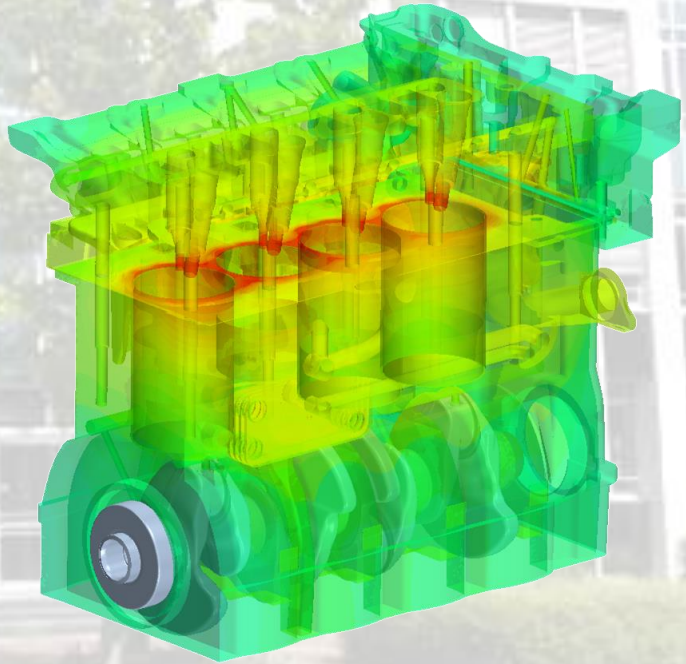
INTEGRATED DESIGN ANALYSIS GmbH InDesA

STAR Global Conference 2016 PRAGUE

Engine Warm-up Prediction of Combustion Engines for Fuel Economy Drive Cycles



Gerald Seider
Fabiano Bet
Uliana Bryakina

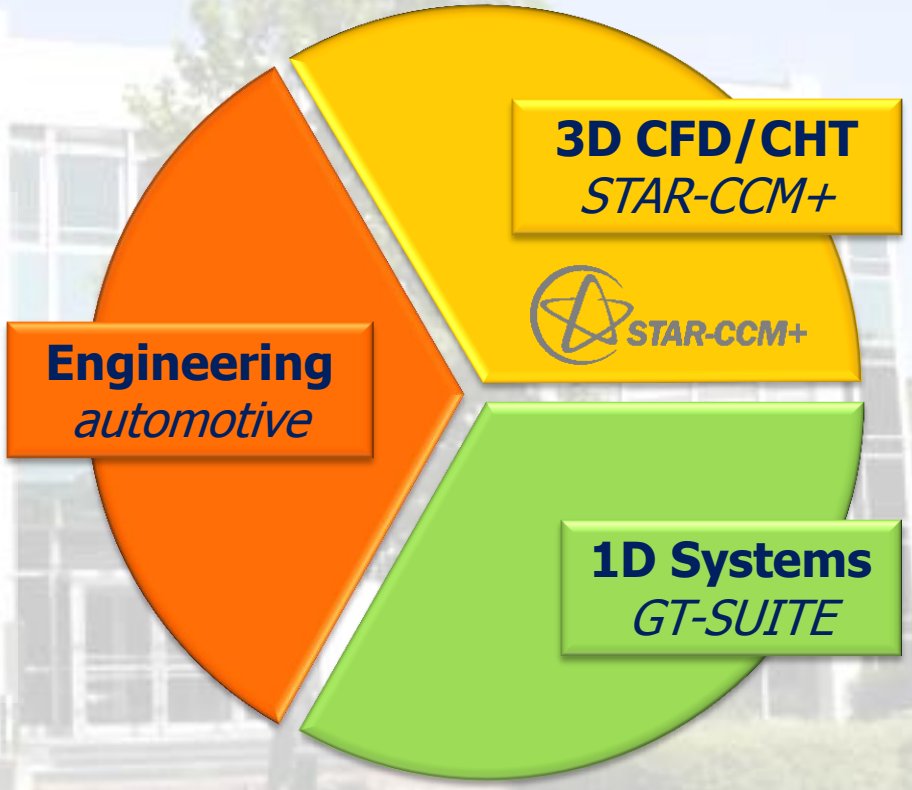
Prague, March 8, 2016

INTEGRATED DESIGN ANALYSIS GmbH **InDesA**

STAR Global Conference 2016 PRAGUE

Consulting, Engineering Services & Virtual Bench Testing

- Simulation and Design Analysis of complex systems for engineering and industrial applications
  - fluid flow, hydro-/aerodynamics
  - heat transfer, thermal management
  - air-borne acoustics, sound design
- Virtual Performance and Functional Testing for automotive accessory units



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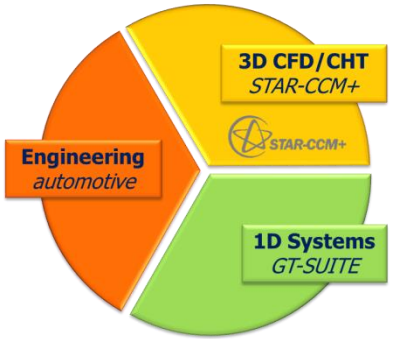
Engine Warm-up Prediction for Fuel Economy
Presentation Overview

E

Engineering:
Development of a Virtual Engine to demonstrate Thermal Management Technologies and Advanced Simulation Techniques



1D

1D System Simulation:
InDesA's state-of-the-art approach to simulate and predict fuel economy for fuel consumption drive cycles (NEDC, WLTC). ⇒ Engine warm-up

3D

1D/3D Co-Simulation:
3D warm-up simulation of the core IC engine with 1D backbone system simulation

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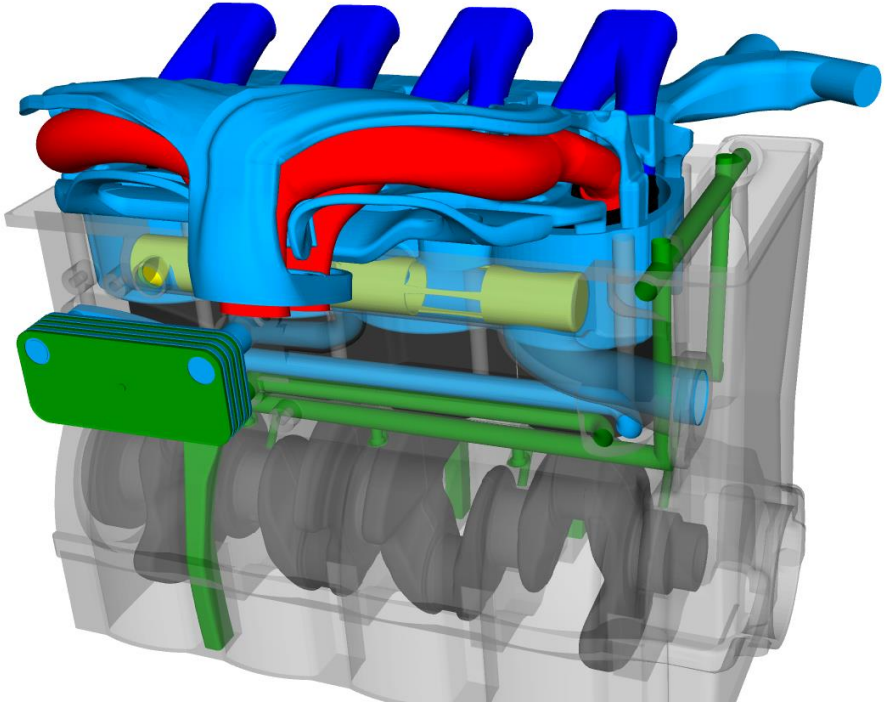
Engine Warm-up Prediction for Fuel Economy
InDesA's Virtual Internal Combustion Engine

Designed to demonstrate thermal simulation techniques with options for different thermal management technologies:

- Split Cooling
- Integrated Exhaust Manifold (water cooled)
- Engine oil Cooler (Heater)
- Integrated Thermal Management Module

Compared to real engines the virtual engine shows a simplified design but with all relevant features to allow for thermal management studies.



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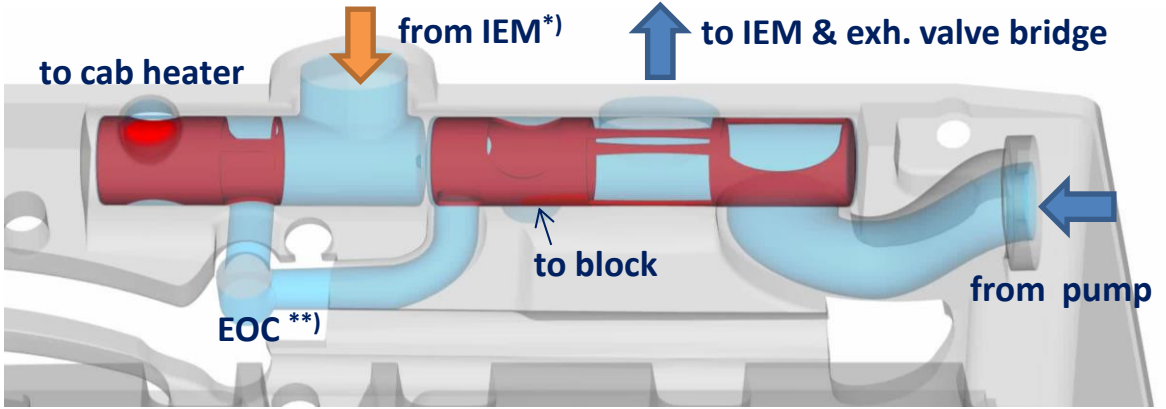
Engine Warm-up Prediction for Fuel Economy
InDesA's Virtual Internal Combustion Engine

Integrated Thermal Management Module

Two rotary slide valves integrated in the engine block to control engine warm-up from cold start:

- Water pump shut off
- Split cooling for
  - ✓ engine block
  - ✓ cylinder head
  - ✓ exhaust manifold
- Oil heating/cooling
- Cabin heating



Warm-up control phases:

I water pump shut off
II circulation of water in IEM, exhaust valve bridges and through EOC
III circulation of water in engine block in addition
IV cooling of water; opening of thermostat
V cooling of engine oil

*) **I**ntegrated **E**xhaust **M**anifold
**) Engine Oil Cooler

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Engine Warm-up Prediction for Fuel Economy
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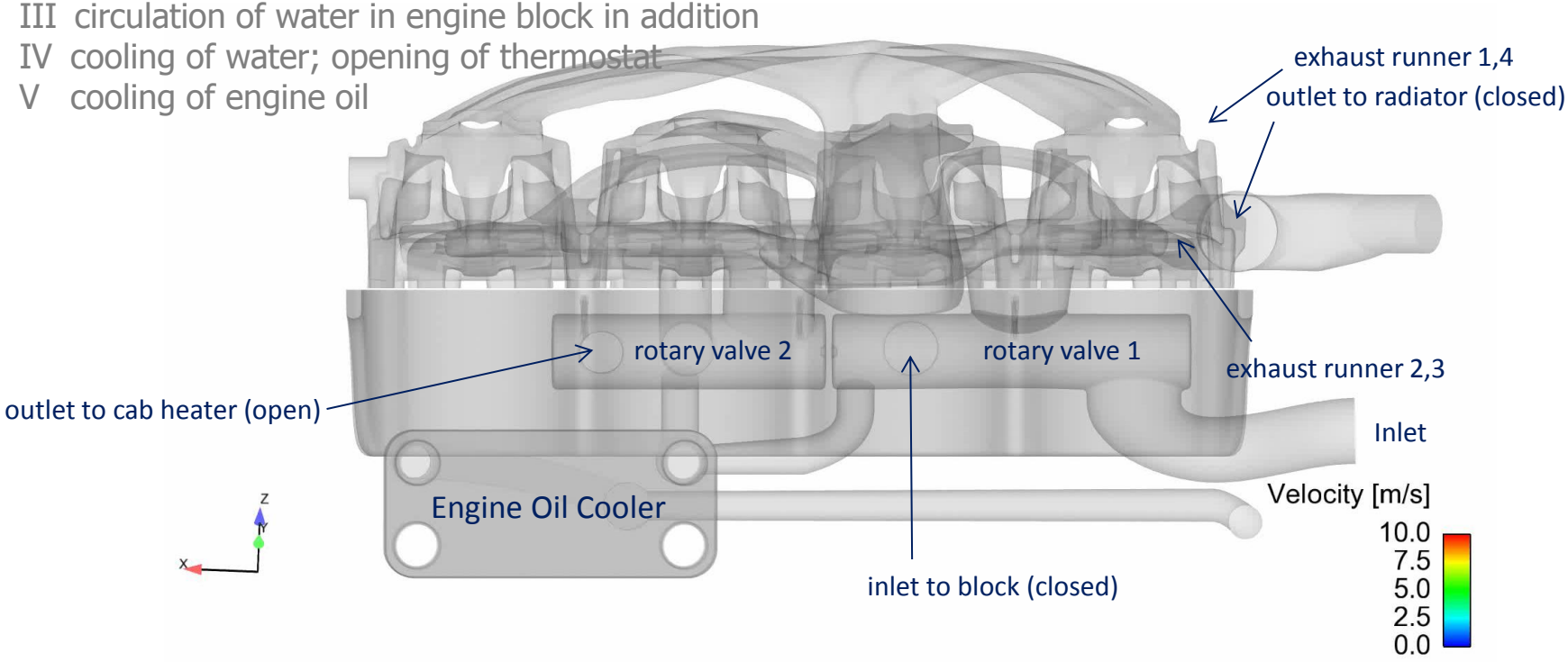

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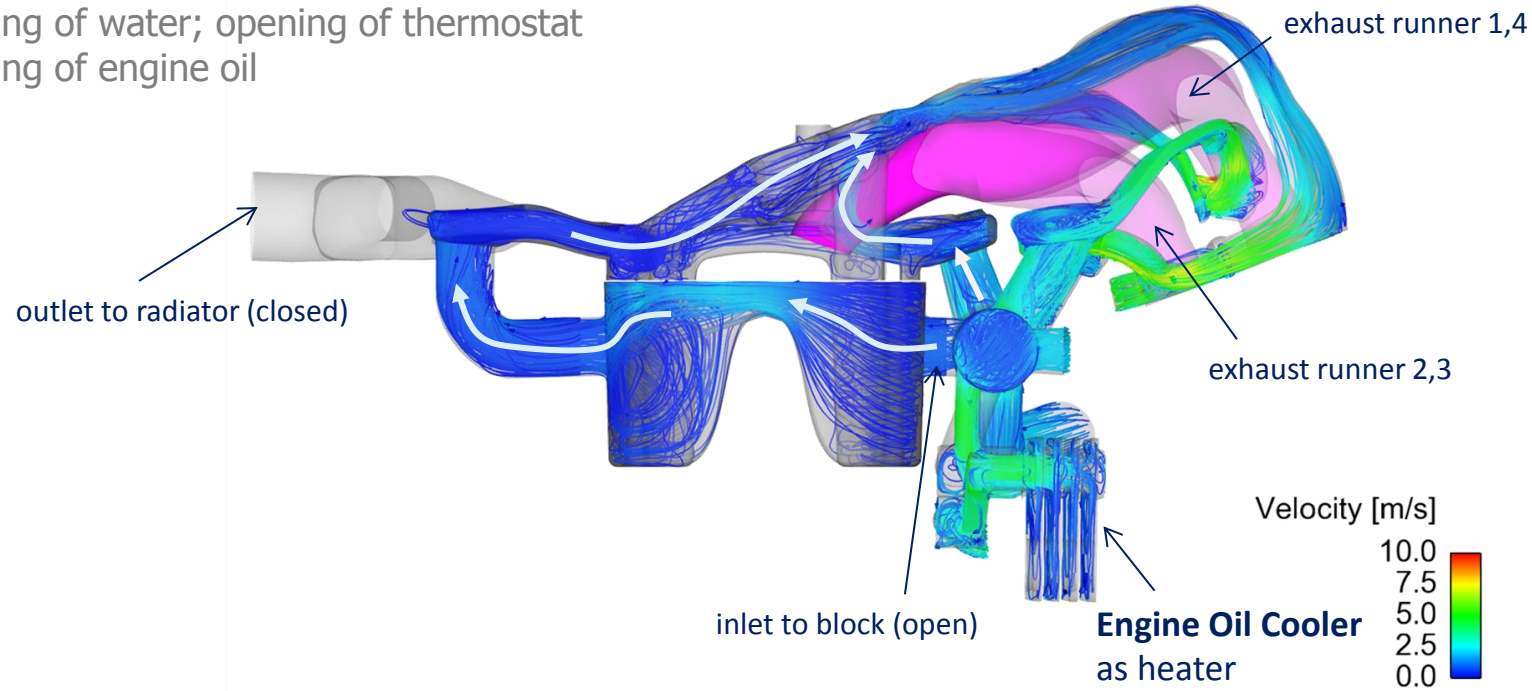

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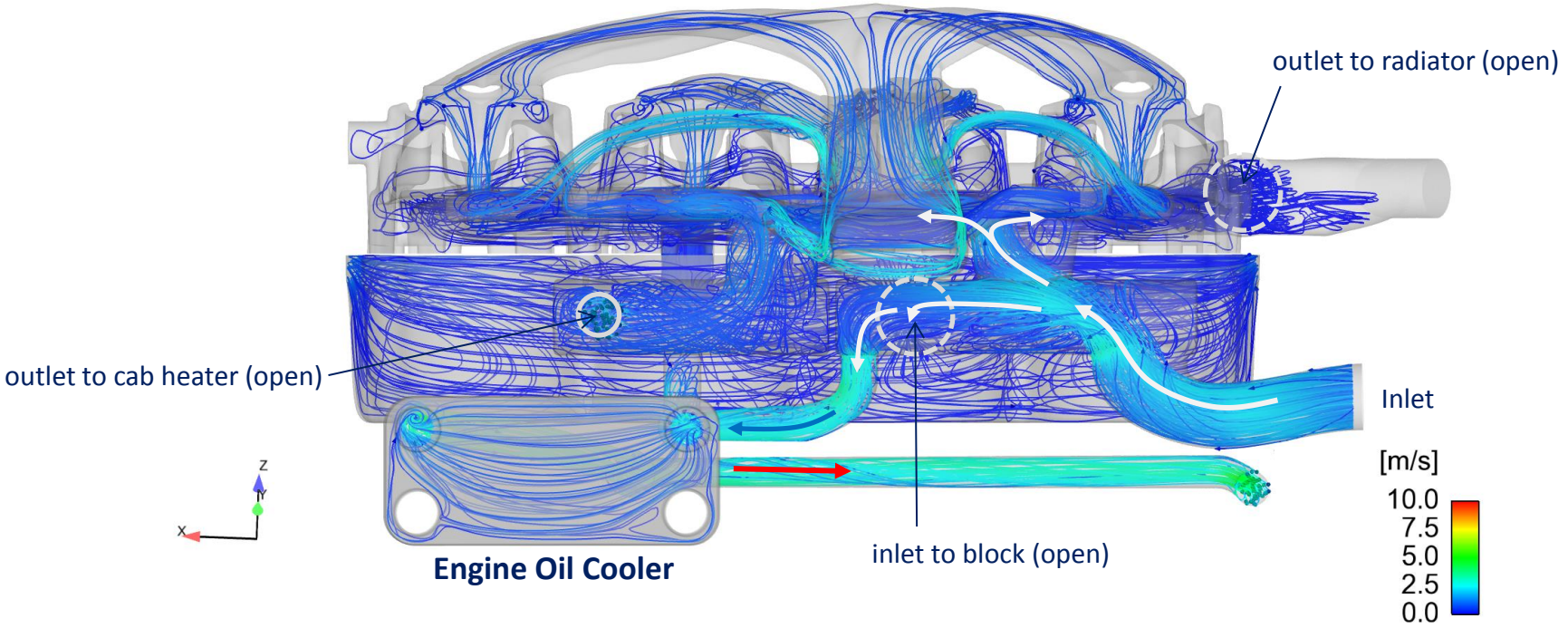

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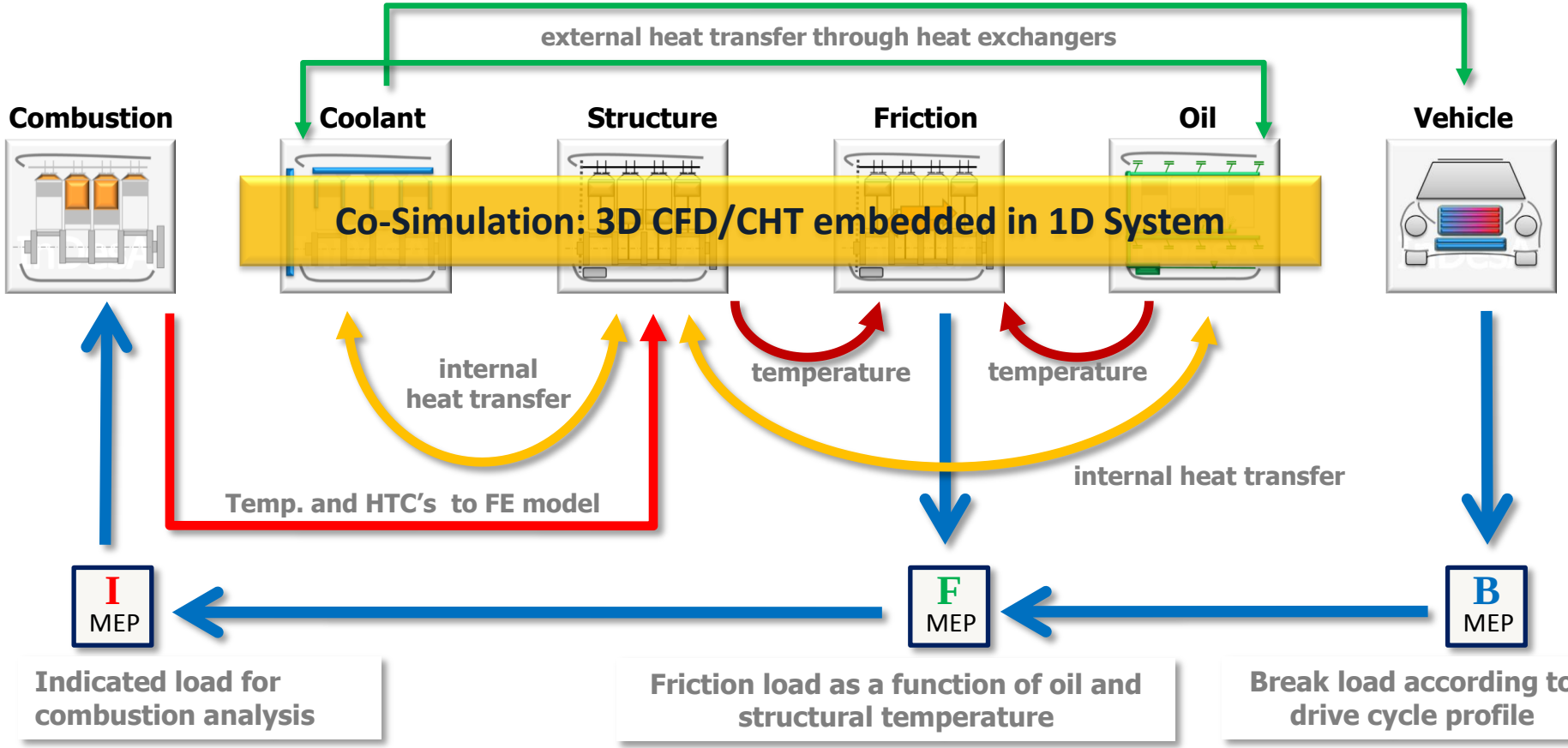
Engine Warm-up Prediction for Fuel Economy

1D System Simulation of Engine Warm-Up



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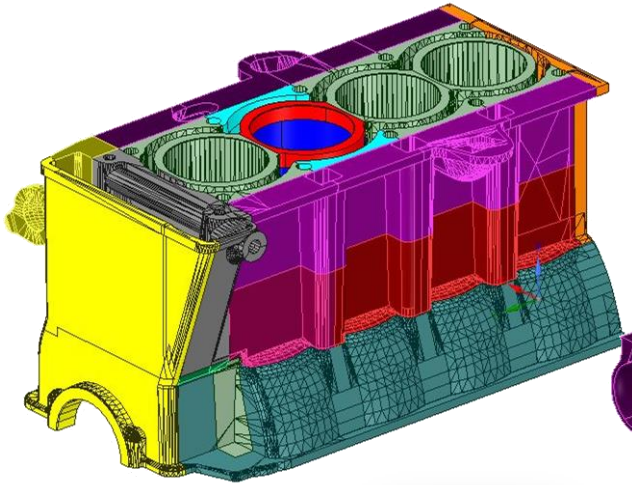
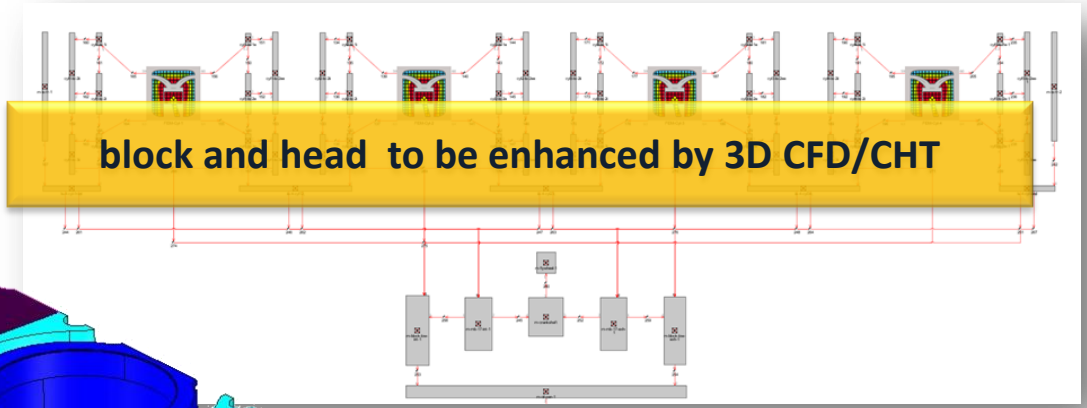
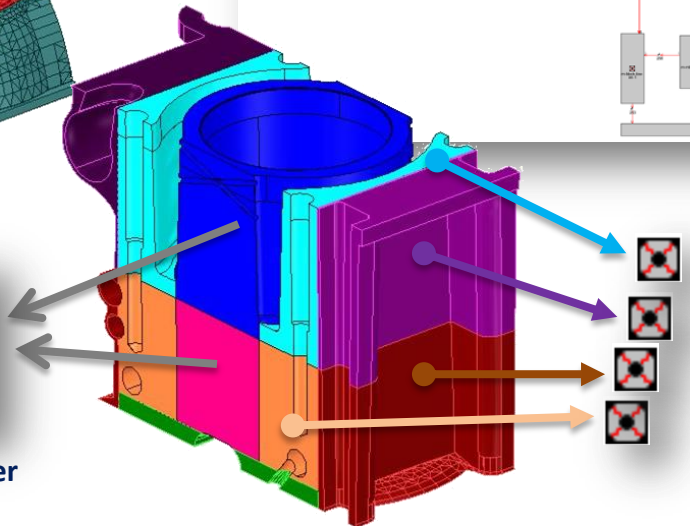
Engine Warm-up Prediction for Fuel Economy
1D System Simulation of Engine Warm-Up

Split of Engine Block to Convert to Lumped Masses





Finite Element Model within *GT-SUITE* for structure around combustion chamber



Outer engine structure converted to lumped masses and be connected to

- coolant
- oil
- ambient

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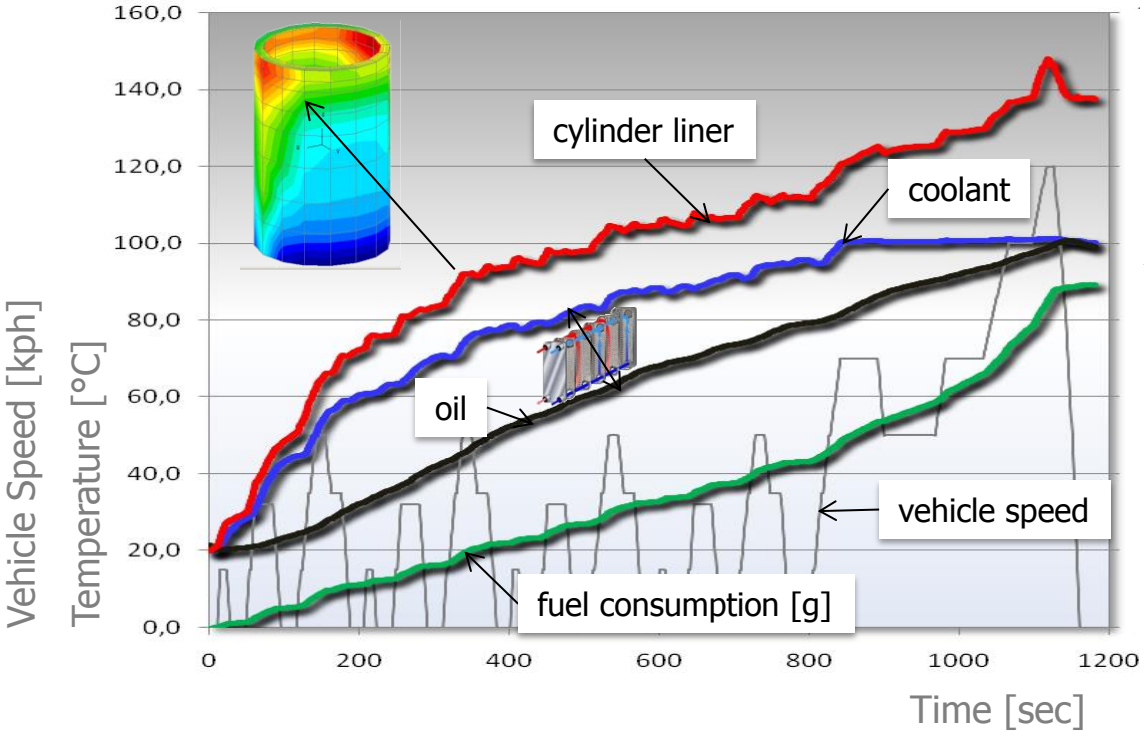
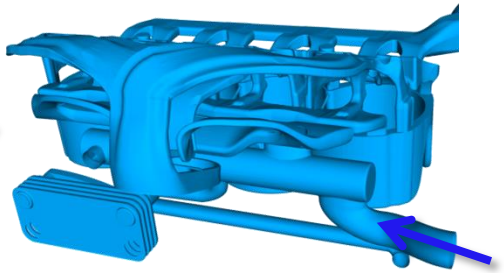
Engine Warm-up Prediction for Fuel Economy

Deriving BC's for 3D CFD/CHT Warm-up Model

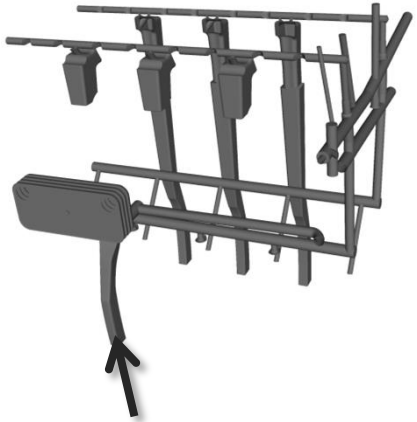
Temperatures and FC for for NEDC Drive Cycle



coolant inlet temperature and volume flow rate *f(time)*



Oil inlet temperature and volume flow rate *f(time)*



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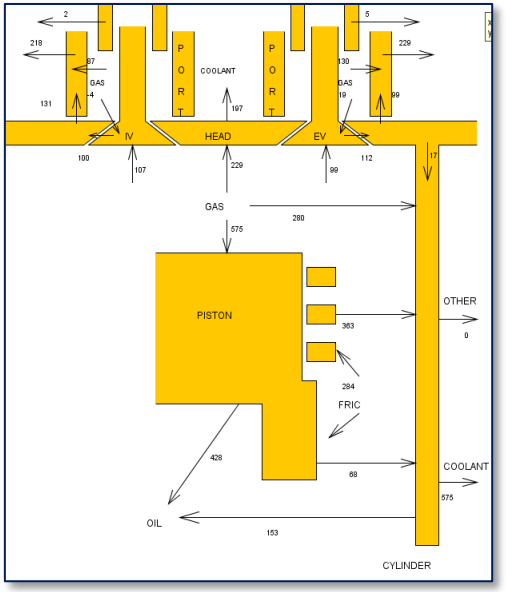
Engine Warm-up Prediction for Fuel Economy
Deriving BC's for 3D CFD/CHT Warm-up Model

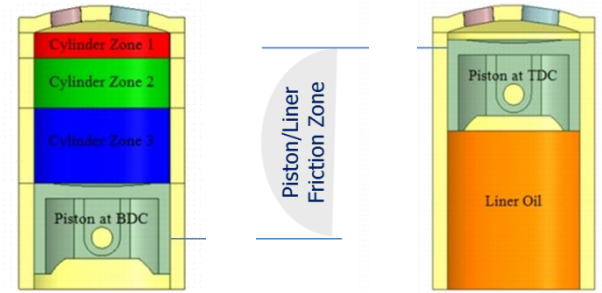
GT-POWER heat transfer analysis



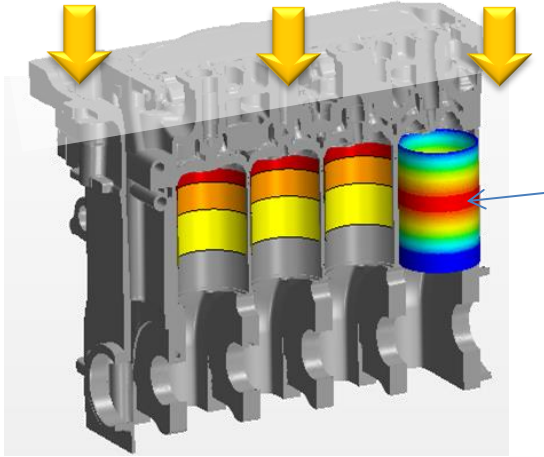
detailed heat flux maps derived for arbitrary engine operating points.

Gas Temperature Zones

Cylinder Oil Zone



T_{gas} and HTC_{gas} | $Heat\ Flux_l$ | T_{oil} and HTC_{oil}



Heat Flux for liner/piston friction group (from testing)

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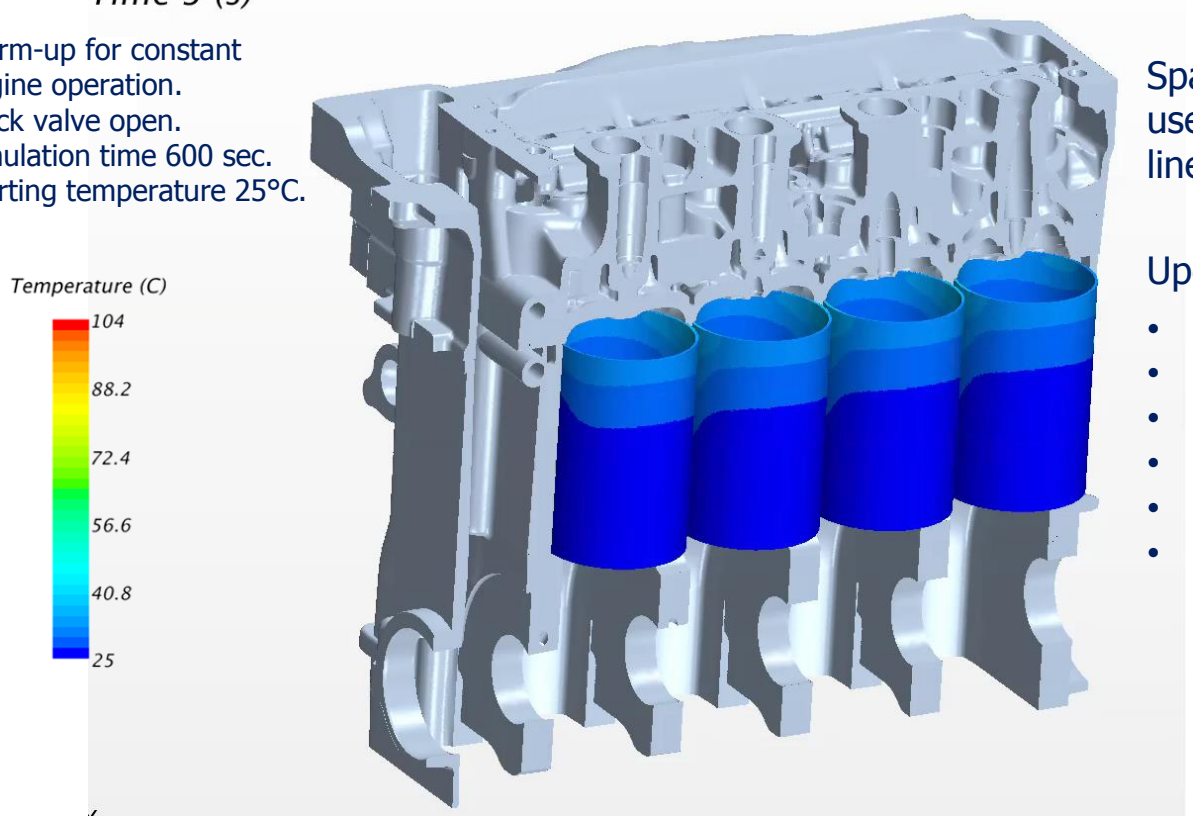
Engine Warm-up Prediction for Fuel Economy

3D Results for Warm-Up of Cylinder Liner

Time 3 (s)

Warm-up for constant engine operation.
Block valve open.
Simulation time 600 sec.
Starting temperature 25°C.



Spatial average liner temperature is used to predict friction losses of the liner piston group

Updated at every time step:

- combustion temperature
- gas side heat transfer coefficient
- dissipated friction losses
- oil temperature
- oil side heat transfer coefficient
- heat transfer from piston

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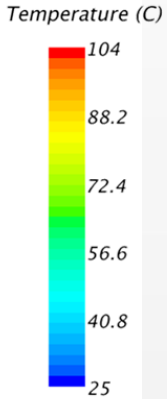
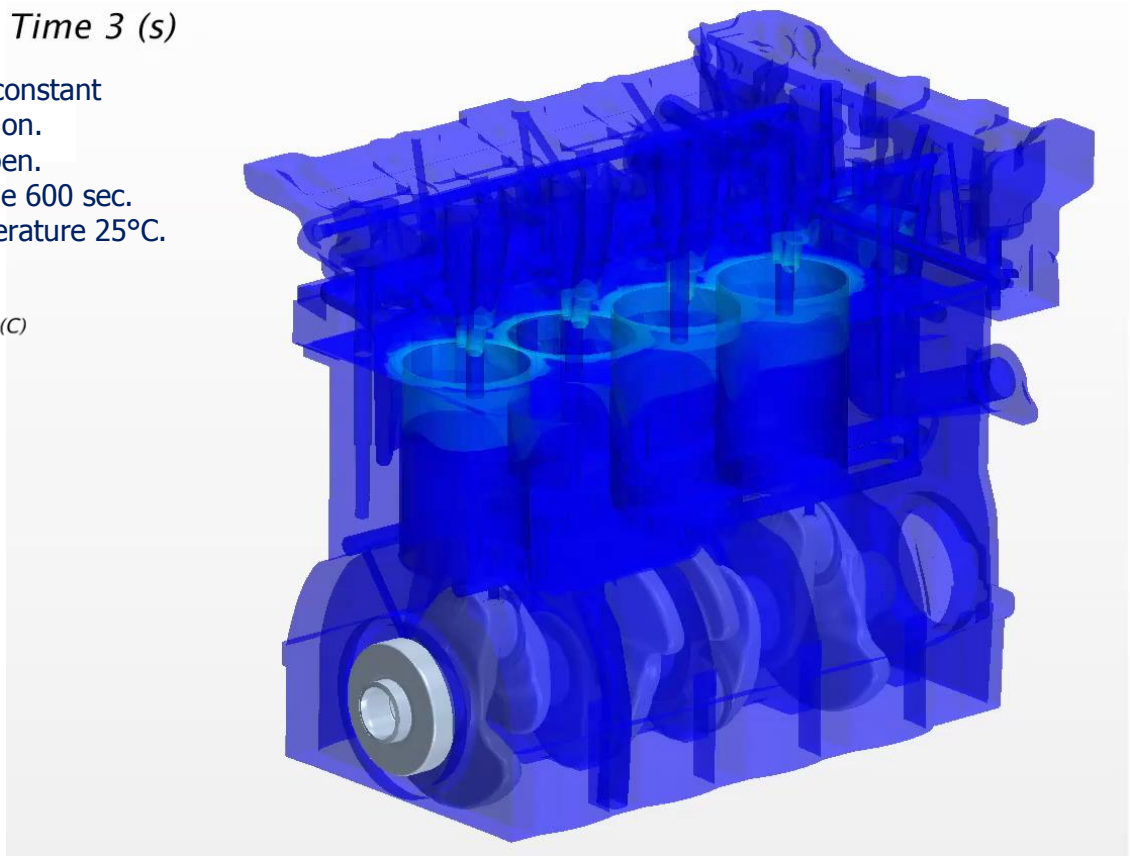
Engine Warm-up Prediction for Fuel Economy

3D Results for Warm-Up of Core Engine Structure

Time 3 (s)

Warm-up for constant engine operation.
Block valve open.
Simulation time 600 sec.
Starting temperature 25°C.





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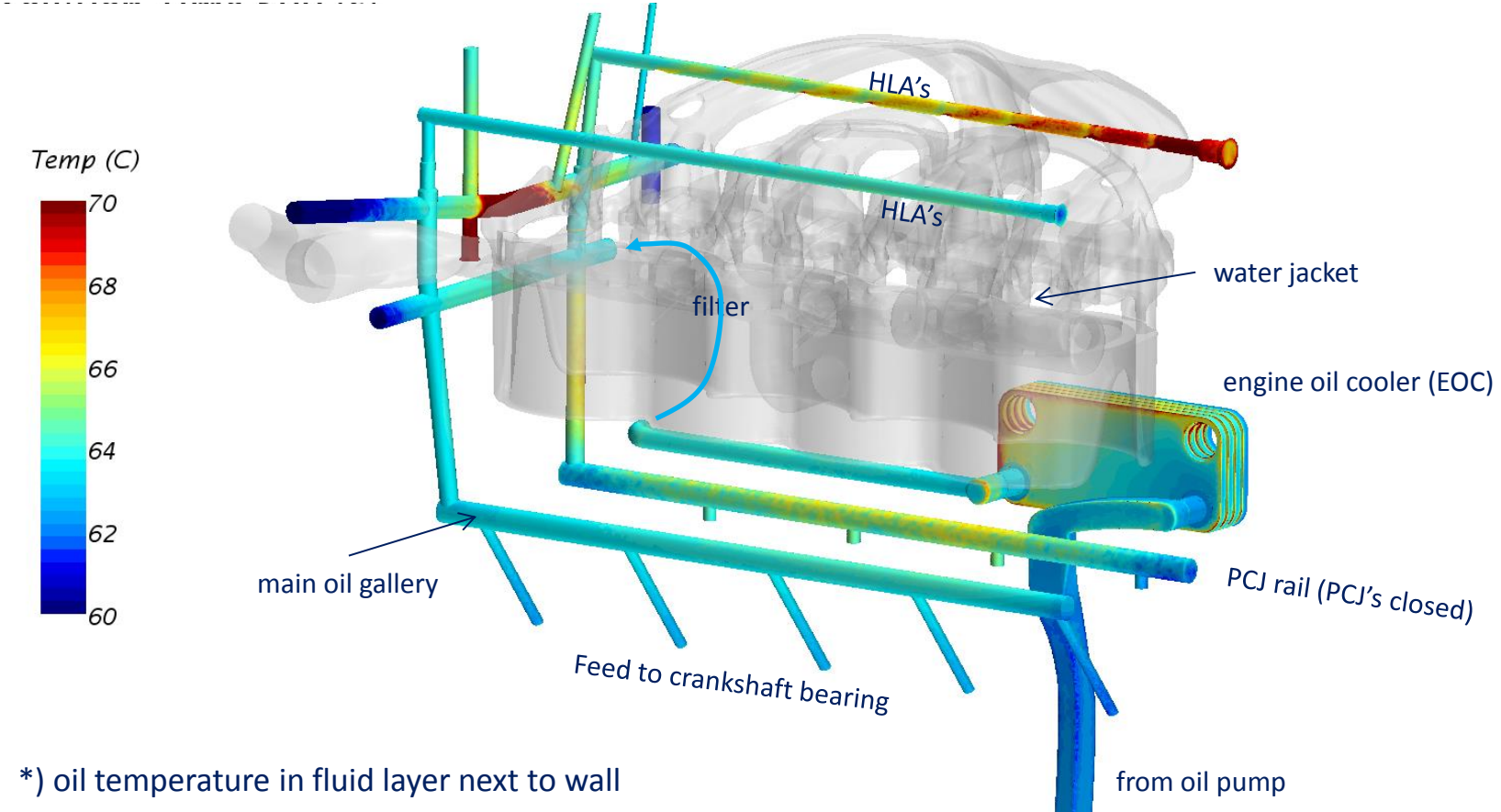
Engine Warm-up Prediction for Fuel Economy

Oil Temperature*) after 500 Seconds Warm-UP



*) oil temperature in fluid layer next to wall

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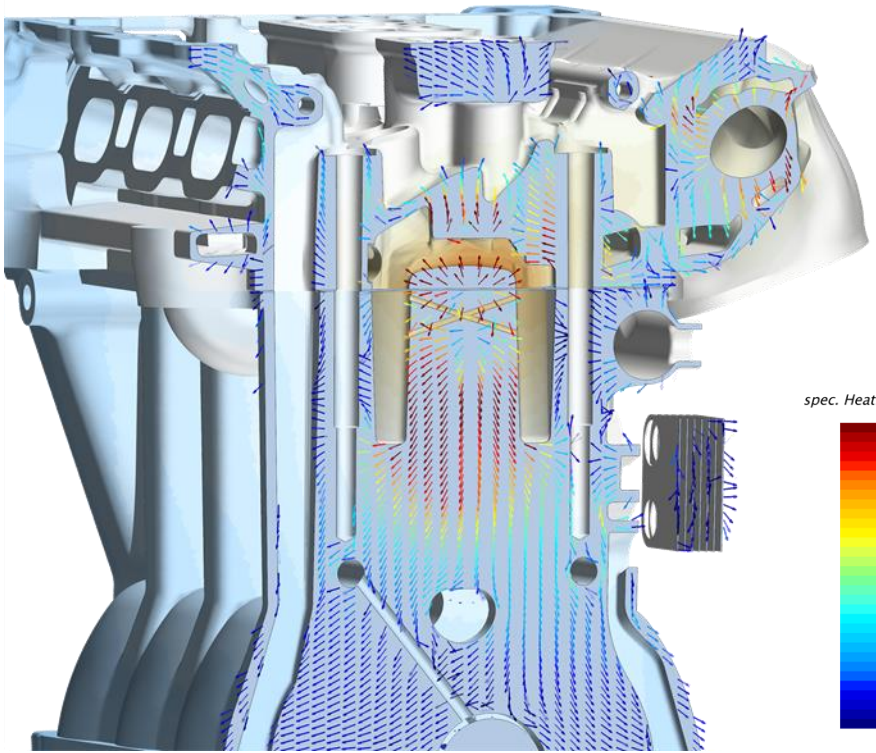
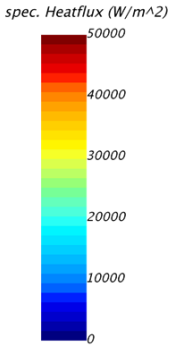
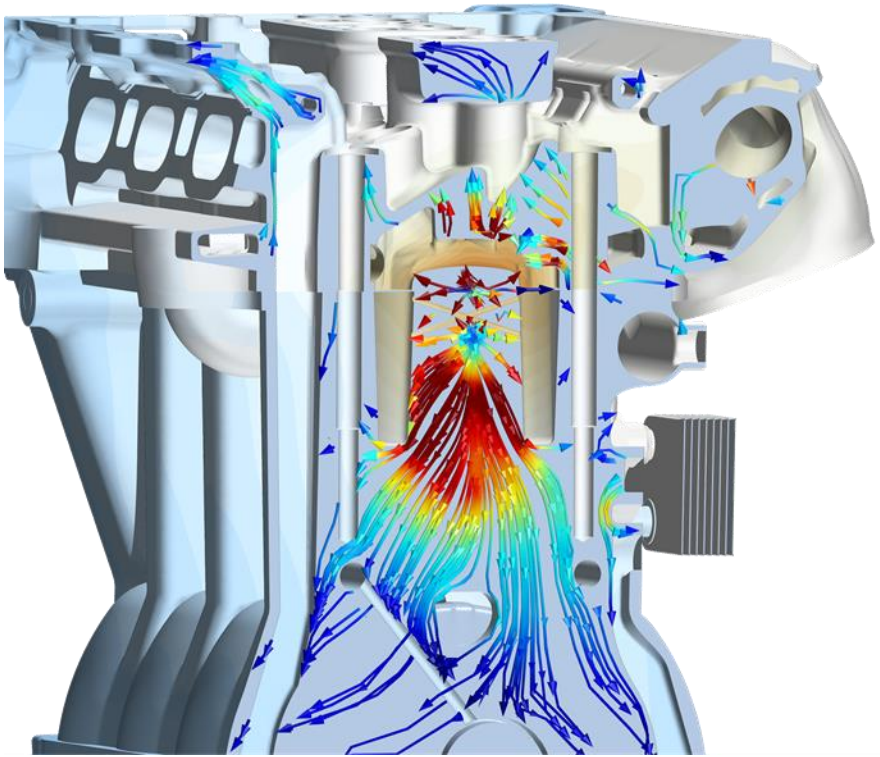
Engine Warm-up Prediction for Fuel Economy

Heat Flux Analysis for Engine Structure (after 500 sec)

section cut between cylinder 3 and 4







vector representation

streamline representation

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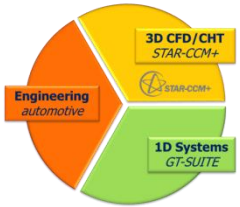
Engine Warm-up Prediction for Fuel Economy
Summary

1D/3D Co-Simulation Approach enables us to …

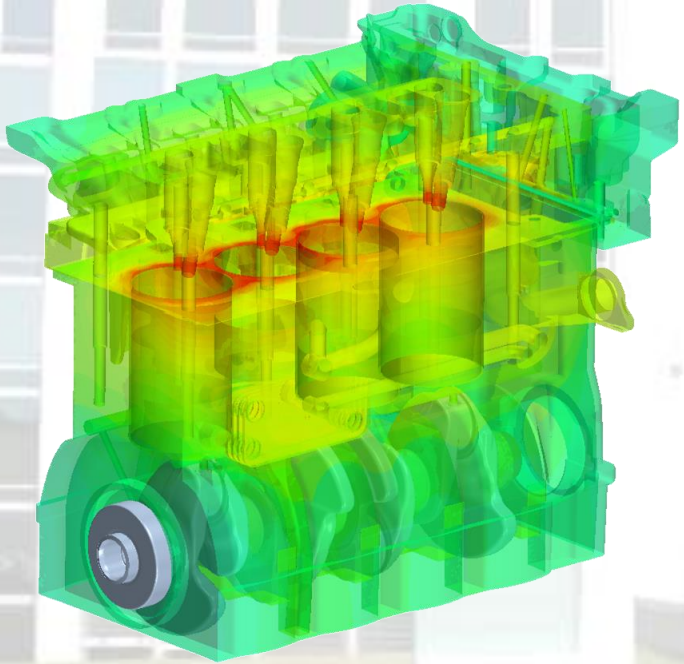


- simulate engine warm-up for FE drive cycles more accurately
- investigate local heat transfer phenomena
- develop engines with advanced Thermal Management Technologies (TMT) and control strategies

InDesA's Virtual IC Engine with advanced TMT's

- Triple-Split-Cooling (block, head, water cooled exhaust manifold)
- Integrated Thermal Management Module with
  - ✓ Pump shut-off functionality
  - ✓ Control of triple-split-cooling
  - ✓ Oil heating/cooling functionality

Thank you for your attention!



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