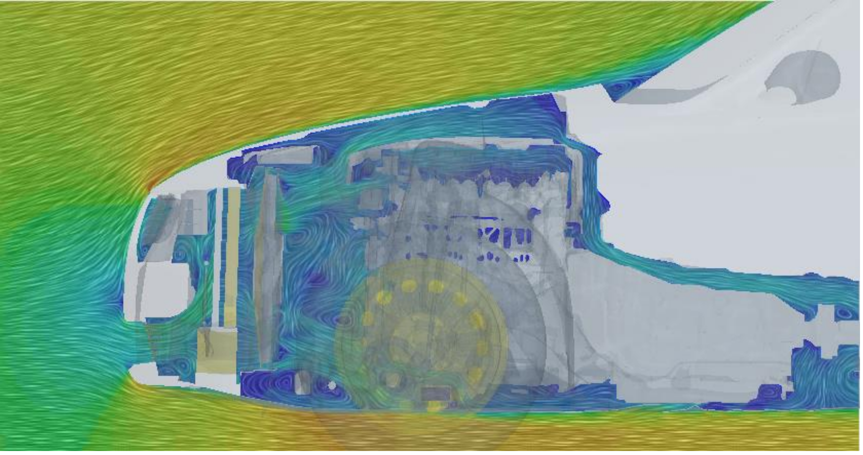

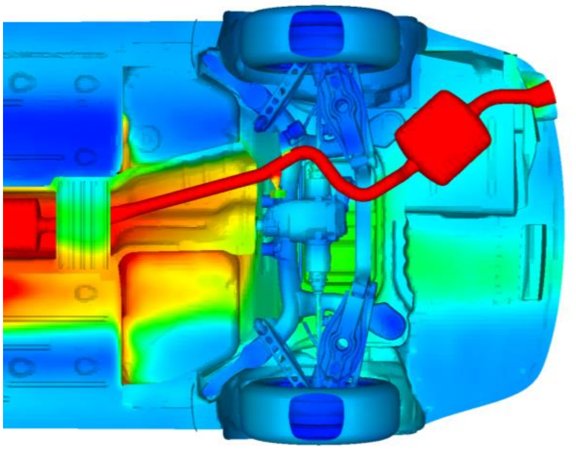

Automotive Thermal Management for Full Vehicles

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.

Thermal Coupling

The different heat transport mechanisms convection, conduction and radiation are solved by specialized codes.

Coupling CFD and Thermal simulations with MpCCI

MpCCI CouplingEnvironment offers the possibility to couple your favorite CFD-Code with a code that is specialized to radiative and solid body conduction heat transfer. The starting of the separate codes, the synchronization for different coupling schemes and the data exchange between the non-matching discretizations or even geometries is handled fully automatically by MpCCI.

MpCCI can be used to check whether the coupling regions are well defined and thereby avoid errors after the MpCCI initialization.

During or after the coupled simulation the coupling regions and exchanged quantities can be visualized in the MpCCI Monitor or MpCCI Visualizer.

Computational Fluid Dynamics Simulation

- OpenFOAM 1.7 – 2.4
- ANSYS Fluent 12.0 – 16.2
- STAR-CCM+ 7.02 – 10.04
- Inhouse code

Computational Radiation and Solid Heat Conduction Simulation

- RadTherm 11.0.0 – 11.3.2
- TAITherm 12.0.0 – 12.1.0
- Abaqus 6.12. – 2016

MpCCI

- GUI: define coupling regions and algorithms
- Monitoring and Visualizing of coupled quantities during and after the simulation
- Integration into batch systems

Demonstration Model:

- Full vehicle thermal coupling for a BMW passenger car

Services:

- Integration of MpCCI tools into your CAE workflow
- Customization for specific requirements
- Best practice analysis for your setup

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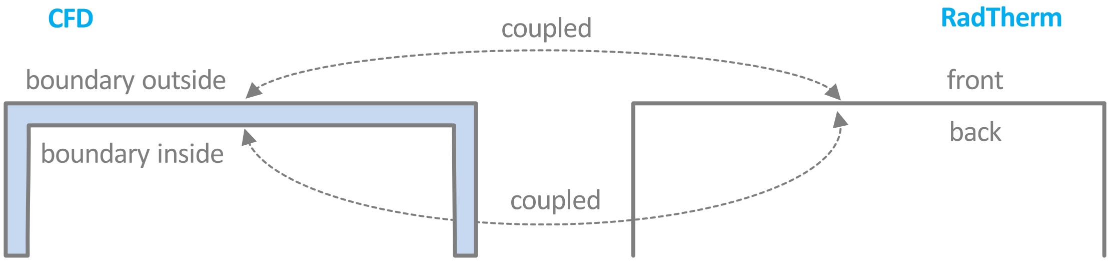
Motivation and Problem Description

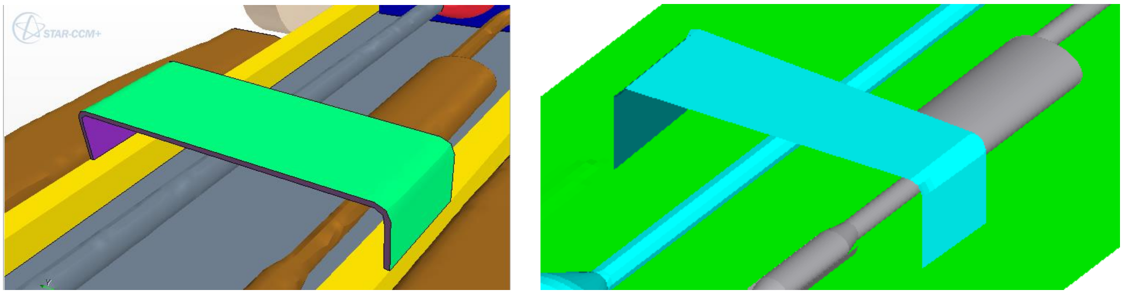
Concerning the thermal behavior of automotive vehicles it is pursued to accomplish simulations for the full complexity of a vehicle’s geometry and transport phenomena of heat including convection, radiation and conduction in fluids and solid bodies. There are several simulation codes meeting these requirements.

On each transport mechanism the simulation codes have more or less effectiveness and accuracy, so that for a simulation procedure a combination of different codes is preferable. This procedure can be realized with MpCCI, which offers the following advantages compared to common file-based approaches.

Accuracy with Shell Parts

Usually in CFD models **thin solids** like heat shields have two sides wetted, whereas the distance between the two sides, the thickness of the heat shield, is in the majority of cases small. If in RadTherm parts are modeled as shell elements a certain thickness must be assigned to the shell elements to properly account for heat conduction and heat capacity. When surfaces, boundaries and shells are coupled it has to be assured that front and back side of the coupled surfaces are correctly assigned. When setting up a model, the boundaries of thin parts of the CFD model have to be separated in a front and back side as depicted. In the MpCCI Coupling Step the front and back side can be assigned to different coupling regions, so that the mesh correlations are properly assigned.



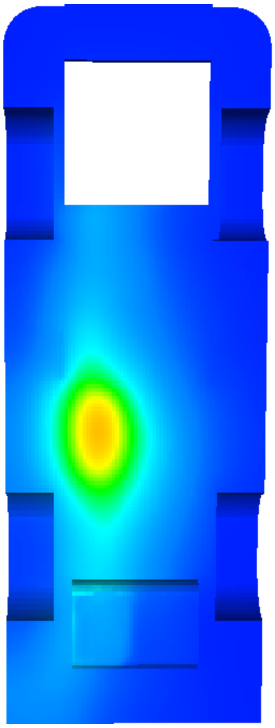


A solid part in CFD code is coupled with a shell part in RadTherm

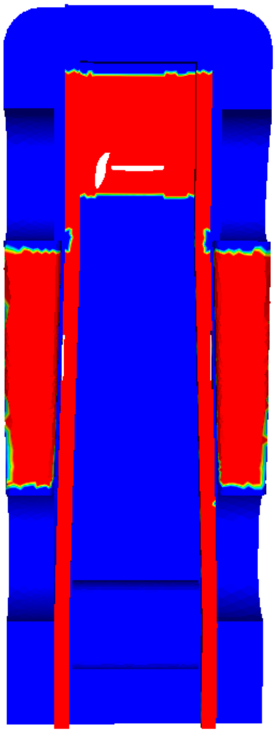
Handling of Geometry Deviations

Although it is not desired in large full vehicle models, there are quite often **geometrical discrepancies** between the coupled models, which usually leads to orphaned regions.

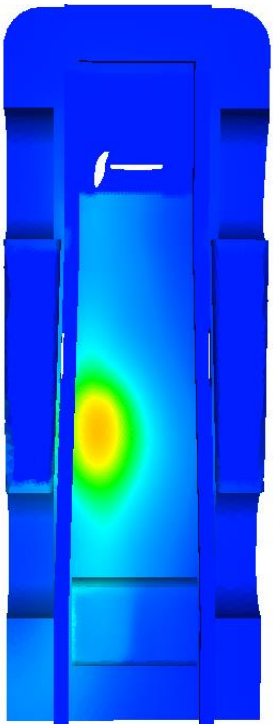
There are three procedures for handling these orphaned regions. It is possible to modify the search parameter in order to catch geometry deviations. Either the multiplicity factor for a dimensionless search or the normal dimensionful search distance is raised. If the granularity of the coupling regions is coarse, e.g. all components in one coupling region, it might result in wrong neighborhood associations especially when parts come in close contact. The second procedure is to accept a default value for orphaned regions. As this might be reasonable for the heat coefficient which is usually set to zero(adiabatic), for wall temperatures it is kind of random and therefore restrictive. To overcome this problem MpCCI offers extrapolation to orphaned regions, where matched parts around the orphans define the inter- and extrapolated values. In the following picture the procedures are compared for a hot spot in an under-hood simulation. It is visible that in smaller orphaned regions the extrapolation is a pretty good approximation compared to the sender source distribution, but in large orphaned regions the extrapolated temperature distribution is getting more vague.



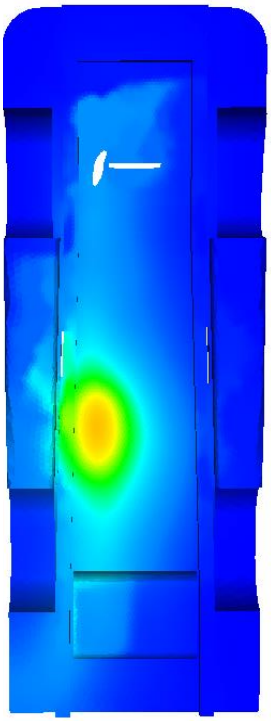
Temperature distribution on sender side



Orphaned regions on receiver side



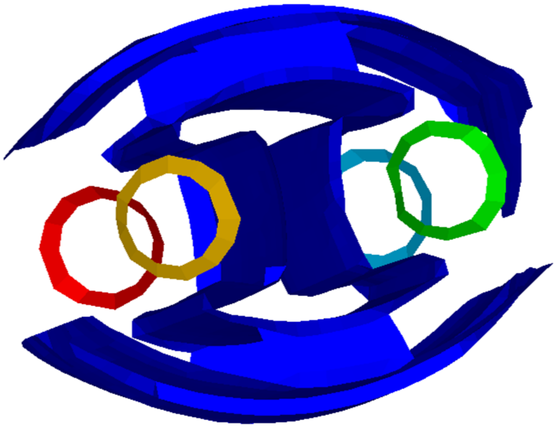
Temperature on receiver side with default value



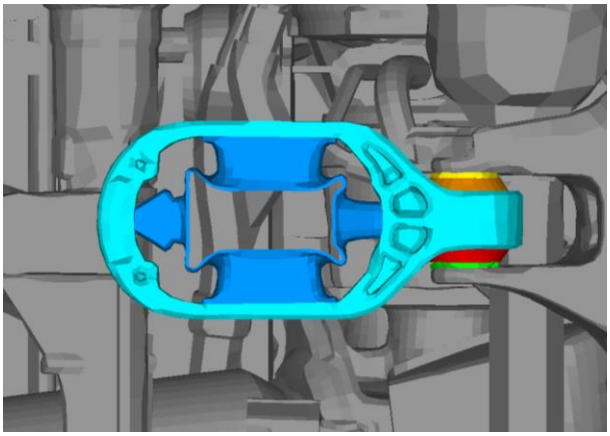
Temperature on receiver side with extrapolated value

Check-up of Coupling Model Set-Up

Large full vehicle models use a common CAD information to create a fluid model and thermal model setup. During the meshing and modelling processes the fluid and thermal model may be modified to fit the requirements of the target application.
MpCCI provides some methods in the earlier stage of the co-simulation preparation to detect any troublesome issues coming from the modelling processes.
In the first step MpCCI provides a model check where issues such as unit system incompatibilities, mesh overlapping and connectivity are highlighted. The user needs to improve the model either if the verification has reported problems or the model connectivity (e.g. unwanted thermal disconnection) for the thermal model needs additional modifications.
In the second step MpCCI offers for large full vehicle models an automated component association search. MpCCI will propose a list of component pairs to be combined for the co-simulation. The user can furthermore visualize for each component association the resulting number of orphans to check for incompatibilities. The user can tune the neighborhood search parameters, e.g. multiplicity factor, normal search distance on each selected association.
In the next step the user is able to group one or several associations into one coupling region and is able to validate the new created coupling regions by recalculating the number of orphans.



Identification of a fragmented component



Displaying disconnected components by color

Full Vehicle Thermal Management Configuration

The MpCCI co-simulation offers a dedicated and flexible framework for the full vehicle thermal management supporting the modelling of:

- A **stationary case**: a full steady-state approach for the solid and fluid model.

This configuration focuses on getting a stationary solution of the airflow for a chosen load case. Such configuration can be used as initial condition for the transient analysis.

- A **transient case**: a full transient thermal model with a pseudo-transient fluid model.

This method provides a good and fast compromise in terms of the computational time to predict the temperature in case of simulating dynamic driving cycles.

- A **full transient case**: a full transient thermal and fluid model.

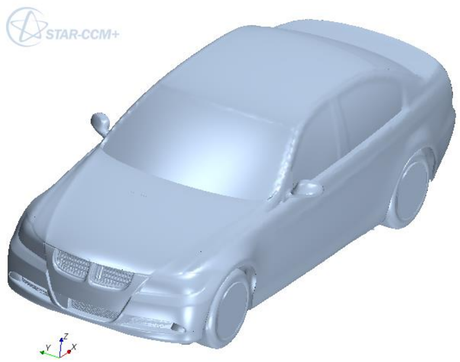
This methodology is employed if the transient behavior of the flow has to be taken into account to accurately calculate the temperature of the solid parts. The solid and fluid models are highly coupled in time.

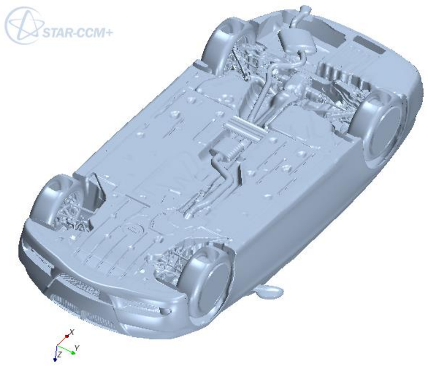
Case Study BMW Full Vehicle

In this study the steady state temperature distribution of a BMW passenger car is simulated by coupling STAR-CCM+ and RadTherm.

CFD Model

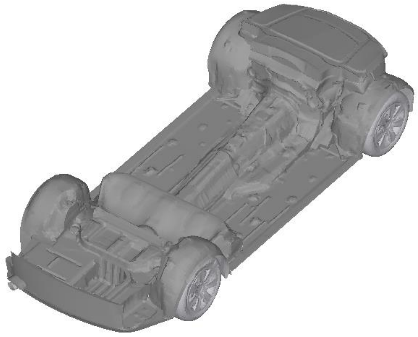
The **STAR-CCM+** model consists of approximately 45 mio. cells with 15 regions and 525 boundaries. It includes Multiple Reference Frames for fans and wheels and porous regions for heat exchangers and cooling devices. There is a rotation speed set for shafts and wheels.

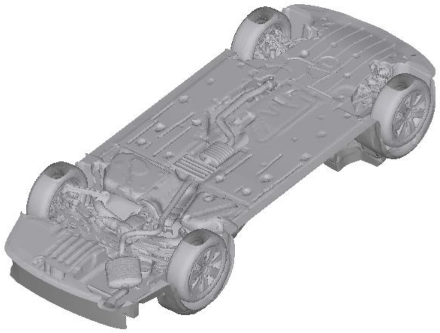




RadTherm Model

The **RadTherm (TAITherm)** mesh has 900,000 cells grouped into over 300 shell parts. There are 13 fluid parts integrated for the exhaust system.





MpCCI

The coupled quantities in **MpCCI** are:

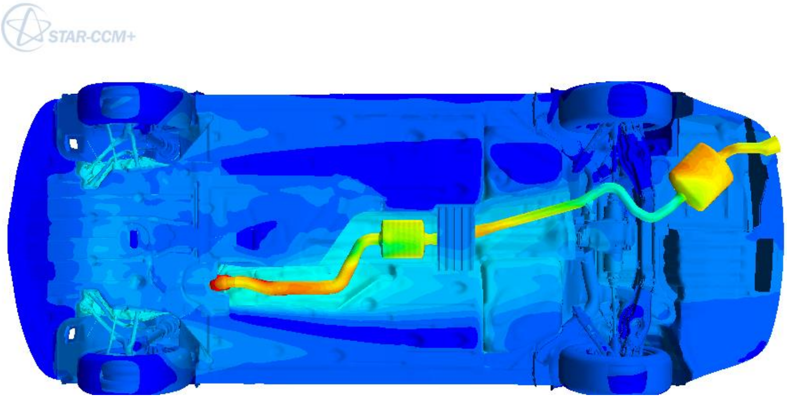
STAR-CCM+ → RadTherm film temperature, heat coefficient

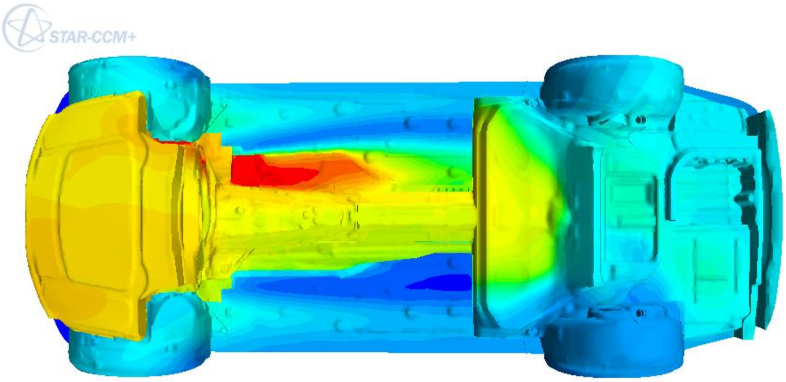
RadTherm → STAR-CCM+ wall temperature

Approximately 2 mio. cells are coupled .

Results

Temperature distribution of the underbody





Temperature distribution of the floor unit

Temperature distribution of the front axle including engine mounting and steering gear