# MPCCI – THE GENERL CODE COUPLING INTERFACE

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**Abstract:**

There is an increasing need for multidisciplinary simulations in various research and engineering fields. Fluid-structure interaction, magneto-hydro dynamics, thermal coupling, plasma computations or coupled manufacturing processes define only a subset of recent multi-physics activities. There is a common feeling in the community that in most cases not a single (proprietary) simulation system can provide all necessary features but that coupling the best codes of each discipline will enable more flexibility and simulation quality to the end user.
The MpCCI interface has been accepted as a 'de-facto' standard for simulation code coupling. MpCCI is developed at Fraunhofer Institute for Algorithms and Scientific Computing (SCAI).
This article will describe the MpCCI concepts and some coupled applications. Some special emphasis will be put on 'unusual' code couplings like

- N-Code-Interactions,
- Fluid-Electro combinations,
- FEM-FEM interactions,
- 1D-3D coupling, and
- coupling of commercial codes with in-house tools

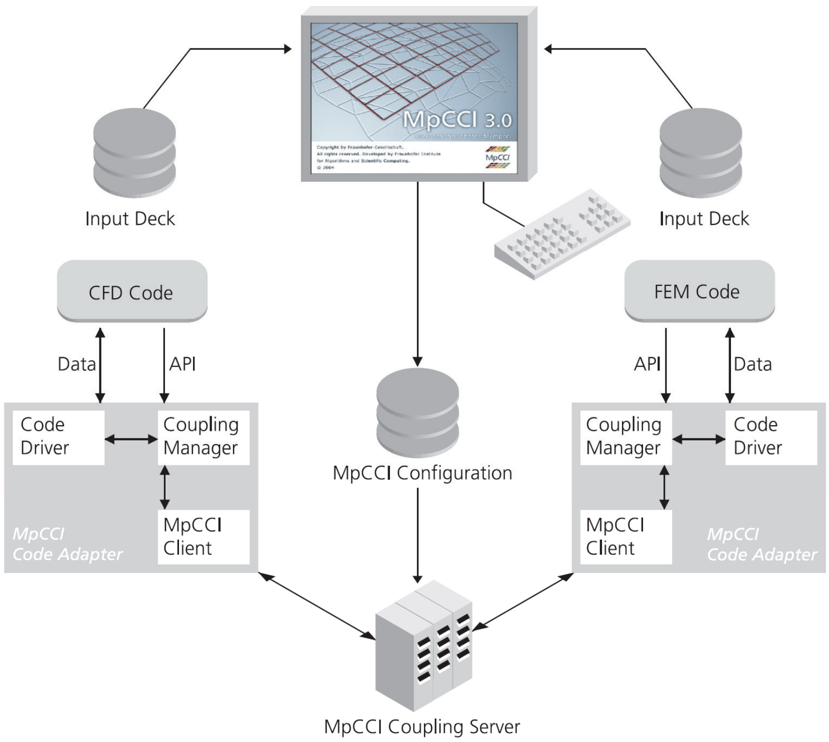
**Keywords:**

Code Coupling Interface, Open Programming Interface, Distributed Simulation, Fluid-Structure-Interaction, Fluid-Electro-Coupling, 1D-3D-Simulation

# 1 MPCCI COUPLING INTERFACE

MpCCI (Mesh-based parallel Code Coupling Interface) has been developed at the Fraunhofer Institute SCAI in order to provide an application independent interface for the coupling of different simulation codes. MpCCI is a software environment which enables the exchange of data between the meshes of two or more simulation codes in the coupling region. 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.
Within the MpCCI 3.0 system the code adapters establish a direct connection between the MpCCI Coupling Server and the codes themselves. The adapters make use of the APIs of the commercial codes and thus (in most cases) need no modified versions of these codes. A code adapter is a library which will be linked to the code either statically or dynamically. Any code adapter consists of two modules - the Coupling Manager and the Code Driver. Additionally there are for each code specfic scripts to scan the model input data, to start the codes and finally to stop the codes properly. In figure 1 the general architecture of the MpCCI 3.x coupling environment is shown.




*MpCCI 3.x Architecuture*

# 2 CODE ADAPTATION

## 2.1 Supported Codes

The current version 3.0.5 of the MpCCI simulation coupling environment supports ABAQUS, Ansys, Fluent, Flux3D, ICEPAK, MSC.Marc, Permas, StarCD, and RadTherm. Adapters for further codes like the 1D pipeline code Flowmaster are under development. To ensure best compatibility to the codes listed above Fraunhofer SCAI has established long term cooperations with most of the software vendors. Joint development plans, combined marketing activities and cooperative support for end users ensure solution quality and success in application.

## 2.2 MpCCI for In-house Codes

Besides for these commercial codes there is a strong request for combinations of commercial codes with dedicated in-house codes.

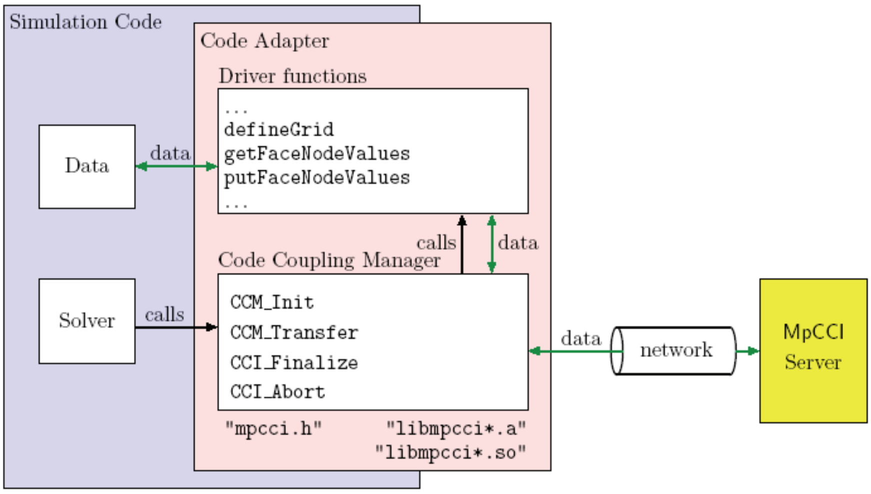
 

- Especially in aerospace industry engineers trust on their own high-end in-house tools for aerodynamics; on the other side these people use commercial FEM codes to analyse e.g. deformations and stresses in structure.

- Universities and research institutes have realised their own codes either for educational purposes or for evaluation of specific details in CFD or FEM.

### *2.2.1 Code API and MpCCI Code Adapter*

During the coupling process the code must be able to provide certain information to MpCCI. There are two general types of data needed by MpCCI.




Mesh information - as MpCCI exchanges data between non-matching grids it needs to know
- the related position of coupled coordinate systems,
- a unique identification of mesh regions (partitions, sets, components),
- the number of nodes and their location, and
- the type of elements and their topology.

Physical values – during the coupling process physical data is communicated and interpolated by MpCCI. Thus MpCCI needs details about
- position of value (node or element),
- memory location or access routine for this value, and
- type of data (scalar, vector, .. ).

The code adapter itself consists of three major parts:
- Coupling Manager: this generic part is used in each code adapter and is responsible for a consistent runtime behaviour. It reads the application specific model setup and - during coupling process – controls which model regions has to send or receive which boundary values from the 'other' code.
- Communication Client: the small module realises the communication through a distributed heterogeneous network. The client is connected to the MpCCI server system using TCP/IP sockets.
- Code Driver: The code driver acts as an interface between the data structures of the code and the MpCCI coupling manager. The access to the code's data can be realised through e.g. Fortran common blocks, C-subroutines, or data base functions. The driver is the only code specific part in the adapter.

Linking the code adapter to the code may be done either in a static or in a dynamic way.

### *2.2.2 MpCCI environment for a code*

A MpCCI code interface is composed of several parts:
- a configuration file which specifies the coupling capabilities of this code, and

- some PERL scripts to setup and control the runtime environment of this code inside the coupled application, and
- generic and code specific adapter subroutines (F70 or C) which need to be linked to the code.

The code configuration file specifies the code name, versions and location of executables. Standard extension for input files and further options or parameters should also be described in this configuration. Last but not least a list of quantities which can be coupled through MpCCI should be given.
For each code in MpCCI there is a set of standardised scripts:

- Scanner: This module investigates the code's input model and extracts those region names (set, component, partition, …). These extracted names are then presented in the MpCCI GUI and the user can select those he needs as coupling regions.
- Starter: to guarantee compliance with code startup procedure a wrapper script is responsible for setting up a proper runtime environment for the code. Additional variables needed by the MpCCI code adapter at runtime have to be set in this starter script.
- Stopper: For a smooth shutdown of a running code the stopper script sets some environment variables or files.

## 3 COUPLING OF STRUCTURAL AND FLUID DYNAMICS CODES

### 3.1 Fluid-Structure with Deformable Structures

Typical FSI example are defined by the dynamic effects over a deformable structure which is located in a fluid or air stream. Flexible flaps or valves may deform due to the normal and viscous fluid forces of the moving fluid or air stream. Or the structure might deform due to external loads – and the fluid domain has to follow these deformations. In the following few examples will highlight different aspects of FSI with deformable structures.

#### *3.1.1 Biomechanical Applications (JAERI)*

Computational biomechanics of vascular system, diseases, and thrombosis has been often concerned with the local hemodynamics conditions of blood flow that are computed by various of CFD (Computational Fluid Dynamics) methods, since it is well known that unusual hemodynamics condition may cause an abnormal biological response. Meanwhile, since pulse blood flow in arteries causes wall stresses to oscillate and non-uniform, biologists become recently more and more interesting in computational analyses of arterial wall stresses by CSD (Computational Structure Dynamics) methods to predict patient disease risks, like plaque rupture endothelial injury, etc., or to help plan surgery operation. Herein wall elasticity has to be taken into account which is neglected on many situations as the secondary importance feature generally. Consequently, it is necessary to analyze hemodynamics conditions of blood flow by CFD and stress distribution on arterial wall by CSD simultaneously from view of clinical request [2]. In the figure the velocity distribution on carotid artery is shown.

#### *3.1.2 Piezo Elements*

In the electric industries, the piezoelectric actuators are used as pump, speaker and fan. The piezoelectric device oscillates by alternately changing axial strains caused by A.C. voltage loading. In order to analyze such phenomena, only the piezoelectric/structural analyses have been used usually. In these cases, one of the key components, the fluid force, is simplified as an easy damping model. However MpCCI enables the coupling analysis between CSM and CFD now and the more realistic behavior can be solved by defining the exact fluid forces on the device.

#### *3.1.3 Automotive Door Seals and Compressor Valves*

Automotive door seals are an example where external forces cause a significant structural deformation. However, to get accurate results the simulation should take into account the damping effect of the enclosed fluid domain. The enclosed air in the seal cannot escape at once, thus providing additional resistance to the moving and closing door. A major design question now is to find the optimal geometry and best number of vents which allow for a smooth closing of the door. This example setup was proposed by Metzeler Automotive Profile Systems in Germany; simulation was done with a coupled Abaqus-Fluent environment and visualised with EnSight [4].
Another example is the valve in the compressor used in the various fields. These valves are opened by the gas compressed by the piston motion and exhaust the gas (see figure, pressure field around the valve). This is solved as FSI case because the valve is deformed by the pressure force of the compressed gas. The analysis results of the pressure and deformation of valve are compared with the

experimental data. The coupling analysis via MpCCI is going to be useful for the design of the compressor [8].

#### *3.1.4 Tire Hydroplaning Simulation*

Tire hydroplaning simulations are of high interest for automotive and tire companies. Together with NUMECA S.A. and the two tyre companies Pirelli and Michelin MSC Netherlands realised a solution for multi-physics tyre simulation. The relevant design variables for tyres under hydroplaning conditions are, among others, the pressure distribution on the ground, the stresses in the reinforcing cords in the tyre and the contact patch of the tyre on the ground. Tyre modelling then is a complex non-linear process that has to take into account the contact between the tyre and the ground (including friction), the interaction with the water and the strongly non-linear behaviour of the tyre itself, due to its large elastic deformations. For this application the codes MSC.Marc and Numeca's FINE/Hexa CFD code were coupled through MpCCI interface [9].

### 3.2 Thermal Coupling and Radiation

#### *3.2.1 Automotive Manifolds*

An important issue for numerical analysis in automotive industry is to provide solutions for the thermal management of cars. A fully coupled (two-way) temperature-stress analysis was used to simultaneously solve for both displacement and temperature fields for problems in which both the stress and temperature are dependent upon each other. The transfer of temperature fields and heat transfer coefficients in an engine exhaust manifold may illustrate the importance of thermal coupling in the transient heating due to the flow of the internal hot exhaust gas stream.
In this case the internal flow was modelled in FLUENT while the structural heating and extraction were calculated with ABAQUS. MpCCI provides the transfer of the wall heat flux from FLUENT to ABAQUS and passes back the resulting surface temperature from ABAQUS to FLUENT. ABAQUS further computes the thermal stress and deformation of the exhaust manifold due to heating.

#### *3.2.2 Radiation*

RadTherm is another specialised radiation code provided by ThermoAnalytics Inc. In the figure on the right the results of a coupled Fluent-RadTherm calculation for the underhood flow and the radiation effects under a car are shown. The fluid flow was calculated assuming steady, turbulent flow conditions using a k-$\varepsilon$-turbulence model. For the modelling of the flow inside the exhaust system a 1D-model in RadTherm was used. In the calculations, the exhaust mass flows, inlet temperatures of the exhaust gas as well as the flow velocities (corresponding to the cruising speed of the vehicle) have been varied. [3].

#### *3.2.3 Coupled CFD/FEM of a Diesel Engine Cylinder Head*

Deutz is a leading manufacturer of diesel and gas engines from 4 to 4000 kW. They are using a MpCCI coupled solution (Fluent-Permas) to analyse the cooling jacket of a diesel engine cylinder head. Their test case was a 6-cylinder in-line water cooled engine of 190kW power (automotive engine BF6M2013). In the coupled application the CFD side provided local wall heat fluxes via MpCCI to the structural side; FEM sent back the solid temperatures. The goal was to calculate local stress distribution and deformations.
In the former standalone calculations of CFD and FEM only one initial mapping of mean heat transfer coefficients and fluid temperatures from CFD to FEM was used. Compared to these standalone calculations the coupled simulation now provides more detailed and probably more realistic results. Some areas are hotter than expected, there are areas with reverse heat transfer from fluid to structure, and the maximum tensions are 5% higher compare to standalone calculations [1].

## 4 OTHER TYPES OF CODE COUPLINGS

### 4.1 Thermo-Electrical Coupling

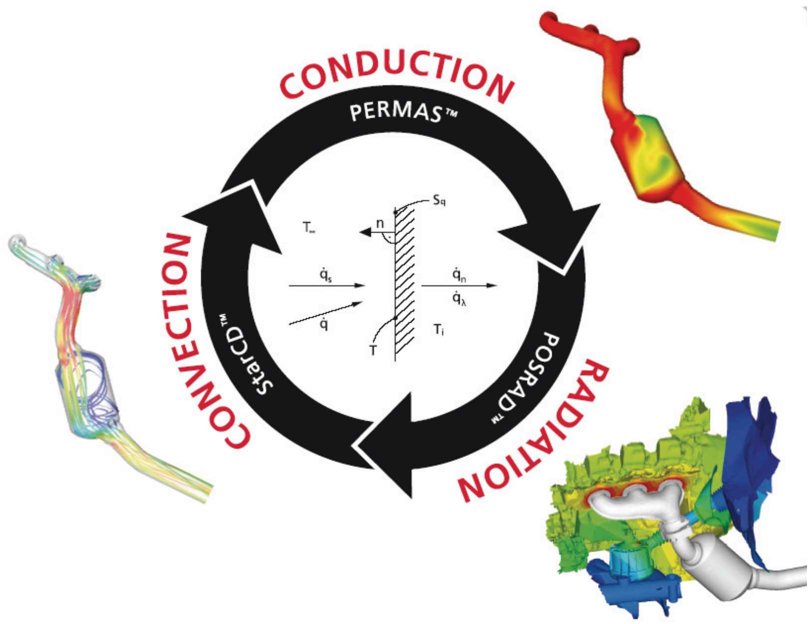
The prediction of heating and cooling processes is of eminent importance in the development of electrical devices. The flow of the alternating current induces heating due to losses by Ohms' law and the usual mechanism for cooling is free convection. The increasing tendency of miniaturization requires to fully utilizing the thermal potential of the materials involved. Heat dissipating surfaces are, however, reduced in a way that can result in temperatures which may destroy the complete device or parts of it [13].

The free convection is simulated by the CFD Software (FLUENT or StarCD). The electromagnetic quantities, governed by the Maxwell equations, are calculated using Finite Element Code ANSYS. It calculates Joulean heat in the conducting cables and sends it to the flow simulator as an energy source term. The conductivity depends on temperatures; it is, therefore, being calculated within CFD by means of a user defined function. The complete data transfer between the flow and the electromagnetic simulation is done by MpCCI .
The FLUENT simulation leads to a stationary solution, ANSYS operates in frequency domain. The power loss density can be derived from the harmonic solution and the exchange of data between the two simulations codes is performed as soon as new results (power loss densities and conductivities) are available.
The cables are insulated by a non-conducting PVC layer. Skin and proximity effects lead to a non-uniform distribution of the current density resulting in a non-uniform temperature field. Skin- and proximity effects which are taken into account in the coupled simulation actually play an important role. If one neglects such effects and assumes a constant power loss density the heating behaves substantially different. The figure shows results from a simulation based on a constant power loss density. It is obvious, that the heating of the middle phase is definitely underestimated.

### 4.2 Structural-Structural Couplings

Simulation of manufacturing processes like metal stamping is a well established procedure in all of the automotive companies today. Dedicated stamping codes like Autoform, Indeed, Pam-Stamp and other more general codes like LS-Dyna or Abaqus Explicit can be used for these purposes.
However, in all applications of stamping simulation today there is one major assumption about the behaviour of the stamping tool itself: the tools is expected to be stiff enough and no deformations due to friction of the stamped plate are considered during simulation.
In a recently started project the coupling of a stamping simulation with the structural analysis of the deforming stamping tool will be realised. The deformation of the stamping tool will lead to locally different friction parameters – compared to a standalone stamping simulation. It is one of the challenges in this research projects to evaluate influence of changing friction parameters onto the quality of the final stamped plate.

### 4.3 N-Code Coupling

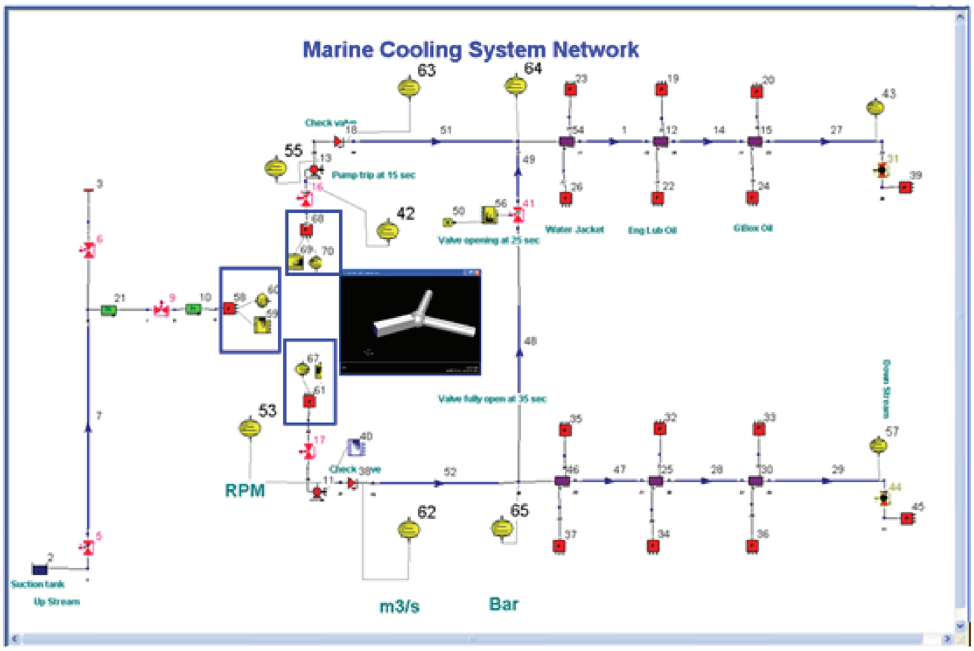



*3-Code coupling for automotive thermal management analzsis*

Thermal protection is of vital importance for the development process of passenger cars. Underhood component temperatures are sensitive to all three modes of heat transfer: conduction, convection and radiation. Calculation of underhood component temperatures of passenger cars requires the combination of even three different disciplines: structural analysis, fluid dynamics and radiation. For the simulation of thermal conduction and convective heat transfer a coupled fluid-structure environment is needed. With regard to the whole car geometry also radiation plays an important role in the overall heat management calculation. In areas with relevant fluid flows (e.g. engine compartment, gear box or exhaust system) convective heat transfer and radiation need to be calculated in a coupled environment. DaimlerChrysler starts to use a fully coupled 3-code environment based on StarCD, Permas and Posrad (radiation code from CD adapco) to solve thermal management applications [7] [10].

### 4.4 1D-3D Interactions

Flowmaster is a 1D fluid system modelling tool. It enables engineers to simulate various fluid systems such as fuel systems for aircrafts, Vehicle Thermal Management Systems with Air-conditioning and Air-side for automotive industry, piping systems for ship building organisations, cooling systems for satellites etc. Flowmaster is equipped with libraries of components populated with loss data, allowing users to build and analyse a model of complete systems with compressible or incompressible fluid flows.




*A typical Marine Cooling system Network schematic*

Interaction between CFD (such as FLUENT and STAR-CD) software and Flowmaster can enable design or system engineers to build virtual prototype test bed or models for small or large systems thereby reducing significant prototyping costs and design time. For example, in the automotive industry various parts of the Underwood vehicle thermal management system are simulated using CFD packages. Such models with complex geometry consist of many hundreds of thousands of cells and take considerable time to construct and validate. Modelling in isolation can compromise the accuracy of the overall system performance. At the same time, at the earlier design stage it is impractical to represent a complete system in CFD that consists of water jacket, pump, expansion tank, valves, heat exchangers, grills, thermostat etc with individual physical characteristics. In such scenarios, 1D modelling can provide a significant advantage by both reducing model complexity and computational design time. This can allow the engineers to design and analyse system performance more rapidly.

By coupling 1D and 3D models together it can provide a more flexible and robust approach in fluid system design that can be utilised throughout the design cycle in numerous applications [6].

## 5 CONCLUSIONS

MpCCI 3.0 provides a lot of new features for the coupling of simulation codes. Together with MpCCI code adapters now a complete toolbox for multidisciplinary simulation is ready for use with standard commercial simulation codes. Various solutions demonstrate the applicability of this concept and the valuable outcome for the end users. A growing number of commercial codes is supported by MpCCI code adapters.

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