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Klaus Wolf, Barbara Steckel (Eds.)

Mesh-based Parallel Code Coupling Interface

2nd MpCCI User Forum

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GMD –
Forschungszentrum Informationstechnik GmbH
Schloß Birlinghoven
D-53754 Sankt Augustin
Germany
Telefon +49 -2241 -14 -0
Telefax +49 -2241 -14 -2618
http://www.gmd.de

Anschrift der Herausgeber/Address of the editors:
Klaus Wolf
Dr. Barbara Steckel
Institut für Algorithmen und Wissenschaftliches Rechnen
GMD – Forschungszentrum Informationstechnik GmbH
D-53754 Sankt Augustin
E-Mail: klaus.wolf@gmd.de
barbara.steckel@gmd.de

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Abstract: MpCCI (*Mesh-based parallel Code Coupling Interface*) is an interface for multidisciplinary simulations. It provides industrial end-users as well as commercial code-owners with the facility to combine different simulation tools in one environment. Thereby new solutions for multidisciplinary problems will be created. This opens new application dimensions for existent simulation tools.
This *Book of Abstracts* gives a short overview about ongoing activities in industry and research - all presented at the *2nd MpCCI User Forum* in February 2001 at GMD Sankt Augustin.

Keywords:Multidisciplinary simulation, code coupling, fluid dynamic simulation, structural analysis, MpCCI

Zusammenfassung: MpCCI (*Mesh-based parallel Code Coupling Interface*) definiert eine Schnittstelle für multidisziplinäre Simulationsanwendungen. Sowohl industriellen Anwender als auch kommerziellen Softwarehersteller wird mit MpCCI die Möglichkeit gegeben, Simulationswerkzeuge unterschiedlicher Disziplinen miteinander zu koppeln. Dadurch entstehen neue Lösungen für multidisziplinäre Problemstellungen und für etablierte Simulationswerkzeuge ergeben sich neue Anwendungsfelder.
Dieses *Book of Abstracts* bietet einen Überblick über zur Zeit laufende Arbeiten in der Industrie und in der Forschung, präsentiert auf dem *2nd MpCCI User Forum* im Februar 2001 an der GMD Sankt Augustin.

Schlüsselwörter: Multidisziplinäre Simulation, Kopplung von Simulationscodes, Berechnung von Strömungsdynamik, Strukturanalyse, MpCCI

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Welcome

Dr. Ullrich Becker-Lemgau
Pallas GmbH

Today, numerical simulation plays a key role in both industry and research. Simulation tools and the results they are providing are an integral part in design and development of new and better products. Our understanding and prediction of natural processes in areas like biology, chemistry, climate, etc. is often only possible through highly specialized numerical codes running on parallel computers. A complete industry and research sector is dedicated to provide hardware, software, models and services to the numerical simulation community.

Several years ago SCAI and Pallas have identified in this community a need for multidisciplinary simulations, also referred to as coupled applications. This cooperation has led to the development of MpCCI, the Mesh-based parallel Code Coupling Interface. With MpCCI already existing codes can be coupled to do multidisciplinary simulations.

Since one year MpCCI is available to the simulation community. The growing interest and specifically the growing number of users are very encouraging. More than 100 users from all kinds of industrial and research areas have downloaded MpCCI from the web. Several projects with partners from industry, code owners, and research have been set up or already started. For the simulation codes STAR-CD and PERMAS MpCCI will be the interface for coupling to other codes.

All of this makes MpCCI a real success and will encourage us, the MpCCI team at SCAI and Pallas, to push further the development of MpCCI and to provide MpCCI services to the simulation community. The new release MpCCI 1.2 will be available shortly after the User Forum via download from the MpCCI homepage at **http://www.mpcci.org**.

This MpCCI User Forum 2001 will present a special code owner session and a wide variety of coupled applications reflecting the general approach of MpCCI. As for the last User Forum we hope for interesting talks and vivid discussions.

The MpCCI-Team wishes you all the best and hope that the 2nd MpCCI User Forum 2001 will be a successful meeting for all participants, the MpCCI team, and of course for you.

MpCCI - Mesh-based parallel Code Coupling Interface

Dr. Peter Post
GMD/SCAI, Sankt Augustin, Germany

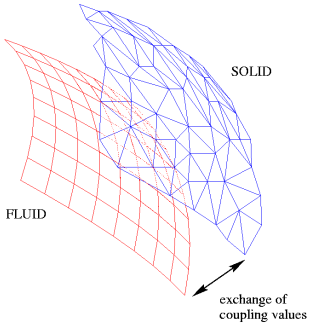


Fig. 1: Coupled Simulation Meshes

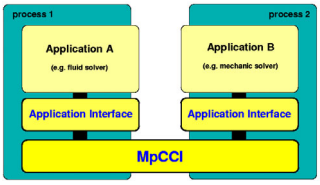


Fig. 2: MpCCI Software-Layers

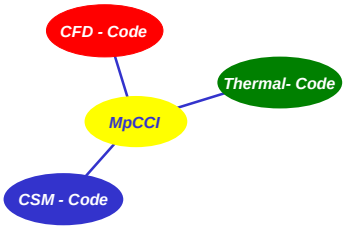


Fig. 3: Interface for Code Coupling

During the life cycle at industrial fabrication, prototyping and testing define a significant step on the way towards a new and successful product. For both - prototyping and testing - numerical simulation is more and more a becoming standard working tool.
Many aspects of the product behavior are affected by the interaction of different physical phenomena. Fluid-structure interactions at aircraft wings, ship propellers, or large bridges are some examples. Others are heat transfer from hot flows onto turbine blades, plasma flows interfering with changing electromagnetic fields or interactions between atmosphere, ocean and landscape in climate modeling. In general, there is a growing demand for interdisciplinary solutions in industry as well as in research.
Simulation codes are available for most physical disciplines: computational fluid dynamics codes, structural mechanics codes, thermal codes, plasma codes, electromagnetic codes, climate submodels, etc. However, apart from some very specific and application dependent implementations there is no environment which provides a general solution for multi-disciplinary simulations.

The MpCCI Concept

To overcome this problem SCAI, has developed the MpCCI (*Mesh based parallel Code Coupling Interface*) software library. Funded by the C.E.C project CISPAR and the BMB+F projects GRISSLi and COSIMA-V, work started in 1996.
The basic concepts of MpCCI are:
• to enable interaction between nearly any two physical disciplines,
• to allow the coupling of any two or more simulation codes (Fig. 3),
• to provide a validated coupling numeric,
• to require only few software changes in the simulation codes themselves.

Technical and Scientific Approach

The basic principle of MpCCI is to provide a software interface, that allows the adaptation of each of simulation codes without knowing anything about the code on the other side of the interface. Each code specifies its coupling area based on its own numerical mesh definitions; multiple meshes per code and any partitioning for parallel programs are allowed. MpCCI automatically computes the mesh neighborhoods of the coupled codes. Each code states which physical quantities (e.g. pressure, velocity, temperature, …) it can provide and which quantities it needs from the other side.

During a simulation run each code presents its own current quantities to MpCCI. Based on the computed mesh neighborhood, MpCCI can interpolate values from the sender mesh onto the receiver mesh (Fig. 1). If there are application specific needs, the user can link his own interpolation rules to MpCCI. Finally MpCCI does the communication of the quantities between the coupled codes.

MpCCI provides a procedural interface to Fortran and C. It is linked to the simulation codes as a library (Fig. 2). MpCCI is currently basedon the MPI standard. For parallel codes, the code internal communication is separated from the MpCCI communication due to the MPI communicator concept.

The MpCCI Software Product

The name *MpCCI - Mesh-based parallel Code Coupling Interface* and its logo are registered trademarks of GMD. Since February 2000, SCAI provides the software solution **MpCCI V1.0**, which is available for binary download from the web (www.mpcci.org). User registration and an electronic license agreement are part of the MpCCI download area. There are ports for nearly all standard UNIX environments and Linux. A full documentation enables basic code-couplings in a do-it-yourself way.
MpCCI V1.2 (February 2001) will additionally provide a programming interface for the introduction of user defined numerics, a graphical user interface and a visualisation tool.

The MpCCI Services

Users, who want more than just the MpCCI software, can ask for additional services on a contract basis:
• adaptations of simulation codes,
• installation of the complete software environment at the user's site,
• assistance with the first steps in multidisciplinary applications, and
• development of application specific extensions for numerics and software.

Coupling at Computational Dynamics

Mattijs Janssens
Computational Dynamics Ltd, London, Great Britain

Computational Dynamics Ltd, is one of the world's major developers of software for industrial CFD analysis. STAR-CD is the CFD technology leader for fluid flow analysis in the automotive, aerospace, turbo-machinery, chemical process and power generation industries.
It is a tool designed to help engineers find practical solutions to CFD related problems, no matter how complex.
Linking STAR-CD with leading FEM codes means that engineers can tackle an ever wider range of problems. The linkage provided through MpCCI allows them to work within their areas of expertise whilst gaining access to the features of best in class CFD and FEM codes.

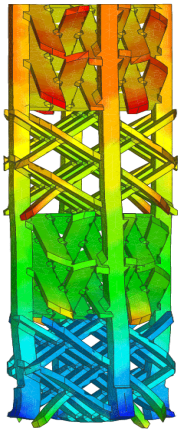


Fig. 1: Polymer mixer (courtesy of Sulzer Innotec)

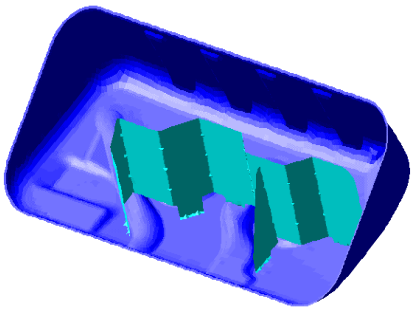


Fig. 2: Automobile fuel tank (courtesy of DaimlerChrysler)

Coupling Solutions

The transfer of information from the fluids side to the structures side and vice versa depends on the type of application. If there is little or no information going from the structures side to the fluids side the exchange can either be done during the run ("on-line") or as a postprocessing step ("off-line"). An example would be a typical stress analysis, where the displacements usually are insufficient to cause significant change of the flow. The second application is where there is significant feedback to the fluids side to require both physics to run be run simultaneously with. Star will cater for both communication options, one way coupling through its pre- and postprocessor Prostar or through MpCCI; two way coupling through an optional built-in linear substructure solver or through MpCCI.

Satisfying the User's Needs

The advantages offered by the MpCCI path have been fully utilized in the Star implementation. Setup of a coupled case is identical to that of a non-coupled, i.e. fluid only case. All the standard unstructured mesh capabilities can be used. Zero thickness elements, e.g. structural shells, can be accommodated through the MpCCI 'tag' facility. The additional information for an MpCCI run consists only of the specification of the boundaries which are involved in the coupling process and of the quantities which are to be sent or received.

Typical MpCCI applications of Star involve either a stress or heat-transfer analysis. This requires being able to send forces and temperatures and receive heat fluxes and displacements. Mesh displacements usually require the internal mesh to be adapted. For these situations either the extensive facilities of Prostar can be used or a built-in mesh smoother. Turnaround times for coupled simulation have been kept to a minimum by having full parallel running capabilities, including for the mesh smoother. Implementation of a coupled convergence check means that for those cases where the simulation reaches a steady state the run will automatically finish. It also provides users with a coupled stop and restart facility.

Collaboration

Computational Dynamics Ltd. has been involved from start in the European program which led to the development of the predecessor of MpCCI, Cocolib and also now is actively involved in providing feedback. We are currently closely collaborating with two major industrial partners, DaimlerChrysler AG and Sulzer Innotec AG and leading FE technology provider Intes GmbH to mature the coupling technology by applying it to real engineering problems. Two examples are shown: a polymer mixer used in the chemical industry (Fig. 1) and a petrol fuel tank for automobiles (Fig. 2). Both problems are successfully being run and used to provide design information.

Star and MpCCI

All the mentioned MpCCI functionality has been integrated into the Star solver and Prostar preprocessor and will be available in next major releases. The aforementioned collaboration is providing lots of feedback, both related to the product and to actual cross-department problem setup.
All in all the Star - MpCCI coupling is providing our users with a dramatic increase in simulation capabilities and we foresee a bright future ahead.

Fluid-Structure Interaction with CFX

Florian Menter
AEA Technology, Otterfing, Germany

The first part of the presentation will give a short overview of AEA as a company and the positioning of the CFX business within AEA.

CFX Software

The second part will present the CFX software products and tools developed by AEA Technology and their areas of application:

- CFX-TASCflow
- CFX-4
- CFX-5

Past Coupling Projects

The central portion of the presentation will discuss some of the fluid-structure coupling projects, which have been carried out in the past with the CFX software suite:

- Simulation of structural loads and deformations on a gas generator for airbag systems (CFX-4 – TRW)
- Simulation of fluid-structure interaction for turbine blades under steady and unsteady conditions (CFX-TASCflow, PCA).
- Simulation of the interaction of blood flow with artificial heart valves (BLOODSIM EU Project).

Project DEBUT

The last part of the presentation will give information on the new EU project DEBUT. The project will deal with multi-disciplinary engineering by using the MpCCI coupling technology.

The project is co-ordinated by Pallas GmbH; partners are AEA Technology GmbH, MSC, and TRW. The project will run for 18 months. The CFD application in this project will be based on CFX-5.

The objectives are:

- Coupling of CFX-5 software and MSC/Marc software via MpCCI coupling library
- Extension of current fluid-structure coupling technology for compressible application cases
- Application to TRW gas generator system
- Extension of CFX-5 coupling to large mesh deformations

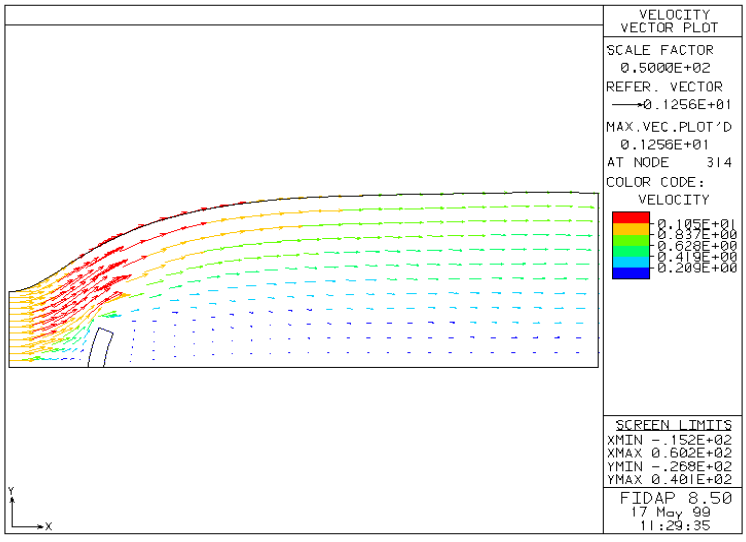
Contact: Info@otterfing.aeat.com

Coupling at Fluent

Dr. Markus Braun
Fluent Deutschland GmbH, Darmstadt, Germany

Fluent provides advanced CFD-tools in all areas of computational fluid dynamics with its products POLYFLOW, FIDAP and FLUENT. POLYFLOW has its strengths in laminar general Newtonian and viscoelastic flows, while FIDAP and FLUENT are widely used to compute turbulent flows in incompressible as well as compressible media. Due to the successful integration of hexahedral and tetrahedral cells into unstructured hybrid meshes combined with solution-based cell adaptation, the products allow the discretisation of complex geometries with an appropriate number of cells/elements leading to efficient computing times for real life applications on both desktop computers and high-performance parallel computing frameworks.

In the past coupling to other codes has been based on a one-way coupling leading to export filters from FLUENT to Abaqus, ANSYS, IDEAS, NASTRAN and PATRAN. Recently two-way couplings to 1D gas dynamics codes like GT-POWER have been implemented into FLUENT, too.



Velocity vectors and free surface

Others are in progress. In addition, interfacing of process and network tools like ASPEN to FLUENT has gained interest in that way that US Dept. of Energy is funding this coupling in its VISION 21 program.

In FIDAP the coupling to structural finite element analysis programs began in early 90's, when file-based interfaces have been established to PATRAN, ANSYS and MARC. These couplings were based on a quasi-steady-state approach.

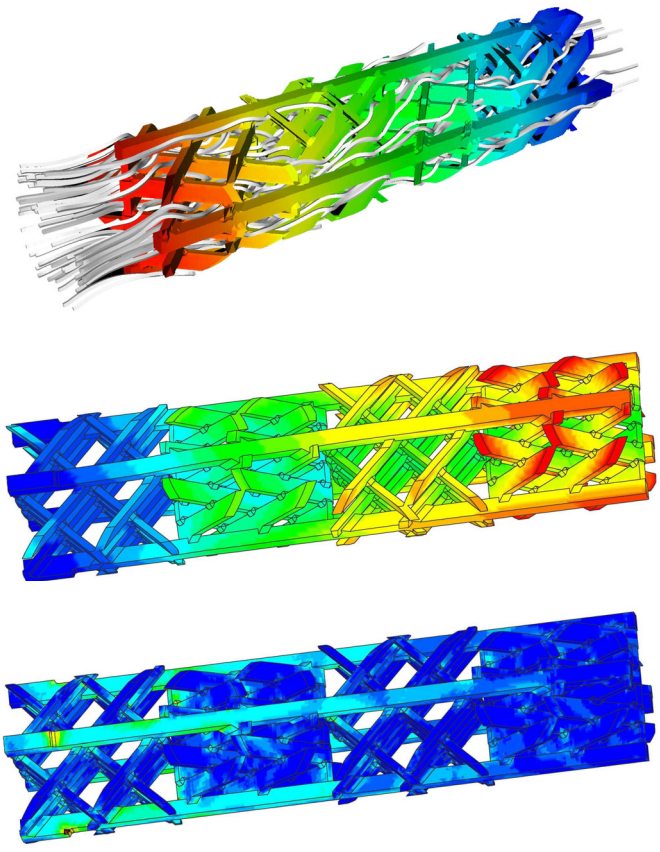
In the meantime a built-in Fluid-Structure-Interaction capability is available in FIDAP, which allows a fully coupled transient calculation. It consists of modules for Computational Fluid Dynamics (CFD), Computational Structure Dynamics (CSD) and Computational Mesh Dynamics (CMD). All modules have been integrated directly into FIDAP. The typical application of these modules is Fluid-Structure-Interaction. The CSD module uses Finite Elements to compute linear and non-linear elasticity of isotropic materials. The usage of an elastostatic solver allows the treatment of the mesh as an elastically deforming "solid". The computed displacements are used in the CMD module as boundary conditions to recompute the deflected mesh. In Figure 1 results are shown for a free-surface flow over an obstruction. The obstruction produces the displacement of the free surface and is bended due to viscous forces of the flow.
Figure 1: Velocity vectors and free surface

Other applications of the three modules are in the area of roller coating, pulsatile flow of blood, piezelectronic devices, etc. In the presentation some results of these applications are shown.

Fluid-structure interaction and the use of MpCCI at Sulzer

Torsten Wintergerste
SULZER Innotec, Winterthur, Switzerland

Sulzer develops products in a wide range of specific fields such as turbomachinery, pumps, compressors, medical systems, process engineering, ventilation and building aerodynamics. The knowledge of the behavior of fluid flow in these systems is one of the most important key technologies for the development. The departments of Fluid Dynamics and Structural Mechanics at Sulzer Innotec serve all business units of Sulzer for their development of new products and for the industrial research on the field of fluid mechanics and structural mechanics with regards to the their products.



The Sulzer mixer (SMB) used for laminar mixing with streamlines and pressure (top), structural displacement (middle) and stresses (bottom).

Additionally Sulzer Innotec is a partner of external (Non-Sulzer) companies which need the knowledge of the people at Sulzer Innotec in the fields of fluid dynamics, FEM-simulations for structural mechanics and surface technology. Problems of fluid-structure-interactions (FSI) occur in different types of applications at Sulzer. Analyzing the problems by experimental work were done in most of the cases. The reduction of the mathematical complexity of the real application to simpler models or applications which should represent the original one was another alternative. The industrial investigation of fluid-structure-interaction based on the simultaneous solution of the Navier-Stokes-equations and the structural equations (the so-called Multiphysics-simulation) is a capability available in commercial codes now. Sulzer has tested a number of codes like Spectrum, Adina, Radioss, etc. during the last years. In spite of the advantages of these integrated codes we are still interested in the coupling of fluid flow and structural computations with our existing and daily used codes. This has resulted in the participation of the development of Cocolib (MpCCI) during the last years.

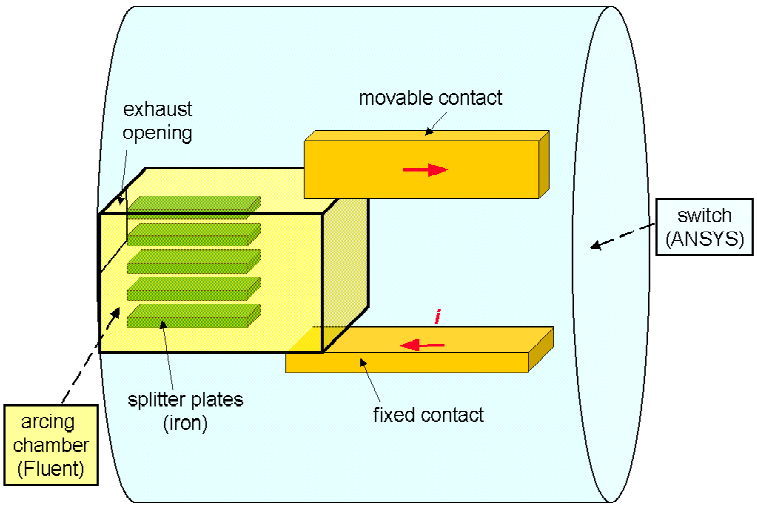
During the talk we will present our work in the computation of the Sulzer Mixer SMB on high pressure load by coupling STAR-CD and Permas using MpCCI. The mixer is designed for laminar mixing. Pressure losses of 300 bar can be obtained for the mixing of highly viscous fluids. The coupling interface between the fluid and the structural is very complex and consists more than 120’000 triangular elements. The deformations of the mixer, the different stages of complexity of the FEM-model and an outlook on the future work will be given. The use of STAR-CD, Permas and MpCCI gives us the opportunity to a more realistic computation of the forces on the structure and a better design of the mixer geometry.

Coupling for arc simulations at MOELLER

Dr. Hartwig Stammberger
MOELLER GmbH, Bonn, Germany

Moeller is an electrical engineering company specializing in industrial automation, building automation and systems for electricity distribution in low-voltage and medium voltage applications. The family owned company located in Bonn with about 12000 employees reached a turnover of about 2,300 Mio. DM in the last business year; about 60 % of that outside of Germany. 26 production sites are located in 4 continents, and 370 sales offices in about 80 countries ensure that Moeller products and engineering solutions are being used throughout the world.

Physical modelling and simulation plays an important role in the development process at Moeller. The simulation topics include mechanics, temperature, magnetics, dynamical behaviour of multibody systems, fluid mechanics, rheology and short circuit calculations. Increasingly coupling of the disciplines becomes more important; that is why a cooperation with GMD, St. Augustin, has been reached to extend the existing MpCCI code to allow for volume coupling.



The focus of this contribution is the simulation of the electric arc that occurs in breaking operations of electro-mechanical switchgear, especially in *circuit breakers* that are capable of switching currents up to 150 kA. During the breaking operation a power of up to several MW is generated in the arcing chamber for a short period of time (ms to some 10 ms) resulting in ionization of the ambient air with maximum temperatures of 30000 K and peak pressures in the chamber of around 12 bar. The figure shows a sketch of the breaker with the fixed and movable contact leading the current *i* towards the arcing chamber (yellow) with iron splitter plates and the exhaust opening.

The governing physical phenomena are *magnetic fields* due to the electrical current and ferromagnetic parts in the breaker, *current conduction* in the current leads and the ionized air due to the temperature- and pressure-dependent electrical conductivity, and *magneto-hydrodynamics* (MHD) including the mass-, momentum- and energy balance as well as radiation transport that lead to a fluid flow within the breaker towards the exhaust openings.

The reason for using MpCCI is that there is no single program available that is capable of solving all the equations simultaneously. Thus we plan to use the finite element code ANSYS to solve for the magnetic field and the Lorentz-forces on the arc using Maxwell's equations and the finite volume program Fluent to calculate the fluid flow in the chamber. In a first step only hexahedral meshes with non-intersecting boundaries will be used, i. e. an integer number of finite volume cells will be included in one finite element. Results will be interpolated from the coarse FE-mesh to the fine FV-mesh taking into account the results of adjacent elements.

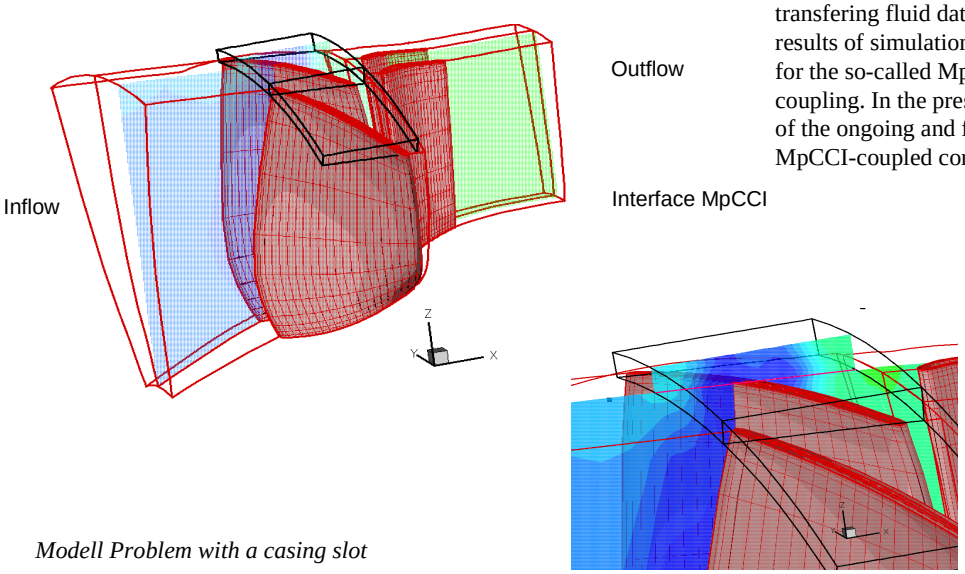
The author is group leader for physical modelling and simulation in the pre-development of Moeller.
E-Mail: hartwig.stammberger@moeller.net

Coupling of Navier-Stokes Solver Processes using MpCCI at MTU Aero Engines

Bernard Brouillet[1)], Heiko Sbresny[2)]
[1)]MTU Aero Engines, [2)]ATENA, Munich, Germany

During the recent years, the increasing computational resources have made it feasible to apply 3D-Navier-Stokes methods within the design process of turbo-machinery components in every day´s work as state-of-the-art. Important design parameters, such as efficiency, pressure ratio, mass flow, etc., can be calculated with high precision in an early stage of machine design. Within the design, it has to be especially paid attention to the fact that little differences of design parameters can have large (economical) consequences for long-term operation of turbo-machines. Because of this, in the very near future numerical determinations of the design parameters have to be made not only for an ideal casing of the turbo-machine, but also considering the influence of numerous geometrical details, such as cavities. This results in more detailed, complicated geometries in CFD. For simulation of flows through those geometries, methods on block-structured or unstructured meshes are commonly known.

On the other hand, the numerical methods applied for design, such as TRACE_S at MTU, contain a very specific know-how which has been accumulated during many years. The methods are well-known by the design engineers and all information about implemented models which may be needed during interpretation of results is available to them. Furthermore, with respect to a short design period, the code has been well implemented into the over-all design process to allow a quick, trouble-free application. To keep the long-term experience which is included in this code while coping with increasing demands of geometrical resolution of the calculated flows, the possibility of coupling TRACE_S with other, geometrically more flexible methods is going to be investigated. As a first step to this, the coupling of multiple TRACE_S computation processes using MpCCI has been applied to a model problem.With support of the GMD, the general feasibility has been shown, the necessary steps for implementation have been evaluated, and the influence of transfering fluid data via MpCCI on the results of simulation have been estimated for the so-called MpCCI fluid-fluid coupling. In the presentation a short review of the ongoing and first results of the MpCCI-coupled computation are given.



Modell Problem with a casing slot

Application of MpCCI to a Wing Aeroelasticity Problem

Ryoichi Onishi, Mitsubishi Research Institute , Inc.
Zhihong Guo, Surigiken, Co. Ltd.
Toshiyuki Imamura, Toshio Hirayama
Japan Atomic Energy Research Institute (JAERI)

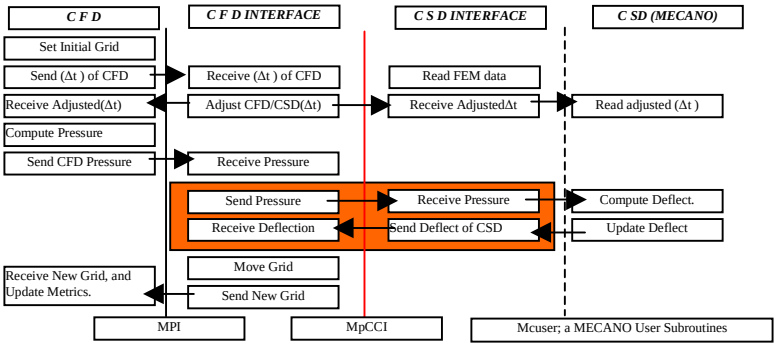


Figure 1: Interfaces and process flows of CFD and CSD(MECANO)

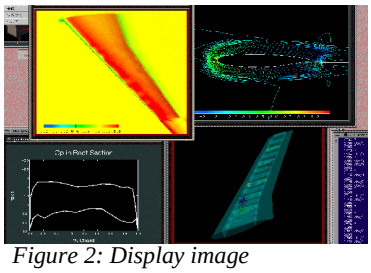
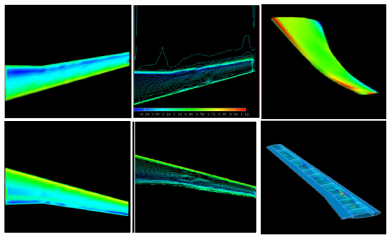


Figure 2: Display image demonstrating simultaneous fluid-structural analysis.



Vertical Stress in Upper/Lower Skins.

Airflow Pressures on Upper/Lower Skins. (M0.715, Re=5.2×10⁶)

1st Mode Bending. Elastic Strain Concentration in Internal Structures.

Figure 3: Transonic Aeroelasticity Analysis of a Twin-jet Transport Wing.

Introduction

A research on multidisciplinary integrated simulations is in progress at Japan Atomic Energy Research Institute. Loosely coupled codes of fluid-structural dynamics have been integrated on the institute's parallel computers.

Configuration of the System

Unsteady compressible Euler fluid dynamics and structural dynamics codes are integrated as shown in Figure 1. Interface of the two codes has the capabilities of converting fluid pressures and structural deflections into structural forces and flow-field deformations respectively. Figure 2 is some of the computational results, demonstrating simultaneous evaluations of aerodynamics and structure of a swept back wing. The programs of fluid and structural dynamics are loosely coupled on parallel computers. The two codes are simultaneously executed exchanging fluid and structural information. Simultaneous executions of the two codes have an advantage in reducing computational time(1). The flow-field and structure are differently decomposed into the parallel processing domains.

Application

Figure 3 shows the application of the system to the transonic aeroelastics analysis of a wing of twin-engine transport aircraft.
Airflow pressures, generated stresses in wing skins, internal structural conditions, and the 1st bending mode are presented.

MpCCI Implementation

Coupling algorithms employed in the current system is based on simple interpolation technique, and it is anticipated to perform analysis of more complex constructions by improving interface capabilities.

MpCCI is expected to provide coupling capabilities of fluid and structural meshes with complicated geometries. Also the introduction of a commercial code MECANO(2) is in progress for the sophistication of structural analysis.
Figure 1 illustrates how the integration of the two different codes of CFD which is based on MPI and MECANO which has indigenous interface mechanism called MCUSER is accomplished through MpCCI. The two interface programs of MPI and MCUSER are connected by the send-and receive functions of MpCCI. The red-box represented in the figure shows the send - receive processes between fluid and structural meshes. Search and interpolation algorithms associated in MpCCI will provide a coupling capability of two meshes with complicated geometries.

Subject

Loose coupling integration on heterogeneous computers is planned using Stampi(3), a communication software which enables to execute different codes on networked computers. Also the applications to complex assembly constructions incorporating internal components such as fuel tanks are expected.

Acknowledgement

We would like to thank Mr.Fumio Kamijyo , a director of Computational Science and Engineering Div.Surigiken Co. Ltd., for his help in development of the system.

Reference

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Increasing functionality by using MpCCI based on Stampi

Toshiyuki Imamura
Japan Atomic Energy Research Institute (JAERI)

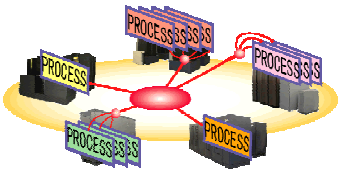

Fig.1: Process mapping on a heterogeneous environment

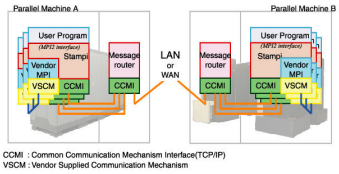

Fig.2: Stampi Architecture

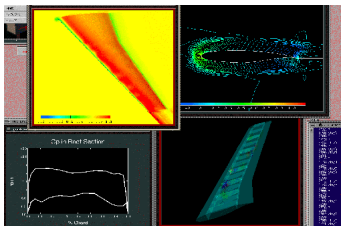

Fig.3: Output images of wing aeroelasticy problem

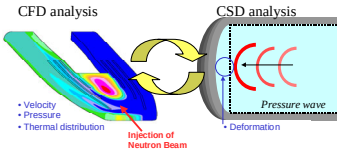

Fig.4: Coupling of Mercury target code

The new concept of metacomputing is proposed as a method that realizes a virtual computational system assembling worldwide resources, for example super-computers, database, remote-experiments, etc. It is expected to save computing time and to provide users with useful access to the remote devices and powerful resources such as larger memory area. To establish metacomputing, heterogeneity should be removed from computational environment. For example, subtasks should be allocated over all parallel machines (see Fig. 1) and standardized inter-machine communication is an inevitable technique. Japan Atomic Energy Research Institute, JAERI, developed a new MPI implementation, Stampi [1, 2], in order to break calculation impediment.

What is Stampi?

Stampi was developed as an extension of existing MPI implementations and currently represents an MPI2-subsets with focus on process creation and remote-I/O. Basic architecture is shown in Fig. 2 and main features of Stampi are:

- To enable inter-machines communication on TCP/IP and that for intra-machine on fast network devices.
- A selector mechanism, inter-machines and intra-machine within the MPI communication semantics.
- To support dynamic process creation like MPI_Comm_spawn, MPI_Open_port.
- Automatic data type conversion, e.g. endian, the floating data formats, etc.
- To support transparent point to point communication with Java applets.

Currently more than 10 platforms are supported including Hitachi SR2201, Fujitsu VPP300, NEC SX-4, CRAY T90, IBM SP, SGI Onyx / Origin, Intel Paragon, CRAY T3E, WS cluster (Solaris, HP-UX, Linux, etc) and so forth. Stampi is a free software and available from the web [2].

Coupling MpCCI and Stampi

Linking MpCCI and Stampi instead of a native MPI library will perform effectively in distributed manner and enable us to couple the parallel codes with ease, which were developed on different platforms. It is a natural solution between GMD and JAERI, and two parties started to develop a joint product, MpCCI/Stampi, at the middle of 2000.

Since APIs of Stampi are fully compatible to the native MPI libraries, the software layer of MpCCI/Stampi is basically equivalent to the original MpCCI. Concerning the timing of process of CCI_Init, we proposed some extension to the initial files in order to describe heterogeneous- or multi- platform and included parent-child spawning mechanism by using Stampi MPI2 functionality. This additional functionality is designed to be hiding from the user interface of MpCCI, thus users only have to re-compile their codes on the machines and setup their initial files.

Currently, MpCCI based on Stampi is available on IBM SP/3 and NEC SX-4. The number of supported platforms is planned to increase in future.

MpCCI/Stampi Application

The application of MpCCI, Fluid/Structure coupling code for wing aeroelasticity problem, is now developing in JAERI and this will be the first application to MpCCI / Stampi. In this coupling, a commercial CSD code, *MECANO* [3] is used. We modified the dummy routine provided to users as an interface between MECANO and MpCCI to enable us coupling a CFD code to MECANO via MpCCI. Several graphical images of computational results are presented in Fig. 3.

The second application for analysis of a mercury target for nuclear spallation will be also developed with a help of MpCCI / Stampi. This is a core code for designing a target part of a proton synchrotron. In this application, thermal flow of mercury (CFD) and structural dynamics of target vessel (CSD) are coupled (see Fig. 4).

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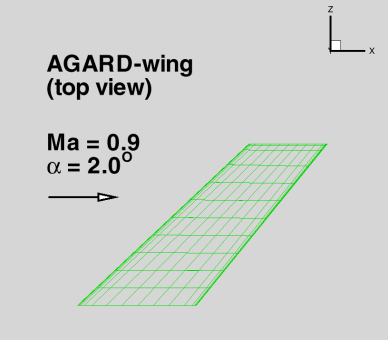
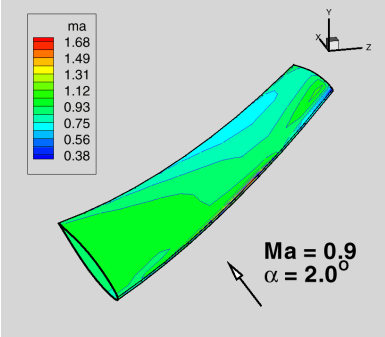
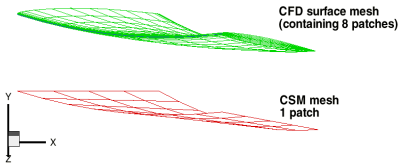
Aerodynamic/Structure Coupling using FLOWer and SIMPACK

Dr. Ralf Heinrich, Institute of Design Aerodynamics
Dr. Wolf Krüger, Institute of Aeroelasticity; DLR







CFD and structural model of the AGARD wing

To enable a realistic assessment of the aeroelastic phenomena of aircraft, a simultaneous application of computational fluid dynamics (CFD) and computational structural mechanics (CSM) has to be performed. Each discipline has developed powerful specialized tools which have to be adapted for multidisci-plinary applications. One approach is made in the DLR/HGF project AMANDA (A Multidisciplinary High Performance Numerical Development System for Aircraft, [1]). Among the CFD and CSM tools to be integrated in this project are the blockstructured FLOWer code and the multi-body simulation (MBS) tool SIMPACK; both tools have been developed at DLR. The exchange of data is realized by MpCCI (Mesh based parallel Code Coupling Interface), a development of GMD.

A first problem to be regarded is the coupling of a CSM and a CFD model of the AGARD wing, a standard aeroelastic test case [2]. The data of the wing is available as a NASTRAN structural model, a plate with 121, rather equally distributed, nodes, and a CFD mesh with approximately 10000 cells, resulting in 873 grid points on the wing surface.

The code used to solve the structural side is SIMPACK, the multi-body simulation code of DLR [3]. Flexible bodies are included in the MBS model by means of the modal approach, i.e. an eigen-mode / eigenvector analysis is performed in NASTRAN; selected eigenmodes and nodes are then transferred by the pre-processor FEMBS into SIMPACK. The resulting elastic deformation is a linear superposition of those eigenmodes.

For the numerical flow simulations, the program system FLOWer is used. FLOWer is a blockstructured CFD solver which has been developed at the Institute of Design Aerodynamics of DLR [4]. It is capable of parallel computing on several processors and/or computers. The aerodynamic multiblock mesh has been set up by the grid generator MegaCads and is adapted to the structural deformation by a deformation module developed by EADS Military Aircraft.

The MPI-based data flow between the codes as well as the projection of the CFD surface on the CSM plate is performed by MpCCI [5]. For the proof-of-concept calculations, the transformation has been performed using standard MpCCI interpolation routines. For further applications, additional interpolation routines have been implemented in MpCCI in the course of the AMANDA project which also allow the use of elastic beams on the CSM side [6], [7].

During the coupled simulation, FLOWer calculates a pressure distribution on the surface for a given plate deformation, converts the pressure to forces on the grid points, and sends those forces to MpCCI. Here they are transformed to the distribution of the nodes on the structural plate model and passed to SIMPACK, where the forces are applied to the nodes. The structure converges by means of a time simulation to a new steady deflection which is in turn transferred back to the CFD code, where the aerodynamic mesh is deformed and a new pressure distribution is calculated. The used models and preliminary results of the proof-of concept calculations can be seen in the figures. The next steps will be the use of the new algorithms in the grid transformation and the implementation of a larger model, most likely a wing of a civil transport aircraft, where comparisons with measurements can be performed. Final goal of the AMANDA project is the simulation of aeroelastic dynamic phenomena in the time domain.

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Development of an Aeroelastic Solver using MpCCI as a Code-Coupling Interface

Dr. Armin Beckert

EADS - Military Aircraft / MT24, Munich, Germany

Fig. 1: Experimental aircraft X-31 at high angle of attack maneuver

In the field of Aeroelasticity, interactions between elastic structures and fluid flow are investigated. In Static Aeroelasticity, load distributions on elastic aircraft structures, the effectiveness and reversal of control surfaces and divergence are determined whereas in Dynamic Aeroelasticity phenomena like Buffeting, Limit Cycle Oscillations (LCO) and Flutter are investigated. Most of the above mentioned phenomena can be associated to stability and response problems. The precise description of the aeroelastic behavior of an aircraft is of importance for its design process since the elasticity of the structure highly influences the aerodynamic and flight mechanical attributes and effectiveness of an aircraft.

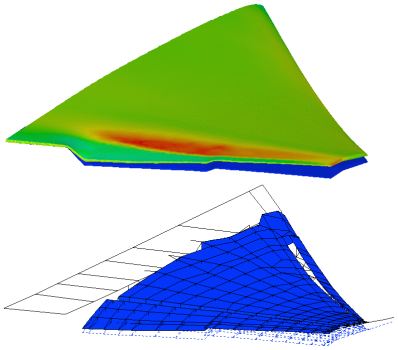

Fig. 2: Static aeroelastic equilibrium of a wing model in transonic fluid flow

Classical analysis methods in Aeroelasticity assume linear models for the structure and the fluid flow. As a consequence the application of these methods is limited to small elastic deformations of the structure and to an inviscid fluid flow neglecting nonlinear effects like shock waves, turbulence and flow separation.

Modern civil transport aircraft cruise within a transonic speed range where the fluid flow is characterized by viscous effects. Furthermore during flight, wings with high aspect ratio lead to large elastic deformations. In contrast to civil transport aircraft, the operational speed range of military aircraft such as the X-31 (see Fig.1) includes sub-, trans- and supersonic speeds. Additionally, maneuvers at high angle of attack cause nonlinear aerodynamic effects in the fluid flow such as flow separation and turbulence. Therefore, the design of modern aircraft requires the consideration of nonlinearities that occur in the solution of coupled aeroelastic equations.

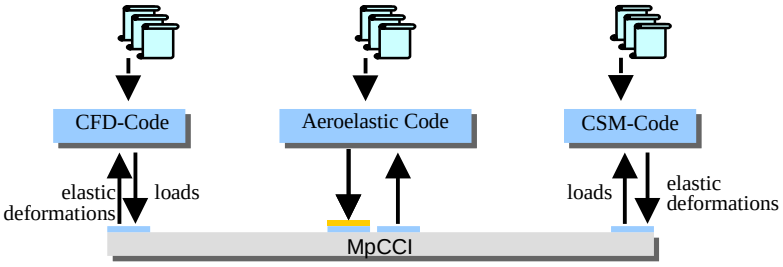

Fig. 3: Environment for coupled aeroelastic computations

Aeroelastic Analysis Code

In the fields of structural mechanics and computational fluid dynamics (CFD) several methods and powerful analysis tools have been developed to solve the respective nonlinear equations. In order to take full advantage of the developments in these single disciplines, the coupling of fluid and structural models is desirable to solve nonlinear aeroelastic problems. EADS-M started the development of an aeroelastic code which communicates with structural mechanics and CFD analysis programs (see Fig.3). It is designed to include several time-integration procedures and a selection of spatial coupling schemes. For coupling in the time-domain, staggered and implicit algorithms will be used whereas for coupling in space, a variety of 3D Multivariate Interpolation schemes and a Neutral Surface approach have been chosen. The main task of the aeroelastic code is to manage the coupled computation and to transform the related load and motion data between the different discretizations.

Code Coupling

For aeroelastic applications, MpCCI has been chosen as a platform for coupling the related analysis codes used at EADS-M. In the current phase the sources of the codes have been provided with an MpCCI interface. It is planned to validate the computational environment in the current year running aeroelastic computations on massive-parallel systems and on Linux workstation-cluster.
Concerning the capability of the code-coupling interface it has to be stated, that MpCCI limits the data exchange to scalar and vector type floating-point arrays. For the practical use however, it would be helpful to exchange also character and integer values of arbitrary array-size. The planned applications at EADS-M require an exchange of control parameters and tensor type data (i.e. stress). An improvement of MpCCI's capability in 3D interpolation is also desirable since in practice the discretizations of fluid and structural models differ remarkably.

Applications

The computational environment is needed for both, static and dynamic aeroelastic computations of wings (see Fig.2) and complete aircraft configurations. The main objective is to investigate the stability and response behavior of aircraft during flight and maneuvers

MpCCI Roadmap

Klaus Wolf
GMD/SCAI, Sankt Augustin, Germany

Besides being the begin of the new millenium, the year 2000 was also the start for MpCCI on the market. In February 2000 MpCCI V1.0 was put on the Web. Since that date more than 120 engineers and scientists downloaded the software.
The application areas where MpCCI is used to coupled mono-disciplinary codes, are wide-spread:
• the most important one: static fluid-structure interaction for wings, spoilers, mixers, tanks, gas generators, …..
• dynamic fluid-structure controlled by dedicated aeroelastic codes,
• fluid-structure-thermal for the computation of turbine blades or combustion chambers,
• fluid-fluid coupling in industry and research (climate and weather coupling),
• fluid-structure-electro-magnetics in the area of electrical components, and
• various other areas in a planning status.
All in all there is a growing demand for multidisciplinary solutions realised on top of MpCCI.

Numerical Extensions

To fulfill all requirements coming from very different application areas, new numerical features have to be added to MpCCI:
• Internal **performance** will be improved to run efficiently on massive parallel systems.
• **3D interpolation** schemes to enable volume coupling are under development (see e.g. MOELLER application). It will be investigated, how far general schemes can be used and for which cases more spcialised solutions are necessary.
• For **conservative interpolations** in fluid-fluid-couplings (see e.g. MTU case) algorithms based on accurate element overlaps are planned.
• For various other coupling application specific solutions are necessary (see e.g. DLR case): to do a multidisciplinary simulation based on CFD and MBS codes, a dedicated scheme for **spatial interpolation** has been implemented in a prototype.
• To enable code-vendors and users to introduce their own interpolation schemes into MpCCI-coupled systems, during 2001 a '**MpCCI Developers Version'** will be provided. Through an API this versions offers access to MpCCI internal data structures; user defined numerical functions for neighborhood definition and interpolation then can be linked to the coupled system.

Tools around MpCCI

The acceptance of any kind of software is strongly dependent from the user friendliness. Around MpCCI several tools will be provided within the next year, which provide the user with more comfort and with more insight into the running applications:
• A graphical user interface (**GUI**) allows the easy definition of any input variables and the control of the running system.
• A '**Playback Tool'** enables code owners (see CD abstract) to debug code crashes without having access to the code on 'the other side'.
• **COCOVis** (a tool of NEC CCRLE Germany) is a kind of 'graphical debugger' for MpCCI; it provides a deeper look into the neighborhood definitions, interpolations and communications done by MpCCI.
• Adapters to some standard **Visualisation Tools** (like AVS) will be implemented.
• MpCCI will be instrumented to support **Vampire** monitoring information. Vampire is a performance measurement tool offered by PALLAS GmbH.

Platforms

The portability of MpCCI is mostly defined by the availability of suitable MPI 1 implementations.
• **Dynamic starting** and terminating of codes will be an extensions of MpCCI for those architectures, where MPI-2 features are implemented. This work will be based on MPI implementations like StaMPI (see presentation from JAERI), MetaMPI or PACX.
• To integrate MpCCI coupled systems into **distributed workflows**, adaptations to CORBA and JAVA frameworks have been realised in prototypes (see DLR abstract)

From a Coupling Library to a Coupling Environment

There is a general trend towards more sophisticated solution environments instead of 'purely coupling codes'. For few but large application areas the MpCCI group will develop complete working environments including customised GUI, visualisation and data-management tools. The numerical functionality will be tuned towards the application specific needs and will be supported by integrated physical know-how.

The MpCCI Team at GMD

• Regine Ahrem
• Matthias G. Hackenberg
• Dr. Ute Karabek
• Michael Krüger
• Dr. Peter Post
• Dr. René Redler
• Josef Roggenbuck
• Dr. Barbara Steckel
• Klaus Wolf

The MpCCI Team at PALLAS

• Dr. Ullrich Becker-Lemgau
• Klaus-Dieter Oertel
• Karl Solchenbach

MpCCI Version 1.2

MpCCI is a trademark of GMD. The MpCCI 1.2 code coupling library is available since February 2001. Detailed information about MpCCI such as manuals, sample applications, references and a free copy of the software itself can be downloaded from **http://www.mpcci.org**.

MpCCI Services

MpCCI is a development of GMD/SCAI. Marketing and services around MpCCI are done in cooperation with PALLAS GmbH (Brühl, Germany). Together they provide to end users and code owners any kind of support like
• analysis of coupled applications,
• integration of MpCCI into simulation codes,
• training in using MpCCI, and
• e-mail or on-site support.

MpCCI Contact Points

Institute for Algorithms and Scientific Computing (SCAI)
GMD – German National Research Center for Information Technology

Klaus Wolf / Dr. Barbara Steckel
Schloss Birlinghoven
D-53754 Sankt Augustin

Tel: +49-2241-14-2557 / -2768
Fax: +49-2241-14-2181
E-mail: mpcci@gmd.de
http://www.gmd.de/SCAI

PALLAS GmbH

Hermühlheimer Strasse 10
D-50321 Brühl

Tel: +49-2232-1896-0
Fax: +49-2232-1896-29
Email: mpcci@pallas.com
http://www.pallas.com

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