ModelFile type="filename" required="true"
     default="" description="Select model file:" >
       <filename suffix=".inp" />
       <filename suffix=".inp.gz" />
   </ModelFile>
</ModelsMenuEntries>
```

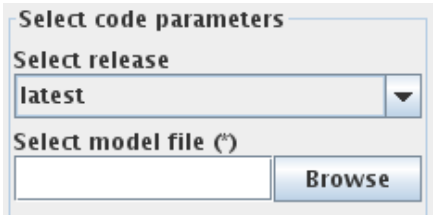


Figure 8: Example of a `<ModelsMenuEntries>` definition in `"gui.xcf"` and the resulting Models step.

2.4.4 Component Types: `<ComponentTypeDimensions>`

Here, you specify the dimension for component types. The components and their types are returned by the scanner in the scanner output file. Because the types for the components differ from code to code each type name used in the scanner output file has to be associated with a dimension. These dimensions correspond with the labels of the element collections in the MpCCI GUI Coupling Step.

Global	means the component is a data structure and its elements are global values.
Ipoint	means the component comprises 0-dimensional integration point elements.
Point	means the component comprises 0-dimensional point elements.
Line	means the component comprises 1-dimensional line elements.
Face	means the component comprises 2-dimensional face elements.
Volume	means the component comprises 3-dimensional volume elements.

Add each component type to the appropriate `<ComponentTypeDimensions>` block.

```
<ComponentTypeDimensions>
  <Global  type="string" default="globalType ..." />
  <Ipoint  type="string" default="ipointType ..." />
  <Point   type="string" default="pointType  ..." />
  <Line    type="string" default="lineType   ..." />
  <Face    type="string" default="faceType   ..." />
  <Volume  type="string" default="volumeType ..." />
</ComponentTypeDimensions>
```

The tags Global, Ipoint, Point, Line, Face and Volume indicate the associated dimension of the MpCCI GUI Coupling Step. The type is "string" and default should be set to the component type names used in the scanner output file. Several component types are separated by a blank. If no type name exists for a dimension, the block for that dimension may be omitted.

2.4.5 List of Quantities: `<SupportedQuantities>`

Before the actual list of quantities, the storage options are defined in the element `<StorageOptions>`. You need not change the definition given in the template. More definitions are only useful, if your code supports different storage locations of the quantities and the user should select them in the MpCCI GUI.

The tag <SupportedQuantities> contains a list of all quantities which are supported by the simulation code. The template which you unpacked in your code subdirectory contains a complete list of all quantities, which can be handled by MpCCI. For a description of the quantities see also the quantities list in the Appendix.

So please remove or comment out all quantities your code does not support.

The remaining lines must be fitted to the simulation code. Each line has following attributes, e. g. :

```
<Temperature    type="quantity" loc="node elem" so="Direct" ro="Direct"
                valid="Point Line Face Volume"/>
```

- The type is "quantity".
- The attribute loc which defines the location of the quantity can be "code", "node", "elem" or "global" or a combination of these e. g. "node elem", which means it can be of either location.
  - "code" The location of the quantity is defined by the code itself.
  - "node" Nodal quantity, i. e. the values are defined for each node.
  - "elem" Element quantity, i. e. the values are defined per element, also for quantities defined at special points of the element, e. g. at integration points.
  - "global" Global quantity, which is not related to nodes or elements, e. g. a time step size.
- The attributes so and ro which stand for "send option" and "receive option" can be set to any of the storage methods defined in <StorageOptions> or combinations like "Direct Usrmem". Usually so and ro are either set to the empty value "", which means no receiving or sending of this quantity is possible, or to "Direct", which means the values are read and written directly to the nodes or elements in the simulation code. The predefined storage methods are also listed in the description of the code API macros in ▷ 2.9.9 Quantities ◁.
- The attribute valid assigns the quantity to the element types Global, Point, Line, Face and Volume which are the labels of the element collections in the MpCCI GUI Coupling Step. Quantities which are valid for the element type Point are also valid for integration point elements. There exists no extra Ipoint type for the quantity valid attribute. If the valid attribute is omitted the quantity is valid for all of its defined coupling dimensions (see Quantity Reference in Appendix) which is often used for global values. On the other hand if it's set to the empty value "", the quantity isn't valid for any dimension and won't be offered in the MpCCI GUI Coupling Step.

Finally a quantity definition block should look like

```
<Quantities>
  <DeltaTime  type="quantity" loc="global" so="Direct" ro="Direct" />
  <WallForce  type="quantity" loc="elem "  so="Direct" ro=""       valid="Face"/>
  <NPosition  type="quantity" loc="node"   so=""       ro="Direct" valid="Face"/>
</Quantities>
```

which means that the simulation code can exchange three different quantities. The time step size is a global quantity and can be sent or received, wall forces are defined at elements and can only be sent, while the node positions can only be received. Time step size has no valid attribute and therefore can be exchanged on its defined coupling dimension which is Global. The wall forces and node positions can only be exchanged on 2D surfaces indicated by valid="Face". For the element types Point, Line and Volume no quantities are supported.

2.4.6 Algorithm Step: <CouplingMenuEntries>

This section defines the code specific coupling algorithm for the simulation code. You find following default major blocks to be set up (cf. ▷ V-4.7 Algorithm Step ◁):

- Analysis type

This Analysis section is common to all codes. The type of the analysis results from the "Scanner.pm" script by setting the solution type field.

```
<Analysis type="panel" description="Analysis">
  <AnalysisType type="enum" default="Transient"
   description="Analysis type" infoID="Info.analysisType.code" >
      <enum value="Transient" />
      <enum value="Steady state" />
  </AnalysisType>
</Analysis>
```

- Solver settings
  This section defines how the solver step size is managed for the different analysis type and coupling scheme combinations (Steady state, Transient implicit, Transient explicit), which is mostly Defined by model.

```
<Solver type="panel" description="Solver settings" >
  <StepSize description="Solver step size" default="Defined by model" . . ./>
  . . .
</Solver>
```

- Coupling steps
  This section defines the frequency of the data exchange, i. e. subcycling. The step size can be constant or variable. According to the coupling scheme and the code capabilities you may define some field to feed the number of inner iterations between the data exchanges for Transient implicit analysis or activate the Delay boundary updates.

```
<CouplingSteps type="panel" description="Coupling steps" . . . >
  <StepSizeType description="Coupling step size" . . . ./>
  <StepSize  description="Constant coupling step size (solver steps)" . . . />
  <InnerIters description="Number of inner iterations" . . . />
  <DelayValue description="Delay boundary updates" . . ./>
</CouplingSteps>
```

- Runtime control
  This section defines the options to manage the coupling runtime: start, number of iteration after the coupling finished.

```
<Runtime type="panel" description="Runtime control" >
  <cbegType description="Define coupling start" . . .>
    <enum value="Take latest time"/>
    <enum value="Specify time"/>
  </cbegType>
  <time_cbeg description="Time of coupling start (s)" . . ./>
  <cbegType description="Define coupling start" . . .>
    <enum value="Take latest iteration"/>
    <enum value="Specify iteration"/>
  </cbegType>
  <iter_cbeg description="Iteration number for coupling start" . . ./>
  <iter_pend description="Number of iterations after the coupling" . . ./>
</Runtime>
```

2.4.7 Go Step: <GoMenuEntries>

Similar to the definitions for the Models step, the appearance of the Go step can be defined in "gui.xcf".

Additional Configuration for Parallel Code

A minimum set of definitions have to be provided in order to describe the parallel configuration of the code. This is the set of definitions to insert in <GoMenuEntries>:

```
<ParallelRun type="panel"    default="false" description="Run parallel">
   <NumProcs type="int"      default="2" min="2" max="512"
                             description="No. of parallel processes" />
   <HostList type="hostlist" default=""
                             description="Optional 'host host ...' to be used" />
   <HostFile type="filename" default="" description="Optional hostlist file" >
      <filename   suffix=".hosts"    />
      <filename   suffix=".hostlist" />
      <filename   suffix=".hostfile" />
   </HostFile>
   <DefaultHosts type="bool" default="false" description="Use default hostfile" />
</ParallelRun>
```

The parallel configuration is encapsulated in a panel element. The following information may be configured:

- The number of parallel processes.
- The hosts to be used.

Additionally for the parallel configuration you have to add the following entries in the <Starter> environment which is stated more precisely in the next section.

```
<_MPCCI_<code name>_PARA_RUN      type="string"
                                  default="%(GoMenuEntries.ParallelRun)" />
<_MPCCI_<code name>_PARA_NPROCS   type="string"
                                  default="%(GoMenuEntries.ParallelRun.NumProcs)"/>
<_MPCCI_<code name>_PARA_HOSTLIST type="string"
                                  default="%(GoMenuEntries.ParallelRun.HostList)"/>
<_MPCCI_<code name>_PARA_HOSTFILE type="string"
                                  default="%(GoMenuEntries.ParallelRun.HostFile)"/>
<_MPCCI_<code name>_PARA_DEFHOSTS type="string"
                                  default="%(GoMenuEntries.ParallelRun.DefaultHosts)"/>
```

This environment information will be evaluated by the Perl function code_start_prepare.

```
my ($numProcs,$sharedFS,@hostList) = code_start_prepare($codeName,         # required
                                                        $compressHostList, # optional
                                                        $printHostList,    # optional
                                                        $checkHostList,    # optional
                                                        $checkFS           # optional);
```

This is a helper function to assist the preparation of the parallel run. It has to be called in your "Starter.pm" script. The parameters are:

$codeName The name of your code.

$compressHostList Indicator (1 or 0) whether the returned hostlist shall be compressed or not. When the check is set all multiple defined hosts will be removed from the list.

$printHostList Indicator (1 or 0) whether the hostlist shall be printed to standard output or not.

$checkHostList Indicator (1 or 0) whether the hosts shall be checked for being alive. When the check is set and at least one listed host isn't alive an error message will be shown and the start of your code will fail.

$checkFS Indicator (1 or 0) whether it shall be checked if the hosts share one file system. The result of the check will be returned in $sharedFS.

The function will create a list of hosts where we fire up the processes. It returns the number of processes ($numProcs), the hostlist (@hostlist) and whether the hosts share one file system ($sharedFS = 1 or 0) if this was indicated to be checked. You may post process the returned values to parametrize the start of your code.

2.4.8 Environments for Scanner, Checker, Starter, Stopper and Killer

The last sections of "gui.xcf" define which information is passed to the Perl scripts which are called by the MpCCI GUI (see ▷2.5 Perl Scripts◁). Values are transferred in form of environment variables, which are defined in "gui.xcf" as follows:

Each of the elements <Scanner>, <Checker>, <Starter>, <Stopper> and <Killer> contains one sub-element <Environment> in which the variables are set to values which are defined in other sections of "gui.xcf" (e. g. ▷2.4.7 Go Step: <GoMenuEntries>◁).

There are two classes of values:

Required values must be set. These are

Value	Variable name	Required for script
The name of the model file	_MPCCI_MODEL_FILE	Scanner, Checker, Starter, Stopper, Killer
Coupling configuration settings	MPCCI_TINFO_SCHEME MPCCI_TINFO_DURATION MPCCI_TINFO_CSTEP MPCCI_TINFO_DELAY	Checker, Starter

MPCCI_TINFO_DELAY is only required if delayed coupling is supported.

Optional values can be added as necessary. All optional variables should follow the name convention and start with _MPCCI_<*code name*> to avoid conflicts with other variables.

All variables must be of type "string" like text field elements described in ▷2.4.9 General MpCCI GUI Elements◁. The default option is used to reference the value and the description option is unused.

A short definition of the environment of the starter script for the code "example" could look as follows:

```
<Starter>
 <Environment>
  <MPCCI_TINFO_SCHEME      type="string" default="%(CouplingMenuEntries..." />
  <MPCCI_TINFO_DURATION    type="string" default="%(CouplingMenuEntries..." />
  <MPCCI_TINFO_CSTEP       type="string" default="%(mpcciserver:CouplingMenuEntr..." />
  <MPCCI_TINFO_DELAY       type="string" default="%(mpcciserver:CouplingMenuEntries..."
                           dependsOn="%(mpcciserver:Couplin...DelayedUpdate.DelayCode)"
                           dependingValue="%(#codename)" />

  <_MPCCI_MODEL_FILE       type="string" default="%(ModelsMenuEntries.ModelFile)"/>

  <_MPCCI_EXAMPLE_VERSION type="string" default="%(ModelsMenuEntries.Version)"/>
  <_MPCCI_EXAMPLE_MODE     type="string" default="%(GoMenuEntries.batchMode)"/>
 </Environment>
</Starter>
```

2.4.8.1 MPCCI_TINFO_* Variables

The MPCCI_TINFO_* variables are required to set the transfer information MPCCI_TINFO used by the adapter for the application (see ▷ 2.9.6 Transfer Information: MPCCI_TINFO ◁). It is set automatically within the MpCCI GUI before starting an application. This variable is composed of several pieces of information for the coupling configuration.

The MPCCI_TINFO_* variables in the "gui.xcf" take the required information as references from the settings in the CouplingMenuEntries group, either of the code itself or of the server which is then marked by the mpcciserver: prefix.

The syntax of each variable is as follows:

```
MPCCI_TINFO_SCHEME = Analysis type : Coupling scheme : Algorithm : Algorithm code :
```

with these references and values:

Analysis type = %(CouplingMenuEntries.Analysis.AnalysisType)
value = transient or steady state.

Coupling scheme = %(mpcciserver:CouplingMenuEntries.Analysis.CouplingScheme)
value = explicit or implicit.

Algorithm = %(mpcciserver:CouplingMenuEntries.AlgorithmDef.Algorithm)
value = serial for a Gauss Seidel algorithm or parallel for a Jacobi algorithm.

Algrorithm code = %(mpcciserver:CouplingMenuEntries.AlgorithmDef.Code)
value = name of leading code for serial algorithm or initializing code for parallel algorithm with initialization. This field is empty for parallel algorithm without initialization.

```
MPCCI_TINFO_DURATION = Coupling start time : Total coupling time :
                       Coupling start iteration : Maximum number of coupling steps :
                       Number of iterations after coupling :
```

with these references and values:

Coupling start time = %(CouplingMenuEntries.Runtime.time_cbeg)
value = time in seconds or empty if the latest time of the model should be taken (only set for transient analysis).

Total coupling time = %(mpcciserver:CouplingMenuEntries.CouplingDuration.TotalTime)
value = time in seconds or empty if no time is specified in the MpCCI GUI (only set for transient analysis).

Coupling start iteration = %(CouplingMenuEntries.Runtime.iter_cbeg)
value = iteration number for coupling start or empty if the latest iteration of the model should be taken (only set for steady state analysis).

Maximum number of coupling steps = %(mpcciserver:CouplingMenuEntries.CouplingDuration.MaxSteps)
value = a number >= 1 (only set for steady state analysis).

Number of iterations after coupling = %(CouplingMenuEntries.Runtime.iter_pend)
value = a number >= 0 (only set for steady state analysis).

```
MPCCI_TINFO_CSTEP = Type of coupling step size : Coupling step size :
                    Maximum number of coupling step iterations :
                    Number of solver's inner iterations :
```

with these references and values:

Type of coupling step size = %(mpcciserver:CouplingMenuEntries.CouplingSteps.StepSizeType)
value = Defined by each code, Sent by code, Constant or Negotiation.

Coupling step size = %(CouplingMenuEntries.CouplingSteps.StepSize)
value = a number >= 1 or a string list with variable step sizes (see ▷ V-4.7.2 Code Specific Algorithm Settings ◁).

Maximum number of coupling step iterations = %(mpcciserver:CouplingMenuEntries.CouplingDuration.MaxIterSteps)
value = a number >= 1 (only set for implicit coupling scheme).

Number of solver's inner iterations = %(CouplingMenuEntries.CouplingSteps.InnerIters)
value = a number >= 1 (only set for implicit coupling scheme).

```
MPCCI_TINFO_DELAY = DelayUnit : DelayValue :
```

with these references and values:

DelayUnit = %(mpcciserver:CouplingMenuEntries.CouplingSteps.IdleTimeReduction.DelayedUpdate.DelayUnit)
value = Number of substeps or Number of update tries.

DelayValue = %(mpcciserver:CouplingMenuEntries.CouplingSteps.IdleTimeReduction.DelayedUpdate.DelayValue)
value = a number >= 1 or a string list with variable step sizes (see ▷ V-4.7.1 Common Basic Algorithm Settings ◁).

2.4.9 General MpCCI GUI Elements

There is a choice of MpCCI GUI elements, which can be used in `"gui.xcf"` within `<ModelsMenuEntries>` or `<GoMenuEntries>`. For each element applies:

`Identifier`	is a unique identifier for that element. It can be arbitrary but should not begin with a number and it should not contain special characters.
`type`	defines the type for the special element.
`description`	is always used as title for the respective element.

Text Field

```
<Identifier type="string" default="mpccirun"
            description="Job name prefix for job files"/>
```

`default` is the default value of the text. It may contain references but in that case it is read-only and cannot be changed by the user.

Figure 9: Text field representation

File Selector

```
<Identifier type="filename" default="" dironly="false"
                            description="Data file (optional)">
  <filename value=".suffix1"/>
  <filename value=".suffix2"/>
</Identifier>
```

`default`	should be left empty.
`dironly`	optional attribute which can be set to `true` when the selection of a directory is desired.
`value`	is one accepted and selectable file suffix in addition to the predefined selectable `"All Files"` option.

Figure 10: File selector representation

Enumeration

```
<Identifier type="enum" default="value" description="Select value" sort="true"
                        expandable="false"/>
```

`default` is the default value and will be added to the begin of the enumeration value list if it doesn't exist.

`sort` optional attribute which can be set to false if the enumeration value list shall be presented in the given order. If omitted or set to true the values of the list will be sorted in an ascending alphabetical order.

`expandable` optional attribute which can be set to true if the enumeration value list shall be expanded when attempting to set a value which is not in the list (e. g. opening a project with an actually not supported release). If set to true the value will be added to the list. If this attribute is omitted or set to false setting a value which is not in the list will not be done (the default value is set instead) and leads to an error message.

There are three ways for getting the enumeration values:

1. List them in a value list.
2. Specify a local file as source which holds the values line by line.
3. Specify a command which will be executed at runtime when selecting this value for the first time. The command will provide the values line by line to standard output.

1. Value list:

```
<Identifier type="enum" default="SI" description="Select unit system">
  <enum value="British"/>
  <enum value="cgs"/>
  <enum value="mm-t-s"/>
  <enum value="US-ft-lbf-s"/>
  <enum value="US-in-lbf-s"/>
  <enum value="variable"/>
</Identifier>
```

`enum value` is one value of the value list.

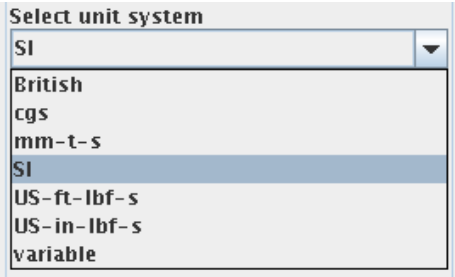


Figure 11: Enumeration representation

2. Source file:

```
<Identifier type="enum" default="typeA" description="Title"
            source="fileWithEnumValues"/>
```

`source` is the name of the file which holds the value list. The file will be looked for in the current user directory and in the user home directory. Each line in the source file corresponds to an `enum value` in the value list.

3. Command:

```
<Identifier type="enum" default="latest" description="Title"
            command="command with arguments and %(reference)"
            hostref="%(ModelsMenuEntries.ModelFile)"/>
```

`command` is the command which will be executed to get the value list. References to other elements are allowed and are replaced with their current values (cf. ▷ 2.4.9 General MpCCI GUI Elements ◁ on page 36).

`hostref` is an optional specification of the host on which the command shall be executed. Therefore the referenced object has to be a file. The host of this file will be used to execute the command. If no `hostref` is specified the command is executed on the local host.

Range Value

There are two types of range values. You may create a range value of

- integer values, in that case you have to use the type int.
- floating values, in that case you have to use the type float.

```
<Identifier type="int" default="1"
            min="1" max="512"
            description="No. of parallel processes"/>
```

```
<Identifier type="float" default="0.01"
            min="1e-10" max="1e10"
            description="Coupling time step"/>
```

`default`	is the initial default value.
`min`	defines the lower limit.
`max`	defines the upper limit.

The `min` and `max` options are optional. If one of them lacks the minimum respectively maximum value of the system will be taken. If neither `min` or `max` is given the value is set to the default value and may not be changed.

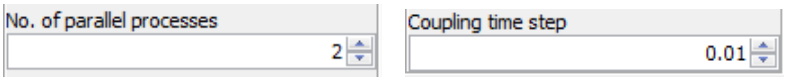


Figure 12: Range value representation for int and float types

Checkbox

```
<Identifier type="bool" default="true"
            description="Start additional control process"/>
```

`default` must be initialized with true or false.

Figure 13: Checkbox representation

Command

A command is an element which executes a defined command. It is represented by a button which has to be clicked to execute the command.

```
<Identifier type="command" default="cmd arg1 -option %(ModelsMenuEntries.Release)"
            description="Decompose case"
            hostref="%(ModelsMenuEntries.ModelFile)"
            addComponentEnvironment="true"/>
```

`default`	is the command to be executed with its arguments. References to other elements are allowed and are replaced with their current values (cf. ▷ 2.4.9 General MpCCI GUI Elements ◁ on page 36).
`hostref`	is an optional specification of the host on which the command is to be executed. A file must be referenced for this. The host of this file is used to execute the command. If no `hostref` is specified, the command is executed on the local machine.
`addComponentEnvironment`	is an optional specification whether the environment with the components and quantities (as used for the starter) shall be set or not. If no `addComponentEnvironment` is specified the environment won't be set.

Hostlist

A hostlist is an element which checks the list of host names. It verifies the resolvability of the host and if it is alive.

Figure 14: Command representation

Whitespace, comma or semicolon may be used as delimiters to define the list of host names. A host name may be given as "[user@]host".

```
<Identifier type="hostlist" default=""
            description="Optional 'host host ...' to be used"/>
```

`default` is the initial default value and may be left empty.

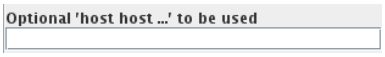


Figure 15: Hostlist representation

Panel

A panel is used to group elements by surrounding them with a border. There exist two types of panels:

- Enabling or disabling a special feature with its subelements.
- Grouping related elements.

Enabling or disabling a special feature with its subelements
The panel consists of a checkbox - named by the description of the feature - which indicates whether this special feature is used or not. If the checkbox is set, the panel expands and shows its subelements. Now these subelements can be set and will be evaluated. If the checkbox is unset, the panel will disappear and hide its subelements.

```
<Identifier type="panel" default="false" description="Run parallel">
   ... subelements ...
</Identifier>
```

`default` must be initialized with true or false.

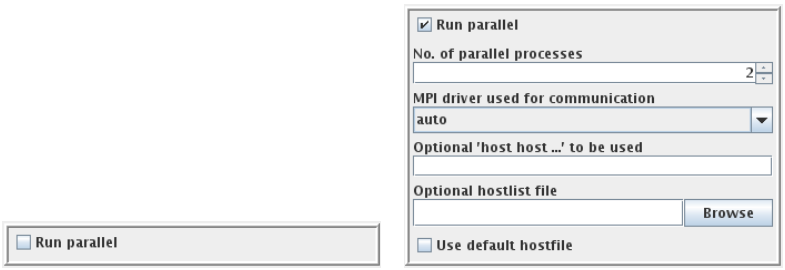


Figure 16: Panel representation for unused and used feature

Grouping related elements
The panel consists of several subelements and has no default value. Its description will be shown at the top of the panel. The panel can be opened and closed by clicking on its description. The subelements will be evaluated even when the panel is closed.

```
<Identifier type="panel" description="Setting for remote server start">
   ... subelements ...
</Identifier>
```

`description` is used as heading of this panel.

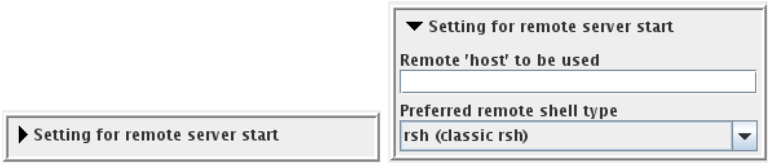


Figure 17: Panel representation for a closed and opened element group

Common Feature: References

Sometimes it is necessary for a value to reference another value. Examples are:

- Setting environment variables for a code (e. g. ▷ 2.4.7 Go Step: `<GoMenuEntries>` ◁, ▷ 2.4.8 Environments for Scanner, Checker, Starter, Stopper and Killer ◁)
- Referencing a host when executing a command like in Enumeration or Command.
- Using the Dependency feature.
- Referencing just another value which e. g. acts as a parameter for a command like in Enumeration or Command.

The following references are possible:

`%(<element>.<subelement>)`	value of an element specified within this configuration file.
`%(mpcciserver:<element>.<subelement>)`	the same as before but the element will be taken from the MpCCI server configuration file.
`%(properties:<element>.<subelement>)`	value of a control parameter which can be edited in the Settings step of the MpCCI GUI.
`%(#codename)`	references the instance name of this code which is also used in the MpCCI GUI to specify this code.
`$(`*<environment variable name>*`)`	value of the specified environment variable on the local machine.

```
<Identifier type="enum" default="latest" description="Title"
            command="command_for_code %(#example)"
            hostref="%(ModelsMenuEntries.ModelFile)"/>

<BaffleOption  type="enum" default="None"
               description="Define baffle thickness location"
               dependsOn="%(properties:BaffleShift.Enable)" dependingValue="true" >

<SampleDir type="filename" dironly="true" default="$(HOME)"
           description="Select directory for %(mpcciserver:GuiMenuEntries.Jobname)">
```

Common Feature: Dependency

For each of the previous elements a dependency may be added. This means that an element is only shown in the MpCCI GUI if the set dependency is complied.

```
<Identifier type="<element type>" default="<default value>" description="Title"
            dependsOn="%(ModelsMenuEntries.Units)" dependingValue="variable"
            dependingCompare="<startsWith | exact | exactIgnoreCase>"
            dependingCondition="<true | false>"/>
```

`dependsOn` is a reference to the element this element depends on.

`dependingValue` is the value the referenced value will be compared to. If this element depends on more than one value of the referenced element this depending value may be a list of values separated by a `|` (i.e.: `dependingValue="value 1 | value 5"`)

`dependingCompare` provides the compare method used for the comparison between the depending value and the referenced value. Possible values are:

startsWith Checks whether the referenced value starts with the depending value.

exact Checks whether the referenced value matches the depending value case-sensitive.

exactIgnoreCase Checks whether the referenced value matches the depending value case-insensitive. This is default used if no compare method is specified.

`dependingCondition` provides the condition for the comparison between the depending value and the referenced value. If the condition is true this depending element is only shown if the compared values (resp. one of the compared values if the depending value is a list of values) are equal. On false this element is shown if the compared values (resp. all of the compared values if the depending value is a list of values) are not equal. The default condition true is taken when the `dependingCondition` is omitted.

If the dependency is used in a panel the panel cannot be set or unset by the user anymore because this will be done automatically in reliance on its dependency then.

An example can be viewed in the template which you unpacked in your code subdirectory. There the element `GridLengthUnit` in the `<ModelsMenuEntries>` block depends on the `Units` element of the same block. The `GridLengthUnit` element is only shown if the value of `Units` is set to "variable".

Common Option: Required

Another option which is common to all previously described MpCCI GUI elements is the required option.

```
<Identifier type="<element type>" default="" description="Title"
            required="true | false" />
```

`required` states that this element must be set before going on with the next step in the MpCCI GUI. Normally the default value for the element is left empty so that the user must choose a value explicitly e. g. as with the `<ModelFile>`. In MpCCI GUI required elements are marked with a (*) at the end of the title. A dialog box is shown if required elements are not set while going on with the next step. The default for the required option is false.

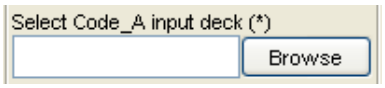


Figure 18: Required representation for a file selector element

Common Options: Info and InfoId

Another option which is common to all previously described MpCCI GUI elements is the info option.

```
<Identifier type="<element type>" default="" description="Title"
            info="Some information about the current element." |
            infoId="Info.ipolOrder" />
```

`info` contains a short description of the element. Line breaks can be given by "\n" whereas other formatting instructions are not supported.

`infoId` contains a link to a short description of the element. The content of the link is looked up in the MpCCI GUI configuration properties file `"$MPCCI_HOME/gui/mpcciBundle_en.properties"`. Here some HTML formatting can be added e. g. for generating lists, paragraphs or formatted text. The information tags in this file are primary for multiple used tags, so that they don't need to be written down several times. You may use these predefined tags in your own configuration file.

You may either use info or infoId. If both options are used in an element the text for the info is appended to the text of infoId.

In MpCCI GUI info elements are marked with an symbol at the end of the title. A dialog box with the information message is shown by clicking on the information symbol. By default no information is assigned.

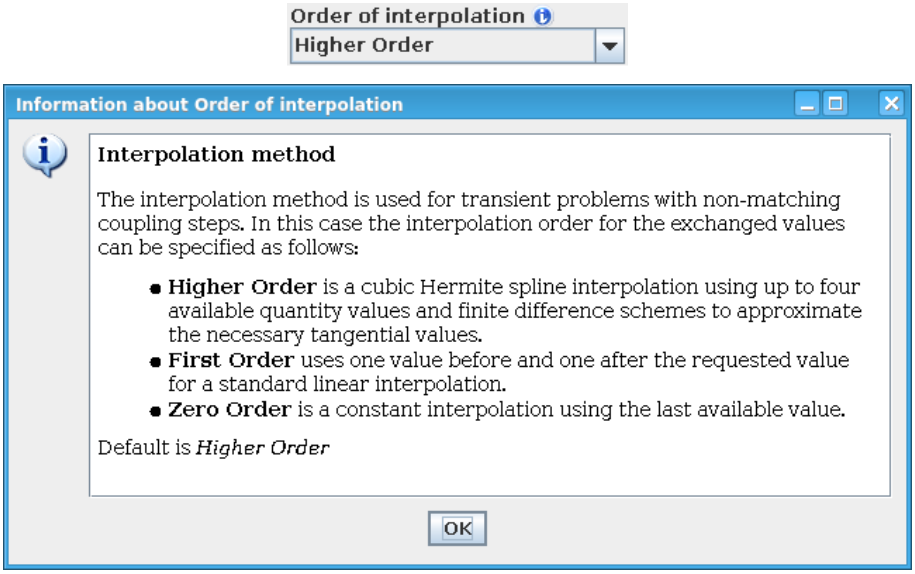


Figure 19: Info representation with its dialog

Common Option: Visible

Another option which is common to all previously described MpCCI GUI elements is the visible option.

```
<Identifier type="<element type>" default="" description="Title"
            visible="true | false" />
```

`visible` states whether this element is visible or hidden in the MpCCI GUI. This option is very rarely used and only makes sense for special needs. The default for the visible option is true.

2.4.10 Testing "gui.xcf"

Testing of the files in the configuration directory is described in ▷ 2.2.2 Step-by-Step Procedure for Code Integration ◁.

2.5 Perl Scripts

You need not really learn Perl to write the scripts to run with your code. Basic documentation on the language (Linux/UNIX: `man perl`) is included in the Perl distributions, Schwartz et al. [2005] is recommended as a book for beginners.

So just edit the provided templates.

2.5.1 Using Information from `"gui.xcf"` in Scripts

As mentioned in the description of `"gui.xcf"` you need to pass information from the MpCCI GUI to the scanner, checker, starter, stopper and killer scripts. This information is exported from the MpCCI GUI into the Perl world via environment variables. These variables need to be defined in the `"gui.xcf"` as described in ▷ 2.4.8 Environments for Scanner, Checker, Starter, Stopper and Killer ◁ and are then evaluated within the Perl scripts. As a Perl programmer you can access the environment variables via the global Perl hash %ENV

```
$value = $ENV{'VARIABLE_NAME'};
```

During testing it may be helpful to read the variables with an automatic error check. For this purpose some Perl routines are provided in a Perl module `MpCCICore::Env` which needs to be included (`use` or `require`) in your Perl scripts.

- `env_optional_value(`<*variable name*>`)` gets value of a variable, returns an empty string if not defined.
- `env_required_value(`<*variable name*>`)` same as above, but exits with an error if variable is not defined.
- `env_boolean_value(`<*variable name*>`)` interprets value of the variable as Boolean value, the variable must be one of `t`,`true` or `1` to yield "true" and `f`, `false` or `0` to yield "false".
- `env_optional_int(`<*variable name*>`, `<*default*>`, [`<*min*>`,[ `<*max*>` ] ])` gets value of a variable as an integer value. If the variable is not defined, the given default value is returned. If <*min*> and <*max*> are given, it is checked if the value lies within the given limits.
- `env_required_int(`<*variable name*>`, [`<*min*>`,[ `<*max*>` ] ])` Same as above, but the variable must be defined, i. e. a default value is not needed.

2.5.2 `"Scanner.pm"`

This file contains one subroutine which is called by MpCCI to scan the model file, which is named `sub code_scanner($$$)`. It has three arguments:

`$codename` The name of your code.

`$modelFile` The name of the model file which shall be scanned.

`$tmpName` The name of a temporary file, which can be used during the scanning process if necessary. Sometimes the scanner does not only retrieve information but also applies some changes to the model file.

It returns up to four hashes (i. e. associative arrays):

`%componentList` contains all possible coupling components. The hash with the `$componentName` as key has the following structure:

```
$componentList{$componentName} = [$componentName, $componentType, $partId];
  $componentName = string with the name of the component for later use in adapter
```

```
$componentType = type of the component for later use in gui.xcf
$partID        = number with ID of the component for later use in the adapter
```

See ▷ 2.4.4 Component Types: <ComponentTypeDimensions> ◁ for the definition of the dimension of `$componentType` (corresponds to the component type name) in `"gui.xcf"`.

`%modelInfo` contains some general information on the model file and has the following structure:

```
MDIM => '3', # Model dimension: 1,2,3
CSYS => 'C', # Coordinate system: C=Cartesian, S=Spherical, A=axis symmetric
SOLU => 'S', # Solution type: S=Static, T=Transient, ?=undefined
LCAS => '?', # Load cases: Number of loaded cases
UNIT => '?', # Unit system
PREC => 'D'  # Precision: S=Single precision (32 bit),
                         D=Double precision (64 bit),
                         L=Long double precision (128 bit)
```

`%userInfo` is optional and contains some additional scanner information on the model file. This additional scanner information will be printed as comment into the scanner output. For example:

```
Global variables     => 'Autogenerated by the scanner'
Solver type          => 'Explicit'
```

Sometimes the scanner has to add some components generated from the given ones (e. g. in case of shell elements with front and backside). Therefor the new components get a name composed of the old one and an extra prefix or suffix, sometimes in combination with a special region type or component id. When MpCCI GUI looks for components matching by their name it makes sense to compare to the original name and not to the newly generated which would also consider the prefix and suffix. The key Generated Components provides a list of specifications for those automatically generated coupling components which enables the MpCCI GUI to reconstruct the name of the original component. Following attributes may be used by the scanner to specify the automatically generated components:

prefix	Specifies the pattern for the prefix added.
suffix	Specifies the pattern for the suffix added.
type	Specifies a list of region types to be worth considering.
id	Specifies the special ids by either a list of possible ids separated by blank or the keyword negative meaning any $id < 0$.

The attributes may be used in combination or alone where at least one of prefix or suffix must be present. They will be analyzed top down so the more general specifications should appear at the end of the list. For example:

```
Generated Components => 'prefix="CopyOf-" type="Wall Surface" id="101 102 103"'
                        'prefix="V-1_" suffix="-backside" id="negative"'
                        'suffix="-backside" id="negative"'
```

`%varHash` is optional and contains values of variables to be set into the MpCCI GUI configuration file `"gui.xcf"`. They will be printed as comment into the scanner output file which will be interpreted by the MpCCI GUI. The name of the variable is built as a dot separated xml tag path. For example:

```
ScannerInfo.SolverType => 'Explicit', # set used solver type.

# set default for maximum number of iterations:
GoMenuEntries.MpCCITinfo.IterationControl.iter_max => '300'
```

The `"Scanner.pm"` consists of three steps:

1. Parsing the model file. The file is opened, and a loop is run over all lines of the file. In the loop the file is scanned for coupling components. The search process must be adapted to your model file format to get the name, type and id of the component. A numerical id can also be omitted (specify `0`) if your file does not use ids.
2. Adding further variables, which are not contained in the model file, but always present. Usually this is only the case for global variables.
3. Defining the basic model information, which can be retrieved during the scan or given as fixed values.

The scanner may be tested by using the command `mpcci <codename> scan modelfile`.

2.5.3 "Checker.pm"

"Checker.pm" is called by MpCCI to check the code configuration. It is only required if a checker environment in the code configuration file "gui.xcf" exists (see ▷ 2.4.8 Environments for Scanner, Checker, Starter, Stopper and Killer ◁).

This Perl module contains one subroutine named `sub code_checker($$@)`. It has two required arguments and one optional:

`$codename` The name of your code.

`$modelFile` The name of the model file assigned to your code.

`@optional` A place marker for possibly coming up arguments in the future.

The script may e. g. check that the end time or iteration of the coupling lies after the start or that the number of coupling steps or subiterations are plausible. Remember that every information needed to do the checking must be transported via environment variables.

Each result of the configuration check shall be printed out depending on its type. Use

`checkInfo` for writing it to stdout if it is an information message,

`checkWarn` for writing it to stderr if it is a warning message,

`checkErr` for writing it to stderr if it is an error message and use

`checkSummaryEntry($text,$value)` for adding information to the table of coupling configuration summary entries.

The subroutine should return an array with the number of errors and warnings.

These messages will be gathered by MpCCI GUI and shown in one single dialog including all results from the Check action. The type of the result depends on the number of errors and warnings returned.

This script should return true if the check could be done, false if something went wrong while executing this checker script.

2.5.4 "Starter.pm"

"Starter.pm" contains a subroutine which does not actually start the code, but provides the necessary information. The starter function is named `sub code_starter($$@)` and obtains the arguments,

`$codename` The name of your code.

`$modelFile` The name of the model file assigned to your code.

`@optional` A place marker for possibly coming up arguments in the future.

As return values it must provide the command line arguments for starting the code and put it into the variable `@arg`, which is the first return value.

Additionally, `%infoHash` is required to be returned to determine how the output of the simulation code is handled. The following options can be chosen:

option	default	description
`STDOUT`	`null`	What to do with data written to `stdout`, can be any of `xterm` (i. e. write to an xterm), `mpcci` (i. e. output handled by MpCCI), `null` (ignore output), combined with the keyword `file` if it shall also be written to a log file.
`STDERR`	`null`	Same as `STDOUT`, but for `stderr`.
`STDLOG`	*<emtpy string>*	Name of logfile
`BACKGR`	`white`	Background color of xterm.
`FOREGR`	`black`	Foreground color of xterm
`ATSTART`	*<not set>*	Reference to a Perl subroutine which is called before the code starts. You can define this routine in `"Starter.pm"`.
`ATEXIT`	*<not set>*	Reference to a Perl subroutine which is called as soon as the code exits. You can define this routine in `"Starter.pm"`.

A test for the starter is provided in `"test_Starter.pl"` of the MpCCI API Kit.

2.5.5 `"Stopper.pm"`

The stopper script should cause the code to perform a regular exit, i. e. not simply kill the code, but save data and quit. This is often achieved with a stop file, which is read by the code.

`"Stopper.pm"` contains a subroutine named `sub code_stopper($$$)` and obtains the three arguments:

`$codename` The name of your code.

`$modelFile` The name of the model file assigned to your code.

`$mpcciProcessId` The process identification of the code.

As for the starter, a testing script is provided for `"Stopper.pm"`, which is named `"test_Stopper.pl"`.

2.5.6 `"Killer.pm"`

The killer script should kill the code with all its sub processes and clean up all files not needed anymore.

`"Killler.pm"` contains a subroutine named `sub code_killer($$$)` and obtains the three arguments:

`$codename` The name of your code.

`$modelFile` The name of the model file assigned to your code.

`$mpcciProcessId` The process identification of the code.

2.5.7 `"Info.pm"`

In the Perl module `"Info.pm"` the subroutine `sub code_information($)` is defined which collects application specific information. It has one argument:

`$codename` The name of your code.

This subroutine will be called by MpCCI, e. g. when `sub code_print_releases` or `sub code_print_info` is called in `"Subcmd.pm"`.

It finds out the installed releases for the code and returns a hash table `%infoHash` (i. e. an associative array) with one entry for each release token. The array structure for each entry is:

1. Name — The official name of the code.
2. Home — The home path of the code installation.
3. Executable — The full pathname of the executable to start the application.
4. Release — The code internal release token.
5. Architecture — The architecture token of the application.
6. Adapter release — The adapter release token (should be equal to the code internal release token or `'STATIC'`).
7. Adapter architecture — The adapter architecture token (should be equal to the architecture token of the application).

Example:

```
$infoHash{$release} = [
    $codeName='solverxy',
    $codeDirectory='/opt/code',
    $pathToExecutable="$codeDirectory/bin/code.exe",
    $release='1.2.4',
    $architecture='linux_x86',
    $adapterRelease=$release,
    $arch=$architecture
];
```

2.5.8 "Subcmd.pm"

In this Perl module exactly one public subroutine `sub code_subcommand($)` is defined. This subroutine is called from the MpCCI command as a code specific subcommand like `mpcci` <*codename*> `releases`.

This file is optional, but it is recommended to use it! The subroutine has one argument:

`$codename` The name of your code.

You need to inspect the global Perl array `@ARGV` and then make decisions based on its contents. The simplest way of implementing a command line parser is to use the parsing tools which come with MpCCI. You just define a Perl hash `%hash3` with the command line options as the key. The value for each command line option is a reference to an array containing three entries:

- The MpCCI environment setup level: 0=no, 1=arch 2=core, 3=gui
- A short help message
- The name of an environment variable or a code reference

The Perl subroutine `sub code_subcommand($)` then has to call `hash3ref_run('option',%hash3)` to process the hash. `hash3ref_run` then either prints the help text, displays the value of the environment variable or calls the subroutine specified via the code reference.

The returned value of `sub code_subcommand($)` is irrelevant. `sub code_subcommand($)` may either call exit(0) or exit(1) in case of a failure or simply return.

2.5.9 Testing the Perl Scripts

For some scripts, a `"test_*.pl"` script is included in the MpCCI API Kit, which can be used to test the scripts separately. Testing of the scripts in the configuration directory is described in ▷ 2.2.2 Step-by-Step Procedure for Code Integration ◁. The other scripts like `"Info.pm"` or `"Subcmd.pm"` may be tested with the `mpcci` <*code name*> subcommands as described in ▷ VI-1.1 Common MpCCI Subcommands for Simulation Codes ◁.

2.6 MpCCI Adapter Implementation

2.6.1 How to Initialize the Code?

The code has an `initcoupling()` method available to implement some stuff to initialize the code. At this level the information about the mesh should be available.
The following call sequence must be implemented in the `initcoupling()`:

1. `umpcci_msg_functs` (▷ 2.7.1 Definition of Output Functions: `umpcci_msg_functs` ◁)
2. `umpcci_msg_prefix` (▷ 2.7.2 Definition of Output Prefix: `umpcci_msg_prefix` ◁)
3. `ampcci_tinfo_init` (▷ 2.7.3 Get Transfer Information: `ampcci_tinfo_init` ◁). After calling this function the code must update the current time and / or iteration information from the `MPCCI_TINFO` structure.
4. A `MPCCI_CINFO` data structure (▷ 2.9.7 Code Specific Information: `MPCCI_CINFO` ◁) must be defined. The current time and iteration of the code should be set.

   - For a steady state iterative code it is recommended to set the time information to the value `-1` and just update the iteration field. The same rule must be applied to the `MPCCI_TINFO` data structure.
   - For a transient code it is recommended to set the time information and optionally the iteration field could be used. If this iteration information is set to the value `-1`, this designs the code to be an explicit transient code. Otherwise this notifies an implicit transient code and enables the code to request data inside the same time step for different iteration steps.
5. `mpcci_cinfo_init` (▷ 2.7.4 Initialize the Code Information Structure ◁) initializes the job settings according to the `MPCCI_TINFO`.
6. `mpcci_init` (▷ 2.7.5 Connect and Initialize an MpCCI Server: `mpcci_init` ◁).
7. `ampcci_config` (▷ 2.7.6 Configure the Code Adapter: `ampcci_config` ◁) The list of driver functions must be passed to `ampcci_config` at this point.

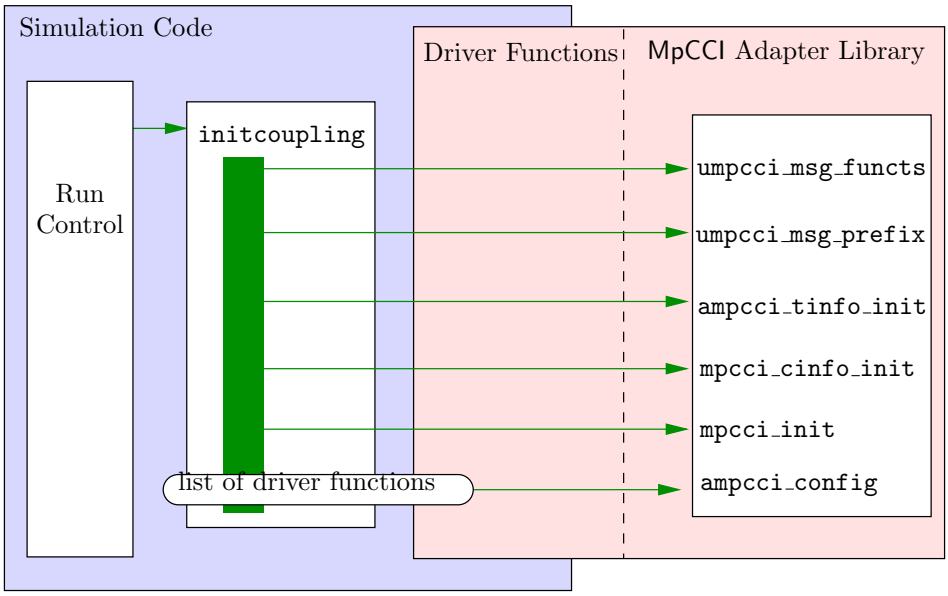


Figure 20: Call sequence for initializing the code with MpCCI

2.6.2 How to Define the Mesh?

There are two ways to define the mesh to MpCCI.

1. First method: you implement the driver functions `MpCCI_Driver_definePart` and `MpCCI_Driver_partUpdate`.
2. Second method: you implement the driver functions `MpCCI_Driver_partInfo`, `MpCCI_Driver_getNodes` and `MpCCI_Driver_getElems`.

One of these methods will be used by the coupling manager. The driver functions are described in ▷ 2.8.3 Driver Mesh Definition Methods ◁.

First method

In order to provide the current number of nodes and elements for each part, the driver function `MpCCI_Driver_partUpdate` has to be implemented. The main objective is to update:

- the number of nodes for the part by assigning the new value with this macro: `MPCCI_PART_NNODES(part)`,
- the number of elements for the part by assigning the new value with this macro: `MPCCI_PART_NNELEMS(part)`.

These macros can be reused later e. g. in the function `smpcci_defp`, see also `"adapter.c"` of the MpCCI API Kit.
The code manages the memory for allocating the arrays for storing the coordinates, node ids, element ids, etc. .
These functions have to be used for implementing the `MpCCI_Driver_definePart`:

- `smpcci_defp` (▷ 2.7.7 Definition of Part: `smpcci_defp` ◁)
- `smpcci_delp` (▷ 2.7.8 Delete a Part: `smpcci_delp` ◁)
- `smpcci_pnod` (▷ 2.7.9 Definition of Nodes: `smpcci_pnod` ◁)
- `smpcci_pels` (▷ 2.7.10 Definition of Elements: `smpcci_pels` ◁)
- `smpcci_pmot` (▷ 2.7.11 Definition of the Moving Reference Frame: `smpcci_pmot` ◁)
- `smpcci_pshf` (▷ 2.7.12 Definition of the Baffle Thickness: `smpcci_pshf` ◁)

In this driver function, you may check the number of elements for the coupled part and delete it from the MpCCI server if no elements are available. This may be necessary in case of a parallel code. If elements are available, define the part, optionally define the moving reference frame (MRF) and then define the list of nodes and elements (see Figure 21).

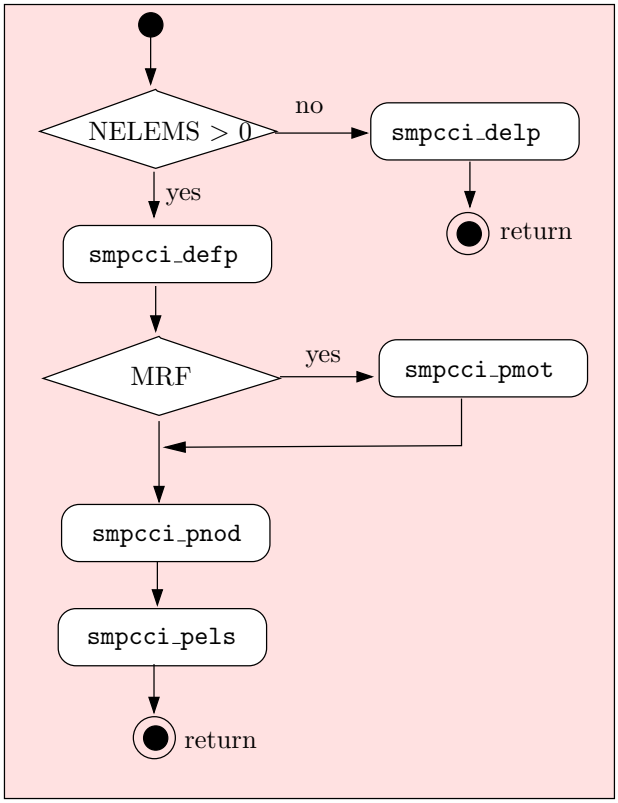


Figure 21: Call sequence for mesh definition using `MpCCI_Driver_definePart`

Second method

The memory allocation to store the node coordinates, node ids, element ids, etc. is done by the coupling manager.

The code needs to implement this minimal set of driver functions:

- `MpCCI_Driver_partInfo` should provide the basic information about the couple part like the number of nodes, elements, coordinates system etc.
- `MpCCI_Driver_getNodes` should provide the node coordinates.
- `MpCCI_Driver_getElems` should define the element topology for the part.

2.6.3 How to Deal with Angular Coordinates?

There are many different formalisms to express rotations. If you intent to couple AngularCoordinates with a partner code, MpCCI must know which formalism is used to correctly interpret the received values. You can provide this information to MpCCI in the function `MpCCI_Driver_partUpdate` by adding a flag to your quantity with the line of C–code `quant->flags |= CONVENTION;`, where `CONVENTION` is one of the following.

- `MPCCI_QFLAG_AC_QUATERNION` : MpCCI expects four values that represent a unimodular quaternion. The last value is assumed to be the real part.
- `MPCCI_QFLAG_AC_AXIS` : MpCCI expects three values that represent an axis of rotation. The magnitude of this axis corresponds to the angle in radians.
- `MPCCI_QFLAG_AC_AXISANGLE` : MpCCI expects four values, of which the first three represent a normalized axis of rotation. The forth value is the angle of rotation in radians.
- `MPCCI_QFLAG_AC_EULER321` : MpCCI expects three values and interprets them as intrinsic Tait-Bryan-angles in z,y,x convention, i.e. as yaw, pitch and roll.

2.6.4 How to Transfer Data?

The code has an `dotransfer()` method available to implement a call to the MpCCI data transfer function `ampcci_transfer` (▷ 2.7.13 Data Exchange: `ampcci_transfer` ◁). This basic sequence must be done before calling the transfer function:

1. First the code must update the `MPCCI_TINFO` data structure (See ▷ 2.9.6 Transfer Information: `MPCCI_TINFO` ◁). The current time, iteration must be set.
2. then the call of `ampcci_transfer` could be performed.

2.6.5 How to Terminate the Coupling?

The code has an `exitcoupling()` method available to implement a call to the MpCCI exit function `mpcci_quit` or `mpcci_stop` (▷ 2.7.15 End of Coupled Simulation: `mpcci_quit` and `mpcci_stop` ◁).

2.6.6 How to Notify a Remeshing?

If the code has the capability to remesh the grid, it could use the `ampcci_remesh` (▷ 2.7.14 Notifying the Remeshing: `ampcci_remesh` ◁) routine to notify a remesh event by setting the remesh flag information (see ▷ 2.9.5 Remesh Flag Information ◁). Otherwise the coupling manager could check if a remeshing action occured by calling the driver function `MpCCI_Driver_getPartRemeshState` (see ▷ 2.8.2 Driver Methods Called Before/After Some Action ◁). The code should implement this function and return the corresponding remesh state. In case of grid morphing the code should implement the driver function `MpCCI_Driver_moveNodes` (see ▷ 2.8.3 Driver Mesh Definition Methods ◁).

2.7 MpCCI Coupling Manager Functions

The coupling manager functions are called by the calling code. They are defined in some MpCCI header files and you should add `#include "mpcci.h"` to the source files, from which you call the coupling manager functions.

Example calls are given in `"adapter.c"` in the MpCCI API Kit.

The coupling manager functions are:

Meaning of the function naming convention:

umpcci_* represent MpCCI utility functions.

smpcci_* functions are low level single server communication functions.

mpcci_* functions are designed for multi server communication.

ampcci_* are auxiliary adapter level functions.

2.7.1 Definition of Output Functions: `umpcci_msg_functs`

```
void umpcci_msg_functs( void (*printFullMessage)(const char *str, int len),
                        void (*printFullWarning)(const char *str, int len),
                        void (*printFullFatal  )(const char *str, int len),
                        void (*printLineMessage)(const char *str, int len),
                        void (*printLineWarning)(const char *str, int len),
                        void (*printLineFatal  )(const char *str, int len),
                        void (*atExitHandler)(void));
```

Before calling any other coupling manager function, the functions for input and output should be defined. There are seven different functions, the three first functions get multi-line strings for ordinary output messages, warnings and fatal messages together with the string length.

The second set of functions only receives one line at a time, i. e. the strings contain no newline characters (line-printer mode), which is useful for calling from FORTRAN.

It is not necessary to define all functions (give `NULL` pointers instead), but you should define either the first set of three functions or the second set of three functions.


Do not use `printf` for output as the strings are already formatted and may contain percent (`%`) signs!

2.7.1.1 Description Values

`void printFullMessage(const char *str, int len)`

For printing a message, typically use a pop-up window or print to log file.

`void printFullWarning(const char *str, int len)`

Called for printing of warnings.

`void printFullFatal(const char *str, int len)`

Called for printing of fatal errors, i. e. the program will be terminated by the code adapter after this call, Please do not include any cleaning up into this routine, only the printing. See also `atExitHandler` below.

`void printLineMessage(const char *str, int len)`

Line print for ordinary messages.

`void printLineWarning(const char *str, int len)`

Line print for warnings.

`void printLineFatal(const char *str, int len)`

Line print for fatal errors.

`void atExitHandler(void)`

This method is called before the code adapter terminates the code in case of fatal errors. You can use this method for cleaning up.

2.7.2 Definition of Output Prefix: `umpcci_msg_prefix`

This function is used to set a prefix for the coupled simulation. You may use this function for identifying the output of the running parallel processes for example.

```
void umpcci_msg_prefix(const char *prefix);
```

The arguments is:
`const char *prefix` Character string to use for output as prefix.

2.7.3 Get Transfer Information: `ampcci_tinfo_init`

This function is used to determine the transfer information selected in the MpCCI GUI. In the MpCCI GUI for each code the option Coupling configuration is available and provides the access to different options such as :

- the option Initial quantitites transfer set to exchange, skip, receive or send.
- the option Send mode set to always, onewait or allwait.
- the option Receive mode set to all, available, any or complete.
- the option Check mode set to none or forward. Whereas forward provides further options to configure the coupling such as:
  - the option Time for starting the coupling,
  - the option Time for ending the coupling,
  - the option Time step size without coupling,
  - the option Iteration No. for starting the coupling,
  - the option Iteration No. for ending the coupling,
  - the option No. of iterations without coupling.

This information is given to the executed code via the environment variable `MPCCI_TINFO`. Each of the possible values corresponds to a bit mask, which can be retrieved with `ampcci_tinfo_init`.

```
int ampcci_tinfo_init (MPCCI_TINFO *mpcciTinfo, const char* config);
```

The arguments are:

`MPCCI_TINFO *mpcciTinfo`	Pointer to the `MPCCI_TINFO` structure for the code. This structure will be initialized.
`const char* config`	Specify another environment variable to read the transfer information definition other than the standard variable `MPCCI_TINFO` (See ▷ 2.9.6 Transfer Information: `MPCCI_TINFO` ◁). Provide `NULL` to use the standard environment.

The return value is 1 if the transfer information was successfully set up.

2.7.4 Initialize the Code Information Structure

This function is used to determine the job information selected in the MpCCI GUI: the coupling scheme explicit or implicit, the coupling algorithm serial or parallel.

```
void mpcci_cinfo_init(MPCCI_CINFO *cinfo, const MPCCI_TINFO *mpcciTinfo);
```

2.7.5 Connect and Initialize an MpCCI Server: `mpcci_init`

The initialization function must be called from your code before the beginning of the iteration or time loop. This call should establish a connection to the MpCCI server.

```
MPCCI_JOB mpcci_init(const char *porthost, const MPCCI_CINFO *cinfo);
```

The arguments are:

`const char *porthost`	The broker location `porthost`, only needed for coupling a code with a multi server configuration, should be `NULL` in other cases.
`MPCCI_CINFO *cinfo`	Code information structure. This structure keeps code specific information. (See ▷ 2.9.7 Code Specific Information: `MPCCI_CINFO` ◁).

The return value is an `MPCCI_JOB` value and not null if a connection to the server could be established. This can be used to detect whether a coupled or uncoupled simulation is run.

The initialization routine performs the following tasks:

- Check the code name.
- Check the job id by using the environment `MPCCI_JOBID` if it is not statically defined by the adapter.
- Check the code id by using the environment `MPCCI_CODEID` if it is not statically defined by the adapter.
- Define the server host by using the environment `MPCCI_SERVER` if no broker is defined.
- Connect to the server.
- Get the type of grid to use for the grid definition. See ▷ 2.9.7 Code Specific Information: `MPCCI_CINFO` ◁ for the types.

2.7.6 Configure the Code Adapter: `ampcci_config`

The code adapter configuration function must be called from your code before the beginning of the iteration or time loop and after having called the initialization function `mpcci_init` with a valid `MPCCI_JOB`. However, the geometry of the mesh should already be known, as it is passed to MpCCI at this point.

```
int ampcci_config(MPCCI_JOB **job, const MPCCI_DRIVER *driver);
```

The arguments are:

`MPCCI_JOB **job`	The `MPCCI_JOB` value returned after calling the `mpcci_init` containing the connection information to the MpCCI server. This should be passed to this function
`const MPCCI_DRIVER *driver`	Pointer to list of driver functions. See ▷ 2.8 MpCCI Driver Functions ◁.

The return value is

- 1 if the code successfully defined the mesh and quantities to the server.
- 0 if the co-simulation runs in pre-check mode. In this case only the mesh and quantities definition are sent to the server for a mesh check with a neighborhood calculation.
- -1 if an error occurs during the mesh and quantities definition to the server.

The adapter configuration routine performs the following tasks:

- Check if the supplied driver functions match the MpCCI version.
- Register driver functions, i. e. the pointers to the function pointers are saved to internal data structures.
- Get the coupled parts and their quantities and all globals from the server, i. e. all information defined in the MpCCI GUI, including the coupling components.
- Call the driver function `MpCCI_Driver_appendParts` if it is defined.
- Loop over all coupling components:
  - Call `MpCCI_Driver_partSelect` if `MpCCI_Driver_partUpdate` or `MpCCI_Driver_partInfo` is defined.
  - Call `MpCCI_Driver_partUpdate`, in which the quantity could be checked and the part updated.
  - Call `MpCCI_Driver_partInfo` to get the mesh information, e. g. coordinate system, number of nodes and elements, part id, etc. .
  - Check the quantity setting.
- Print the list of partner codes.
- Loop over all coupling components:
  - Call `MpCCI_Driver_partSelect`.
  - Define the grid:
    - Call `MpCCI_Driver_definePart` if defined (see Figure 22), otherwise
    - Call `MpCCI_Driver_getNodes` and `MpCCI_Driver_getElems`, in which the mesh is automatically defined by calling `smpcci_defp`, `smpcci_pnod`, `smpcci_pels` and calls `MpCCI_Driver_getFaceNomals` and `MpCCI_Driver_getElemSize` if defined (see Figure 23).
- Define the mesh based and global quantities.
- List the information about coupled components and quantities.
- Call the driver function `MpCCIDriver_afterCloseSetup`.
- Return to the calling code.

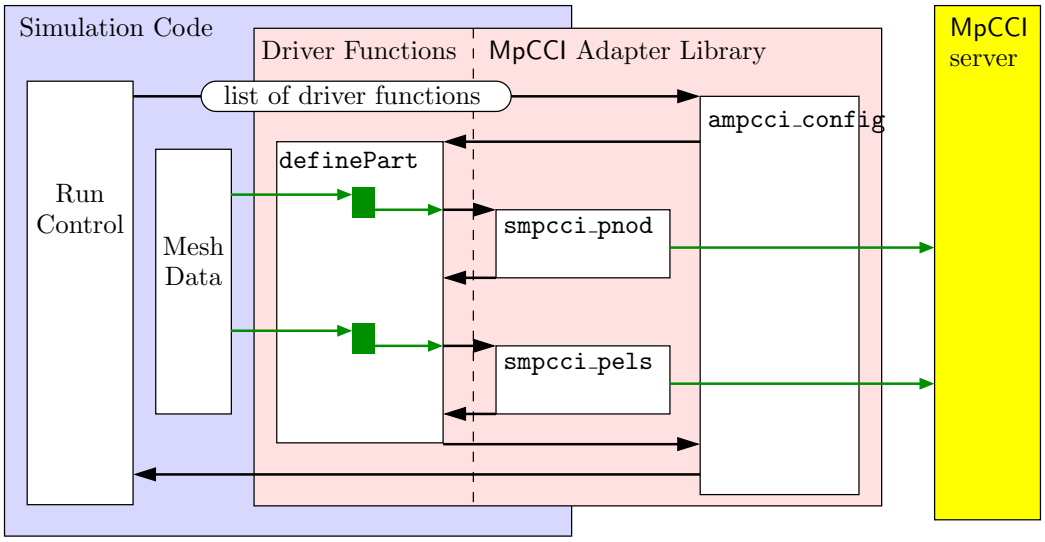


Figure 22: Call of `ampcci_config`: `MpCCI_Driver_definePart` is hooked

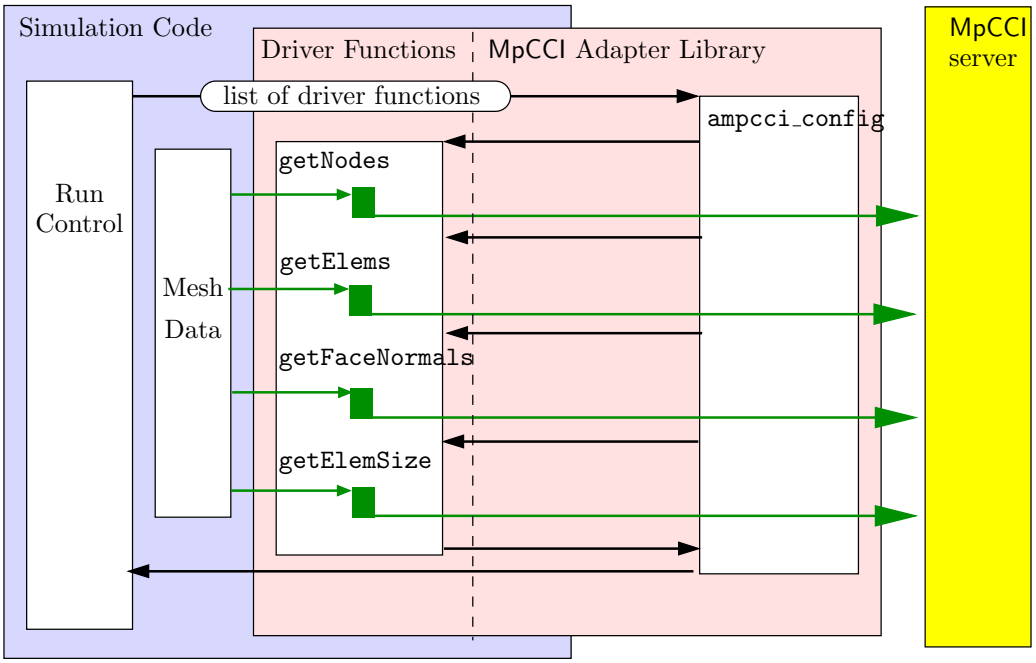


Figure 23: Call of `ampcci_config`: `MpCCI_Driver_getNodes` and `MpCCI_Driver_getElems` are hooked

2.7.7 Definition of Part: `smpcci_defp`

The part definition should be called from the driver function `MpCCI_Driver_definePart` to define the coupling component, see also `"adapter.c"` of the MpCCI API Kit.

The syntax is:

```
int smpcci_defp(MPCCI_SERVER *server,
                int           mid,
                int           pid,
                unsigned      csys,
                int           nnodes,
                int           nelems,
                const char    *name)
```

The parameters are:

`MPCCI_SERVER *server`	The MpCCI server pointer passed by the `MpCCI_Driver_definePart`.
`int mid`	mesh ID, should be set by `MPCCI_PART_MESHID(part)`. The part is provided by `MpCCI_Driver_definePart`.
`int pid`	part ID, should be set by `MPCCI_PART_PARTID(part)`
`unsigned csys`	coordinates system of your mesh (see ▷2.9.2 Coordinates System Definition◁, should be set to `MPCCI_PART_CSYS(part)` if this has been defined in `MpCCI_Driver_partInfo`.
`int nnodes`	number of nodes of the component, can be simply set by `MPCCI_PART_NNODES(part)`.
`int nelems`	number of elements of the component, can be simply set by `MPCCI_PART_NELEMS(part)`.
`const char *name`	name of the component, can be simply set by `MPCCI_PART_NAME(part)`.

It returns 0 for a successful operation.

2.7.8 Delete a Part: `smpcci_delp`

The part deletion should be called from the driver function `MpCCI_Driver_definePart` to delete the coupling component if the current process does not have any elements to couple.

The syntax is:

```
int smpcci_delp(MPCCI_SERVER *server,
                int           mid,
                int           pid);
```

The parameters are:

`MPCCI_SERVER *server`	The MpCCI server pointer passed by the `MpCCI_Driver_definePart`.
`int mid`	mesh ID, should be set by `MPCCI_PART_MESHID(part)`. The part is provided by `MpCCI_Driver_definePart`.
`int pid`	part ID, should be set by `MPCCI_PART_PARTID(part)`

It returns 0 for a successful operation.

2.7.9 Definition of Nodes: `smpcci_pnod`

The node definition should be called from the driver function `MpCCI_Driver_definePart` to define the nodes of a coupling component, see also `"adapter.c"` of the MpCCI API Kit. Only those nodes which send or receive data during the coupling process should be given.

The syntax is:

```
int  smpcci_pnod(MPCCI_SERVER *server,
                 int           mid,
                 int           pid,
                 unsigned      csys,
                 int           nnodes,
                 const void   *coords,
                 unsigned      realsize,
                 const int    *nodeids,
                 const void   *angles)
```

The parameters are:

`MPCCI_SERVER *server`	The MpCCI server pointer passed by the `MpCCI_Driver_definePart`.
`int mid`	mesh ID, should be set by `MPCCI_PART_MESHID(part)`. The part is provided by `MpCCI_Driver_definePart`.
`int pid`	part ID, should be set by `MPCCI_PART_PARTID(part)`
`unsigned csys`	coordinates system of your mesh (see ▷2.9.2 Coordinates System Definition◁, should be set by `MPCCI_PART_CSYS(part)` if this has been defined in `MpCCI_Driver_partInfo`.
`int nnodes`	number of nodes of the component, can be simply set by `MPCCI_PART_NNODES(part)`.
`const void *coords`	Array of node coordinates: (x,y) list or (x,y,z) list. This array should be allocated by the code.
`unsigned realsize`	The size of the floating point value written for the node coordinates.
`const int *nodeids`	Array of the node IDs. Optional value. This could be set to NULL.
`const void *angles`	Array of the node angles: (x,y) list or (x,y,z) list. Optional value. This could be set to NULL.

It returns 0 for a successful operation.

2.7.10 Definition of Elements: `smpcci_pels`

The element definition should be called from the driver function `MpCCI_Driver_definePart` after the node definition to define the elements of a coupling component, see also `"adapter.c"` of the MpCCI API Kit.

All nodes used in `smpcci_pels` must be already defined with `smpcci_pnod`.

The syntax is:

```
int  smpcci_pels(MPCCI_SERVER   *server,
                 int             mid,
                 int             pid,
                 int             nelems,
                 unsigned        eltype1,
                 const unsigned *eltypes,
                 const int      *elnodes,
                 const int      *elemids)
```

The parameters are:

`MPCCI_SERVER *server`	The MpCCI server pointer passed by the `MpCCI_Driver_definePart`.
`int mid`	mesh ID, should be set by `MPCCI_PART_MESHID(part)`
`int pid`	part ID, should be set by `MPCCI_PART_PARTID(part)`
`int nelems`	number of elements, can be set by `MPCCI_PART_NELEMS(part)`.
`unsigned eltype1`	one element type. Define this element type if all elements use the same element type, otherwise the eltypes array should be defined.
`const unsigned *eltypes`	element types. This can be one of the predefined element types, which are given in ▷ 2.9.1 Supported Element Types ◁.
`const int *elnodes`	array of the node numbers (your node numbers) of the element nodes. See description below.
`const int *elemids`	array of element IDs. Size should be `nelems`. Optional value. This could be set to NULL.

It returns 0 for a successful operation.

2.7.10.1 Definition of Element Nodes

The nodes of each element are given in two arrays. The first, `eltypes`, contains one unsigned integer value for each element, which corresponds to the number of nodes for the element. This array is optional if all the elements have the same type. The nodes for all elements are simply listed in `elnodes`, the size of this array is therefore difficult to give, but it does not matter if it is too big.

So, if you have a 4-node quad element with nodes 1, 2, 3, 4 and two 3-node triangle elements with nodes 11, 12, 13 and 21, 22, 23, you should define:

```
int eltypes[] = { MPCCI_ETYP_QUAD4, MPCCI_ETYP_TRIA3, MPCCI_ETYP_TRIA3};
int elemNodes[] = { 1, 2, 3, 4,  11, 12, 13,  21, 22, 23 };
```

It is important to specify the nodes in the correct order! The order which you must use is given in ▷ 2.9.1 Supported Element Types ◁.

2.7.10.2 Definition of Element Types

The element types are listed in ▷ 2.9.1 Supported Element Types ◁ and defined in the file `"mpcci_elements.h"`.

The element types can be given in two ways: Either you have a mesh, which consists of elements of the same type. In this case you can set `eltype1` and `eltypes[] = NULL`, i. e. the list of element types only

consists of one type, which is valid for all elements.

If you have a mesh which consists of different types you can give the type for each element. Then size of `eltypes` should have the same value as `nelems` and the argument `eltype1` should be set to 0.

2.7.11 Definition of the Moving Reference Frame: `smpcci_pmot`

The moving reference frame should be defined from the driver function `MpCCI_Driver_definePart` before the node definition (▷ 2.7.9 Definition of Nodes: `smpcci_pnod` ◁) or if the driver function `MpCCI_Driver_definePart` is not implemented, the `MpCCI_Driver_closeSetup` should be implemented and call the definition function for the moving reference frame.
You should then use the `MPCCI_SERVER *server` to loop over the coupled part and set the `motion` structure.

The syntax is:

```
int  smpcci_pmot(MPCCI_SERVER       *server,
                 int                 mid,
                 int                 pid,
                 const MPCCI_MOTION *motion);
```

The parameters are:

`MPCCI_SERVER *server`	The MpCCI server pointer passed by the `MpCCI_Driver_definePart`.
`int mid`	mesh ID, should be set by `MPCCI_PART_MESHID(part)`. The part is provided by `MpCCI_Driver_definePart`.
`int pid`	part ID, should be set by `MPCCI_PART_PARTID(part)`.
`const MPCCI_MOTION *motion`	moving reference frame information (See ▷ 2.9.4 Moving Reference Frame Definition ◁).

It returns 0 for a successful operation, otherwise a number less than 0.

2.7.12 Definition of the Baffle Thickness: `smpcci_pshf`

The baffle thickness definition is an optional function.

This function can be called from the driver function `MpCCI_Driver_definePart` and it should be called after the element definition (▷ 2.7.10 Definition of Elements: `smpcci_pels` ◁).

The syntax is:

```
int  smpcci_pshf(MPCCI_SERVER      *server,
                 int                mid,
                 int                pid,
                 double             sval);
```

The parameters are:

`MPCCI_SERVER *server`	The MpCCI server pointer passed by the `MpCCI_Driver_definePart`.
`int mid`	mesh ID, should be set by `MPCCI_PART_MESHID(part)`. The part is provided by `MpCCI_Driver_definePart`.
`int pid`	part ID, should be set by `MPCCI_PART_PARTID(part)`
`double sval`	the thickness of the baffle. The thickness defines how much the current part ID should be shifted on the MpCCI server side.

Usually a baffle will be defined twice for the front and rear side. The call of this function should be done of the side you would like to shift.
It returns 0 for a successful operation.

2.7.13 Data Exchange: `ampcci_transfer`

The transfer function must be called from your code before or after the solver.

```
int ampcci_transfer(MPCCI_JOB *job, MPCCI_TINFO *tinfo)
```

The arguments are:

`MPCCI_JOB *job`	The current `MPCCI_JOB` returned during the initialization.
`MPCCI_TINFO *tinfo`	The transfer information containing the current time, iteration for the quantities transferred and the transfer type to execute.

The return value is:

`-1` : Error.
`1` : Transfer done.
`0` : No transfer occurred.

The transfer information `tinfo` is updated by the call. The code can check if all quantities have been received for comparing for example tinfo.nquant_req and tinfo.nquant_r, etc.

The transfer routine performs the following tasks:

- Check if the `MPCCI_JOB` is valid and that it is a coupled process.
- Get the first initial transfer action and check if the transfer is valid.
- If the check mode is set to forward, check if the transfer should be executed.
- Get the remesh status of each individual part if `MpCCI_Driver_getPartRemeshState` is defined. If remeshing:
  - Call the driver function `MpCCI_Driver_moveNodes` if it does not concern all the parts.
  - Redefine the topology.
- Check if any partner is waiting for a quantity.
- Check if any quantity is available
- Set the transfer information on each server.
- If the code should send:
  - Call the driver function `MpCCI_Driver_beforeGetAndSend`.
  - Loop over all coupling components:
    - Check if the quantity selection mode is matching (▷ 2.9.6 Transfer Information: `MPCCI_TINFO` ◁).
    - Call the driver function `MpCCI_Driver_partSelect` if the component was not selected.
    - Call the corresponding get data driver function according to the coupled dimension.
    - Send the data to the server.
  - Call the driver function `MpCCI_Driver_getGlobValues`
  - Send the global values to the server.
  - Call the driver function `MpCCI_Driver_afterGetAndSend`
- Update the convergence flag `tinfo.conv_code` and check if no error occured.
- If the code should receive:
  - Call the driver function `MpCCI_Driver_beforeRecvAndPut`.
  - Loop over all coupling components:
    - Check if the quantity selection mode is matching (▷ 2.9.6 Transfer Information: `MPCCI_TINFO` ◁).
    - Call the driver function `MpCCI_Driver_partSelect` if the component was not selected.
    - Receive the data from the server.
    - Call the corresponding put data driver function according to the coupled dimension.

  - Receive the global values from the server.
  - Call the driver function `MpCCI_Driver_putGlobValues`
  - Call the driver function `MpCCI_Driver_afterRecvAndPut`
- Save the current job.
- Return to calling code.

2.7.14 Notifying the Remeshing: `ampcci_remesh`

To notify a remeshing to MpCCI the following function must be called from the code. MpCCI will automatically get the new definition of the mesh.

The syntax is:

```
int  ampcci_remesh(MPCCI_JOB *job, unsigned flags);
```

The parameters are:
`MPCCI_JOB *job` The MpCCI job pointer created by the `mpcci_init`.
`unsigned flags` Specify the type of remeshing (See ▹ 2.9.5 Remesh Flag Information ◃).

It returns 0 for a successful operation.

2.7.15 End of Coupled Simulation: `mpcci_quit` and `mpcci_stop`

The code quits and the MpCCI server continues

```
int mpcci_quit(MPCCI_JOB **job)
```

The arguments are:
`MPCCI_JOB **job` The MpCCI job.

The code stops and the other partners are informed and the MpCCI server stops, too

```
int mpcci_stop(MPCCI_JOB **job, const char *message);
```

The arguments are:
`MPCCI_JOB **job` the MpCCI job.
`const char *message` error message to print and send before disconnecting the MpCCI server.

These functions always return 0.

2.8 MpCCI Driver Functions

The driver functions are responsible for the exchange of data between the code adapter and the application. To enable a coupled simulation a set of functions must be provided. Exemplary implementations of the necessary driver functions are given in "adapter.c" of the MpCCI API Kit. A description of all functions is given on the following pages.

The driver functions are called by the coupling manager functions as described in ▷ 2.7 MpCCI Coupling Manager Functions ◁, therefore they can be regarded as the passive part of the adapter.

A structure of pointers to these functions is handed over to MpCCI via the `ampcci_config` routine, see also "adapter.c" of the MpCCI API Kit and ▷ 2.7.6 Configure the Code Adapter: ampcci_config ◁. The names of the functions can be chosen arbitrarily. Only two functions are *required* functions, which must be provided, all other functions need not to be defined, a NULL-pointer can be given instead. The complete structure without NULL pointers is:

```
struct _MPCCI_DRIVER
{
/*****************************************************************************
 * REQUIRED: information for compatibility checks
 *****************************************************************************/
unsigned this_size;     /* (unsigned)sizeof(MPCCI_DRIVER) */
unsigned this_version;  /* value of MPCCI_CCM_VERSION defined in mpcci.h */

/*****************************************************************************
 * REQUIRED: bitmask for or'ing MPCCCI_TINFO.tact
 *****************************************************************************/
unsigned tact_required;   /* bitmask: MPCCI_TACT_* */

/*****************************************************************************
 * REQUIRED: define symbolic names for the types of parts in code terminology
 *           example:
 *             [0] = "Point(s) with coordinates, single point or point cloud",
 *             [1] = "Line",
 *             [2] = "Surface",
 *             [3] = "Volume domain",
 *             [4] = "Single integration point",
 *             [5] = "Global variable"
 *             [6] = NULL, not yet used
 *             [7] = NULL, not yet used
 *****************************************************************************/
const char *part_description[8];

/*****************************************************************************
 * REQUIRED: (unsigned)sizeof(real) for all received quantities
 *****************************************************************************/
unsigned realsize;

/*****************************************************************************
 * OPTIONAL: methods called before/after some actions
 *****************************************************************************/
void (*afterCloseSetup) (void);  /* method called after def_close */
void (*beforeGetAndSend)(void);  /* method called before send operation */
void (*afterGetAndSend) (void);  /* method called after send operation */
```

```
void (*beforeRecvAndPut)(void);  /* method called before receive operation */
void (*afterRecvAndPut) (void);  /* method called after receive operation */

void (*partSelect)         (const MPCCI_PART *part);
int  (*partUpdate)         (      MPCCI_PART *part, MPCCI_QUANT  *quant);
void (*appendParts)        (const MPCCI_JOB  *job , MPCCI_SERVER *server);
int  (*getPartRemeshState) (const MPCCI_PART *part, unsigned flags);

/*****************************************************************************
 * REQUIRED: methods to get information about a part
 *****************************************************************************/
/* variante #1: fast & dirty: returns the MpCCI error code */
int (*definePart)(MPCCI_SERVER *server, MPCCI_PART *part);

/* variante 2: may be slow but better interface */
void (*partInfo) (      int  *rDim,
                  unsigned  *csys,
                       int  *nNodes,
                       int  *nElems,
                       int  *maxNodesPerElem,
                       int  *regId,
                 const char *regName,
                       int   len);
int  (*getNodes) (const MPCCI_PART *part, unsigned *csys, void *coords, int *nodeIds);
int  (*getElems) (const MPCCI_PART *part, unsigned *elemType1, unsigned *elemTypes,
                  int *elemNodes, int *elemIds);

/*****************************************************************************
 * REQUIRED for moving nodes instead of full remeshing: returns the MpCCI error code
 *****************************************************************************/
int (*moveNodes)      (MPCCI_SERVER *server, MPCCI_PART *part);


/*****************************************************************************
 * OPTIONAL(depends): methods used to get quantities from the application
 *****************************************************************************/
int (*getPointValues   )(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
int (*getLineNodeValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
int (*getLineElemValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
int (*getFaceNodeValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
int (*getFaceElemValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
int (*getVoluNodeValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
int (*getVoluElemValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
int (*getGlobValues    )(                        const MPCCI_GLOB  *glob , void *values);

/*****************************************************************************
 * OPTIONAL(depends): methods used to store quantities into the application
 *****************************************************************************/
void (*putPointValues   )(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
void (*putLineNodeValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
void (*putLineElemValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
void (*putFaceNodeValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
```

```
void (*putFaceElemValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
void (*putVoluNodeValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
void (*putVoluElemValues)(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values);
void (*putGlobValues    )(                        const MPCCI_GLOB  *glob , void *values);

};
```

2.8.1 Description Values

size_t this_size

The size of the structure, must be set to `sizeof(MPCCI_DRIVER)`.

unsigned this_version

The version of the code adapter, i. e. the MpCCI version, without dots. Should currently be set to `400` to match this description.

unsigned tact_required;

This defines the actions of the code coupling manager. In most cases it should be set to `0`. Other values `(MPCCI_TACT_GETQ|MPCCI_TACT_PUTQ)` should only be used in special case, e. g. codes with several processes, where the driver functions should be always called to avoid locks.

const char *part_description[8]

An array of descriptions to improve output. You should give a set of names that match the terminology of your code, e. g.

```
{ "point",          /* name for point */
  "edge",           /* name for lines */
  "surface",        /* name for faces */
  "body",           /* name for volumes */
  "ipoint",         /* name for integration point */
  "global variable"}/* name for global quantities */
```

unsigned realsize

The size of the floating point values given to the put functions, usually set to one of `(unsigned)sizeof(float)` or `(unsigned)sizeof(double)`.

2.8.2 Driver Methods Called Before/After Some Action

`void (*afterCloseSetup)(void)`

This method is called at the end of the setup of coupling components.

It is usually not necessary to define this function.

`void (*beforeGetAndSend)(void)`

This method is called before any get functions are called and data is sent. Define this method if you need to perform any actions before the get functions can read data.

`void (*afterGetAndSend)(void)`

This method is called after all required get functions were called and the data was transferred to the MpCCI server.

`void (*beforeRecvAndPut)(void)`

This method is called before data is received and before appropriate put functions are called.

`void (*afterRecvAndPut)(void)`

This method is called after the put functions were called.

`void (*partSelect)(const MPCCI_PART *part)`

You can use this driver function to remember which components were selected in the MpCCI GUI for coupling. It is called once for each component, which is given in `part`.

In most codes this function is not needed.

`int (*partUpdate)(MPCCI_PART *part, MPCCI_QUANT *quant)`

This function is called during `ampcci_config`. You should update the components in this function, namely the number of nodes and elements of each component, the coordinates system. For details please see `"adapter.c"` of the MpCCI API Kit. You can use this driver function to allocate memory for the quantity `quant` on the component `part` or check the quantity setting.
The number of nodes is updated by assigning the value to `MPCCI_PART_NNODES(part)` and the number of elements is set by assigning the value to `MPCCI_PART_NELEMS(part)`.

Return `0` if this is successful.

If your code supports coupling of AngularCoordinates, you should add a flag to the quantity that determines the rotational formalism used by your code, see ▷ 2.6.3 How to Deal with Angular Coordinates? ◁.

`void (*appendParts)(const MPCCI_JOB *job, MPCCI_SERVER *server)`

This method is intended that coupling components `MPCCI_PART` can be added automatically and need not be selected in the MpCCI GUI.

In most codes this function is not needed. All components can be chosen in the MpCCI GUI.

`int (*getPartRemeshState)(const MPCCI_PART *part, unsigned flags)`

This function is called during `ampcci_transfer` to check the state of the mesh. It returns one of these values:

- `MPCCI_REMESH_STATE_NONE` : Nothing was done.

- `MPCCI_REMESH_STATE_REMESHED` : The mesh has been remeshed.
- `MPCCI_REMESH_STATE_SMOOTHED` : The mesh has been smoothed.
- `MPCCI_REMESH_STATE_MIGRATED` : Some nodes have migrated to another process.

The argument `flags` is not used in this function.

2.8.3 Driver Mesh Definition Methods

The mesh definition functions are called if information on the meshes is needed. There are two ways to provide information on meshes:

1. The implementation of `partUpdate`, `definePart`, or
2. The implementation of `partInfo`, `getNodes`, `getElems`

One of them is required.

```
int (*definePart)(MPCCI_SERVER *server, MPCCI_PART *part)
```

You should define nodes and elements of the coupling component given by `part`:

- Define the part `smpcci_defp` see ▷ 2.7.7 Definition of Part: `smpcci_defp` ◁).
- Or delete the part `smpcci_delp` see ▷ 2.7.8 Delete a Part: `smpcci_delp` ◁) if the number of nodes and elements are zero on the current process in case of a distributed memory model.
- Define the node ids and coordinates with `smpcci_pnod` (see ▷ 2.7.9 Definition of Nodes: `smpcci_pnod` ◁).
- Define the element topology with `smpcci_pels` (see ▷ 2.7.10 Definition of Elements: `smpcci_pels` ◁).
- Define the moving reference frame with `smpcci_pmot` (see ▷ 2.7.11 Definition of the Moving Reference Frame: `smpcci_pmot` ◁).

In this case the code is responsible to allocate the memory for the nodes and elements.

The number of nodes and elements should be updated in the `partUpdate` function (see ▷ 2.8.2 Driver Methods Called Before/After Some Action ◁).

It returns 0 for successful operation.

```
void (*partInfo) (int *rDim, unsigned *csys, int *nNodes, int *nElems,
                  int *maxNodesPerElem, int *regId, const char *regName, int len)
```

You should define information on the coupling component given by `regName` or `regId`:

- Set the dimension with `rDim` (see ▷ 2.9.3 Mesh Dimension Definition ◁).
- Set the coordinates system with `csys` (see ▷ 2.9.2 Coordinates System Definition ◁).
- Set number of nodes with `nNodes`.
- Set number of elements with `nElems`.
- Set the maximum number of nodes per element with `maxNodesPerElem`.

This provides information for the coupling manager for allocating the memory for the mesh definition operation.

```
int (*getNodes) (const MPCCI_PART *part, unsigned *csys, void *coords, int *nodeIds)
```

You should provide information on the nodes on the coupling component given by `part`:

- `csys`: coordinates system may be redefined.
- `coords`: the array of coordinates of the nodes.
- `nodeIds`: an optional array of node ids. It could be set to NULL.

This function returns the size of the floating point values written in the coordinates, e. g. `(int)sizeof(double)`.

```
int (*getElems) (const MPCCI_PART *part, unsigned *elemType1,
                 unsigned *elemTypes, int *elemNodes, int *elemIds)
```

You should provide information on the elements on the coupling component given by `part`:

- `elemType1`: element type if all the elements are equal (see ▷ 2.9.1 Supported Element Types ◁).
- `elemTypes`: the array of element types if the mesh is built of different element types.
- `elemNodes`: array of the node numbers (your node numbers) of the element nodes.
- `elemIds`: optional array of element IDs. It could be set to NULL.

This function returns the following bit pattern value:

- `0x0000`: the `elemIds` array is not used.
- `0x0001`: the `elemIds` array is valid.

`int (*moveNodes) (MPCCI_SERVER *server, MPCCI_PART *part)`

This function is required for moving nodes instead of full remeshing. It is called when the remeshing state is set to `MPCCI_REMESH_STATE_SMOOTHED`. In that case the code should define the moving nodes by using the function `smpcci_pnod` (see ▷ 2.7.9 Definition of Nodes: `smpcci_pnod` ◁).

2.8.4 Driver Data Exchange Methods

There are two kinds of exchange functions. The get functions read data from the code and are called before sending data to the partner code via the MpCCI servers. The put functions are called after data was received and must write the data to the code.

The get functions are all similar and have the same syntax:

`int get...Values(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values)`

The parameters are:

`const MPCCI_PART *part`	pointer to coupling component structure.
`const MPCCI_QUANT *quant`	pointer to quantity structure.
`void *values`	pointer to data array.

Return value:

`int floatSize`	size of the floating point values which are written to `*values`. Typically this is `sizeof(float)` or `sizeof(double)`.

In the get functions, the required values must be written to the compact data array, which is already allocated. The pointer is given as parameter. You can give the data in any floating point format.

All information on the coupling component and the requested quantity are given in `part` and `quant`.

The get functions are distinguished by the component dimension, `Point`, `Line`, `Face` or `Volu`, and by the location, i. e. `Node` or `Elem`. You only need to define those functions, which are supported by your code, i. e. if your code only supports coupling on faces with nodal values, only `MPCCI_DRIVER_getFaceNodeValues` must be defined.

In each function, loop over nodes or elements and collect the values. These values must be written to the array, which `values` points to. The size of the array is given by
`MPCCI_PART_NNODES(part) * MPCCI_PART_MDIM(part)` for nodal values and
`MPCCI_PART_NELEMS(part) * MPCCI_QUANT_DIM(quant)` for element values. `MPCCI_QUANT_DIM(quant)` is the dimension of each value, e. g. 3 for a vector.

The order of nodes and elements is given by the order in which they are defined in `smpcci_pnod` and `smpcci_pels` or in `getNodes` and `getElems` in `definePart` or during the initialization stage.

`int getGlobValues(const MPCCI_GLOB *glob, void *values)`

The parameters are:

`const MPCCI_GLOB *glob`	pointer to global variable structure.
`void *values`	pointer to data array.

Return value:

`int floatSize`	size of the floating point values which are written to `*values`. Typically this is `sizeof(float)` or `sizeof(double)`.

`void put...Values(const MPCCI_PART *part, const MPCCI_QUANT *quant, void *values)`

The parameters are the same as for the get functions. The data array is now filled with values which can be read and transferred to the mesh. The values are of the type given as `realsize` in the driver function structure, see ▷ 2.8 MpCCI Driver Functions ◁.

`int putGlobValues(const MPCCI_GLOB *glob, void *values)`

The parameters are the same as for the `getGlobValues` functions.

2.9 Data Structures and Predefined Macros

MpCCI uses some predefined C preprocessor macros, which can be used in function calls and are described here briefly. Most of the macros described below are defined in the files "<*MpCCI_home*>/include/mpcci_defs.h" and "<*MpCCI_home*>/include/mpcci_types.h", which include short descriptions as well.

2.9.1 Supported Element Types

Supported beam elements

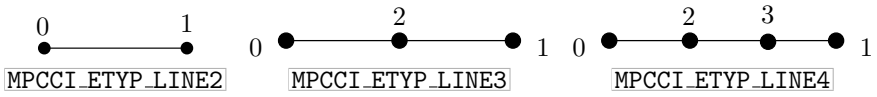


Table 1: Beam element types in the MpCCI code API

Supported triangle elements

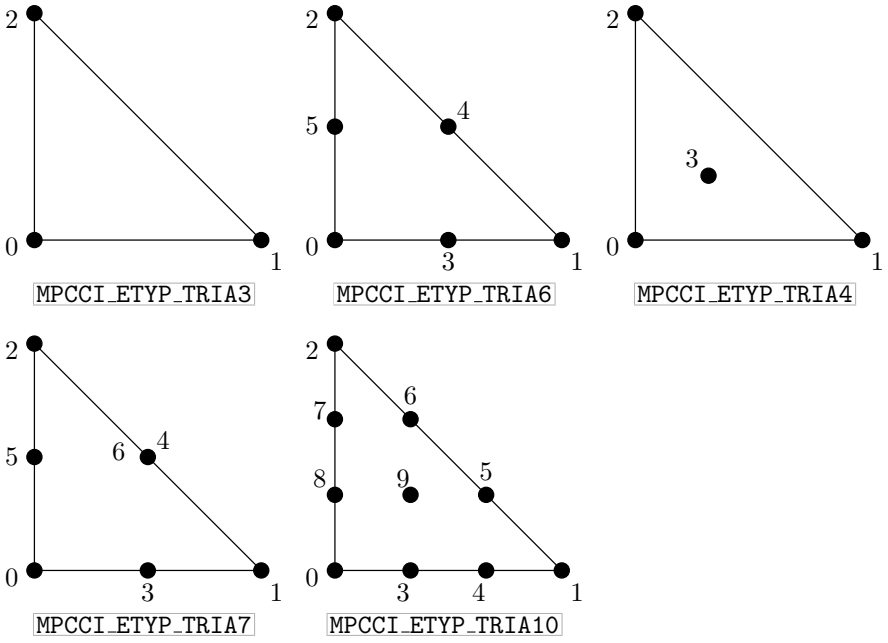


Table 2: Triangle element types in the MpCCI code API

Supported quadrilateral elements

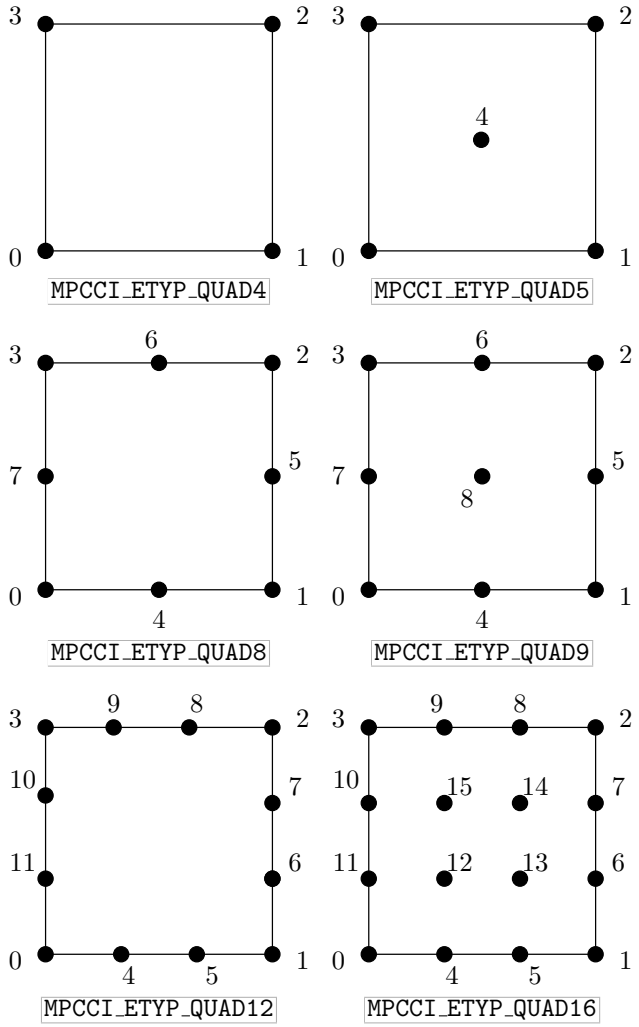


Table 3: Quadrilateral element types in the MpCCI code API

Supported tetrahedral elements

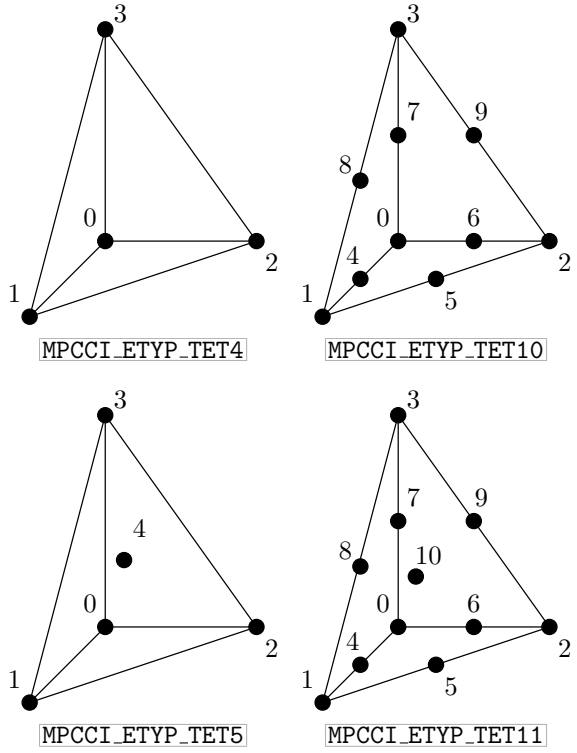


Table 4: Tetrahedral element types in the MpCCI code API

Supported pyramid elements

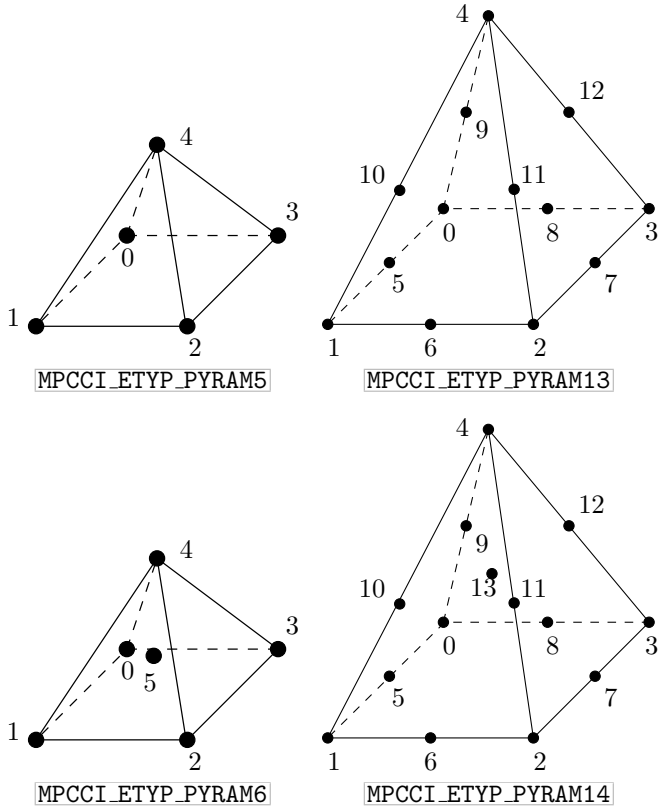


Table 5: Pyramid element types in the MpCCI code API

Supported wedge elements

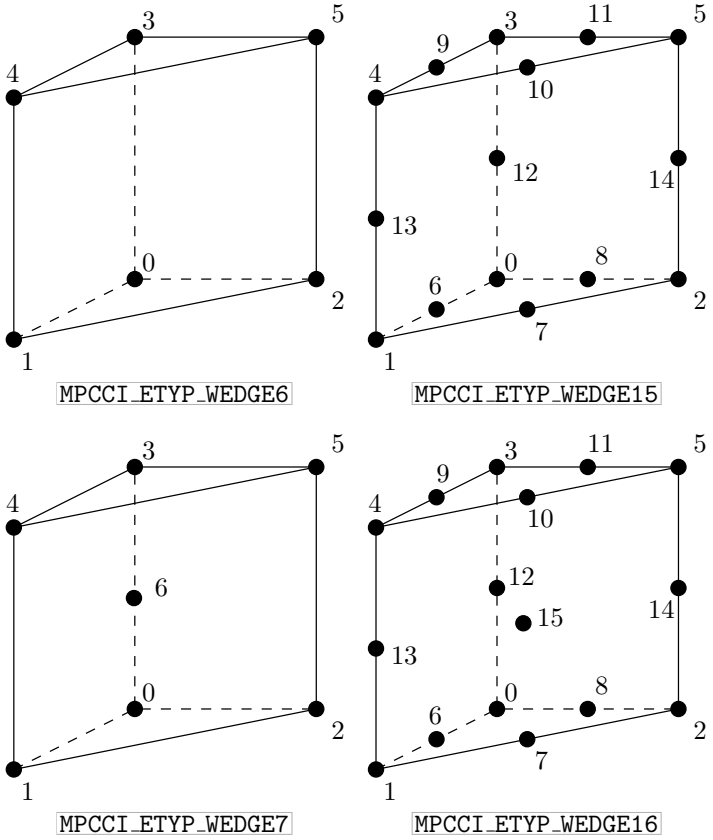


Table 6: Wedge element types in the MpCCI code API

Supported hexahedral elements

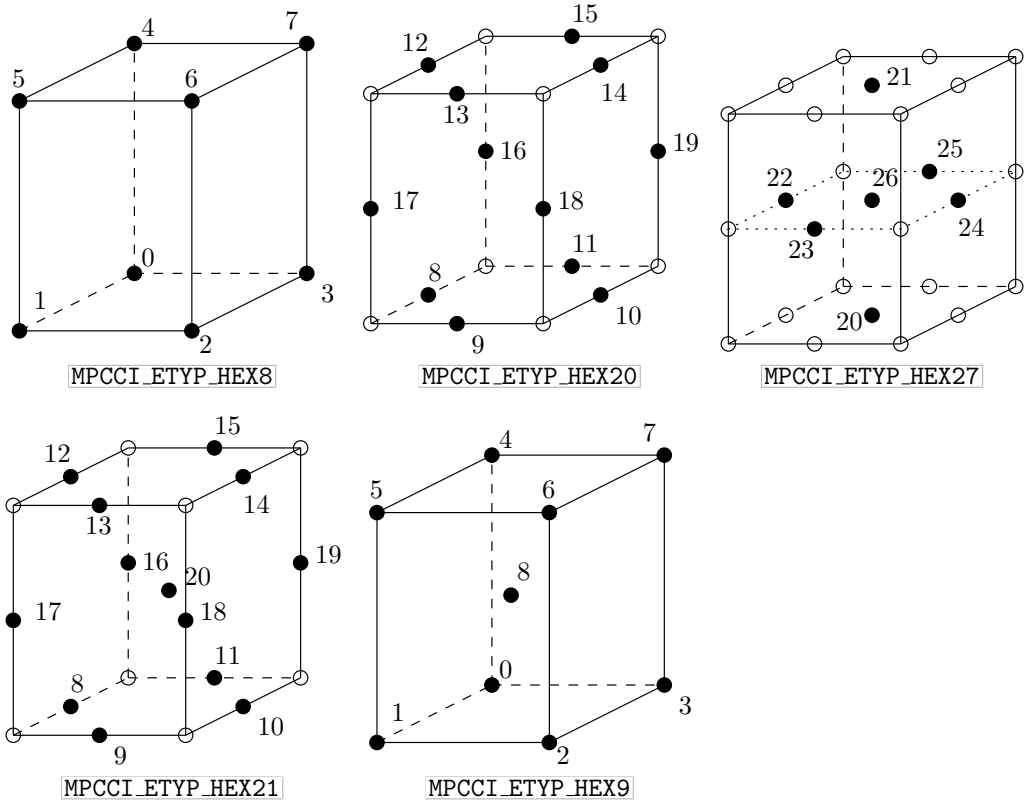


Table 7: Hexahedral element types in the MpCCI code API

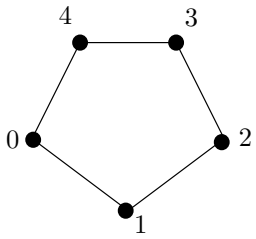
Supported polygonal face elements

To define a polygon face element type

```
unsigned elementType = MPCCI_ESHP_POLY | N;
```

where `MPCCI_ESHP_POLY` is a bitpattern which defines the shape of the polygonal element type and `N` is the number of vertices resp. vertex ids of the polygon. A polygon has at least three vertices. Currently within MpCCI the max. no. of vertices of a polygonal face is limited to 256. Element types `MPCCI_ETYP_POLY2` or `MPCCI_ETYP_POLY300` are invalid and the MpCCI server would complain. You may also use predefined polygonal element types, for example:

```
eltype[3] = MPCCI_ETYP_POLY6;
eltype[4] = MPCCI_ETYP_POLY20;
```



`MPCCI_ETYP_POLY5`

Table 8: Polygonal element types in the MpCCI code API

Supported polyhedral elements

To define a general polyhedron element use this syntax for the element:

```
unsigned elementType = MPCCI_ESHP_PCELL | N
```

where `MPCCI_ESHP_PCELL` is a bitpattern which defines the shape of the element and `N` corresponds to the number of faces+1 plus the number of vertices of all faces. In fact `N` is the number of integer values required to describe the general polyhedron. A tetrahedron for example may also be expressed as a general polyhedron. A tetrahedron is made from four faces with each three vertices:

```
eltype[3] = MPCCI_ESHP_PCELL | (4+1  + 4*3);
```

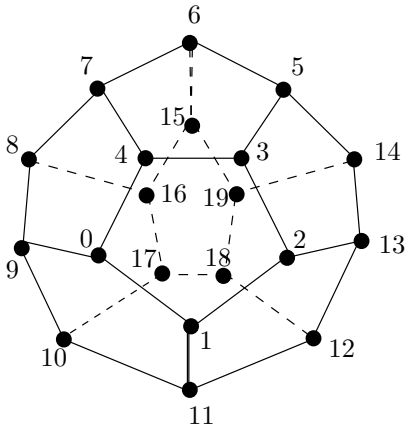
The `elnodes` array of a PCELL is organized in two parts:

- `elnodes[0...elnodes[0]-1]` lookup table for faces node ids
  Example:

`elnodes[0]`	start index of first vertex of face[0] in `elnodes`.
`elnodes[1]`	start index of first vertex of face[1] in `elnodes`.
`elnodes[2]`	start index of first vertex of face[2] in `elnodes`.
`...`	
`elnodes[nface-1]`	start index of first vertex of last face in `elnodes`.
`elnodes[nface]`	start index of last vertex +1, just points behind the last vertex of the last face.

- `elnodes[elnodes[0]...nelems]`
  Example:

`elnodes[elnodes[0]]`	vertex id of first vertex of face 0.
`elnodes[elnodes[0]+1]`	vertex id of second vertex of face 0
`elnodes[elnodes[0]+2]`	vertex id of third vertex of face 0.
`...`	
`elnodes[elnodes[1]]`	vertex id of first vertex of face 1.
`elnodes[elnodes[1]+1]`	vertex id of second vertex of face 1.
`...`	
`elnodes[0]-1`	number of faces in PCELL.



`MPCCI_ETYP_PCELL12`

Table 9: Polyhedral element types in the MpCCI code API

2.9.2 Coordinates System Definition

The mesh coordinates system should specify one of these values:
`MPCCI_CSYS_C1D` : One dimensional Cartesian system.
`MPCCI_CSYS_C2D` : Two dimensional Cartesian system.
`MPCCI_CSYS_C3D` : Three dimensional Cartesian system.
`MPCCI_CSYS_ARZ` : Axis-symmetric with radial and z-axis order definition.
`MPCCI_CSYS_AZR` : Axis-symmetric with z-axis and radial order definition.
`MPCCI_CSYS_CYL` : Cylindrical coordinated system.
`MPCCI_CSYS_SPH` : Spherical coordinated system.

2.9.3 Mesh Dimension Definition

The mesh dimension should specify one of these values:
`MPCCI_MDIM_NONE` : No dimension assigned to this component.
`MPCCI_MDIM_PNTS` : 0 for a system point or a point in a point cloud with coordinates.
`MPCCI_MDIM_LINE` : 1 for line.
`MPCCI_MDIM_FACE` : 2 for face.
`MPCCI_MDIM_VOLU` : 3 for volume.
`MPCCI_MDIM_IPNT` : 4 for an integration point (system nodes without coordinates).

2.9.4 Moving Reference Frame Definition

The structure used to transport mesh specific moving reference frame information specifies the following data:

```
typedef struct _MPCCI_MOTION  MPCCI_MOTION;
struct _MPCCI_MOTION
{
   double   omeg;
   double   axis[3];
   double   orig[3];
   double   velo[3];
   unsigned type;
};
```

2.9.4.1 Description Values

`double omeg`

Define the moving reference frame angular velocity.

`double axis[3]`

Define the moving reference frame rotational axis value components.

`double orig[3]`

Define the moving reference frame axis origin value components.

double velo[3]

Define the moving reference frame velocity value components.

unsigned type

Define the type resp. order of rotation resp. translation.
Valid values for moving reference frame which is neither moving grid nor moving quantity are:

MPCCI_MOTION_FRAME_T	: Translate only.
MPCCI_MOTION_FRAME_R	: Rotate only.
MPCCI_MOTION_FRAME_RT	: Rotate, then translate order.
MPCCI_MOTION_FRAME_TR	: Translate, then rotate order.
MPCCI_MOTION_FRAME_CO	: Simultaneous continuous transformations.

Valid values for moving grid which means that grid and quantities are moved, but the grid is not necessarily sent to the server are:

MPCCI_MOTION_MGRID_T	: Translate only.
MPCCI_MOTION_MGRID_R	: Rotate only.
MPCCI_MOTION_MGRID_RT	: Rotate, then translate order.
MPCCI_MOTION_MGRID_TR	: Translate, then rotate order.
MPCCI_MOTION_MGRID_CO	: Simultaneous continuous transformations.

2.9.5 Remesh Flag Information

Remesh flag values for calling ▷ 2.7.14 Notifying the Remeshing: ampcci_remesh ◁:

MPCCI_REMESH_FLAG_CHECK	: Default value.
MPCCI_REMESH_FLAG_NODES	: Specify a remeshing on nodes level. The topology was not changed.
MPCCI_REMESH_FLAG_ELEMS	: Specify a remeshing on elements level. The mesh topology was changed.
MPCCI_REMESH_FLAG_ALLPARTS	: All parts have been remeshed.
MPCCI_REMESH_FLAG_FULL	: All parts and elements have been remeshed (equal to the bit pattern: MPCCI_REMESH_FLAG_ELEMS|MPCCI_REMESH_FLAG_ALLPARTS).

2.9.6 Transfer Information: MPCCI_TINFO

The C structure MPCCI_TINFO defines the transfer information for the code. This transfer information provides a time stamp for the quantities and allows to request quantities for a specific time stamp, too. The MPCCI_TINFO contains the following attributes (See "mpcci_types.h"):

```
typedef struct _MPCCI_TINFO  MPCCI_TINFO;
struct _MPCCI_TINFO
{
   unsigned this_size;
   unsigned this_version;

   int      mpcci_state;
   int      mpcci_used;

   unsigned tact;
   unsigned tact_init;
   unsigned tact_last;

   int      mode_t;
   int      mode_a;
```

```
unsigned mode_c;
int      mode_s;
int      mode_r;
int      mode_q;

unsigned flag_r;

/*
 * in case of a time >= 0.0 we are transient and might use
 * the time and iteration for testing
 */
double   dt;
double   dt_last;
double   rdt_min;
double   rdt_max;

double   time;

double   time_cbeg;
double   time_cend;
double   time_init;
double   time_last;


double   implt_step;
double   implt_next;
int      impli_step:
int      impli_max;

/*
 * in case of a time < 0.0 we are steady/iterative
 */
int      iter;

int      iter_cbeg;
int      iter_cend;
int      iter_init;
int      iter_last;

/* subcycle */
int      sub_nstep;
int      sub_step;
int      sub_next;

/*
 * information updated per call of ampcci_transfer()
 */
int      count_s;
int      count_r;

int      nquant_s;
int      nquant_r;
```

```
   int      nquant_req;

   int      nglob_s;
   int      nglob_r;
   int      nglob_req;

   /*
    * optional convergence status
    */
   int      conv_code;
   int      conv_job;
   int      conv_last;
};
```

2.9.6.1 Description Values

unsigned this_size

The size of the structure: must be set to `(unsigned)sizeof(MPCCI_TINFO)`.

unsigned this_version

The version: 3.1.0=310, 4.0.0=400

int mpcci_state

This MpCCI state:
-1 : Disconnected from the server.
0 : Nothing done before.
1 : Initially connected to the server.
> 1 : Initialization done and at least one data transfer.

int mpcci_used

True if we use MpCCI.

Information about the exchange communication:

unsigned tact

Bit pattern: `MPCCI_TACT_*`
`MPCCI_TACT_SEND` : Send quantities to the server.
`MPCCI_TACT_RECV` : Receive quantities from the server.
`MPCCI_TACT_XCHG` : Exchange quantities.
`0` : Skip the transfer action.

unsigned tact_init

Bit pattern for the initial transfer.

unsigned tact_last

Bit pattern of the last transfer done.

int mode_t

Define the coupling scheme type:
MPCCI_TMODE_IMPLICIT : Implicit scheme.
MPCCI_TMODE_EXPLICIT : Explicit scheme.
MPCCI_TSOLU_TRANSIENT : The solution is transient.
MPCCI_TSOLU_STEADY : The solution is steady state.
You can use the macros to check the coupling scheme type:

- MPCCI_TINFO_WANT_IMPL(*MPCCI_TINFO): return true if implicit scheme is set.
- MPCCI_TINFO_WANT_EXPL(*MPCCI_TINFO): return true if explicit scheme is set.
- MPCCI_TSOLU_WANT_TRANS(*MPCCI_TINFO) : return true if transient.
- MPCCI_TSOLU_WANT_STEADY(*MPCCI_TINFO) : return true if steady state.

int mode_a

Define the coupling algorithm type:
MPCCI_TMODE_JACOBI : Jacobi algorithm.
MPCCI_TMODE_GAUSSSEIDEL : Gauss-Seidel algorithm.
You can use the macros to check the algorithm type:

- MPCCI_TINFO_WANT_JACOBI(*MPCCI_TINFO)
- MPCCI_TINFO_WANT_GAUSSSEIDEL(*MPCCI_TINFO)

int mode_c

The check mode types:
MPCCI_TMODE_CHECK_NONE : No check is done by the code coupling manager: option none.
MPCCI_TMODE_CHECK_FORWARD : The code can only go forward in time and iteration: option forward.

int mode_s

Levels of send modes:
MPCCI_TMODE_SEND_ALWAYS : The code always sends the data: option always.
MPCCI_TMODE_SEND_ONEWAIT : option onewait.
: Bi-directional coupling: The code sends if at least one partner is waiting, otherwise send is skipped .
: Uni-directional coupling: The code waits for at least one partner before sending the data.
MPCCI_TMODE_SEND_ALLWAIT : option allwait.
: Bi-directional coupling: The code sends if at all partners are waiting, otherwise send is skipped .
: Uni-directional coupling: The code waits for at all partners before sending the data.

int mode_r

Levels of receive modes:
MPCCI_TMODE_RECV_ANY : The code receives all if at least one quantity is available, otherwise the receive action is skipped: option any.
MPCCI_TMODE_RECV_COMPLETE : The code receives only if all quantities are available, otherwise the receive action is skipped: option complete.
MPCCI_TMODE_RECV_ALL : The code always waits for all requested quantities: option all.

int mode_q

Quantity selection mode for the data transfer:
MPCCI_TMODE_QUANT_ALL : Exchange all quantities.
MPCCI_TMODE_QUANT_COORD : Exchange only coordinate type quantities.
MPCCI_TMODE_QUANT_OTHER : Exchange all non coordinate type quantities.

unsigned flag_r

Bit pattern for remeshing (see ▷ 2.9.5 Remesh Flag Information ◁).

Information about transient simulation:

double dt

Current physical time step size updated by the code before the call of `ampcci_transfer()` ▷ 2.7.13 Data Exchange: `ampcci_transfer` ◁.

double dt_last

Physical time step size during the last call.

double rdt_min

Minimum relative time distance to interpolated values.

double rdt_max

Maximum relative time distance to interpolated values.

double time

Current physical time updated by the code before the call of `ampcci_transfer()`.

double time_cbeg

Time when the coupling starts in terms of the code times.

double time_cend

Time when the coupling ends in terms of the code times.

double time_init

Code time when the adapter was initialized.

double time_last

Code time of the last exchange.

Information about implicit coupling parameters:

double implt_step

Time step size for implicit coupling.

double implt_next

Next implicit synchronization time.

double impli_step

No. of iterations between two exchanges.

double impli_max

Maximum no. of coupled iterations.

Information about steady/iterative simulation:

int iter

Current iteration counter: updated by the code before the call of `ampcci_transfer()`.

int iter_cbeg

First iteration where we exchange.

int iter_cend

Last iteration where we exchange

int iter_init

Code iteration when the adapter was initialized.

int iter_last

Iteration of the last exchange.

Information about subcycling:

int sub_nstep

Current coupling step counter, incremented at each call of `ampcci_transfer()` function.

double sub_step

No. of steps between two exchanges. This contains the current step size for the subcycling. This value can be constant or variable if a table definition has been defined.

int sub_next

Step number for the next coupling step , updated after a coupled step number is reached by `ampcci_transfer()` function.

Information updated per call of `ampcci_transfer()`:

int count_s

Number of `ampcci_transfer()` send calls (independent of quantities and meshes).

int count_r

Number of `ampcci_transfer()` receive calls (independent of quantities and meshes).

int nquant_s

Number of sent quantities (sum(mesh * nquant)) within the last `ampcci_transfer()`.

int nquant_r

Number of received quantities (sum(mesh * nquant)) within the last `ampcci_transfer()`.

int nquant_req

Number of requested quantities (sum(mesh * nquant)) within the last `ampcci_transfer()`.

int nglob_s

Number of sent global within the last `ampcci_transfer()`.

int nglob_r

Number of received global within the last `ampcci_transfer()`.

int nglob_req

Number of requested global within the last `ampcci_transfer()`.

Optional convergence status:

int conv_code

Set the convergence state of the code:

`MPCCI_CONV_STATE_ERROR`	: Error occurred.
`MPCCI_CONV_STATE_INVALID`	: Initial convergence state set to invalid.
`MPCCI_CONV_STATE_STOP`	: Simulation is stopped.
`MPCCI_CONV_STATE_DIVERGED`	: Solution diverged.
`MPCCI_CONV_STATE_CONTINUE`	: Continue the simulation computation.
`MPCCI_CONV_STATE_CONVERGED`	: Solution converged.

int conv_job

Set after the transfer and informs about the global convergence state.

int conv_last

Store the last convergence state.

2.9.7 Code Specific Information: `MPCCI_CINFO`

The `MPCCI_CINFO` defines some code specific information (see `"mpcci_types.h"`). It contains the following attributes:

```
typedef struct _MPCCI_CINFO  MPCCI_CINFO;
struct _MPCCI_CINFO
{
   const char *jobid;
   const char *codename;
   const char *codeid;
   const char *clientid;
   double      time;
   unsigned    flags;
   unsigned    jflags;
   int         iter;
   int         nclients;
   int         nprocs;
```

```
};
```

2.9.7.1 Description Values

`const char *jobid`

The job id identifying the coupling job.
Do not set this field, it will be automatically set.

`const char *codename` **(Required)**

The name of the code.

`const char *codeid`

This is the instance name of the code. This may be defined by the environment variable `MPCCI_CODEID` by MpCCI GUI before the start.
Do not set this field, it will be automatically set.

`const char *clientid`

This client id helps to identify parallel processes.
Do not set this field, it will be automatically set.

`double time` **(Required)**

The initial physical time of the code.

`unsigned flags` **(Required)**

Feature flags of the code. This may be defined by using these attributes (defined in `"mpcci_defs.h"`):

`MPCCI_CFLAG_TYPE_FV`	: The code is a finite volume code.
`MPCCI_CFLAG_TYPE_FEA`	: The code is a finite element analysis code.
`MPCCI_CFLAG_TYPE_SYS`	: The code is a system code.
`MPCCI_CFLAG_TYPE_RAD`	: The code is a radiation code.
`MPCCI_CFLAG_GRID_ORIG`	: The code has the original grid available.
`MPCCI_CFLAG_GRID_CURR`	: The code has the current grid available.

`unsigned jflags`

Coupling feature flags of the code and job. This field is initialized by `mpcci_cinfo_init`.

`int iter` **(Required)**

The initial iteration counter of the code.

`int nclients` **(Required)**

The exact number of expected server clients.

`int nprocs` **(Optional)**

The number of parallel processes of the current code. This is not necessarily the number of clients. This field is optional if the number of expected server clients and number of parallel processes are equal.

These information may be used to dynamically reconfigure the MpCCI server at runtime when a code wants to disconnect and reconnect to the coupling server.

2.9.7.2 Code Information Macro

Return value	Macro	Description
bool	MPCCI_CODE_HAS_CURRG(code)	check whether the code has the current grid.
bool	MPCCI_CODE_HAS_ORIGG(code)	check whether the code has the original grid.
bool	MPCCI_CODE_IS_FV(code)	check whether the code is a finite volume code.
bool	MPCCI_CODE_IS_FEA(code)	check whether the code is finite element analysis code.
bool	MPCCI_CODE_IS_SYS(code)	check whether the code is a system code.
bool	MPCCI_CODE_IS_RAD(code)	check whether the code is a radiation code.

2.9.8 Coupling Components

The coupling component descriptor `MPCCI_PART` represents a coupling component for the code. Many driver functions obtain an argument `part` which is a pointer to the coupling component (coupling component pointer).

The structure contains the basic properties of a component and a list of the quantities, which shall be exchanged. The most important macros for `MPCCI_PART` are listed below, all macros take an argument of type `MPCCI_PART *`, thus they can be applied directly to the pointer `part`. E. g. `MPCCI_PART_NNODES(part)` should be used to set or determine the number of nodes of a component.

Return value	Macro	Description
char *	MPCCI_PART_NAME(part)	name of coupling component
int	MPCCI_PART_MDIM(part)	dimension of component. (See ▷ 2.9.3 Mesh Dimension Definition ◁)
MPCCI_QUANT *	MPCCI_PART_QUANTS(part)	list of quantities to transfer
int	MPCCI_PART_NNODES(part)	number of nodes/points in component
int	MPCCI_PART_NELEMS(part)	number of faces/elements/cells in component
int	MPCCI_PART_NODMAX(part)	max. number of nodes per element in this component
int	MPCCI_PART_MESHID(part)	MpCCI mesh id
int	MPCCI_PART_PARTID(part)	MpCCI part id
unsigned	MPCCI_PART_CSYS(part)	coordinates system
void *	MPCCI_PART_USRPTR0(part)	pointer no. 0 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR1(part)	pointer no. 1 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR2(part)	pointer no. 2 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR3(part)	pointer no. 3 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR4(part)	pointer no. 4 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR5(part)	pointer no. 5 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR6(part)	pointer no. 6 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR7(part)	pointer no. 7 to auxiliary optional information defined and used by the application
void *	MPCCI_PART_USRPTR8(part)	pointer no. 8 to auxiliary optional information defined and used by the application

Return value	Macro	Description
`void *`	`MPCCI_PART_USRPTR9(part)`	pointer no. 9 to auxiliary optional information defined and used by the application
`unsigned`	`MPCCI_PART_USRFLAGS(part)`	optional flags information field for the current mesh defined and used by the application
`int`	`MPCCI_PART_USRSTATE(part)`	optional state information for the current mesh defined and used by the application

Return value	macro	description
`bool`	`MPCCI_PART_IS_NONE(part)`	check whether component is nothing
`bool`	`MPCCI_PART_IS_PNTS(part)`	check whether component represents a single point or a point in a point cloud with coordinates
`bool`	`MPCCI_PART_IS_LINE(part)`	check whether component is a line
`bool`	`MPCCI_PART_IS_FACE(part)`	check whether component is a face
`bool`	`MPCCI_PART_IS_VOLU(part)`	check whether component is a volume
`bool`	`MPCCI_PART_IS_IPNT(part)`	check whether component is an integration point (for system nodes without coordinates)

See also ▷ 2.9.10 Loop Functions ◁ for loops over components.

2.9.9 Quantities

The quantity descriptor `MPCCI_QUANT` represents one quantity. It contains the name and properties of the quantity.

Return value	Macro	Description
`const char *`	`MPCCI_QUANT_NAME(quant)`	symbolic name e. g. “temp”, “JHeat” ...
`int`	`MPCCI_QUANT_QID(quant)`	ID code of quantity (see also the Quantity Reference in the Appendix)
`int`	`MPCCI_QUANT_STATE(quant)`	state of transfer `MPCCI_QUANT_TSTATE_xxx` (used by the manager): `MPCCI_QUANT_TSTATE_NONE` no transfer was done before `MPCCI_QUANT_TSTATE_SEND` quantity was sent `MPCCI_QUANT_TSTATE_RECV` quantity was received
`int`	`MPCCI_QUANT_FLAGS(quant)`	contains the direction send/receive bits, the location bits etc. .
`int`	`MPCCI_QUANT_DIM(quant)`	dimension of quantity: 1=scalar, 3=vector etc. .

`int`	`MPCCI_QUANT_LOC(quant)`	location of value, one of:
		`MPCCI_QFLAG_LOC_CODE`
		`MPCCI_QFLAG_LOC_NODE` or `MPCCI_QFLAG_LOC_VERT`
		`MPCCI_QFLAG_LOC_ELEM` or `MPCCI_QFLAG_LOC_CELL`
		`MPCCI_QFLAG_LOC_POINT`

`int`	`MPCCI_QUANT_PHY(quant)`	physical meaning of this quantity, one of `MPCCI_QPHY_ANY` quantity is not further specified `MPCCI_QPHY_MASS` a mass sink/source `MPCCI_QPHY_MOM` a momentum sink/source `MPCCI_QPHY_ENTH` an energy sink/source

Return value	Macro	Description
		MPCCI_QPHY_PROP a property (material) MPCCI_QPHY_BCVAL a boundary condition value MPCCI_QPHY_BCGRAD a boundary condition wall normal gradient MPCCI_QPHY_COORD a grid coordinate/displacement MPCCI_QPHY_MASSFR a chemical component concentration
int	MPCCI_QUANT_DIR(quant)	transfer direction, one of MPCCI_QFLAG_DIR_SEND quantity is sent MPCCI_QFLAG_DIR_RECV quantity is received
int	MPCCI_QUANT_SMETHOD(quant)	how to store sent/received quantities, one of MPCCI_QSM_UNDEF invalid send method MPCCI_QSM_DIRECT directly written into buffer MPCCI_QSM_BUFFER quantity is buffered locally and copied later MPCCI_QSM_USRMEM quantity to store in user's indexed memory MPCCI_QSM_SCALAR quantity to store in user's index scalars MPCCI_QSM_SPECIES quantity to store the chemical species
int	MPCCI_QUANT_SINDEX(quant)	index to user supplied memory or user scalars
void *	MPCCI_QUANT_SBUFFER(quant)	quantities local transfer buffer
int	MPCCI_QUANT_SBFSIZE(quant)	size of allocated local buffer

Return value	macro	description
bool	MPCCI_QUANT_IS_SEND(quant)	check whether the quantity is sent
bool	MPCCI_QUANT_IS_RECV(quant)	check whether the quantity is received
int	MPCCI_QUANT_IS_NODE(quant)	check whether quantity is a nodal quantity
int	MPCCI_QUANT_IS_ELEM(quant)	check whether quantity is an element quantity
int	MPCCI_QUANT_IS_GLOB(quant)	check whether the quantity is a global quantity
int	MPCCI_QUANT_IS_MESH(quant)	check whether the quantity is a mesh based quantity
int	MPCCI_QUANT_IS_COORD(quant)	check whether the quantity is a coordinate/displacement
int	MPCCI_QUANT_IS_FIELD(quant)	check whether the quantity is a field value
int	MPCCI_QUANT_IS_FLUXI(quant)	check whether the quantity is a flux integral value
int	MPCCI_QUANT_IS_FLUXD(quant)	check whether the quantity is a flux density value
bool	MPCCI_QUANT_IS_SCALAR(part)	check whether the quantity is a scalar
bool	MPCCI_QUANT_IS_VECTOR(part)	check whether the quantity is a vector
bool	MPCCI_QUANT_IS_TENSOR(part)	check whether the quantity is a tensor

2.9.10 Loop Functions

In addition to the data access functions, a number of predefined loops is available:

FOREACH(obj,head){ ... }

Loop over all objects provided by the head which is a list of objects.

Example:

```
MPCCI_SERVER *server;
FOREACH(server,job->servers)
   ...
```

FOREACH_COND(obj,head,cond){ ... }

Loop over all objects provided by the head which is a list of objects. This loop stops if the obj verifies the condition cond.
Example:

```
FOREACH_COND(part,server->parts,MPCCI_PART_IS_FACE(part))
   ...
```

FOREACH_QRECV(quant,head){ ... }

Like FOREACH, but the loop is restricted to received-only quantities.
Example:

```
MPCCI_QUANT *quant;
FOREACH_QRECV(quant,MPCCI_PART_QUANTS(part))
   ...
```

FOREACH_QSEND(quant,head){ ... }

Like FOREACH_QRECV, but the loop is restricted to sent-only quantities.
Example:

```
MPCCI_QUANT *quant;
FOREACH_QSEND(quant,MPCCI_PART_QUANTS(part))
```

2.9.11 Memory Management

For some actions, the code adapter needs to allocate memory. If your code has its own memory management system, it is preferable that the code adapter also uses this system. If no methods are specified, the standard C library routines are used.
You need to call the following function to point to the code memory management functions:

```
void umpcci_mem_functs
(
   void *(*mallocp)  (size_t size),
   void *(*reallocp) (void *ptr, size_t ssize),
   void  (*freep)    (void *ptr)
)
```

`void *(*mallocp)(size_t size)`

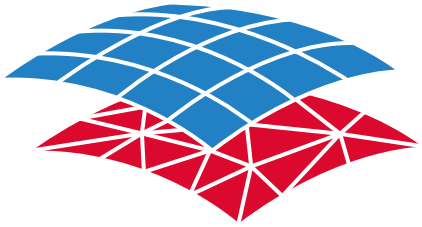
This routine is called for allocating memory, should return a pointer for the memory, a `NULL` pointer if it fails.

`void *(*reallocp)(void *ptr, size_t size)`

This routine is used for reallocation, i. e. changes of size of an array.

`void (*freep)(void *ptr)`

This routine is called for freeing memory.



MpCCI
CouplingEnvironment

Part IX

—

How To

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part IX How To
PDF version
October 29, 2023

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IX How To – Contents

1 Automotive Thermal Management

1.1 Quick Information

Keywords	Full vehicle thermal management, coupled simulation with MpCCI convection, conduction and radiation, steady state and transient
Simulation Codes	STAR-CCM+ FLUENT TAITherm
MpCCI Version	MpCCI 4.2 and higher
Related Tutorials	▷ VII-9 Cube in a Duct Heater ◁

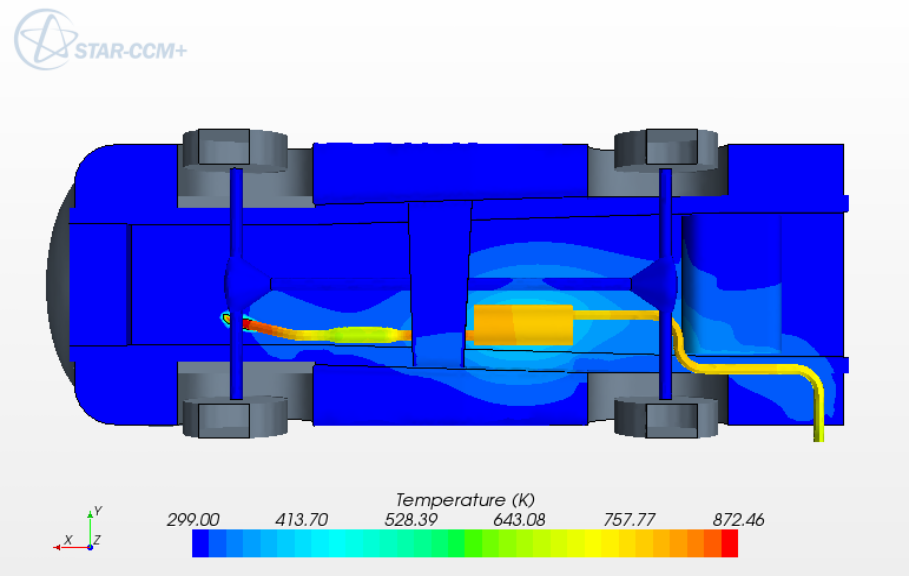


Figure 1: Thermal management

1.2 Problem Description and Motivation

Concerning the thermal behavior of automotive vehicles it is pursued to accomplish simulations for the full complexity of a vehicle's geometry and transport phenomena of heat including convection, radiation and conduction in fluids and solid bodies. There are several simulation codes meeting these requirements. On each transport mechanism the simulation codes have more or less effectiveness and accuracy, so that for a simulation procedure a combination of different codes is preferable. This procedure can be realized with MpCCI, which offers the following advantages compared to common file-based approaches:

- Fully automatic and fast data transfer over socket connections.
- Easy implementation for repeating data transfer as used for iterative steady or transient simulations.
- Fast and robust data mapping between non-matching meshes.
- Data inter- and extrapolation on geometrical irregularities like partially non-matching geometries.
- Flexible steering of simulation procedure for instance with subcycling, time-step sharing and further features depending on the applied simulation codes.

In this code of practice it is intended to demonstrate the procedure of coupling CFD codes STAR-CCM+ or FLUENT with TAITherm for steady state and transient thermal simulations.

1.3 Simulation Procedure

1.3.1 Model Preparation

Usually in CFD models **thin solids** like heat shields have two sides wetted, whereas the distance between the two sides, the thickness of the heat shield, is in the majority of cases small. If in TAITherm parts are modeled as shell elements a certain thickness must be assigned to the shell elements to properly account for heat conduction and heat capacity. When surfaces, boundaries and shells are coupled it has to be assured that front and back side of the coupled surfaces are correctly assigned. When setting up a model, the boundaries of thin parts of the CFD model have to be separated in a front and back side as depicted in Figure 2. Later in the MpCCI Coupling Step the front and back side can be assigned to different coupling regions, so that the mesh correlations are calculated properly.

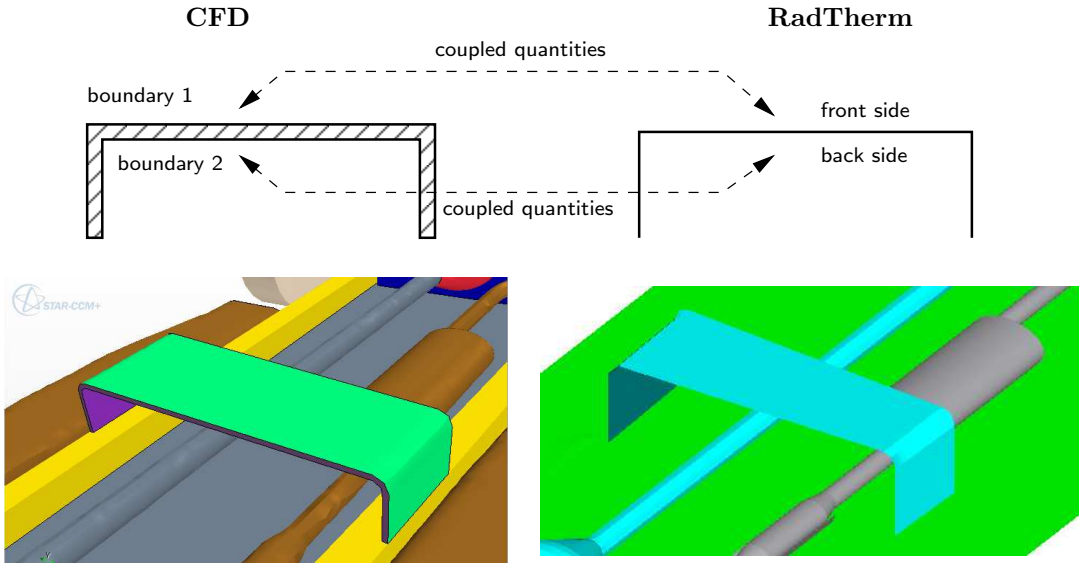


Figure 2: Front and back side assignment for thin parts by separating boundaries

Concerning setting the **heat sources** in the simulation one has to account for the quantities later exchanged in MpCCI. When sending the wall temperature from TAITherm it is not advisable to set wall temperatures for coupled boundaries in the CFD code. For an exhaust system for instance one might set a convection condition, internal heat rate and/or a fluid (stream) part in TAITherm inside the exhaust or model the exhaust flow in the CFD model.

1.3.2 MpCCI Setup

The model set-up in MpCCI corresponds to a typical thermal coupling procedure, where it is common and stable to exchange the heat coefficient and the film temperature to TAITherm and the wall temperature to the CFD code. As already depicted in ▷1.3.1 Model Preparation◁ it is necessary for **thin parts** to separate the boundaries in CFD and define different coupling regions in MpCCI for front and back sides. A full vehicle features a lot of different boundaries which do not have to be coupled in separate coupling regions each. It is advisable to create **groups of coupling regions** which hold different part groups of the vehicle (Figure 3). It is also a good procedure to reflect the group name in the boundary name to use the MpCCI pattern matching (▷V-4.8.5 Automatic Generation of Regions by Rules◁). In STAR-CCM+ it is quite common to combine boundaries in certain groups and regions like engine, exhaust etc. . In this case the boundary names available in MpCCI will already contain the group/region name used in STAR-CCM+.

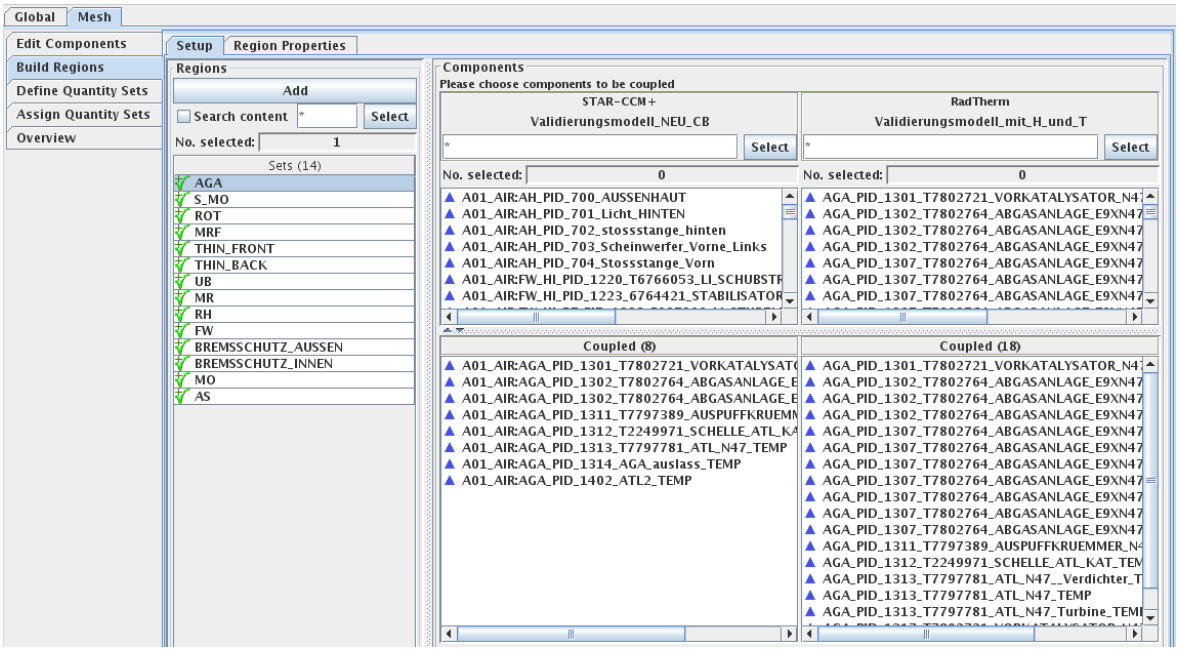


Figure 3: Possible coupling meshes for a full vehicle reflecting part groups

It should be noted that **not insulated back sides** of shell element parts in TAITherm will appear in MpCCI with the string `"-backside"` added to the coupling part name ▷VI-17.2.4 Regions Step◁.

Although it is not desired in large full vehicle models, there are quite often **geometrical discrepancies** between the coupled models, which usually leads to orphaned regions (Figure 4). There are three procedures for handling these orphaned regions. It is possible to modify the search parameter in order to catch geometry deviations. Either the multiplicity factor for a dimensionless search or the normal dimensionful search distance is raised. If the granularity of the coupling regions is coarse, e. g. all components in one coupling region, it might result in wrong neighborhood associations especially when parts come in close contact. The second procedure is to accept a default value for orphaned regions. As this might be reasonable for the heat coefficient which is usually set to zero (adiabatic), for wall temperatures it is kind of random and therefore restrictive. To overcome this problem MpCCI offers extrapolation to orphaned regions, where matched parts around the orphans define the inter- and extrapolated values. In Figure 5 the procedures are compared for a hot spot in an underhood simulation. It is visible that in smaller orphaned regions the extrapolation is a pretty good approximation compared to the sender source distribution, but in large orphaned regions the extrapolated temperature distribution is getting more vague.

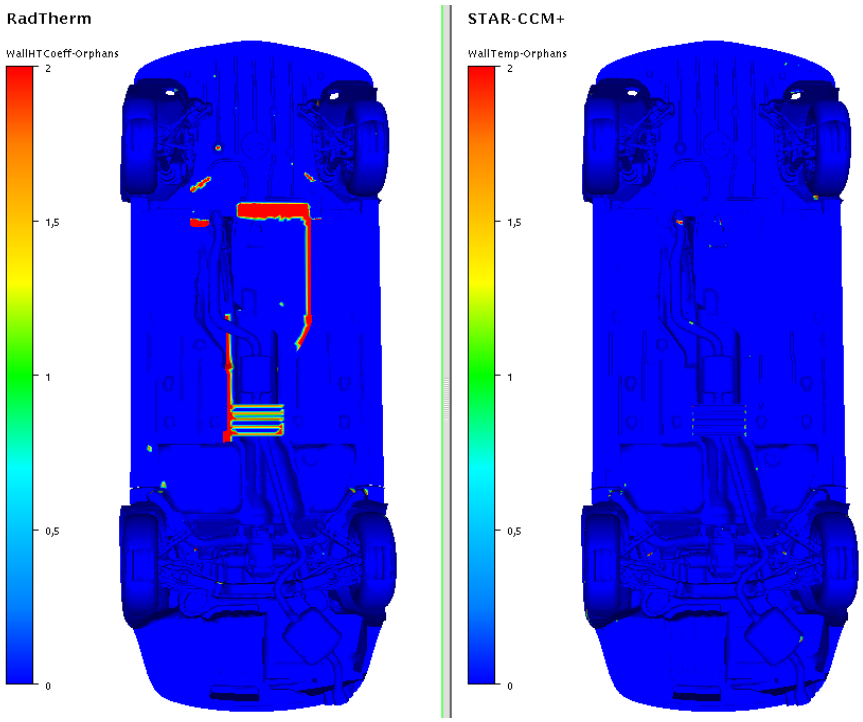
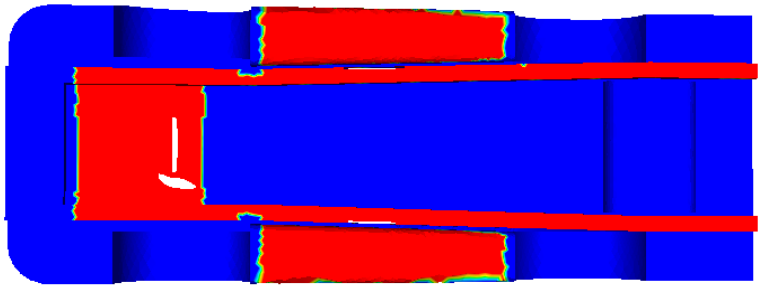
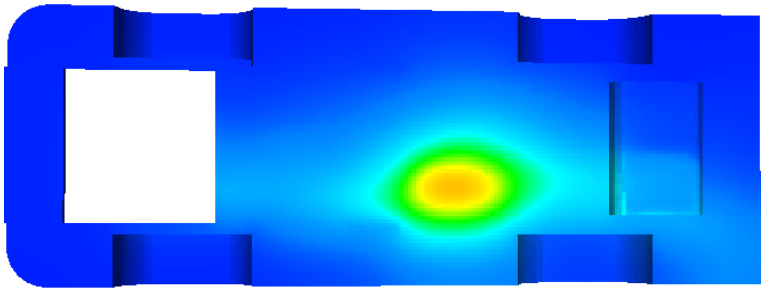


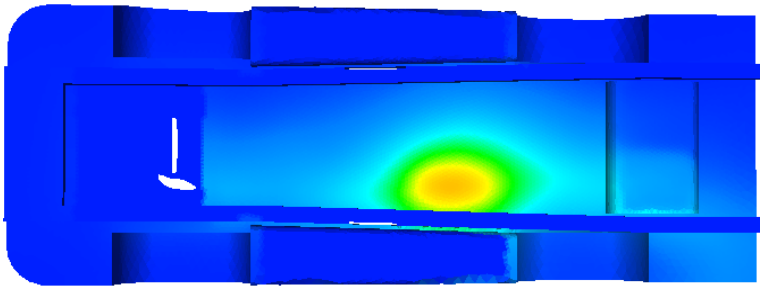
Figure 4: Orphaned regions on bottom of BMW vehicle visualized in the MpCCI visualizer



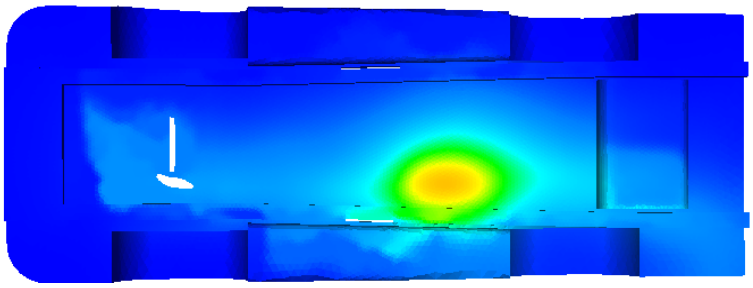
Orphaned regions on sender mesh



Wall temperature distribution on sender mesh



Wall temperature distribution on receiver mesh with default values for orphaned regions



Wall temperature distribution on receiver mesh with extrapolation for orphaned regions

Figure 5: Treatment of orphaned regions in MpCCI

1.3.3 Running the Simulation

The complete simulation process might be started from the MpCCI GUI, simply as batch job e. g. by `mpcci batch case.csp` or via a batch queuing system like PBS, SGE, etc. If the simulation is started from MpCCI GUI, for TAITherm, FLUENT and STAR-CCM+ it is possible to run the coupled simulation with their own GUI. This procedure offers the possibility to display results during simulation besides the MpCCI Visualizer or interact with the simulation model.

TAITherm

TAITherm cannot be steered by a script/macro file. When the necessary MpCCI function hooks are placed, TAITherm will exchange data with MpCCI through these functions. For a steady state simulation (duration=0s) after each iteration and for a transient simulation after each time step the exchange of data will be accomplished.

STAR-CCM+

STAR-CCM+ must be steered by a STAR-CCM+ java macro file, which can be provided in MpCCI or in the STAR-CCM+ GUI. The macro may contain all STAR-CCM+ java structures and additionally will contain MpCCI functions like `"mpcci.init()"`, `"mpcci.exchange()"` and `"mpcci.exit()"`. Usually the macro will contain a loop, where after or before each or several iterations or time-steps an exchange is committed. The information of the initial exchange defined in the MpCCI GUI will be handed over to the first call of `"mpcci.exchange()"`.

FLUENT

In FLUENT the necessary routines (user-defined-functions) will be provided by MpCCI and it is possible to let MpCCI hook the necessary functions automatically. In addition all MpCCI functions might be carried out by the MpCCI Control Panel, which is available in the FLUENT GUI. When FLUENT is started in batch mode a journal file has to be supplied to run the simulation. The journal file might contain all FLUENT structures, in case the user did not allow MpCCI to set the necessary hooks it should additionally contain MpCCI function calls.

Smoothly interrupting a coupled simulation and then restarting the same simulation is a challenging task. If you run the job with the MpCCI GUI you can hit the Stop in order to provide a STOP/ABORT file or a signal to save the solution and quit the simulation codes gracefully. Unfortunately if one code is waiting for data at this moment it might not be successful. When running on a batch system there is actually no way to smoothly stop the codes with a proper file save. In this case it is advisable to turn on periodic auto save of files in the simulation codes and then restart with the last saved states.

For further information of the procedures for each code see the Codes Manual part of the MpCCI manual.

1.3.4 Results

This application for full vehicle thermal simulation is presented by courtesy of BMW Germany.

STAR-CCM+	approx. 45 mio. cells: 15 regions, 525 boundaries MRF for fans and wheels Porous regions for heat exchangers and cooling devices Wall rotation of shafts and axles
TAITherm	approx 900.000 cells, 323 shell parts 13 fluid parts for exhaust system
MpCCI	coupled quantities: STAR-CCM+ →TAITherm: film temperature, heat coefficient TAITherm →STAR-CCM+: wall temperature ⇒ approx. 2 mio. faces coupled

Table 1: Model data

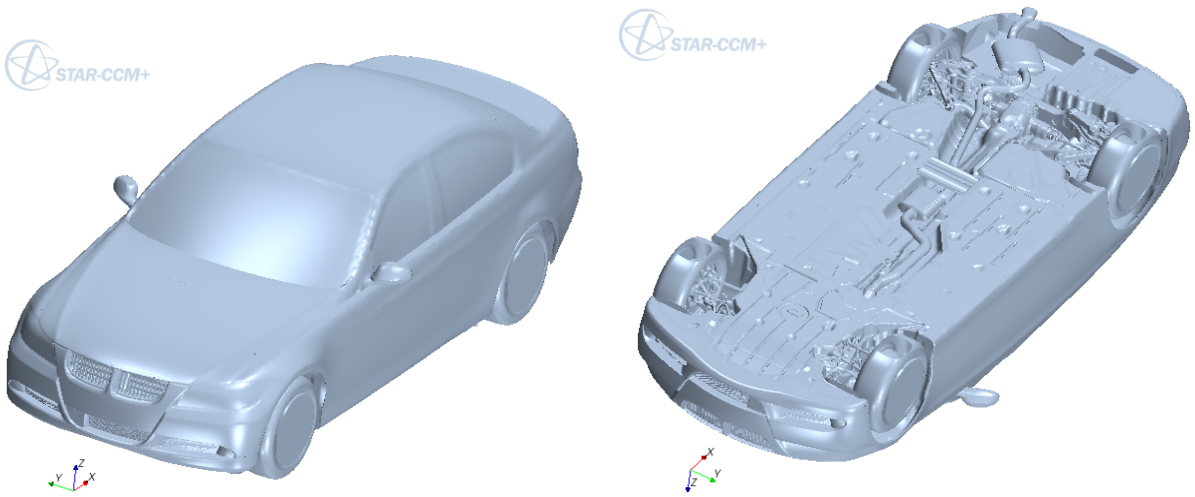


Figure 6: STAR-CCM+ full vehicle model of a BMW top and bottom view

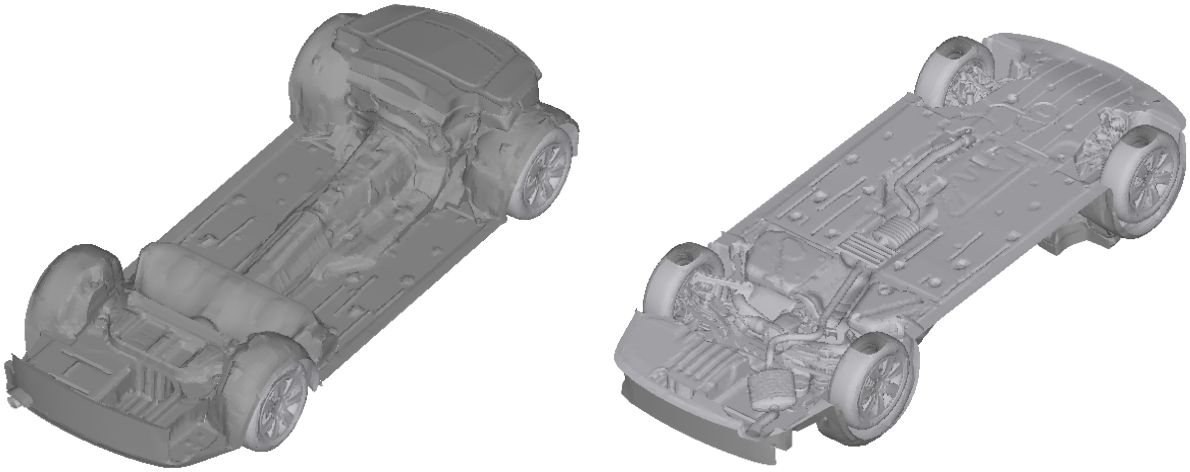


Figure 7: TAITherm underbody model of a BMW top and bottom view

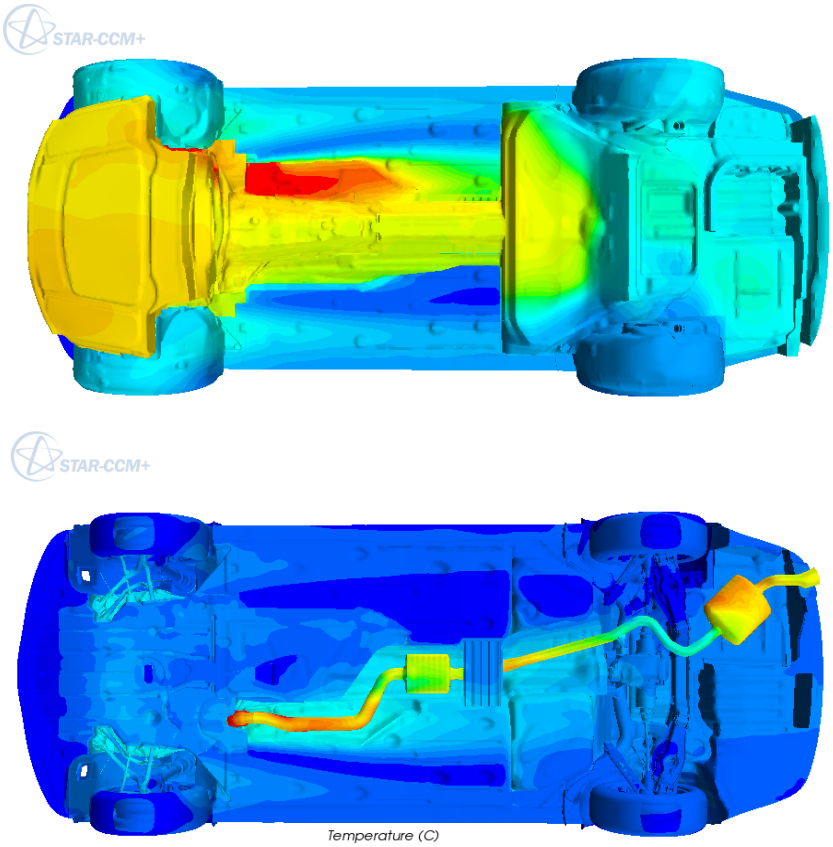


Figure 8: Wall temperature in STAR-CCM+ of BMW vehicle top and bottom view

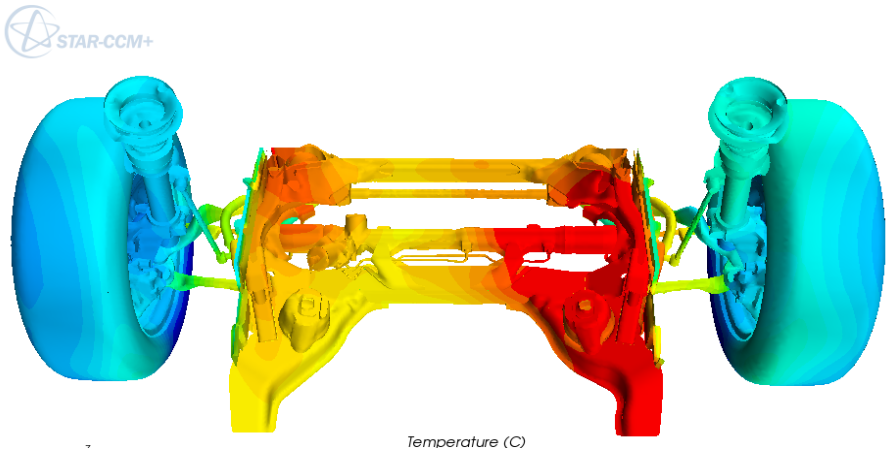


Figure 9: Wall temperature in STAR-CCM+ of BMW vehicle front axle

2 Simulation of Fluid-Structure Interaction for a New Hydraulic Axial Pump

2.1 Quick Information

Keywords	Fluid-structure interaction for compensation chamber in a new pump design coupled simulation with MpCCI
Simulation Codes	STAR-CCM+ FLUENT ANSYS Abaqus
MpCCI Version	MpCCI 4 and higher
Related Tutorials	

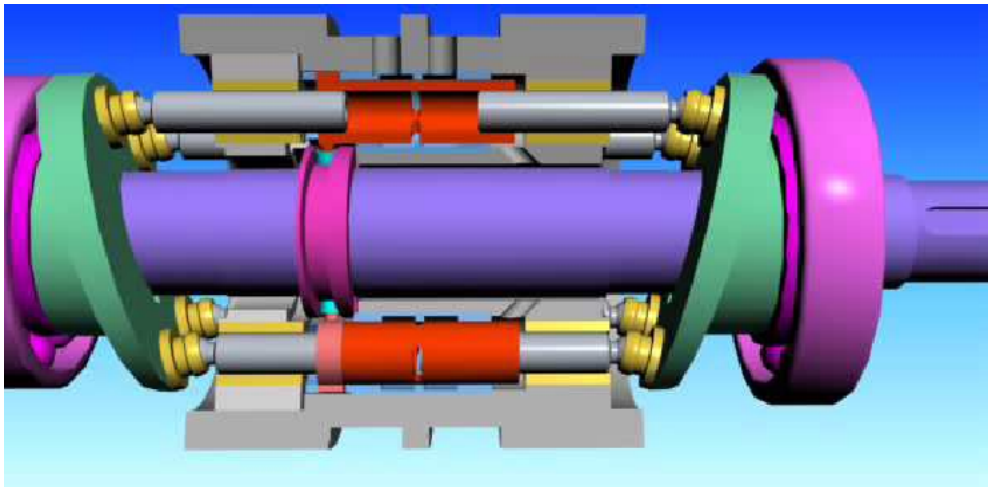


Figure 1: Hydraulic Axial Pump

2.2 Problem Description and Motivation

Numerical simulation plays an important role in the product development and design process in all engineering areas. Depending on the type of machinery developed structural or fluid dynamics simulation codes are used to find optimal designs.

Many real world applications – most prominently fluid-structure interactions – cannot be modeled sufficiently using only one specialized simulation code. The fluid and the structural problem influence each other resulting in the need to transfer information between the two simulation codes.

Therefore, a coupled numerical simulation might be necessary to find optimal designs for complex machinery and tools. MpCCI facilitates the transfer of relevant information between different simulation

codes.

To achieve a robust and easy-to-use coupling of two or more simulation codes MpCCI automatically transfers the necessary quantity values via fast socket connections. Mapping of quantity values between non-matching meshes is realized with fast and robust interpolation methods. For partially non-matching geometries MpCCI provides extrapolation methods.

This document shows how to use MpCCI for numerical simulation of fluid-structure interaction during the design process for a new axial hydraulic pump.

The mechanism of the pump and the need for a FSI simulation will be described in section 2.3.1. Afterwards, a short overview of the used models for the CFD and CSM simulation will be given, followed by the necessary MpCCI settings and the presentation of some results.

2.3 Simulation Procedure

2.3.1 Axial Hydraulic Pumps with Compensation Chambers

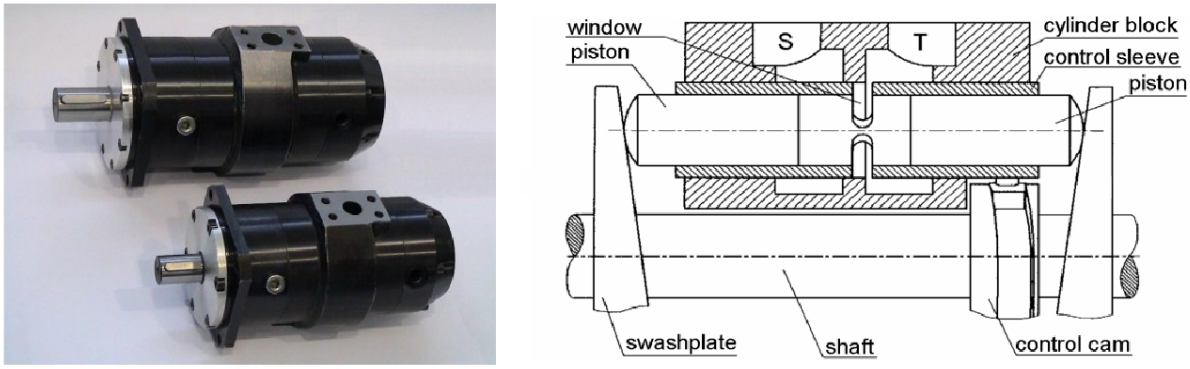


Figure 2: Picture of PWK pumps on the left, main elements of the PWK pump on the right

Axial pumps with cam-driven commutation units – so-called PWK pumps – emerged as a result of a research project conducted in the Department of Hydraulics and Pneumatics at the Gdansk University of Technology. Several – in most cases seven – cylinder chambers are positioned around a rotating shaft with attached swashplates. The movement of the swashplates leads to an alternating increase and decrease of the volume of the cylinder chambers. These chambers connect to the low pressure in- and high pressure outtake channels via a moving bridge. The main elements of the pump can be seen in Figure 2.

Particularly interesting is the development of the variable displacement version of these new pumps. They can be controlled by a low-energy actuator while these pumps usually require a complicated hydraulic servomechanism. This reduces the pump's cost and dimension drastically and is the key feature of the new development.

First prototypes of the new pump have been built and tested, e. g. in lifting devices on ships in extreme temperature environments, and showed good results.

Unfortunately, harmful pressure peaks, that might lead to pump damage, were observed. These peaks occur when the cylinder chamber is disconnected from the intake and outtake channels. For a short period of time the pressure reaches very high values - more than 20 MPa above the average pressure in the chamber (cf. Figure 3).

These peaks are influenced by many different factors ranging from fluid properties to pump speed or leakage

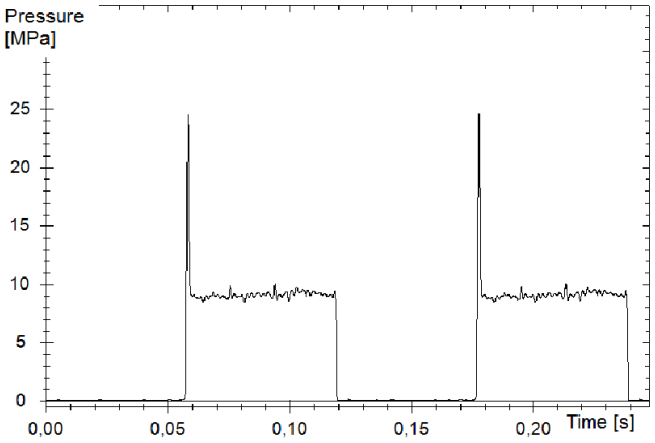


Figure 3: Pressure variation in pump's chamber (rotational speed 500 rpm, oil temperature 35°C, displacement adjustment 22%)

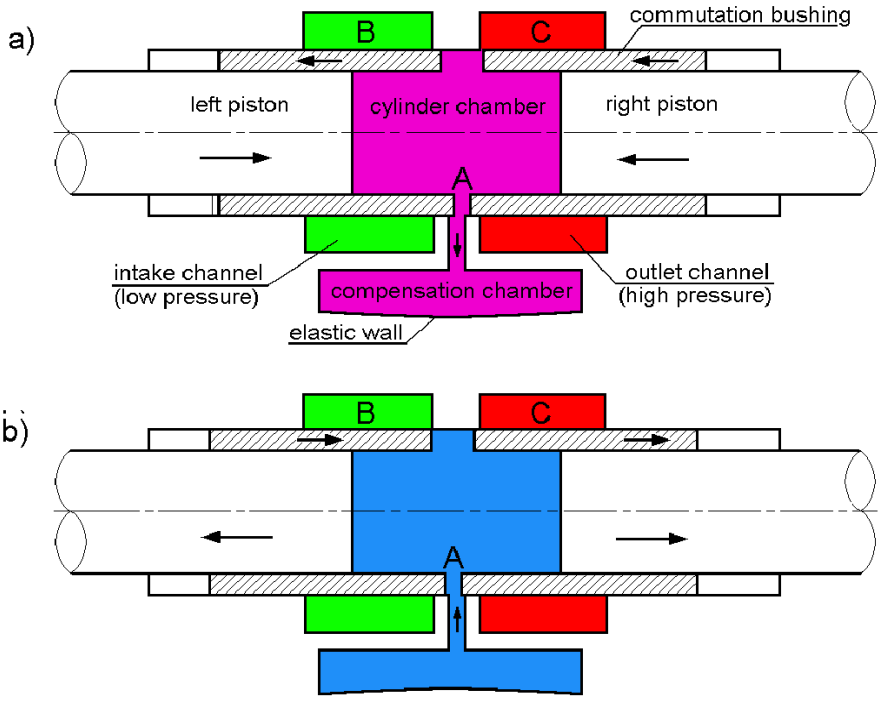


Figure 4: Pressure peak reduction with a compensation chamber with an elastic wall. a) shows high pressure in the cylinder chamber which causes the fluid to flow into the compensation chamber. In b) the pistons are moving outwards and the hydraulic oil flows back into the cylinder chamber.

and have been investigated quite thoroughly. As the very high pressure values might lead to pump damage and produce a lot of noise a compensation chamber was introduced into the pump design.

The compensation chamber significantly shortens the period of disconnection. When the connection bridge

moves from the intake to the outtake channels it connects the cylinder chamber to the compensation chamber. Additionally it gives the fluid more room. All cylinder chambers of one pump can use the same compensation chamber, which is usually located around the rotating shaft.

The elastic wall of the compensation chamber deforms under the load of the hydraulic oil which in turn changes the velocity and pressure field of the fluid leading to the classic case of a fluid-structure interaction.

2.3.2 Model Preparation

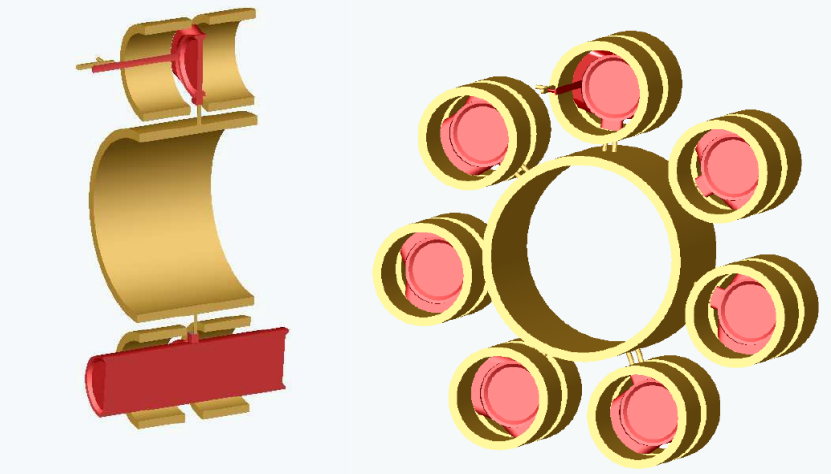


Figure 5: Full CAD model of a pump with seven cylinder chambers (on the right) and a simplified symmetric model of a pump with two chambers (left). Movable parts are shown in red.

As the CAD model of a full pump with seven cylinder chambers is quite big and complicated, for most simulations the simplified symmetric half model on the left of Figure 5 was used.

The CFD model was developed in FLUENT as well as in STAR-CCM+. For both codes a slightly compressible fluid (with user defined functions) and the Spalart-Allmaras turbulence model are used. The motion of the bridge – connecting the cylinder chamber to the in- and outtake channels as well as the compensation chamber – is also realized with user defined functions.

In FLUENT hexahedral elements and the layering method to model the motion of the pistons are used. This is an easy and comfortable method for mesh motion.

In STAR-CCM+ this motion is realized with the help of a remeshing module that has been developed using the Java API of STAR-CCM+. The large motion of the pistons cannot be modeled with morphing and STAR-CCM+ does not provide automatic remeshing. The remeshing module checks with the help of mesh parameters whether remeshing is necessary, generates a new mesh and interpolates the values from the old mesh onto the new one.

The CSM model is a lot simpler than the CFD model since it only consists of the compensation chamber. Abaqus was used to model the deformation of the membrane under the hydraulic load. Two different models – a shell and a volume model – were developed to compare the results.

Isotropic elastic material with a Young's modulus of $E = 2.110^9$, a Poisson ration $\nu = 0.35$ and the density $\rho = 7800\text{kg/m}^3$ was used. The applied loads were ramped linearly over the time step.

2.3.3 MpCCI Setup

The setup of the coupling is quite straightforward for this case.

There is only one coupling surface – the membrane of the compensation chamber – that has to be selected in the MpCCI Coupling Step. The quantities that are exchanged between Abaqus and the CFD code are NPosition and WallForce.

For both quantities under-relaxation or ramping factors have to be defined in the MpCCI Coupling Step.

The movement of the wall and the almost incompressible fluid leads to convergence problems of the coupled simulation.

Using under-relaxation for the displacements as well as the wall forces and ramping the fluid loads over the Abaqus time step is necessary to achieve a convergent solution of the problem.

Problems with moving walls and incompressible fluids often require a strong or implicit coupling to get to a stable solution. In this example a stable solution could be obtained using weak coupling and under-relaxation.

The results of the coupled simulation are very sensitive to the time step size. This leads to very long simulation times with a fixed time increment in Abaqus and in the CFD code.

2.3.4 Running the Simulation

The complete simulation process might be started from the MpCCI GUI, simply as batch job e. g. by `mpcci batch case.csp` or via a batch queuing system like PBS, SGE, etc. If the simulation is started from MpCCI GUI, for Abaqus, FLUENT and STAR-CCM+ it is possible to run the coupled simulation with their own GUI. This procedure offers the possibility to display results during simulation besides the MpCCI Visualizer or interact with the simulation model.

Abaqus

All necessary settings can be made in the MpCCI Go Step. Additional command line options can be entered. The coupling time step and the options to allow subcycling or enforce exact target times can be set. Abaqus simulations always run in batch.

STAR-CCM+

STAR-CCM+ must be steered by a STAR-CCM+ java macro file, which can be provided in MpCCI or in the STAR-CCM+ GUI. The macro may contain all STAR-CCM+ java structures and additionally will contain MpCCI functions like `mpcci.init()`, `mpcci.exchange()` and `mpcci.exit()`. Usually the macro will contain a loop, where after or before each or several iterations or time-steps an exchange is committed. The information of the initial exchange defined in the MpCCI GUI will be handed over to the first call of `mpcci.exchange()`.

FLUENT

In FLUENT the necessary routines (user-defined-functions) will be provided by MpCCI and it is possible to let MpCCI hook the necessary functions automatically. In addition all MpCCI functions might be carried out by the MpCCI Control Panel, which is available in the FLUENT GUI. When FLUENT is started in batch mode a journal file has to be supplied to run the simulation. The journal file might contain all FLUENT structures, in case the user did not allow MpCCI to set the necessary hooks it should additionally contain MpCCI function calls.

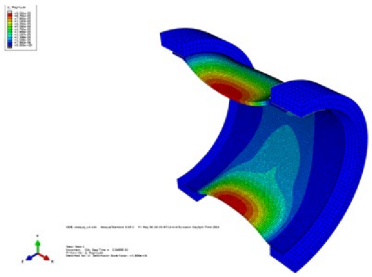


Figure 6: Solid Abaqus model. U displacement contours with a maximum value of 0.0001.

Smoothly interrupting a coupled simulation and then restarting the same simulation is a challenging task. If you run the job with the MpCCI GUI you can hit the Stop button in order to provide a STOP/ABORT file or a signal to save the solution and quit the simulation codes gracefully. Unfortunately if one code is waiting for data at this moment it might not be successful. When running on a batch system there is actually no way to smoothly stop the codes with a proper file save. In this case it is advisable to turn on periodic auto save of files in the simulation codes and then restart with the last saved states.

For further information of the procedures for each code see the Codes Manual.

2.3.5 Results

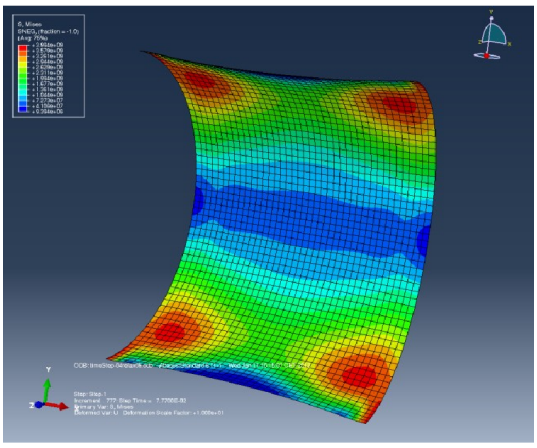


Figure 7: Von-Mises-stress on the (slightly) deformed elastic wall of the compensation chamber.

The simulation results show the necessity of a coupled simulation for this application. The simulation including the fluid-structure interaction at the elastic wall agrees significantly better with the experimental findings than the stand-alone CFD simulation.

Results of the Abaqus simulation can be seen in Figure 6 and Figure 7. The deformation of the elastic wall is quite small and can only be seen when it is scaled.

The pressure contours of the fluid on the moving geometry can be visualized to get a general idea of the working pump and the quality of the simulation (cf. Figure 8) – but the slight differences between the stand-alone CFD solution and the MpCCI solution cannot be perceived visually on these contour plot.

For an easy comparison of simulation results with experimental data the pressure is monitored at three discrete points of the pump during the simulation: one point located in the center of the upper chamber, one in the lower chamber and the last point is located in the center of the compensation chamber. These pressure values can be compared for different pump parameters or simulation variations.

Figure 9 shows two examples for these pressure plots: one for a stand-alone CFD simulation and one for a fluid-structure interaction. The negative pressure peaks are much less pronounced in the FSI solution. Furthermore the pressure in the compensation chamber shows a different behavior in the two cases. The values during the "high pressure phase" are higher for the FSI solution. Also, a qualitative difference can be observed when investigating how the pressure rises or falls in the compensation chamber.

All in all the FSI simulations showed a very good agreement with the experiments that were conducted. The CFD model on its own is not capable of catching the pressure behavior – especially in the compensation chamber – in a satisfactory way.

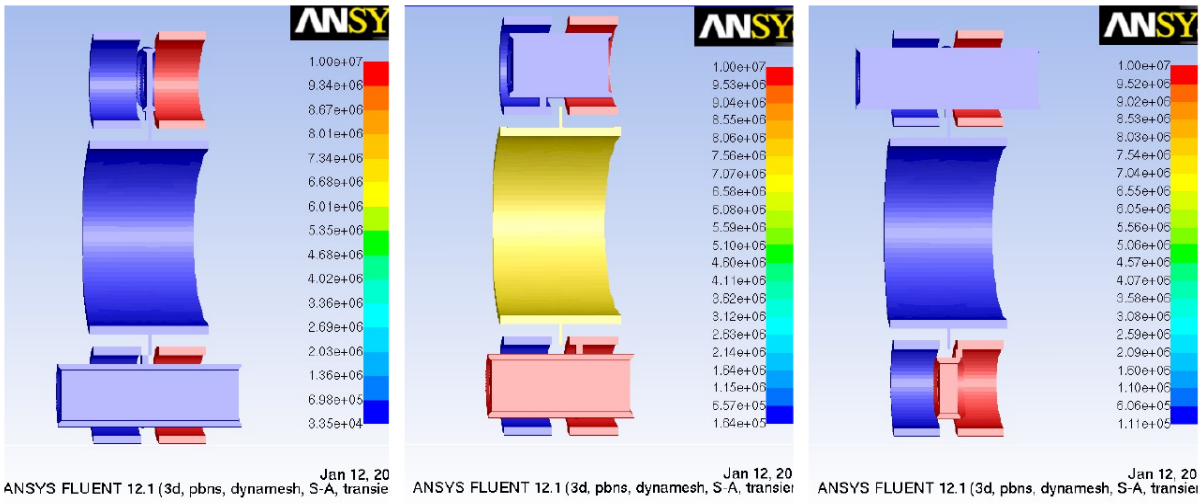


Figure 8: Pressure contours for the PWK pump at different time values: on the left $t = 0.0002$s, in the middle $t = 0.01$s and on the right $t = 0.02$s.

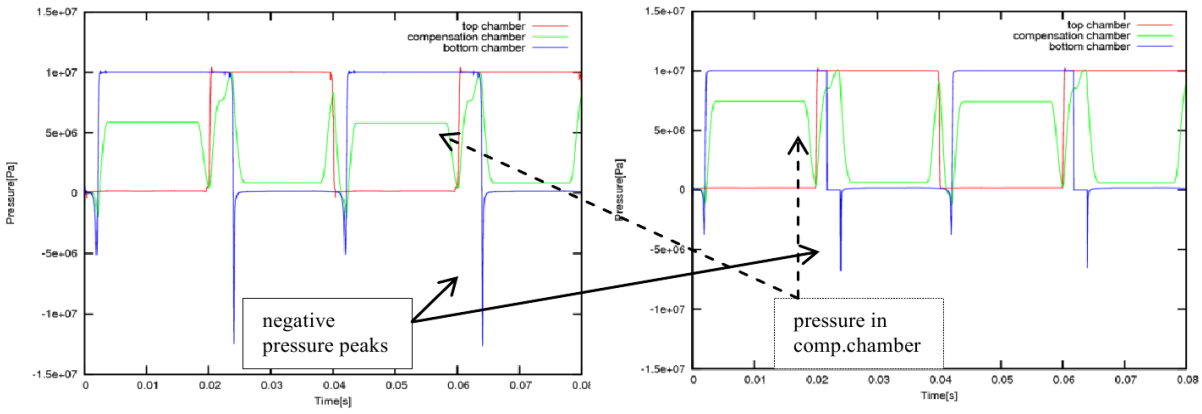
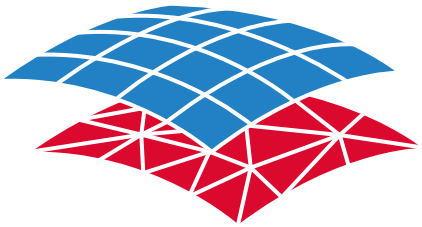


Figure 9: Pressure plots for three discrete points in the pump. CFD stand-alone (FLUENT) results are on the left, FSI results (FLUENT-Abaqus-MpCCI) are on the right. The differences in the pressure peaks and in the pressure value in the compensation chamber can be seen.



MpCCI
FSIMapper

Part X

—

MpCCI FSIMapper

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part X FSIMapper
PDF version
October 29, 2023

Fraunhofer Institute for Algorithms and Scientific Computing SCAI
Schloss Birlinghoven 1, 53757 Sankt Augustin, Germany

X MpCCI FSIMapper – Contents

1 MpCCI FSIMapper Overview

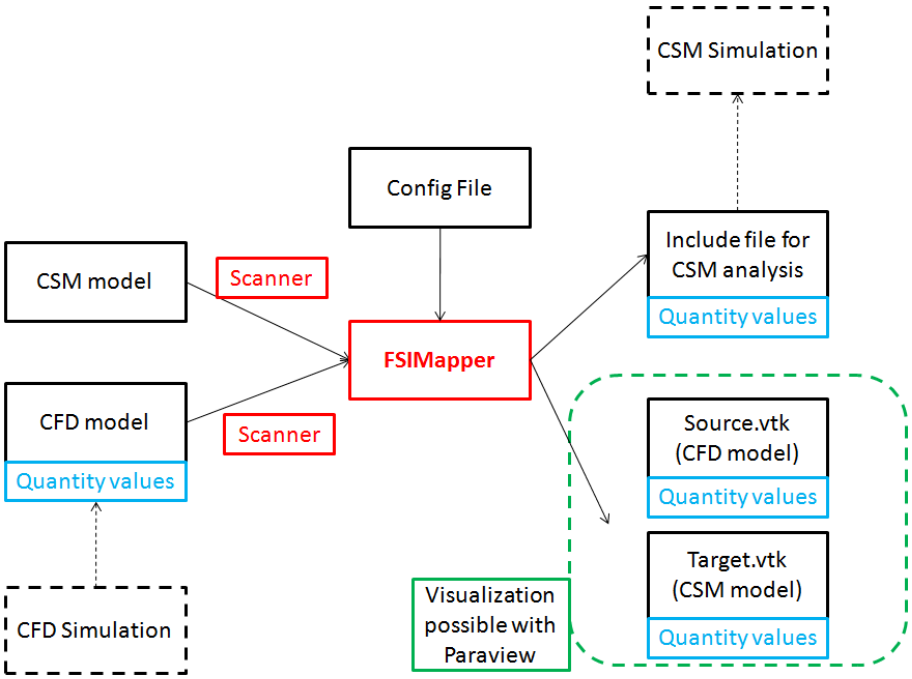


Figure 1: Software architecture of the MpCCI FSIMapper in batch usage (cf. section 6)

Mapping

For many problems the influence of the CFD solution on the CSM solution is a lot more remarkable and significant than vice versa. If a one-way connection between the fluid and the solid solver shall be established, quantity values – namely temperature or pressure values that were calculated as a part of the CFD solution – have to be transferred from the CFD to the FEM mesh. Then the structural mechanics solver can use these values as a boundary condition. At the interface between the fluid and solid domain the two meshes usually do not match and interpolation of quantities becomes necessary. This transfer of quantity values from one mesh to another can be done easily with the MpCCI FSIMapper. While "one–way" fluid–structure interactions certainly are the main application of the MpCCI FSIMapper, the tool can be used generally to map values from one mesh to another.

Supported software

At the moment the MpCCI FSIMapper is able to read FLUENT (.cas and .dat, .cas.h5 and .dat.h5), CFX (.csv), MentorGraphics FloTHERM (.flofea, .csv), MentorGraphics FloTHERM XT (.txt), MentorGraphics FloEFD (.efdfea), MagNet (.vtk), FINE/Turbo (.cgns), MSC NASTRAN Bulk (.bdf, .nas, .dat), Abaqus (.inp), ANSYS Maxwell (*.unv) and EnSight Gold Case as source result files. Since the EnSight Gold Case export is also supported by CFX, FLUENT, ANSYS Icepak, STAR-CD, STAR-CCM+, etc. , so these simulation codes are supported indirectly.

Supported native CSM codes are Abaqus (.inp) input decks, ANSYS (.db and .cdb), MSC NASTRAN Bulk (.bdf) data input files, LS-Dyna keyword (.key, .k, .dynain) and also neutral EnSight Gold Case file format is supported.

Supported meshes and quantities

The two meshes between the interpolation shall take place have to be 2–dimensional surface or 3–dimensional volume meshes in the 3–dimensional space. For Abaqus and MSC NASTRAN also 1–dimensional surfaces of 2–dimensional meshes are supported.

The physical quantities that can be read and mapped are temperature, wall heat transfer coefficient, the wall heat flux, pressure and force density. Furthermore, it is possible to compare two geometries with the MpCCI FSIMapper.

MpCCI FSIMapper output files

For Abaqus, ANSYS, MSC NASTRAN and LS-Dyna mapped quantity values can be written in native solver format, e.g. Abaqus input, ANSYS APDL, MSC NASTRAN Bulk and LS-Dyna keyword format respectively, that can be easily included in the original CSM input deck. In addition to native format, the MpCCI FSIMapper allows export to neutral EnSight Gold Case format which is supported by a wide range of simulation software.

Additionally, the MpCCI FSIMapper saves the source and the target model in the native .ccvx format of MpCCI Visualizer. In this way the mesh and data used for and resulting of the mapping can be visualized afterwards.

For mapped harmonic data or Fourier transformed transient data the MpCCI FSIMapper exports a .ccvx file where the complex excitations are transferred back to the time domain (per frequency). Thus, the real and imaginary part of the excitations can be visualized as transient fluctuations (using pseudo time steps).

Supported operating systems

The tool is available for Windows and Linux for 64–bit machines in graphical and batch mode.

MpCCI FSIMapper concept

The MpCCI FSIMapper comes with a graphical user interface where all relevant parameters for the mapping can be set. The usage of the tool is quite simple: after selecting the models and parts some choices concerning algorithms and parameters have to be made. After the mapping the results and the original values are loaded into the MpCCI Visualizer.

The immediate visualization of the results makes it possible to detect model errors or bad mapping results due to parameter problems. The user can identify the critical areas and start a new mapping process.

Additionally, the MpCCI FSIMapper can be used as a batch tool. The parameters and settings that are normally made in the GUI can be defined in a simple ASCII configuration file.

2 MpCCI FSIMapper Installation

The installation of the MpCCI FSIMapper is quite easy. It may be either part of the MpCCI installation or a standalone version.

2.1 Part of MpCCI Installation

As part of the MpCCI installation the MpCCI FSIMapper is completely integrated into the MpCCI environment.

No further actions have to be done.

2.2 Standalone Version

The installation of the standalone version is based on the following steps:

- The MpCCI FSIMapper has to be installed.
- Perl has to be installed.
- A license for the MpCCI FSIMapper must be available.

There are two ways to install the MpCCI FSIMapper:

- via the *Windows installer* for a local Microsoft Windows only installation and
- via the *multi-platform distribution file* for Linux and file server installations.

A Microsoft Windows installation requires a free disc space of approx. 50 MB and a multi-platform installation of approx. 100 MB (without tutorials).

2.2.1 Local Microsoft Windows Installation

For a local Microsoft Windows installation you download an `"MSI"` file.

Execute this installer file with administrative rights and follow the instructions. The installer unpacks the MpCCI FSIMapper for all users, does registry entries and adds firewall rules which are necessary for the communication between the MpCCI FSIMapper and the MpCCI Visualizer. It also checks if Perl is installed. If no Perl executable could be found in the path, the user is offered an Open button to download Strawberry Perl. This installation also takes place via a Microsoft Windows installer (`"MSI"` file).

The MpCCI FSIMapper software is now installed on your system.

For running the MpCCI FSIMapper a license must be available (see ▷ 2.2.4 License ◁).

If you did not install Perl or if your Perl installation is too old see ▷ 2.2.3 Perl ◁.

2.2.2 Linux or Multi-Platform Installation

If you intend to install MpCCI FSIMapper under Linux or on a file server with access for Linux and Microsoft Windows users you should have downloaded a multi-platform distribution file.

The installation is just done by unpacking the downloaded archive to a folder of your choice. Then the `PATH` environment variable needs to be extended by the `"bin"` directory of the MpCCI FSIMapper. For Linux everything can be done without any administrator privileges if you use a local installation directory. For Windows administrative rights are necessary to add firewall rules.

The steps in detail:

1. Unpack the downloaded archive on Linux:
   - Change to your installation directory e. g. `cd <your home>/software`.
   - Move the downloaded file to your installation directory
   - Extract the MpCCI FSIMapper files from the downloaded file with the command
     `tar zxvf mpccifsimapper-<FSIMapper-version>.tar.gz`
     or, if the z option is not available, with the commands
     `gunzip mpccifsimapper-<FSIMapper-version>.tar.gz`
     `tar xvf mpccifsimapper-<FSIMapper-version>.tar`
2. Update your user PATH environment with the MpCCI FSIMapper "bin" directory:
   Linux: `export PATH=<your install dir>/FSIMapper/bin:$PATH` for korn shell (ksh) and bash resp.
   `setenv PATH <your install dir>/FSIMapper/bin:$PATH` for c-shell (csh) and tc-shell (tcsh) users.
   Windows: In the Windows Control Panel go to where you can change own user environment variables. Extend the PATH environment variable by `<your install dir>\FSIMapper\bin`.
3. Windows only: Add firewall rules for MpCCI FSIMapper executables.
   In the Control Panel → System and Security → Windows Firewall select Allow a program or feature through Windows Firewall. Now click on Allow another program... and add
   - "<*your install dir*>\FSIMapper\bin\windows_x64\mpcci_fsimapper.exe" and also add
   - "<*your install dir*>\FSIMapper\bin\windows_x64\mpcci_visualizer.exe" and finally add
   - "<*your install dir*>\FSIMapper\bin\windows_x64\mpcci_ccvxcat.exe"

The MpCCI FSIMapper software is now installed on your system.

For running the MpCCI FSIMapper a license must be available (see ▷ 2.2.4 License ◁).

If you run into problems with Perl while executing the MpCCI FSIMapper have a look at ▷ 2.2.3 Perl ◁.

2.2.3 Perl

Perl is a platform independent script language which allows running identical scripts under Linux as well as Microsoft Windows. The MpCCI FSIMapper uses perl scripts for executing its commands. Therefor it requires a working Perl installation. If Perl is already installed on your system - this is true for nearly any Linux system - you may check the Perl version by typing

```
> perl -version
```

For MpCCI FSIMapper under Linux you need at least Perl 5.6. Under Microsoft Windows you can either use Strawberry Perl or ActivePerl from version 5.8 up.

If Perl is not installed or if the version is too old, please contact your system administrator for installation resp. upgrade. On Linux systems it's part of the distribution but Perl is never part of your Microsoft Windows system. For Microsoft Windows it can be downloaded from the world wide web. We recommend to have either Strawberry Perl or ActivePerl from version 5.8 up installed.

Strawberry Perl is free of charge and can be downloaded from strawberryperl.com/. A 64 bit version of Strawberry Perl for Windows 64 bit is available.

ActivePerl is covered by the ActiveState Community License and can be downloaded from www.activestate.com/activeperl.

Perl is not part of the MpCCI FSIMapper installation. Only for the local Microsoft Windows installation (▷ 2.2.1 Local Microsoft Windows Installation ◁) the download of the third party software Strawberry Perl is integrated. The installation of Strawberry Perl should be done as the next step.

2.2.4 License

2.2.4.1 Installing the MpCCI License Server

MpCCI FSIMapper uses a FlexNet Publisher based floating license mechanism. FlexNet Publisher license server has to be started on the license server host defined in the MpCCI FSIMapper license file (see ▷ 2.2.4.2 Requesting a License ◁). You can run MpCCI FSIMapper anywhere in your internal network. For more information about FlexNet Publisher, please refer to the FlexNet Publisher license administration guide.

You will find the software packages for the MpCCI license server installation (FlexNet Publisher tools and vendor daemons for SVD) in the SCAI download area (www.mpcci.de → MpCCI Download Area → enter your username and password and login → License Tools). Please select the suitable platform and execute the installer for Microsoft Windows resp. unpack the downloaded package for Linux.

In general FlexNet Publisher comes with some tools (lmutil, lmstat, lmhostid, lmgrd, lmdown etc.) for managing the licenses - please refer to the FlexNet Publisher documentation.

MpCCI FSIMapper only needs three FlexNet Publisher executables:

the utility:	lmutil
the license server:	lmgrd
the vendor daemon:	SVD

The MpCCI FSIMapper vendor daemon is named SVD. The FlexNet Publisher port number of the SVD vendor daemon is 47000. If there are other software packages installed using also FlexNet Publisher there will be several FlexNet Publisher utils available. Depending on your local installation and your own PATH environment it is not always defined which of these lmutils will be executed upon a command call.

2.2.4.2 Requesting a License

You need to acquire a license file for the MpCCI FSIMapper from Fraunhofer SCAI.

Therefor you need to know the hostname and the hostid of the license server:

Please login on the host where the FlexNet Publisher license server for MpCCI FSIMapper should run on. In the following example, "> " is your prompt:

```
> hostname
myHostName

> lmutil lmhostid -n
12345abcd
```

If you have multiple network devices installed (ethernet card, wireless LAN, docking station on a notebook) you may see multiple hostids. For the MpCCI FSIMapper license daemon the integrated ethernet card address should be the correct one.

Please go to the download area at www.mpcci.de to get an MpCCI FSIMapper license file.

If you already have an account for the download area the MpCCI FSIMapper license file can be requested via the *License Request Form Sheet*:

1. At www.mpcci.de go to `Download Area`.
2. Click the link `Log into the MpCCI Download Area` which will redirect you to the Fraunhofer SCAI download portal.
3. Enter your account details in the E-Mail and Password input fields.

4. Go to the menu MpCCI and select your product:
   `MpCCI FSIMapper`.

5. Then click `License Request`.

Please fill in the form with all required data - including the hostname and hostid of the license server (myHostName and 12345abcd in the example above) - select FSIMapper in the Mapper section, leave selections empty for MpCCI Jobs, Parallel Clients, Code Adapter and AddOns and submit. You will receive the required license file soon after via e-mail.

Please copy your received license file into the file "<*fsimapper_home*>`/license/mpcci_fsimapper.lic`".

Then, please start the FlexNet Publisher license server daemon and SVD vendor daemon on the local host with the following command:

```
> lmgrd -c <LICENSE_FILE>
```

In the case of problems you can get information about the license server in a logfile with the command:

```
> lmgrd -c <LICENSE_FILE> -l <LICENSE_LOGFILE>
```

To stop the license server please type:

```
> lmutil lmdown -c <LICENSE_FILE>
```

You should set the generic FlexNet Publisher variable `SVD_LICENSE_FILE`.

For ksh or bash users:

```
> export SVD_LICENSE_FILE=47000@<HOSTNAME>
```

For csh users:

```
> setenv SVD_LICENSE_FILE 47000@<HOSTNAME>
```

For Microsoft Windows users:

```
> set SVD_LICENSE_FILE=47000@<HOSTNAME>
```

This variable is also referred to by other software packages using FlexNet Publisher;

`SVD_LICENSE_FILE` may comprise several entries < *port*@*host* > (one for each application). If there is more than one entry they must be separated by a ":" on Linux and by a ";" on Microsoft Windows.

We suggest that you set the `SVD_LICENSE_FILE` environment variable in your login file (`".cshrc"` or `".profile"` or `".bashrc"`) for Linux users resp. for Microsoft Windows users in the Environment Variables window of the system settings.

FlexNet Publisher stores data of a previous successful connection to a license server in the file `"<HOME>/.flexlmrc"`. You may create or adjust this file.

After setting this environment variable you can check whether the license server is running and can be reached from the machine where you are currently working and from where you plan to start MpCCI FSIMapper:

```
> lmutil lmstat -vendor SVD
```

For more details command

```
> lmutil lmstat -a -c <LICENSE_FILE>
```

2.2.5 Configure a License Manager as UNIX Service

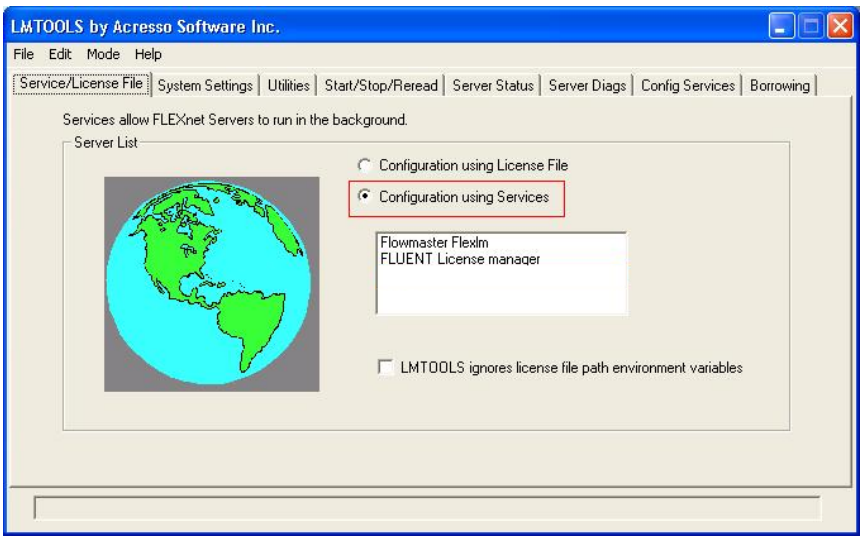
On UNIX, edit the appropriate boot script, which may be "/etc/rc.boot", "/etc/rc.local", "/etc/rc2.d/Sxxx", "/sbin/rc2.d/Sxxxx", etc. Include commands similar to the following.

```
<LICENSE_TOOL_INSTALLATION>/bin/lmgrd -c <LICENSE_FILE> -l <LICENSE_LOG_FILE>
```

The LICENSE_TOOL_INSTALLATION is the full path of the license software installation. This command will create a log file under "LICENSE_LOG_FILE" and you have to ensure that the process could write in the directory.

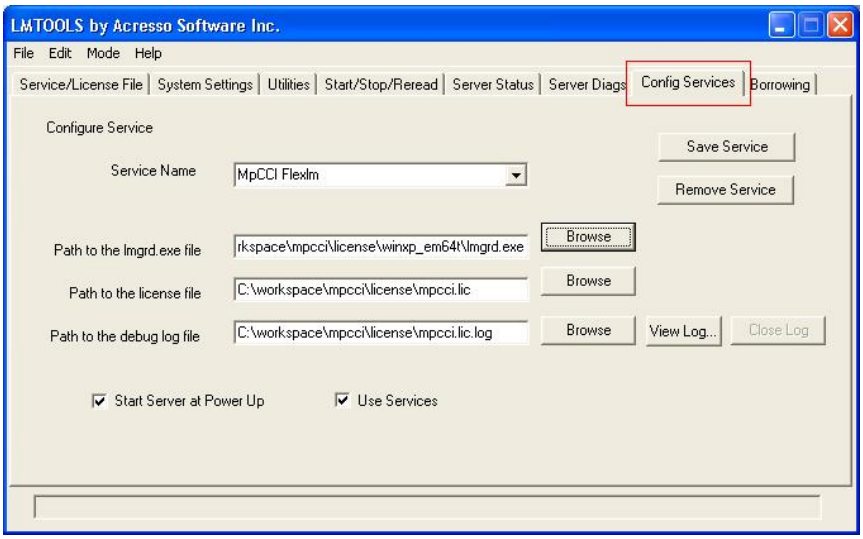
2.2.6 Configure a License Manager as Windows Service

Execute the "lmtools.exe" application from the license manager installation directory: "<LICENSE_TOOL_INSTALLATION>/bin/lmtools.exe"

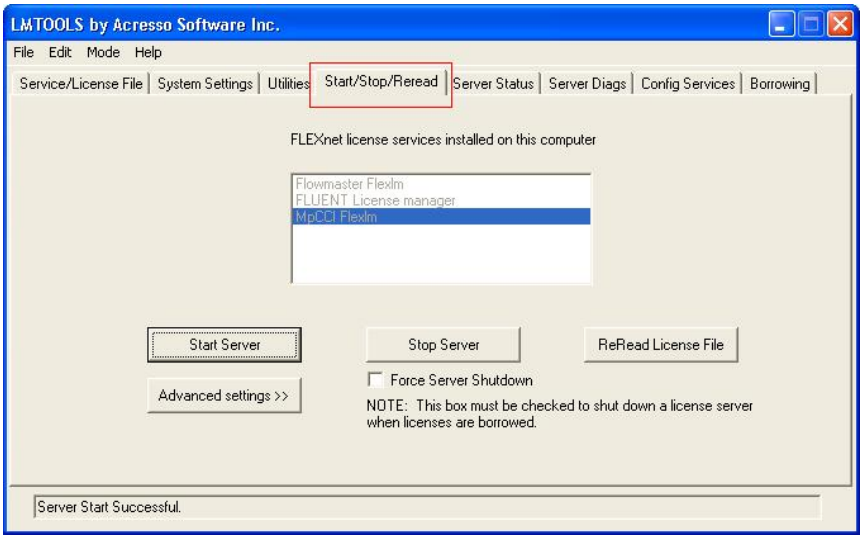


- Select in the Service/License File tab section the option Configuration using Services.

- Click the Config Services tab section.



- Enter a service name e. g. MpCCI license manager or MpCCI FLEXlm.
- Select the path of the program `"lmgrd.exe"` with the Browse button: `"<LICENSE_TOOL_INSTALLATION>/bin/lmgrd.exe"`
- Select the license file `"mpcci.lic"` with the Browse button: `"<LICENSE_TOOL_INSTALLATION>/license/mpcci.lic"`
- Activate the Start Server at Power Up option.
- Activate the Use Services option.
- You can optionally add a log file by providing a file name for the Path to the debug log file option.
- Click on the Save Service button.



- Select in the Start/Stop/Reread tab section the license service.
- Click on the Start Server button.
- The license server is now running and configured to start at power up.

3 MpCCI FSIMapper Command

```
Usage:
   fsimapper [-]option


Synopsis:
   'fsimapper' is used to launch the MpCCI FSIMapper.


Options:
   -batch  <configFile> <source> [source_quant] <target>
         Use this option to launch the MpCCI FSIMapper in batch mode.
         Provide a configuration file, source and target model files and
         an optional source quantity file.

   -help
         This screen.

   -scan  <FORMAT> <model>
         Use this option to scan models with the MpCCI FSIMapper.
         Supported scanner formats are ABAQUS, ANSYS, LSDYNA, FLUENT,
         NASTRAN, CFXCSV, FLOTHERMMAPLIB, FLOEFDMAPLIB, FLOTHERMXT,
         FINETURBO, MAXWELL, 6SIGMAET, VMAP  and ENSIGHT.
         The scanner output will be written to stdout.

   -convert <FORMAT> <fileToConvert> [releaseNumber] [ansysProduct]
         Use this option to convert an input file of special format
         into own intermediate format '.ml'.
         At this time only ANSYS '.cmd' and '.db' files are supported
         to be converted so FORMAT must be ANSYS.
         Optional arguments are the release number for the used ANSYS
         executable and the ANSYS product to use for starting ANSYS.
         By default the latest ANSYS release will be taken.

   -visualize <ccvx-File-1> <ccvx-File-2> ...
         Opens MpCCI Visualizer and loads all passed CCVX files
```

The batch usage is described in ▷6 Batch Usage of the MpCCI FSIMapper ◁ the scan usage in ▷6.1 File Scanners◁ and the convert usage in ▷5.2.4 ANSYS Scanner and Converter◁.

The MpCCI FSIMapper itself is described in ▷4 MpCCI FSIMapper GUI◁.

4 MpCCI FSIMapper GUI

This section describes the usage of the MpCCI FSIMapper. The different panels of the graphical user interface are described in the next sections. Details on the used mapping and orphan filling parameters can be found in ▷7.1 Numerical Methods◁.

4.1 Starting the MpCCI FSIMapper

The MpCCI FSIMapper GUI is embedded in the MpCCI Visualizer and can be started from command line by

```
> fsimapper
```

launching the MpCCI Visualizer with activated plugin for file based mapping. To open the MpCCI FSIMapper GUI press button  after the MpCCI Visualizer has started.

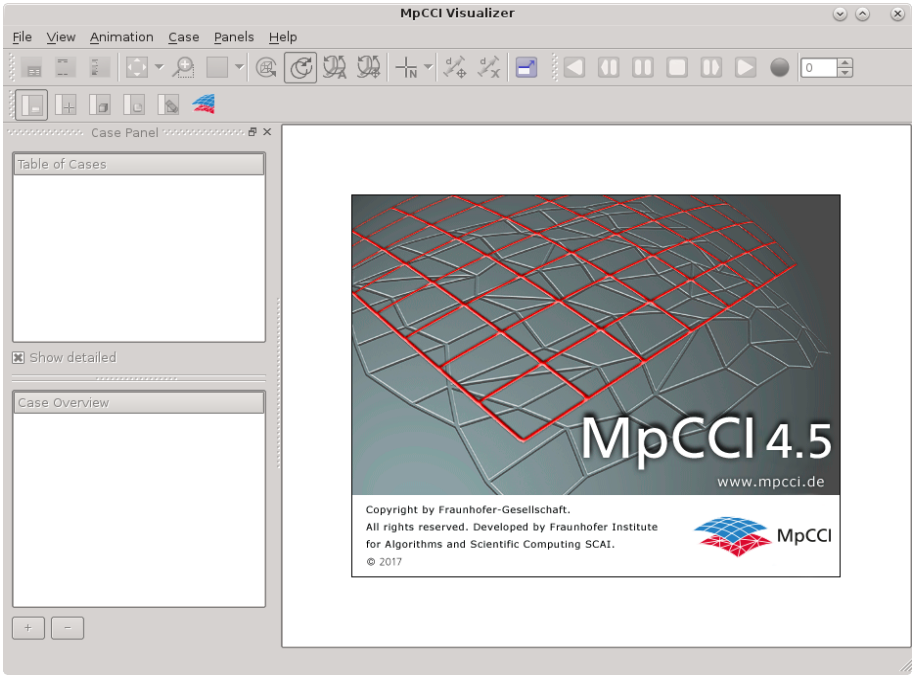


Figure 2: The MpCCI FSIMapper plugin location in the MpCCI Visualizer

The MpCCI FSIMapper writes a configuration setup file containing user model and part selection and launches a separate process which executes the defined tasks. When finished the models together with quantities are being sent to the MpCCI Visualizer where each model appears in a separate viewport.

4.2 The “What to map” Panel

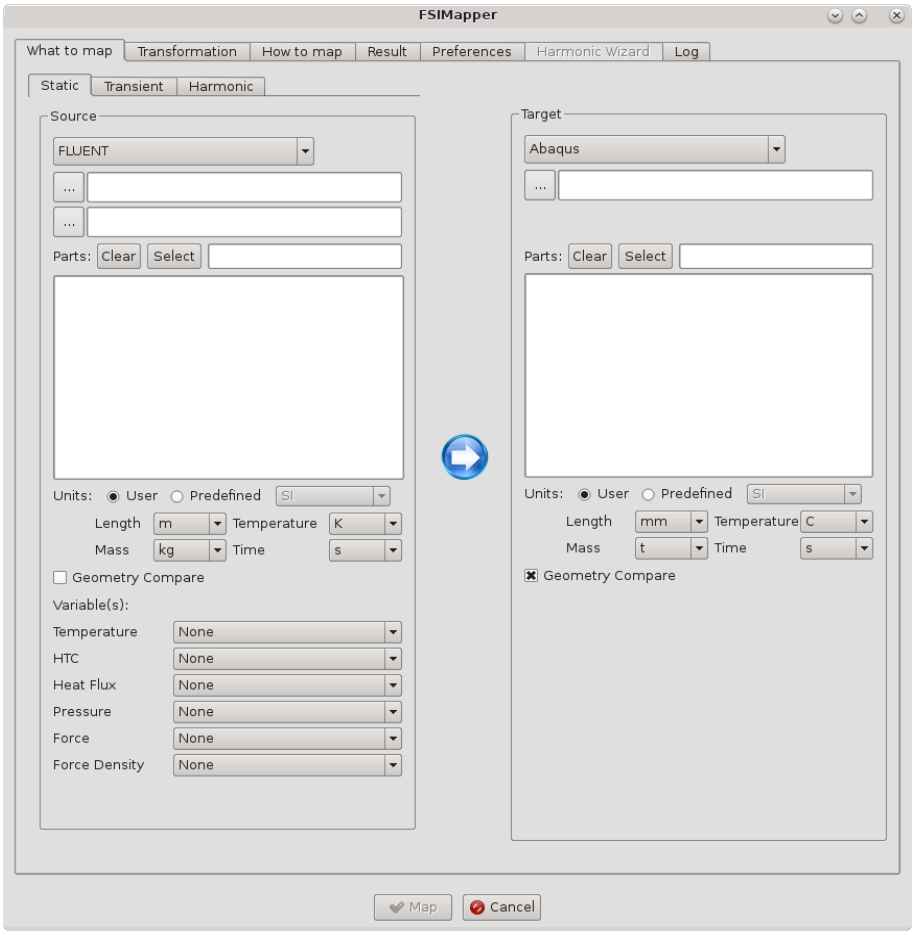


Figure 3: The “What to map” panel of the MpCCI FSIMapper

4.2.1 Selection of Cases, Parts and Quantities

In the “What to map” panel of the mapping dialog, at first the type of analysis needs to be specified. The user can switch between “Static”, “Transient” and “Harmonic”. Using the “Static” panel means to map one state from a source model to a target model. For the “Transient” panel it is assumed that the data is present for several time steps.
Additionally to the creation of transient loading, there is the possibility to perform a Fourier transformation on the transient data in order to do a frequency response analysis, cf. ▷ 4.5.2 Apply Fourier Transformation ◁.
In the “Harmonic” panel, complex loading is assumed in order to map excitation loads for NVH analyses.

At second the source and target models need to be specified. The file type for the two models can be selected in a drop-down list. The files can be selected with the open file dialog.

Source File Specification

For a "Static" source model FLUENT, Mentor Graphic's FloTHERM, FloTHERM XT and FloEFD, CFX, FINE/Turbo, Infolytica's MagNet and EnSight Gold Case are supported. Moreover, the MSC NASTRAN bulk data format and the Abaqus input format is supported.

For a "Transient" source model MSC NASTRAN, MagNet, FloTHERM, ANSYS Maxwell and EnSight Gold are supported. The target model can be either in Abaqus, ANSYS, LS-Dyna or MSC NASTRAN format. Currently only the "Force", "Force Density" and "Pressure" variables are supported for transient analyses.

For a "Harmonic" source model FINE/Turbo and EnSight Gold are supported for the "Pressure" variable. The target model can be either in Abaqus, ANSYS or MSC NASTRAN format.


As harmonic CFD simulations often result in a set of harmonic quantities, the "Harmonic Wizard" offers the possibility to map all or a subset of the available harmonics at once. Refer to ▷ 4.7 The "Harmonic Wizard" Panel ◁.


For transient FloTHERM ∗.csv format as target code only Abaqus is currently supported.

Depending on the selected source code, the following files are required:

- **FLUENT** : the native geometry (∗.cas, ∗.cas.h5) and quantity (∗.dat, ∗.dat.h5) file
- **FloTHERM** : resp. **FloEFD** (∗.flofea, ∗.csv) resp. (∗.efdfea) file exported by the code
- **FloTHERM XT**: (∗.txt) file exported by the code
- **EnSight Gold** : (∗.case) file which references the binary (∗.geom) file and the binary quantity file(s)
- **MagNet** : the Infolytica "MpCCI Exporter" format ∗.vtk, where multiple files can be selected (defining multiple parts)
- **CFX** : the "CFD-Post Generic Export" format (∗.csv)
- **FINE/Turbo** : the native (∗.cgns) file and optionally the (∗.run) file
- **Abaqus** : ASCII file in the native input file format (∗.inp)
- **MSC NASTRAN** : ASCII file in the native bulk data format
- **ANSYS Maxwell**: the Maxwell export of geometry (∗.unv) and quantity (∗.unv) file

Target File Specification

The target model can be either in Abaqus, ANSYS, MSC NASTRAN, LS-Dyna or EnSight Gold Case format. Besides ASCII files in Abaqus input format, MSC NASTRAN bulk data format or ANSYS format, the binary ANSYS format .db and the binary EnSight Gold Case is supported.

Parts Selection

After the selection of the models, their files are scanned automatically and the available model parts are listed in the selection area below. For better distinction of area types the MpCCI FSIMapper lists each "part" by leading 'V' for volumetric parts, 'S' for surfaces or 'E' for element sets (Abaqus only). By clicking on its name, relevant "parts" for the mapping can be selected. In the most common case this is the interface between the fluid and a solid in fluid-structure interaction.


Either homogen volumes, surfaces or element sets can be selected for mapping. A composition of different area types is not supported and has to be mapped separately.

The “parts” selection can be performed by using the string matching function.
Provide the string to match in the input field and click on the button Select to activate the selection.
By clicking on the button Clear it will clear the current selection of “parts”.

Unit Systems

The next step in the GUI is to define the corresponding unit systems for the source and the target meshes. Figure 4 illustrates the part in the “What to map” panel where length, mass, temperature and time units can be defined for both models independently. This is useful when the source and target model length units for the model geometry or the quantity units do not match.

All mapped and displayed quantities are converted and exported due to the defined target unit system.

Figure 4: Overview of unit system configuration in graphical user interface

4.2.2 Geometry Compare

For the source and the target models it is possible to tick a check box labeled “Geometry Compare”. If this option is selected for the source or target model, additional geometric information is computed and the MpCCI Visualizer receives the two additional quantities `NODAL_DISTANCE` and `ASSOCIATION_DISTANCE`. If only the geometry of the models shall be compared without mapping quantities, this option has to be selected for both models.

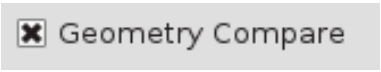
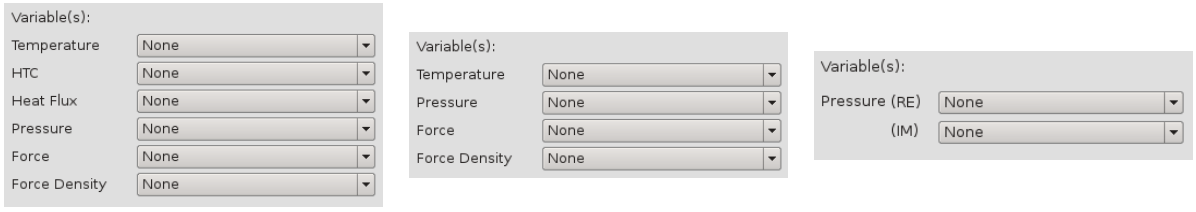


Figure 5: Geometry Compare check box

For each node of one mesh the `NODAL_DISTANCE` is closest geometric distance to a point of the other mesh. However the `ASSOCIATION_DISTANCE` denotes the distance between a point of a mesh and the closest (associated) element surface of the other mesh. If the point lies “in” an element, this would mean that the association distance is 0.

4.2.3 Quantity Identification for CSM Solver Output

As the notation of a physical quantity may differ among native solvers file formats, the user has to specify the physical quantity by its name so that it can be used for export to either Abaqus input, MSC NASTRAN Bulk files or ANSYS Mechanical APDL files. A selection of the relevant quantities can be done in the lower left part of the “What to map” panel, cf. Figure 6.



(a) "Static" panel (b) "Transient" panel (c) "Harmonic" panel

Figure 6: Quantity selection area in graphical user interface

For each of the supported physical quantities "Temperature", "HTC" (Heat Transfer Coefficient), "Heat Flux", "Pressure", "Force" and "Force Density" there exists a drop-down menu where one of the quantity ids of the source file can be selected.

In some cases of the harmonic mapping it is obligatory to specify both real and imaginary part of the excitation quantity, cf. ▷4.3 The "Transformation" Panel◁.
Having in mind that a complex excitation amplitude can be reformulated as amplitude and phase lag of a periodic fluctuation (Euler's formula), it is more realistic to specify both the real and imaginary part of the quantity. If only the real part or only the imaginary part is given, all excitations will vibrate exactly in-phase or out-of-phase (only 0° or 180° phase shift). In this case the vibration amplitudes are the absolute values of the given data.

4.2.4 Execute a Mapping Process

If the actual configuration inside the "What to map" panel is in a valid state, pressing the "Map" button - which is available on all panels - starts the mapping process . A valid mapping state is present if the following prerequisites are satisfied:

- A source model file is specified
- A source quantity file is specified (FLUENT, MSC NASTRAN, Abaqus and ANSYS Maxwell only)
- A target model file is specified
- At least one part of the source model is selected
- At least one part of the target model is selected
- Quantity selection dependent on the analysis type

  Static and Transient panel
  At least one physical quantity selection is made OR both geometry compare boxes are checked

  Harmonic panel
  Depending on cyclic symmetry:
  - **none**
    At least one physical quantity selection is made OR both geometry compare boxes are checked
  - **cyclic symmetric**
    Depending on data periodicity (cf. ▷4.3 The "Transformation" Panel◁):
    * *constant/alternating*
      At least one physical quantity selection is made OR both geometry compare boxes are checked
    * *paired*
      At least both real and imaginary parts of one physical quantity selection are made OR both geometry compare boxes are checked

If the current state is valid the “Map” button gets available otherwise it is disabled.

4.3 The “Transformation” Panel

4.3.1 The “Geometry” Subpanel

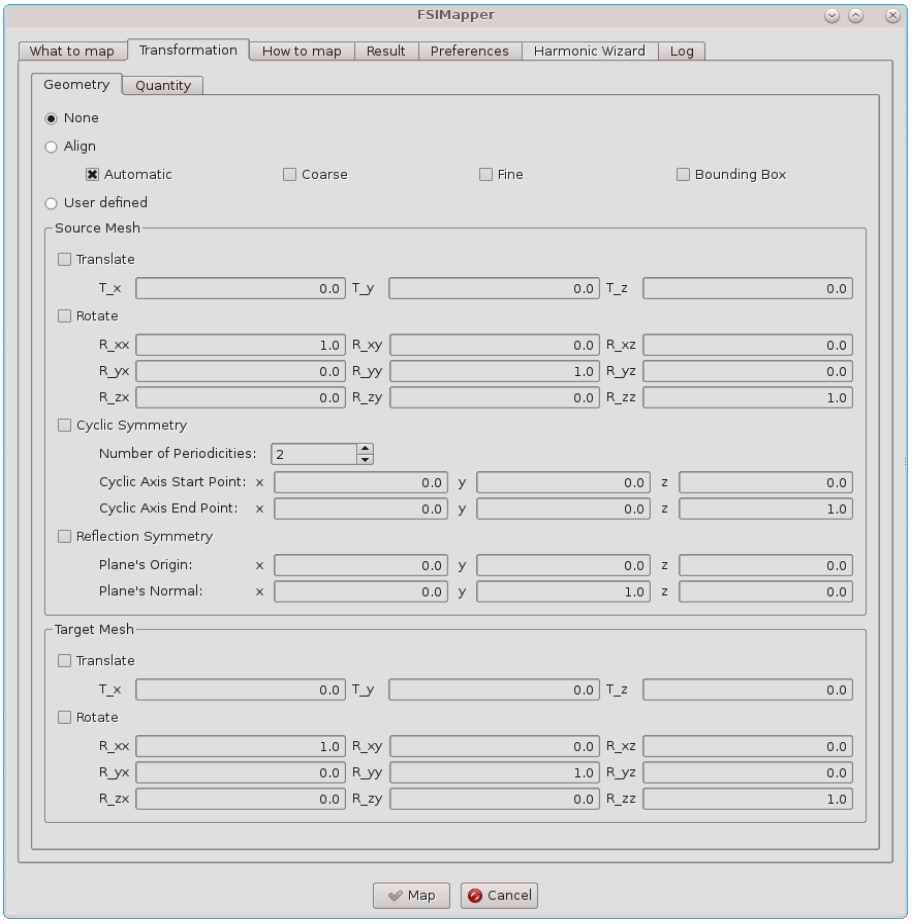


Figure 7: The “Geometry” subpanel of the MpCCI FSIMapper

A common problem in one-way one-step coupling is the use of different local coordinate systems for CFD and CSM simulation. Here the models might not have the same spatial location in a common coordinate system or even represent only a symmetric part of the target model. Hence, for a position-dependent neighborhood computation, both models need to be aligned in a preprocessing step. This alignment step can be done in the “Transformation” panel (Figure 7) where different options for mesh positioning can be selected in the “Geometry” subpanel.

None
No mesh positioning is needed.

Align
Select one of the four different automatic alignment options:

Automatic
The MpCCI FSIMapper first applies a “Coarse” transformation followed by a “Fine” transformation on the source mesh to move it close to the target mesh location.

Coarse
The MpCCI FSIMapper computes the center of gravity of both models and translates the source towards the target. Then the principal axis of the models will be aligned.

Fine
The MpCCI FSIMapper minimizes the global total nodal distance from the source to the target model.

Bounding Box
The MpCCI FSIMapper computes the global expansion of the models and then translates the source model bounding box to the target one.

User defined
As an automatic alignment might fail in case of symmetric geometry or partial overlap of models the MpCCI FSIMapper also offers an alignment by user defined transformation.

Translate and Rotate
Here for each model the user can define a 3x3 rotation matrix R as well as a translation vector T so that new model coordinates x' are computed as

$$x' = Rx + T.$$

Only a source mesh gets transformed into the target mesh coordinate system

$$x' = R_t^{-1} R_s x + R_t^{-1}(T_s - T_t)$$

where the lower index s denotes source and t target transformation.

Cyclic Symmetry
This transformation provides for cyclic symmetric source models the corresponding full mesh and quantity. In this way a mapping to a full target model or to a periodic target model with a different section shape is possible, as shown in Figure 8. The user needs to define the number of sections as Number of Periodicities and two points (corresponding to the source model position) which define the axis of cyclic symmetry (Cyclic Axis Start Point and Cyclic Axis End Point).

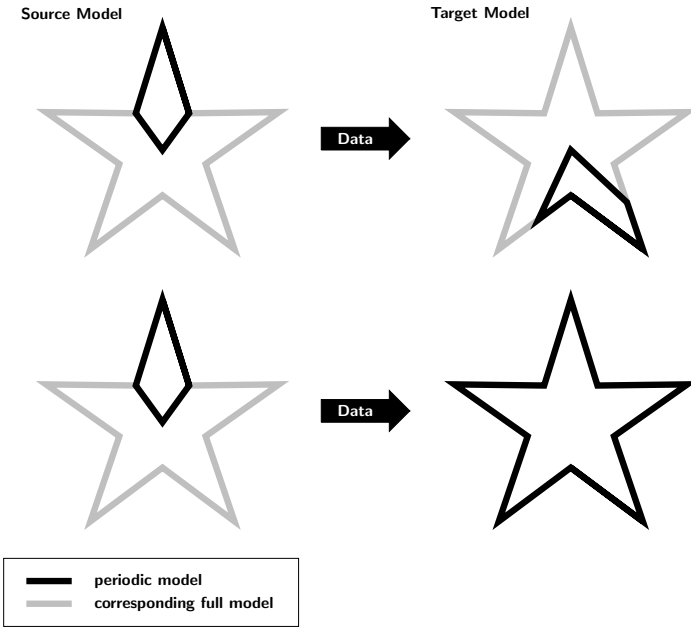


Figure 8: Mapping of data between different periodic sections (black lines) which represent the same full model (grey lines)

Reflection Symmetry

This transformation provides for mirror symmetric source models the corresponding full mesh and quantity by reflection. In this way a mapping to a full target model is possible, as shown in Figure 9. The user needs to define the Plane's Origin and the Plane's Normal vector of the symmetry plane.

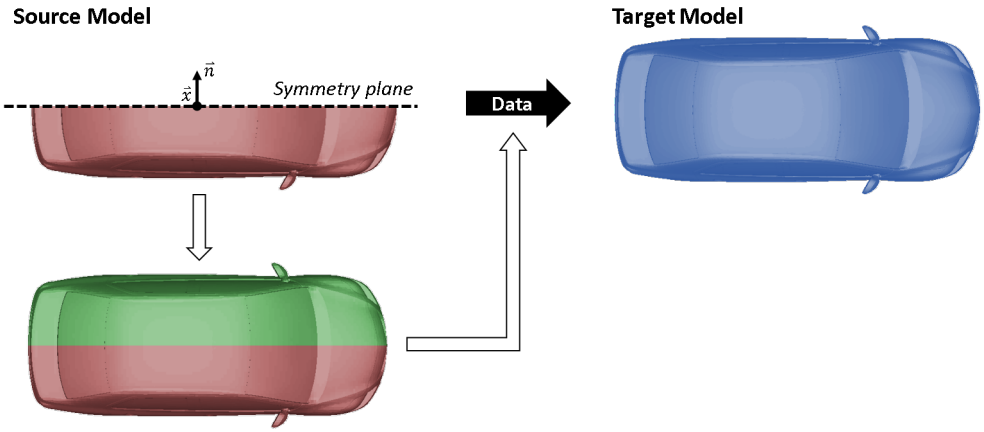


Figure 9: Mapping of data between a mirror symmetric source model and the corresponding full target model.

4.3.2 The "Quantity" Subpanel

In the "Quantity" subpanel (Figure 10), transformations of the quantity can be defined. Following options are available:

None

No quantity transformation is needed.

User defined

Cyclic Symmetry

Enter the cyclic symmetry mode i.e. the Nodal Diameter and the excitation direction (Mode) of the transient or harmonic quantity in order to define the quantity transformation for cyclic symmetric models. For further information refer to ▷ 7.2.2 Cyclic Symmetry of Quantities ◁.

Truncate Transient Data

The data import of transient result data, e.g. pressure and forces, can be truncated using the following options

Filter Transient Id Range

Read transient data beginning and ending at the time step integer IDs given by Start Id and End Id. With the option Step it is possible to read only every n-th time step id.

Filter Time Range

Read transient data beginning at the time value given by Start Time for a defined Period. With the option Step it is possible to read only every n-th time step id.

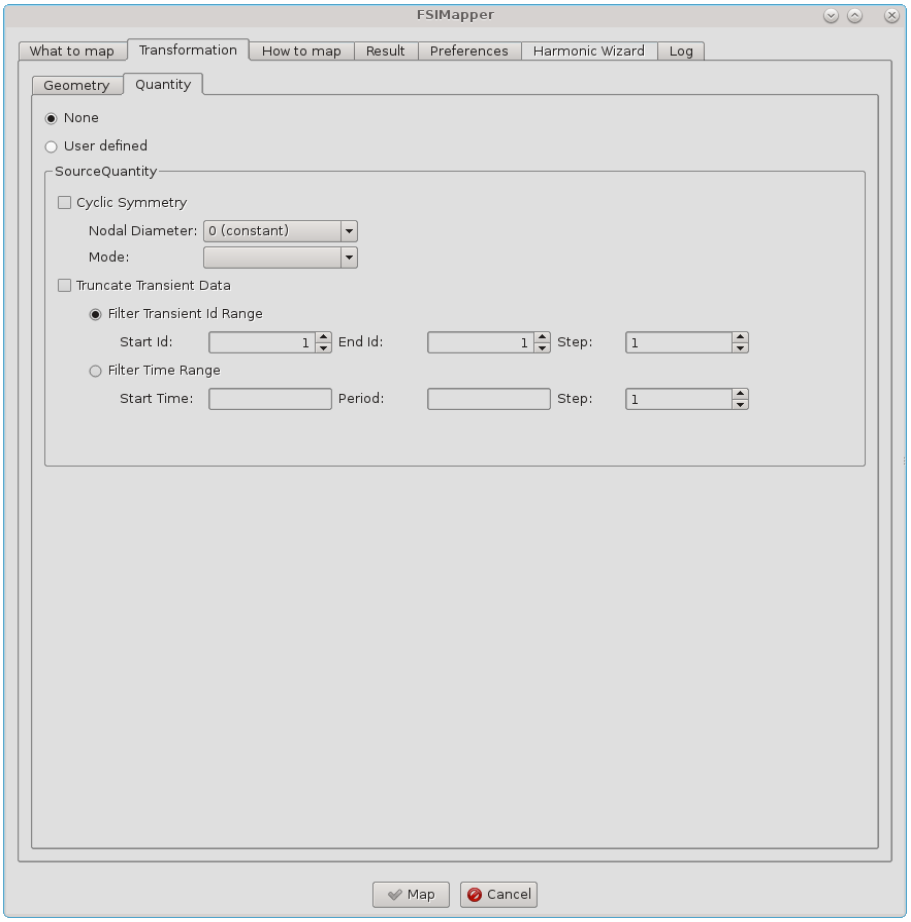


Figure 10: The “Quantity” subpanel of the MpCCI FSIMapper

4.4 The “How to map” Panel

Additional settings concerning the type of algorithm used for the mapping, the necessary parameters, the used orphan fillers or the quantity location can be made in the “How to map” panel (Figure 11).

4.4.1 Mapping Algorithms and Neighborhood Parameters

The MpCCI FSIMapper comes along with three different mapping algorithm approaches that can be used for data interpolation between meshes: the “Shape function”, the “Nearest” and the “Weighted Element” algorithm. Fundamental difference between shape function / weighted element and nearest interpolation is the underlying neighborhood relation which is computed. For shape function and weighted element interpolation an element-node relation is required in contrast to nearest interpolation which uses node-node relation. Detailed descriptions of the algorithms can be found in ▷ 7.1 Numerical Methods ◁.

For each type of mapping algorithm there exist different parameters that control the mapping process. After the selection of the algorithm type the relevant parameters are enabled and can be changed below in the “Neighborhood parameters” section (Figure 18).

It is possible to use “Default” parameter selection which should produce good mapping results for many

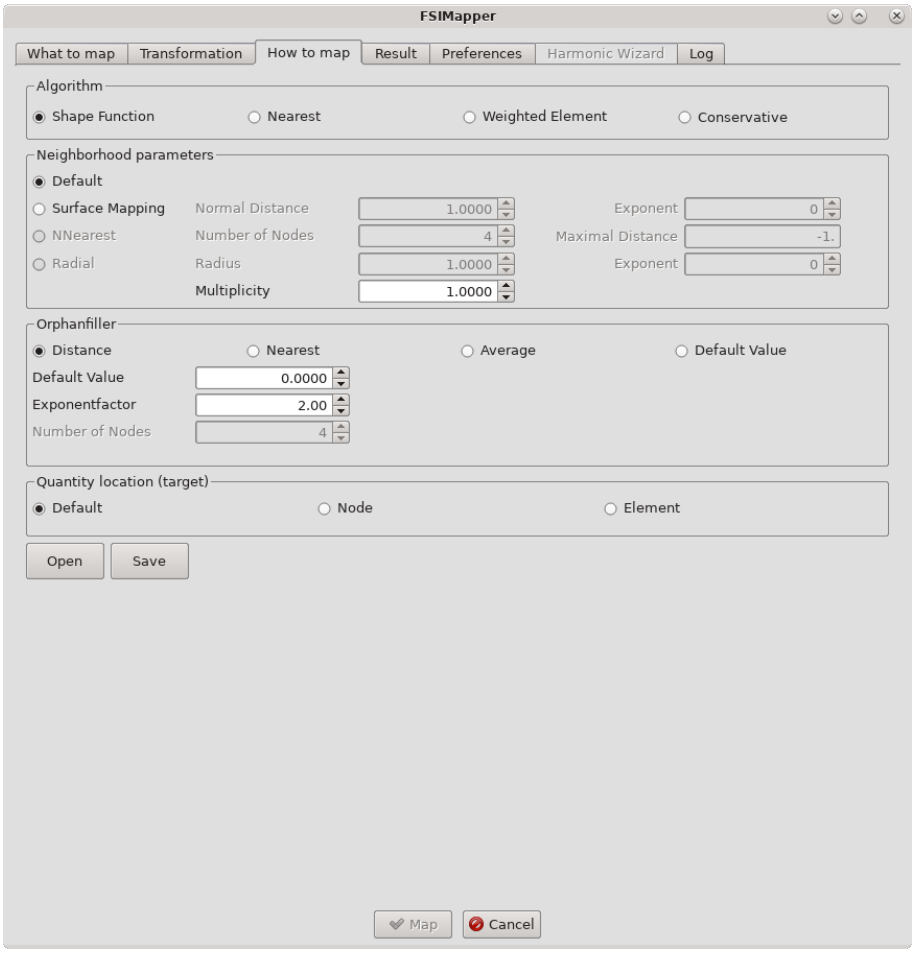


Figure 11: The “How to map” panel of the MpCCI FSIMapper

applications where geometries do not differ too much but they may result in a quite time-consuming neighborhood computation. However, depending on the meshes it might be necessary to adjust the default parameters.

4.4.2 Orphan Filling

Depending on the type of mapping algorithm used, certain elements or nodes of the target geometry may not receive values from the source mesh, for example if the two parts - target and source - do not have the same extension in one direction. These nodes or elements are called “orphans”.

The MpCCI FSIMapper provides different methods to assign values to these “orphans”. These can be selected in the “Orphanfiller” section on the “How to map” panel. Just like the mapping algorithms the orphan filling methods need some parameters that can be edited after selecting the fill type.

Further information about the different fill methods and parameters can be found in ▷7.1 Numerical Methods◁, where the numerical methods are described.

4.4.3 Quantity Location

Finally – in the last part of the “How to map” panel – the type, i. e. the location of the target quantity can be chosen. By default, the mapped quantity on the target mesh will be located on the same entities (either element or node) as the source quantity.

Additionally the possibility exists to force the target quantity values to be located on either elements or nodes – independent of the source quantity location.

4.4.4 Saving Mapping Configurations

At the bottom of the “How to map” panel the button “Save” provides the capability to store the current configuration – the selected algorithms and parameters – in a configuration file. This offers the possibility of interactive adjustment and optimization of neighborhood parameters for future use in batch mode production runs.

4.5 The “Result” Panel

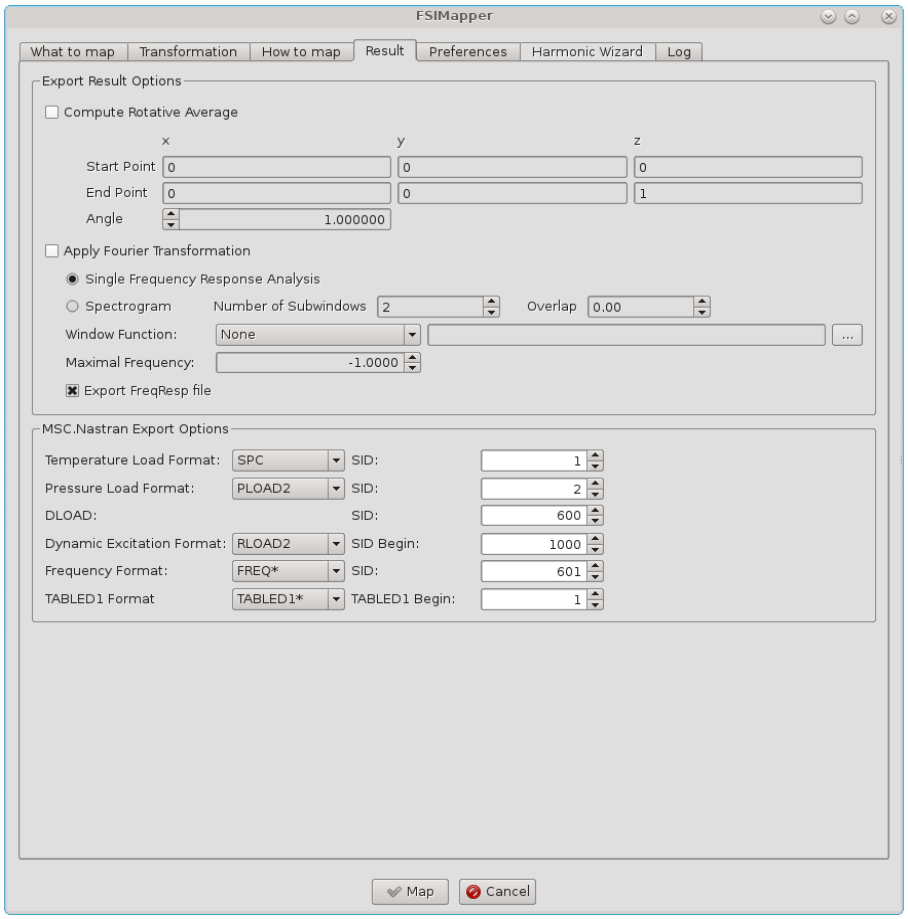


Figure 12: The “Result” panel of the MpCCI FSIMapper

4.5.1 Average over Rotation Axis

The first part of the "Result" panel is only relevant if the CFD simulation uses a so-called "Frozen Rotor" model. In this case the rotation of a geometry part is not modeled with a moving geometry but with the help of additional source terms. This makes the simulation of rotating parts a lot simpler.

The FSIMappper offers the possibility to average these simulation results of a frozen rotor computation by mapping the values on the rotating CSM mesh. Select "Compute Rotative Average" when required.

After ticking the box "Export Result Options" the rotation axis of the target mesh and rotation angle in angular degree need to be specified. The mapping process then is done for a 360° rotation of the target model split up into N substeps where each step is defined by a rotation by the user defined rotation angle around the axis defined through axis start and end point.

4.5.2 Apply Fourier Transformation

MpCCI FSIMapper allows to perform Fourier transformations of transient quantities (currently pressure, force and force density supported). The resulting complex quantities can be used in frequency response or spectrogram analyses.

To export loads for this type of analyses select Apply Fourier Transformation when having selected the "Transient" panel in the "What to map" panel.

The following variants are available:

Single Frequency Response Analysis
: The transient data is mapped to the target model and for each node/element the quantity is reformulated by the Fourier transformation as frequency dependent complex load.

Spectrogram
: The time period is divided into several, equally long, potentially overlapping subwindows. In each subwindow a Fourier transformation is performed in order to create complex frequency dependent loads changing over time. Define the Number of Subwindows and the Overlap (between 0 and 0.99). For a signal of a total length L, a number of subwindows m and an overlap of p, the subwindows have a size of $L_S = \lfloor L/(m-(m-1)\cdot p)\rfloor$ time steps. The overlap consists of $\lfloor L_S \cdot p\rfloor$ time steps.

  Windowing is recommended here.

The created complex data is only exported up to the given Maximal Frequency, where the default -1 means no export truncation.

Windowing is available through the selection of a pre- or user defined Window Function, see ▷ 7.2.1 Fourier Transformation and Windowing ◁.

The time steps have to be constant and at least two time steps need to be present in the transient source model for the use of this option.

If the time steps are only equidistant within a certain tolerance, MpCCI FSIMapper will take the mean time step calculated by the difference of the last and the first time step divided by the number of time steps minus 1. A warning is displayed in the Log panel.

For further information about the Fourier transformation refer to ▷ 7.2.1 Fourier Transformation and Windowing ◁.

For visualization of the complex data a .ccvx file is written, where for each frequency content of the time signal, the complex quantity (here $\hat{q} = x + \mathrm{i}y$) is inverse Fourier transformed into n time steps by

$$q_j = A \cdot \cos(2\pi \cdot j/n + \phi), \quad j = 1, \ldots, n$$

with the amplitude $A = \sqrt{x^2 + y^2}$ and the phase shift $\phi = \mathrm{atan2}(y, x)$. For vector quantities this is done

component-wise.
The ccvx-file can be read into MpCCI Visualizer by File →Open... . By the “Play” button the n generated time steps of the selected frequency (“Scalars” and “Vectors” in “Result Panel”) can be visualized.

4.5.3 MSC NASTRAN Export Options

Mapped quantities can be included as initial or boundary condition in native CSM solver format, i. e. Abaqus input, ANSYS APDL and MSC NASTRAN Bulk.
For definition of MSC NASTRAN temperature and pressure loads there exist several card formats and a unique load id (SID) needs to be specified.
Therefore MpCCI FSIMapper supports the export of temperature either in SPC (MSC NASTRAN single point constraint) or TEMP format, pressure can be exported as PLOAD, PLOAD2 or PLOAD4. In “Result” panel (Figure 12) both temperature and pressure format can easily be selected in a combo box and unique SID can be assigned.

4.6 The “Preferences” Panel

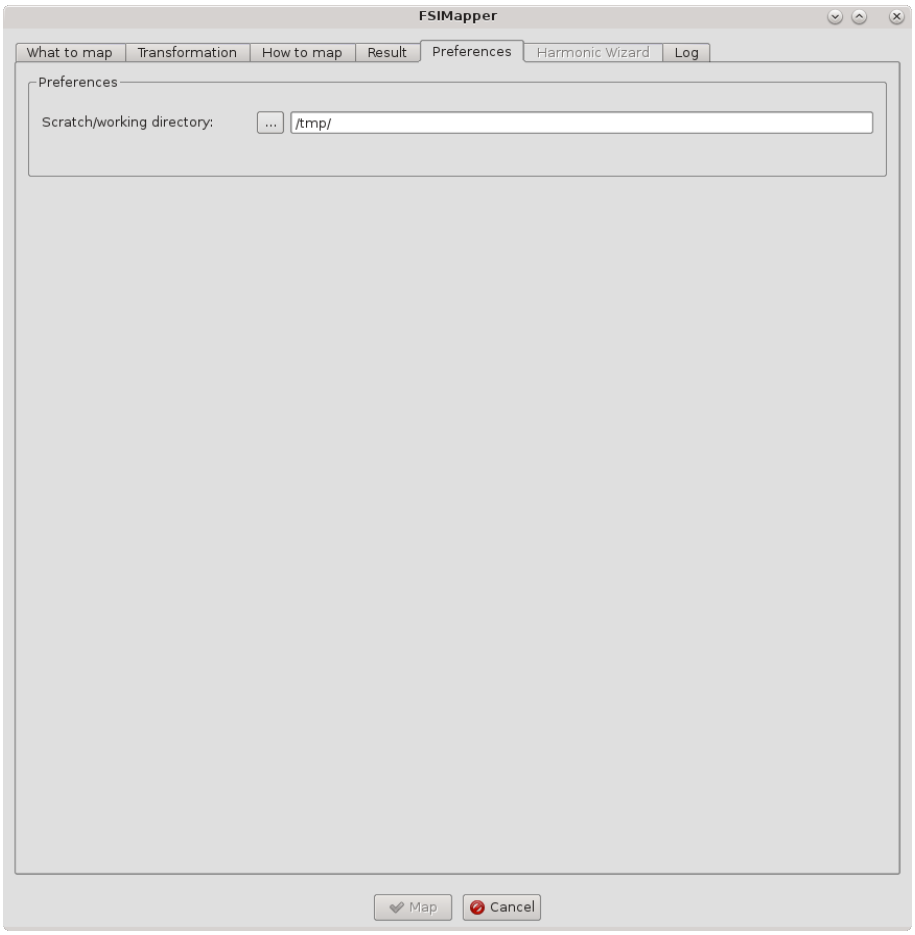


Figure 13: The Preferences panel of the MpCCI FSIMapper

The “Preferences” panel allows just two minor changes: first the user can change the working directory of the MpCCI FSIMapper. The files that are written during the mapping – .vtk files for visualization and include files for a CSM simulation – can be found in the working directory.

Additionally, a box can be ticked if all intermediate files shall be deleted after the mapping is finished.

4.7 The “Harmonic Wizard” Panel

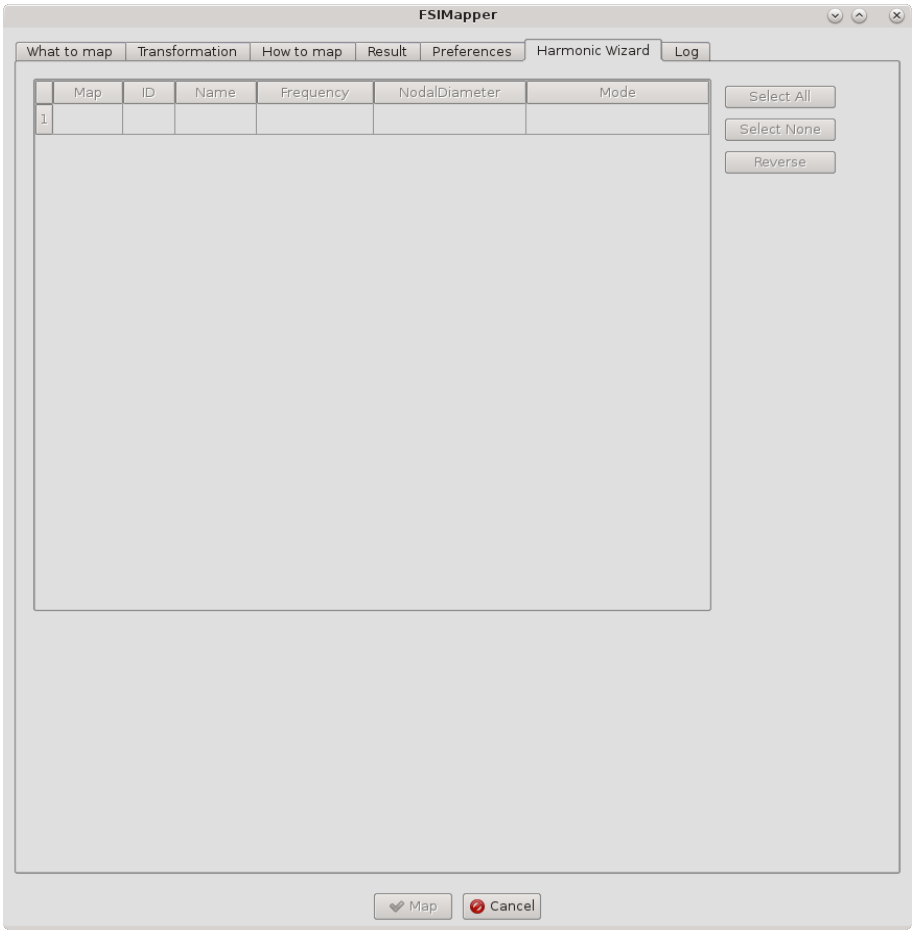


Figure 14: The “Harmonic Wizard” panel of the MpCCI FSIMapper

The “Harmonic Wizard” is designed to map a set of harmonic turbomachinery CFD results at once. It prepares all the necessary information for a mapping between periodic models.

By default, the “Harmonic Wizard” panel is disabled. It is only available for the mapping of harmonic pressure fields simulated by FINE/Turbo, where additionally the FINE/Turbo .run file is given by the user. It can be activated by selecting the check box labeled “Use Harmonic Wizard” at the “What to map/Harmonic” panel.

The “Harmonic Wizard” panel lists all harmonic pressure quantities available in the FINE/Turbo .run file for the selected source parts (which have to belong to one single row). Also the information about the excitation shape (forward/backward nodal diameter) is given for each harmonic, which is used for the mapping between periodic models.

The mapping process (started by pressing the “Map” button) will map the selected harmonics one by one. The mapping results are saved in folders with the naming convention “Row-*RowID*_H-*HarmonicID*”.

4.8 The “Log” Panel

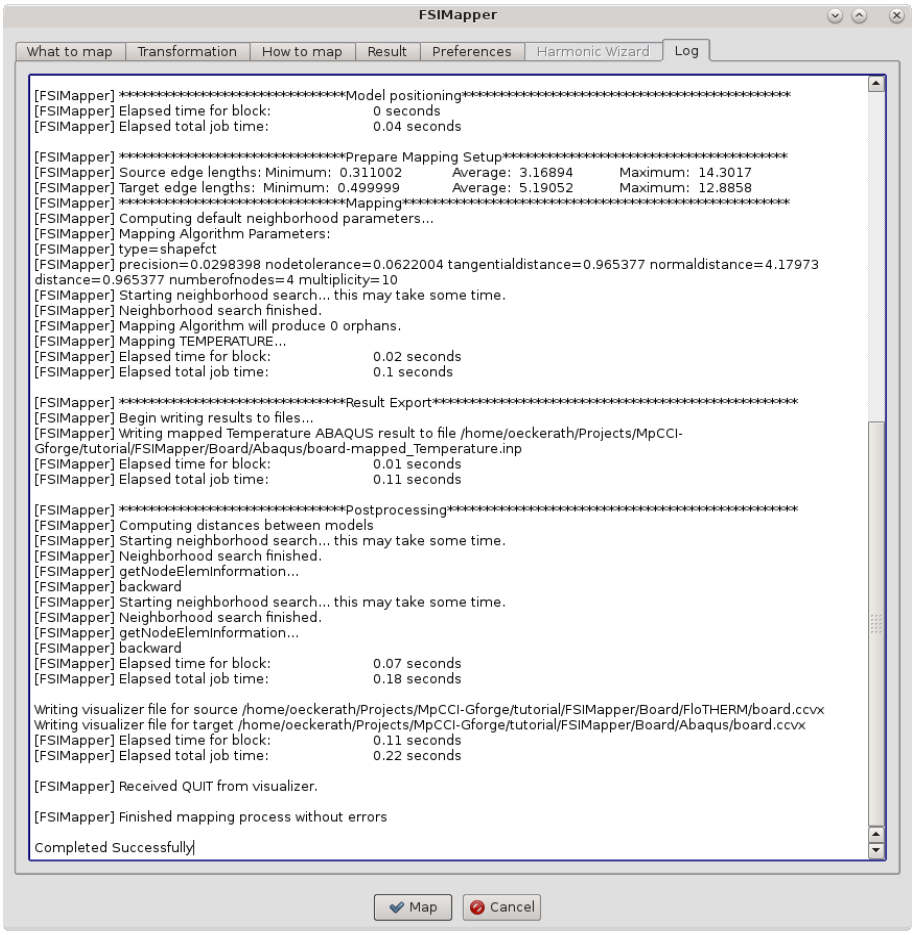


Figure 15: The “Log” panel of the MpCCI FSIMapper

The MpCCI FSIMapper has a fixed workflow which can be viewed in the “Log” panel:

1. Evaluation of configuration file content
2. Reading source mesh, quantities and unit conversions
3. Reading target mesh
4. Model positioning if requested
5. Prepare mapping setup
6. Mapping of quantities
7. Export results to files

5 Codes and Formats Information

5.1 Abaqus

5.1.1 Limitations

Writing For an Abaqus CSM simulation the five quantities "Temperature", "Heat Transfer Coefficient", "Heat Flux", "Pressure" and "Force" can be exported on surface definitions, "Temperature" can also be exported as solid initial condition.

Reading MpCCI FSIMapper supports reading of the Abaqus ASCII input format for static simulation results. Following quantities (with keywords) are supported: nodal temperature (`*TEMPERATURE`), thermal surface film coefficients (`*SFILM`) and nodal force (`*CLOAD`).

5.1.2 Model Preparation

The Abaqus model can be prepared with Abaqus/CAE or as an input file. Please consider the following advice:

- The model can be defined in either SI or mm-t-s unit systems to be specified in the 'What to map' panel of the MpCCI FSIMapper GUI.
- The Abaqus model must contain a definition of coupling components.
  - This can be either an element-based surface for surface coupling:
    Abaqus/CAE: Create a surface using the Surfaces tool. See also "13.7.6 Using sets and surfaces in the Assembly module" in the Abaqus/CAE User's Manual. You can also use surfaces defined in the Part module.
    Input file: A surface is created with `*SURFACE, NAME=`<*surface name*>`, TYPE=ELEMENT`, see section "2.3.3 Defining element-based surfaces" of the Abaqus Analysis User's Manual.
    The surface which serves as coupling component can be selected (marked with 'S' for surface) in the 'What to map' panel of the MpCCI FSIMapper GUI.
  - This can be either an element set for volumetric temperature mapping:
    Abaqus/CAE: Create an element set using the Sets module. See also "13.7.6 Using sets and surfaces in the Assembly module" in the Abaqus/CAE User's Manual.
    Input file: An element set is created with `*ELSET, NAME=`<*elset name*>, see section "2.2.1 Element definition" of the Abaqus Analysis User's Manual.
    The elset which serves as coupling component can be selected (marked with 'E' for elset) in the 'What to map' panel of the MpCCI FSIMapper GUI.

5.1.3 Include Boundary Conditions

To use the mapped quantity values as boundary conditions in an Abaqus CSM simulation a separate Abaqus input file is written for each boundary condition. This file, which is saved in the model directory, can be included in the original Abaqus input deck using the simple Abaqus include option in the input deck.

Include a mapped temperature by:
`*INCLUDE, INPUT="abaqusFile-mapped_FilmTemp.inp"`
Include a mapped temperature and heat transfer coefficient by:
`*INCLUDE, INPUT="abaqusFile-mapped_FilmTempHTC.inp"`
Include a mapped heat flux by:

```
*INCLUDE, INPUT="abaqusFile-mapped_HeatFlux.inp"
```
Include a mapped pressure field by:
```
*INCLUDE, INPUT="abaqusFile-mapped_Pressure.inc"
```
Include a mapped transient pressure field by:
```
*INCLUDE, INPUT="abaqusFile-mapped_TransientPressure.inc"
```
Include a mapped transient pressure field which was Fourier transformed by:
```
*INCLUDE, INPUT="abaqusFile-mapped_FreqRespPressure.inc"
```
Include a mapped harmonic pressure field by:
```
*INCLUDE, INPUT="abaqusFile-mapped_HarmonicPressure_RE.inc"
```
and
```
*INCLUDE, INPUT="abaqusFile-mapped_HarmonicPressure_IM.inc"
```
Include a mapped force field by:
```
*INCLUDE, INPUT="abaqusFile-mapped_Force.inc"
```
Include a mapped transient force field by:
```
*INCLUDE, INPUT="abaqusFile-mapped_TransientForce.inc"
```
Include a mapped transient force field which was Fourier transformed by:
```
*INCLUDE, INPUT="abaqusFile-mapped_FreqRespForce.inc"
```
Include a mapped transient temperature using amplitude definition:
```
*INCLUDE, INPUT="abaqusFile-mapped_Amp.inc"
*INCLUDE, INPUT="abaqusFile-mapped_Temp_Amp.inc"
```

To make sure that the values can be used for an Abaqus analysis, the include has to be placed between the `*STEP` and `*END STEP` keywords. Furthermore, for all thermal quantities the step has to be defined as a heat transfer step, e.g. under *COUPLED TEMPERATURE-DISPLACEMENT for a thermal stress analysis. Please refer to the Abaqus keyword manual for a detailed use.

Definition of a transient temperature using amplitude definition normally requires definition of initial reference temperature, e.g. *Initial Conditions, type=TEMPERATURE. Here also a statically mapped temperature can be used.

5.1.4 Elements

MpCCI FSIMapper	stress/displ.	heat transf./mass diff.	heat transf. conv./diff.	acoustic
3D_VOL_HEX8	C3D8	DC3D8	DCC3D8	AC3D8
3D_VOL_HEX20	C3D20	DC3D20	DCC3D20	AC3D20
3D_VOL_HEX27	C3D27	DC3D27	DCC3D27	AC3D27
3D_VOL_TET4	C3D4	DC3D4	DCC3D4	AC3D4
3D_VOL_TET10	C3D10	DC3D10	DCC3D10	AC3D10
3D_VOL_WEDGE6	C3D6	DC3D6	DCC3D6	AC3D6
3D_VOL_WEDGE15	C3D15	DC3D15	DCC3D15	AC3D15
2D_VOL_TRIA3	CPS3			
2D_VOL_QUAD4	CPS4			
2D_VOL_TRIA6	CPS6			
2D_VOL_QUAD8	CPS8			

Table 1: Supported Abaqus solid (continuum) elements. Type variants like reduced integration or coupled temperature-displacement are handled as base type.

MpCCI FSIMapper	stress/displ.	heat transfer
3D_SHELL_TRIA3	S3	DS3
3D_SHELL_TRIA6	S6	DS6
3D_SHELL_QUAD4	S4	DS4
3D_SHELL_QUAD8	S8	DS8
3D_SHELL_QUAD9	S9	

Table 2: Supported Abaqus structural elements. Type variants like reduced integration or coupled temperature-displacement are handled as base type.

5.1.5 Supported Quantities

Quantity	Dim.	Unit (see Table 3)	Location	Abaqus Keyword
TEMPERATURE	Scalar	θ	*Elset	*TEMPERATURE
FILMTEMPERATURE	Scalar	θ	*Surface	*SFILM
HTC	Scalar	$JT^{-1}L^{-2}\theta^{-1}$	*Surface	*SFILM
WALLHEATFLUX	Scalar	$JL^{-2}T^{-1}$	*Surface	*DFLUX
PRESSURE	Scalar	$ML^{-1}T^{-2}$	*Surface	*DLOAD
FORCE	Vector	MLT^{-2}	*Surface	*CLOAD

Unit	Length	Mass	Temperature	Time	Energy
Symbol	L	M	θ	T	J

Table 3: Abaqus unit symbols.

5.2 ANSYS

5.2.1 Requirements

To use MpCCI FSIMapper for file based mapping to ANSYS you need the following:

- Ordinary ANSYS installation.
- It is required that ANSYS can run in standalone correctly and can get a license without any issue.

5.2.2 Model Preparation

There are some issues which you should consider while creating an ANSYS model for a co-simulation:

Supported element types. Not all ANSYS element types are supported, the supported types are given in Table 4.

Dummy surface elements for surface coupling. For surface coupling, additional surface elements must be used for quantity exchange. For instance SHELL63 elements for a fluid structure interaction or SHELL57 elements for thermal coupling can be used as dummy elements to receive forces from the partner code. The dummy elements must have the corresponding quantities you want to receive or send. Only these elements take part in the coupling process and must either be deselected when the solution is performed or defined so weak that they do not influence the solution in case of fluid structure interaction. They can be deselected before solution is executed if only nodal quantities

ANSYS Element Types	MpCCI FSIMapper
PLANE13, PLANE25, PLANE42, PLANE55, PLANE67, PLANE181, PLANE182, SHELL28, SHELL41, SHELL43, SHELL57, SHELL63, SHELL131 SHELL143, SHELL157, HYPER56, VISCO106, CPT212, SURF252,	3D_SHELL_TRIA3, 3D_SHELL_QUAD4
PLANE2, PLANE35	3D_SHELL_TRIA3, 3D_SHELL_TRIA6
SHELL91, SHELL93, SHELL99, SHELL132, SHELL150, SHELL281 PLANE53, PLANE145,PLANE223, PLANE77, PLANE78, PLANE82, PLANE83, PLANE121, PLANE183, PLANE146, PLANE230 SURF152, SURF154 CPT213, HYPER74, VISCO88, VISCO108,	3D_SHELL_TRIA6, 3D_SHELL_QUAD4, 3D_SHELL_QUAD8
SOLID5, SOLID45, SOLID46, SOLID62, SOLID64, SOLID65, SOLID69, SOLID70, SOLID96, SOLID97, SOLID164, SOLID285, SOLID185, HYPER58, HYPER86, VISCO107, SOLSH190, CPT215	3D_VOL_TET4, 3D_VOL_WEDGE6, 3D_VOL_HEX8, 3D_VOL_PYRAM5
SOLID87, SOLID92, SOLID98, SOLID123, SOLID127, SOLID148, SOLID168, SOLID186,SOLID187, SOLID227, SOLID232,SOLID237, CPT217	3D_VOL_TET4, 3D_VOL_TET10
SOLID90, SOLID95, SOLID122, SOLID117, SOLID122, SOLID128, SOLID147, SOLID186, SOLID191, SOLID226, SOLID231, SOLID236, VISCO89, CPT216	3D_VOL_TET4, 3D_VOL_TET10, 3D_VOL_WEDGE6, 3D_VOL_WEDGE15, 3D_VOL_HEX8, 3D_VOL_HEX20, 3D_VOL_PYRAM5, 3D_VOL_PYRAM13
MESH200	MPCCI_ETYP_LINE2, MPCCI_ETYP_TRIA3, MPCCI_ETYP_QUAD4, MPCCI_ETYP_QUAD8

Table 4: Supported ANSYS element types.

are sent or received, because the data transfer will then put the values to the nodes and the nodes of dummy elements are shared by the "real" solid model elements. In case of thermal coupling the dummy elements can not be deselected because the quantities wall heat transfer coefficient, wall temperature and wall heat flux are only supported as element quantities. Therefore the additional layer of shell elements (SHELL57) have to be a part of the solution. To reduce the influence on the solution you should give the shell elements the same material properties as the adjacent solid elements and a small thickness. Such dummy elements are shown in Figure 16

Put elements for coupling in a component. The elements of the coupling region must be grouped into one or more element components using the `cm` command.

Predefined loads on dummy surface elements. If element based quantities HTC, TEMPERATURE, WALLHEATFLUX or PRESSURE are received by ANSYS using dummy surface elements, you have to predefine surface loads on these elements in order to enable the MpCCI ANSYS adapter to select the correct element sides to store the received values. Therefore select the coupled element set and the attached nodes and define a dummy load, depending on the received quantities:

- HTC and TEMPERATURE: `~SF, ALL, CONV, 1, 300`
- WALLHEATFLUX: `~SF, ALL, HFLUX, 1`
- PRESSURE: `~SF, ALL, PRES, 1`

Possible quantities depend on degrees of freedom. Normally the degree of freedom of the elements involved in the coupling process determines which quantities can be transferred. It is laborious to find out if all degrees of freedom are actually supported by the ANSYS API. As this API is used for the MpCCI ANSYS–adapter, it is not guaranteed that all theoretically supported degrees of freedom are valid.

Not carefully tested. Only few of the element type mappings are already validated with certain quantities. The compatibility index in Table 5 shows the validated element-quantity pairs. It is constantly added. Please contact us if you have problems with other combinations or if you need additional capabilities.

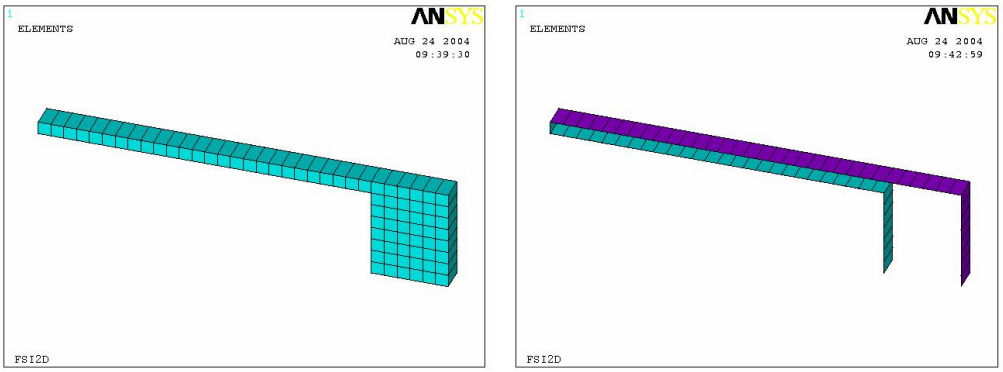


Figure 16: ANSYS volume model and additional dummy SHELL63 elements for surface coupling

Quantity / *Element*	TEMPERATURE	HTC	WALL-HEATFLUX	PRESSURE
SOLID5				+
SOLID45				+
SHELL57	+	+	+	
SHELL63				+
SHELL93				+
SURF151	+	+	+	

Table 5: Quantities supported by MpCCI FSIMapper for different ANSYS elements.

5.2.3 Supported Quantities

Quantity	Dim.	Unit	Location	ANSYS Keyword
TEMPERATURE	Scalar	θ	Solid/Shell	BF,,,TEMP
HTC	Scalar	$JT^{-1}L^{-2}\theta^{-1}$	Shell	SFE,,,CONV
WALLHEATFLUX	Scalar	$JL^{-2}T^{-1}$	Shell	SFE,,,HFLUX
PRESSURE	Scalar	$ML^{-1}T^{-2}$	Shell	SFE,,,PRES

5.2.4 ANSYS Scanner and Converter

ANSYS provides two native solver file formats. The .cmd format is ASCII based whereas the more common data base .db format is binary. The MpCCI FSIMapper makes use of the MpCCI code adapter to convert

both .cmd and .db format into an own intermediate format.

When selecting code ANSYS as target model in "What to map" panel of the MpCCI FSIMapper GUI and specifying either a .cmd or .db file, the model automatically gets converted into intermediate format. This is done by executing the command

`> fsimapper convert ANSYS modelFile.db` (see ▷ 3 MpCCI FSIMapper Command ◁ for details)

creating a new .ml file in same system folder where original model file is located. This result file is automatically selected as target model in the "What to map" panel.
Then the file scanner for intermediate format .ml is launched by

```
> fsimapper scan ANSYS modelFile.ml
```

listing available components that have been converted for a mapping.

5.3 ANSYS CFX

MpCCI FSIMapper supports reading of CFX results exported in "CFD-Post Generic Export" format.

5.3.1 Supported Quantities

Quantity	Dim.	Unit	Location
FILMTEMPERATURE	Scalar	K	Face
HTC	Scalar	$W/(m^2\ K)$	Face
PRESSURE	Scalar	N/m^2	Face

5.4 ANSYS Maxwell

MpCCI FSIMapper supports reading of ANSYS Maxwell export to Universal file format .unv. Universal file node blocks (781 and 2411), element blocks (780 and 2412) and quantity block 2414 with node and element location are supported.

5.4.1 Elements

3D_SURF_TRIA3
3D_SURF_TRIA6
3D_SURF_QUAD4
3D_VOL_TET4
3D_VOL_TET10
3D_VOL_HEX8
3D_VOL_HEX20
3D_VOL_WEDGE6

Table 6: Supported structural elements in Universal file.

5.4.2 Supported Quantities

Quantity	Dim.	Default Unit	Location	Comments
FORCE	Vector	N	wall	Surface Force

5.5 EnSight Gold

MpCCI FSIMapper supports reading and writing of binary EnSight Gold .case and .encas files for static, transient and harmonic simulation results. Only scalar quantities are supported.
EnSight Gold only knows 3–dimensional meshes. If a mapping is performed between the surfaces of 2-dimensional models, "EnSight Case (2D)" must be selected; it converts internally the 3-dimensional model to a 2-dimensional model by removing the third degree of freedom (z).

5.5.1 Supported Quantities

Due to the open structure of the EnSight Gold Case format, MpCCI FSIMapper supports reading of all saved scalar and vector quantities.

5.6 FINE/Turbo

MpCCI FSIMapper supports reading of FINE/Turbo native .cgns files for static and harmonic simulation results. The corresponding .run file (model setup) can be imported in order to insert the surface and volume names originally defined in FINE/Turbo (instead of the internally defined names in the .cgns file).

Mapping is possible only if FINE/Turbo was executed using the expert parameter ICGP3D is set to 1

If the harmonic wizard is to be used, the import of the .run file is necessary

5.6.1 Supported Quantities

Quantity	Dim.	Default Unit	Location	comments
TEMPERATURE	Scalar	K	wall	
HEATTRANSFERCOEF	Scalar	$W/(m^2\ K)$	wall	
HEATFLUX	Scalar	W/m^2	wall	
PRESSURE	Scalar	N/m^2	wall	
REP_x IMP_x	Scalar	N/m^2	volume	complex harmonic pressures (NLH method)

FINE/Turbo only saves the results of the Nonlinear Harmonic method in the fluid volume and not on the wall.

5.7 FloEFD

MpCCI FSIMapper supports reading of FloEFD export format .efdfea available in version 13 for static simulation results.

5.7.1 Supported Quantities

Quantity	Dim.	Default Unit	Location
TEMPERATURE	Scalar	K	solid/wall
HTC	Scalar	$W/(m^2\ K)$	wall
SURFACE_HEAT_FLUX	Scalar	W/m^2	wall
PRESSURE	Scalar	N/m^2	wall
RELATIVE_PRESSURE	Scalar	N/m^2	wall

5.8 FloTHERM

MpCCI FSIMapper supports reading of FloTHERM export format .flofea available in version 10 for static simulation results.

5.8.1 Supported Quantities

Quantity	Dim.	Default Unit	Location
TEMPERATURE	Scalar	C	solid

5.8.2 Combining Static Result Files

MpCCI FSIMapper supports the combination of several static FloTHERM result files of the same geometry by creating a tabular master input file. To assign the individual time step information per *.flofea result file, a comma separated two-column format is used. The master *.csv file has to be located in the same folder to address the individual time step location. The following example shows the master file structure for a mapping setup with four different time step results.

```
#comment line
#time value, file name
 0.0, result_at_0.0.flofea
 5.0, result_at_5.0.flofea
10.0, result_at_10.0.flofea
20.0, result_at_20.0.flofea
```

5.9 FLUENT

MpCCI FSIMapper supports reading of FLUENT native .cas (geometry) and .dat (solution result) files for static simulation results. In general .cas and .dat files between FLUENT version 6.3.26 and version 20.1.x are supported and more recent versions should be compatible if native file format does not change.
FLUENT CFF files (.h5) are supported from FLUENT 20.0.

Only zone types “wall” and “fluid” can be coupled with MpCCI FSIMapper.

5.9.1 Supported Quantities

Quantity	Dim.	Default Unit	Location	Comments
TEMPERATURE	Scalar	K	fluid	
FILMTEMPERATURE	Scalar	K	wall	
HTC (computed)	Scalar	$W/(m^2\ K)$	wall	$\alpha = q/(T_w - T_c)$
wallfuncHTC	Scalar	$W/(m^2\ K)$	wall	stored in UDM0
WALLHEATFLUX	Scalar	W/m^2	wall	
STATICPRESSURE	Scalar	N/m^2	wall	
ABSPRESSURE	Scalar	N/m^2	wall	STATICPRESSURE + operating pressure
OVERPRESSURE	Scalar	N/m^2	wall	STATICPRESSURE + operating pressure - reference pressure
WALLFORCE	VECTOR	N	wall	ABSPRESSURE + SHEARFORCE
RELATIVEWALLFORCE_STATIC	VECTOR	N	wall	STATICPRESSURE + SHEARFORCE
RELATIVEWALLFORCE_OVER	VECTOR	N	wall	OVERPRESSURE + SHEARFORCE

5.9.2 Exporting wallfuncHTC to UDM0 in Data File

For a surface heat transfer analysis "FILMTEMPERATURE" as well as the wall heat transfer coefficient need to be mapped onto a CSM model. The latter, defined as

$$\alpha = \frac{Q}{A\Delta T}$$

where

- Q = heat flow, J/s = W
- α = heat transfer coefficient, $W/(m^2K)$
- A = heat transfer surface area, m^2
- ΔT = difference in temperature between the solid surface and surrounding fluid area, K.

It can be displayed in the FLUENT GUI Display/Graphics and Animations/Contours/Set Up/Wall Fluxes.. /Wall Func. Heat Tran. Coef.. By default the wall heat transfer coefficient is not stored to a FLUENT data (.dat) file but can be added by following the steps:

1. Define/User-Defined/Memory:
   Set number to 1
2. Define/Custom-Field-Function:
   Select "wallfuncHTC" below "Wall Fluxes".
   Accept by 'Define'.
3. Solve/Initialization/Patch:
   Activate "Use Field Function" and select defined custom field function from previous step.
   Select all fluids and solids as well as "Variable User Memory 0" at bottom left side.
   Select "Patch".
4. Case/Data:
   Save HTC to new .dat file.

5.10 JMAG

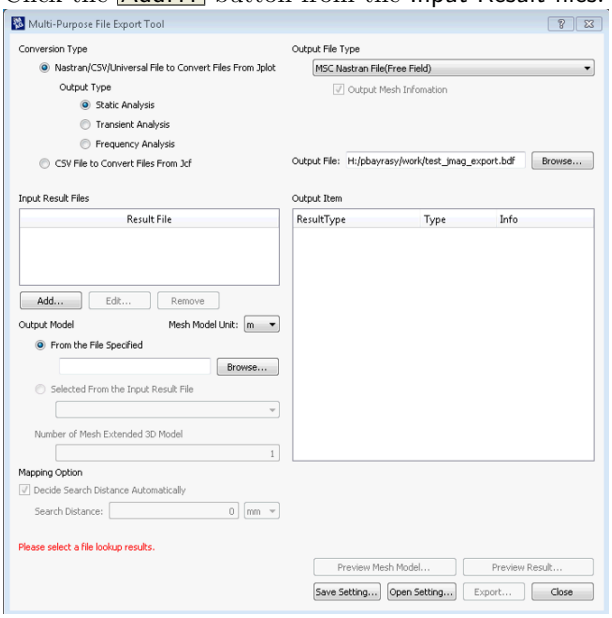
MpCCI FSIMapper supports reading of JMAG export format MSC NASTRAN .bdf available from the Multi-Purpose File Export Tool. This tool requires the JMAG results file `"*.jplot"` for the export process.

5.10.1 Limitations

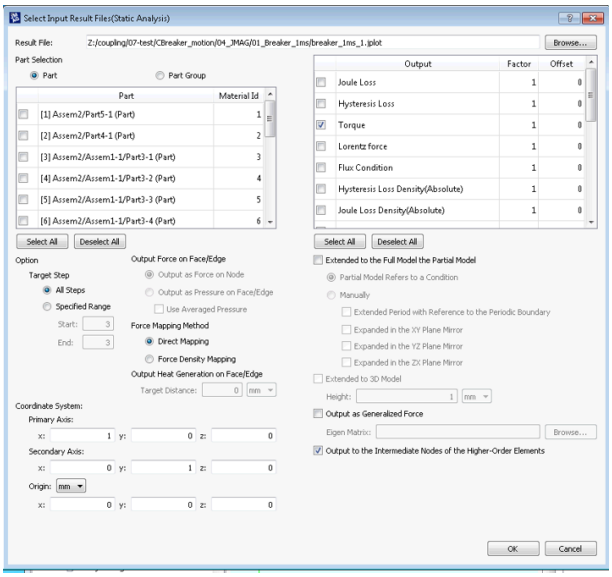
- The Multi-Purpose File Export Tool is only available from JMAG Designer on Windows platform. The access to the tool is provided under the menu Tool → Multi-Purpose File Export Tool...
- Please check the restrictions on the MSC NASTRAN format for reading the data. MpCCI FSIMapper supports force and heat source definition from MSC NASTRAN format (▷ 5.13 MSC NASTRAN ◁).
- Output type is a Static Analysis from JMAG.

5.10.2 Exporting JMAG Data to MSC NASTRAN Format With Multi-Purpose Export

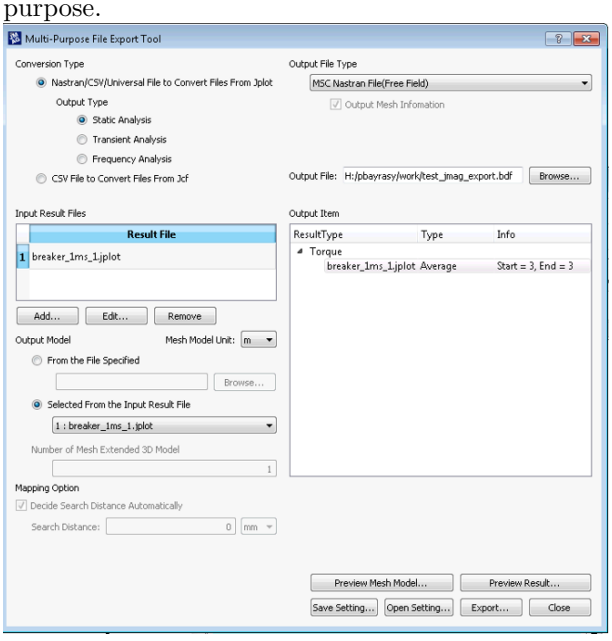
1. Open the Multi-Purpose File Export Tool dialog.
2. Select Conversion Type to Nastran/CSV/Universal File to Convert Files From Jplot.
3. Select Output File Type to MSC Nastran File(Free Field)
4. Provide the output file name in the Output File field.
5. Click the Add... button from the Input Result files.



6. The next dialog to select the JMAG result file is opening. Pick up the `"jplot"` file with the Browse.



7. Check the parts you want to export the values from in the optionPart selection.
8. Select the output value you want to export from the model.
9. Close this dialog on pressing OK.
10. Back to the main dialog, select under Output Model the Selected From the Input Result File in the droplist.
11. Finish by clicking on Export... button.
12. The exported file is used as source file in MpCCI FSIMapper. Select the MSC NASTRAN code for this purpose.



5.11 LS-Dyna

MpCCI FSIMapper supports code LS-Dyna as mapping target using it's ASCII keyword data format.

5.11.1 Limitations

The structural code LS-Dyna is only available for "Static" or "Transient" applications. On "Harmonic" source panel, the code will not be available in the target code dropdown menu. The quantity TEMPERATURE can be transferred to either solid or shell elements, PRESSURE and FORCES can only be used on shell elements. If PRESSURE or FORCES shall be transferred onto a solid model, it is required to define additional shell elements on solid outer surface.

5.11.2 Elements

LS-Dyna	MpCCI FSIMapper
3 node shell elements	3D_SHELL_TRIA3
4 node shell elements	3D_SHELL_QUAD4
4 node solid elements	3D_VOL_TETRA4
6 node solid elements	3D_VOL_WEDGE6
8 node solid elements	3D_VOL_HEXA8

Table 7: Supported LS-Dyna elements.

5.11.3 Supported Quantities

Quantity	Dim.	Default Unit	Element	LS-Dyna Keyword
TEMPERATURE (static, transient)	Scalar	θ	Shell Volume	*INITIAL_TEMPERATURE_NODE *LOAD_THERMAL_VARIABLE_NODE *DEFINE_CURVE
PRESSURE (static, transient)	Scalar	$ML^{-1}T^{-2}$	Shell	*LOAD_SHELL_ELEMENT *DEFINE_CURVE
PRESSURE (frequency)	Scalar	$ML^{-1}T^{-2}$	Shell	*DATABASE_FREQUENCY_BINARY_D3SSD *FREQUENCY_DOMAIN_SSD *DEFINE_CURVE
FORCE (static, transient)	Vector	MLT^{-2}	Shell	*LOAD_NODE_POINT *DEFINE_CURVE
FORCE (frequency)	Vector	MLT^{-2}	Shell	*DATABASE_FREQUENCY_BINARY_D3SSD *FREQUENCY_DOMAIN_SSD *DEFINE_CURVE

Table 8: Mapping variables overview with used LS-Dyna keywords.

5.11.4 Include Boundary Conditions

To use the mapped quantity values as boundary conditions in an LS-Dyna CSM simulation a separate LS-Dyna input file is written for each boundary condition. This file, which is saved in the model directory, can be included in the original LS-Dyna input deck using the simple LS-Dyna include option in the input deck.

To include a mapped result file use the statement

TEMPERATURE static	`*include lsdynaFile-mapped_Temperature.inc`
TEMPERATURE transient	`*include lsdynaFile-mapped_Transient_Temperature.inc`
PRESSURE static	`*include lsdynaFile-mapped_Pressure.inc`
PRESSURE transient	`*include lsdynaFile-mapped_Transient_Pressure.inc`
PRESSURE frequency	`*include lsdynaFile-mapped_FreqRespPressure.inc`
FORCE static	`*include lsdynaFile-mapped_Forces.inc`
FORCE transient	`*include lsdynaFile-mapped_Transient_Forces.inc`
FORCE frequency	`*include lsdynaFile-mapped_FreqRespForce.inc`

5.12 MagNet

MpCCI FSIMapper supports reading of MagNet export format .vtk available from version 7.5.1 for static and transient simulation results. Multiple components are written to distinct .vtk files which can be inputted to MpCCI FSIMapper by multi selection. Mapping of static and transient data is possible.

5.12.1 Limitations

Currently only stationary components can be considered for mapping in both static and transient analyses.

5.12.2 Elements

MpCCI FSIMapper	VTK Element Type
3D_SURF_TRIA3	5
3D_SURF_TRIA6	22
3D_SURF_QUAD4	9
3D_SURF_QUAD8	23
2D_SURF_LINE2	3
2D_SURF_LINE3	21

Table 9: Supported MagNet (.vtk) structural elements.

5.12.3 Supported Quantities

Quantity	Dim.	Default Unit	Location	Comments
SFD	Vector	N/m^2	wall	Surface Force Density

5.13 MSC NASTRAN

5.13.1 Limitations

Writing As boundary conditions for a CSM simulation with Nastran temperature, pressure or force values can be exported. For temperature values the keywords `TEMP` or `SPC` are used and the quantity values

are mapped to and written on nodes. The keywords PLOAD, PLOAD2 and PLOAD4 are used for the export of element-based pressure values (see also ▷4.5.3 MSC NASTRAN Export Options◁). Forces from a static mapping are exported using the keywords FORCE, a transient mapping uses the keywords TSTEP, TLOAD1, DAREA and TABLED1. When a Fourier transformation has been performed on transient data, then the keywords FREQ, RLOAD1, RLOAD2,DAREA and TABLED1 are used.

The Nastran mesh has to consist of shell elements for exporting pressure in the PLOAD* format.
The Nastran mesh has to consist of shell elements for exporting force.
The Nastran mesh has to consist of shell or solid elements for exporting temperatures in TEMP or SPC format.

When analysing solid MSC NASTRAN models with surface loads and MpCCI FSIMapper can handle only shell elements, create a shell mesh at the coupled surface using the same grids as the solid model. Use this model for the mapping process.

Reading Moreover, MpCCI FSIMapper supports reading of MSC NASTRAN files in bulk data format. For static simulation results the following quantities (with keywords) are supported: temperature (TEMP and TEMP*), pressure (PLOAD2 and PLOAD2* (single element per line assumed), PLOAD4 and PLOAD4* (assuming a constant value per element)), force (FORCE and FORCE* (ignoring the coordinate system identification number)) and heat source (QVOL and QVOL*).
For transient results, only force is supported (defined by the keywords TLOAD1 (ignoring the delay), DAREA, TABLED1 or their corresponding long formats).

5.13.2 Include Boundary Conditions

To use the mapped quantity values as boundary conditions in an MSC NASTRAN CSM simulation a separate MSC NASTRAN input file is written for each boundary condition. This file, which is saved in the model directory, can be included in the original MSC NASTRAN input deck using the simple MSC NASTRAN include option in the input deck.
The file extension of the exported include files is the same as of the target mesh file. Here, the Bulk Data Entries are shown for .bdf. Include a mapped temperature using the TEMP keyword by:

```
INCLUDE 'nastranFile-mapped_Temp.bdf'
```

Include a mapped temperature using the SPC keyword by:

```
INCLUDE 'nastranFile-mapped_Temperature_SPC.bdf'
```

Include a mapped pressure field by:

```
INCLUDE 'nastranFile-mapped_Pressure.bdf'
```

Include a mapped transient pressure field by:

```
INCLUDE 'nastranFile-mapped_TransientPressure.bdf'
```

Include a mapped transient pressure field which was Fourier transformed by:

```
*INCLUDE, INPUT="nastranFile-mapped_FreqRespPressure.bdf"
```

Include a mapped harmonic pressure field by:

```
*INCLUDE, INPUT="abaqusFile-mapped_HarmonicPressure.bdf"
```

Include a mapped force field by:

```
INCLUDE 'nastranFile-mapped_Force.bdf'
```

Include a mapped transient force field by:

```
INCLUDE 'nastranFile-mapped_TransientForce.bdf'
```

Include a mapped transient force field which was Fourier transformed by:

```
INCLUDE 'nastranFile-mapped_FreqRespForce.bdf'
```

To make sure that the values can be used for an MSC NASTRAN analysis, the include has to be placed between the BEGIN BULK and ENDDATA keywords.

The set identification numbers (MSC NASTRAN `SID` of Bulk Data Entry) defined by MpCCI FSIMapper have to be referenced in the Case Control Commands of the MSC NASTRAN analysis deck. Please refer to the MSC NASTRAN keyword reference manual for a detailed use.

5.13.3 Elements

MSC NASTRAN	MpCCI FSIMapper
CTRIA3	3D_SHELL_TRIA3
CTRIA6	3D_SHELL_TRIA6
CQUAD4	3D_SHELL_QUAD4
CQUAD8	3D_SHELL_QUAD8
CQUAD	3D_SHELL_QUAD9
CTETRA	3D_VOL_TET4/10
CHEXA	3D_VOL_HEX8/20
CPENTA	3D_VOL_WEDGE6

Table 10: Supported MSC NASTRAN structural elements.

5.13.4 Supported Quantities

Quantity	Dim.	Default Unit	Location	MSC NASTRAN Keyword
(FILM)TEMPERATURE	Scalar	θ	Shell/Volume	TEMP SPC
PRESSURE	Scalar	$ML^{-1}T^{-2}$	Shell	PLOAD PLOAD2 PLOAD4 RLOAD1 RLOAD2
FORCE	Vector	MLT^{-2}	Node	FORCE TLOAD1 RLOAD1 RLOAD2

5.14 VMAP

VMAP is an open and free standard www.vmap.eu.com for the transfer of information between simulations within a process chain, no matter what software is used to carry these out. This provides engineers with a fast solution to pass information from one calculation to another without needing to create one-off interfaces.

VMAP provides a detailed and well-defined open-source standard, accompanied by a software library of input/output tools to read/write the VMAP data files and enable fast development of transfer operations between different software packages. Many software companies and suppliers have included, or are working on including, VMAP into their tools.

The VMAP format is currently available in MpCCI FSIMapper for "static" mapping applications. As VMAP is a neutral file format, the assigment of variables can be done via name selection in the variables drop down menu.

5.15 6SigmaET

6SigmaET is an electronics thermal modeling tool. MpCCI FSIMapper supports reading of both “static” and “transient” simulation results. For “static” use case VTK legacy *.vtk and *.vtm format is supported, “transient” *.vtm and *.ptu forat is available for reading. Variables TEMPERATURE and PRESSURE can be imported on surface or volume meshes.

6 Batch Usage of the MpCCI FSIMapper

The MpCCI FSIMapper can also be used as a batch tool. All functionalities of the graphical user interface are also available in the batch version.

The basic MpCCI FSIMapper is an executable that needs several arguments for execution: the file names of the source and the target models and a configuration file where all necessary mapping parameters are set (see ▷ 3 MpCCI FSIMapper Command ◁). A detailed description of the configuration file format can be found in ▷ 6.5 Configuration File ◁.

To find the relevant parts of the models for the interface file scanners for FLUENT, Abaqus, ANSYS, FloTHERM, FloEFD and EnSight Gold are part of the MpCCI FSIMapper. These perl modules list all found parts and the assigned ids.

6.1 File Scanners

The MpCCI FSIMapper uses a configuration file to decide which quantities to map between which geometry parts. All geometry parts of a model can be addressed by ids, which can be identified by the file scanners. The user has to enter the relevant ids for the CFD and the FEA mesh into the configuration file.

For a thermal mapping case usually only the ids for the interface between the fluid and solid domain will be entered in the configuration file. The rest of the geometry does not need to be read by the MpCCI FSIMapper. Depending on the type of application the user can decide which geometry parts are to be read by the MpCCI FSIMapper.

To get the ids of the geometry parts, solver files can be scanned by perl modules that are part of the MpCCI FSIMapper package. The only requirement is a running perl installation with its executables in the system PATH variable. All file scanners – for FLUENT, Abaqus, ANSYS, FloTHERM, FloEFD, EnSight Gold, CFX and FINE/Turbo– can be called via the command line:

```
> fsimapper scan FLUENT  file_name.cas
> fsimapper scan ABAQUS  file_name.inp
> fsimapper scan ANSYS   file_name.ml
> fsimapper scan ENSIGHT file_name.case
> fsimapper scan FLOEFDMAPLIB file_name.efdfea
> fsimapper scan FLOTHERMMAPLIB file_name.flofea
> fsimapper scan FINETURBO file_name.cgns
> fsimapper scan CFXCSV file_name.csv
```

MpCCI FSIMapper does not allow scanning of native ANSYS solver formats directly but of converted .ml files generated by “fsimapper convert ANSYS” (▷ 5.2.4 ANSYS Scanner and Converter ◁).

6.1.1 FLUENT

The FLUENT scanner lists all zones that are defined in the .cas file. The names of the zones are listed, as well as the zone type and the zone id. The type of the zones is important to find the parts of the model that form the interface between the fluid and the structural domain.

Usually, the zones of type “wall” are to be considered for the MpCCI FSIMapper. The zone id is used in the configuration file to identify the part of the model from which quantity values shall be mapped to the CSM model.

The format of the output is the following:

```
   Zonename        Zonetype              ZoneID
```

6.1.1.1 Example

As an example the output of the FLUENT scanner for a simple case file "exampleFluent.cas" is shown below.

```
> fsimapper scan FLUENT ./exampleFluent.cas
<CPLDATA>
# This file was automatically created for the MpCCI GUI.
#@ Code: "FLUENT"
#@ Scan: ".../MpCCI/codes/FLUENT/Scanner.pm"
#@ File: "exampleFluent.cas"
#@ Path: "..."
#@ Date: "..."
#@ User: "..."
#@ Host: "..."
#
# MpCCI relevant information:
#   Model dimensions  : 3D
#   Coordinate system : Cartesian
#   Solution type     : Steady state
#   Load cases        : 1
#   Unit system       : SI
#   Precision         : Double precision (64 bit)
#
# Additional scanner information:
#   Global variables  : Autogenerated by the scanner
#   Release           : 13.0.0
#   Saved by          : fluent
#   Used UDM          : 0
#   Used UDS          : 0
#   Version           : 3ddp
#
   fluid_1                  fluid                     7
   wall_1                   wall                     64
   interior_1               interior                 78
   interface_1              interface                79
</CPLDATA>
```

This FLUENT model consists of four different zones: one of each of the four types "fluid", "wall", "interior" and "interface". The zone with the name `wall_1` of type "wall" has the id 64. If we now want to couple `wall_1` we have to add the following lines to the configuration file (▷ 6.5 Configuration File ◁) defining FLUENT as source file format and part 64 to be read:

```
sourceFileType
FLUENT
sourceMeshPartIds
64
```

For the mapping of quantity data usually the zones of type "wall" are of interest, as the interface between

the CFD and FEA domains is normally a wall boundary in the CFD model.

For large FLUENT models and Linux machines it might be helpful to only list the wall zones of the model:
`> fsimapper scan FLUENT ./exampleFluent.cas | grep wall`
This gives a clearer overview of the possible interfaces without listing all interior or fluid zones.

6.1.2 MentorGraphics

In cooperation Fraunhofer SCAI and MentorGraphics have developed a neutral file format allowing export of FloEFD and FloTHERM simulation results for mapping to a CSM code.

6.1.3 FloEFD

The scanner for FloEFD export files can be selected by its name `FLOEFDMAPLIB` in the generic MpCCI FSIMapper scan command, e.g.

```
> fsimapper scan FLOEFDMAPLIB file_name.efdfea
```

The resulting output of the scanner has a simple tabular format with just the keywords MESH, PART or QUANT. MESH assigns the name of the model to be read in. PART specifies 'S' or 'V', if it is a surface or a volume, the part name as well as two integers specifying the total number of nodes and elements of the part. Parts are implicitly numbered by their order of appearance starting at index 1. Keyword QUANT announces a quantity followed by its name, location of the values, the number of values and the file position of the quantity.

6.1.3.1 Example

```
> fsimapper scan FLOEFDMAPLIB ./Plate.efdfea
MESH EFD_MESH
PART   S   Surface-1    302     600
PART   V   Volume-1     390     216
QUANT RELATIVE_PRESSURE ELEM   816      54917
QUANT PRESSURE          ELEM   816      58198
QUANT SURFACE_HEAT_FLUX ELEM   816      61470
QUANT TEMPERATURE       ELEM   816      64751
QUANT HTC               ELEM   816      68026
```

One surface (`Surface-1`) addressed by 'S' and id 1 and one volume (`Volume-1`) addressed by 'V' and with id 2 are defined in this FloEFD model. In addition FloEFD file does contain a list of element based quantities, e.g. RELATIVE_PRESSURE, PRESSURE, SURFACE_HEAT_FLUX, TEMPERATURE and HTC, which can be read from file.

Parts to be mapped can be selected by its ids separated by whitespace in the configuration file. In this example we now want to couple the volume part and therefore have to add the following lines to the configuration file:

```
sourceFileType
FLOEFDMAPLIB
sourceMeshPartIds
2
```

A mapping of the surface `Surface-1` would require to add

```
sourceFileType
FLOEFDMAPLIB
sourceMeshPartIds
1
```

to configuration file.

6.1.4 FloTHERM

The scanner for FloTHERM export files can be selected by its name `FLOTHERMMAPLIB` in the generic MpCCI FSIMapper scan command, e.g.

```
> fsimapper scan FLOTHERMMAPLIB file_name.flofea
```

The resulting output of the scanner has a simple tabular format with just the keywords MESH, PART or QUANT. MESH assigns the name of the model to be read in. PART specifies 'S' or 'V', if it is a surface or a volume, the part name as well as two integers specifying the total number of nodes and elements of the part. Parts are implicitly numbered by their order of appearance starting at index 1. Keyword QUANT announces a quantity followed by its name, location of the values, the number of values and the file position of the quantity.

6.1.4.1 Example

```
> fsimapper scan FLOTHERMMAPLIB ./BGA_detailed.flofea
MESH Root_Assembly
PART   V   encapsulant          7168      5766
PART   V   die                  1200       722
PART   V   solder_ball_1_1        20         4
PART   V   solder_ball_1_2        20         4
QUANT TEMPERATURE ELEM          39475   2966255
```

In this example four volumes are addressed by 'V', they have the ids 1,2,3 and 4. In addition FloTHERM file does contain element based TEMPERATURE which can be read from file. One or more ids can be entered separated by whitespaces in the configuration file to obtain mapped quantity values.
In this example we now want to couple all volume parts of the model and therefore have to add the following lines to the configuration file:

```
sourceFileType
FLOTHERMMAPLIB
sourceMeshPartIds
1 2 3 4
```

6.1.5 ANSYS

The MpCCI FSIMapper scanner for ANSYS does not work with native solver files so that original `".cdb"` and `".db"` files need to be converted with `fsimapper convert ANSYS model.db` (see ▷ 5.2.4 ANSYS Scanner and Converter ◁ for details) producing intermediate .ml format related to FloTHERM and FloEFD format described in ▷ 6.1.4 FloTHERM ◁ and ▷ 6.1.3 FloEFD ◁.

Please note ANSYS requirements and model preparation section of ▷ 5.2 ANSYS ◁.

The scanner for ANSYS export files can be selected by its name `ANSYS` in the generic MpCCI FSIMapper scan command, e.g.

```
> fsimapper scan ANSYS file_name.ml
```

The resulting output of the scanner has a simple tabular format with just the keywords MESH or PART. MESH assigns the name of the model to be read in. PART specifies 'S' or 'V', if it is a surface or a volume, the part name as well as two integers specifying the total number of nodes and elements of the part. Parts are implicitly numbered by their order of appearance starting at index 1.

6.1.5.1 Example

```
> fsimapper scan ANSYS ./plate.ml
MESH ANSYSDB2MAPLIB
PART   S   SHELLS__     5802    11600
PART   V   SOLIDS__     15565   76037
```

One shell or surface part (`SHELLS__`) addressed by 'S' and id 1 and one solid part (`SOLIDS__`) addressed by 'V' and with id 2 are defined in this ANSYS model.

A mapping of the surface component `SHELLS__` would require to add

```
targetFileType
ANSYS
targetMeshPartIds
1
```

of the solid component `SOLIDS__` would require to add

```
targetFileType
ANSYS
targetMeshPartIds
2
```

to the configuration file.

6.1.6 Abaqus

The part of the Abaqus model on which the quantity values are going to be mapped, has to be defined as a surface (with the keyword `*SURFACE` in the input deck) or in case of solid temperature mapping as a seperate element set (`*ELSET`) in the Abaqus model.

The Abaqus file scanner will list all defined elsets and surfaces found in the Abaqus input deck and assign unique positive ids for surfaces and negative ids for elsets.

For the MpCCI FSIMapper surfaces or elsets to be mapped need to be addressed in the configuration file.

Please see the following example in ▷ 6.1.6.1 Example ◁ how to determine a correct surface or elset id for a given input deck.

If the scanned .inp file contains *INCLUDE directives for other parts of the Abaqus model stored in separate .inp files, the scanner also lists all surfaces found in the included input decks due to their appearance in the file flow.

6.1.6.1 Example

As an example the output of the Abaqus scanner for a simple input file "exampleAbaqus.inp" is shown below.

```
> fsimapper scan ABAQUS exampleAbaqus.inp
[FSIMapper] SET-1               elset    -1
[FSIMapper] SET-2               elset    -2
[FSIMapper] FLAP_SLAVE          surface   0
[FSIMapper] WALL_MASTER         surface   1
[FSIMapper] COUPLING_SURFACE    surface   2
```

Three surfaces (`FLAP_SLAVE`, `WALL_MASTER` and `COUPLING_SURFACE`) addressed by the global ids 0, 1 and 2 and two elsets (`SET-1` and `SET-2`) with ids -1 and -2 are defined in this Abaqus model.

One or more ids can be entered separated by whitespace in the configuration file to obtain mapped quantity values on the surfaces or elsets.
In this example we now want to couple the last surface for an Abaqus target model and therefore have to add the following lines to the configuration file:

```
targetFileType
ABAQUS
targetMeshPartIds
2
```

A mapping of temperature on elset `SET-1` would require to add

```
targetFileType
ABAQUS
targetMeshPartIds
-1
```

to the configuration file.

MpCCI FSIMapper does not support mixing elset and surface ids in targetMeshPartIds, e.g. a target model can either be defined by surface ids or elset ids.

6.1.7 EnSight Gold Case

The EnSight Gold Case scanner lists all scalar variables which are defined in the given .case file. At present the MpCCI FSIMapper reads all defined surfaces and volume parts together with user selected quantities. As in EnSight Gold Case format the quantity names may vary but denote the same physical meaning, the user has to select the quantities of interest by its name. The scanner process is split up into two steps. At first the given Case master file is scanned for available scalar quantities followed by geometric scan process which identifies and lists the part structures of containing geometries.

6.1.7.1 Example

As an example the output of the EnSight Gold Case scanner for a simple case file "exampleEnSight.case" is shown below.

```
> fsimapper scan ENSIGHT exampleEnSight.case
<CPLDATA>
# This file was automatically created for the MpCCI GUI.
```

```
#@ Code: "EnSight"
#@ Scan: "1"
#@ File: "exampleEnSight.case"
#@ Path: "..."
#@ Date: "..."
#@ User: "..."
#@ Host: "..."
#
# MpCCI relevant information:
#   Model dimensions  : unknown
#   Coordinate system : unknown
#   Solution type     : unknown
#   Load cases        : unknown
#   Unit system       : unknown
#   Precision         : unknown
#
   Total_Temperature        SCALAR     1
</CPLDATA>
<CPLDATA>
#@ Code: "EnSight"
#@ File: "exampleEnSight.case"
#@ Path: "..."
wall_1          S       2
inlet           S       3
wall_2          S       4
flexible_pin    S       5
outlet          S       6
Region_1        V       1
</CPLDATA>
```

The first “CPLDATA” block lists all defined scalar variables by name, the second block lists available volumetric ’V’ and surface ’S’ parts which can be used with MpCCI FSIMapper. To inform the MpCCI FSIMapper to handle variable “Total_Temperature” as physical temperature quantity, the user has to select it by name in the GUI or add

```
EXPORT_1002_TEMPERATURE
Total_Temperature
```

to the configuration file when using batch mode. Currently supported keywords in the MpCCI FSIMapper configuration file are:

```
EXPORT_1002_TEMPERATURE
Name_Of_Temperature
EXPORT_1003_WALLHTCOEFF
Name_Of_Heat_Transfer_Coefficient
EXPORT_1004_WALLHEATFLUX
Name_Of_Heat_Flux
EXPORT_1010_PRESSURE
Name_Of_Pressure
```

As the EnSight Gold Case reader can be used as source or target model we additionally have to add

```
sourceFileType
ENSIGHTGOLD
```

to the MpCCI FSIMapper configuration file if the case EnSight is used as source format

```
targetFileType
ENSIGHTGOLD
```

otherwise.

6.2 Comparing Geometries

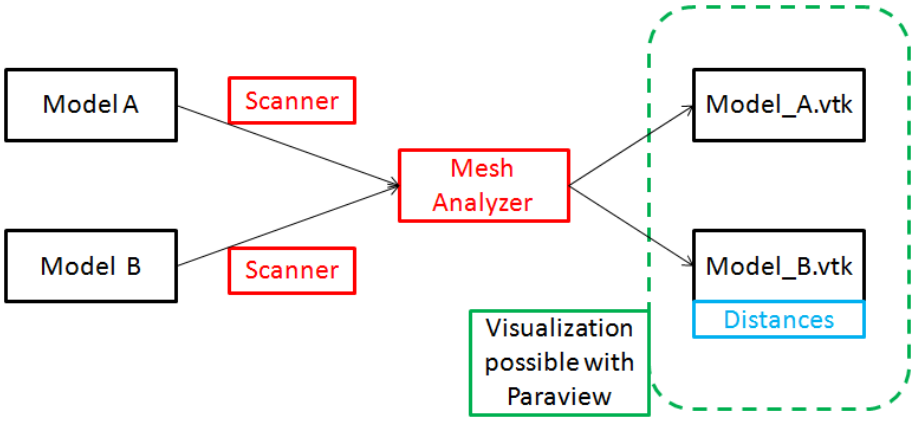


Figure 17: The workflow of the MpCCI FSIMapper in batch usage when comparing two geometries

It is possible to use the MpCCI FSIMapper to compare two geometries defined in two model files `source` and `target`.

For the comparison of geometries the nodal distance as well as the association distance are computed. As can be seen in Figure 17 these distances are written to the .vtk file containing the target geometry.

For each node of the target mesh the nodal distance is the distance to the nearest point of the source mesh. The association distance is the distance between the point of the target mesh and the closest (associated) element of the source mesh. If the point lies "in" a source element, this would mean that the association distance is 0.

If the MpCCI FSIMapper is used to compare two geometries rather than map actual quantity values, this has to be set in the configuration file via the option sourceQuantityMode or targetQuantityMode (one of them is sufficient):

```
sourceQuantityMode
GEOMETRYCOMPARE
```
or
```
targetQuantityMode
GEOMETRYCOMPARE
```

Furthermore, the configuration file needs to contain all relevant information about the source and target file types, units and part ids. More information concerning these parameters is given in ▷ 6.5 Configuration File ◁, that gives an introduction to the MpCCI FSIMapper configuration file. The ids for the different mesh parts can be obtained by the respective mesh scanners.

With the appropriate configuration file the MpCCI FSIMapper can now be started by the command line:
`> fsimapper batch configFile source target`
(see ▷ 3 MpCCI FSIMapper Command ◁)

6.3 Mapping Quantities

The mapping of quantity values can be done with the same command line call as the comparison of geometries:

```
> fsimapper batch configFile source [source_quant] target
```

The configuration file contains all relevant parameters that are necessary for the mapping process. The different keywords and values are described in ▷6.5 Configuration File◁.

The quantity file `source_quant` is an optional argument. It is necessary if the names of the model and quantity files are not the same, for example if the FLUENT.cas and .dat files do not have the same base name.

The MpCCI FSIMapper will print some output to the console while the mapping is in progress. After the mapping the result files can be found in the working directory.

6.4 Files Written by the MpCCI FSIMapper

As mentioned before MpCCI FSIMapper exports

- mapped quantities as input files for CSM codes and
- both source and target meshes as .vtk files.

The results with the mapped quantities can be used for an Abaqus (▷5.1 Abaqus ◁), ANSYS or MSC NASTRAN (▷5.13 MSC NASTRAN ◁) analysis.

Files in the open source format .vtk can be visualized by the open source viewer "Paraview" (www.paraview.org). Each of the two files (named for example "abaqus-mapped.vtk" and "fluent.vtk") contains the mesh definition as well as the original or mapped quantity data respectively. For the most common case of thermal mapping from e.g. FLUENT to Abaqus this means, that the FLUENT file contains the temperature, film temperature and wall heat flux values while the Abaqus file holds the mapped values of the film temperature and the wall heat coefficient.

6.5 Configuration File

The configuration file contains all parameters about file formats, geometry parts, quantities and mapping or orphan filling algorithms that define the complete process. The file is in a simple ASCII format. Different keywords define certain parameters. In the line following the keyword the respective value for the keyword is given. Lines starting with a "#" sign will be ignored.

```
#Example of configuration format structure
keyword_1
value
keyword_2
value
keyword_3
value_1 value_2 ... value_n
```

Information about the geometry or quantities have to be given for the source and the target models respectively.

Several different units are supported. Length, time, mass and temperature units can be specified for the source and the target model. The unit of pressure is expected to fit to the given mass, length and time units: Pa $= \frac{\text{kg}}{\text{m s}^2}$, for example, would be the matching pressure unit to kg, m and s. If the two models use different units all necessary conversions are done by the MpCCI FSIMapper.

Minimum required configuration file parameters:

```
#define source format type
sourceFileType

#define target format type
targetFileType

#define quantity mode for mapping
sourceQuantityMode

#define source parts
sourceMeshPartIds
id_1 ... id_n
#define target parts
targetMeshPartIds
id_1 ... id_m
#use default mapping algorithm and parameters
optionUseNeighborhoodDefaultParameters
true
```

All possible keywords and values are listed in the following table.

Keyword	**Value**
sourceFileType	FLUENT → Code FLUENT FLOTHERMMAPLIB → Code FloTHERM FLOEFDMAPLIB → Code FloEFD ENSIGHTGOLD → EnSight Case Gold
targetFileType	ABAQUS → Code Abaqus ANSYS → Code ANSYS NASTRAN → Code MSC NASTRAN ENSIGHTGOLD → EnSight Case Gold
sourceQuantityMode	ABSPRESSURE ⇒ Read and map pressure STATICPRESSURE ⇒ Read and map static pressure OVERPRESSURE ⇒ Read and map overpressure PRESSURETRANSIENT ⇒ Read and map transient pressure PRESSUREHARMONIC ⇒ Read and map harmonic pressure FILMTEMPHTC ⇒ Read and map surface film temperature and htc

	FILMTEMPUDM0 ⇒ Read and map surface film temperature and htc stored in UDM0 (only FLUENT) FILMTEMP ⇒ Read and map surface film temperature TEMPERATURE ⇒ Read and map volumetric temperature TEMPERATURETRANSIENT ⇒ Read and map transient temperature WALLHEATFLUX ⇒ Read and map surface heat flux FORCE ⇒ Read and map surface forces FORCETRANSIENT ⇒ Read and map transient surface forces FORCEHARMONIC ⇒ Read and map harmonic surface forces FORCEDENSITY ⇒ Read and map surface force density FORCEDENSITYTRANSIENT ⇒ Read and map transient surface force density GEOMETRYCOMPARE ⇒ Compare both geometries default: NONE
targetQuantityMode	GEOMETRYCOMPARE default: NONE
sourceMeshPartIds targetMeshPartIds	the zone ids of source and target mesh from the file scanner separated by whitespace
sourceMeshLengthUnit targetMeshLengthUnit	m, ft, in, cm or mm default: m
sourceTemperatureUnit targetTemperatureUnit	K or C default: K
sourceMeshMassUnit targetMeshMassUnit	kg, t or g default: kg
sourceMeshTimeUnit targetMeshTimeUnit	s or ms default: s
targetQuantityLocation	NODE, ELEMENT or DEFAULT default: DEFAULT = same location as source
optionMapAlgoType	type=shapefct type=weightedelement type=nearest type=conservative default: type=shapefct
optionUseNeighborhoodDefaultParameters	true or false default: false
optionNeighborhoodSearch	list of parameters [targetMeshLengthUnit unit] necessary for the neighborhood search: normaldistance, numberofnodes and radius
optionMultiplicity	value that increases neighborhood searching range default: 1

orphanFillType	type=distance type=average type=nearest type=none default: type=distance
fillOrphansValue	value that is assigned to orphaned nodes or elements. default: 0
optionComputeRotativeAverage	true or false default: false
rotationAngle	angle in angular degree
rotationAxisBeginPoint	x–, y– and z–coordinate of starting point separated by whitespace
rotationAxisEndPoint	x–, y– and z–coordinate of end point separated by whitespace
temperatureScaleValue	instead of several simulations with different temperatures it is also possible to scale temperature values by a certain factor e.g. having done a simulation with 500K and wanting to map a simulation with 600K the necessary scaling value would be 600/500 = 1.2
EXPORT_1002_TEMPERATURE	Assign the quantity name to be regarded as temperature
EXPORT_1003_WALLHTCOEFF	Assign the quantity name to be regarded as wall heat transfer coefficient
EXPORT_1004_WALLHEATFLUX	Assign the quantity name to be regarded as wall heat flux
EXPORT_1010_PRESSURE	Assign the quantity name to be regarded as pressure
EXPORT_1016_FORCE	Assign the quantity name to be regarded as force

A detailed description of the mapping algorithms and the concept of orphan filling can be found in ▷ 7.1 Numerical Methods ◁. The meaning of the parameters for the different mapping algorithms is also explained in this chapter in ▷ 7.1.2 Parameters for the Mapping ◁. The easiest solution for many applications might be to use the default parameters.

6.6 Example for a Configuration File

Here you find an example for an MpCCI FSIMapper configuration file. Lines starting with the "#" sign will be ignored. This example is a mapping from a FLUENT mesh (with unit system "m") to an Abaqus mesh (with unit system "mm").

The FLUENT film temperature (in K) is read from the .dat file. The temperature is written for an Abaqus simulation in ° C. The target quantity location is element–based and the shape function mapping algorithm is used with default parameters. The orphaned elements are going to be filled with 0.0. The optionComputeRotativeAverage keyword is set to false.

```
sourceFileType
```

```
FLUENT

targetFileType
ABAQUS

sourceQuantityMode
FILMTEMPHTC

targetQuantityMode
NONE

sourceMeshPartIds
136 146 114

targetMeshPartIds
1

sourceMeshLengthUnit
m

targetMeshLengthUnit
mm

sourceTemperatureUnit
K

targetTemperatureUnit
C

sourceMeshMassUnit
kg

targetMeshMassUnit
kg

sourceMeshTimeUnit
s

targetMeshTimeUnit
s

targetQuantityLocation  # location of quantities on Abaqus mesh
ELEMENT

# mapping algorithm type option
optionMapAlgoType       # mapping algorithm type option
type=shapefct

# neighborhood search options
optionUseNeighborhoodDefaultParameters
true
```

```
# fill orphans with a distance, average or nearest method
orphanFillType
type=distance

# fill-value for orphaned entities
fillOrphansValue
0.

optionComputeRotativeAverage
false

rotationAngle
30

rotationAxisBeginPoint
0 0 0

rotationAxisEndPoint
1 0 0

temperatureScaleValue
1.2
```

7 Theory Guide

7.1 Numerical Methods

7.1.1 Mapping Algorithms

The MpCCI FSIMapper currently offers three different algorithms to map quantity values between non-matching discretizations (see Figure 18). The distinctions and basic features of the mapping algorithms are:

Shape Function
Shape function mapping simply interpolates a field using the shape functions. It can map linear functions exactly if linear elements are used; respectively quadratic functions need quadratic elements (i. e. elements with mid-nodes) to be mapped exactly.

Weighted Element
Weighted element algorithm is designed to map element based values with quite small smoothing. It creates a relation between each target mesh node to a source mesh element and computes target element value by a distance weighted approach. Due to less smoothing it does recover higher gradients much better than the shape function approach.

Nearest
The nearest mapping is based on a very simple neighborhood search algorithm. Every node in the target mesh receives the average value of the k closest nodes in the source mesh. The number k of nodes to be searched is given to the searching algorithm as a parameter. Alternatively, the average values from nodes lying within a certain radius can be used. Since for every node the k closest nodes can be found – no matter how far away they are positioned – this mapping algorithm never produces any orphaned nodes.

Conservative
The conservative mapping is based on the nearest mapping algorithm and dedicated to integral quantities, e.g. forces. Every node in the target mesh receives a relative amount of the k closest nodes in the source mesh. Then, all unused nodes of source mesh distribute their information onto the k closest nodes of the target mesh.

Since for every node the k closest nodes can be found – no matter how far away they are positioned – this mapping algorithm never produces any orphaned nodes.

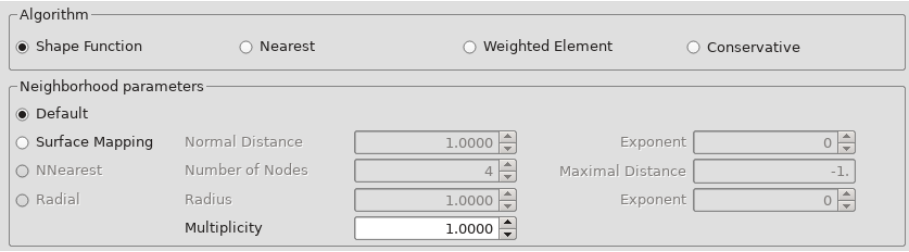


Figure 18: Mapping algorithms and parameters in MpCCI FSIMapper

7.1.2 Parameters for the Mapping

The mapping algorithms need different parameters to control the mapping process (see Figure 18).

According to the chosen mapping algorithm the following parameters need to be set:

Default

No further parameter values are needed. The MpCCI FSIMapper uses default values for the chosen algorithm. These values depend on the source and target discretizations. For many applications, where the distances between the two geometries is quite small, this should yield good mapping results.

SurfaceMapping – Normal Distance

The maximal distance which is still accepted in normal direction. This is needed for "Shape Function" and "Weighted Element".

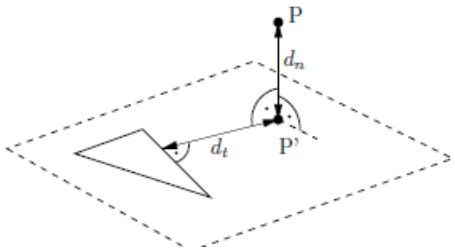


Figure 19: Normal distance d_n computation for element to node neighborhood used in shape function and weighted element mapping

A reasonable choice for the distance parameter might be

Normal Distance max(SourceMaxEdgeLength, TargetMaxEdgeLength)

NNearest – Number of Nodes

This parameter is only needed for the neighborhood search used by the "Nearest" mapping algorithm. It gives the number of close nodes that are searched for every target point in the source mesh. A sensible choice for this parameter is e. g. 4.

Radial – Radius

This parameter is only needed for the neighborhood search used by the "Nearest" mapping algorithm. As an alternative to the search for a certain number of close nodes, the specification of this parameter leads to a search for all source nodes lying in a circle around the target point with the given radius.

Conservative – Maximal Distance

This parameter is only needed for the neighborhood search used by the "Conservative" mapping algorithm. If the target model is only a subset of the source model, a conservative transfer of non-matching areas to the subset will lead to unwanted cummulation of loads. Thus, the maximal search distance of data transfer can be limited.

Multiplicity

This parameter is needed for "Shape Function" and "Weighted Element" mapping algorithms. There it is used for the iterative neighborhood search leading to a more robust algorithm. The default value is 1.0. If a bigger value is chosen by the user, the searching radius (distance up to which a point is still regarded as a neighbor) will be enlarged (doubled) step-by-step until the given multiplicity of the starting radius is reached.

These suggestions for parameter settings should work fine with well matching geometries.

The parameter `Normal Distance` is not needed for the "Nearest" mapping algorithm. If the quantity values are mapped using this algorithm only one of the two parameters `NNearest – Number of Nodes` or `Radial – Radius` needs to be given.

7.1.3 Orphan Filling

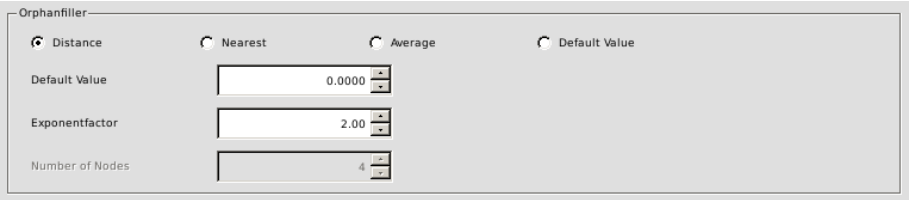


Figure 20: Methods and parameters for orphan filling in MpCCI FSIMapper

The MpCCI FSIMapper offers four different methods to fill the orphaned nodes or elements of a mesh. These are the nodes or elements of the target mesh, that did not receive any quantity values during the mapping process. This can happen if the two geometries do not match closely, e. g. if the target geometry contains model parts that are not present in the source geometry.

The easiest way to assign a value to the orphaned nodes is to define a constant "orphan fill value". Alternatively one of four available methods for orphan filling can be used. The distance filler can take an exponent value as an optional parameter.

During the filling process the orphan filler builds a "hole list". Most orphans will be located in one of these holes, but it is possible for orphans to not appear in the hole list. For example free floating orphaned regions of a mesh, that are not connected to any other part, do not form a hole because there are no border points from where values might be interpolated.

It is possible to hand one optional parameter to the distance type orphan filler. For all other fillers the specification of the type is all that is needed. The four different available orphan filling methods are:

Distance
: This orphan filler computes the distance to every border point for each orphaned node in a hole. The border values are then scaled with the reciprocal distance and added up for every orphan. One optional parameter can be handed to this filler: The `Exponentfactor`. This parameter determines to which power the distance - in the denominator - is taken. The default value for the `Exponentfactor` is 2.0, achieving a scaling with the square distance.

Nearest
: The `Nearest` orphan filler divides the target mesh by mapped and orphaned points or elements into two parts. It then uses a nearest search algorithm finding the by `Number of Nodes` specified number of closest mapped values for an orphan and computes the orphan value by a distances weighted averaging. The default value for `Number of Nodes` is 4.

Average
: This simple algorithm assigns the average quantity value of the border points to every orphan. The quantity therefore is constant on every hole.

Default Value
: All orphans are going to receive the specified orphan fill value.

7.2 Geometry and Quantity Transformations

7.2.1 Fourier Transformation and Windowing

The Fourier transformation of the discrete transient signal $(s(t_k))_{k=0}^{L-1}$ with L equidistant time steps of size τ results in frequency dependent complex data. The maximal frequency, which can be extracted from the signal is $F = 1/2\tau$. The size of the discrete frequency steps is determined by the reversed time period of s.

If the transient signal does not build a full period, Windowing is recommended. This feature multiplies the signal with a so-called window function w. The Fourier transformation is then applied to the signal $(s(t_k) \cdot w(k))_{k=0}^{L-1}$.

Several predefined window functions[1] are offered:

- **Hann**
$$w(k) = 0.5 - 0.5 \cdot \cos\left(\frac{2\pi k}{L-1}\right), \quad k = 0, \ldots, L-1$$
- **Hamming**
$$w(k) = 0.54 - 0.46 \cdot \cos\left(\frac{2\pi k}{L-1}\right), \quad k = 0, \ldots, L-1$$
- **Blackman**
$$w(k) = 0.42 - 0.5 \cdot \cos\left(\frac{2\pi k}{L-1}\right) + 0.08 \cdot \cos\left(\frac{4\pi k}{L-1}\right), \quad k = 0, \ldots, L-1$$
- **Blackman-Harris**
$$w(k) = a_0 - a_1 \cos\left(\frac{2\pi k}{L-1}\right) + a_2 \cos\left(\frac{4\pi k}{L-1}\right) - a_3 \cos\left(\frac{6\pi k}{L-1}\right), \quad k = 0, \ldots, L-1$$
with $a_0 = 0.35875, \quad a_1 = 0.48829, \quad a_2 = 0.14128, \quad a_3 = 0.01168.$
- **Blackman-Nuttall**
$$w(k) = a_0 - a_1 \cos\left(\frac{2\pi k}{L-1}\right) + a_2 \cos\left(\frac{4\pi k}{L-1}\right) - a_3 \cos\left(\frac{6\pi k}{L-1}\right), \quad k = 0, \ldots, L-1$$
with $a_0 = 0.3635819, \quad a_1 = 0.4891775, \quad a_2 = 0.1365995, \quad a_3 = 0.0106411.$
- **Barlett**
$$w(k) = \frac{2}{L-1} \cdot \left(\frac{L-1}{2} - \left|k - \frac{L-1}{2}\right|\right), \quad k = 0, \ldots, L-1$$
- **Barlett-Hann**
$$w(k) = 0.62 - 0.48 \cdot \left|\frac{k}{L-1} - 0.5\right| - 0.38 \cdot \cos\left(\frac{2\pi k}{L-1}\right), \quad k = 0, \ldots, L-1$$
- **Cosinus**
$$w(k) = \cos\left(\frac{\pi k}{L-1} - \frac{\pi}{2}\right), \quad k = 0, \ldots, L-1$$

[1] taken from `https://de.wikipedia.org/wiki/Fensterfunktion`, July 5, 2016

- **Tukey**

$$w(k) = \begin{cases} \frac{1}{2}\left[1 + \cos(\frac{2\pi k}{\alpha(L-1)} - \pi)\right], & \text{if} \quad 0 \le k \le \frac{\alpha(L-1)}{2} \\ 1, & \text{if} \quad \frac{\alpha(L-1)}{2} \le k \le (L-1)(1-\frac{\alpha}{2}) \\ \frac{1}{2}\left[1 + \cos(\frac{2\pi k}{\alpha(L-1)} - \pi(\frac{2}{\alpha} - 1))\right], & \text{if} \quad (L-1)(1-\frac{\alpha}{2}) \le k \le (L-1) \end{cases}$$

  with $\alpha = 0.5$.

- **Lanczos**

$$w(k) = \operatorname{sinc}\left(\frac{2k}{L-1} - 1\right), \quad k = 0, \ldots, L-1$$

The user can define his own window function as a one-columned file, where the L window function values $w(k),\ k = 0, \ldots, L-1$ are defined.

7.2.2 Cyclic Symmetry of Quantities

The mapping of quantities present on a cyclic symmetric source model to a full target model requires to build previously the corresponding full source mesh with data.

The (complex) data on cyclic symmetric models can exhibit a special periodicity, defined by the so-called (forward/backward) nodal diameter $ND \in \mathbb{N}, 0 \le ND \le \lfloor n/2 \rfloor$ (or cyclic symmetry mode).

It defines the temporal phase lag between the data of two neighboring sections as $\frac{2\pi \cdot ND}{n}$ (forward) or $\frac{-2\pi \cdot ND}{n}$ (backward). A nodal diameter 0 means that the data are the same on each section ("constant"). For an even number of cyclic symmetric sections, the nodal diameter $n/2$ indicates, that the data changes sign from section to section ("alternating"). An illustration of the meaning of nodal diameters is given in Figure 21 for the example of a periodic model with $n = 8$.

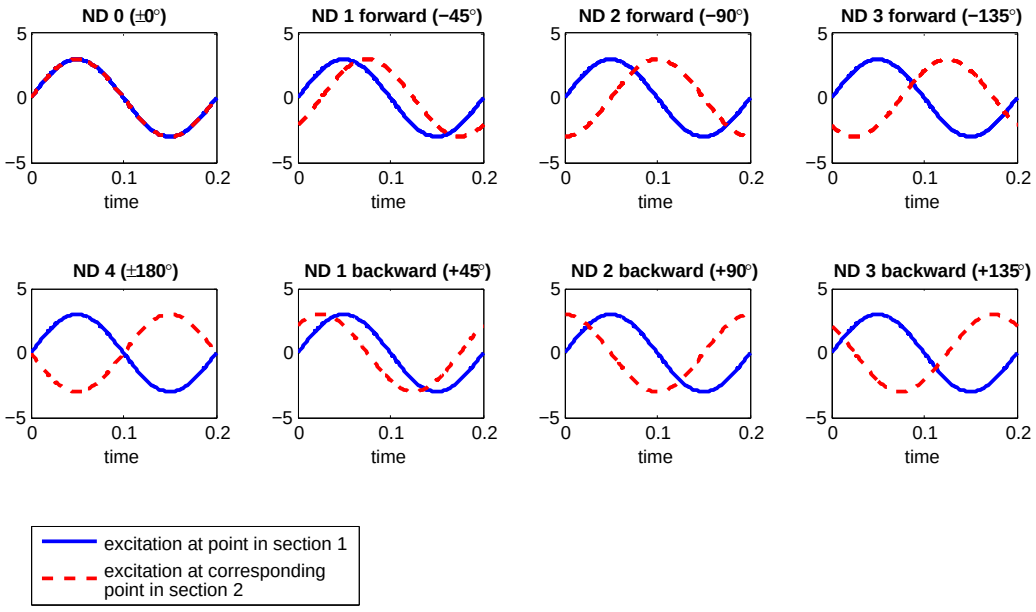


Figure 21: Phase lag between two neighboring sections for different nodal diameters on a 8-periodic model

Quantities of cyclic symmetric structures can exhibit the following nodal diameters in MpCCI FSIMapper:

Analysis Type	**n even/odd**	**Available Nodal Diameters**
Static		0
Transient	n even	0, $n/2$
	n odd	0
Harmonic	n even	$0, 1, \ldots, n/2$
	n odd	$0, 1, \ldots, (n-1)/2$

The nodal diameters $0 < ND < n/2$, which only occur for harmonic cyclic symmetric data, are referred to as "paired". Those quantities are described with both real and imaginary part and both are used simultaneously in order to create the data of the full model.

The data's cyclic symmetry mode, which is needed to calculate the quantity's values on the full model, is determined by the periodicities in the considered system.

For instance, periodic (rotating) disturbances produced by the k-th harmonic of an m-periodic part lead to a forward excitation nodal diameter $ND \in \{0, 1, \ldots, \lfloor n/2 \rfloor\}$, if there exists a positive integer a with $ND = -(k \cdot m - a \cdot n)$. If there is a positive integer b with $ND = k \cdot m - b \cdot n$ the excitation shape is in backward mode. The cyclic symmetry axis needs to be chosen, such that the relative rotation speed is positive around this axis. Please refer to Wirth and Oeckerath [2015] for further information.

Only with a properly selected (forward/backward) nodal diameter, the data will be spatially continuous over the periodic boundaries in the corresponding full model. This is the prerequisite of a correct mapping to a full model or a model with different section shape, as shown in Figure 8.

The direction of the axis of cyclic symmetry and the forward/backward excitation mode are closely connected through the following: if the excitation shape is defined by a forward resp. backward nodal diameter ND with given cyclic symmetry axis $\overrightarrow{a}$, then it is equivalent to define it as backward resp. forward nodal diameter ND with axis $-\overrightarrow{a}$.

For harmonic analyses, please check how the structural solver defines the nodal diameter/cyclic symmetry mode of the excitation. If the solver only knows the forward excitation mode (e.g. Abaqus) use the previous note in order to switch between backward and forward by changing the sign of the cyclic axis in the structural solver.

8 Tutorial

The tutorials demonstrate the use and the capabilities of FSIMapper for some special applications.

The general process of mapping data from a result file ("source") to a structural model ("target") is visualized in Figure 1. First, the simulation of the source model is performed. The source result file (native or special export depending on simulation software) and a prepared mesh of the target model are read by MpCCI FSIMapper. With application dependent settings, which need to be defined in the GUI or for batch usage in the config file, the mapping is done. As a result MpCCI FSIMapper creates a file(s) which contains the mapped quantities for the target mesh in the target code format. The file(s) is included in the target simulation in order to define the loading applied by the mapped source data.

8.1 Mapping of Electromagnetic Forces for Transient and Harmonic Analyses

8.1.1 Problem Description

In this tutorial, a two pole generator, called TEAM-24, is studied with respect to its vibration behavior. A transient electromagnetic simulation is performed using Infolytica MagNet where the resulting forces acting on the stator are calculated. By a transient mapping and a subsequent Fourier transformation of the data, the loading for a frequency response analysis is created. Here, MSC NASTRAN is used as target simulation code.

Rotor and stator exhibit two poles each (cf. Figure 22), where the rotor turns 1° per ms, i. e. with a frequency of $2.\overline{7}$ Hz. Due to the symmetry of the problem the model is truncated at its symmetry plane.

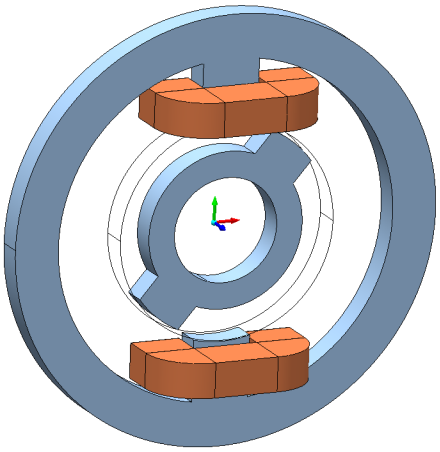


Figure 22: TEAM-24 model in MagNet

The files concerning this tutorial are located in

- MpCCI FSIMapper as part of the MpCCI installation:
  "<*MpCCI_home*>/tutorial/FSIMapper/Team24-Stator_ElectromagneticForces"
- MpCCI FSIMapper standalone installation:
  "<*MpCCIFSIMapper_home*>/tutorial/Team24-Stator_ElectromagneticForces"

Before mapping, copy the files to your working directory.

8.1.2 Source Result File

In MagNet the TEAM-24 generator is simulated by the Solve→Transient 3D with Motion... solver. The transient solver options (Solve→Set Transient Options...) are set such that a constant time step is used (cf. Figure 23) which is obligatory for the Fourier transformation in MpCCI FSIMapper. It is sufficient to simulate only one half turn (180° in 180 ms) because of the cyclic symmetry with two poles.
The magnitude of the force density at 23 ms calculated by MagNet is shown in Figure 24.

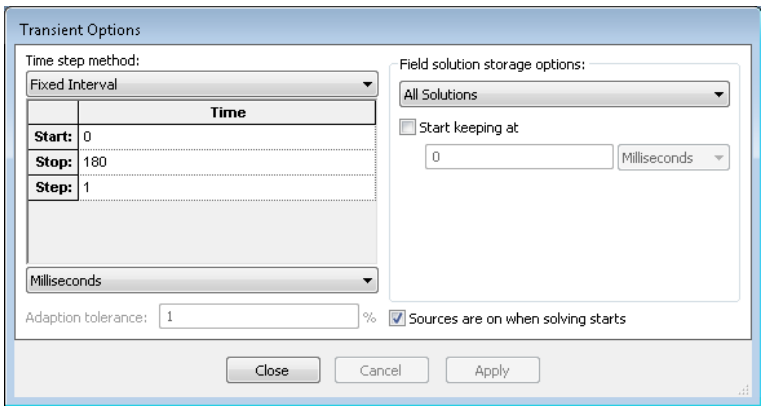


Figure 23: Options for transient MagNet simulation

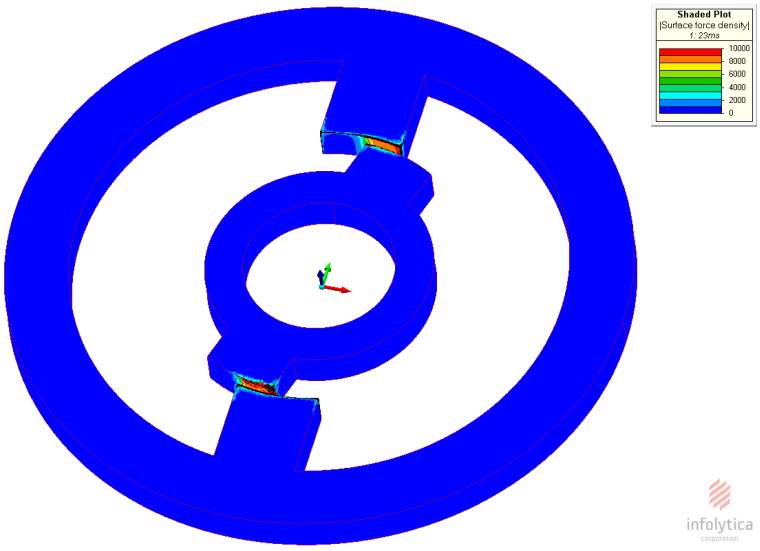


Figure 24: Surface force density at 23 ms computed by MagNet

For the use in MpCCI FSIMapper the surface force density has to be exported in MagNet using a special export called "Exporter for MpCCI". The procedure is the following (cf. Figure 25):

- Select in the object tree the component whose surface load is to be exported (here "Stator")
- Open Extensions→Exporter for MpCCI
- Enter as "Period" 180

- Push the Start button

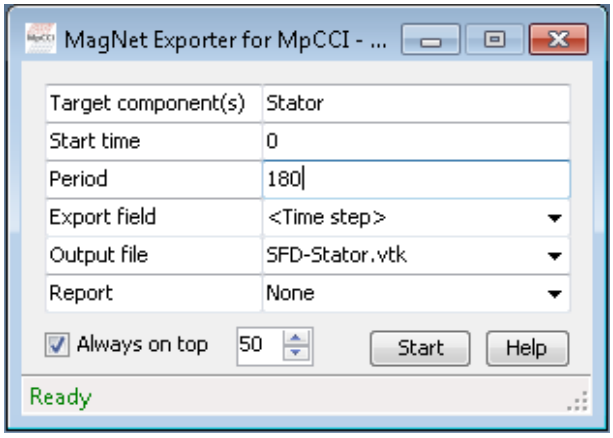


Figure 25: MagNet's "Exporter for MpCCI"

The exporter creates the file `"SFD-Stator.vtk"` including all time steps between 0 ms and 179 ms.

For a Fourier transformation without windowing (as it is implemented in MpCCI FSIMapper) it is necessary to use transient data points which can be stacked one behind the other in order to create continously the data for the following periods, as shown in the first picture in Figure 26.

As the data at 180 ms is exactly the same as at 0 ms and the time steps 0 to 179 prescribe one period (in the sense of the first picture in Figure 26), the prerequisites for a correct Fourier transformation are fulfilled.

In the .vtk file the SI unit system is used.

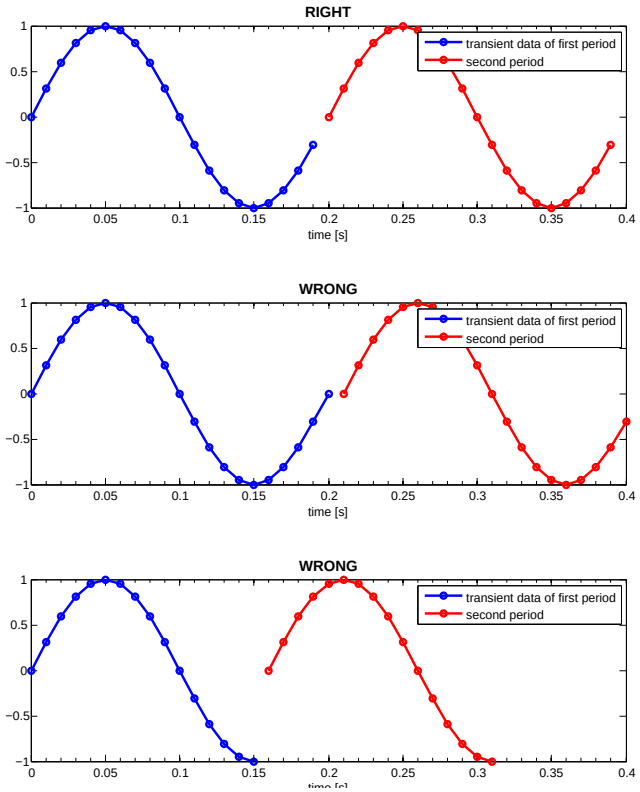
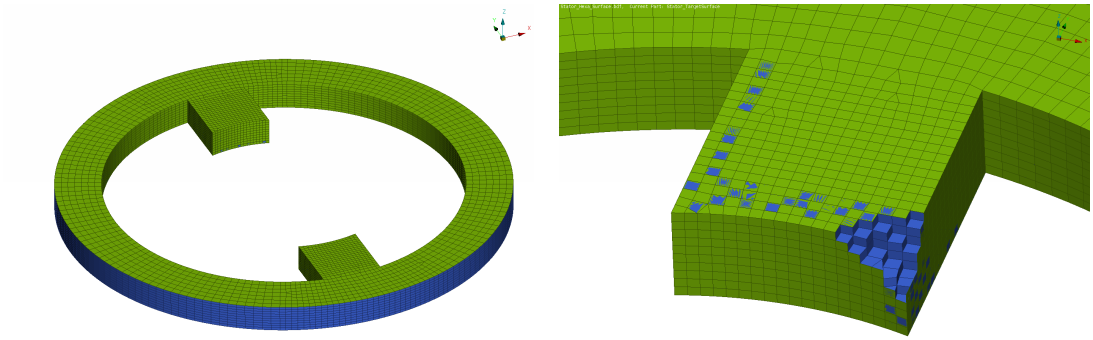


Figure 26: How to define transient data used by the Fourier transformation (without windowing). The blue dots are the data points provided for the mapping (here, a discrete sine-signal of frequency 5 Hz and sampling time step 0.01 s). The red dots are generated by stacking the data behind the end of the provided time signal. Only the first definition is correct

8.1.3 Target Mesh File

The MSC NASTRAN target mesh models the stator by first order hexa and penta elements, see Figure 27. The mapping surface is defined by shell elements (green) which use the same nodes as the volume elements (blue).



(a) Overview (b) Zoom to Interior

Figure 27: Target structural mesh (blue) with shell elements (green) defining the mapping surface

The unit system used is *mm-t-s* which leads to force unit *N*.

8.1.4 Mapping

Open the MpCCI FSIMapper GUI and change the settings in the "How to map/Transient" panel as follows (shown in Figure 28):

1. Select MagNet in the source file type drop-down menu and choose the `"SFD-Stator.vtk"` by pressing the `...` button
2. Select "SFD-Stator.vtk" from the parts list
3. Set the source unit system to SI
4. Select the force density "SFD" in the "Force" variable drop-down menu
5. For the target simulation code select MSC NASTRAN and the mesh file `"Stator_Hexa_Surface.bdf"`
6. Select the surface abbreviated by "S" with MSC NASTRAN `PSHELL` PID 2 in the parts box.
7. Set the unit system of the target model to *mm-t-s*.

This configuration maps for each time step the electromagnetical surface force density to the stator. In this tutorial we want the mapped transient force density to get transformed using Fourier analysis. Therefore, check "Apply Fourier Transformation" in the "Result" panel in order to output a corresponding include file that defines the loading for linear vibration analyses, cf. Figure 29.

Pressing the Map button starts the mapping process.

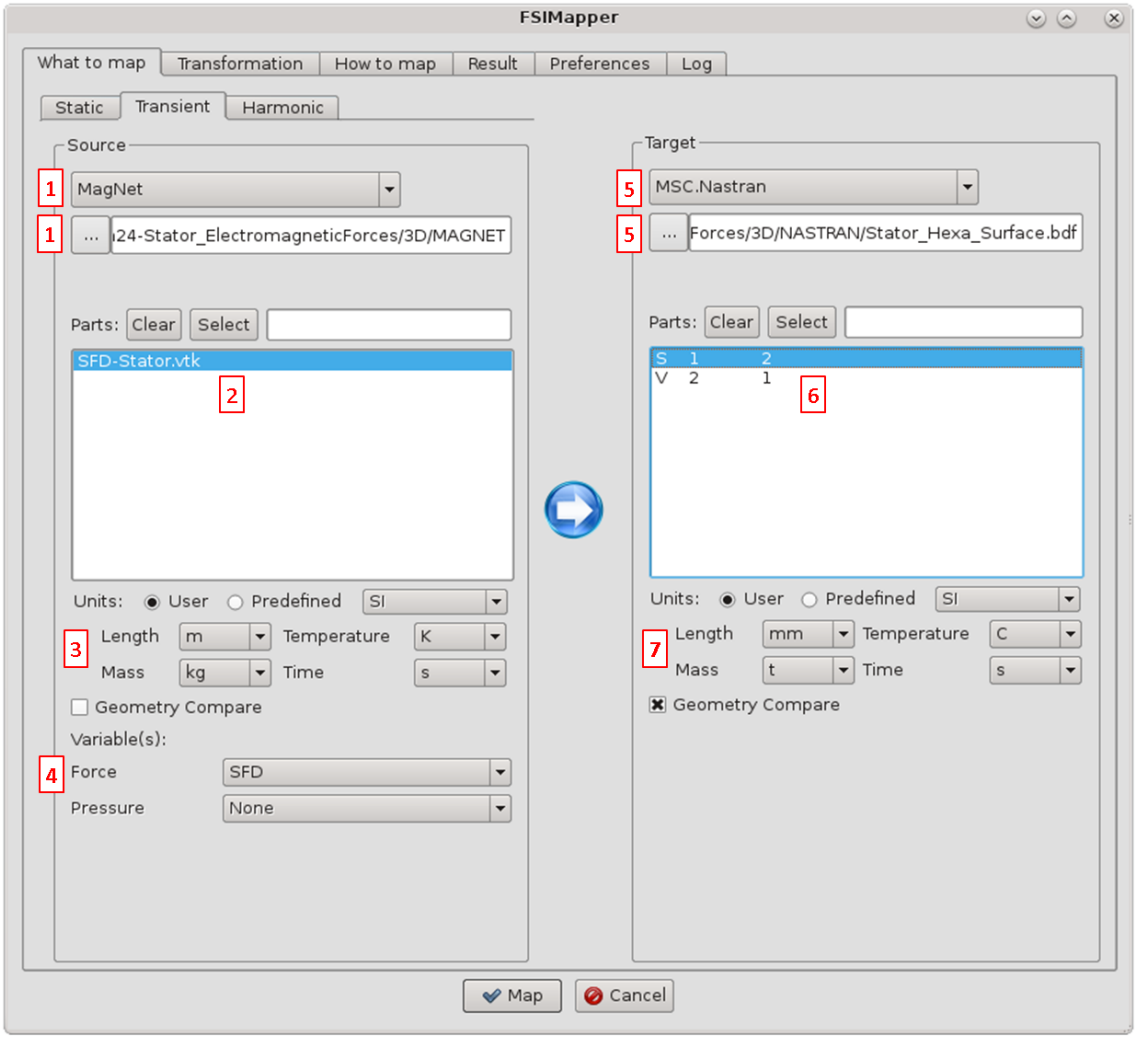


Figure 28: The “What to map” panel

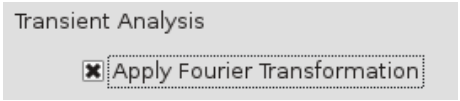


Figure 29: The “Apply Fourier Transformation” option in the “Result” panel

When the mapping finishes, the MpCCI Visualizer shows the mapping results for each time step (cf. Figure 30 at 23 ms). Due to the coarser target mesh, the mapped surface force density differs at first glance from the source data. But integrating both densities will lead to the same total force.

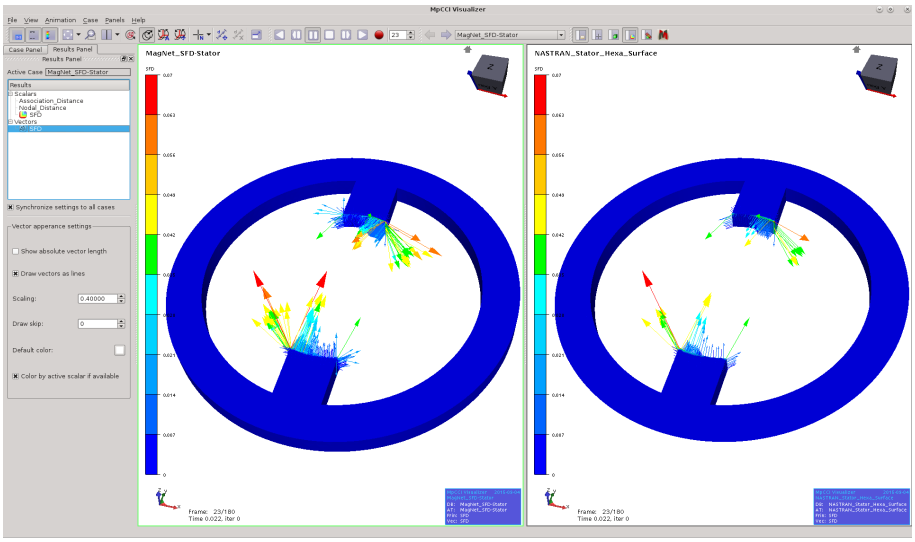


Figure 30: Transient mapping result shown in MpCCI Visualizer at 23 ms

With a sampling time step of $\tau = 0.001\,\mathrm{s}$ and a number of samples $L = 180$ the Fourier transformation results in the frequency range from

$$0\,\mathrm{Hz} \quad \text{to} \quad \frac{\lfloor L/2 \rfloor}{\tau \cdot L} = 500\,\mathrm{Hz} \quad \text{in} \quad \frac{1}{\tau \cdot L} = 5.\overline{5}\,\mathrm{Hz} \quad \text{steps}$$

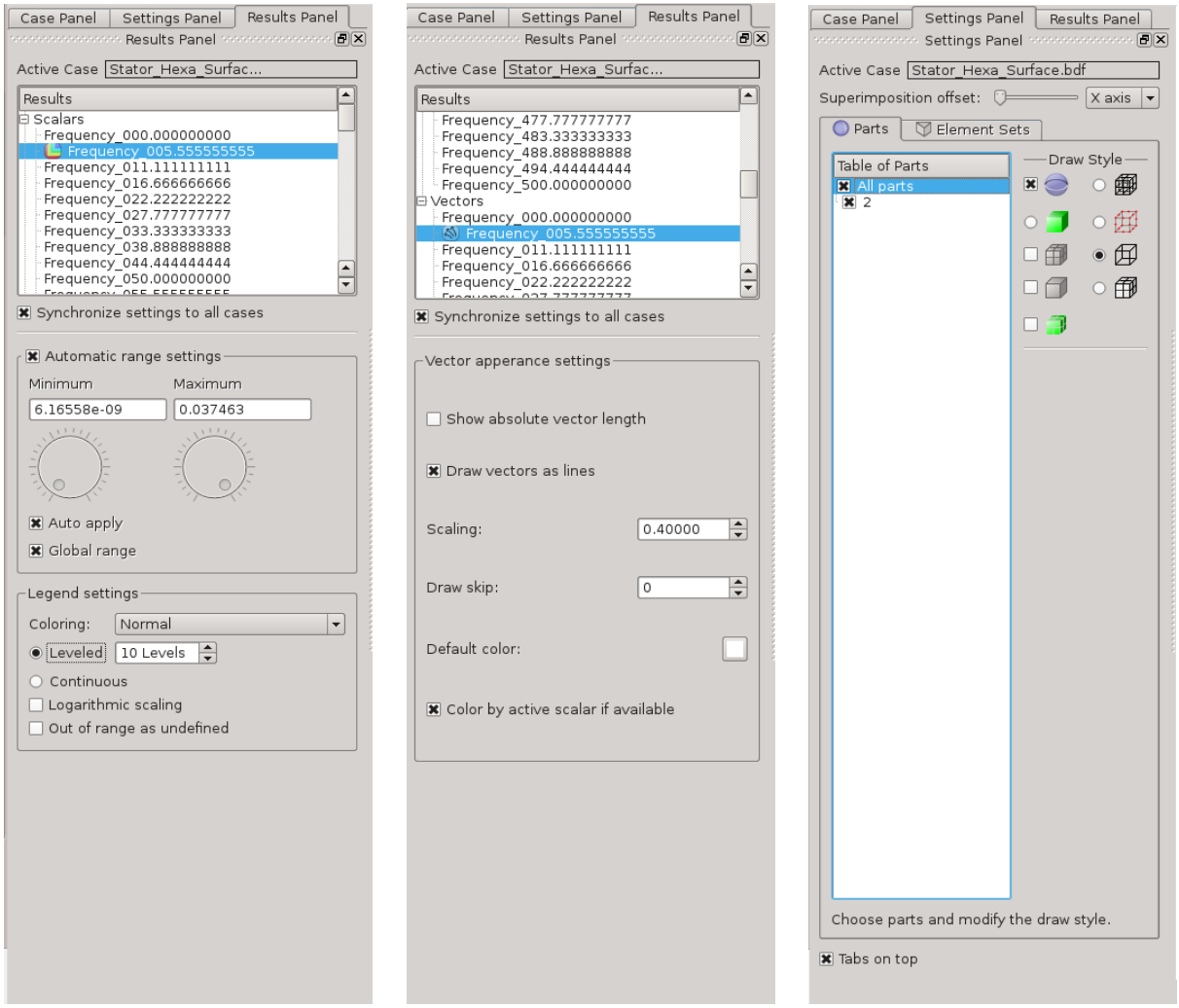
MpCCI FSIMapper creates a MSC NASTRAN include file `"Stator_Hexa_Surface-mapped_FreqRespForce.bdf"` where the Fourier transformation results are applied as complex forces to the nodes building the mapping surface. It also defines the frequencies for the frequency response analysis:

```
$
$ DLOAD = 600
$ FREQ  = 601
$
$-------2-------3-------4-------5-------6-------7-------8-------9-------0-------
FREQ*                 601 0.000000000E+00 5.555555556E+00 1.111111111E+01
*        1.666666667E+01 2.222222222E+01 ...
...
$
$-------2-------3-------4-------5-------6-------7-------8-------9-------0-------
$ Node 1, DOF 1
RLOAD1       600       1                       1       2
DAREA          1       1       11.00E+00
$ Real part for each frequency
TABLED1*               1
*
*        0.000000000E+00 5.050313394E-03 5.555555556E+00-1.127201827E-03
*        1.111111111E+01-2.292065593E-03 1.666666667E+01 1.449636200E-03
```

```
*        2.222222222E+01 2.616820479E-04 ...
...
$ Imaginary part for each frequency
TABLED1*               2
*
*        0.000000000E+00 0.000000000E+00 5.555555556E+00-3.482561041E-03
*        1.111111111E+01 1.660795053E-03 1.666666667E+01 1.071458938E-03
*        2.222222222E+01-8.023966910E-04 ...
...
```

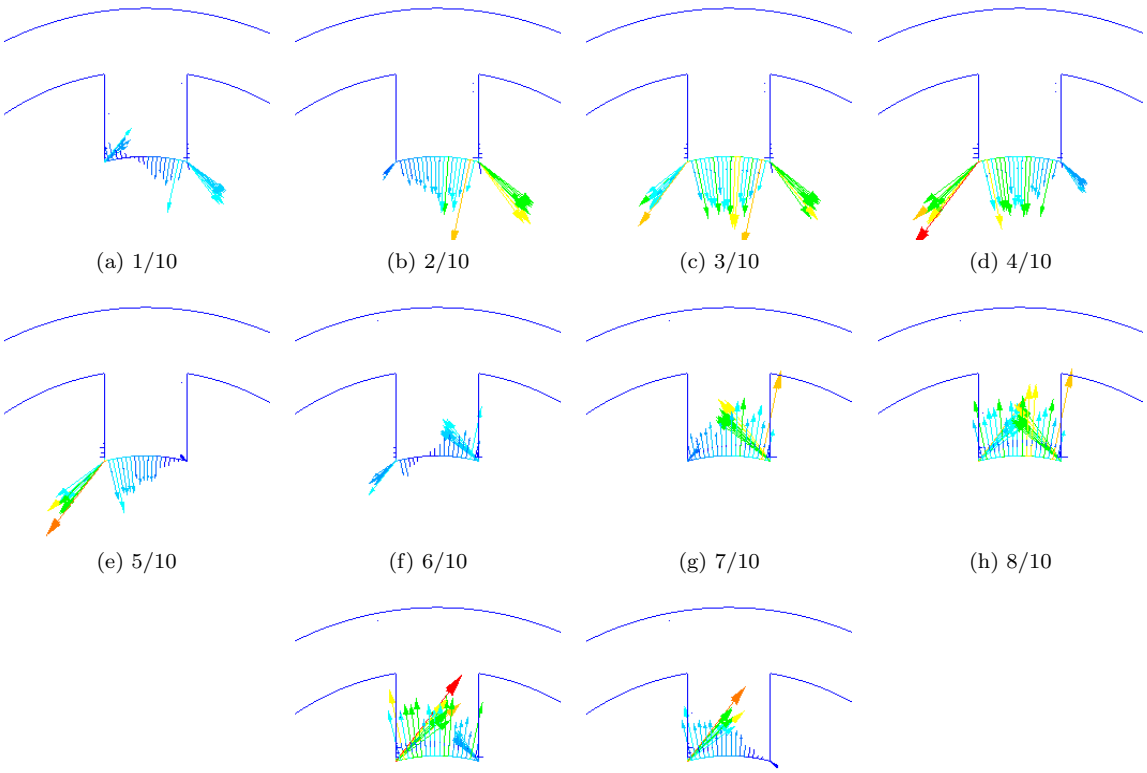
Moreover, MpCCI FSIMapper creates the file `"Stator_Hexa_Surface-mapped_FreqRespForce.ccvx"` in order to post-process the Fourier transformed forces. It is opened in MpCCI Visualizer and shows the corresponding transient force fluctuations (at 10 pseudo time steps) for each frequency. Open Panels→Results Panel and select in the "Results" list e. g. "Frequency_005.555555555" as "Scalar" and "Vector" quantity, see Figure 31a and 31b. Switch off View→Perspective Projection and select in the Panels→Settings Panel the outline representation as shown in Figure 31c.

Pressing the  button animates the 10 pseudo time steps. With the value given in File→Preferences→Maximum animation FPS the animation speed is set. In this way one can visualize the frequency content of the transient signal, see Figure 32. Frequency $5.\overline{5}$ Hz has the highest influence in the transient force progression which is twice the rotation speed (resulting from the two poles). The higher orders play a decreasing role and the excitation shapes get more and more complicated.



(a) "Results Panel", "Scalar" quantity (b) "Results Panel", "Vector" quantity (c) "Settings Panel"

Figure 31: MpCCI Visualizer settings



(a) 1/10 (b) 2/10 (c) 3/10 (d) 4/10

(e) 5/10 (f) 6/10 (g) 7/10 (h) 8/10

(i) 9/10 (j) 10/10

Figure 32: Corresponding transient force excitation at $5.\overline{5}$ Hz generated for 10 pseudo time steps

8.1.5 Target Simulation

MpCCI FSIMapper exported a MSC NASTRAN include file containing the nodal force excitation resulting from a Fourier transformation of the electromagnetic surface force density calculated by MagNet. It is located in the same folder as the MSC NASTRAN input deck. The load case definition in MSC NASTRAN uses the file in the following way:

```
$
SOL 111 $ Modal Frequency Response
CEND
$
TITLE = Team-24_Stator3D_FreqResp
$
$
  METHOD = 150
  SPC = 1
  FREQ = 601
  DLOAD = 600
  DISP(PLOT) = ALL
  STRESS(PLOT) = ALL
  RESVEC = NO
  ECHO = NONE
$
$
BEGIN BULK
$
$-------2-------3-------4-------5-------6-------7-------8-------9-------0------
EIGRL   150     -0.1    1250
$
INCLUDE 'Stator_Hexa.bdf'
INCLUDE 'Stator_Hexa_Surface-mapped_FreqRespForce.bdf'
$
$-------2-------3-------4-------5-------6-------7-------8-------9-------0-------
$
PARAM, POST, -1
$
ENDDATA
```

For the simulation the MSC NASTRAN mesh `"Stator_Hexa.bdf"` is used, i. e. the volume mesh without the shells defining the mapping surface (keeping the same node ID's). Please refer to the MSC NASTRAN Dynamic Analysis User's Guide for more information about the frequency response analyses types `SOL 108` and `SOL 111`.

If the "Apply Fourier Transformation" option is not checked in the "Result" panel, then MpCCI FSIMapper creates the file `"Stator_Hexa_Surface-mapped_TransientForce.bdf"` which contains the mapped transient nodal forces. It can be used in `SOL 109` and `SOL 112` analyses.

8.2 Mapping of Harmonic Pressure Excitations in Turbomachinery

Periodic pressure fluctuations excite blade vibrations which can endanger the integrity of the whole system.

The harmonic CFD methods offer the possibility to simulate those excitations in an efficient way without the initial attack time. They approximate the transient steady state flow behavior as a superposition of the time-averaged state variable and periodic fluctuations around this mean value.

Due to the periodic nature of steady state turbomachinery flows the pressure oscillations can be splitted into frequency components (harmonics) which are multiples of the blade passing frequency.
The solution approach of the harmonic CFD methods is to determine the complex amplitudes (magnitude and phase lag) for each of the superposed harmonics. Thus, the methods do not step successively in time but work in frequency domain.

Structural frequency response analyses can use directly the complex pressure data of the harmonic CFD simulation. They define the flow-induced excitations at every considered frequency.

In this tutorial the mapping process is shown for the Harmonic Balance Method of STAR-CCM+ and the Nonlinear Harmonic Method of FINE/Turbo. Here, the concept of cyclic symmetry and nodal diameters is exemplarily discussed.

8.2.1 Using the Harmonic Balance Method of STAR-CCM+

8.2.1.1 Problem Description

In this tutorial the flow-induced blade vibration of the NASA Rotor37 in operation is simulated. It is based on the STAR-CCM+ tutorial "Harmonic Balance: Single Stage Periodic Flow" where the transient pressure fluctuation is approximated by three harmonics and the time-averaged pressure. Here, the target simulation code is Abaqus.

The mapping process presented here creates the loading for a structural frequency response analysis in the following steps:

1. map 1^{st} harmonic pressure excitation
2. map 2^{nd} harmonic pressure excitation
3. map 3^{rd} harmonic pressure excitation
4. map time-averaged pressure

The tutorial also shows the mapping capability of MpCCI FSIMapper for periodic source and full target models.

Rotor37 has a geometrical periodicity of $n = 36$ blades. The upstream stator exhibits a periodicity of $m = 48$ blades; only the influence of this component is considered for this tutorial. The rotor rotates around the z-axis by $\omega = 17200\,\text{rpm} = 286.\overline{6}\,\text{Hz}$.

The files concerning this tutorial are located in

- MpCCI FSIMapper as part of the MpCCI installation:
  "<*MpCCI_home*>`/tutorial/FSIMapper/Rotor37`"
- MpCCI FSIMapper standalone installation:
  "<*MpCCIFSIMapper_home*>`/tutorial/Rotor37`"

Before mapping, copy the files to your working directory.

8.2.1.2 Source Result File

In the STAR-CCM+ tutorial "Harmonic Balance: Single Stage Periodic Flow" the flow conditions in the Rotor37 are simulated using the Harmonic Balance method. The transient solution is approximated by 3 harmonics (in STAR-CCM+ called "modes"), where the 48-bladed stator is modelled as Gaussian wake (so not geometrically). Only one blade passage is modelled of the rotor.
The magnitude of the first ($k = 1$) pressure harmonic at $k \cdot m \cdot \omega = 13760\,\text{Hz}$ is shown in Figure 33. $m \cdot \omega$ refers to as blade passing frequency.

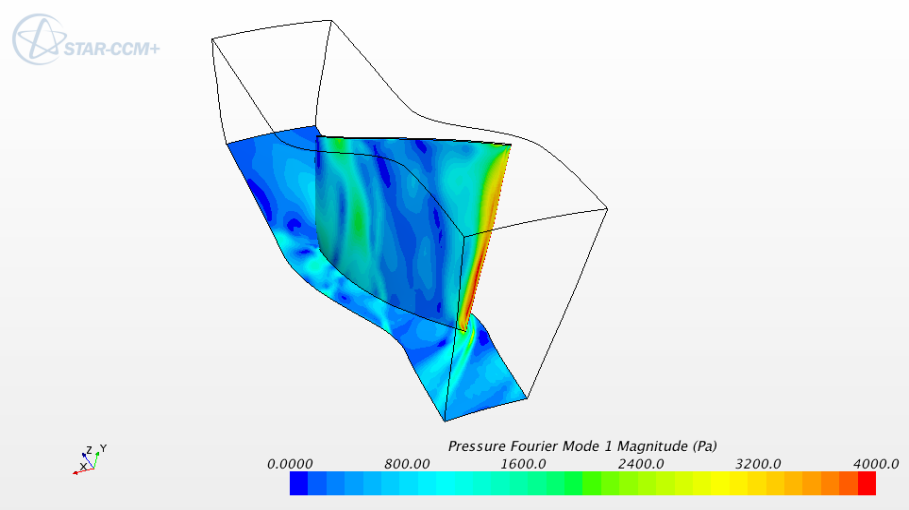


Figure 33: Magnitude of the first pressure harmonic

The harmonic results of the simulation are exported for the wetted surfaces into the EnSight Gold case format via File→Export... in STAR-CCM+, as shown in Figure 34.

The main resulting file is `"singleRowHarmonic.case"` which refers to the geometry file `"singleRowHarmonic00000.geo"`, the exported time-averaged (`"*.PressureFourierMode0"`) and harmonic pressures (`"*.PressureFourierMode*Real"`, `"*.PressureFourierMode*Imag"`).

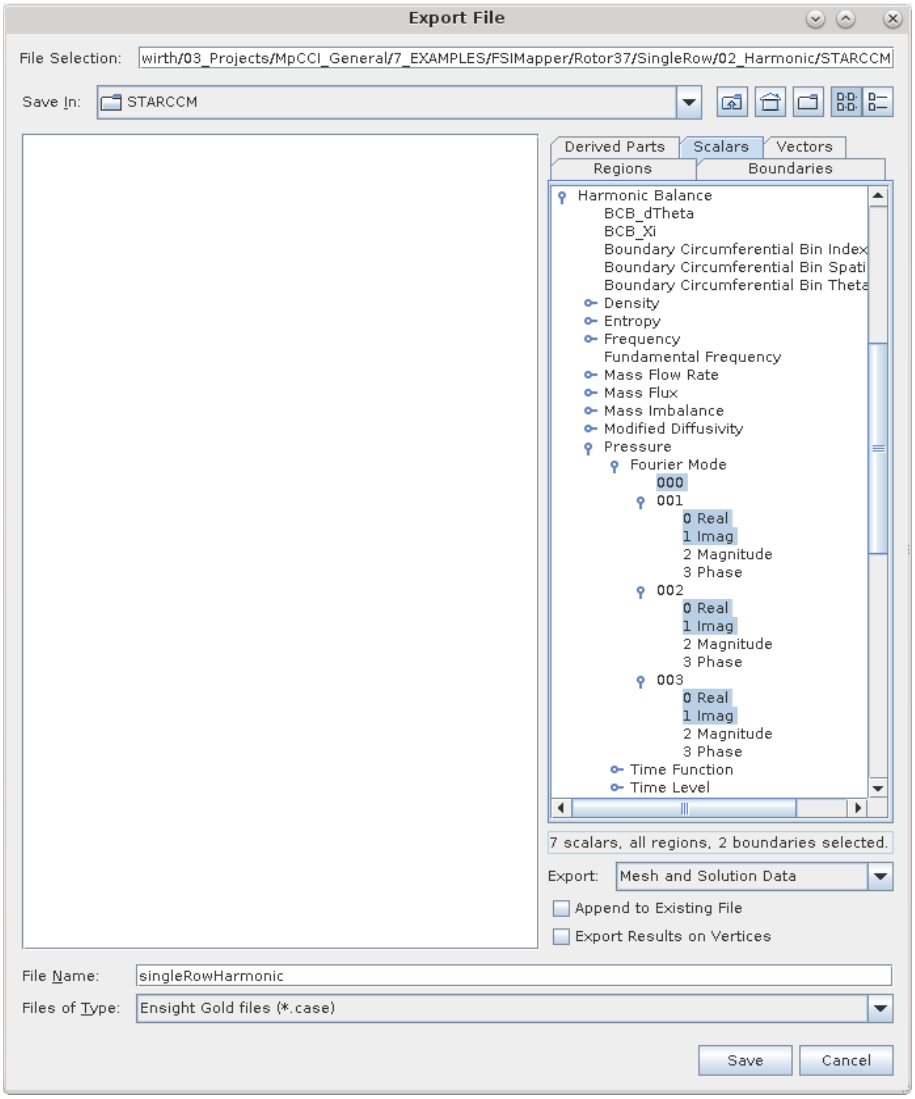
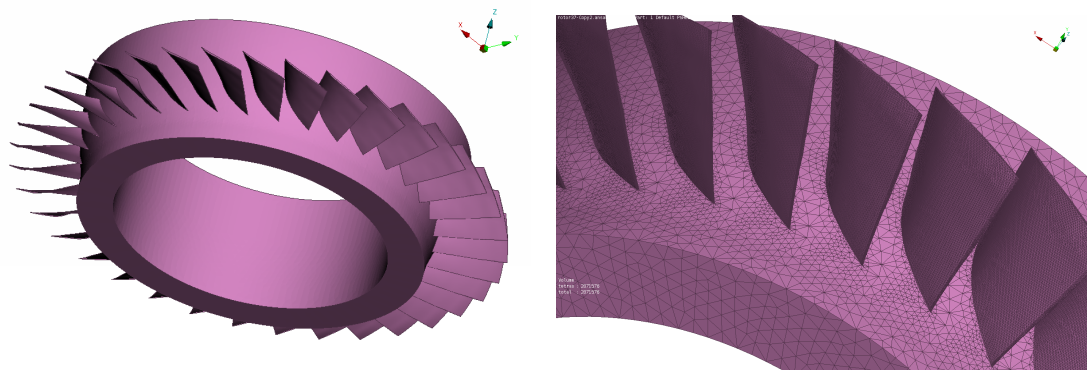


Figure 34: Export the harmonic results as EnSight Gold case file

8.2.1.3 Target Mesh File

The structural target mesh file `"rotor37_fine.inp"` comprises the whole rotor, as shown in Figure 35. Second order tetra elements were used.



(a) Overview (b) Zoom

Figure 35: Target structural mesh of the full Rotor37

The mapping surface, i. e. the surface where the pressure excitation acts, needs to be defined. Internally, Abaqus uses the keyword `*SURFACE, NAME=WettedSurface, TYPE=ELEMENT`.

8.2.1.4 Mapping

First we map the first harmonic ($k = 1$) to the structural Abaqus model. Open the MpCCI FSIMapper GUI and change the settings in the "How to map/Harmonic" panel as follows (shown in Figure 36):

1. Select "EnSight Case" in the source file type drop-down menu and choose the file `"singleRowHarmonic.case"` by pressing the `...` button.
2. Select the wetted surfaces in the source model: "Hub_Surface_Blade_Row_1" and "Blade_Surface_Blade_Row_1"
3. Set the source unit system to SI
4. Select for the real part of the mapped quantity "PressureFourierMode1Real" and for the imaginary part "PressureFourierMode1Imag"
5. For the target simulation code select "Abaqus" and the mesh file `"rotor37_fine.inp"`
6. Select the surface "WettedSurface" in the parts box.
7. Set the unit system of the target model to *mm-t-s*.

Since the source mesh models only a periodic section of the rotor and the target mesh comprises the full rotor, a transformation is needed in order to generate matching geometries. For this purpose give the following information in the "Transformation/Geometry" subpanel (cf. Figure 37):

- Select the "User defined" transformation and check the option "Cyclic Symmetry"
- For the number of periodicities put in 36
- Define the cyclic symmetry axis via the two points $[0, 0, 0]$ and $[0, 0, 1]$, which is the positive z-axis

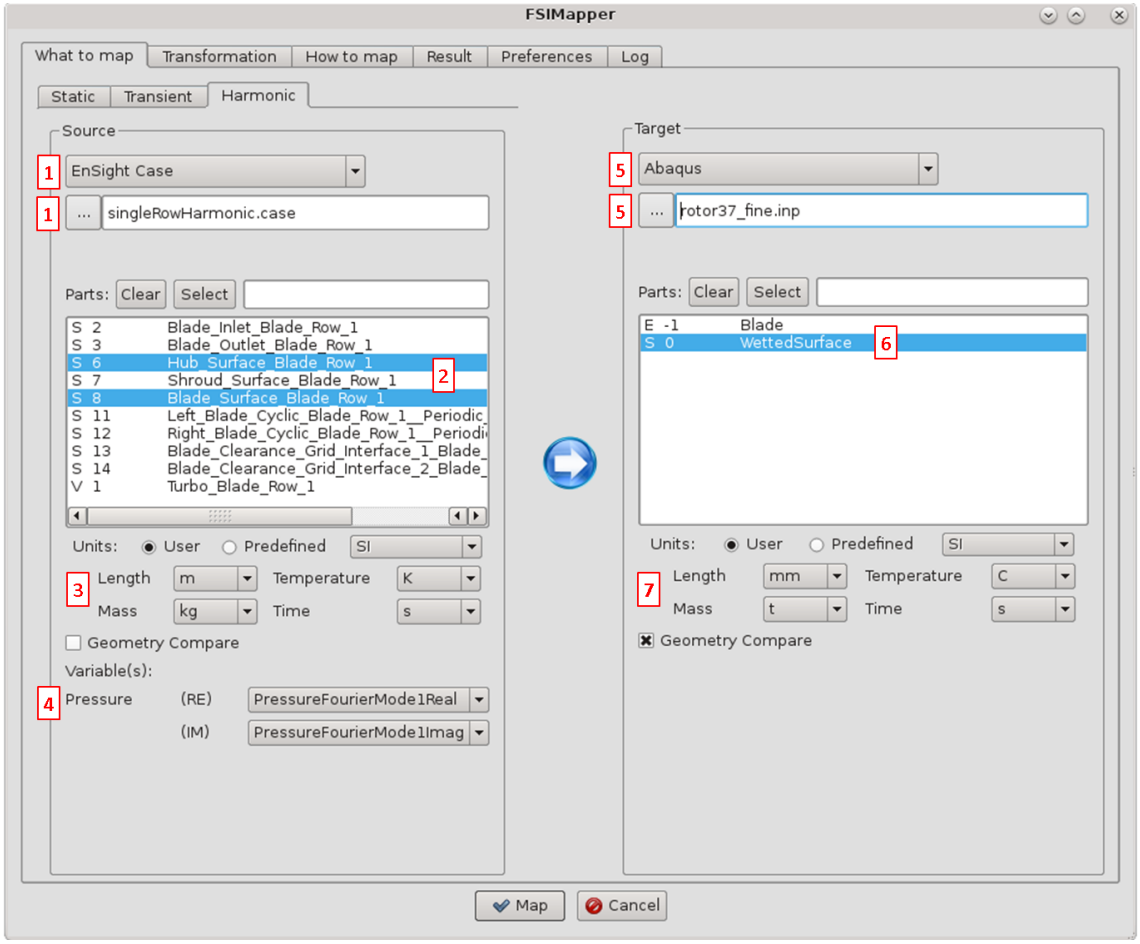


Figure 36: The “What to map” panel

Due to the 48-bladed stator, the excitation of the first harmonic is of a nodal diameter 12 periodicity in backward mode, i. e. the excitation travels in the opposite direction as the rotation sense.
This can be seen by the formula given in a note in ▷ 4.3 The “Transformation” Panel ◁:

$$ND = k \cdot m - b \cdot n = 1 \cdot 48 - b \cdot 36 = 12 \quad \text{with} \quad b = 1$$

Since the rotation is positive around the z-axis, which was given as cyclic symmetry axis in the “Geometry” subpanel, select the paired backward nodal diameter 12 in the “Quantity” subpanel.

Pressing the Map button starts the mapping process.

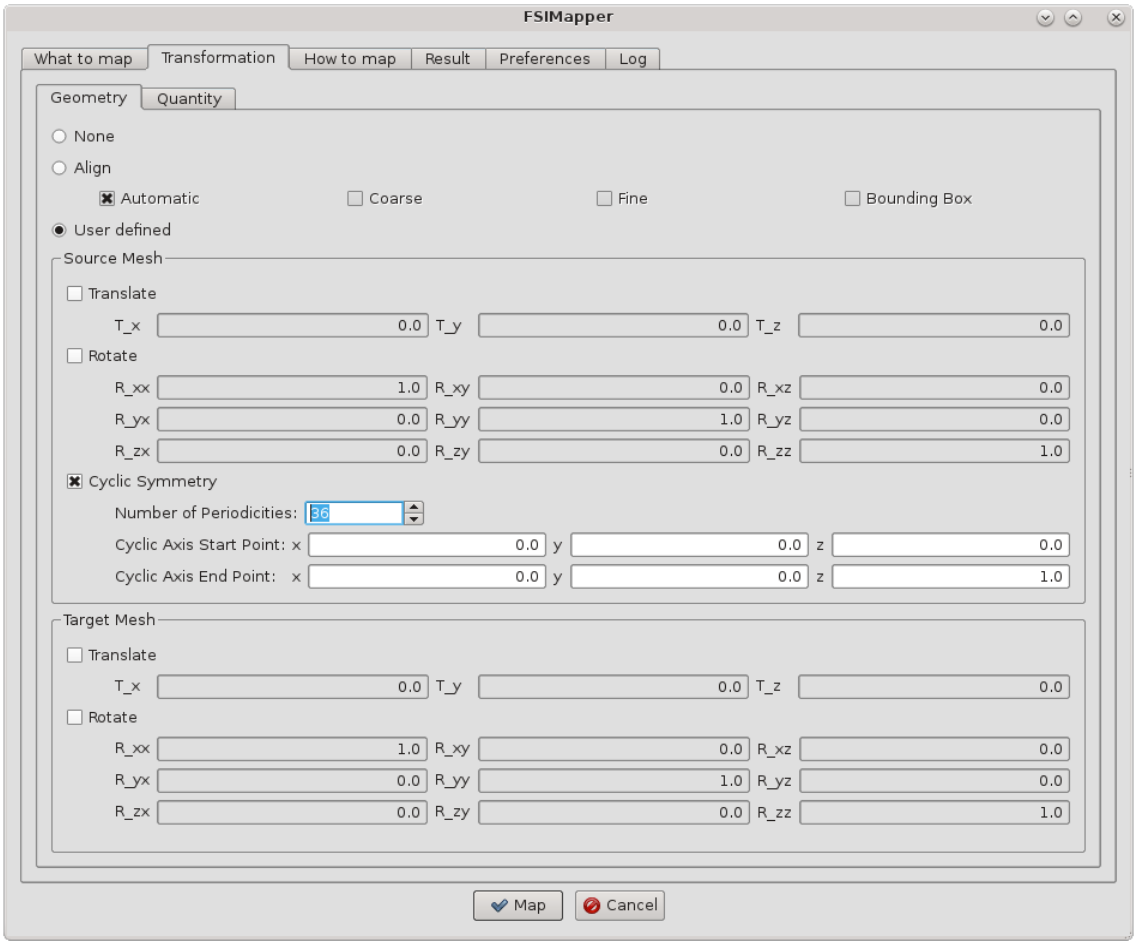
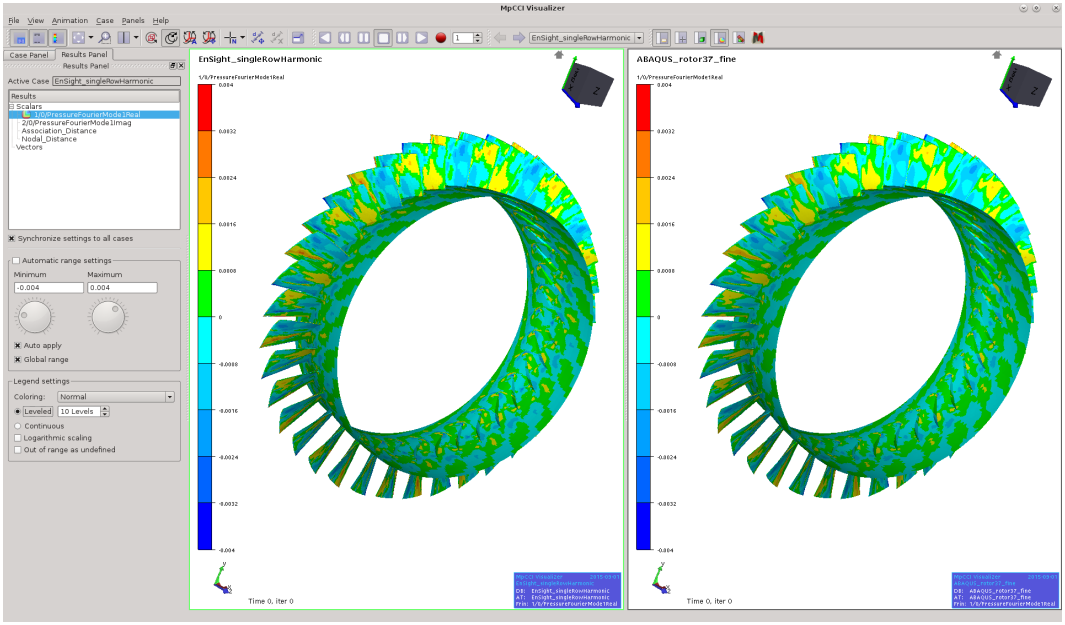
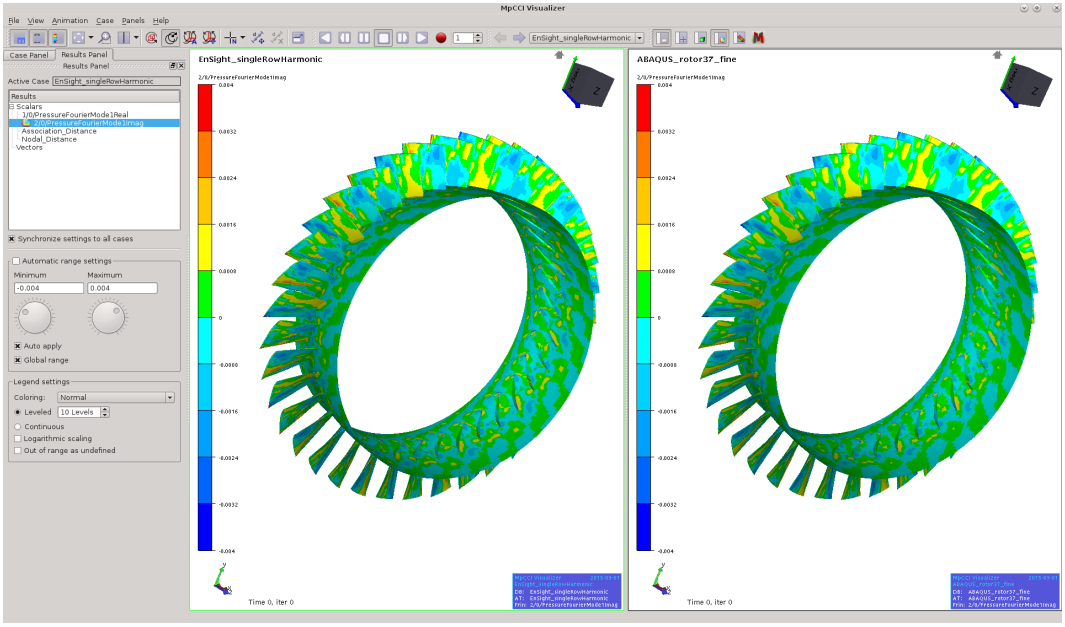


Figure 37: The “Transformation/Geometry” subpanel

When the mapping finishes, the MpCCI Visualizer shows the mapping results, cf. Figure 38.



(a) Real Part



(b) Imaginary Part

Figure 38: Harmonic mapping result shown in MpCCI Visualizer

The periodic mesh and data were transformed by the given information in order to create the full source model and the corresponding data. The first harmonic complex pressure excitation has been revolved such that the data are spacially continuous over the periodic boundaries, see Figure 39. This is only the case for the correctly selected nodal diameter and excitation mode.

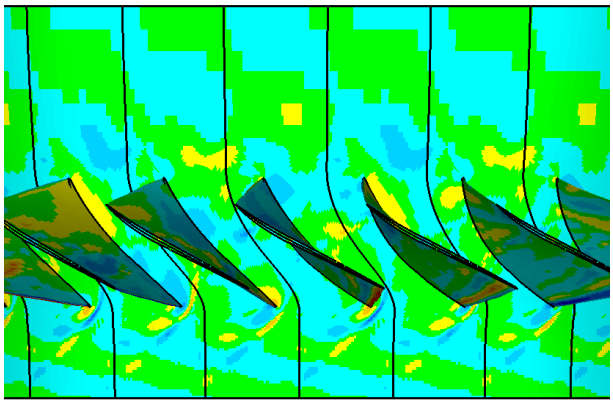


Figure 39: Cyclic Symmetry transformation creates continuous data over the periodic boundaries

MpCCI FSIMapper creates two Abaqus include files `"rotor37_fine-mapped_HarmonicPressure_RE.inc"` and `"rotor37_fine-mapped_HarmonicPressure_IM.inc"` where the real and imaginary part of the pressure is applied to the elements building the wetted surfaces:

```
**
** Exported real part of surface pressure
** *DLOAD, REAL
205,  P1,  -0.00033113
473,  P1,  -0.00028541
10650,  P1,  0.00043067
10651,  P1,  0.00057767
10654,  P1,  -0.00037426
10656,  P1,  -0.00048984
...
```

```
**
** Exported imaginary part of surface pressure
** *DLOAD, IMAGINARY
205,  P1,  -0.00009977
473,  P1,  -0.00007182
10650,  P1,  -0.00031675
10651,  P1,  -0.00037232
10654,  P1,  0.00042306
10656,  P1,  0.00062463
...
```

Moreover, MpCCI FSIMapper creates the file `"rotor37_fine-mapped_HarmonicPressure.ccvx"`. It can be opened in MpCCI Visualizer and shows the corresponding transient pressure fluctuations for 18 pseudo time steps. Pressing the ▶ button animates them with a speed set in File→Preferences→Maximum animation FPS. In this way one can observe the backward travelling wave respective to the rotation sense.

Before mapping the two remaining harmonics, rename the exported files as `"<filename>_H1.<extension>"`.

For the second harmonic ($k = 2$) select the variables “PressureFourierMode2Real” and “PressureFourierMode2Imag”. The nodal diameter 12 in forward mode has to be selected in the “Quantity” subpanel. Also rename the newly created files as "<*filename*>_H2.<*extension*>". Repeat the procedure for the third harmonic with a nodal diameter 0.

Also, we map the time-averaged pressure which represents the pressure level around which the harmonics oscillate. Switch in the “What to map” panel to “Static” and select the same file and parts as in the “Harmonic” subpanel, see Figure 40. Select the quantity “PressureFourierMode0” and map by pressing the Map button. For static analyses only the nodal diameter 0 is available which is selected here by default.

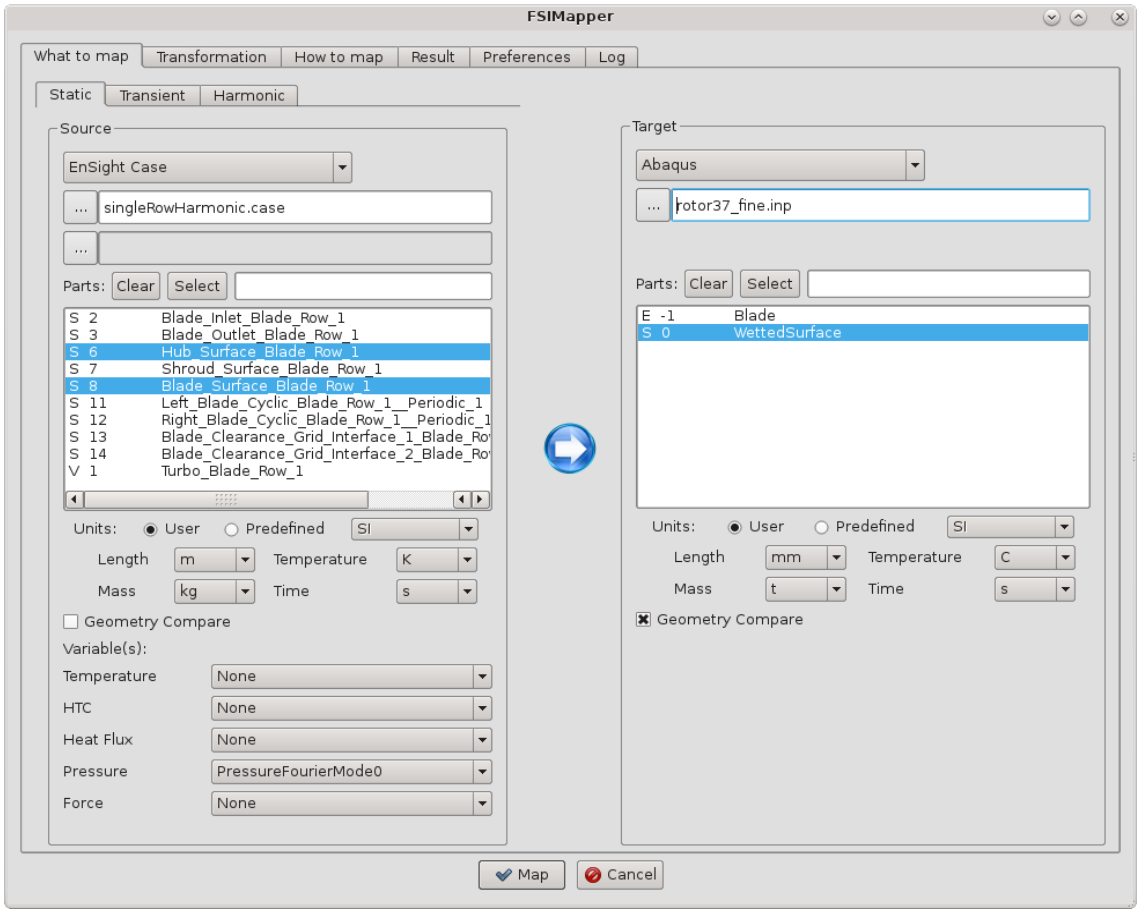


Figure 40: The “What to map/Static” panel

The mapped static pressure is shown in Figure 41.

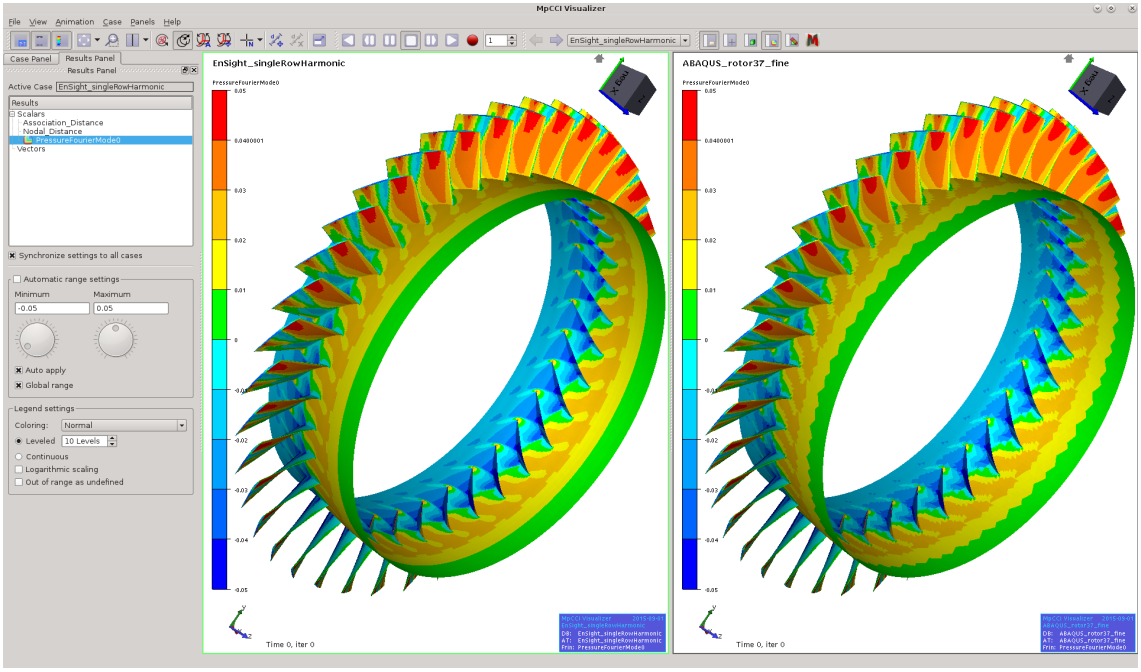


Figure 41: Mapping result of the time-averaged pressure

8.2.1.5 Target Simulation

MpCCI FSIMapper exported in summary for each of the tree harmonics two include files containing the real and the imaginary part of the pressure excitation. Moreover, an include file was exported which defines the mean/time-averaged loading. They are located in the same folder as the Abaqus input deck.
The load case definition in Abaqus uses these files in the following way:

```
**
*STEP, NAME=MeanPressure, NLGEOM=YES, INC=100000
**
*STATIC
0.1,1,1e-4,1
**
*DLOAD, OP=MOD
*INCLUDE, INPUT=rotor37_fine-mapped_Pressure.inc
**
*END STEP
**
**
**
*STEP, NAME=ModalAnalysis
**
*FREQUENCY, EIGENSOLVER=LANCZOS
 , 0, 100000, , , ,
**
*END STEP
**
**
**
*STEP, NAME=SSD_1H
**
*STEADY STATE DYNAMICS
13760, 0, , ,
**
*DLOAD, REAL
*INCLUDE, INPUT=rotor37_fine-mapped_HarmonicPressure_RE_H1.inc
**
*DLOAD, IMAGINARY
*INCLUDE, INPUT=rotor37_fine-mapped_HarmonicPressure_IM_H1.inc
**
*END STEP
**
**
**
*STEP, NAME=SSD_2H
**
*STEADY STATE DYNAMICS
27520, 0, , ,
**
*DLOAD, REAL
*INCLUDE, INPUT=rotor37_fine-mapped_HarmonicPressure_RE_H2.inc
**
*DLOAD, IMAGINARY
```

```
*INCLUDE, INPUT=rotor37_fine-mapped_HarmonicPressure_IM_H2.inc
**
*END STEP
**
**
**
*STEP, NAME=SSD_3H
**
*STEADY STATE DYNAMICS
41280, 0, , ,
**
*DLOAD, REAL
*INCLUDE, INPUT=rotor37_fine-mapped_HarmonicPressure_RE_H3.inc
**
*DLOAD, IMAGINARY
*INCLUDE, INPUT=rotor37_fine-mapped_HarmonicPressure_IM_H3.inc
**
*END STEP
**
```

Please check the Abaqus User's Keywords Reference Guide for the options of `*STEADY STATE DYNAMICS` concerning direct and modal solution methods.

For the sake of completeness use in the first step also the centrifugal and the Coriolis forces (by the keyword `*DLOAD`).

The damping in the system has fundamental influence to the magnitude of blade vibration, so it is recommended to define it.

Here, the full Rotor37 is simulated. Another possibility would have been to model it in Abaqus by a periodic section using the keyword `*CYCLIC SYMMETRY MODEL`. The data periodicity (nodal diameter) is given in Abaqus by the option `CYCLIC MODE=<nodal diameter>` in the keywords `*DLOAD` or `*CLOAD`.

Since Abaqus only knows forward excitation modes, for backward excitations the cyclic symmetry axis (which was determined such that the rotation is positive) has to be turned around (only) for the definition in the Abaqus keyword `*CYCLIC SYMMETRY MODEL`.

8.2.2 Using the Nonlinear Harmonic Method of FINE/Turbo

8.2.2.1 Problem Description

In this tutorial the blade vibration of the axial turbine "Aachen" in operation is simulated. It is based on the FINE/Turbo tutorial "2. Axial Turbine" and the transient pressure fluctuation is approximated by three harmonics and the time-averaged pressure. Here, the target simulation code is Abaqus.

In this tutorial, the 1st harmonic pressure excitation is mapped to a structural frequency response analysis. The remaining harmonics can be mapped in the same way using the information given in ▷ 8.2.2.4 Mapping ◁. The time-averaged pressure is mapped in the "What to map/Static" panel.

The tutorial also shows the mapping capability of MpCCI FSIMapper for periodic source and target models with different section shapes.

The considered rotor in the "Aachen" turbine has a geometrical periodicity of $n = 41$ blades. The upstream and downstream stators exhibit a periodicity of $m = 36$ blades both. The rotor rotates around the z-axis by $\omega = -3500\,\text{rpm} = -58.\overline{3}\,\text{Hz}$.

The files concerning this tutorial are located in

- MpCCI FSIMapper as part of the MpCCI installation:
  "<*MpCCI_home*>`/tutorial/FSIMapper/AxialTurbineAachen`"
- MpCCI FSIMapper standalone installation:
  "<*MpCCIFSIMapper_home*>`/tutorial/AxialTurbineAachen`"

Before mapping, copy the files to your working directory.

8.2.2.2 Source Result File

The result of the static FINE/Turbo tutorial "2. Axial Turbine" is used as initial solution for a Nonlinear Harmonic simulation, where the transient solution is approximated by 3 harmonics in a rank-1 approach (equivalent to "Basic"). Only one blade passage is modelled for each of the three stages. For demonstration purposes the computation has been performed on grid level 1.
The magnitude of the first ($k = 1$) pressure harmonic at $k \cdot m \cdot \omega = 2100\,\text{Hz}$ is shown in Figure 42. $m \cdot \omega$ refers to as blade passing frequency. Since the stators have the same number of blades, the influence of both is included in this harmonic.

The results of the simulation are comprised in the FINE/Turbo .cgns result file
`"Tutorial2_NLH_Rank1_Har3_111.cgns"`.

The harmonic data are only available in the volume mesh.

8.2.2.3 Target Mesh File

The structural target mesh file `"aachenBlade.inp"` comprises one section of the rotor, as shown in Figure 43. The section shape is different to the section in FINE/Turbo. First order hexa and penta elements were used.

The mapping surface, i. e. the surface where the pressure excitation acts, needs to be defined. Internally, Abaqus uses the keyword `*SURFACE, NAME=MappingSurface, TYPE=ELEMENT`.

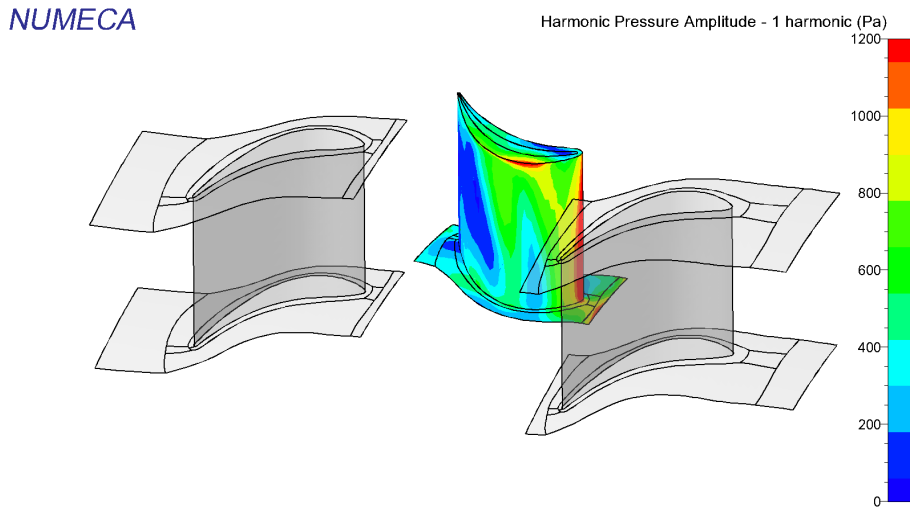


Figure 42: Magnitude of the first pressure harmonic at 2100 Hz

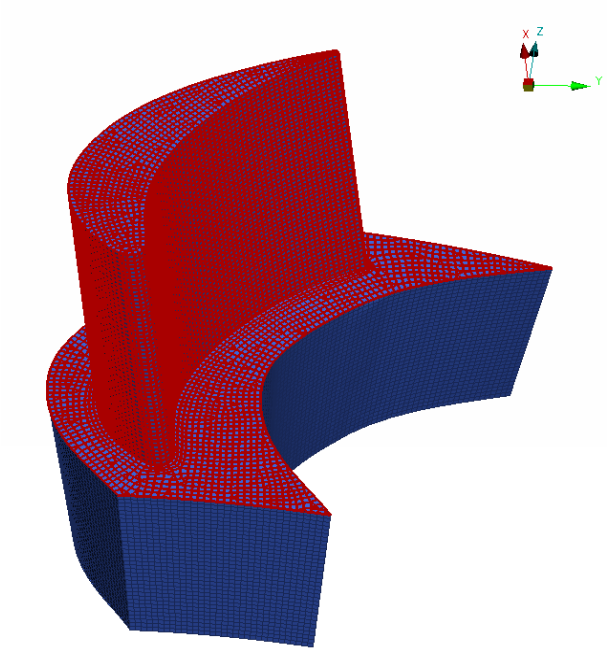


Figure 43: Target structural mesh (blue) with wetted surface definition (red) of one periodic section of the axial turbine “Aachen”

8.2.2.4 Mapping

Here, we map only the first harmonic ($k = 1$) to the structural Abaqus model. The remaining two harmonics are handled equivalently ($k = 2$: forward nodal diameter 10, $k = 3$: forward nodal diameter 15).
Open the MpCCI FSIMapper GUI and change the settings in the "How to map/Harmonic" panel as follows (shown in Figure 44):

1. Select "FINE/Turbo" in the source file type drop-down menu and choose the file `"Tutorial2_NLH_Rank1_Har3_111.cgns"` by pressing the ... button.
2. Select the volume blocks (abbreviated by "V") which suround the wetted surface of the rotor in the source model: "domain8" to "domain16".
3. Set the source unit system to SI
4. Select for the real part of the mapped first harmonic pressure "ReP_1" and for the imaginary part "ImP_1"
5. For the target simulation code select "Abaqus" and the mesh file `"aachenBlade.inp"`
6. Select the surface "MappingSurface" in the parts box.
7. Set the target unit system to *mm-t-s*.

Since the source mesh models a periodic section, which does not match the target mesh section, a periodic transformation is needed in order to provide the data on the surfaces which are not covered by the source mesh. For this purpose give the following information in the "Transformation/Geometry" subpanel (cf. Figure 45):

- Select the "User defined" transformation and check the option "Cyclic Symmetry"
- For the number of periodicities put in 41
- Define the cyclic symmetry axis via the two points $[0, 0, 0]$ and $[0, 0, -1]$, which is the negative z-axis (which implies a positive rotation direction)

Due to the 36-bladed stators, the excitation of the first harmonic is of a nodal diameter 5 periodicity in forward mode, i. e. the excitation travels in the same direction as the rotation sense.
This can be seen by the formula given in a note in ▷ 4.3 The "Transformation" Panel ◁:

$$ND = -(k \cdot m - a \cdot n) = -(1 \cdot 36 - a \cdot 41) = 5 \quad \text{with} \quad a = 1$$

Since the rotation is positive around the negative z-axis, which was given as cyclic symmetry axis in the "Geometry" subpanel, select the paired forward nodal diameter 5 in the "Quantity" subpanel, see Figure 46.

Pressing the Map button starts the mapping process.

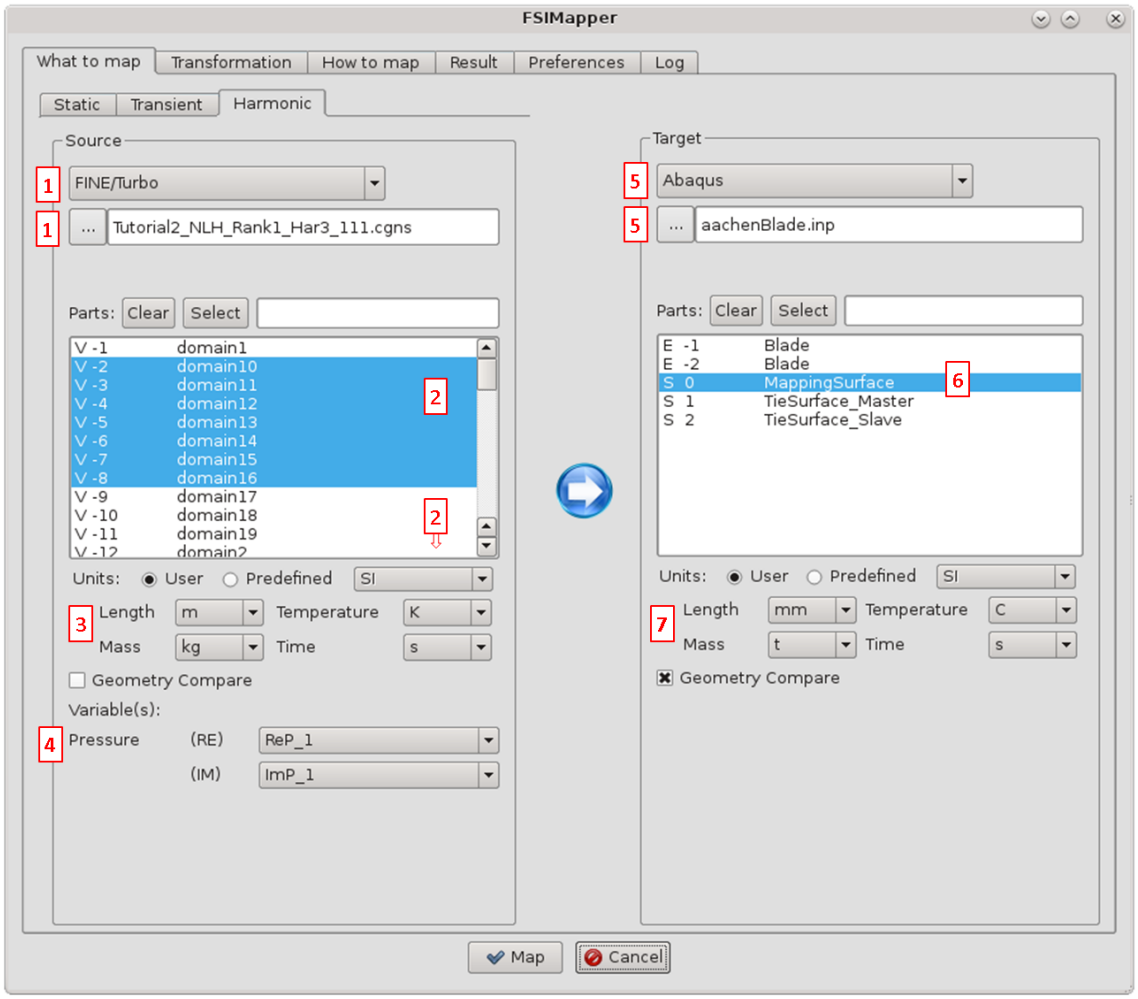


Figure 44: The “What to map” panel

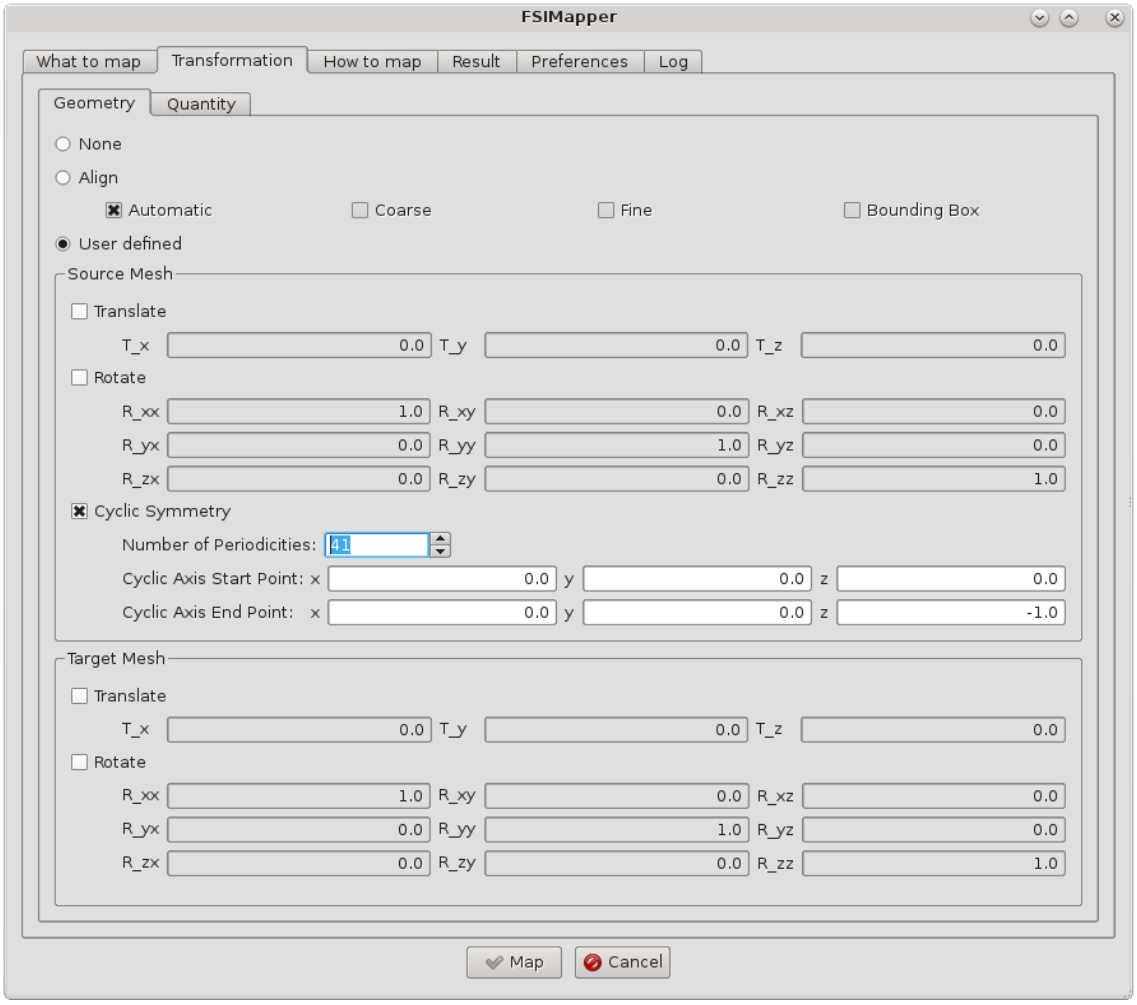


Figure 45: The “Transformation/Geometry” panel

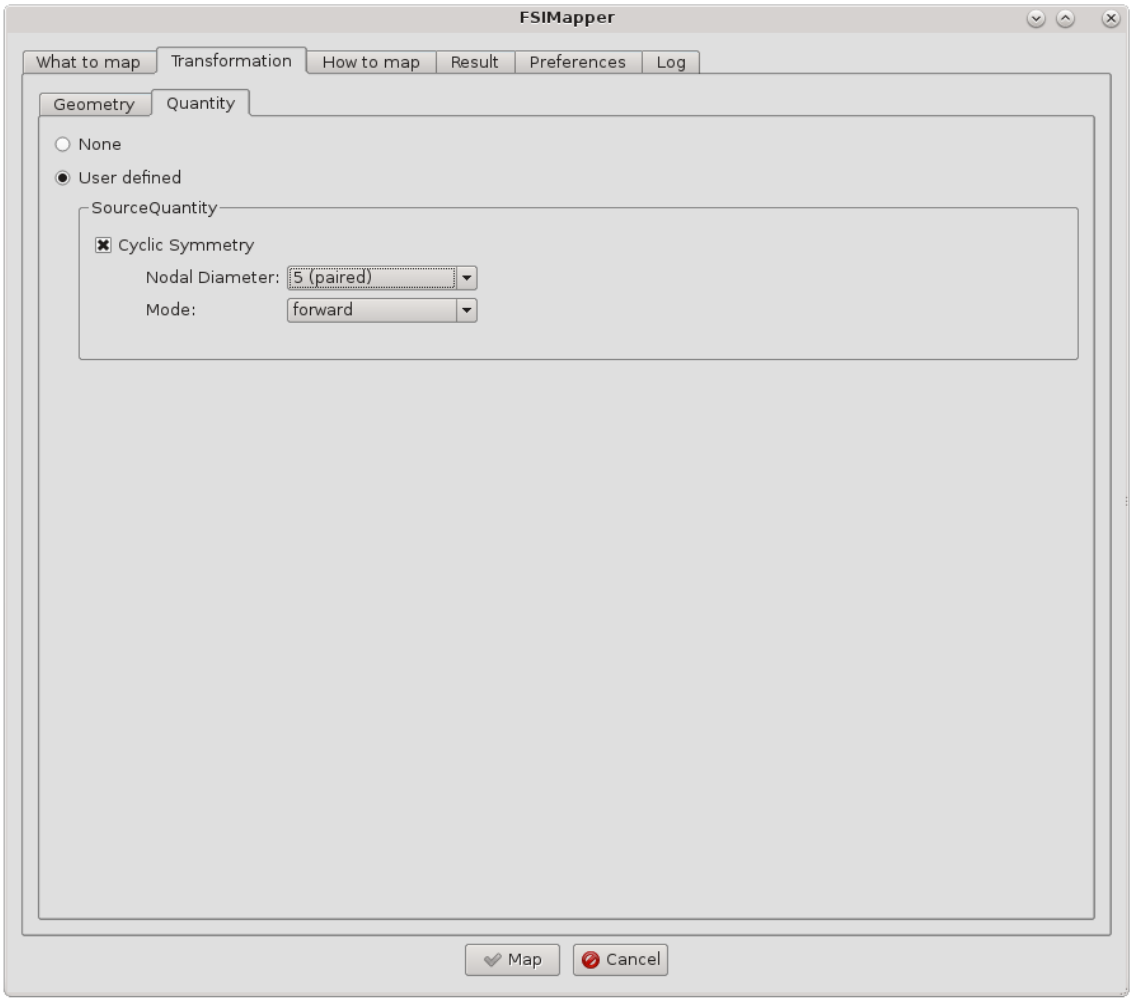
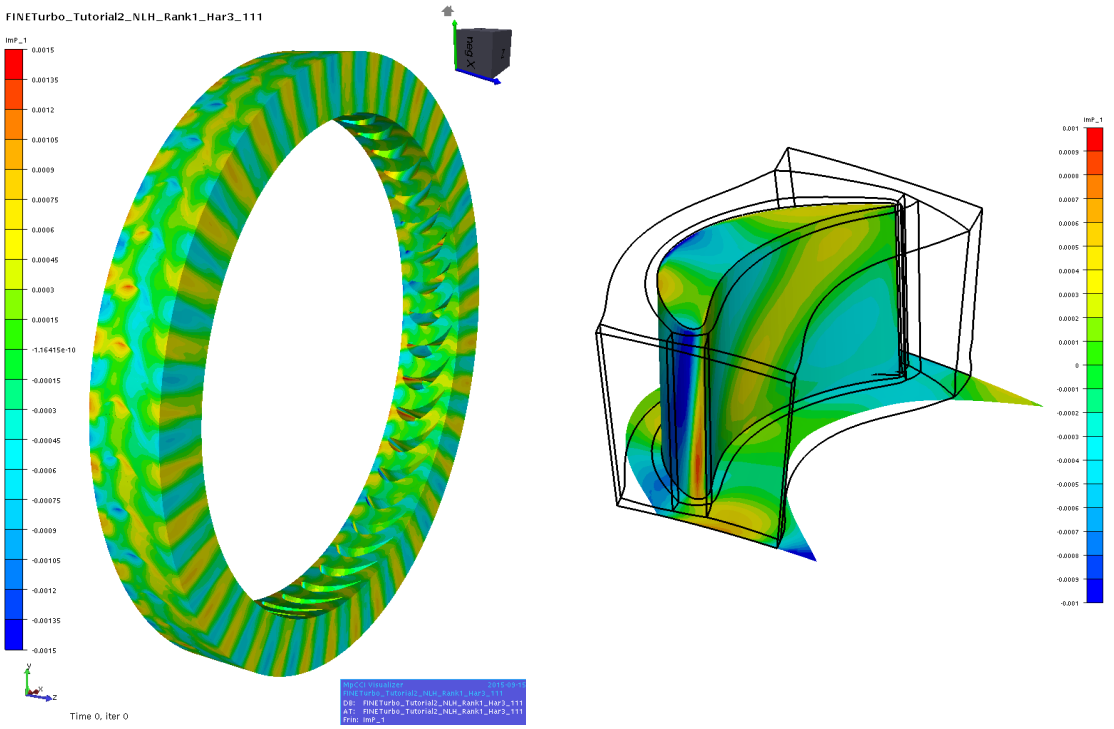


Figure 46: The "Transformation/Quantity" panel

When the mapping finishes, the MpCCI Visualizer shows the mapping results, cf. Figure 47.



(a) Full source model

(b) Mapping result (imaginary pressure) on target model with superimposed source model section shape (black outlines)

Figure 47: Harmonic mapping result shown in MpCCI Visualizer

The periodic mesh and data were transformed by the given information in order to create the full source model and the corresponding data (cf. Figure 47a). The first harmonic complex pressure excitation has been revolved such that the data are spacially continuous over the periodic boundaries, which ensures a correct mapping to the target surfaces which are not covered by the periodic source mesh, see Figure 47b. The continuity over the periodic source boundaries is only provided for the correctly selected nodal diameter and excitation mode.

MpCCI FSIMapper creates two Abaqus include files `"aachenBlade-mapped_HarmonicPressure_RE.inc"` and `"aachenBlade-mapped_HarmonicPressure_IM.inc"` where the real and imaginary part of the pressure is applied to the nodes building the wetted surfaces:

```
**
** Exported real part of surface pressure
** *CLOAD, REAL
37881,  8,  0.00040665
37882,  8,  0.00046127
37883,  8,  0.00038815
37884,  8,  0.00032466
37885,  8,  0.00037576
37886,  8,  0.00031139
...
```

```
**
** Exported imaginary part of surface pressure
** *CLOAD, IMAGINARY
37881,  8,  -0.00018233
37882,  8,  -0.00010771
37883,  8,  0.00001771
37884,  8,  -0.00033982
37885,  8,  -0.00023237
37886,  8,  -0.00014165
...
```

For an element-based pressure definition, select "Element" in the "How to map" panel in "Quantity location (target)". The keyword defining the pressure is then `*DLOAD` instead of `*CLOAD`.

Moreover, MpCCI FSIMapper creates the file `"aachenBlade-mapped_HarmonicPressure.ccvx"`. It can be opened in MpCCI Visualizer and shows the corresponding transient pressure fluctuations for 18 pseudo time steps. Pressing the button animates them with a speed set in File→Preferences→Maximum animation FPS.

8.2.2.5 Target Simulation

MpCCI FSIMapper exported for the first harmonic two include files containing the real and the imaginary part of the pressure excitation. They are located in the same folder as the Abaqus input deck. The load case definition in Abaqus uses these files in the following way:

```
**
*CYCLIC SYMMETRY MODEL, N=41
0, 0, 0, 0, 0, -1
**
...
**
*STEP, NAME=ModalAnalysis
**
*FREQUENCY, EIGENSOLVER=LANCZOS
 , 0, 5250, , , ,
*SELECT CYCLIC SYMMETRY MODES, NMIN=5, NMAX=5
**
*END STEP
**
**
**
*STEP, NAME=SSD_1H
**
*STEADY STATE DYNAMICS
2100, 0, , ,
**
*CLOAD, REAL, CYCLIC MODE=5
*INCLUDE, INPUT=aachenBlade-mapped_HarmonicPressure_RE.inc
**
*CLOAD, IMAGINARY, CYCLIC MODE=5
*INCLUDE, INPUT=aachenBlade-mapped_HarmonicPressure_IM.inc
**
```

```
*END STEP
**
```

The periodicity of the "Aachen" rotor blade is defined in Abaqus via the keyword `*CYCLIC SYMMETRY MODEL`. Since the excitation is in forward mode with respect to the negative z-axis, `0, 0, 0, 0, 0, -1` is given here to define the symmetry axis. The first harmonic pressure will excite only nodal diameter 5 mode shapes, which are determined in the `*FREQUENCY` step.
The excitation shape needs to be defined in the keyword `*CLOAD` by the option `CYCLIC MODE=5`.

Please check the Abaqus User's Keywords Reference Guide for the options of `*STEADY STATE DYNAMICS` concerning direct and modal solution methods.

For the sake of completeness use also the mean pressure (by a "Static" mapping), the centrifugal and the Coriolis forces (by the keyword `*DLOAD`).

The damping in the system has fundamental influence to the magnitude of blade vibration, so it is recommended to define it.

Since Abaqus only knows forward excitation modes, for backward excitations the cyclic symmetry axis (which was determined such that the rotation is positive) has to be turned around (only) for the definition in the Abaqus keyword `*CYCLIC SYMMETRY MODEL`.

8.3 Mapping of Temperature for Microelectronic Devices

8.3.1 Problem Description

In this tutorial, called "Board", the stationary temperature field inside a microelectronic device was simulated using Mentor Graphics computational fluid dynamics software FloTHERM. By a volume mapping of the resulting temperature field to a structural mechanics model a thermal stress analysis can be performed. Here, the mapping of temperature field is demonstrated for the software packages Abaqus, ANSYS and MSC NASTRAN.

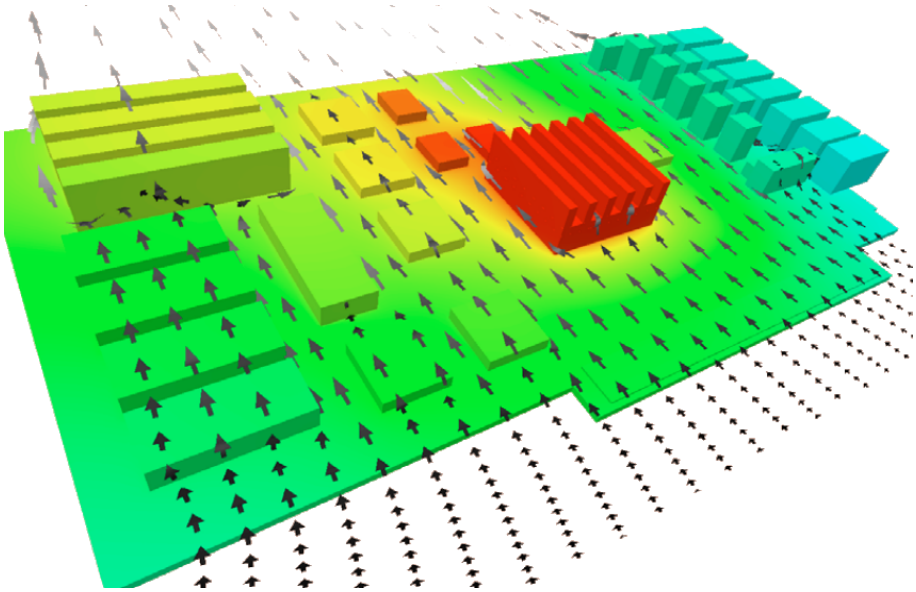


Figure 48: Temperature destribution and external flow field simulated by FloTHERM

The files concerning this tutorial are located in

- MpCCI FSIMapper as part of the MpCCI installation:
  "<*MpCCI_home*>/tutorial/FSIMapper/Board"
- MpCCI FSIMapper standalone installation:
  "<*MpCCIFSIMapper_home*>/tutorial/Board"

Before mapping, copy the files to your working directory.

8.3.2 Source Result File

The stationary simulation of the temperature field under operating conditions was performed using FloTHERM. The native FloTHERM model is not part of the MpCCI FSIMapper tutorial but its result exported (as .flofea file) from FloTHERM project manager. To export a simulation result from FloTHERM V10 and later, select the assembly in the Model panel. Using right-click on selected assembly, choose format "FLOFEA" below "Export Assembly".

The FloTHERM model consists of 14611 hexahedron elements, as length unit meter and temperature unit Celsius is used.

8.3.3 Target Mesh Files

The structural target mesh consists of 1279 8-node brick elements, as unit system mm-ton-second-celsius is used.

Abaqus

In Abaqus DC3D8 elements are used. The model is split up in three Abaqus parts. Each part has a single part instance in the Abaqus *ASSEMBLY section. To receive volumetric temperature distribution, one *ELSET definition per part is created.

ANSYS

In ANSYS SOLID185 elements are used. The elements of the model are grouped in three components using the ANSYS cm command.

MSC NASTRAN

In MSC NASTRAN CHEXA elements are used. The elements of the model are assigned to three part ids.

8.3.4 Mapping of Temperature

Open the MpCCI FSIMapper GUI and go to the "Static" tab of the "What to map" panel.

1. As source code select FloTHERM in the format selection dropdown menu.
2. Click on "Specify source geometry file" and select `"Board/FloTHERM/board.flofea"`
3. Confirm selection by pressing Open
4. The selected file is scanned in background and available parts for mapping are listed
5. Select all parts of the source model
6. In "Temperature" dropdown menu select "TEMPERATURE"
7. As target code select:

Abaqus

a) Abaqus in the format selection dropdown menu.
b) Click on "Specify target geometry file" and select `"Board/Abaqus/board.inp"`
c) Confirm selection by pressing Open
d) The selected file is scanned in background and available parts for mapping are listed
e) Select Elset -1 "Chips_All_Elements", Elset -2 "Board_All_Elements" and Elset -3 "Cooling_All_Elements"
f) The "What to map" panel of the mapping process now should look as shown in figure 49

ANSYS

a) ANSYS in the format selection dropdown menu.
b) Click on "Specify target geometry file" and select `"Board/ANSYS/board.db"`
c) Confirm selection by pressing Open

Scanning of ANSYS.db files requires a present ANSYS Mechanical APDL installation If no installation is available for this tutorial select `"Board/ANSYS/board.ml"` instead. See section 5.2.4 for details about scan process.

d) The selected file is scanned in background and available components for mapping are listed
e) Select Volume 1 "BOARD", Volume 2 "CHIPS" and Volume 3 "COOLING"

f) The “What to map” panel of the mapping process now should look as shown in figure 49

MSC NASTRAN

a) MSC NASTRAN in the format selection dropdown menu.
b) Click on “Specify target geometry file” and select `"Board/MSC.Nastran/board.bdf"`
c) Confirm selection by pressing Open
d) The selected file is scanned in background and available parts for mapping are listed
e) Select Volume 1 “1”, Volume 2 “2” and Volume 3 “2”
f) The “What to map” panel of the mapping process now should look as shown in figure 49

8. Go to the “How to map” panel and select Node in the “Quantity location” section
9. Press Map at the bottom of the MpCCI FSIMapper GUI and perform mapping

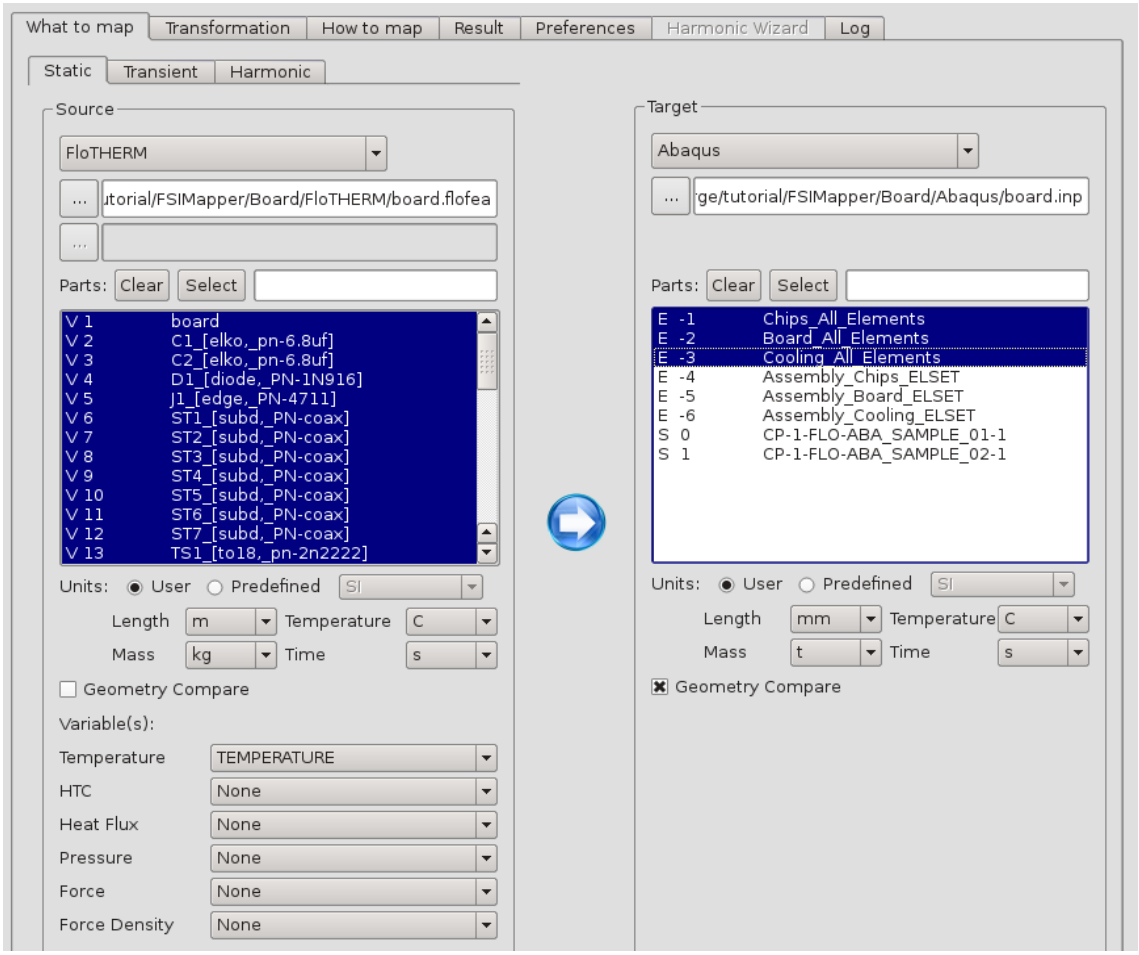


Figure 49: The “What to map” panel after step 7 for target code Abaqus

8.3.5 Results and Target Simulation

After pressing the “Map” button, using the predescribed process setup, the MpCCI FSIMapper runs the mapping. In the background both source and target model as well as the temperature distribution are

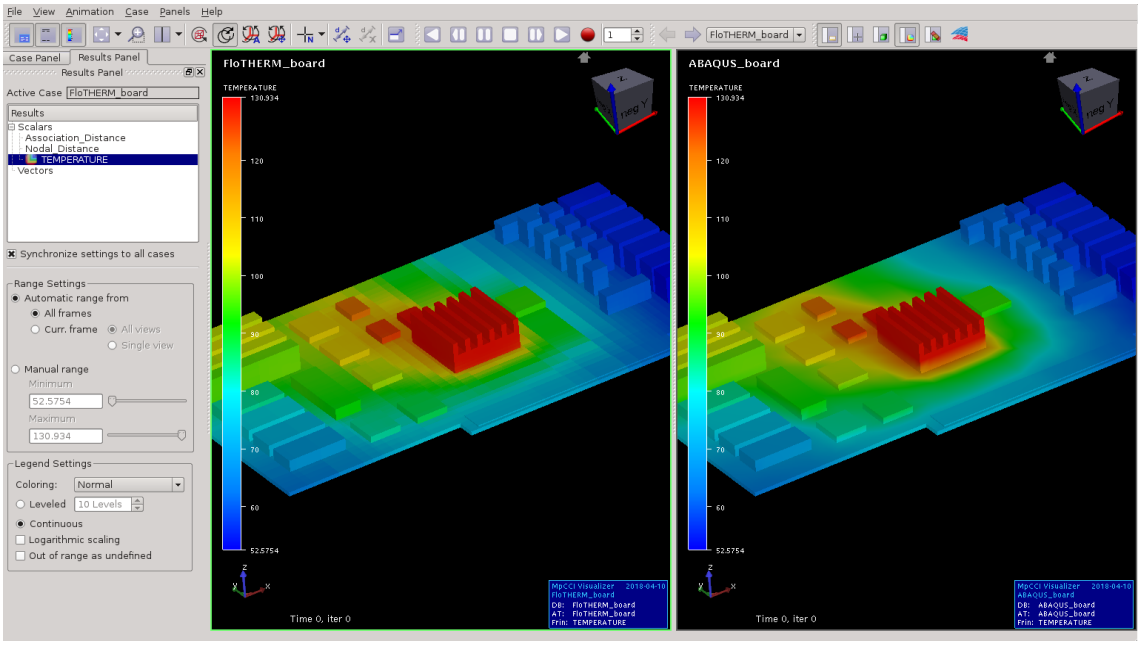


Figure 50: Temperature mapping result of the microelectronic device at the end of the mapping process.

read from file system and the data is interpolated to the new geometry. Then, all data is sent to MpCCI Visualizer for postprocessing (cf. figure 50). Then, MpCCI FSIMapper exports nodal based temperature to an ASCII-based input file in the native solver syntax. They are located in the same folder as the structural mechanics input deck.

Abaqus

For Abaqus the include file `"board-mapped_Temperature.inp"` is written, wherein the *TEMPERATURE keyword is used to define initial temperature values.

```
** Exported nodal temperature
** *TEMPERATURE
ChipsInstance.1,95.07985578
ChipsInstance.2,87.69397911
ChipsInstance.3,83.75685351
ChipsInstance.4,91.68932411
ChipsInstance.5,91.48773958
ChipsInstance.6,91.26212328
```

The temperature mapping result file can be included in another Abaqus simulation using the following include statement at *STEP level of the loadcase definition:

```
*INCLUDE, INPUT=board-mapped_Temperature.inp
```

ANSYS

For ANSYS the include file `"board-mapped_Temperature.inc"` is written, wherein the BF keyword in compination with TEMP is used to define initial temperature values.

```
C*** Exported nodal temperature
/PREP7
BF,       1,TEMP, 9.507985421E+01
BF,       2,TEMP, 8.769398132E+01
BF,       3,TEMP, 8.375684495E+01
BF,       4,TEMP, 9.168932019E+01
BF,       5,TEMP, 9.148773962E+01
BF,       6,TEMP, 9.126212312E+01
```

The temperature mapping result file can be included in another ANSYS simulation by "Read Input" inside ANSYS Mechanical APDL.

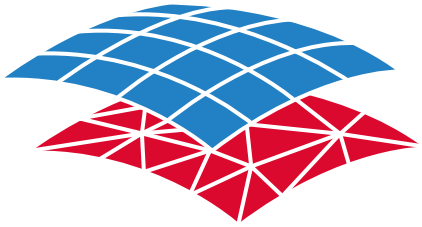
MSC NASTRAN

For MSC NASTRAN the include file `"board-mapped_Temperature_SPC.inc"` is written, wherein the SPC keyword is used to define initial temperature values.

```
$ Exported nodal temperature
SPC             1       1       195.07985
SPC             1       2       187.69398
SPC             1       3       183.75684
SPC             1       4       191.68932
SPC             1       5       191.48774
SPC             1       6       191.26212
```

The temperature mapping result file can be included in another MSC NASTRAN simulation using the following include statement:

```
INCLUDE 'board-mapped_Temperature_SPC.inc'
```



MpCCI
CouplingEnvironment

Part XI

—

Appendix

Version 4.7.1

MpCCI 4.7.1-1 Documentation
Part XI Appendix
PDF version
October 29, 2023

Fraunhofer Institute for Algorithms and Scientific Computing SCAI
Schloss Birlinghoven 1, 53757 Sankt Augustin, Germany

XI Appendix – Contents

Quantity Reference

Quantity	ANSYS	Abaqus	Adams	FINE/Open	FINE/Turbo	FLUENT	FloMASTER	ANSYS Icepak	JMAG	MATLAB	Marc	MSC NASTRAN	OpenFOAM	SIMPACK	STAR-CCM+	TAITherm
AbsPressure	s/r	r		s	s	s/r				s/r	r		s		s	
Acceleration		s/r	s/r							s/r						
AcstPressure						s/r										
AngularAcceleration		s/r	s/r							s/r						
AngularCoordinate		s/r	s/r							s/r				s		
AngularVelocity		s/r	s/r			r				s/r				s	r	
BodyForce	s	s/r				s/r				s/r						
CGAngle	s/r					s/r										
CGOmega	s/r					s/r										
CGPosition	s/r					s/r										
CGVelocity	s/r					s/r										
ChargeDensity	s/r					s/r										
Current1	s/r					s/r										
Current2	s/r					s/r										
Current3	s/r					s/r										
Current4	s/r					s/r										
CurrentDensity	s/r					s/r			s	s/r						
DeltaTime	s/r	s/r	s/r	s	s	s/r	s/r	s/r	s	s/r	s/r	s/r	s/r	r	s/r	s
Density				s	s	s/r										
DynPressure						s										
ElectrCond1	s/r					s/r			r	s/r						
ElectrCond3	s/r					s/r			r	s/r						
ElectrCondX	s/r					s/r				s/r						
ElectrCondY	s/r					s/r				s/r						
ElectrCondZ	s/r					s/r				s/r						
ElectricField	s					s/r										
ElectricFlux	s					s/r										
ElectricPot	s/r									s/r						
ElectrRes1	s/r					s/r				s/r						
ElectrRes3	s/r					s/r				s/r						
ElectrResX	s/r					s/r				s/r						
ElectrResY	s/r					s/r				s/r						
ElectrResZ	s/r					s/r				s/r						
Enthalpy	s					s/r		s/r								
FilmTemp	r	r				s/r		s/r		s/r	r		s		s	r
Force	s/r	s/r	s/r			s			s	s/r				s/r	s	
gs00																
gs01																
gs02																
gs03																
gs04																
gs05																

Quantity	ANSYS	Abaqus	Adams	FINE/Open	FINE/Turbo	FLUENT	FloMASTER	ANSYS Icepak	JMAG	MATLAB	Marc	MSC NASTRAN	OpenFOAM	SIMPACK	STAR-CCM+	TAITherm
gs06																
gs07																
gv00																
gv01																
gv02																
gv03																
gv04																
gv05																
gv06																
gv07																
HeatFlux	s					s/r		s/r								
HeatRate		r				s							s		s	
HeatSource	s					s/r		s/r								
IntFlag	s/r					s/r		s/r								
IterationNo	s/r			s		s/r		s/r							s/r	s
JouleHeat	s/r					s/r		s/r	s	s/r						
JouleHeatLin						s/r		s/r								
LorentzForce	s/r					s/r			s	s/r						
MagneticField	s					s/r										
MagneticFlux	s					s/r				s/r						
MassFlowRate						s/r	s/r			s/r			s/r		s/r	
MassFlowVect																
MassFluxRate						s/r	s/r			s/r			s/r		s/r	
MassFluxVect																
NPosition	s	s		r	r	s/r			s/r	s/r	s	s	r		r	
OverPressure	s/r	r		s	s	s/r					r		s		s	
PhysicalTime	s/r			s	s	s/r	s/r	s/r							s/r	s
PointPosition	s/r	s/r	s/r							s/r				s		
PorePressure		s/r				s/r										
PorousFlow		s/r														
RealFlag	s/r		s/r			s/r		s/r		s/r				r		
RefPressure	s/r			s	s	s/r									s/r	
RelWallForce	r	r		s	s	s/r					r	r	s		s/r	
Residual	s/r					s/r		s/r								s
SpecificHeat						s/r		s/r		s/r						
StaticPressure															s/r	
Temperature	s/r	s/r				s/r	s/r	s/r	r	s/r			s/r		s/r	
ThermCond1	s					s/r		s/r		s/r						
ThermCond3	s					s/r		s/r		s/r						
ThermCondX	s					s/r		s/r		s/r						
ThermCondY	s					s/r		s/r		s/r						
ThermCondZ	s					s/r		s/r		s/r						
TimeStepNo	s/r			s		s/r		s/r							s/r	s
Torque	s/r	s/r	s/r							s/r				s/r	s	

Quantity	ANSYS	Abaqus	Adams	FINE/Open	FINE/Turbo	FLUENT	FloMASTER	ANSYS Icepak	JMAG	MATLAB	Marc	MSC NASTRAN	OpenFOAM	SIMPACK	STAR-CCM+	TAITherm
TotalPressure						s/r	s/r			s/r			s/r		s/r	
TotalTemp																
Velocity	r	s/r	s/r	s		s/r				s/r		s	s/r	s	s/r	
VelocityMagnitude						s/r	s/r			s/r						
Voltage1	s/r					s/r										
Voltage2	s/r					s/r										
Voltage3	s/r					s/r										
Voltage4	s/r					s/r										
VolumeFlow																
VolumeFlowRate																
WallForce	r	s/r			s	s/r				s/r	r	r	s		s/r	
WallHeatFlux	s/r	r		s	s	s/r		s/r			r		s		s/r	r
WallHTCoeff	r	r				s/r		s/r		s/r	r		s		s	r
WallTemp	s/r	s/r		s/r	s/r	s/r		s/r		s/r	s		s/r		s/r	s
YI00																
YI01																
YI02																
YI03																
YI04																
YI05																
YI06																
YI07																
YI08																
YI09																

Table 12: Codes and Quantities: s = “code can send quantity”, r = “code can receive quantity”

AbsPressure Absolute pressure [N/m^2]

Code API symbol: `MPCCI_QID_ABSPRESSURE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct ETAB	Direct
Abaqus	Face	Code		Buffer
FINE/Open	Face	Node, Element	Direct	
FINE/Turbo	Face	Code	Direct	
FLUENT	Face, Volume	Code	Dir	UDM
MATLAB	Face	Code, Element	Direct	Direct
Marc	Line, Face, Volume	Element		Direct
OpenFOAM	Line, Face, Volume	Code	Dir	
STAR-CCM+	Face	Code	Direct	

Acceleration Acceleration vector [m/s^2]

Code API symbol: `MPCCI_QID_ACCELERATION`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
Abaqus	Point	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
MATLAB	Point	Code	Direct	Direct

AcstPressure Acoustic pressure [N/m^2]

Code API symbol: `MPCCI_QID_ACSTPRESSURE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Volume	Code	Dir	UDM

AngularAcceleration Angular acceleration [rad/s^2]

Code API symbol: `MPCCI_QID_ANGULARACCELERATION`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Point, Line

Code	Coupling Dimensions	Location	Send option	Receive option
Abaqus	Point	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
MATLAB	Point	Code	Direct	Direct

AngularCoordinate quaternion (i,j,k,w) [–]

Code API symbol: `MPCCI_QID_ANGULARCOORD`
Default value: 0.0
Dimension: Quaternion
Physical meaning: Grid displacement/coordinate
Interpolation type: mesh coordinate
Coupling Dimensions: Point, Line

Code	Coupling Dimensions	Location	Send option	Receive option
Abaqus	Point	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
MATLAB	Point	Code	Direct	Direct
SIMPACK	Point	Node	Direct	

AngularVelocity Angular velocity [rad/s]

Code API symbol: `MPCCI_QID_ANGULARVELOCITY`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Point, Line

Code	Coupling Dimensions	Location	Send option	Receive option
Abaqus	Point	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
FLUENT	Point	Code		Buf
MATLAB	Point	Code	Direct	Direct
SIMPACK	Point	Node	Direct	
STAR-CCM+	Point	Code		Direct

BodyForce General body force density vector [N/m^3]

Code API symbol: `MPCCI_QID_BODYFORCE`
Default value: 0.0
Dimension: Vector
Physical meaning: Momentum source
Interpolation type: flux density
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Volume	Node, Element	ETAB	
Abaqus	Volume	Code	Direct	Buffer
FLUENT	Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

CGAngle Moving obstacle CG angle [rad]

Code API symbol: `MPCCI_QID_MO_ANGLE`
Default value: 0.0
Dimension: Vector
Physical meaning: Grid displacement/coordinate
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

CGOmega Moving obstacle CG angular velocity [rad/s]

Code API symbol: `MPCCI_QID_MO_OMEGA`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

CGPosition Moving obstacle CG position [m]

Code API symbol: `MPCCI_QID_MO_POSITION`
Default value: 0.0
Dimension: Vector
Physical meaning: Grid displacement/coordinate
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

CGVelocity Moving obstacle CG velocity [m/s]

Code API symbol: `MPCCI_QID_MO_VELOCITY`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

ChargeDensity Charge density [C/m^3]

Code API symbol: `MPCCI_QID_CHARGEDENSITY`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Volume	Element	ETAB	Direct
FLUENT	Volume	Code	UDM	UDM

Current1 Electric current - phase 1 [A]

Code API symbol: `MPCCI_QID_CURRENT1`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

Current2 Electric current - phase 2 [A]

Code API symbol: `MPCCI_QID_CURRENT2`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

Current3 Electric current - phase 3 [A]

Code API symbol: `MPCCI_QID_CURRENT3`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

Current4 Electric current - phase 4 [A]

Code API symbol: `MPCCI_QID_CURRENT4`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

CurrentDensity Electric current density vector [A/m^2]

Code API symbol: `MPCCI_QID_CURRENTDENSITY`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: face normal gradient
Interpolation type: flux density
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Face, Volume	Code	UDM UDS	UDM
JMAG	Volume	Element	Direct	
MATLAB	Volume	Node, Element	Direct	Direct

DeltaTime Time step size [s]

Code API symbol: `MPCCI_QID_TIMESTEP_SIZE`
Default value: 1.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-min
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
Abaqus	Global	global	Direct	Direct
Adams	Global	global	Direct	Usermemory
FINE/Open	Global	global	Direct	
FINE/Turbo	Global	global	Direct	
FLUENT	Global	global	Dir	Dir
FloMASTER	Global	global	Direct	Direct
ANSYS Icepak	Global	global	Dir	Dir
JMAG	Global	global	Direct	
MATLAB	Global	global	Direct	Direct
Marc	Global	global	Direct	Direct
MSC NASTRAN	Global	global	Direct	Direct
OpenFOAM	Global	global	Dir	Dir
SIMPACK	Global	global		Direct
STAR-CCM+	Global	global	Direct	Direct
TAITherm	Global	global	Direct	

Density Density [kg/m^3]

Code API symbol: `MPCCI_QID_DENSITY`
Default value: 1.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
FINE/Open	Volume	Node, Element	Direct	
FINE/Turbo	Volume	Code	Direct	
FLUENT	Volume	Code	Dir	UDM

DynPressure Dynamic pressure [N/m^2]

Code API symbol: `MPCCI_QID_DYNPRESSURE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Face	Code	Dir	

ElectrCond1 Electric conductivity - xyz [S/m]

Code API symbol: `MPCCI_QID_ELECTCOND1`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Face, Volume	Code	UDM	UDM
JMAG	Volume	Node		Direct
MATLAB	Volume	Node, Element	Direct	Direct

ElectrCond3 Electric conductivity - (x,y,z) [S/m]

Code API symbol: `MPCCI_QID_ELECTCOND3`
Default value: 0.0
Dimension: Vector
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Face, Volume	Code	UDM	UDM
JMAG	Volume	Node		Direct
MATLAB	Volume	Node, Element	Direct	Direct

ElectrCondX Electric conductivity - x [S/m]

Code API symbol: `MPCCI_QID_ELECTCONDX`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ElectrCondY Electric conductivity - y [S/m]

Code API symbol: `MPCCI_QID_ELECTCONDY`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ElectrCondZ Electric conductivity - z [S/m]

Code API symbol: `MPCCI_QID_ELECTCONDZ`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ElectricField Electric field vector [V/m]

Code API symbol: `MPCCI_QID_ELECTRICFIELD`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: face normal gradient
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Volume	Element	ETAB	
FLUENT	Volume	Code	UDM UDS	UDM

ElectricFlux Electric flux vector [C/m^2]

Code API symbol: `MPCCI_QID_ELECTRICFLUX`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: face normal gradient
Interpolation type: flux density
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Volume	Element	ETAB	
FLUENT	Face, Volume	Code	UDM UDS	UDM

ElectricPot Electric Potential [V]

Code API symbol: `MPCCI_QID_ELECTRICPOT`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Node	Direct	Direct
MATLAB	Volume	Node, Element	Direct	Direct

ElectrRes1 Electric resistivity - xyz [ohm m]

Code API symbol: `MPCCI_QID_ELECTRESV1`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Face, Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ElectrRes3 Electric resistivity - (x,y,z) [ohm m]

Code API symbol: `MPCCI_QID_ELECTRESV3`
Default value: 0.0
Dimension: Vector
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Face, Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ElectrResX Electric resistivity - x [ohm m]

Code API symbol: `MPCCI_QID_ELECTRESVX`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ElectrResY Electric resistivity - y [ohm m]

Code API symbol: `MPCCI_QID_ELECTRESVY`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ElectrResZ Electric resistivity - z [ohm m]

Code API symbol: `MPCCI_QID_ELECTRESVZ`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	Direct
FLUENT	Volume	Code	UDM	UDM
MATLAB	Volume	Node, Element	Direct	Direct

Enthalpy Enthalpy density [W/m^3]

Code API symbol: `MPCCI_QID_ENTHALPY`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: flux density
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Volume	Node, Element	ETAB	
FLUENT	Volume	Code	Dir	UDM
ANSYS Icepak	Volume	Code	Dir	UDM

FilmTemp Film temperature [K]

Code API symbol: `MPCCI_QID_FILMTEMPERATURE`
Default value: 300.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Line, Face

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Face	Element		Direct
Abaqus	Face	Code		Buffer Direct
FLUENT	Face	Code	Dir	UDM
ANSYS Icepak	Face	Code	Dir	UDM
MATLAB	Face	Code, Element	Direct	Direct
Marc	Line, Face	Element		Direct
OpenFOAM	Line, Face	Code	Dir	
STAR-CCM+	Face	Code	Direct	
TAITherm	Face	Code		Direct

Force Force [N]

Code API symbol: `MPCCI_QID_FORCE`
Default value: 0.0
Dimension: Vector
Physical meaning: Momentum source
Interpolation type: flux integral
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Point	Node	Direct	Direct
Abaqus	Point, Face	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
FLUENT	Face	Code	Dir	
JMAG	Volume	Node	Direct	
MATLAB	Point	Code	Direct	Direct
SIMPACK	Point	Node	Direct	Direct
STAR-CCM+	Face	Code	Direct	

gs00 Global scalar 00 [–]

Code API symbol: `MPCCI_QID_UGS_00`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

The quantity is currently not supported by any standard code.

gs01 Global scalar 01 [–]

Code API symbol: `MPCCI_QID_UGS_01`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

The quantity is currently not supported by any standard code.

gs02 Global scalar 02 [–]

Code API symbol: `MPCCI_QID_UGS_02`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

The quantity is currently not supported by any standard code.

gs03 Global scalar 03 [–]

Code API symbol:	`MPCCI_QID_UGS_03`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gs04 Global scalar 04 [–]

Code API symbol:	`MPCCI_QID_UGS_04`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gs05 Global scalar 05 [–]

Code API symbol:	`MPCCI_QID_UGS_05`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gs06 Global scalar 06 [–]

Code API symbol:	`MPCCI_QID_UGS_06`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gs07 Global scalar 07 [–]

Code API symbol:	`MPCCI_QID_UGS_07`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv00 Global vector 00 [–]

Code API symbol:	`MPCCI_QID_UGV_00`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv01 Global vector 01 [–]

Code API symbol:	`MPCCI_QID_UGV_01`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv02 Global vector 02 [–]

Code API symbol:	`MPCCI_QID_UGV_02`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv03 Global vector 03 [–]

Code API symbol:	`MPCCI_QID_UGV_03`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv04 Global vector 04 [–]

Code API symbol:	`MPCCI_QID_UGV_04`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv05 Global vector 05 [–]

Code API symbol:	`MPCCI_QID_UGV_05`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv06 Global vector 06 [–]

Code API symbol:	`MPCCI_QID_UGV_06`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

gv07 Global vector 07 [–]

Code API symbol:	`MPCCI_QID_UGV_07`
Default value:	0.0
Dimension:	Vector
Physical meaning:	General
Interpolation type:	g-max
Coupling Dimensions:	Global

The quantity is currently not supported by any standard code.

HeatFlux Heat flux density vector [W/m^2]

Code API symbol:	`MPCCI_QID_HEATFLUX`
Default value:	0.0
Dimension:	Vector
Physical meaning:	Boundary condition: face normal gradient
Interpolation type:	flux density
Coupling Dimensions:	Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Volume	Node, Element	ETAB	
FLUENT	Volume	Code	UDM	UDM
ANSYS Icepak	Volume	Code	UDM	UDM

HeatRate Heat rate [W]

Code API symbol: `MPCCI_QID_HEATRATE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
Abaqus	Face	Code		Buffer
FLUENT	Face	Code	Dir	
OpenFOAM	Face	Code	Dir	
STAR-CCM+	Face	Code	Direct	

HeatSource General heat source density [W/m^3]

Code API symbol: `MPCCI_QID_HEATSOURCE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Energy source
Interpolation type: flux density
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Volume	Node, Element	ETAB	
FLUENT	Volume	Code	UDM	UDM
ANSYS Icepak	Volume	Code	UDM	UDM

IntFlag Control switch(Int) [–]

Code API symbol: `MPCCI_QID_INT_SWITCH`
Default value: 0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir
ANSYS Icepak	Global	global	Dir	Dir

IterationNo Iteration number [–]

Code API symbol: `MPCCI_QID_ITERATION_COUNT`
Default value: 0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FINE/Open	Global	global	Direct	
FLUENT	Global	global	Dir	Dir
ANSYS Icepak	Global	global	Dir	Dir
STAR-CCM+	Global	global	Direct	Direct
TAITherm	Global	global	Direct	

JouleHeat Joule heat density [W/m^3]

Code API symbol: `MPCCI_QID_JOULEHEAT`
Default value: 0.0
Dimension: Scalar
Physical meaning: Energy source
Interpolation type: flux density
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Volume	Element	Direct ETAB	Direct
FLUENT	Volume	Code	UDM	UDM
ANSYS Icepak	Volume	Code	UDM	UDM
JMAG	Volume	Element	Direct	
MATLAB	Volume	Node, Element	Direct	Direct

JouleHeatLin Joule heat linearization [$W/m^3\,K$]

Code API symbol: `MPCCI_QID_JOULEHEATLIN`
Default value: 0.0
Dimension: Scalar
Physical meaning: Energy source
Interpolation type: flux density
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Volume	Code	UDM	UDM
ANSYS Icepak	Volume	Code	UDM	UDM

LorentzForce Lorentz force density vector [N/m^3]

Code API symbol: `MPCCI_QID_LORENTZFORCE`
Default value: 0.0
Dimension: Vector
Physical meaning: Momentum source
Interpolation type: flux density
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Volume	Node, Element	Direct ETAB	Direct
FLUENT	Volume	Code	UDM	UDM
JMAG	Volume	Element	Direct	
MATLAB	Volume	Node, Element	Direct	Direct

MagneticField Magnetic field vector [A/m]

Code API symbol: `MPCCI_QID_MAGNETICFIELD`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: face normal gradient
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Volume	Element	ETAB	
FLUENT	Volume	Code	UDM UDS	UDM

MagneticFlux Magnetic flux density vector [T]

Code API symbol: `MPCCI_QID_MAGNETICFLUX`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: face normal gradient
Interpolation type: flux density
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	
FLUENT	Face, Volume	Code	UDM UDS	UDM
MATLAB	Volume	Node, Element	Direct	Direct

MassFlowRate Mass flow rate [kg/s]

Code API symbol: `MPCCI_QID_MASSFLOWRATE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Mass source
Interpolation type: flux integral
Coupling Dimensions: Point, Face

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Face	Code	Dir	UDM
FloMASTER	Point	Code	Direct	Direct
MATLAB	Point	Code	Direct	Direct
OpenFOAM	Face	Code	Dir	Dir
STAR-CCM+	Face	Code	Direct	Direct

MassFlowVect Mass flow vector [kg/s]

Code API symbol:	`MPCCI_QID_MASSFLOWVECT`
Default value:	0.0
Dimension:	Vector
Physical meaning:	Mass source
Interpolation type:	flux integral
Coupling Dimensions:	Volume

The quantity is currently not supported by any standard code.

MassFluxRate Mass flux rate [$kg/m^2\,s$]

Code API symbol:	`MPCCI_QID_MASSFLUXRATE`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Mass source
Interpolation type:	flux density
Coupling Dimensions:	Point, Face

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Face	Code	Dir	UDM
FloMASTER	Point	Code	Direct	Direct
MATLAB	Point	Code	Direct	Direct
OpenFOAM	Face	Code	Dir	Dir
STAR-CCM+	Face	Code	Direct	Direct

MassFluxVect Mass flux vector [$kg/m^2\,s$]

Code API symbol:	`MPCCI_QID_MASSFLUXVECT`
Default value:	0.0
Dimension:	Vector
Physical meaning:	Mass source
Interpolation type:	flux density
Coupling Dimensions:	Volume

The quantity is currently not supported by any standard code.

NPosition Nodal position [m]

Code API symbol: `MPCCI_QID_NPOSITION`
Default value: 0.0
Dimension: Vector
Physical meaning: Grid displacement/coordinate
Interpolation type: mesh coordinate
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Node	Direct	
Abaqus	Face, Volume	Code	Direct	
FINE/Open	Face	Node		Direct
FINE/Turbo	Face	Code		Direct
FLUENT	Face, Volume	Code	Dir	Buf
JMAG	Volume	Node	Direct	Direct
MATLAB	Face, Volume	Code	Direct	Direct
Marc	Line, Face, Volume	Node	Direct	
MSC NASTRAN	Line, Face	Code	Direct	
OpenFOAM	Line, Face, Volume	Code		Dir
STAR-CCM+	Face	Code		Direct

OverPressure Relative pressure [N/m^2]

Code API symbol: `MPCCI_QID_OVERPRESSURE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct ETAB	Direct
Abaqus	Face	Code		Buffer
FINE/Open	Face	Node, Element	Direct	
FINE/Turbo	Face	Code	Direct	
FLUENT	Face, Volume	Code	Dir	UDM
Marc	Line, Face, Volume	Element		Direct
OpenFOAM	Line, Face, Volume	Code	Dir	
STAR-CCM+	Face	Code	Direct	

PhysicalTime Physical time [s]

Code API symbol: `MPCCI_QID_PHYSICAL_TIME`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-min
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FINE/Open	Global	global	Direct	
FINE/Turbo	Global	global	Direct	
FLUENT	Global	global	Dir	Dir
FloMASTER	Global	global	Direct	Direct
ANSYS Icepak	Global	global	Dir	Dir
STAR-CCM+	Global	global	Direct	Direct
TAITherm	Global	global	Direct	

PointPosition Point position [m]

Code API symbol: `MPCCI_QID_POINTPOSITION`
Default value: 0.0
Dimension: Vector
Physical meaning: Grid displacement/coordinate
Interpolation type: mesh coordinate
Coupling Dimensions: Point

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Point	Node	Direct	Direct
Abaqus	Point	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
MATLAB	Point	Code	Direct	Direct
SIMPACK	Point	Node	Direct	

PorePressure Pore pressure [N/m^2]

Code API symbol: `MPCCI_QID_POREPRESSURE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
Abaqus	Face, Volume	Code	Direct	Buffer
FLUENT	Volume	Code	Dir	UDM

PorousFlow Pore fluid flow [m/s]

Code API symbol: `MPCCI_QID_POREFLOW`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: face normal gradient
Interpolation type: flux density
Coupling Dimensions: Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
Abaqus	Face, Volume	Code	Direct	Buffer

RealFlag Control switch(Real) [–]

Code API symbol: `MPCCI_QID_REAL_SWITCH`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
Adams	Global	global	Direct	Usermemory
FLUENT	Global	global	Dir	Dir
ANSYS Icepak	Global	global	Dir	Dir
MATLAB	Global	global	Direct	Direct
SIMPACK	Global	global		Direct

RefPressure Reference pressure [N/m^2]

Code API symbol: `MPCCI_QID_REF_PRESSURE`
Default value: 1.12e5
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FINE/Open	Global	global	Direct	
FINE/Turbo	Global	global	Direct	
FLUENT	Global	global	Dir	Dir
STAR-CCM+	Global	global	Direct	Direct

RelWallForce Boundary relative force vector [N]

Code API symbol: `MPCCI_QID_RELWALLFORCE`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: flux integral
Coupling Dimensions: Line, Face

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Face	Node		Direct
Abaqus	Face	Code		Buffer
FINE/Open	Face	Element	Direct	
FINE/Turbo	Face	Code	Direct	
FLUENT	Face	Code	Dir	UDM
Marc	Line, Face	Node		Direct
MSC NASTRAN	Line, Face	Code		Direct
OpenFOAM	Line, Face	Code	Dir	
STAR-CCM+	Face	Code	Direct	Direct

Residual Global residual [–]

Code API symbol: `MPCCI_QID_GLOBAL_RESIDUAL`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir
ANSYS Icepak	Global	global	Dir	Dir
TAITherm	Global	global	Direct	

SpecificHeat Specific heat [J/kg K]

Code API symbol: `MPCCI_QID_SPECHEAT`
Default value: 1.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Volume

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Volume	Code	Dir	UDM
ANSYS Icepak	Volume	Code	Dir	UDM
MATLAB	Volume	Node, Element	Direct	Direct

StaticPressure Static pressure [N/m^2]

Code API symbol: `MPCCI_QID_STATICPRESSURE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
STAR-CCM+	Face	Code	Direct	Direct

Temperature Temperature [K]

Code API symbol: `MPCCI_QID_TEMPERATURE`
Default value: 300.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Volume	Node, Element	Direct ETAB	Direct
Abaqus	Volume	Code	Direct	Buffer
FLUENT	Face, Volume	Code	Dir	UDM
FloMASTER	Point	Code	Direct	Direct
ANSYS Icepak	Volume	Code	Dir	UDM
JMAG	Volume	Node		Direct
MATLAB	Point, Volume	Code, Element	Direct	Direct
OpenFOAM	Line, Face, Volume	Code	Dir	Dir
STAR-CCM+	Face	Code	Direct	Direct

ThermCond1 Thermal conductivity - xyz [W/m K]

Code API symbol: `MPCCI_QID_THERMCOND1`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	
FLUENT	Face, Volume	Code	Dir	UDM
ANSYS Icepak	Face, Volume	Code	Dir	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ThermCond3 Thermal conductivity -(x,y,z) [W/m K]

Code API symbol: `MPCCI_QID_THERMCOND3`
Default value: 0.0
Dimension: Vector
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	
FLUENT	Face, Volume	Code	Dir	UDM
ANSYS Icepak	Face, Volume	Code	Dir	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ThermCondX Thermal conductivity - x [W/m K]

Code API symbol: `MPCCI_QID_THERMCONDX`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	
FLUENT	Volume	Code	Dir	UDM
ANSYS Icepak	Volume	Code	Dir	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ThermCondY Thermal conductivity - y [W/m K]

Code API symbol: `MPCCI_QID_THERMCONDY`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	
FLUENT	Volume	Code	Dir	UDM
ANSYS Icepak	Volume	Code	Dir	UDM
MATLAB	Volume	Node, Element	Direct	Direct

ThermCondZ Thermal conductivity - z [W/m K]

Code API symbol: `MPCCI_QID_THERMCONDZ`
Default value: 0.0
Dimension: Scalar
Physical meaning: Material property/general property
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Line, Face, Volume	Element	Direct	
FLUENT	Volume	Code	Dir	UDM
ANSYS Icepak	Volume	Code	Dir	UDM
MATLAB	Volume	Node, Element	Direct	Direct

TimeStepNo Time step number [–]

Code API symbol: `MPCCI_QID_TIMESTEP_COUNT`
Default value: 0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FINE/Open	Global	global	Direct	
FLUENT	Global	global	Dir	Dir
ANSYS Icepak	Global	global	Dir	Dir
STAR-CCM+	Global	global	Direct	Direct
TAITherm	Global	global	Direct	

Torque Torque [N m]

Code API symbol: `MPCCI_QID_TORQUE`
Default value: 0.0
Dimension: Vector
Physical meaning: Momentum source
Interpolation type: flux integral
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Point	Node	Direct	Direct
Abaqus	Point	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
MATLAB	Point	Code	Direct	Direct
SIMPACK	Point	Node	Direct	Direct
STAR-CCM+	Face	Code	Direct	

TotalPressure Total pressure [N/m^2]

Code API symbol: `MPCCI_QID_TOTALPRESSURE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: flux density
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Face	Code	Dir	UDM
FloMASTER	Point	Code	Direct	Direct
MATLAB	Point	Code	Direct	Direct
OpenFOAM	Line, Face, Volume	Code	Dir	Dir
STAR-CCM+	Face	Code	Direct	Direct

TotalTemp Total Temperature [K]

Code API symbol: `MPCCI_QID_TOTALTEMP`
Default value: 300.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

The quantity is currently not supported by any standard code.

Velocity Velocity vector [m/s]

Code API symbol: `MPCCI_QID_VELOCITY`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Volume	Element		Direct
Abaqus	Point, Face, Volume	Code	Direct	Buffer
Adams	Point	Node	Direct	Usermemory
FINE/Open	Face	Node, Element	Direct	
FLUENT	Point, Face, Volume	Code	Dir	UDM Buf
MATLAB	Point	Code	Direct	Direct
MSC NASTRAN	Line, Face	Code	Direct	
OpenFOAM	Line, Face, Volume	Code	Dir	Dir
SIMPACK	Point	Node	Direct	
STAR-CCM+	Point, Face	Code	Direct	Direct

VelocityMagnitude Velocity magnitude [m/s]

Code API symbol: `MPCCI_QID_VELOCITYMAG`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Point, Line, Face, Volume

Code	Coupling Dimensions	Location	Send option	Receive option
FLUENT	Face	Code	Dir	UDM
FloMASTER	Point	Code	Direct	Direct
MATLAB	Point	Code	Direct	Direct

Voltage1 Electric voltage - phase 1 [V]

Code API symbol: `MPCCI_QID_VOLTAGE1`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

Voltage2 Electric voltage - phase 2 [V]

Code API symbol: `MPCCI_QID_VOLTAGE2`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

Voltage3 Electric voltage - phase 3 [V]

Code API symbol: `MPCCI_QID_VOLTAGE3`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

Voltage4 Electric voltage - phase 4 [V]

Code API symbol: `MPCCI_QID_VOLTAGE4`
Default value: 0.0
Dimension: Scalar
Physical meaning: General
Interpolation type: g-max
Coupling Dimensions: Global

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Global	global	APDL	APDL
FLUENT	Global	global	Dir	Dir

VolumeFlow Volume flow vector [m^3/s]

Code API symbol: `MPCCI_QID_VOLFLOWVECT`
Default value: 0.0
Dimension: Vector
Physical meaning: Mass source
Interpolation type: flux integral
Coupling Dimensions: Volume

The quantity is currently not supported by any standard code.

VolumeFlowRate Volume flow rate [m^3/s]

Code API symbol: `MPCCI_QID_VOLFLOWRATE`
Default value: 0.0
Dimension: Scalar
Physical meaning: Mass source
Interpolation type: flux integral
Coupling Dimensions: Point, Face

The quantity is currently not supported by any standard code.

WallForce Boundary absolute force vector [N]

Code API symbol: `MPCCI_QID_WALLFORCE`
Default value: 0.0
Dimension: Vector
Physical meaning: Boundary condition: value
Interpolation type: flux integral
Coupling Dimensions: Line, Face

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Face	Node		Direct
Abaqus	Face	Code	Direct	Buffer
FINE/Turbo	Face	Code	Direct	
FLUENT	Face	Code	Dir	UDM
MATLAB	Face	Code, Element	Direct	Direct
Marc	Line, Face	Node		Direct
MSC NASTRAN	Line, Face	Code		Direct
OpenFOAM	Line, Face	Code	Dir	
STAR-CCM+	Face	Code	Direct	Direct

WallHeatFlux Boundary normal heat flux density [W/m^2]

Code API symbol: `MPCCI_QID_WALLHEATFLUX`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: face normal gradient
Interpolation type: flux density
Coupling Dimensions: Line, Face

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Face	Element	Direct	Direct
Abaqus	Face	Code		Buffer
FINE/Open	Face	Element	Direct	
FINE/Turbo	Face	Code	Direct	
FLUENT	Face	Code	Dir	UDM
ANSYS Icepak	Face	Code	Dir	UDM
Marc	Line, Face	Element		Direct
OpenFOAM	Line, Face	Code	Dir	
STAR-CCM+	Face	Code	Direct	Direct
TAITherm	Face	Code		Direct

WallHTCoeff Boundary heat transfer coefficient [$W/m^2\,K$]

Code API symbol: `MPCCI_QID_WALLHTCOEFF`
Default value: 0.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Line, Face

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Face	Element		Direct
Abaqus	Face	Code		Buffer
FLUENT	Face	Code	Dir	UDM
ANSYS Icepak	Face	Code	Dir	UDM
MATLAB	Face	Code, Element	Direct	Direct
Marc	Line, Face	Element		Direct
OpenFOAM	Line, Face	Code	Dir	
STAR-CCM+	Face	Code	Direct	
TAITherm	Face	Code		Direct

WallTemp Boundary temperature [K]

Code API symbol: `MPCCI_QID_WALLTEMPERATURE`
Default value: 300.0
Dimension: Scalar
Physical meaning: Boundary condition: value
Interpolation type: field
Coupling Dimensions: Line, Face

Code	Coupling Dimensions	Location	Send option	Receive option
ANSYS	Face	Node, Element	Direct	Direct
Abaqus	Face	Code	Direct	Buffer
FINE/Open	Face	Element	Direct	Direct
FINE/Turbo	Face	Code	Direct	Direct
FLUENT	Face	Code	Dir	UDM
ANSYS Icepak	Face	Code	Dir	UDM
MATLAB	Face	Code, Element	Direct	Direct
Marc	Line, Face	Node	Direct	
OpenFOAM	Line, Face	Code	Dir	Dir
STAR-CCM+	Face	Code	Direct	Direct
TAITherm	Face	Code	Direct	

YI00 Species mass fraction 00 [–]

Code API symbol: `MPCCI_QID_YI_00`
Default value: 0.0
Dimension: Scalar
Physical meaning: Chemical component
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

The quantity is currently not supported by any standard code.

YI01 Species mass fraction 01 [–]

Code API symbol: `MPCCI_QID_YI_01`
Default value: 0.0
Dimension: Scalar
Physical meaning: Chemical component
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

The quantity is currently not supported by any standard code.

YI02 Species mass fraction 02 [–]

Code API symbol: `MPCCI_QID_YI_02`
Default value: 0.0
Dimension: Scalar
Physical meaning: Chemical component
Interpolation type: field
Coupling Dimensions: Line, Face, Volume

The quantity is currently not supported by any standard code.

YI03 Species mass fraction 03 [–]

Code API symbol:	`MPCCI_QID_YI_03`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Chemical component
Interpolation type:	field
Coupling Dimensions:	Line, Face, Volume

The quantity is currently not supported by any standard code.

YI04 Species mass fraction 04 [–]

Code API symbol:	`MPCCI_QID_YI_04`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Chemical component
Interpolation type:	field
Coupling Dimensions:	Line, Face, Volume

The quantity is currently not supported by any standard code.

YI05 Species mass fraction 05 [–]

Code API symbol:	`MPCCI_QID_YI_05`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Chemical component
Interpolation type:	field
Coupling Dimensions:	Line, Face, Volume

The quantity is currently not supported by any standard code.

YI06 Species mass fraction 06 [–]

Code API symbol:	`MPCCI_QID_YI_06`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Chemical component
Interpolation type:	field
Coupling Dimensions:	Line, Face, Volume

The quantity is currently not supported by any standard code.

YI07 Species mass fraction 07 [–]

Code API symbol:	`MPCCI_QID_YI_07`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Chemical component
Interpolation type:	field
Coupling Dimensions:	Line, Face, Volume

The quantity is currently not supported by any standard code.

YI08 Species mass fraction 08 [–]

Code API symbol:	`MPCCI_QID_YI_08`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Chemical component
Interpolation type:	field
Coupling Dimensions:	Line, Face, Volume

The quantity is currently not supported by any standard code.

YI09 Species mass fraction 09 [–]

Code API symbol:	`MPCCI_QID_YI_09`
Default value:	0.0
Dimension:	Scalar
Physical meaning:	Chemical component
Interpolation type:	field
Coupling Dimensions:	Line, Face, Volume

The quantity is currently not supported by any standard code.

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Glossary

The aim of this glossary is to give a short description of the most important technical terms which are used in this manual and the context of MpCCI. For further reference, links to the corresponding manual sections are given.

Algorithm step
: The *Algorithm* step is a panel of the wizard-like MpCCI GUI, where the coupling algorithm is defined. It specifies as well basic as code specific settings for the analysis type, solver settings, coupling steps, algorithm type, simulation duration, and code runtime see ▷ V-4.7 Algorithm Step ◁.

architecture
: In the MpCCI context, architecture refers to the computer system, i. e. the combination of operating system and system hardware. Each characteristic combination supported by MpCCI is denoted by an *architecture token*, see ▷ V-2.3.1 MPCCI_ARCH - Architecture Tokens ◁. A list of current architecture tokens is given in the ▷ II-5 Supported Platforms in MpCCI 4.7 ◁.

association
: Association is the search for nodes/elements which lie close to a node/element of the partner mesh, also referred to as *contact search* or *neighborhood search*. The association is carried through during the initialization phase of MpCCI as a preparation for data interpolation. See ▷ V-3.3.1 Association ◁.

client
: A *simulation code* with a *code adapter* acts as a client of the MpCCI server, i. e. the term *client* refers to a code or adapter, see ▷ V-3.6.1 Client-Server Structure of MpCCI ◁.

code adapter
: A *code adapter* is a plug-in into a *simulation code* which allows coupling of the code with other codes via MpCCI. Code adapters can be based on user-defined functions and are usually linked with the simulation code, preferably as a shared library, see ▷ V-3.6.1 Client-Server Structure of MpCCI ◁. Code adapters are provided for all codes which are officially supported by MpCCI, further code adapters can be added using the code API (see ▷ VIII-2 MpCCI API ◁).

coupling algorithm
: A *coupling algorithm* is the procedure of a coupled simulation. It determines when data is transferred, which code starts computing a new time step, etc. . An overview of possible coupling algorithms is given in ▷ V-3.4 Coupling Process ◁.

coupling component
: A coupling component is a part of a coupling region, typically a set of elements, see description of *coupling region*.

coupling region
: Coupling regions define a part of a mesh which is coupled. In one coupling region, certain quantities are exchanged with the partner code. Each coupling region has a counterpart in the mesh of the partner code, which should have roughly the same geometry. A coupling region is composed of one or several coupling components. Coupling regions are defined in the MpCCI GUI (see ▷ IV-2.6 Regions Step – Defining Coupling Regions and Quantities ◁ and ▷ V-4.8 Regions Step ◁).

coupling type
: *Coupling types* (cf. ▷ V-3.1.2 Coupling Types ◁) correspond to specific physical domains (cf. ▷ V-3.1.1 Physical Domains ◁), recommended coupling settings, and predefined selection of quantities. When creating a new project in the MpCCI GUI, coupling specifications can be selected for typical *coupling types*, see ▷ V-4.5 Coupling Specifications ◁ for details.

Settings step
: The *Settings* step is a panel in the wizard-like MpCCI GUI. The control parameters for MpCCI can be set in this panel as described in ▷ V-4.10 Settings Step ◁.

exchange
Other term for *transfer*.

field
One of the two interpolation principles. Field interpolation is applied for quantities which do not depend on the element area, e. g. density, electric resistivity or temperature. See ▷ V-3.3.2.2 Field Interpolation ◁.

grid
See *mesh*.

Go step
The *Go* step is the last panel in the wizard-like MpCCI GUI, where options for starting the simulation codes can be set and the coupled simulation is started (and stopped). See ▷ V-4.11 Go Step ◁.

initialization
The *initialization* is carried through at the beginning of a coupled simulation. Both codes send their mesh data to MpCCI and the meshes are *associated*. See ▷ V-3.4 Coupling Process ◁ for details.

interpolation
In most coupled simulations, data is transferred between non-matching grids. I. e. the data is given on one mesh and a corresponding set of data for a different mesh is expected by the other code. The process of finding such a distribution is called *interpolation*. Different methods for this procedure are described in ▷ V-3.3 Data Exchange ◁.

iterative coupling
Explicit steady-state and implicit coupling schemes are referred to as iterative coupling. For a steady-state analysis the final solution is reached by iterating the problem until a converged solution is reached. For implicit transient analyses each coupling step is repeated until a converged solution for the current coupled time step is reached. (cf. ▷ V-3.4.2 Coupling Schemes ◁).

mesh
The *mesh* (also called *grid*) consists of a set of nodes which are given by their spatial coordinates and a set of elements each which is connected to a typical number of nodes. The connection of nodes and elements is known as *mesh topology*. MpCCI can transfer data between mesh-based simulation codes, e. g. Finite Element (FE) or Finite Volume (FV) codes.

Models step
The *Models* step is the first panel in the wizard-like MpCCI GUI, where the models which shall be coupled are selected. In addition some code-specific options can be selected, see ▷ V-4.6 Models Step ◁.

Monitors step
The *Monitors* step is a panel in the wizard-like MpCCI GUI, where components and quantities of a code can be selected for monitoring, see ▷ V-4.9 Monitors Step ◁.

multiphysics
The purpose of MpCCI is to couple codes for the solution of *multiphysics* problems. Such problems consist of partial problems each of which can be classified into a different physical domain. Typical domains are *fluid mechanics*, *solid mechanics*, *heat transfer* or *electromagnetism*. See ▷ V-3.1 Multiphysics ◁ for details.

neighborhood search
Other term for *association*.

orphaned nodes
If mesh *association* fails, some nodes cannot be associated with nodes or elements of the other mesh. This means they cannot be considered during data transfer, which usually yields severe errors. See ▷ V-3.3.2.3 Orphaned Nodes and Elements ◁.

quantity
Physical *quantities* must be exchanged between meshes for a coupled simulation. For each coupling case a typical set must be selected in the *Regions* step of MpCCI. A quantity has a typical SI-unit.

Regions step
The *Regions* step is a panel in the wizard-like MpCCI GUI where the *coupling regions* and their quantities are defined, see ▷ V-4.8 Regions Step ◁.

remote file browser
MpCCI uses a *remote file browser* for model file selection, which allows to connect to a remote computer via a remote shell. By selecting model file on a remote computer, a user determines where to run a simulation code. See ▷ V-4.12 Remote File Browser ◁ for a description of the MpCCI remote file browser.

scanner
In the *Models* step of the MpCCI GUI the scanner must be started to scan the model file. The scanner searches the file for definition of possible coupling regions and further code-dependent information. See ▷ VIII-2.5.2 Scanner.pm ◁ for a detailed description of what the scanner does.

server
The communication of a *simulation code* with MpCCI is based on a client-server model, i. e. during a computation a set of MpCCI servers is started, which are connected to the simulation codes (*clients*). The servers perform all tasks required for data transfer between two codes. See ▷ IV-1.3 Code Coupling with MpCCI ◁ and ▷ V-3.6.1 Client-Server Structure of MpCCI ◁ for a description.

simulation code
All software programs which can be coupled by MpCCI are commonly referred to as *simulation codes*. A description of all codes is given in the Codes Manual.

staggered method
MpCCI uses the *staggered* approach to solve multiphysics problems: Each code computes one time step independently and data is only exchanged after such a partial solution is obtained. This is also known as *weak coupling*. The solution procedure is discussed in ▷ IV-1.2 Solution of Coupled Problems ◁.

tracefile
The *tracefile* can be best described as graphical log file. If a tracefile is written during a computation (by an additional control process), the mesh geometry and transferred data is stored. The contents of the *tracefile* can be viewed with the MpCCI Visualizer as described in ▷ V-7 MpCCI Visualizer ◁.

Keyword Index

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Important entries are **bold**, *italic* entries refer to the glossary.