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Fraunhofer Institute for Algorithms and Scientific Computing SCAI

Multiphysics solutions for the automotive industry

Software and applications

Content

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Preface

Fraunhofer SCAI

The Fraunhofer Institute for Algorithms and Scientific Computing SCAI combines expertise in mathematical and computational methods with a focus on developing innovative algorithms and their take-up in industrial practice – bringing benefits to customers and partners.

SCAIs research fields in computational science include machine learning and data analysis, optimization, multiphysics, energy network evaluation, virtual material design, multiscale methods, high-performance computing, and computational finance.

In the field of bioinformatics, SCAI offers its customers comprehensive services in information extraction (text mining). Here, the most important application field is modeling neurodegenerative diseases.

The institute has close links with the chair of Prof. Dr. Michael Griebel, Institute Director of Fraunhofer SCAI, at the University of Bonn. SCAI also cooperates with the Bonn-Aachen International Center for Information Technology (B-IT) and the Bonn-Rhein-Sieg University of Applied Sciences.

SCAI's business area multiphysics

The virtual design and development of efficient manufacturing processes and advanced products is a key goal for any industry. Multiphysics co-simulation and integrated virtual engineering workflows are used to model the effects of the complete manufacturing history of the used materials and components, as well as the inferences of physical effects represented by coupled CAE models. Fraunhofer SCAI's MpCCI interface portfolio provides vendor-neutral software solutions for direct code coupling and seamless data transfer in integrated CAE workflows.

MpCCI software solution

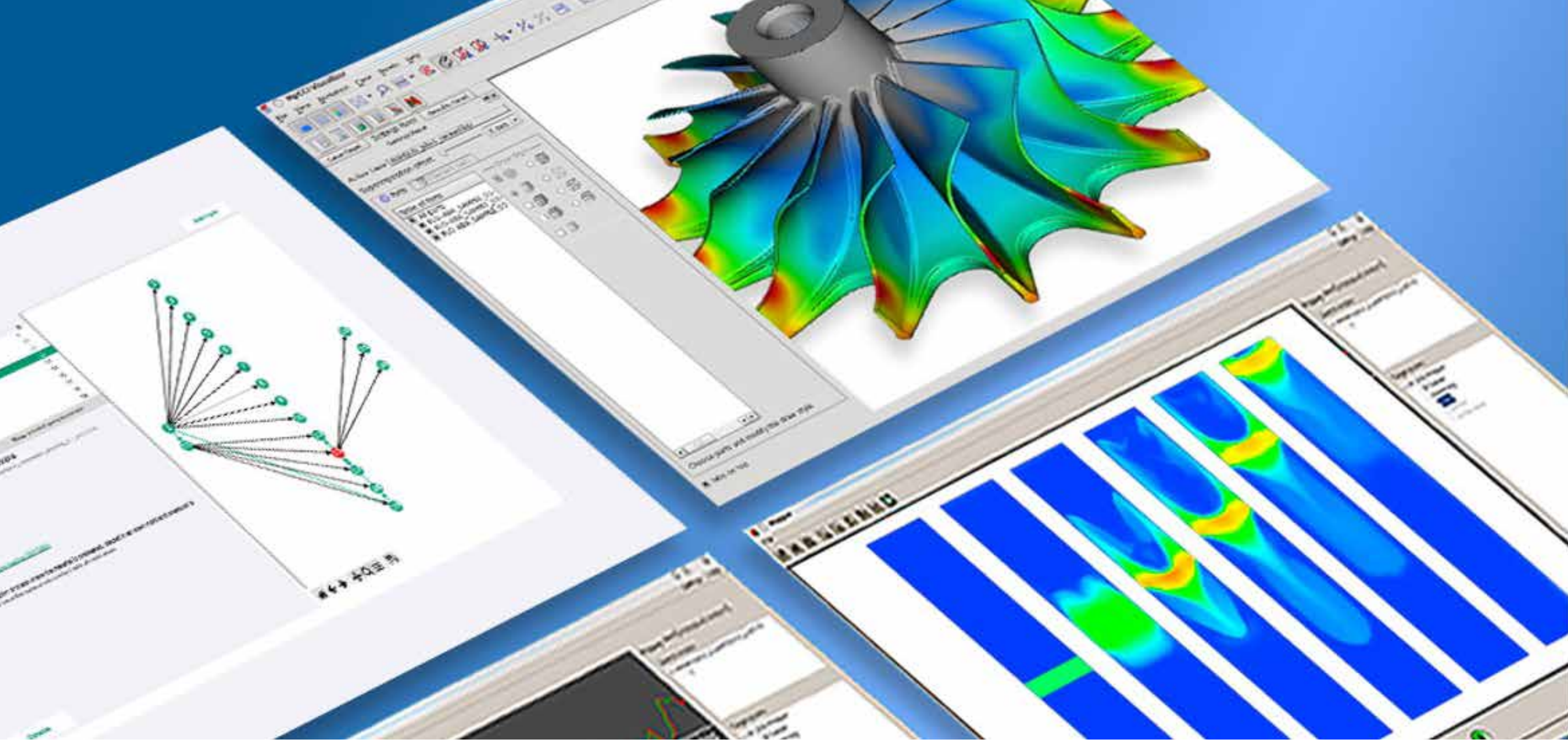
The MpCCI portfolio comprises a range of multiphysics interface solutions for co-simulation, integrated CAE workflows, digital twins, and accompanying CAE service solutions. The MpCCI interface software is a vendor-neutral solution for co-simulation and file-based data transfer. MpCCI supports a growing number of commercial and research simulation tools in different engineering disciplines.

scapos AG

Since its foundation in 2009, scapos AG has been providing support to research institutions and SMEs in the distribution of their software products.

Technical software products from research institutions such as the Fraunhofer Gesellschaft and solutions from innovative start-ups characterize the scapos AG offering. The focus is on simulation (CAE), cutting and packaging optimization, metrology and language technologies.

In the area of CAE, scapos offers software products for optimizing and accelerating existing simulation applications and solutions for multiphysics simulation.



Multiphysics modeling
Solutions for automotive engineering

Benefits of multiphysics modeling

Multiphysics modeling offers several benefits that contribute to a deeper understanding of complex systems and phenomena:

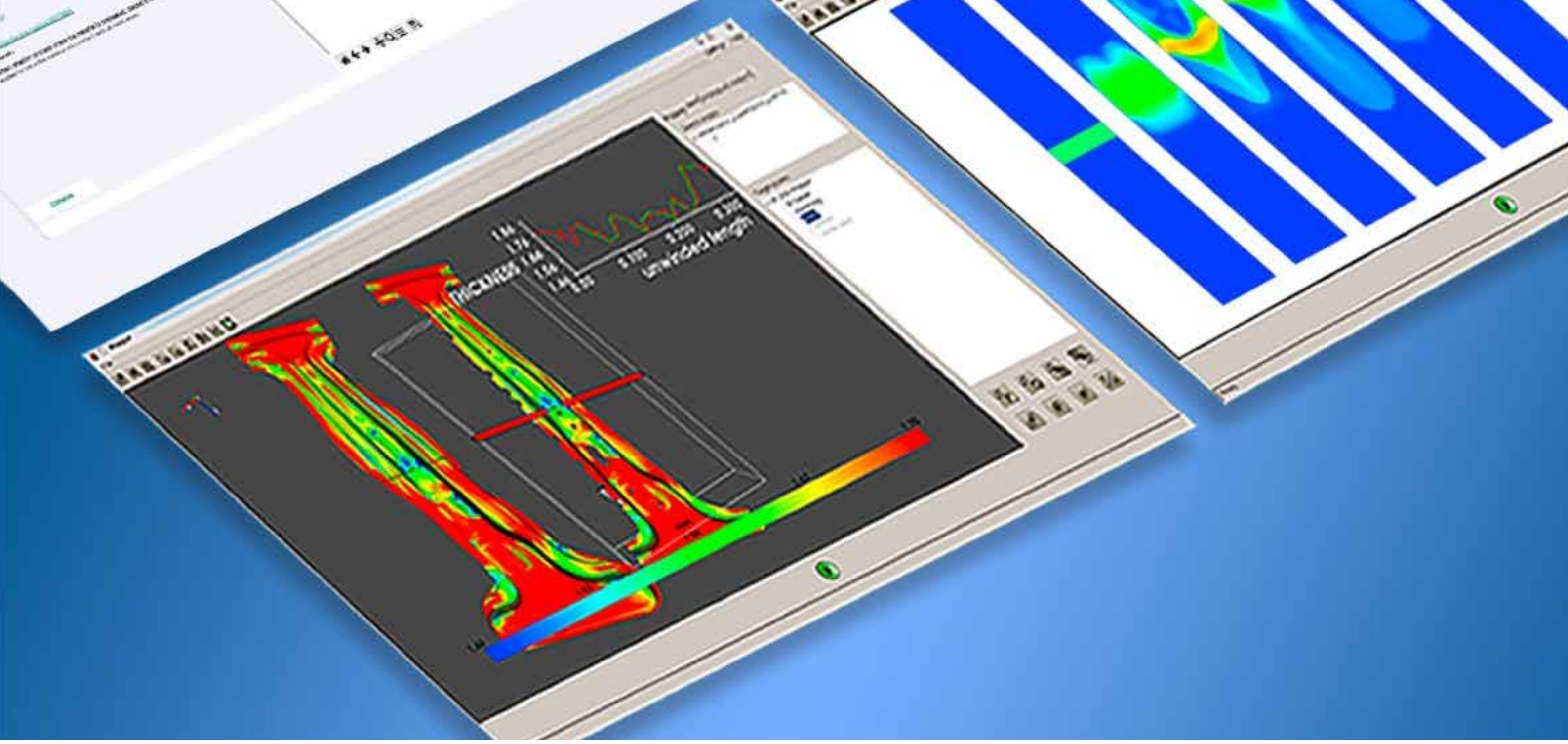
- **Realistic representation and comprehensive analysis:** Multiphysics modeling allows for a more accurate representation of real-world systems by considering the interactions and coupling between different physical phenomena. It enables engineers to understand how different physical processes interact and affect each other, leading to more accurate results and improved decision-making. Thus, it leads to a better understanding of the system as a whole.
- **Cost and time efficiency:** By integrating multiple physics into a single simulation, multiphysics modeling can save time and resources compared to performing separate simulations for each physical phenomenon. It reduces the need for iterative testing and prototyping, resulting in cost and time savings in the design and development process.
- **Cross-disciplinary collaboration:** Multiphysics modeling promotes collaboration between experts from different disciplines. They can combine their expertise to solve complex problems and explore innovative solutions.

Overall, multiphysics modeling enables a more holistic and comprehensive approach to understanding and analyzing complex systems, leading to improved designs, optimized performance, and better decision-making.

Combining multiple CAE tools

Combining different CAE tools in a single multiphysics application offers several advantages, including:

- **Enhanced flexibility:** CAE tools have different features, capabilities, and user interfaces. By combining them, you can leverage the strengths of each tool to address specific aspects of your multiphysics problem.
- **Using comprehensive simulation capabilities:** Different CAE tools specialize in simulating specific physics or phenomena.
- **Improved accuracy:** Each CAE tool may have its own solver algorithms and methodologies optimized for specific physics.
- **Specialized pre- and post-processing:** CAE tools often provide specialized pre- and post-processing capabilities for specific physics domains.



- **Cost and resource optimization:** Instead of investing in a single CAE tool that claims to cover all physics, combining different tools allows you to select the best-in-class software for each physics domain.

Combining different CAE tools, allows you to leverage their unique capabilities, enhance accuracy, streamline workflow, and optimize resources, leading to better insights, improved designs, and more reliable predictions in multiphysics applications.

MpCCI interface portfolio

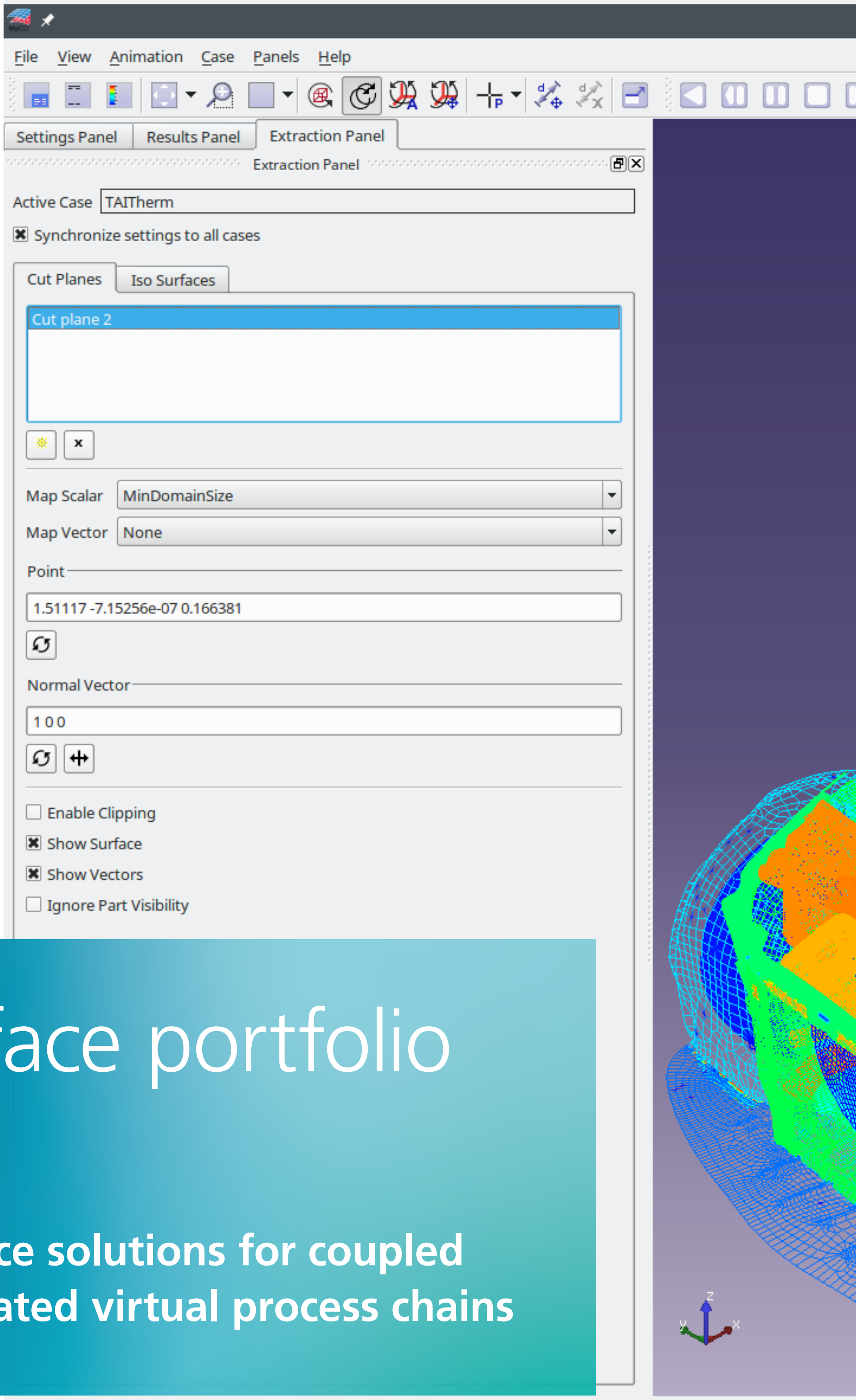
The MpCCI interface portfolio from Fraunhofer SCAI provides a vendor-neutral software solution for direct code coupling and seamless data transfer in integrated CAE workflows:

- **MpCCI CouplingEnvironment** enables a co-simulation of CAE tools to model, e.g., fluid-structure interactions, thermal and radiation coupling, thermal management of electrical engines, or magneto-hydrodynamics in electric arcs. It provides an analysis-centered coupling definition and a smart automatic configuration for fast and robust FSI. A growing number of code interfaces and tutorials demonstrate the broad applicability of this MpCCI solution.
- The **MpCCI FSIMapper** tool can read various CFD export formats and input decks for Abaqus, Ansys, and Nastran. The two meshes between which the interpolation shall take place must be 2-dimensional surface meshes in a 3-dimensional space. The quantities that can be read and mapped are film temperature, wall heat transfer coefficient, wall heat flux, standard and complex pressure, and force densities.
- **MpCCI Mapper** is a dedicated solution for integrated virtual manufacturing chains. It allows checking off the geometric compliance of two models. The (automatic) mesh alignment helps to adjust the positions of two models if they are not in a non-conformal coordinate system. A robust mapping algorithm enables the transfer of various physical quantities for all standard shell elements and mesh types. The mapping works for different integration types and for other numbers of integration points in the thickness direction for the source and target model.

Application support

Fraunhofer provides additional MpCCI Services covering various CAE disciplines and engineering domains:

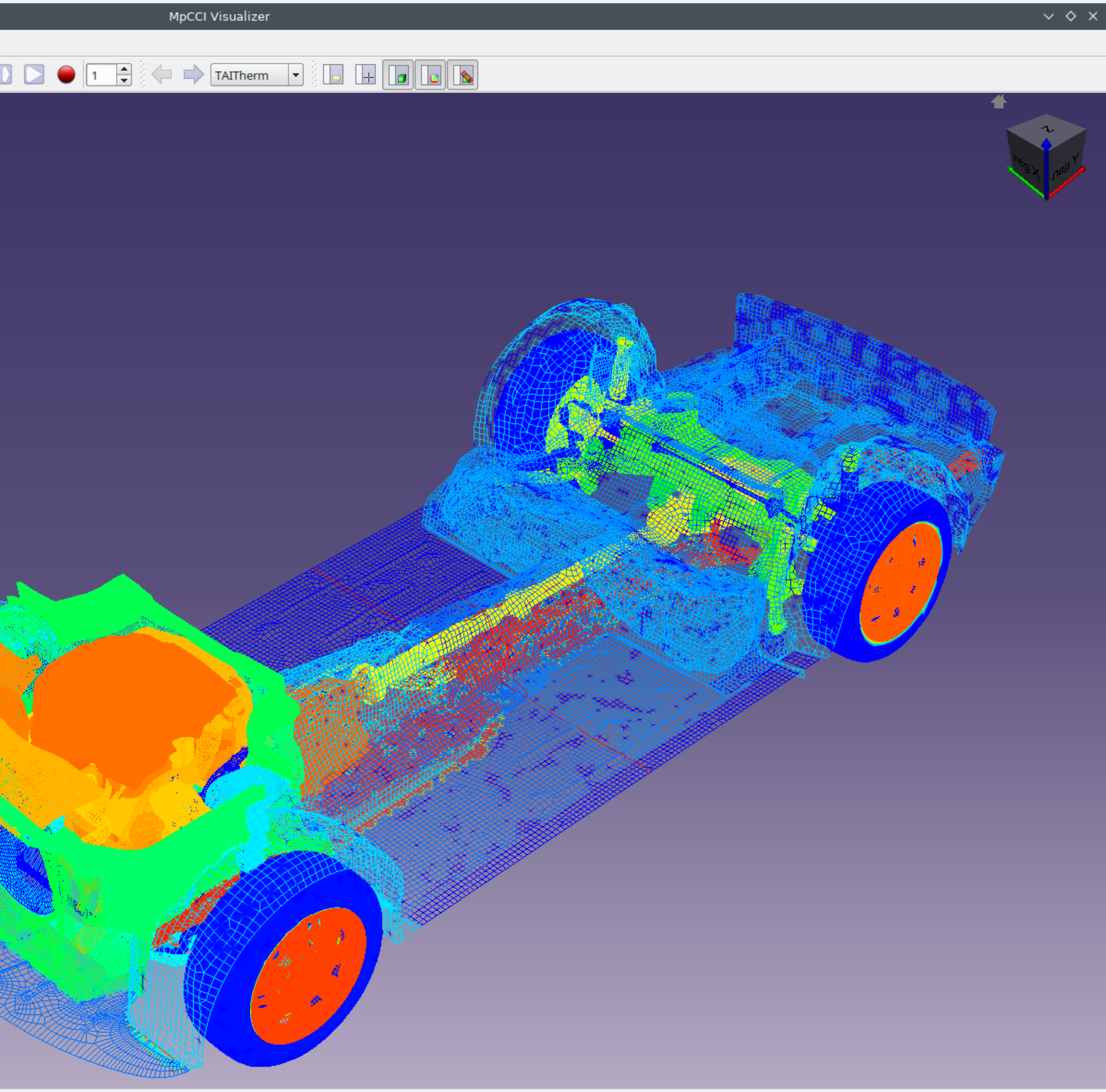
- **Training and workshops:** Fraunhofer SCAI will offer on-demand training covering the fundamentals of MpCCI–based multiphysics simulations, software usage, and best practices. Hands-on training and interactive sessions allow a deeper understanding of the subject matter.
- **Consultation and mentoring:** Fraunhofer SCAI may offer guidance in formulating the problem, selecting appropriate software tools, setting up the simulation, defining boundary conditions, interpreting results, and troubleshooting.
- **Software support:** Fraunhofer SCAI will provide guidance on software features, functionalities, and troubleshooting specific to the multiphysics application.
- **Collaborative projects:** Fraunhofer SCAI is open for joint development and R&D projects. Such co-operations allow all parties to gain deeper insights into the practical aspects of multiphysics modeling, problem-solving techniques, and industry-specific considerations.



MpCCI

MpCCI interface portfolio

Vendor-neutral interface solutions for coupled simulations and integrated virtual process chains

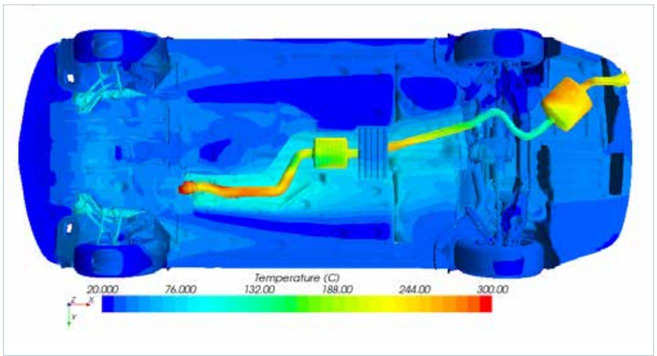

MpCCI Visualizer
TAITherm
Z
neg X
neg Y

MpCCI CouplingEnvironment
Ready-to-use co-simulation platform

Concept

MpCCI CouplingEnvironment is a vendor-neutral and application-independent interface for co-simulation.

- Staggered solution approach
- Bi-directional coupling of simulation codes for static and transient multiphysics problems
- Support of models with non-matching geometry and mesh discretization
- Treatment of periodic and rotating models
- Exchange of nearly any kind of data, e.g., energy and momentum sources, material properties, mesh definitions, or global quantities
- Integration of native parallel code execution types
- Non-intrusive plugin solution for commercial codes through their standard code APIs
- Open programming interface for in-house codes
- User-guided comfortable way to define the coupling setup
- GUI and batch access

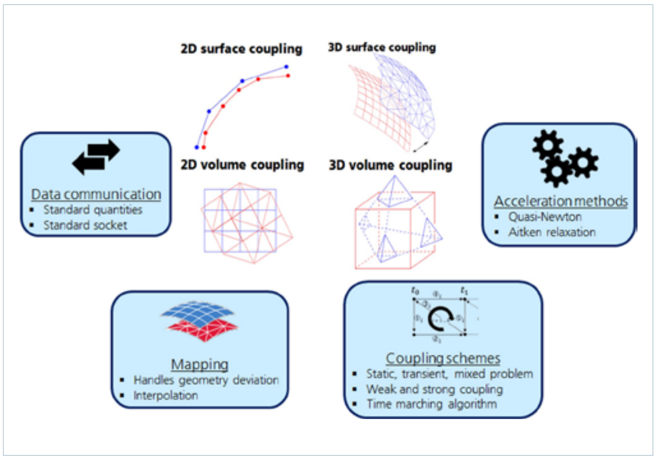


Automotive thermal management using TAITherm and STAR-CCM+

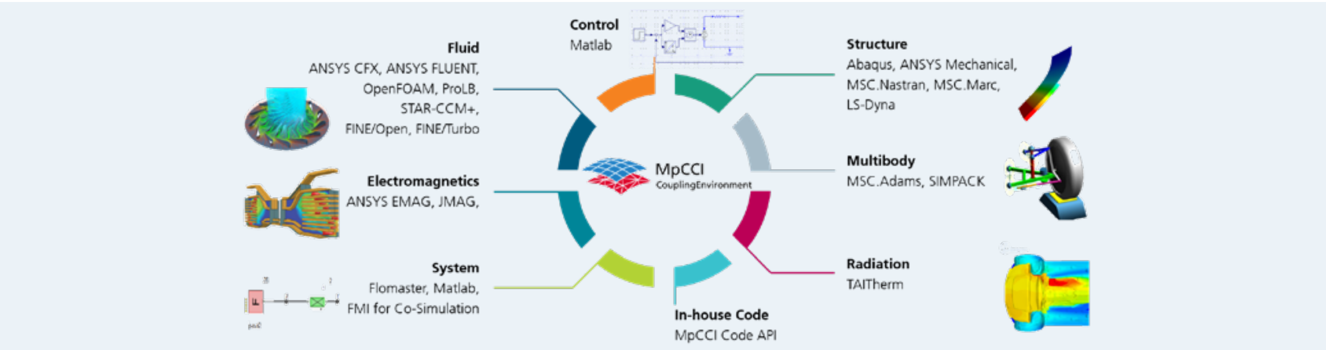
Co-simulation strategy

MpCCI CouplingEnvironment uses advanced and proven features for multiphysics modeling:

- Accurate and robust neighborhood calculation and mapping algorithms
- Various numeric stabilization methods, e.g., ramping, relaxation
- Convergence acceleration with the Quasi-Newton method
- Interpolation for non-matching time step sizes
- 2D and 3D surface and volume coupling and 1D-3D cross-dimension coupling
- Coupling specifications:
  - Algorithm type: parallel Jacobi, serial Gauss-Seidel
  - Coupling scheme: weak explicit, strong implicit
  - Analysis type: steady state, transient, mixed solution



Spatial coupling domains in 2D and 3D communication and synchronisation schemes



Code adapter for commercial and open-source simulation codes

Architecture

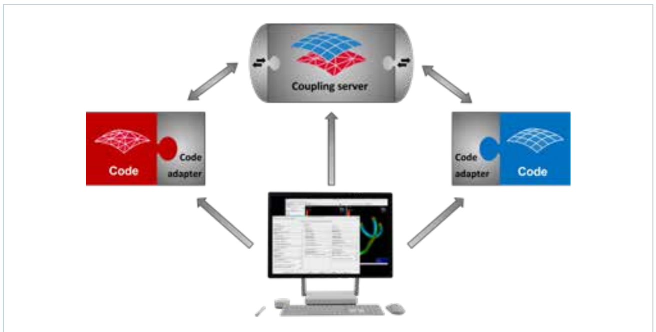
- **Code adapter:** enables direct communication between the coupled codes by providing adapters for each code. This technique allows an easy installation at the end user's site without changing the standard installation of the simulation codes.
- **MpCCI server:** the core of MpCCI CouplingEnvironment managing:
  - Environment handling
  - Communication between the codes
  - Neighborhood computation
  - Mapping and interpolation between meshes
- **MpCCI GUI:** a comfortable way to define the coupling setup and start the simulation

Infrastructure requirements

- Platform Linux and Windows 64 bits system
- TCP/IP connection
- Standard solver installation
- Remote shell: ssh
- Perl installation

Runtime

- Run on heterogeneous operating systems
- Run with solver-specific parallel environment
- Access to known batch queuing systems like LSF, PBS, SGE, and SLURM with automatic resource distribution



Runtime architecture of a coupled simulation

Supported simulation codes

- **Structural analysis**
  - Abaqus
  - ANSYS Mechanical
  - MSC.Nastran
  - MSC.Marc
  - *LS-DYNA (in development)*
- **Computational fluid dynamics**
  - FLUENT & ANSYS Icepak
  - FINE/Open & FINE/Turbo
  - OpenFOAM
  - ProLB
  - STAR-CCM+
  - *ANSYS/CFX (in development)*
- **Electromagnetic analysis**
  - ANSYS Emag
  - JMAG
- **Radiation**
  - TAITherm
- **System**
  - FloMASTER
  - MATLAB
- **Multibody**
  - MSC.Adams
  - SIMPACK
- **In-house code**
  - Documented programming interface for adaptation to in-house codes

MpCCI
CouplingEnvironment

Advantages of the MpCCI CouplingEnvironment

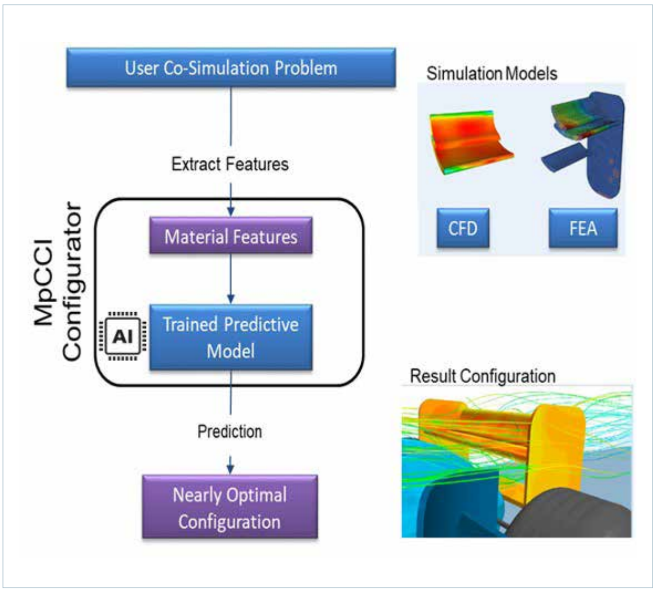
- Vendor-neutral and application-independent
- Suitable for various application domains: automotive, electrical components, machinery design, bio-medical applications, etc.
- Direct communication between the coupled codes
- Supports leading simulation codes
- Regular updating of the code adapter for the latest releases

MpCCI CouplingEnvironment
Ready-to-use co-simulation platform

MpCCI GUI

MpCCI GUI provides a comfortable way to define the coupling setup and start the simulation.

- Offers predefined coupling specifications to simplify the determination of suitable settings
- Smart configuration for fluid-structure interaction (FSI) with Abaqus, FLUENT, and OpenFOAM
- Tutorial with several examples to demonstrate the usage of MpCCI

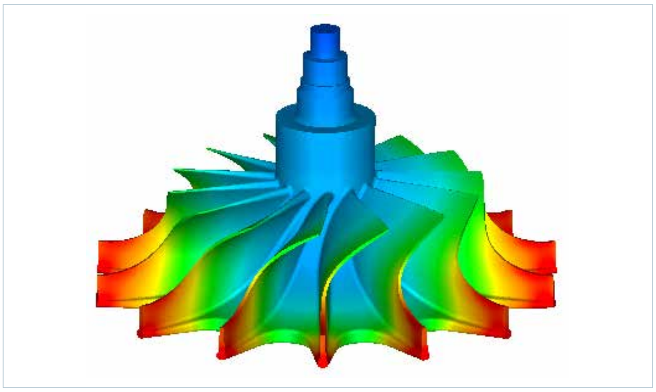


Steps involved in the MpCCI configurator

Smart coupling

Not all simulation engineers are fully trained to carry out FSI co-simulations successfully. An inappropriate choice of parameters leads to a divergent or very time-consuming calculation with no valuable results. This led to the development of the MpCCI Configurator based on the smart coupling method to make software usage simpler and more efficient.

- Optimization of the runtime by predicting the configuration parameters:
  - Coupling scheme
  - Coupling algorithm
  - Relaxation
  - Time step size
- Material features already included are, e.g.:
  - Solid material density
  - Ratio between the density of solid and fluid
  - Solid stiffness
  - Fluid compressibility
- Prediction along with the relevant material features and the trained predictive model
- Offer a couple of methods to provide
  - the models with the least costs or
  - the models with the valid configurations
- Introduced for FSI with Abaqus, FLUENT, and OpenFOAM



Temperature distribution on a turbine wheel as a result of a thermal coupling

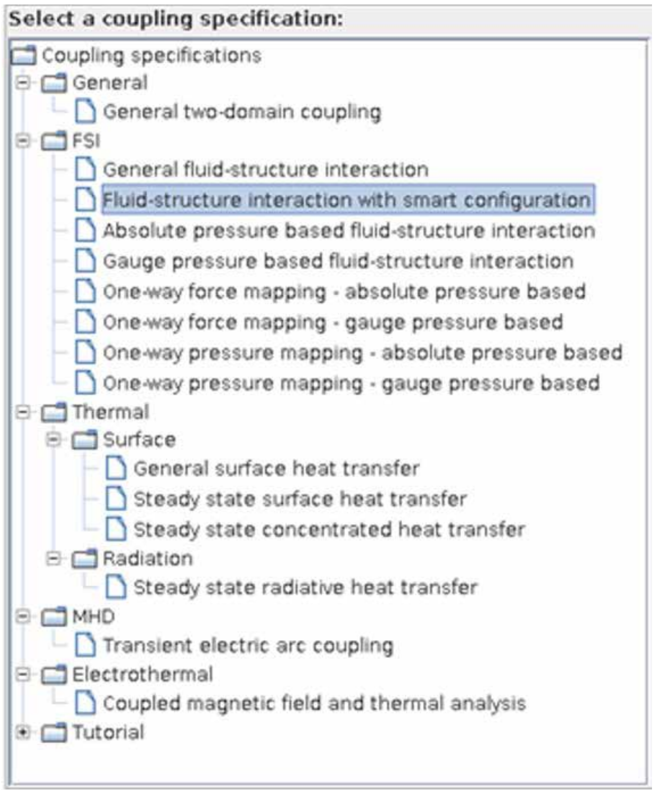
Analysis-centered coupling definition

To simplify the determination of suitable settings for the user, MpCCI GUI offers predefined coupling specifications:

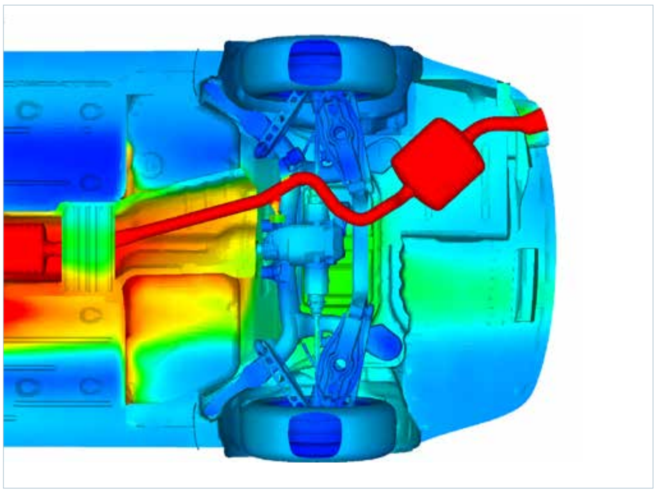
- for various coupling types
- corresponding to specific physical domains and
- a typical set of quantities that are exchanged.

Coupling specifications are offered, among others, for:

- **General two-domain coupling**
  Coupling of two domains with no restriction to domain types, quantities, or coupling parameters.
- **General fluid-structure interaction**
  Coupling of solid and fluid mechanics domains by exchanging nodal positions and pressure-based quantities.
- **Fluid-structure interaction with Smart configuration**
  The configuration depends on the used models and will be set automatically.
- **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.
- **General surface heat transfer**
  Describes heat transfer analysis governed by conduction and convection effects for solid and fluid thermal domains.
- **Steady-state surface heat transfer**
  The configuration is suited for heat transfer in conduction and convection effects for solid and fluid thermal domains.
- **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.
- **Transient electric arc coupling**
  Magnetohydrodynamics settings to describe a plasma application.
- **Coupled magnetic field and thermal analysis**
  Recommended for analyzing the thermal-magnetic behavior of electrical machines.



The coupling specifications provided in v 4.7



Thermal simulation of an exhaust system

Advantages of MpCCI GUI and smart coupling

- AI-based improved settings parameters for FSI
- Faster to a stable solution
- Predefined coupling specifications for various coupling types

MpCCI FSIMapper
File-based data transfer

Concept

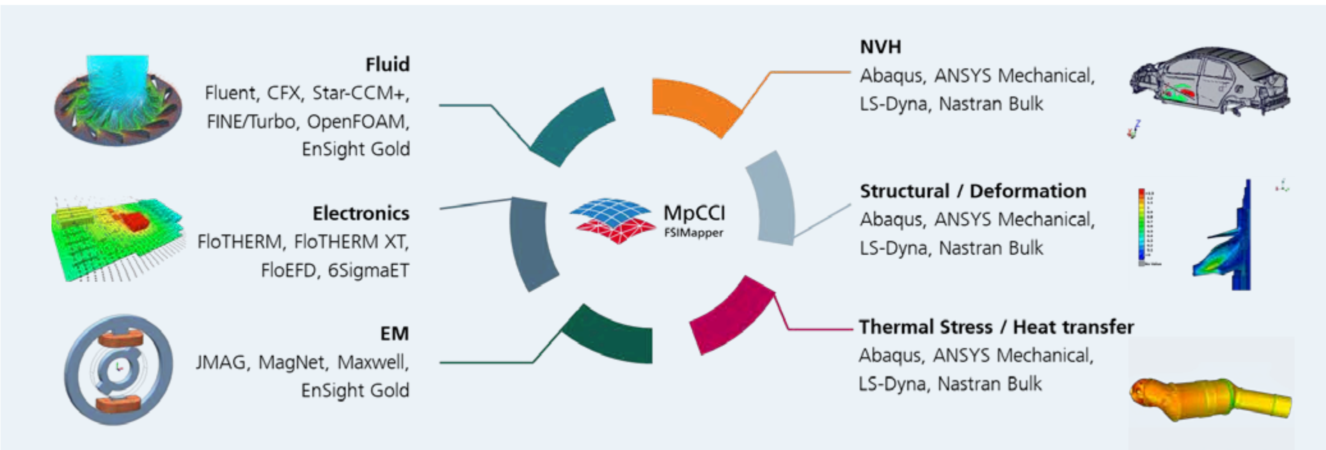
MpCCI FSIMapper is a file-based mapping tool for weak-coupled fluid-structure interaction (FSI) applications. Structural deformation does not significantly affect the fluid flow, so the coupling is realized only in one direction.

- Data transfer of one simulation result (“source”) into a second simulation (“target”) as load or boundary condition.
- Read various computational fluid dynamics (CFD) and electromagnetics (EM) export formats, as well as input decks for computational structure mechanics (CSM) codes.
- Provide advanced, robust, and configurable mapping and extrapolation methods.
- The two meshes between which the interpolation shall take place have to be:
  - 2-dimensional surface or 3-dimensional volume meshes in a
  - 3-dimensional space
- Quantities that can be read and mapped are:
  - temperature and film temperature
  - wall heat transfer coefficient
  - wall heat flux
  - standard and complex pressure
  - forces and force densities

Features

- File-based mapping solution
- Static, transient, and harmonic analyses
- Robust, efficient, and configurable algorithms
- Application-specific mapping types
- Different mesh densities and element types
- Geometric deviation treatment (orphan handling)
- Unit system translation
- Automated model positioning
- Periodic models
- Fourier transform of pressure and forces for harmonic analyses
- Windowing support in Fourier transform
- Geometric comparison
- Interactive visualization
- Batch capability

A specific feature is the possibility of computing ”average over rotation axis”. If the CFD model uses the frozen-rotor option, the quantity values from the frozen-rotor computations will be averaged, and these quantity values will be mapped to the CSM model.
Extensive toolset to translate transient structural loading into harmonic space. Comprises data truncation, filtering, Fourier analysis, and windowing architecture.



Solver and format interfaces in MpCCI FSIMapper by application

MpCCI FSIMapper GUI

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:
Select the models and parts, element sets, or surfaces

- Make choices concerning algorithms and parameters
- Initiate mapping process
- The mapping results and the original models and values are automatically loaded into MpCCI Visualizer for inspection

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.
- MpCCI FSIMapper provides a broad range of visual inspection capabilities. The CFD source data as well as the target FEA model can be viewed both in synchronised and overlay mode. Cut planes, adaption of value ranges, and many other features are available.

Batch execution

- Parameters and settings that are normally made in the GUI can be exported to a simple ASCII configuration file.
- Enables embedding in a CAE workflow by batch mapping run.

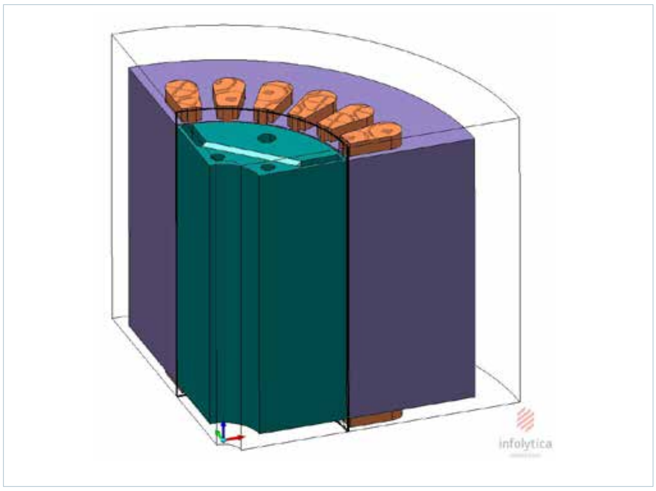
Platforms

The tool is available for

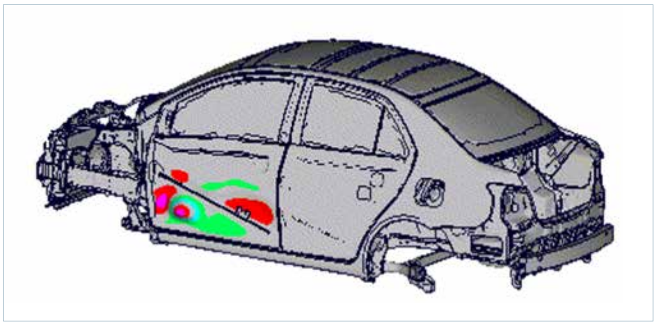
- Windows and
- Linux
- 64–bit machines in graphical and batch mode

File formats

- Source:
  - 6SigmaET (.vtm, .pvd)
  - ANSYS CFX (.csv)
  - ANSYS Fluent (.cas/.dat, .cas.h5/.dat.h5)
  - ANSYS Maxwell (.unv)
  - Ensight Case (.case) exported by e.g.
  - ANSYS Fluent (transient data)
  - OpenFOAM
  - STAR-CCM+
  - FINE/Turbo (.cgns)
  - FloEFD (.floefd)
  - FloTHERM (.flofea), FloTHERM XT (.txt)
  - JMAG via Nastran Bulk (.bdf)
  - MagNet (.vtk)
  - VMAP (.vmap)
- Target:
- Abaqus (*.inp)
  - ANSYS Mechanical (*.db, .cdb)
  - Ensight Case (.case)
  - LS-Dyna (.key, .k, .dynain)
  - Nastran Bulk (*.nas / *.bdf)
  - VMAP (.vmap)



Partial model of a 4-pole 24-slots motor



Frequency response analysis on a door using Nastran and CDH tools

MpCCI
FSIMapper

Advantages of MpCCI FSIMapper

- File-based mapping solution
- Robust and efficient algorithms
- Interactive visualization
- Various CFD, EM, and CSM formats
- Easy integration

MpCCI Mapper
Integrated virtual manufacturing chains

Concept

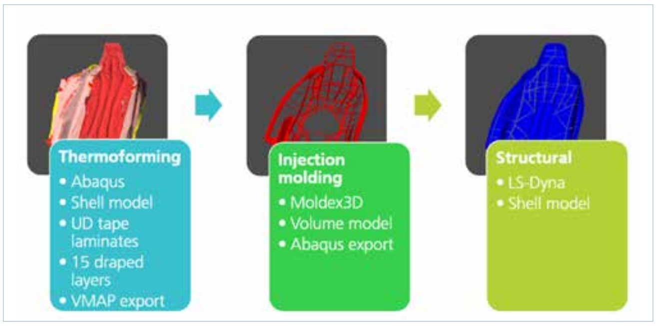
MpCCI Mapper is a file-based mapping tool passing on mechanical material properties in virtual manufacturing process chains. The tool provides advanced and robust methods to map, compare and transfer simulation results and experimental data between models to link them in integrated simulation workflows.

- Data transfer of one simulation result (“source”) into a second simulation (“target”) as initial condition.
- Supports extensive list of native CAE file formats and optical measurement data commonly used in virtual manufacturing processes.
- Mapping of mechanical variables as thickness, stresses, strains, equivalent plastic strain, material direction, long and short fiber orientations or other local material properties and displacements.

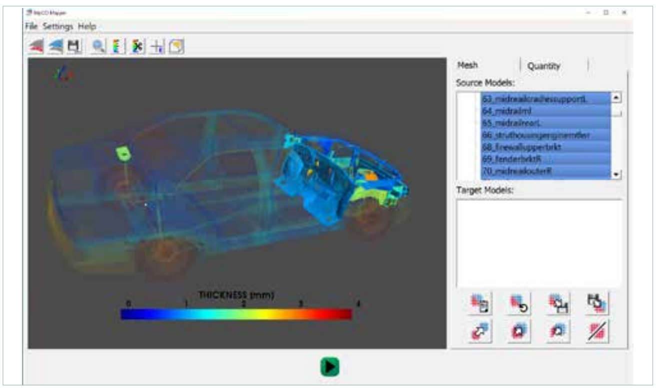
Car seat crash simulation

Features

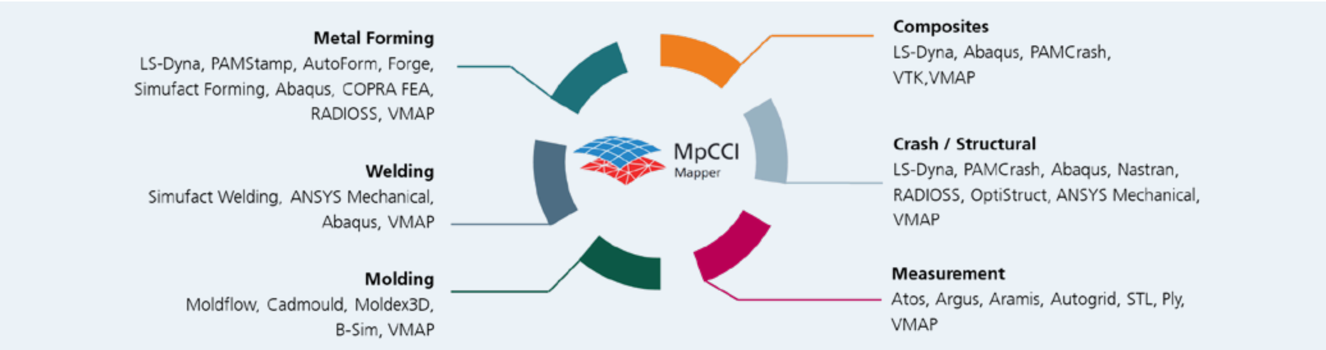
- Automatic and interactive mesh positioning
- Robust and efficient algorithms for mapping various element types and mechanical quantities
  - Shell to shell
  - Solid to solid
  - Solid to shell
  - Shell to solid
- Node, element, or element integration point data
- Interpolation in thickness direction when transferring between different numbers of integration points in shell thickness direction
- Handling of non-matching geometry in source and target model
- Configuration of mapping algorithms
- Validation of mapping accuracy
- Homogenization of fiber orientation tensors
- Model replication and symmetry handling
- Batch capability
- Be productive in less than 15 minutes of instruction



Virtual process chain for the Digital Twin of a hybrid seat backrest



User interface of MpCCI Mapper: This model has been developed by the National Crash Analysis Center (NCAC) of the George Washington University under a contract with the FHWA and NHTSA of the US DOT.



Solver and measurement format interfaces in MpCCI Mapper

MpCCI Mapper GUI

MpCCI Mapper comes with a graphical user interface where all relevant parameters for the mapping can be set.

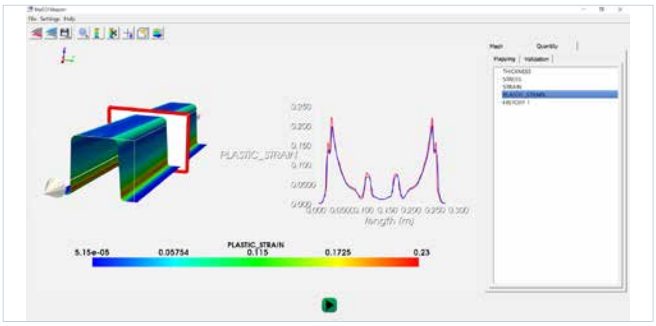
The usage is intuitive and simple:
- Select the models and parts to be used
- Select mapping variables
- Make choices concerning algorithms and parameters
- Initiate mapping step
- Immediate visualization of the results
- Detect model errors or low mapping quality results due to model coarsening
- Identify the critical areas and start a new mapping process

The mapping process can be performed in 4 steps:
1. The main viewport, where loaded models and quantities can be interactively displayed, is located on the left of the window.
2. A list of buttons above the viewport form, the so-called "toolbar," where basic operations of MpCCI Mapper are linked.
3. A panel region is displayed nearby the viewport, where
   – the mapping
   – the list of meshes and parts
   – the validation of mapping and also
   – certain quantities
   – can be analyzed.
4. At the bottom of the window, a single button is present for starting mapping, validation, or analysis processes.

File formats and simulation disciplines

MpCCI Mapper supports most of the leading file formats for the following analyses:
- Forming/stamping
- Structural analysis
- Crash behavior
- Welding
- Measurement tools (incl. photogrammetric)

Simulation disciplines:
- Sheet metal forming
- Massive forming
- Buckling analysis
- Crash analysis
- Structural analysis
- Welding
- Injection molding
- Composites
- Measurement (incl. photogrammetric)
- Additive manufacturing
- NVH (noise, vibration, harshness)

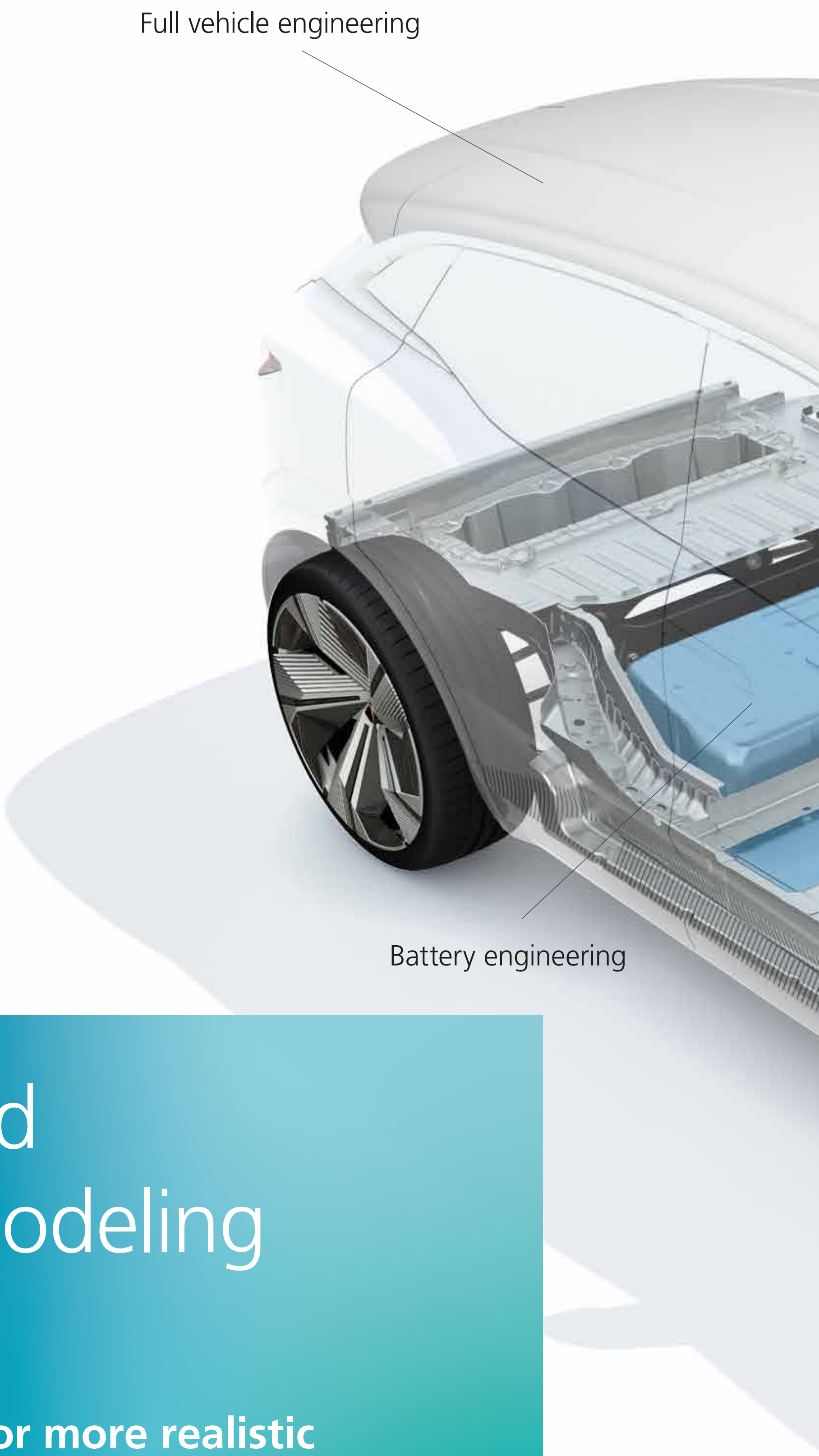


Mapping result analysis for equivalent plastic strain of a press-hardened 22MnB5 hat profile

MpCCI
Mapper

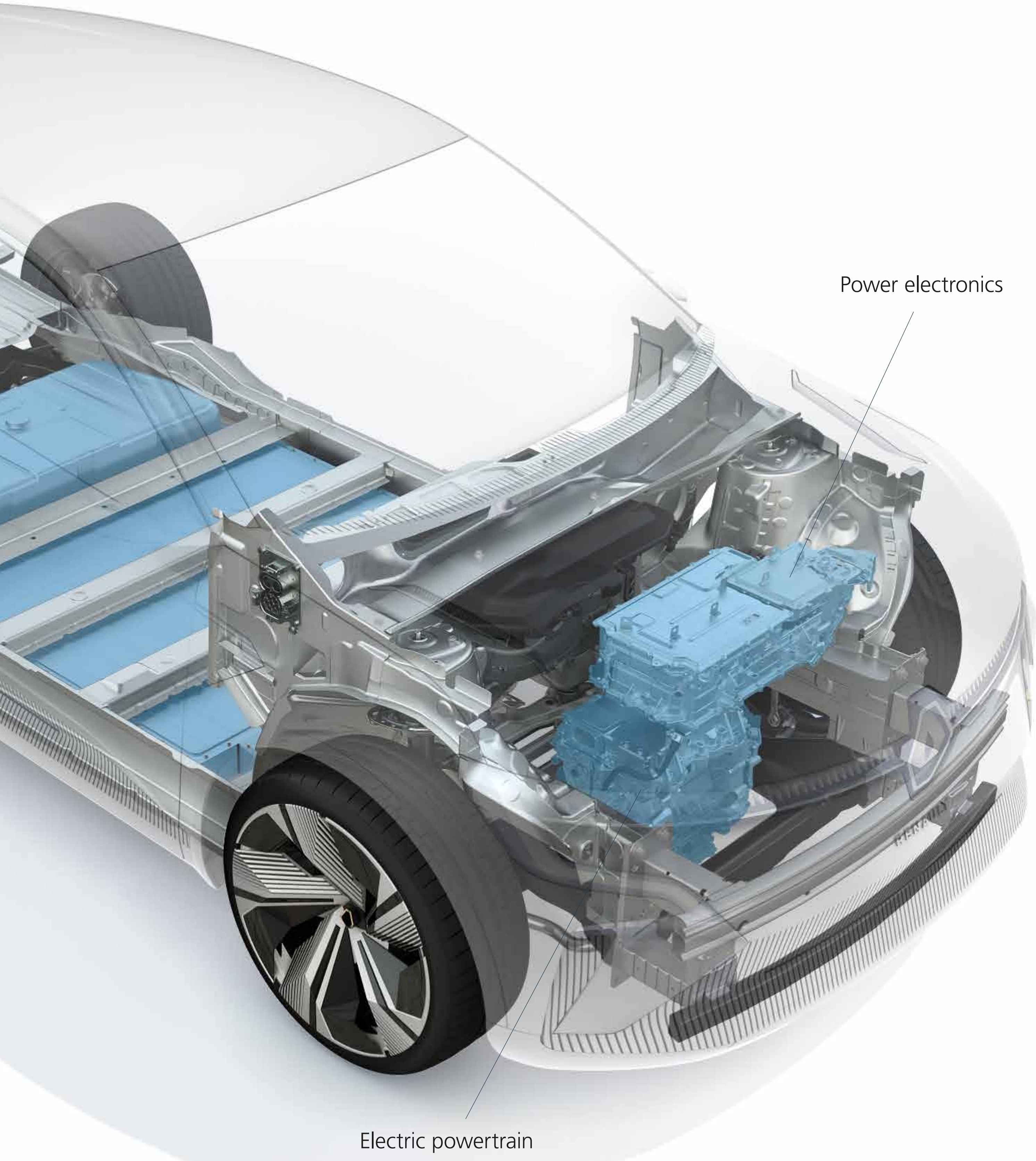
Advantages of MpCCI Mapper

- Robust mapping algorithm
- Automatic mesh alignment
- Supports most of the leading solver formats
- Be productive in less than 15 minutes of instruction



Full vehicle and component modeling

MpCCI-based solutions for more realistic modeling of automotive vehicles


Power electronics
Electric powertrain

Full vehicle modeling

Vehicle dynamics

Vehicle dynamics is the study of how vehicles behave and respond to various forces and inputs, such as acceleration, braking, steering, and road conditions. Multibody system simulation (MBS) involves analyzing the interactions between the vehicle's various components, including its suspension, tires, brakes, and transmission, and how they affect its overall performance and behavior.

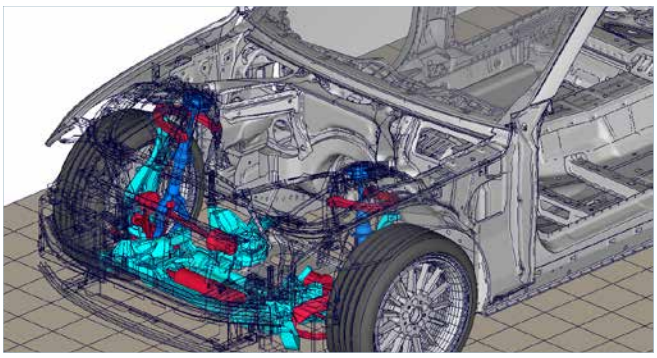
By combining finite element analysis (FEA) and multibody dynamics in vehicle simulation, a comprehensive understanding of the vehicle's performance and behavior can be gained across various aspects, including the non-linear deformation of components.

Using **MpCCI CouplingEnvironment** for combining FEA and MBS helps

- Decreasing computational complexity without loss of accuracy in the critical parts,
- Optimizing the design of a vehicle for increased performance, safety, and reliability,
- Simulating a vehicle's performance under different conditions reduces the need for physical testing and potentially lowers costs, yielding a speed-up of the design process.

Available simulation codes:

- Abaqus
- MSC.Adams, SIMPACK



An MBS–FEA coupling setup for a coupled 1D-3D automotive model

Vehicle thermal management

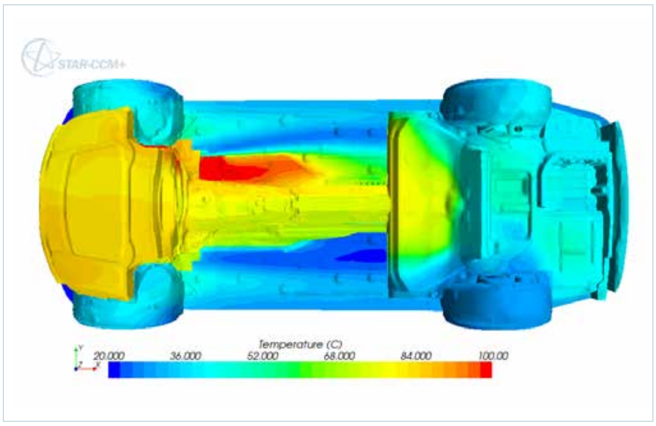
Concerning the thermal behavior of automotive vehicles, it is pursued to accomplish simulations for the full complexity of a vehicle's geometry and transport phenomena of heat, including convection, radiation, and conduction in fluids and solid bodies. The different heat transport mechanisms described are solved by specialized codes.

MpCCI CouplingEnvironment offers the possibility to couple your favorite CFD code with a code that is specialized for radiative and solid body conduction heat transfer. The coupled approach supports steady-state, transient, and mixed-type (quasi-stationary with transient) solutions to address the following applications:

- Thermal protection
- Cooling airflow
- Thermal driving cycle

Available simulation codes:

- TAITherm, Abaqus, ANSYS Mechanical
- FLUENT, OpenFOAM, ProLB, STAR-CCM+



Thermal simulation of a full vehicle

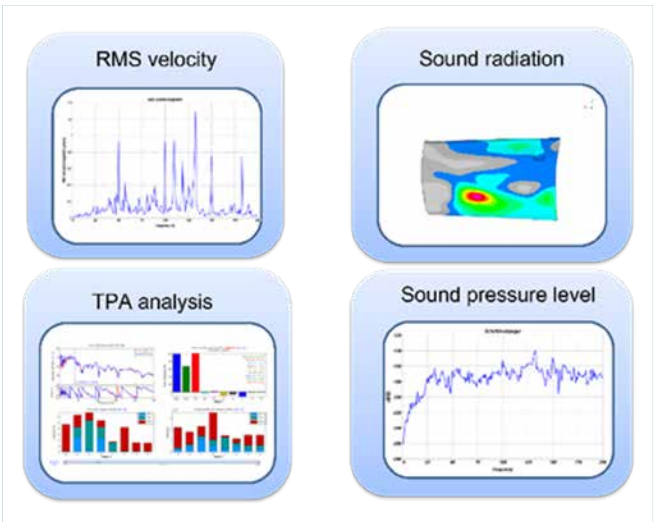
Noise, Vibration and Harshness (NVH)

Full-vehicle NVH analysis can help identify noise and vibration issues that may not be apparent when analyzing individual vehicle components. By evaluating the entire vehicle as a system, engineers can better understand how different components interact with each other and identify sources of noise and vibration that interactions between these may cause.

Analyzing the aerodynamic loads in a full-vehicle NVH helps
- Optimizing sound insulation and thus improving customer comfort,
- Reducing development time and cost,
- Verification of damping concepts.

The tool **MpCCI FSIMapper** builds the link between the simulation of the vehicle's aerodynamics and the NVH simulation. It includes
- Transfer of pressure-excitation from the CFD calculation to the (not necessarily matching) NVH-mesh,
- Automatic Fourier transform of transient pressure data,
- User-defined windowing, time range filtering, and frequency truncation for the export,
- Optimized export format for Nastran NVH analyses available for efficient simulations.

Most used simulation format:
- STAR-CCM+, OpenFOAM
- MSC Nastran



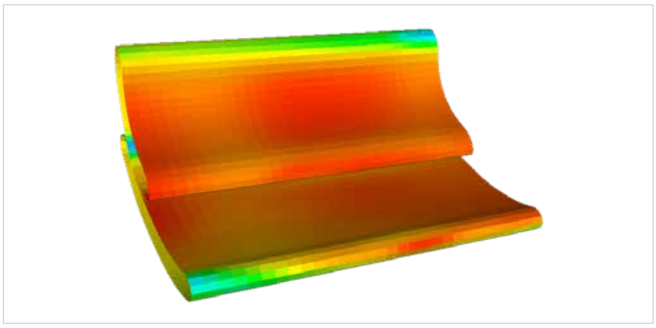
Post processing of a NVH calculation

Vehicle aerodynamic

Simulation of the Fluid-Structure-Interactions (FSI) can be used to predict the aerodynamic behavior of a vehicle by modeling the interaction between the airflow and the vehicle's body. This can help optimize the shape of the vehicle's body for minimum drag and maximum downforce, resulting in improved performance and fuel efficiency. An air dam or chin spoiler is used in vehicle design to improve aerodynamics by redirecting airflow under the vehicle. That part could be made of soft plastics that deform under aerodynamic loading or, when hit, without breaking.

MpCCI CouplingEnvironment is an ideal tool for coupled FSI simulations predicting the deflection of a soft chin spoiler under aerodynamic loads, which changes the fluid pressure field resulting in a drag change.

Available simulation codes:
- Abaqus, ANSYS Mechanical, LS-Dyna, MSC.Nastran, MSC.Marc
- FLUENT, OpenFOAM, STAR-CCM+



Fluid loads on a racing car spoiler

Advantages of using MpCCI

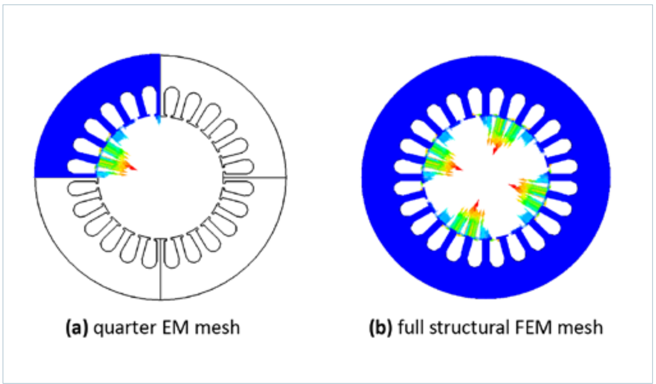
- Best-in-class solver for each physical domain
- Optimization of the development process by reuse of existing models
- Reduce computational cost by combining FEA and MBS
- Enable FSI for simulation codes without intrinsic morphing method
- Co-simulation compatibility with models doing re-meshing

Electric powertrain

Vibrations in electric motors

The rotating electromagnetic field in electric motors produces periodic forces that excite the structure's vibrations and cause noise in the surroundings. On the one hand, the electromagnetic forces are computed in an EM code. On the other hand, the vibrations are computed in CSD codes.

The tool **MpCCI FSIMapper** builds the missing link between both simulation disciplines: it maps the electromagnetic forces from the EM simulation as boundary conditions to the structural vibration simulation.



Mapping between a quarter stator model in MagNet and a full representation in the structural code

Cooling electric motors

A coupled approach that combines electromagnetic analysis with a conjugate heat transfer (CHT) analysis can be used to model the thermal behavior of an electric motor. The heat generated from the electromagnetic simulation is used as input for the CHT analysis. The tool **MpCCI CouplingEnvironment** enables this workflow.

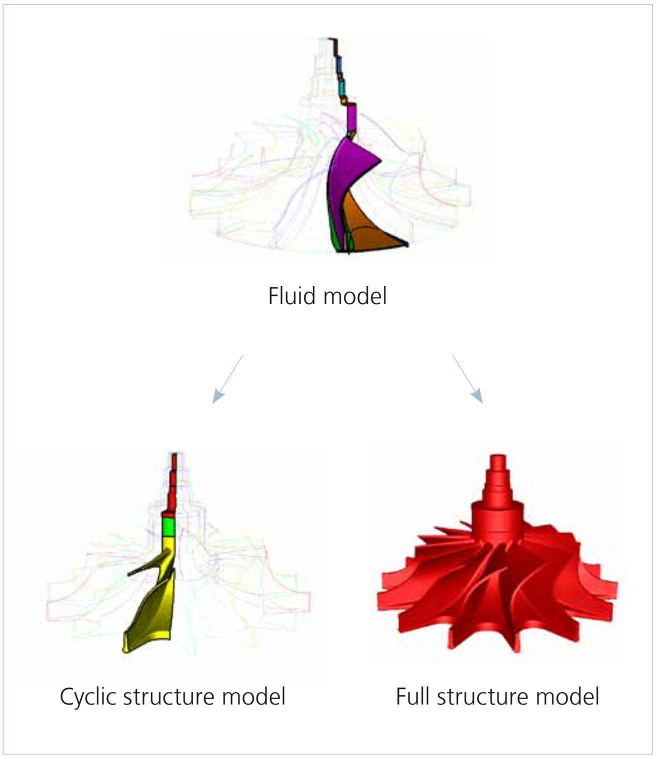
Available simulation codes:
- JMAG
- FLUENT, STAR-CCM+

Fuel cell compressor

The design of a fuel cell compressor is crucial to the performance and efficiency of a fuel cell system.
The compressor must be designed to withstand the harsh operating conditions of a fuel cell system, including high pressures, high temperatures, and exposure to corrosive gases.

Using **MpCCI CouplingEnvironment** and **MpCCI FSIMapper** for combining CFD and structural analysis helps optimize the performance and reliability of the compressor.

The following problems can be addressed by this coupled approach:
- Blade deformation influence on dynamic component stresses due to excitation from the fluid flow
- Impact of hot fluid flow on thermal stresses in components



Possible scenarios to couple cyclic and full models

Battery engineering

Thermal management

Lithium-ion batteries used in electric vehicles generate significant heat during charging and discharging. If the battery's temperature rises too high, it can cause thermal runaway, which is a potentially dangerous situation where the battery overheats and catches fire.

The performance of a battery is directly related to its temperature. If the battery's temperature is too low, it may not be able to deliver the required power output. On the other hand, if the temperature is too high, it can degrade the battery and reduce its lifespan.

Thermal management of batteries is necessary for safety, performance, and range optimization in electric vehicles. Proper thermal management techniques, such as active cooling and heating systems, are essential to ensure electric vehicles' safe and efficient operation.

Using **MpCCI CouplingEnvironment**, such cooling or heating systems can be modeled by a co-simulation between a CFD code and a specialized code in radiative and solid body conduction heat transfer.

Available simulation codes:

- TAITherm, Abaqus
- FLUENT, STAR-CCM+

Advantages of using MpCCI

- Improve the virtual model by integrating additional physical effects
- Optimizing the performance and reliability of components
- Simplified application modeling for non-matching rotating frame models without loss of fidelity
- Bridging incompatibility of periodic models

Power electronics

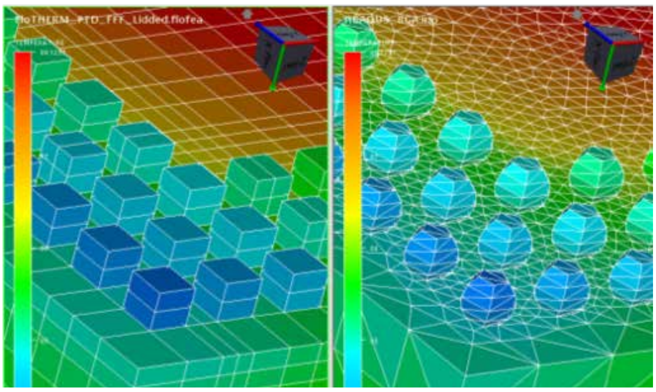
Power inverter

Thermal influence upon an electrical system caused by each transistor's self-heating and tightly coupled thermal interaction with neighboring devices cannot be neglected since excessive temperatures can cause deterioration.

However, it is not the temperature that directly causes product failure. In most cases, it is some mechanical fracture or deformation fueled by thermo-mechanical effects. Differences in temperature and material properties cause objects to bend, deform and possibly break. When applied to electrical circuits, any break in that circuit is catastrophic in that, to put it simply, the product stops working.

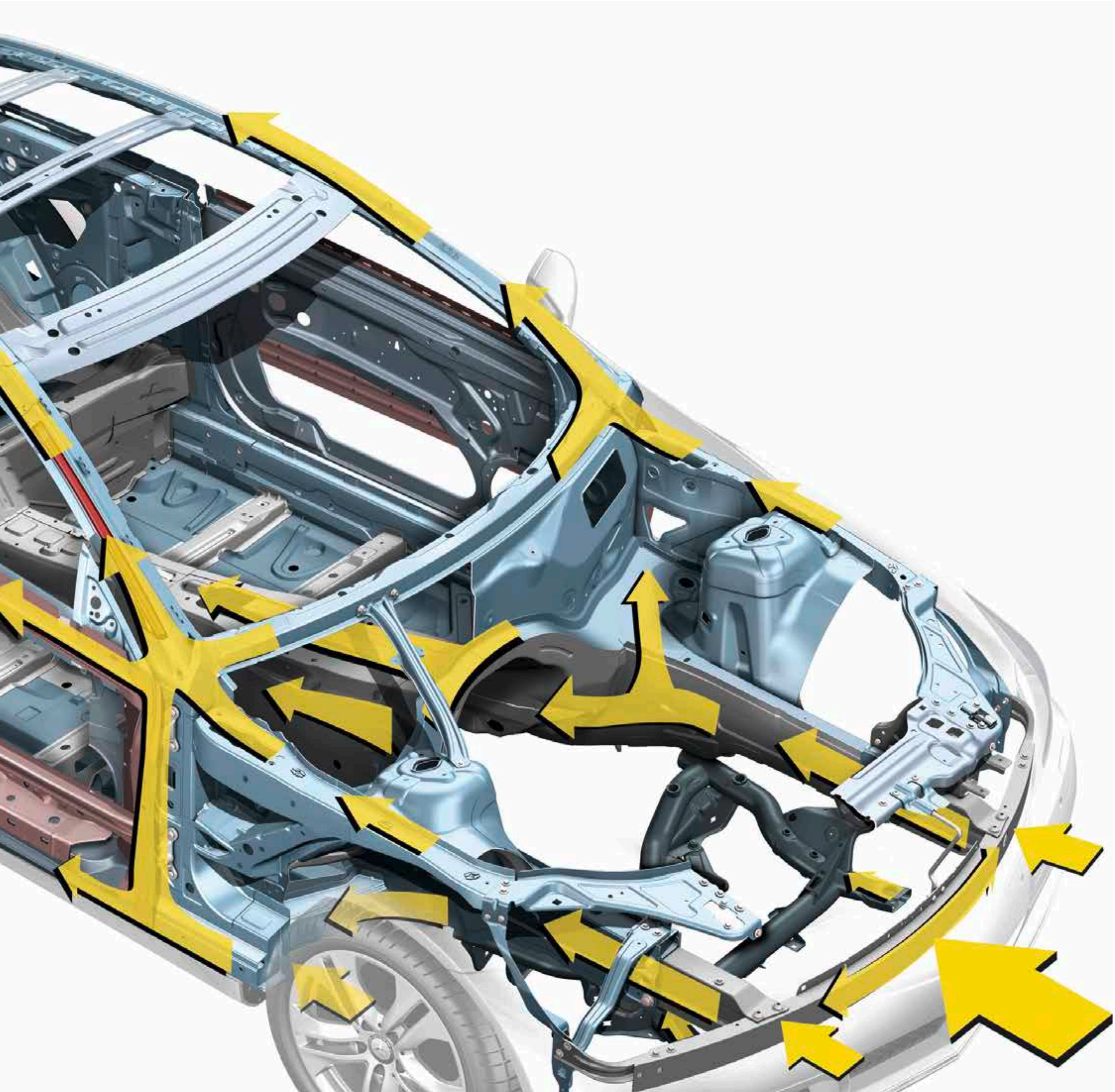
Using **MpCCI FSIMapper** enhances the thermal stress analysis workflow for electronic devices.

- Seamless CFD data integration on the FEA model
- Support leading CFD thermal simulation code format for electronics: 6SigmaET, FloTHERM, FloTHERM XT and FloEFD
- Automatic handling of incompatible mesh discretization and geometry deviations
- Support native FEA solver format



Mapping temperatures from a dedicated CFD model to a thermal stress analysis

Integrated virtual manufacturing chains and passive safety



Manufacturing process simulation

Metal sheet forming to crash

Sheet metal forming is a manufacturing process that involves shaping and transforming flat metal sheets into various 3D shapes and structures through bending, punching, cutting, and stretching. The process is commonly used in automotive, aerospace, and construction industries.

Determining the crashworthiness of a vehicle or structure, the material properties of the metal, such as its strength and ductility, as well as the geometry and thickness of the formed parts, can significantly impact the structural integrity of the vehicle during a crash.

The tool **MpCCI Mapper** builds the link between both simulation disciplines transferring local material properties such as thickness, stresses, strains, equivalent plastic strain, or anisotropic material direction from forming simulation results as initial conditions into a crash analysis model. This enables the calculation engineer to make an accurate crash prediction of the entire vehicle and its components.

Metal forming simulation codes:
- Autoform, LS-Dyna, PAM-Stamp, Simufact Forming, Forge, Abaqus, RADIOSS

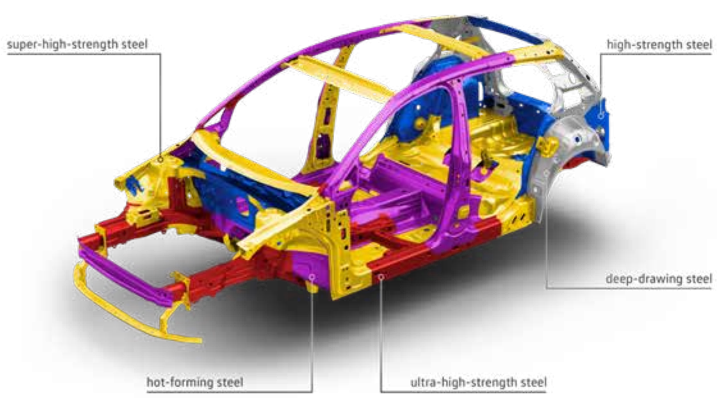
Crash simulation codes:
- LS-Dyna, PAM-Crash, Abaqus, RADIOSS, MSC.Nastran

Part assembly

Resistance spot welding is the most common welding technique used in car manufacturing. It involves passing an electric current through two overlapping sheets of metal, creating heat and pressure that melt the metal and fuse it together. The welding process must be carefully controlled to ensure that the welds are solid and durable and that the finished product meets safety standards. For reliable process simulation, local material information from metal forming must be considered in welding simulation. MpCCI Mapper links the process chain for accurate prediction of welded connections.

Adhesive joining is a versatile and efficient process in car manufacturing that enables the production of lightweight and durable vehicles with complex designs. The process involves applying a special adhesive to the surfaces of the parts to be joined and then curing the adhesive under specific temperature and pressure conditions to create a solid and durable bond. Using MpCCI CouplingEnvironment, the interaction of highly viscous adhesive fluid and the deformable structure during the joining process can be simulated to design and optimize the manufacturing process.

Available simulation codes:
- OpenFOAM
- Abaqus



Steel grades of a Golf

Short and long fiber reinforced plastics

Short fiber reinforced plastics (SFRPs) and **long fiber reinforced plastics** (LFRPs) are commonly used in various applications in the automotive industry due to their high strength-to-weight ratio, corrosion resistance, and design flexibility.

SFRPs are typically used for applications where cost and production speed are the main concerns. These plastics are reinforced with short glass fibers and are commonly used in parts such as underbody shields, air intake manifolds, and engine covers.

On the other hand, **LFRPs** are preferred for parts that require higher strength and stiffness. These plastics are reinforced with continuous glass or carbon fibers. Some common applications of **LFRPs** in the automotive industry include body panels, seat structures, and suspension components.

The anisotropic behavior of **SFRTPs** and **LFRTPs** can have important implications for their design and use and must be carefully considered for parts with complex loading conditions. **MpCCI Mapper** allows to incorporate **injection molding** and **organo-sheet forming** process results in structural and crash analysis. Through this link, the anisotropic behavior of these materials can be exploited to optimize their performance in specific applications by orienting the fibers in the direction of the anticipated load.

Hybrid LFRP – SFRP car seat backrest

Blow molded tanks

Blow molding is a manufacturing process that creates hollow plastic parts, including fuel tanks. The process involves melting plastic pellets and then injecting them into a mold. The mold is then inflated with compressed air to form the desired shape of the fuel tank.

Compared to rotomolding, the manufacturing process allows for greater control over the shape and dimensions of the fuel tank. The process can produce more uniform and precise products with consistent wall thickness. In addition, it enables a higher production speed and lower costs for large-scale production due to increased efficiency.

As fuel tanks must prevent leakage under all conditions, several quality tests are made, including drop tests or sloshing behavior. The final product performance can be predicted using static or dynamic structural loading, but local thicknesses and degree of orientation must be considered. Therefore, **MpCCI Mapper** and **MpCCI CouplingEnvironment** complement each other by first transferring manufacturing history from blow molding to structural model, followed by a coupled fluid-structure interaction of the liquid and the tank under certain test conditions.

Available simulation codes:

- B-SIM
- OpenFOAM
- Abaqus

Advantages of MpCCI

- Best-in-class solver for each simulation domain
- Vendor-neutral and application-independent
- Single toolset for various applications

VMAP for workflow integration

Application and problem description

The lack of software standards in virtual engineering workflows and incompatible interfaces for the transfer of virtual data not only causes additional costs and complex manual adaptation but also leads to inflexible IT solutions, loss of information, and significant delays in the overall design process. Standardizing data interfaces in CAE is vital for all industry segments where simulation processes are central to the product and process design.

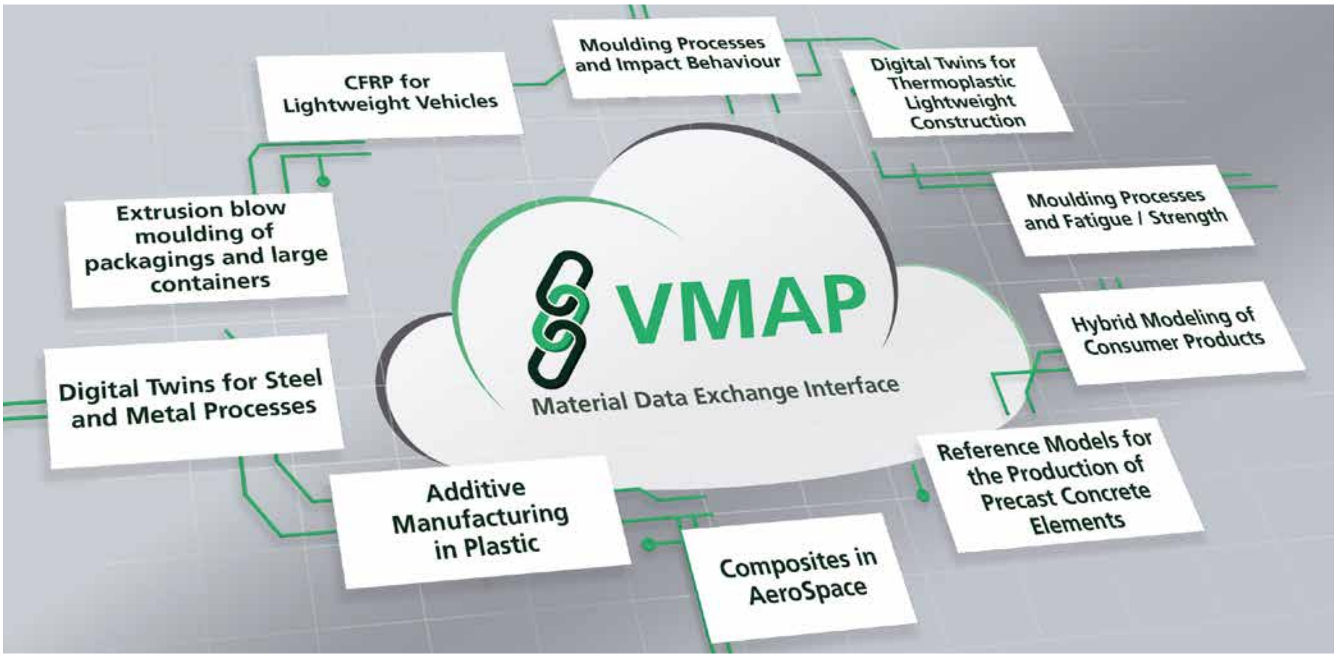
Various industry partners have already adopted their own CAE workflows to the VMAP standard and could gain significant benefits in saving time and implementation efforts. The initial ITEA VMAP project highlights some typical engineering cases from different material and manufacturing domains. The VMAP Standard is a software interface developed by 29 contracting parties from six countries.

The VMAP Standards Community

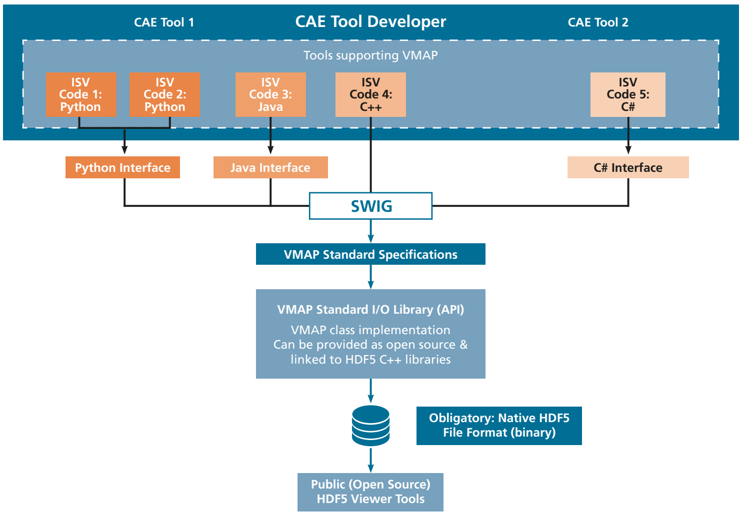
In December 2022, sixteen founding members established the VMAP Standards Community (VMAP SC) as a registered not-for-profit association. VMAP SC will be open to all who intend to contribute to the VMAP Standard and its extension.

The VMAP SC makes the software parts of the standard available to the general public as open-source software free of charge. Especially companies in the manufacturing industry, software companies, and research institutes can profit from the software use.

Through the technical maintenance of the standard and the supervision of its further development, the VMAP association will offer the possibility to make the developed standard accessible to a broad interested public. To explain its application, and to further develop the technology according to the user's requirements will make the standard accessible to a wide audience. Furthermore, the VMAP SC will ensure equal opportunities for all potential users.



Industrial use cases from ITEA VMAP and other R&D project show the need and benefits of a standardised material data exchange interface.



VMAP software architecture

The VMAP standard format

Major features of VMAP are:

- Meta and user data
- Geometry and discretization
- Coordinate and unit systems
- Result and state variables
- Parameters for (material) models
- Based on HDF5 (High-performance data management and storage suite)
- Software library available to read/write VMAP data files
- Tutorials and test cases

The VMAP Standard Specifications aim to provide best-practice guidelines for the community. These specifications form the core of the standard. Since VMAP is driven by industry and software vendors, the main focus of VMAP has been to align the CAE data in a generic form and, at the same time, encompass all aspects of it. The VMAP group has aligned the data into groups and found commonalities among many software to build the standard. Keeping this in mind, the VMAP storage structure defines the four main groups that form any simulation's essence – geometry, variables, system, and material. Within these four main groups, the CAE data is sorted into datasets and attributes.

VMAP integration services from Fraunhofer SCAI

The VMAP standard is based on HDF5, a widely accepted implementation platform for many IO-related applications. The freely available SWIG wrapper tool can be utilized to bind the VMAP IO software library into software written in any other programming or script language, see. As such, the VMAP IO library is universally available. Many ISVs, both large and small players, have already implemented the VMAP Standard directly within their software to extract the maximum speed and efficiency.

VMAP provides a library of IO routines to help engineers speed up their workflow creation, thereby removing the emphasis on considering data formats. It enables easier and more flexible data transfer, using different software for different simulations, and creating reusable processes that can be easily adapted to include more or different data. It enables software interoperability for pre- & post-processing and data manipulation.

Fraunhofer provides training and integration support for the VMAP IO library for software owners and engineering users.

Advantages of VMAP

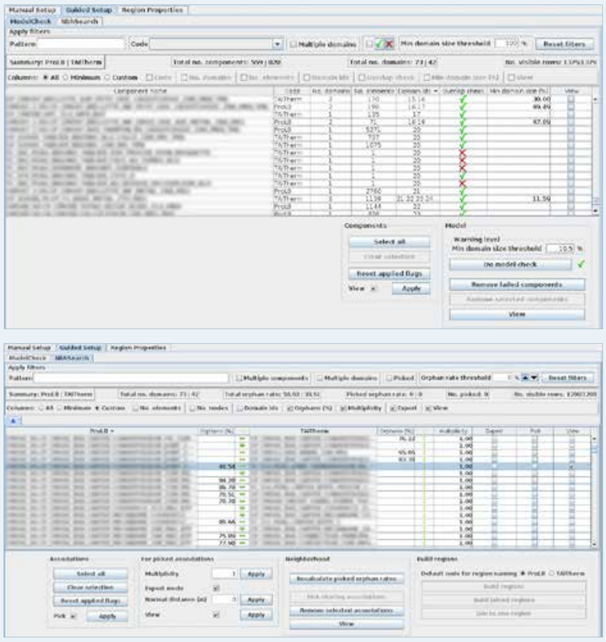
- Open and cost-free CAE standard
- Open-source library for connecting own CAE tools to VMAP
- Efficient and transparent data storage through HDF5

Customized solutions and R&D projects

The MpCCI solutions and methods are constantly being further developed within the framework of third-party funded and commissioned projects.


R&D
Research and Development

MpCCI runs on heterogeneous computer networks.



Guided setup in MpCCI GUI

Software customization and services

Development of code adapters on request

MpCCI CouplingEnvironment supports most of the leading commercial codes for fluid dynamics, structural analysis, electromagnetics, and other disciplines. The maintenance of these widely used interfaces is part of the continuous development of the MpCCI solution.

On request and within the framework of funded contract projects, Fraunhofer SCAI offers the adaption of previously unsupported CAE tools to enable customers to implement their specific multiphysics model setups. If desired, these new CAE code adapters can be integrated into the standard portfolio of MpCCI CouplingEnvironment and offered for general licensing.

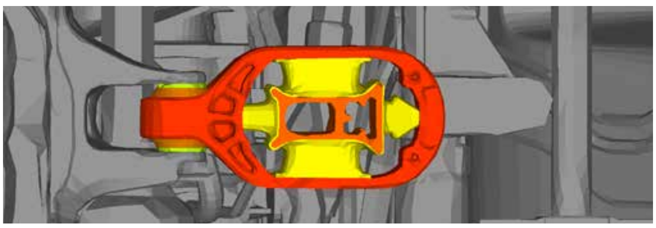
Some examples are:

- The connection of the MBS code SIMPACK was implemented in cooperation with JaguarLandrover and used as an example for the first deep wading simulations.
- Together with EDAG and BMW, the combination of ABAQUS with MSC.Adams was extended and adapted for load cases in vehicle dynamics like driving over barriers or cross-drains.
- In close cooperation with another car manufacturer, LS-DYNA is connected to MpCCI CouplingEnvironment to be used in combination with STAR-CCM+ to model flexible air intake flaps and aerodynamic components.

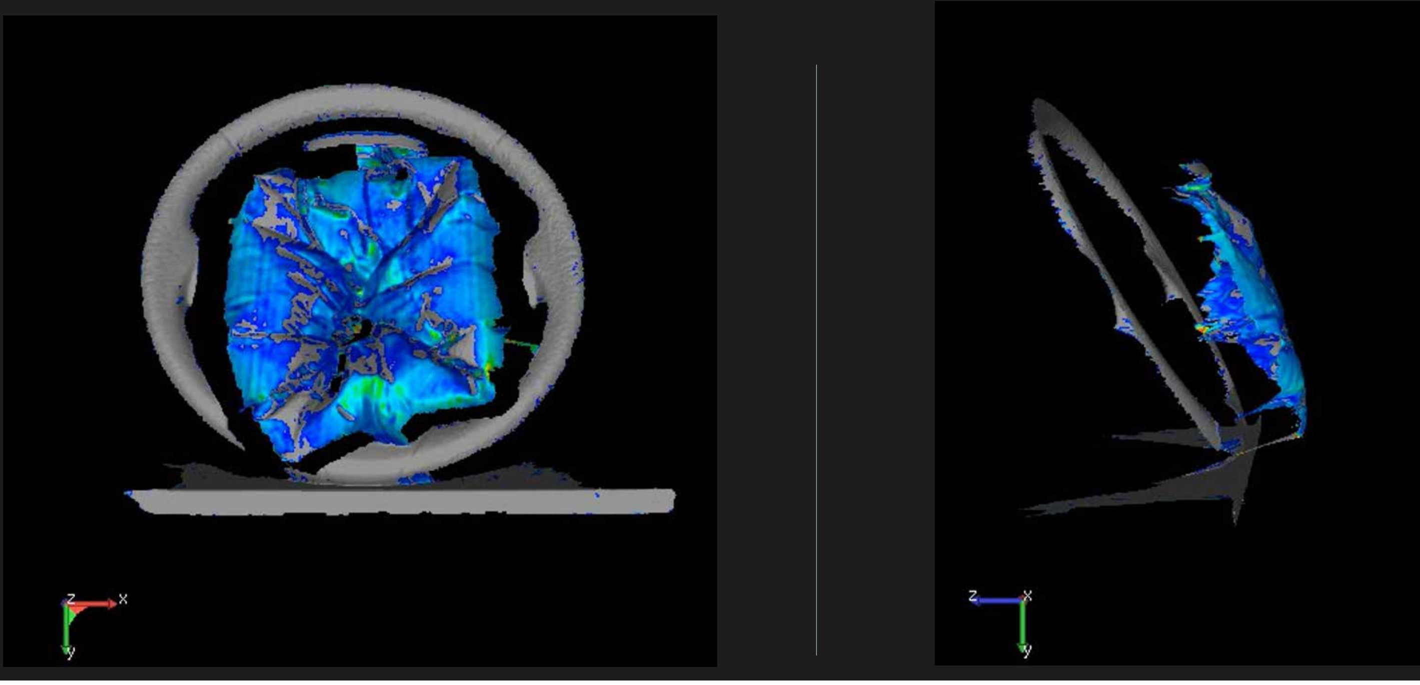
Integration into Renault's CAE workflows

CAE Process methods have tightly been integrated into **MpCCI CouplingEnvironment** to provide additional robustness to the setup of the co-simulation of full-vehicle thermal management. The management of large models, as used by Renault, is optimized in MpCCI GUI by using predefined rules to filter the parts of interest and using a standard workflow to set up the co-simulation parts. Pre-calculation of parts compatibility, such as bounding box and domain checks, allows to guide the user to select the parts to couple. Automatic generation of coupled regions assists the user in the preliminary phase of the co-simulation setup.

The co-simulation on the HPC system plays a key role in optimizing the vehicle lifecycle development. The command line interface has been extended for maximum flexibility in creating customized and HPC-adapted workflows.



Displaying disconnected components by color



Airbag deployment

3D high-speed measurement analysis

In today's manufacturing and industrial processes, high-speed 3D measurement technology is becoming increasingly important. With the use of high-speed 3D scanners, manufacturers can obtain accurate and detailed measurements of parts and products under conditions of use.

One class of high-speed 3D scanners works by projecting a speckle noise or non-periodic stripe pattern on the surface of the object being scanned. Using triangulation by digital image correlation, a 3D point cloud of the measured object is generated. Those scanners can capture millions of data points with a time resolution in the millisecond range.

In a joined research project with Fraunhofer SCAI, **the Fraunhofer for Applied Optics and Precision Engineering IOF** developed a gobo (graphical optical blackout) based high-speed measurement system to measure objects under highly dynamic situations, e.g., crash and airbag testing.

Fraunhofer SCAI developed an analysis tool to transfer high-speed 3D measurement data generated from previously described gobo measurement system into a CAE post-processor GNS Animator. Therefore, the varying 3D point cloud representation of the object surface is translated into a finite element mesh, including transient nodal displacement and object color.

The translation of high-speed 3D measurement data into a ‚simulation grid representation makes it possible to use sophisticated evaluation routines of a CAE post-processor daily used in the evaluation of highly dynamic safety tests instead of the previously time-consuming tracking of adhesive marks. In particular, the evaluation of airbag deployment and the tracking of impact tests, a high-resolution two-dimensional recording of object data over the entire course of a test, was previously impossible.

Fraunhofer SCAI has already proven the concept of the MpCCI GeoAnalyzer in several OEM projects.

Sensor head of gobo measurement system developed by Fraunhofer IOF

Research projects

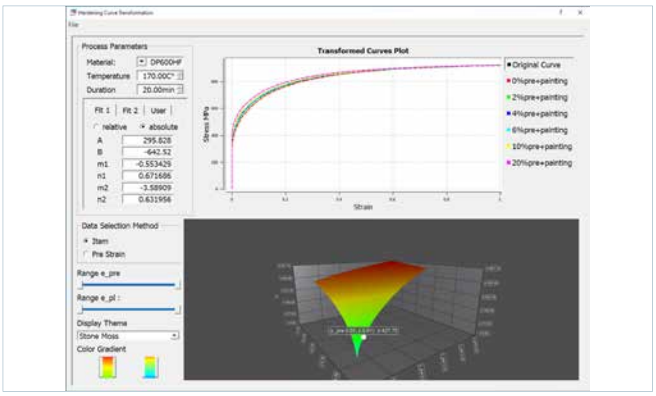
UmLaC

The ever-increasing demands on the crash safety of automobiles require more precise predictions through crash simulation. In the automotive sector, SMEs mainly act as simulation service providers, suppliers of subcomponents, and software developers. It must adapt to the increasing requirements of OEMs to be competitive. In recent years, simulation in the industrial application of modern steel materials has focused on continuously mapping the process chain.

Due to the increasing integration of the forming simulation results into the crash simulation, it is necessary to consider a further step of the process chain: The thermal hardening of the paint. In this process, the body is heated to approx. 170 °C for approx. 20 minutes. Despite the relatively low temperature, the modern steel materials used undergo changes that influence the mechanical behavior, mainly tempering effects and bake-hardening. The tempering effects occur mainly with the highest strength press hardening steels and lead to a reduction in strength. Bake-hardening occurs in many steel classes and leads to higher strength.

Fraunhofer SCAI provided
- MpCCI mapper for process chain forming – crash
- Implementation of transformation module and application to crash model

The AiF funds this project in a program for the promotion of Joint Industrial Research of BMWi.



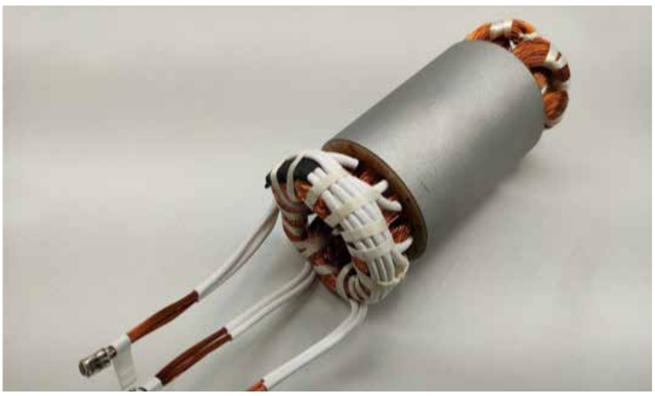
MpCCI Mapper for forming – heating – crash process chain

HABICHT

The project aims to design and develop a high-speed motor for a fuel cell compressor to enable innovation in the utility vehicle and aviation domain. The high-speed motor should at least achieve a power density of 30 kW/kg by using innovative materials to directly cool the stator and rotor. The rotor design will use a new manufacturing process to glue and pot the magnet in order to be suitable for high-speed operation.

The design process will rely on a simulation framework. This framework will combine multiphysics simulations to consider all aspects of the thermal, mechanical, and electromagnetic interactions in the early design stage. Specific machine learning methods combined with surrogate modeling and uncertainty quantification will assist in some optimization questions and decisions during the design phase. A dedicated data space will connect the engineering knowledge, data results from the virtual design, and the experimental data gained from testing and measurement combined.

This project is funded by the Fraunhofer PREPARE program.



A geometry and winding demonstrator developed in HABICHT.

FORTISSIMO 602

The industrial use of carbon-fiber-reinforced plastic (CFRP) is being driven by the increasing use of composites to reduce weight in the automotive industry, where cost and performance are major factors. Legislation around the world is increasing the requirement for lightweight vehicles. With worldwide tooling budgets running well into hundreds of millions of Euros, the simulation of processes and the prediction of manufacturing times are central to delivering high-quality products at an affordable price.

This project developed an integrated virtual process chain to simulate the manufacture of high-performance composite structures. This CAE chain combined all essential simulation steps to enable integrated product development. The chain firstly considered manufacturing effects from previous steps in the simulation and, secondly, allowed an iterative structural optimization over multiple simulation steps.

It was essential to reduce overall development and production costs to make high-performance CFRP economically viable for large-scale production. The big advantage of a continuous virtual CAE chain was the acceleration of the development loops, with every single loop covering the simulation of manufacturing processes (draping, molding, and curing), the automated transfer of process simulation results, and the structural simulations of the product itself.

FORTISSIMO I was funded by the European Union (Grant agreement 609029).

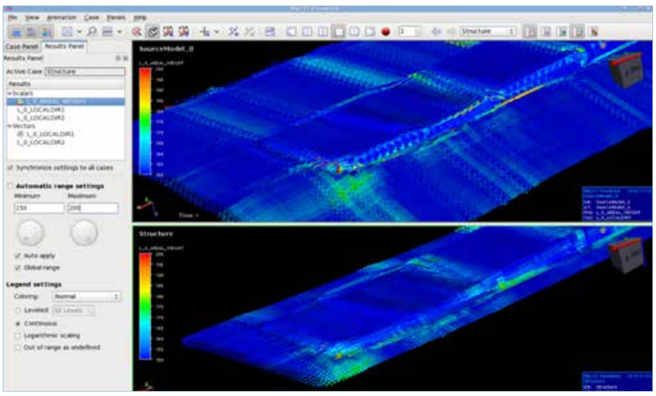
PIONEER

PIONEER aims to develop and implement an interoperable material modeling and manufacturing ecosystem that enables multi-directional data flow along the material value chain by linking product design and distributed modeling data with information from material characterization, manufacturing processes, and product quality criteria. PIONEER combines a design-by-simulation approach with manufacturing and quality data to optimize product development strategies in high-mix/low-volume production systems.

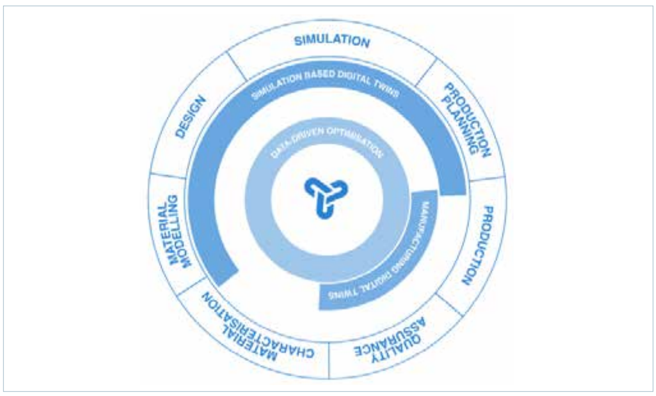
- Support the transition towards industrial digitalization.
- Optimize and facilitate the quick adoption of research results.
- Design digital tools for the industry to enhance efficiency and product quality and increase the capability for better and faster reactions to market changes.
- Design digital tools for the industry to enhance efficiency and product quality and increase the capability for better and faster reactions to market changes.
- Enhance data interoperability and a new type of service related to data analysis, simulations, and visualization techniques in each stage of the material value chain.

Fraunhofer SCAI is responsible for seamlessly integrating CAE workflows by introducing and extending VMAP standards to PIONEER's engineering applications.

PIONEER is funded by the European Union (Grant agreement 101091449).



Mapping for high-performance composite structures



Visualisation of multidirectional data-flow

MpCCI

Contact

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

Dipl. Inform. Klaus Wolf
Phone +49 2241 14-4058
mpcci@scai.fraunhofer.de
www.mpcci.de

Worldwide distribution

scapos AG
Schloss Birlinghoven 1
53757 Sankt Augustin
Germany

Phone +49 2241 14-4400
www.scapos.com