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Simcenter STAR-CCM+ In-cylinder solution add-on

Using an application-specific workflow for in-cylinder simulations

Benefits

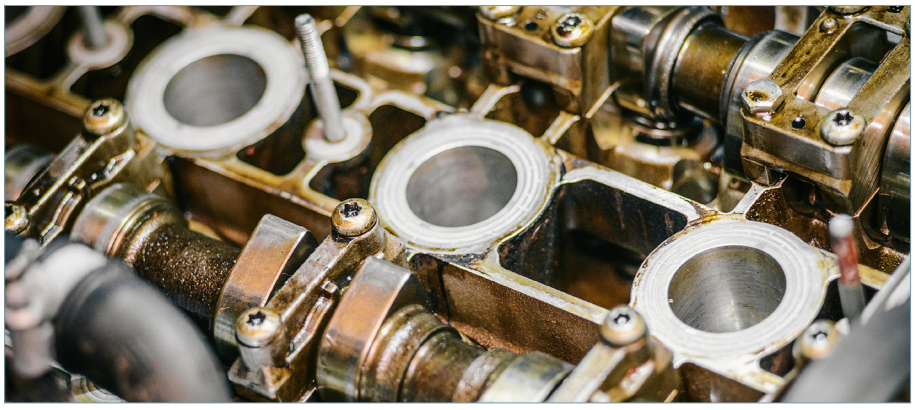
- Perform accurate cold flow, charge motion and combustion simulations
- Set up in-cylinder simulations in minutes through an interface designed for engine engineers
- Save valuable engineering time through automatic meshing, handling refinements in critical areas and creating prism layers at boundaries
- Analyze simulations efficiently through automatic postprocessing, specific to in-cylinder simulations
- Optimize engine performance using automatically created parametric in-cylinder models and Design Manager

Summary

The automotive industry is transitioning to new business models and technologies. With increasing customer expectations on fuel economy and tighter legislative requirements on emissions, there is not a unique recipe for tomorrow's propulsion system. Powertrain developers need to consider systems ranging from all-electric to conventional and hybrid powertrains, where the internal combustion engine remains an integral part of the solution.

Updates to existing combustion systems and the development of new combustion concepts will require in-cylinder simulations to avoid expensive experimental campaigns. With shorter development cycles, fewer experts in in-cylinder simulations and harder engineering problems to solve, digital product development is essential to achieve the right solution at the right time. A digital twin for in-cylinder simulations needs to provide:

- Built-in best practices for meshing, solver settings, and modeling of complex in-cylinder physics such as turbulence, sprays, combustion, emissions and heat transfer
- An easy-to-use workflow to help non-experts set up complex simulations and give experts the ability to apply their knowledge when specifying model-specific details
- Efficient numerical schemes and solver technology designed for modern high performance computing (HPC) systems and high core counts
- Design exploration, allowing for multi-objective optimization of geometry, charging, injection strategy and combustion phasing to achieve maximum performance while meeting legislative requirements



Simcenter STAR-CCM+ In-cylinder solution add-on

Simcenter STAR-CCM+ offers the solution
Siemens Digital Industries Software's Simcenter™ STAR-CCM+™ software is a multipurpose computational fluid dynamics (CFD) tool with strong multiphysics capabilities that allows users to build a high-fidelity digital twin of any real-life application. Built into Simcenter STAR-CCM+, the Simcenter STAR-CCM+ In-cylinder solution add-on provides an in-cylinder simulation specific interface with a top-down workflow that allows for quick and easy setup.

With the Simcenter STAR-CCM+ In-cylinder solution add-on, users can:

- Take advantage of streamlined computer-aided design (CAD) import, automated mesh generation and mesh motion
- Quickly specify operating conditions, boundary conditions and valve lift profiles
- Create injectors and ignitors, and select advanced combustion and emission models
- Analyze simulation results efficiently through automated postprocessing of liquid and vapor penetration, fuel mass tracking, heat release and emissions
- Use their in-cylinder simulation setup as a starting point for more sophisticated simulations that leverage the full power of Simcenter STAR-CCM+

Capabilities

Automatic meshing
Mesh generation and mesh motion are handled automatically. Starting from CAD geometry, built-in best practice settings allow for a quick set up of the mesh, comprised of trimmed cells and prism layers. Capabilities to support automatic meshing include:

- Prism layers that accurately capture boundary layer flow features
- Refinements that are generated automatically without any manual user intervention in critical areas such as around the valve, the valve seat, the valve throat, into the port and around the gasket gap
- Giving the user full control over the mesh setup, and additional regions of refinements are easily added, for example, around the spark plug
- Mesh motion which is handled without user intervention. The mesh is automatically morphed and mapped to account for piston and valve movement. Quality checks are performed on the mesh during morphing and a new, undistorted mesh is generated automatically as required
- The morph-map-remesh approach, which has been extensively tested and is highly mass conservative for all practical applications

Cold flow
In-cylinder simulations are among the most complex CFD simulations performed, combining high-speed flows, mesh motion, spray (with droplet-wall interaction and wall films) and combustion (ignition, flame propagation, emission formation, knock). Therefore, early in the combustion system design process the focus is on optimizing the airflow in the cylinder to maximize trapped mass and examine the swirl and tumble induced by the flow. With the Simcenter STAR-CCM+ In-cylinder solution, you can go from a CAD geometry to running a cold flow simulation in minutes. Capabilities to support cold flow simulations include:

- Automation of the geometry handling process with the ability to parametrize CAD within the 3D CAD module of Simcenter STAR-CCM+, enabling design space exploration utilizing Design Manager
- Customizable filters to support company-specific naming conventions for geometry
- Accurate and fast solutions using the Pressure-Implicit with Splitting of Operators (PISO) algorithm
- Fast turnaround times for large models (large eddy simulation) by leveraging the highly scalable framework of Simcenter STAR-CCM+ for running large cell counts on HPC systems

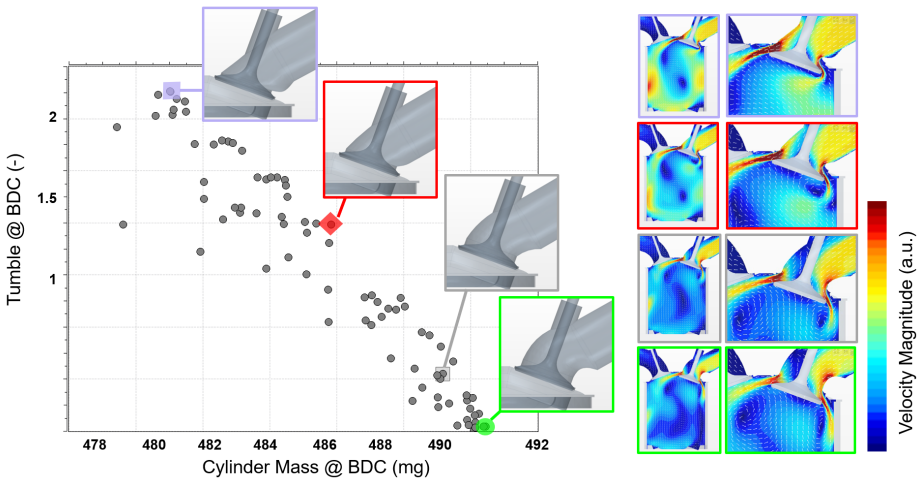


Figure 1. Design exploration. Transient intake port performance evaluation in cold flow conditions.

Charge motion

Charge motion simulations allow engine manufacturers to design the injection process to obtain a high-quality air-fuel mixing in the combustion chamber, which is a prerequisite for an efficient combustion process. With the Simcenter STAR-CCM+ In-cylinder solution add-on, a cold flow simulation can be augmented into a charge motion simulation, with the injection of a multicomponent liquid fuel, with only a few mouse-clicks.

Charge motion simulations show how the fuel injection event affects bulk flow and turbulence, how fast the liquid fuel evaporates, where fuel droplets hit the combustion chamber's surfaces and where the charge is rich or lean. These metrics can be correlated to the quality of the combustion process and to the magnitude of emission formation, allowing for optimization and issue mitigation early in the design process.

Capabilities to support charge motion simulations include:

- Modeling of premixed and direct-injection systems with flexible injector positioning and fuel convection options
- Advanced injection models for primary and secondary breakup commonly applied for diesel and gasoline injectors, including Huh, Reitz-Diwakar and Kelvin-Helmholtz-Rayleigh-Taylor (KH-RT)
- Direct replication of experimental data, when available, using user-specified Lagrangian parcel size distributions
- Efficient analysis of the charge motion process through automatically generated postprocessing

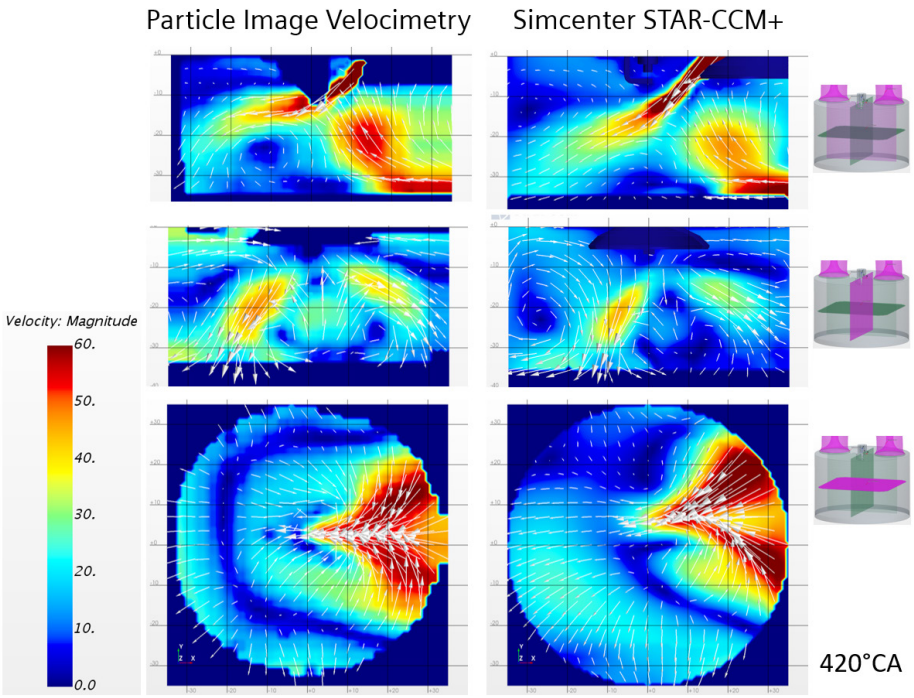


Figure 2. Accuracy. Particle image velocimetry PIV measurements from the turbulent combustion chamber (TCC)-III engine and velocity field predicted by Simcenter STAR-CCM+.

Combustion

The Simcenter STAR-CCM+ In-cylinder solution add-on provides combustion and emission modeling capabilities for all modes of combustion, including nitrogen oxide (NOx) and carbon monoxide (CO) emission modeling. The breadth of combustion and emission modeling capabilities is extended with every new release, three times per year. Capabilities to support combustion simulations include:

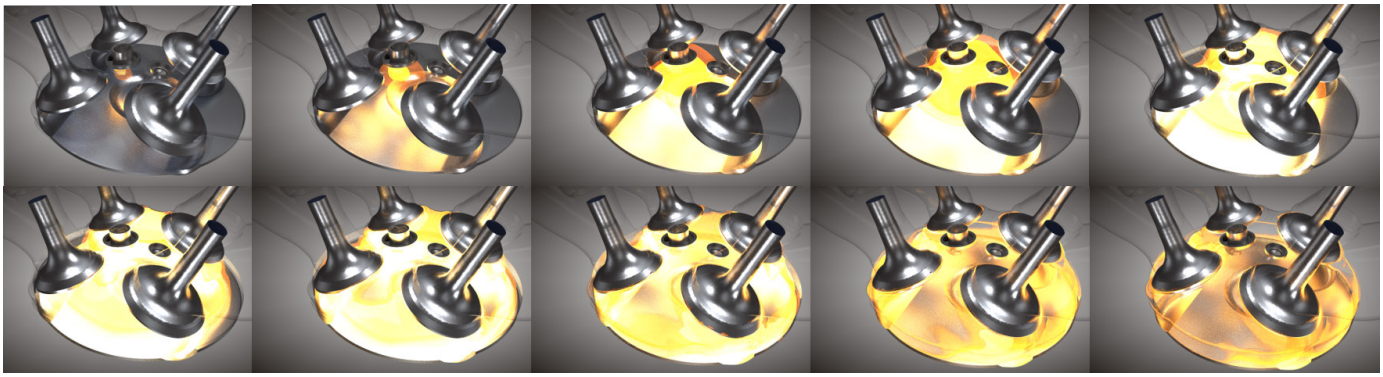


Figure 3. Flame propagation simulated with the Simcenter STAR-CCM+ In-cylinder solution add-on.

- Accurate combustion predictions using the 3-Zones Extended Coherent Flame Model (ECFM-3Z) and the Extended Coherent Flame Model with Combustion limited by Equilibrium Enthalpy (ECFM-CLEH) combustion models
- Modeling of the spark-ignition process through the FI spark model and the advanced Imposed Stretch Spark Ignition Mode (ISSIM)
- Prediction of NOx emissions using the advanced Nitrogen Oxide Relaxation Approach (NORA) NOx model
- Prediction of auto-ignition and knock using the Tabulated Kinetics for Ignition (TKI) model
- Simulation of non-standard fuels through import of user-generated tables for ECFM-3Z and ECFM-CLEH

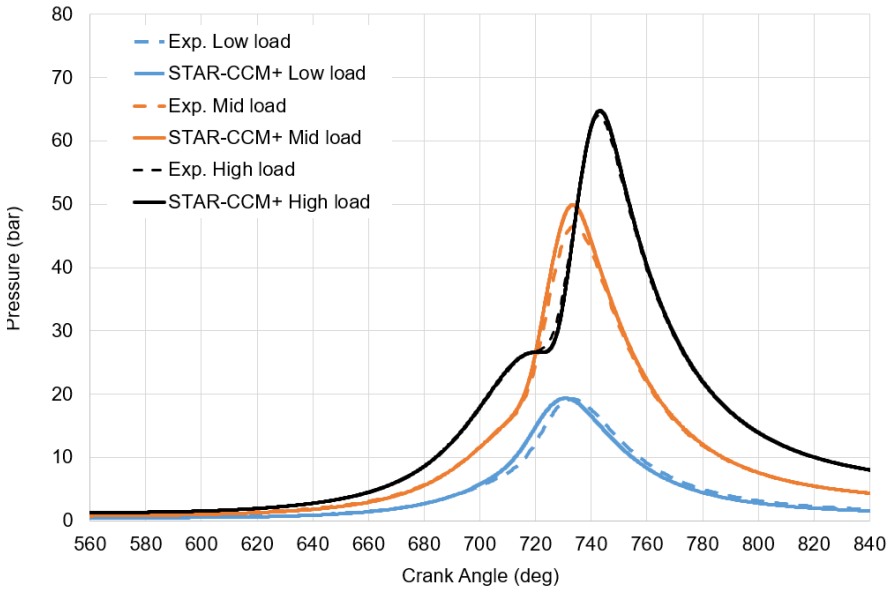


Figure 4. Experimental and simulated pressure traces for three different GDI engine operating conditions.

Automated design exploration

With the power of the Simcenter STAR-CCM+ platform and Design Manager, users can leverage the platform's automation capabilities, scalability and flexibility to quickly and easily execute engine optimization design studies. Design Manager handles the design exploration process without any user intervention. Model updates and execution of simulations are performed automatically, and built-in, industry-leading intelligent search methods cater for efficient design space exploration.

The Simcenter STAR-CCM+ In-cylinder solution add-on automatically creates parametric models, and only a few mouse clicks are required to turn an existing setup into a design exploration study. Examples of design exploration include:

- Transient optimization of the intake port geometry, using a parametric CAD model, to maximize entrained mass and tumble at bottom dead center
- Optimization of a gasoline direct-injection multipulse injection strategy, using a parametrized injection rate profile, to maximize turbulent kinetic energy and mixture uniformity at spark timing and to minimize the amount of liquid fuel in the ports and in the cylinder
- Optimization of spark timing for maximum engine performance and minimum fuel consumption
- Optimization of piston bowl geometry, injection strategy and spray target position to maximize diesel engine performance and minimize fuel consumption and harmful emissions

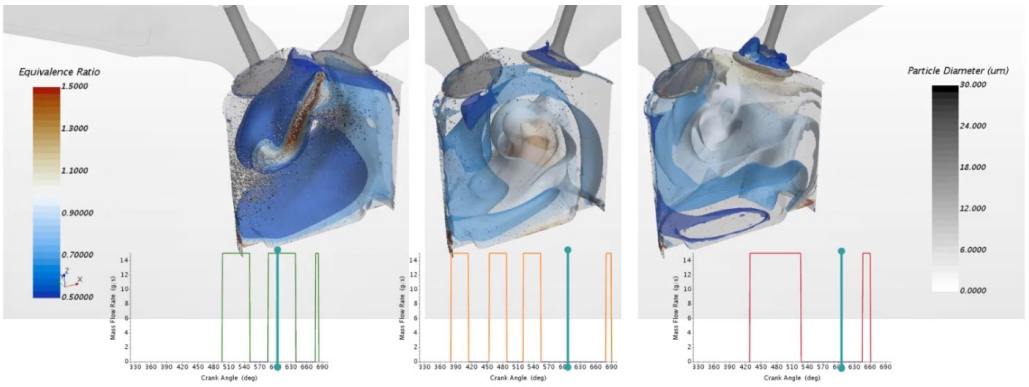


Figure 5. Optimization of multi-pulse injection strategy examining equivalence ratio at the spark plug using Design Manager and the Simcenter STAR-CCM+ In-cylinder solution add-on.

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