Simcenter STAR-CCM+ powertrain thermal management

Maximize performance and reliability with optimized components

Benefits

- Maximize performance and thermal reliability with optimized components
- Determine the optimal engine cooling architecture design
- Increase engine and aftertreatment reliability
- Achieve faster engine and after-treatment warmup
- Minimize energy consumption
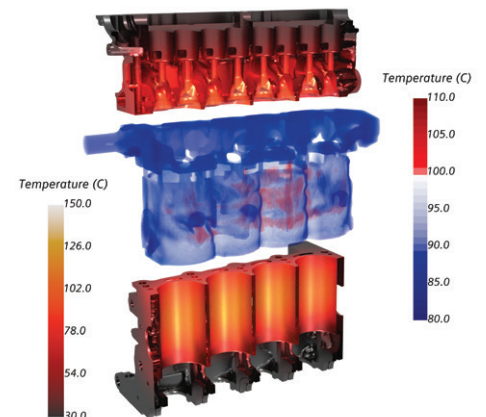- Meet emissions requirements

Summary

With higher thermal management demands being placed on powertrains, accurately simulating multiple solid and fluid regions on a three-dimensional level has become key for developing efficient components. This is especially true for problems in which highly non-uniform distribution of temperature and heat transfer coefficients exist, such as in the engine block, exhaust manifold and aftertreatment systems. Simcenter™ STAR-CCM+™ software allows you to accurately assess the thermal performance of these powertrain subsystems by leveraging the latest high-fidelity physics models and efficient simulation techniques for multiphase flow and fluid-solid heat transfer. Conducting embedded design exploration and coupling with system simulation using Simcenter Amesim™ software facilitates efficient frontloaded design, validation and integration throughout the development process. As a result, the Simcenter STAR-CCM+ solution for powertrain thermal management delivers maximum fuel economy and

reliability, meeting emission standards at minimal development cost.
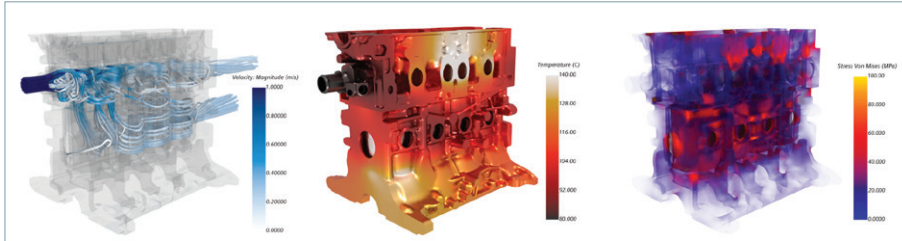
Engine and exhaust system

Engine thermal analysis

Using Simcenter STAR-CCM+ allows the analyst to simulate the thermal behavior of the engine, including the cylinder head, valves, seats, guides, engine block, gasket and pistons. Using a conjugate heat transfer (CHT) analysis, the solid temperature field can be coupled with the fluid regions for the coolant circuit and, optionally, the intake and exhaust gas path, the combustion chamber and oil circuit. By separating problems of different timescales into individual simulations coupled with a co-simulation approach, run times can be cut from potentially weeks to a few hours. Typically, the temperature field and heat transfer coefficients are assessed on the fluid side for a given boundary condition until a quasi-steady state is reached, then mapped to the other simulation as the boundary condition at the interface and the respective

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Design exploration

Thanks to the embedded Design Manager and the SHERPA algorithm, CHT simulations of the engine can easily be extended to design exploration studies; for example, to determine the optimal gasket holes to minimize cooling jacket pressure loss and satisfy all thermal constraints.

steady state is obtained on that side. This process is iterated until a steady solution of the temperature field is reached on either side. For the combustion chamber, boundary conditions stemming from cycle-averaged results of an in-cylinder combustion simulation can be considered.

Leveraging an explicit mapping interface can further enhance usability and even enable multi-timescale CHT within a single simulation. This further improves computational speed compared to the co-simulation approach by reducing the number of fluid-solid exchanges. Furthermore, using Simcenter STAR-CCM+ enables CHT analysis using a finite element (FE) based solid energy solver to not only solve for the solid temperature field, but also the thermal stresses within the solid domain.

Typical applications of the technology range from identifying hot spots and

preventing thermal fatigue cracks with the delivery of highly accurate boundary conditions for in-cylinder combustion to the optimization of the coolant circuit, cylinder head, piston or exhaust port and manifold design.

Cycle-average tool

For an integrated holistic engine thermal simulation, the cycle-average tool is available as a free add-on to Simcenter STAR-CCM+. It systematically combines work done by individual fluid subsystem simulations into a single simulation environment to accurately predict the cycle-averaged temperature and heat-flux distribution in the solid. With the cycle-average tool, users can simulate transient engine warmup scenarios and load changes, incorporating all relevant thermal heat and cooling sources in three dimensions, thus avoiding error-prone data transfer from one tool to another.
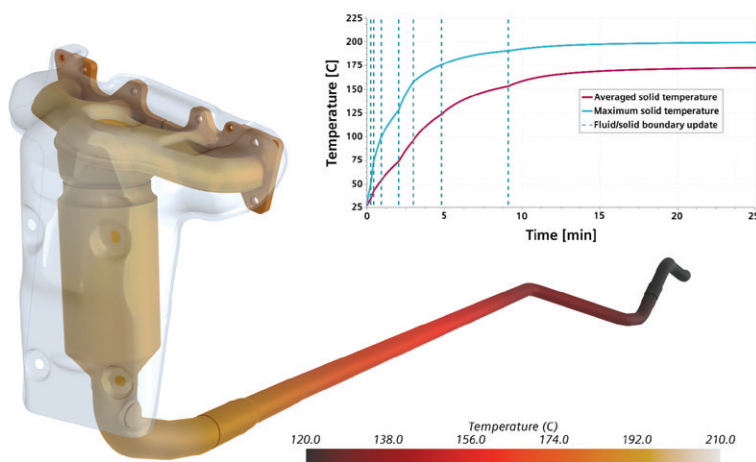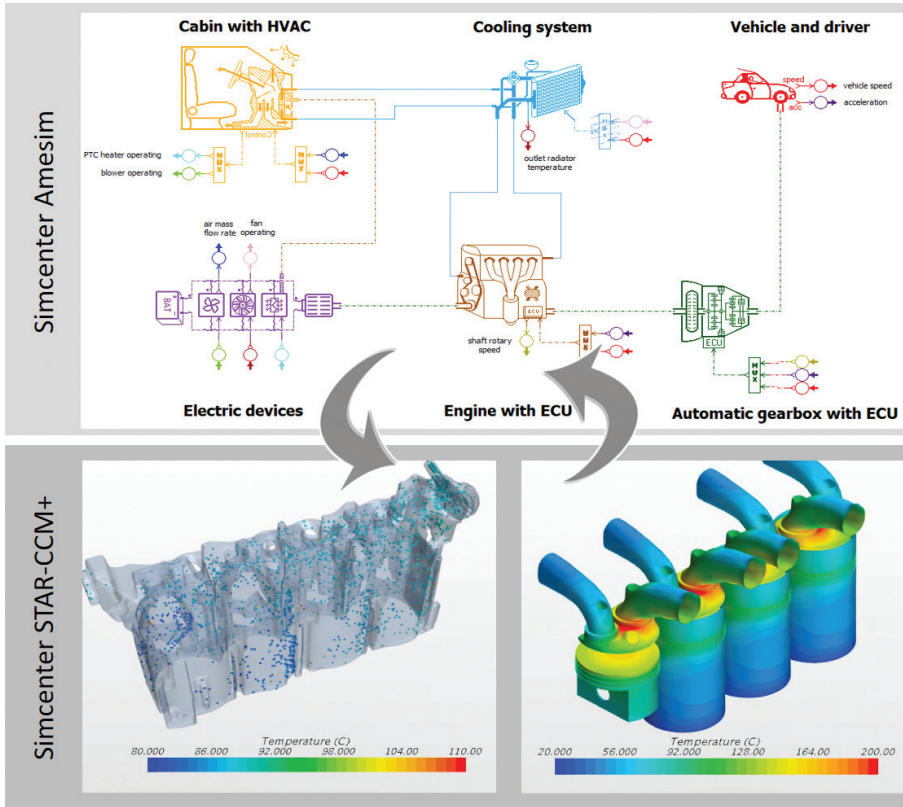

Baseline | Improved
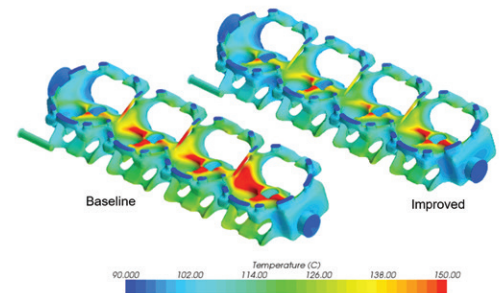
Coupling with 1D simulation using Simcenter Amesim

To compute the coolant and solid temperature evolution under realistic transient drive-cycle conditions, an accurate prediction of local heat exchanges is required. Although the thermal behavior of a complete powertrain system can in principle be captured with a fully resolved three-dimensional computational fluid dynamics (CFD) model for complete drive-cycle assessments, for maximum engineering efficiency it is advisable to couple the 3D CFD in regions of high local effects with a 1D system simulation approach. Using Simcenter Amesim and Simcenter STAR-CCM+ enable you to co-simulate the complex three-dimensional flow and heat transfer for individual powertrain components along with the complete dynamics of the system. A dedicated interface in Simcenter STAR-CCM+ provides an easy-to-setup and robust coupling of the tools. The coupled approach allows the modeling of system interactions, delivers more realistic boundary conditions for the CFD simulation and the 1D system simulation respectively, making it a valued approach that improves both 1D and 3D CFD results with minimal additional computational effort.

Simcenter Amesim

Cabin with HVAC | Cooling system | Vehicle and driver

PTC heater operating
blower operating

air mass flow rate | fan operating

outlet radiator temperature

shaft rotary speed

Electric devices | Engine with ECU | Automatic gearbox with ECU

Simcenter STAR-CCM+

Temperature (C)
80.000   86.000   92.000   98.000   104.00   110.00

Temperature (C)
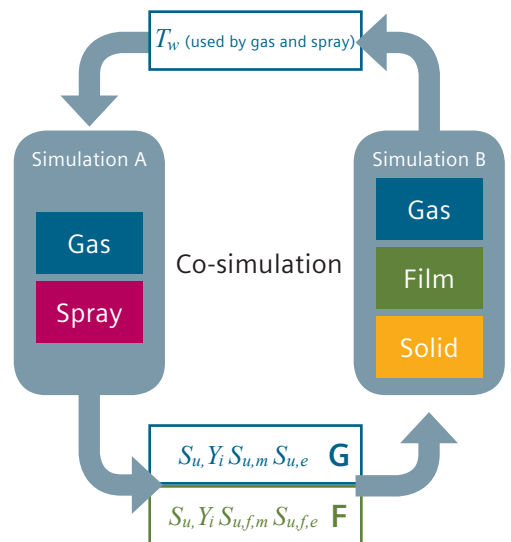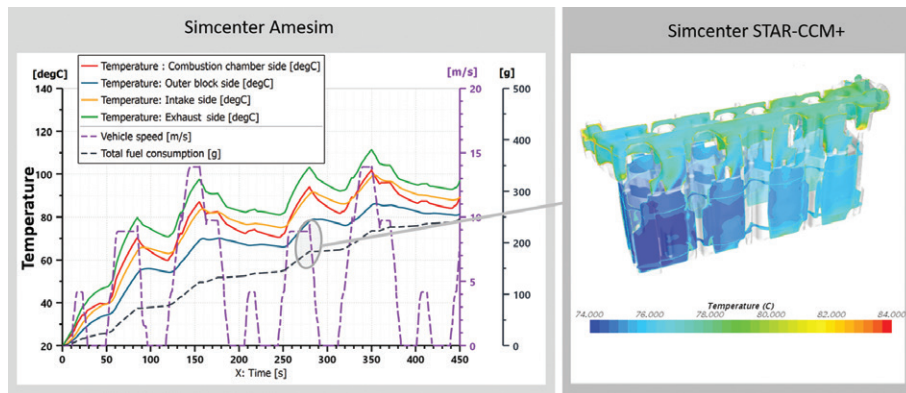20.000   56.000   92.000   128.00   164.00   200.00

under realistic thermal loads stemming from component design variations. That way the coupled approach allows you to maximize engine-thermal performance and reliability in a cost-effective manner, replacing early physical testing and avoiding late troubleshooting.
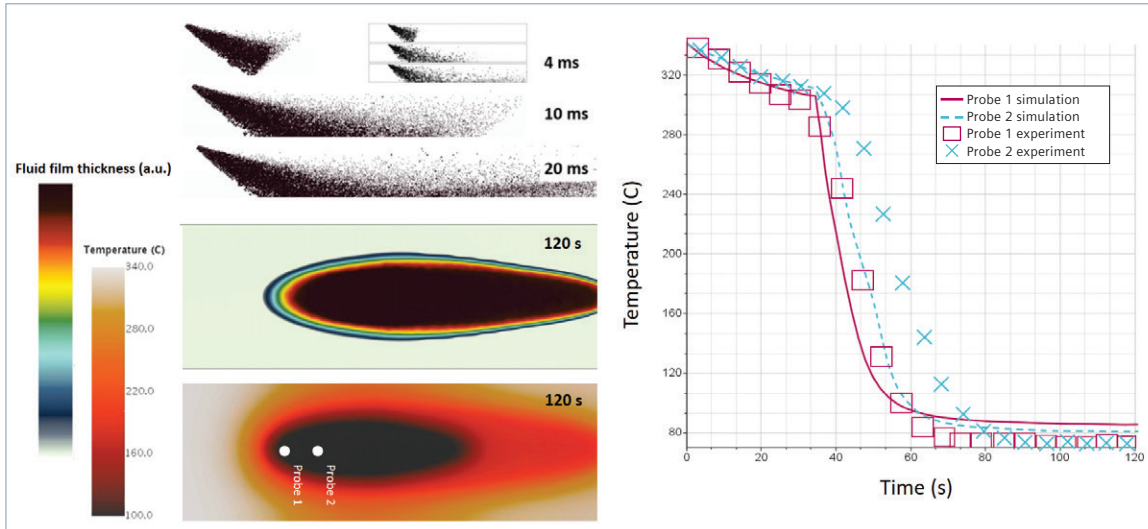
Exhaust gas aftertreatment components

For selective catalytic reduction (SCR) diesel aftertreatment systems, Simcenter STAR-CCM+ offers an innovative technique to predict the thermal interaction between the fluid film and the exhaust system and mixing element walls. This innovative co-simulation approach works in three steps. The simulation is split in two parts: A and B. Simulation B is used to model the fluid film and send the wall temperature to simulation A. Simulation A is used to model one spray injection cycle and sends the source from spray to film and gas averaged over the injection cycle to simulation B. Simulation A is launched by simulation B when a change in the wall temperature is detected that affects the spray boundary condition.

A typical application is to simulate a complete engine thermal management system considering local effects of the water jacket design. For example, this type of study allows you to assess the complete detailed coolant behavior during the startup phase in the water jacket under realistic transient boundary conditions. It also enables you to explore the design space of the water jacket geometry. Coupling full-vehicle system simulations with high-fidelity engine thermal and flow simulations allows the user to identify hot spots and evaluate coolant temperatures in real-world driving conditions. By covering the dynamics of the complete engine system, including the engine thermal model with metal masses, oil circuit and external heat exchanges, Simcenter Amesim enables you to assess the vehicle fuel economy and performance

Simcenter Amesim

[degC]
140
— Temperature : Combustion chamber side [degC]
— Temperature: Outer block side [degC]
— Temperature: Intake side [degC]
— Temperature: Exhaust side [degC]
-- Vehicle speed [m/s]
-- Total fuel consumption [g]

[m/s] [g]
20   500

120
100
Temperature
80
60
40
20
0   50   100   150   200   250   300   350   400   450
X: Time [s]

Simcenter STAR-CCM+

Temperature (C)
74.000   76.000   78.000   80.000   82.000   84.000

T_w (used by gas and spray)

Simulation A
Gas
Spray

Co-simulation

Simulation B
Gas
Film
Solid

$S_u, Y_i\, S_{u,m}\, S_{u,e}$ **G**

$S_u, Y_i\, S_{u,f,m}\, S_{u,f,e}$ **F**

With this method numerous validation proofs for transient temperatures are captured at significantly reduced computational cost, making it a key enabler for predicting fluid film reactions and deposit formation in SCR systems.

Although the technique was developed to allow for computationally efficient long transient runs in an SCR, it may be used in other areas in which long time cooling effects are triggered by spray impingement and wall wetting phenomena, such as port fuel injection engines.