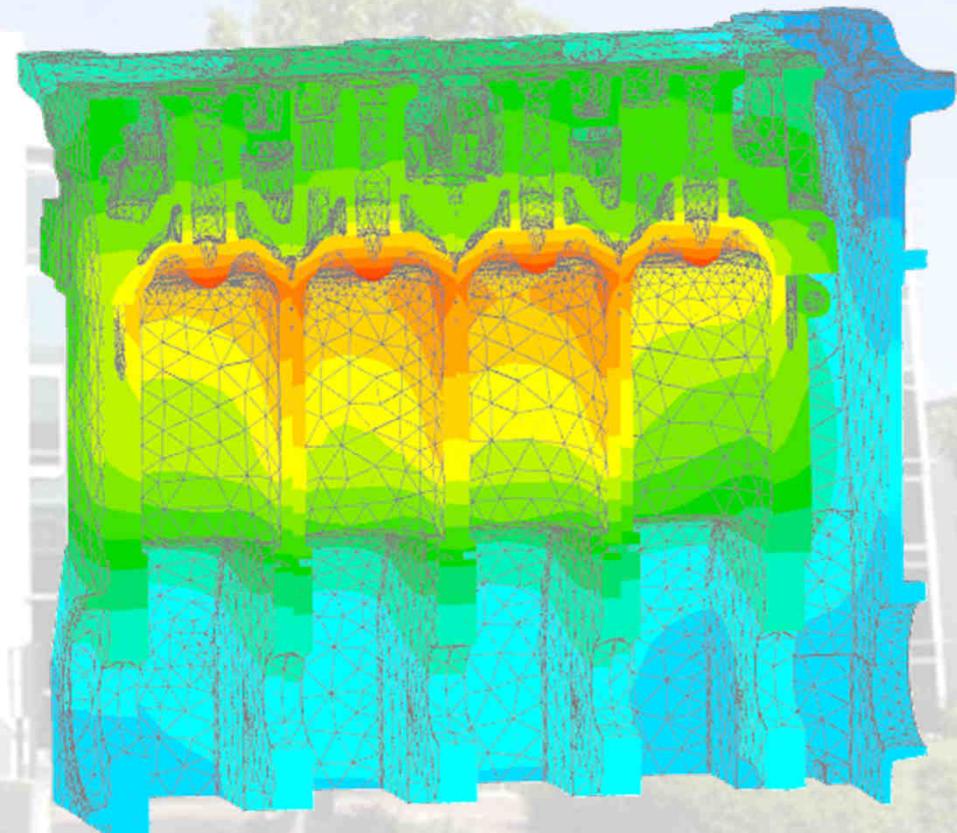


Prediction of Engine Warm-up and Fuel Economy utilizing GT's Customized FE Cylinder Structure Objects

Uliana Bryakina
Gerald Seider

Frankfurt, October 16, 2016



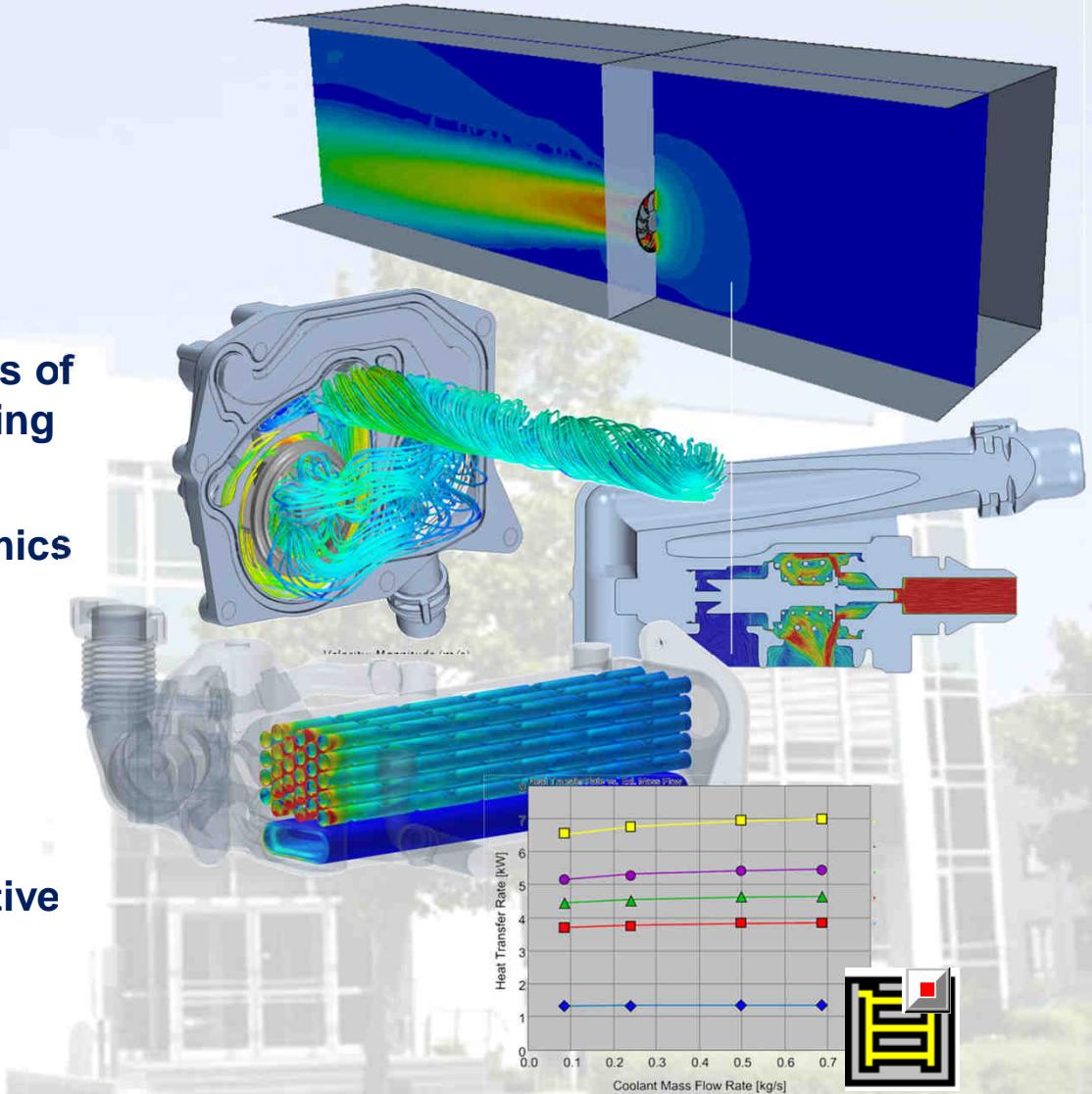
Consulting, Engineering Services & Virtual Bench Testing

- 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



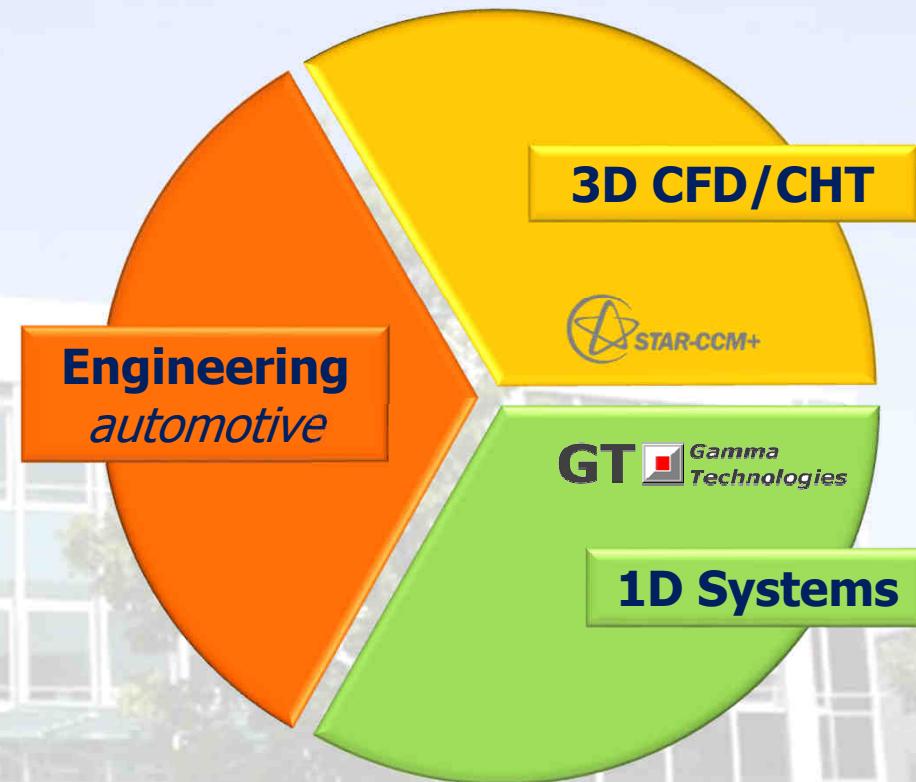
Consulting, Engineering Services & Virtual Bench Testing

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 - air-borne acoustics, sound design
- Virtual Performance and Functional Testing for automotive accessory units



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 - air-borne acoustics, sound design
- Virtual Performance and Functional Testing for automotive accessory units
- Virtual Heat Rejection Testing of combustion engines



Customized FE Cylinder Structure Objects

Presentation Overview

E

Engineering:

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

1D

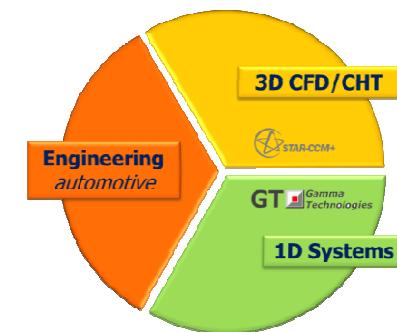
1D System Simulation:

- InDesA's state-of-the-art approach to simulate engine structure temperatures for the prediction of fuel economy (NEDC, WLTP).
- Customized FE Cylinder Structure Objects.

3D

1D Model Calibration and Comparison with 3D CFD/CHT:

1D Customized FE Cylinder model is calibrated and bench marked with 3D CFD/CHT warm-up simulation of the core IC engine.

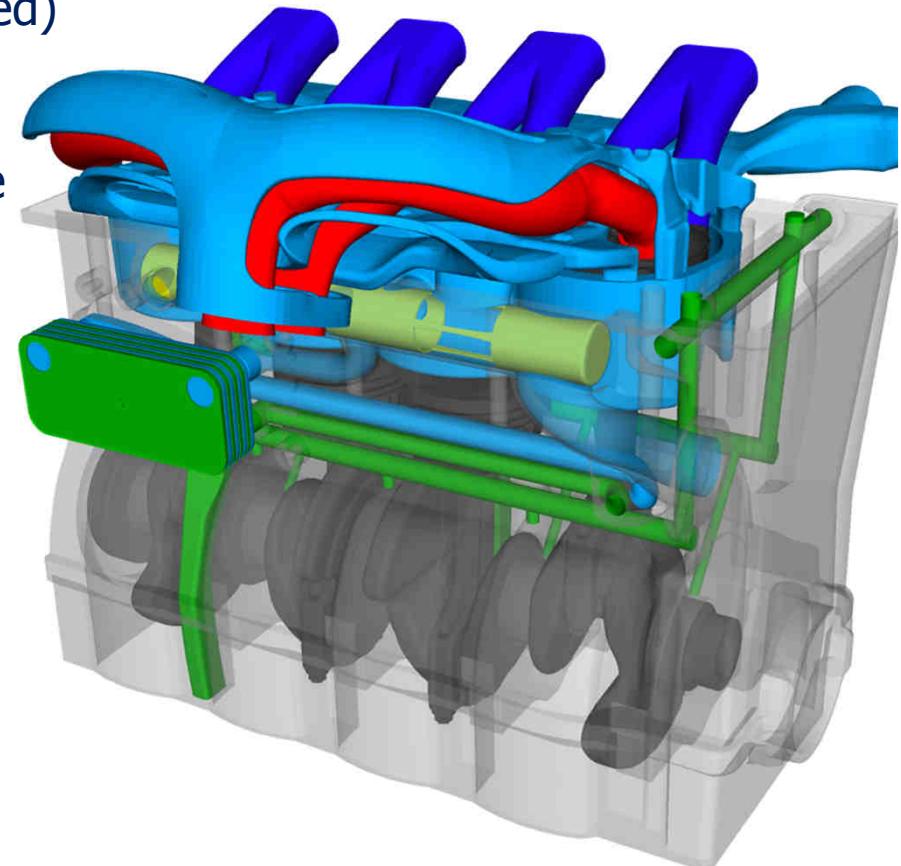


Customized FE Cylinder Structure Objects InDesA's Virtual Internal Combustion Engine

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.



Customized FE Cylinder Structure Objects

InDesA's Virtual Internal Combustion Engine

Warm-up control phases:

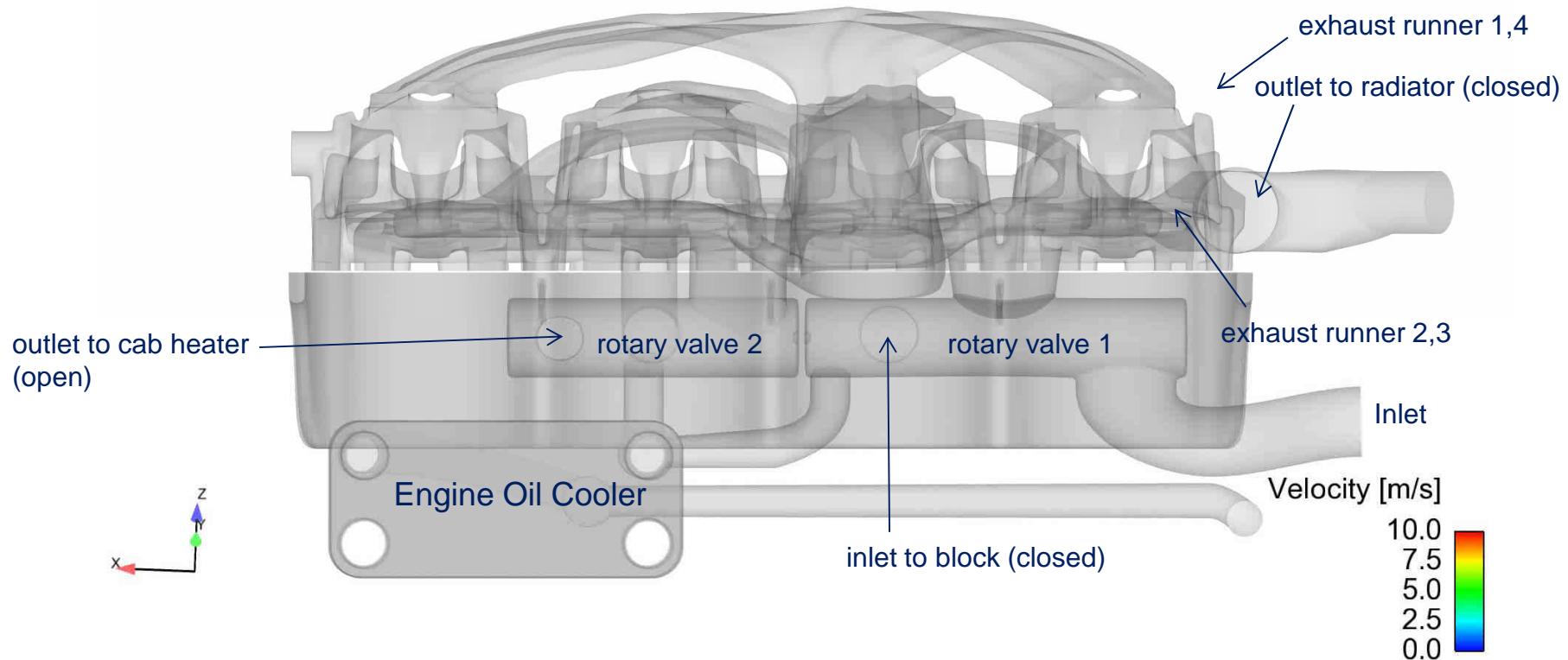
I water pump shut off

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

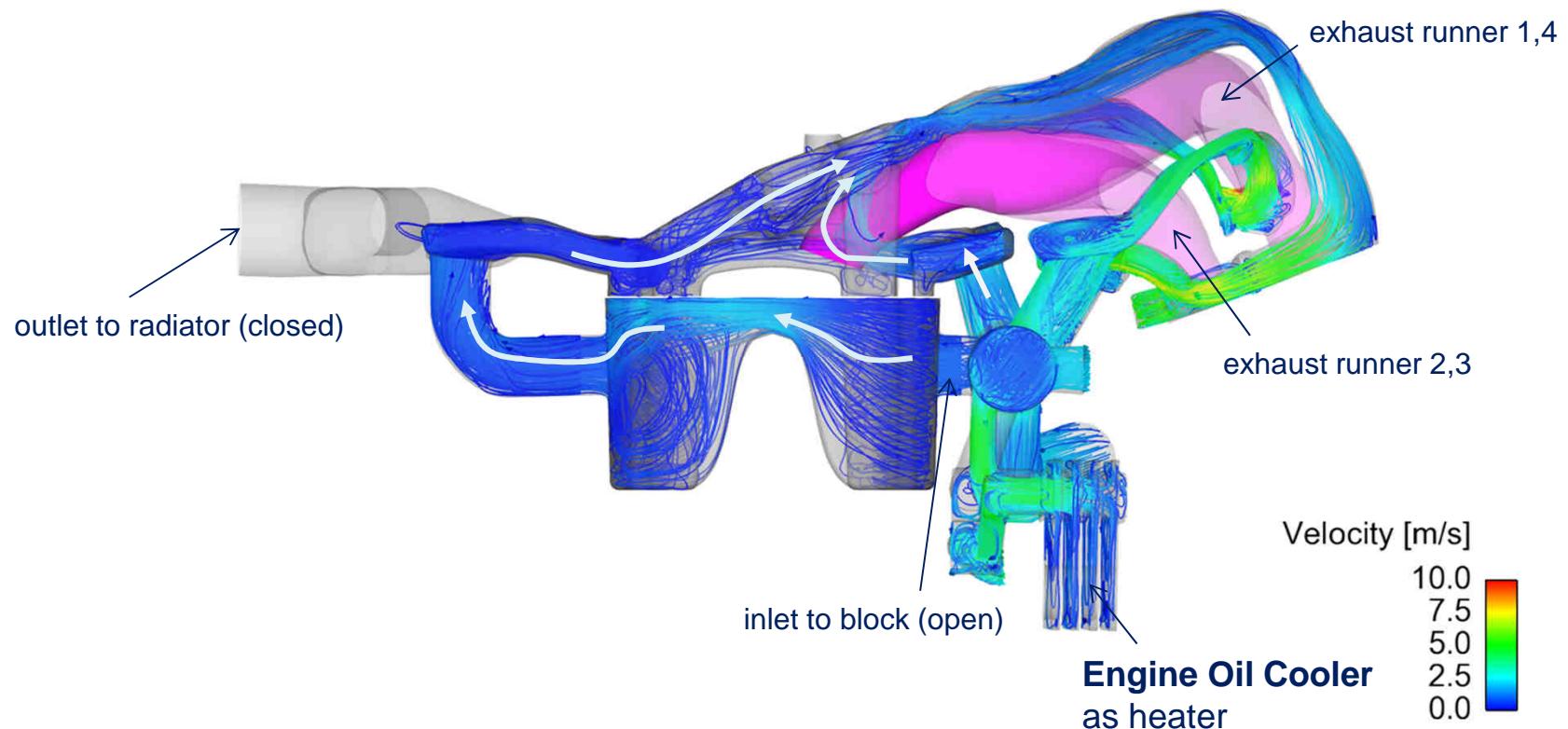


Customized FE Cylinder Structure Objects

1D System Simulation of Engine Warm-Up

Warm-up control phases:

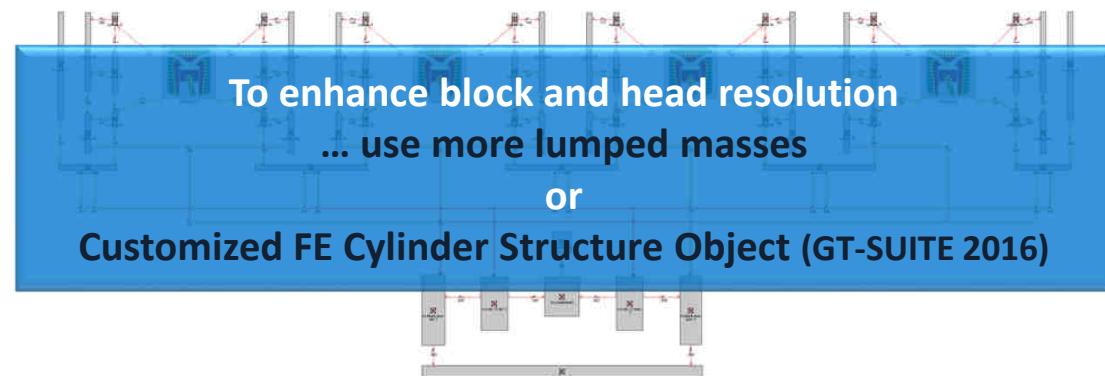
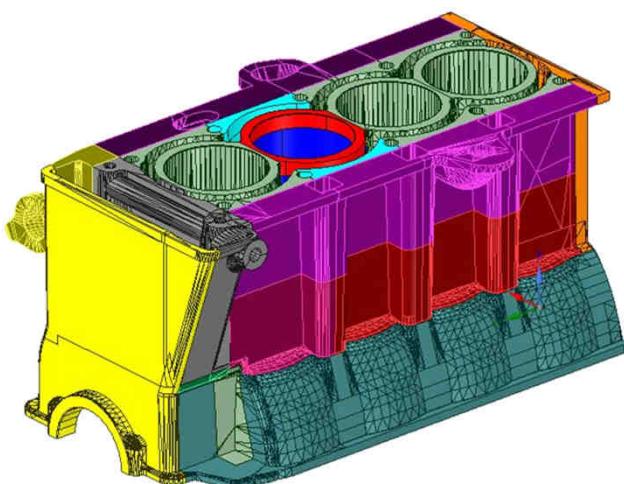
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- IV cooling of water; opening of thermostat
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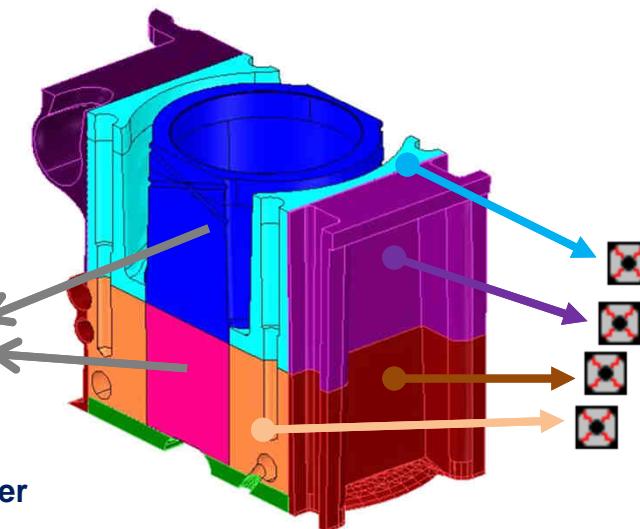
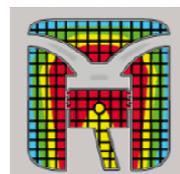
Customized FE Cylinder Structure Objects

1D System Simulation of Engine Warm-Up

Conventional Approach : Split of Engine Block to Convert to Lumped Masses



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



- coolant
- oil
- ambient

Customized FE Cylinder Structure Objects

Case Study for Engine Structure Modelling

Case Study	Inner Engine Structure	Outer Engine Structure	Coolant & Oil	SW Tool	Coolant & Oil Circuit
1D Conventional	Generic FE	Lumped Masses	1D	GT-SUITE	1D integrated
1D Customized	Customized FE	Customized FE	1D	GT-SUITE v2016	1D integrated
3D CFD/CHT	FE	FE	3D	Star-CCM+	1D bound. cond.

Use case:

- Transient Warmup over **600 seconds** with constant engine operation at **2000 rpm** and **2 bar IMEP**.
- Starting temperature for structure, coolant and oil: **25 °C**
- Coolant and Oil volume flow rate & temperature for 3D CFD/CHT at engine inlet is derived from 1D coolant and oil circuit simulation.

Customized FE Cylinder Structure Objects

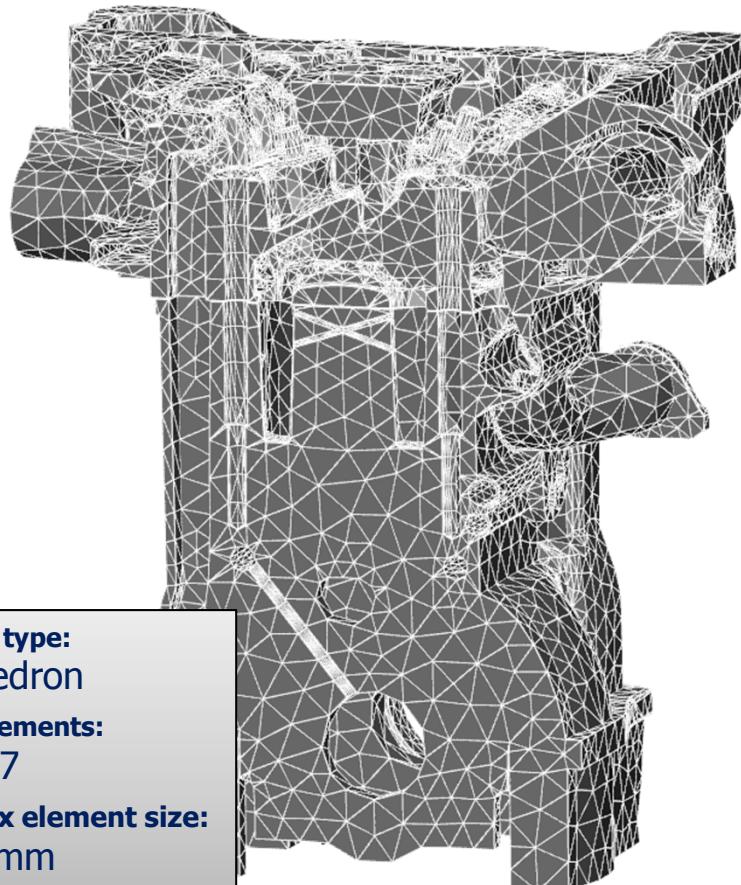
3D Mesh Generation



Customized FE v2016



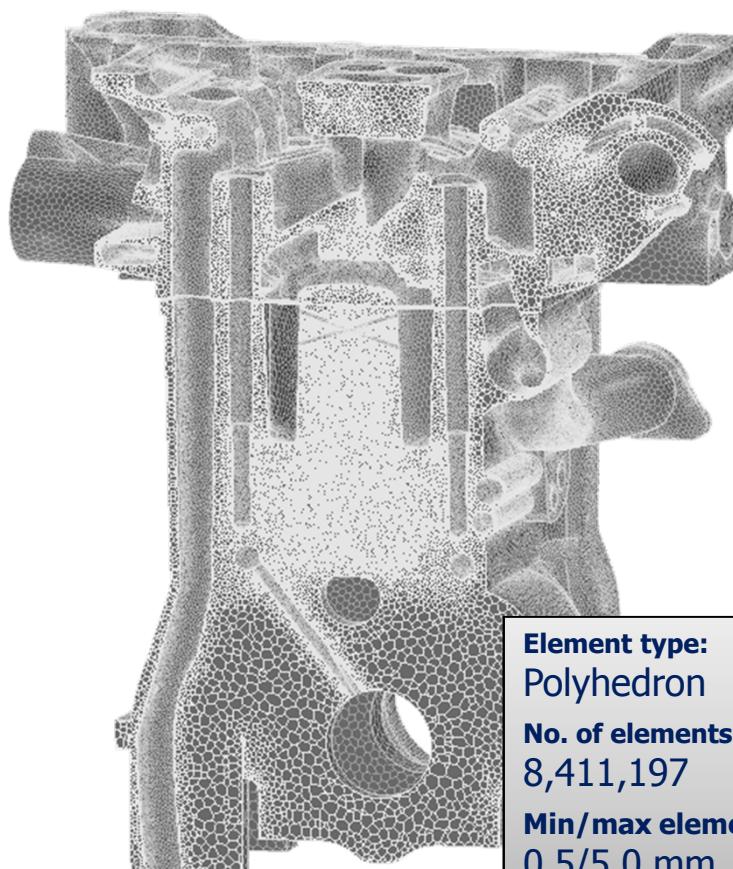
3D CFD/CHT



Element type:
Tetrahedron

No. of elements:
506,047

Min/max element size:
10/20 mm



Element type:
Polyhedron

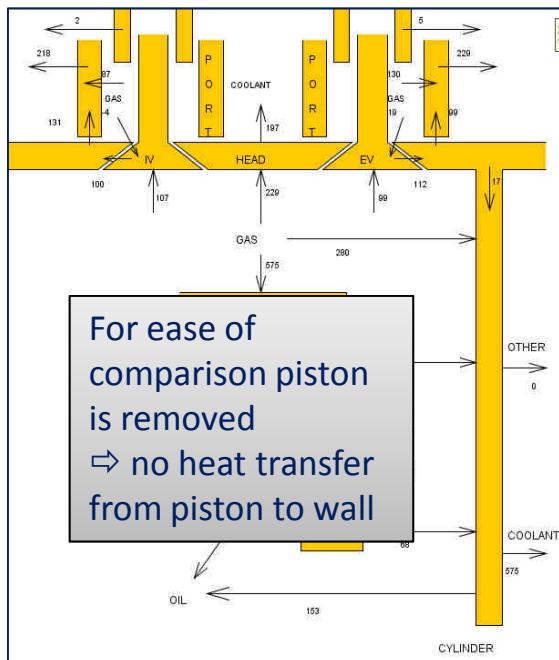
No. of elements:
8,411,197

Min/max element size:
0.5/5.0 mm

Customized FE Cylinder Structure Objects

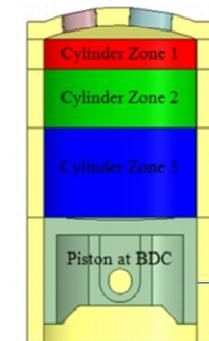
Deriving BC's for Combustion Chamber

GT-POWER heat transfer analysis



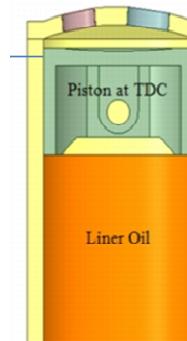
Gas temperatures and HTC's for
GT Customized FE model and
STAR-CCM+ model
are identical.

Gas Temperature Zones

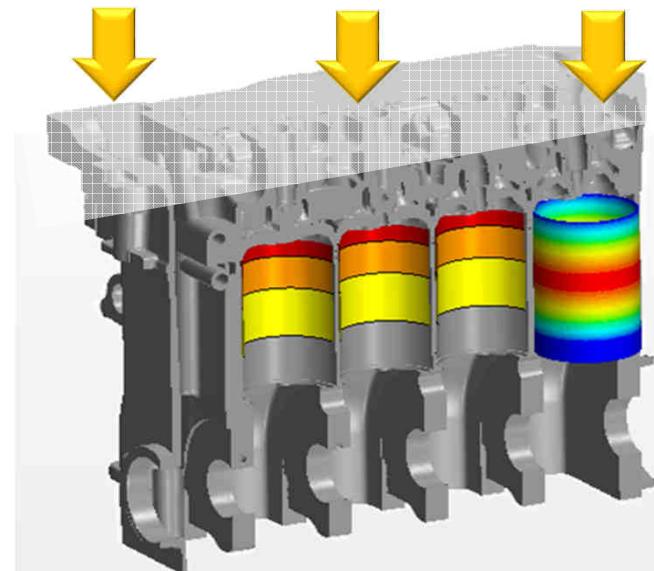


T_{gas} and HTC_{gas}

Cylinder Oil Zone



T_{oil} and HTC_{oil}



Customized FE v2016

3D CFD/CHT

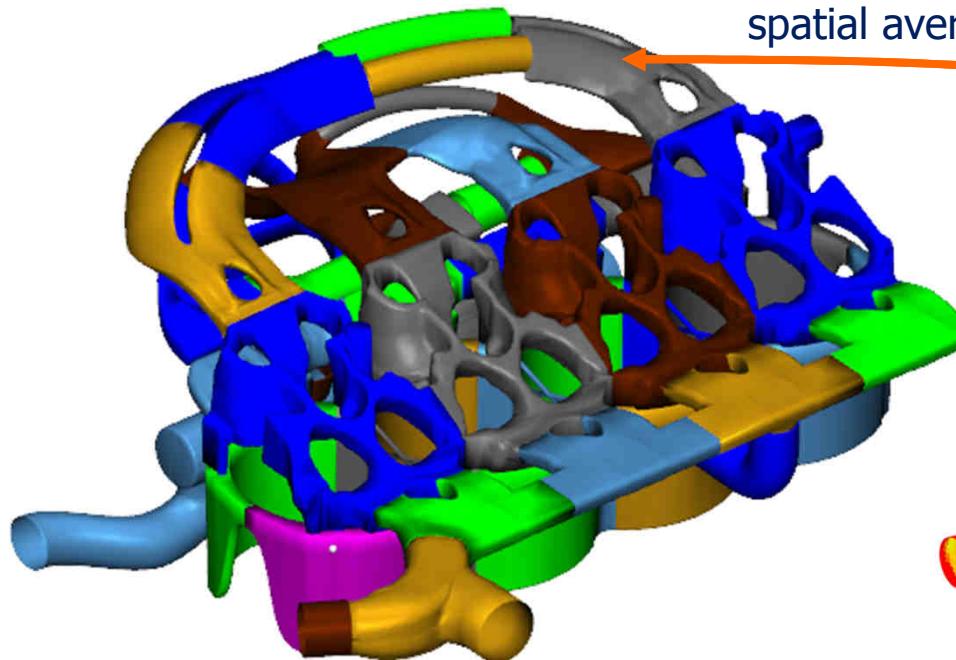
Customized FE Cylinder Structure Objects

Deriving BC's for Coolant Water Jacket



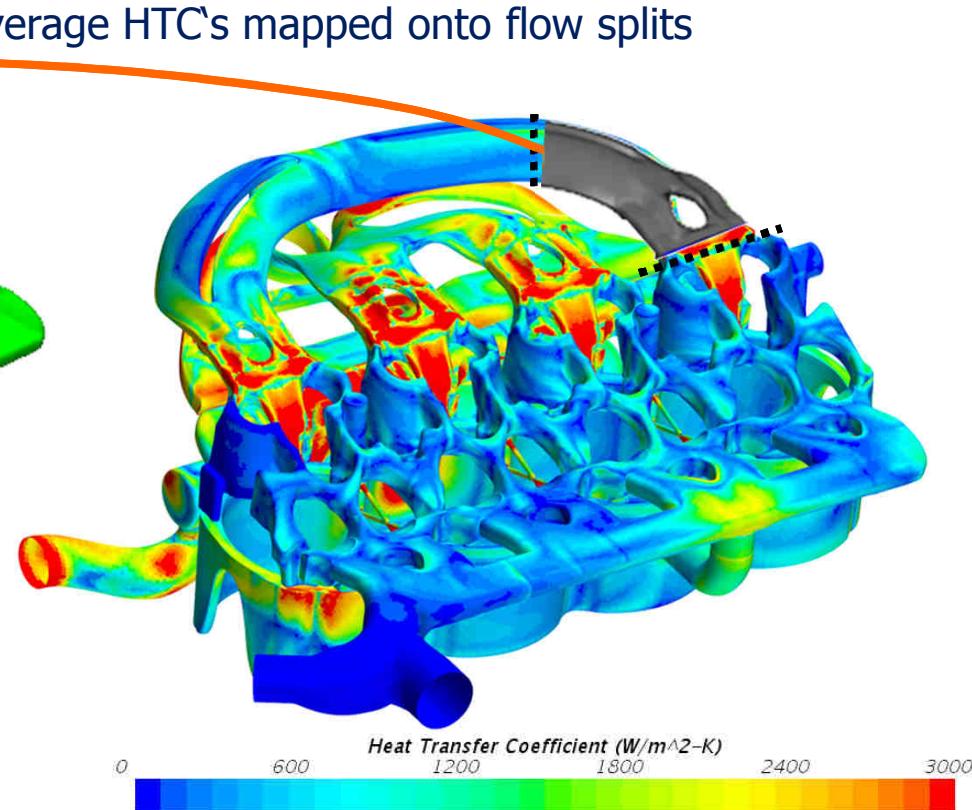
Customized FE v2016

- Water jacket split into segments with GEM3D
- Each segment represented by a flow split



3D CFD/CHT

- Local flow field and heat transfer coefficients (HTC's) available



- Pressure drop and flow distribution calibrated with respect to 3D CFD

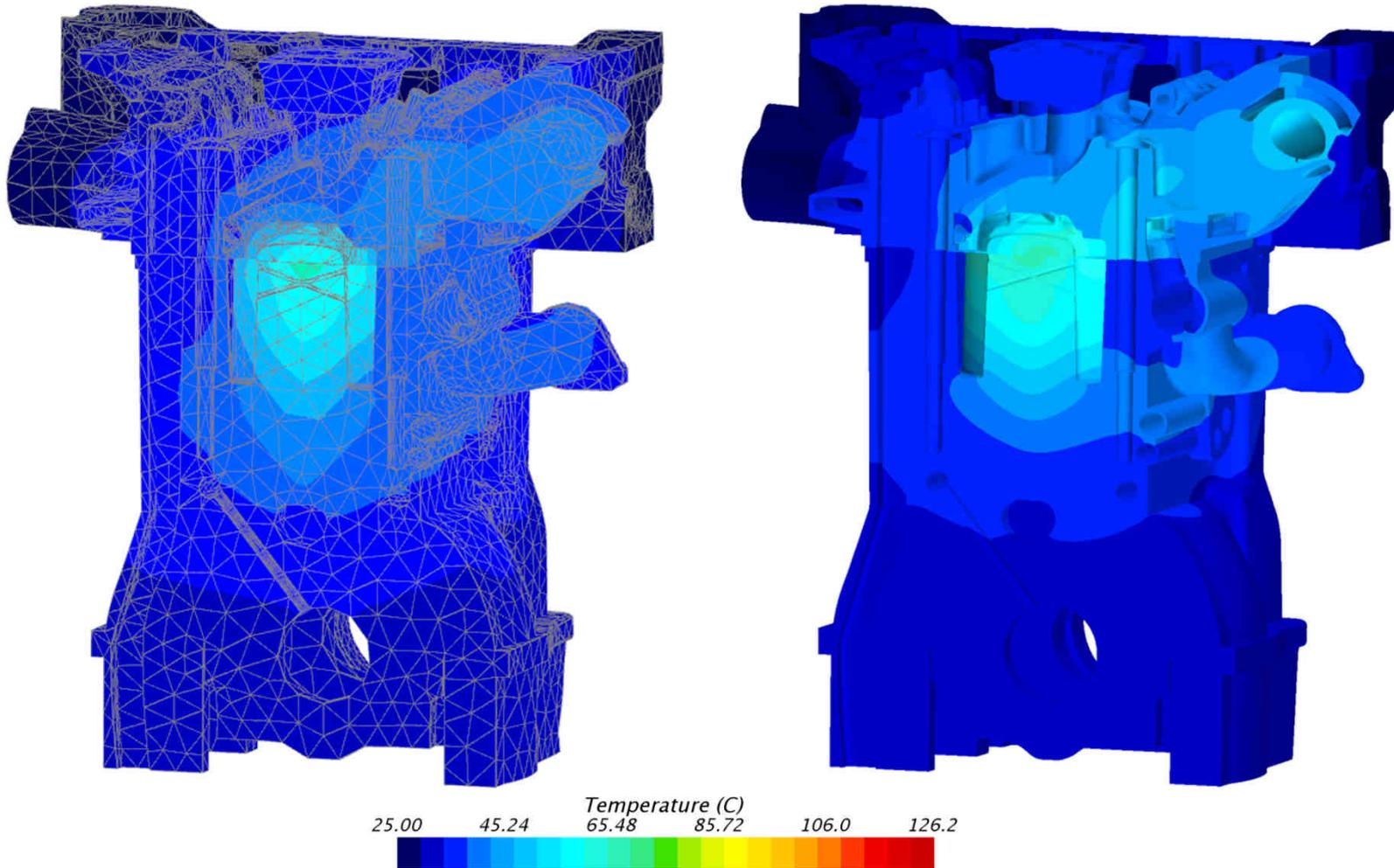
Customized FE Cylinder Structure Objects Engine Structure Temperature after 100 sec



Customized FE v2016



3D CFD/CHT



Customized FE Cylinder Structure Objects

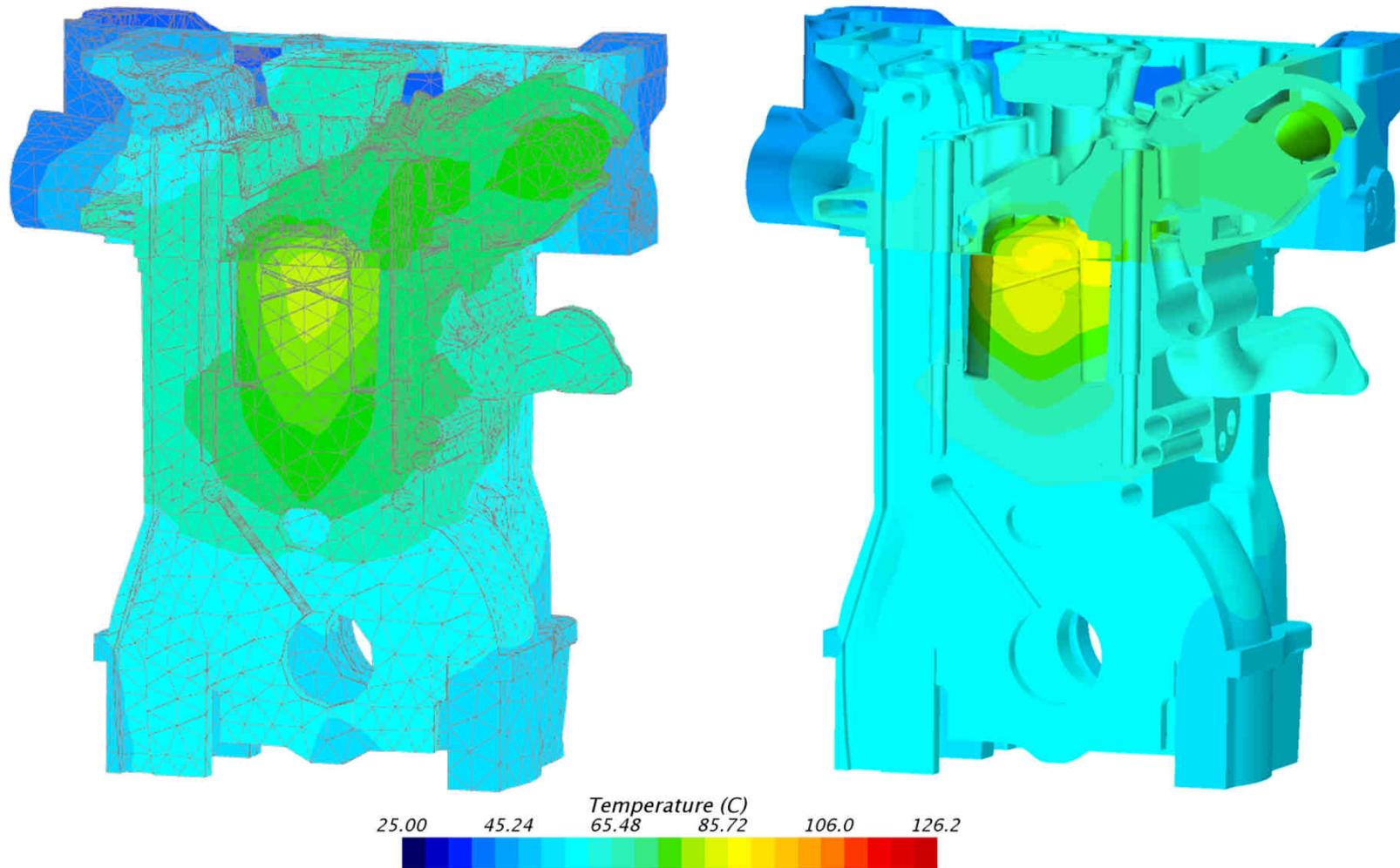
Engine Structure Temperature after 300 sec



Customized FE v2016



3D CFD/CHT



Customized FE Cylinder Structure Objects

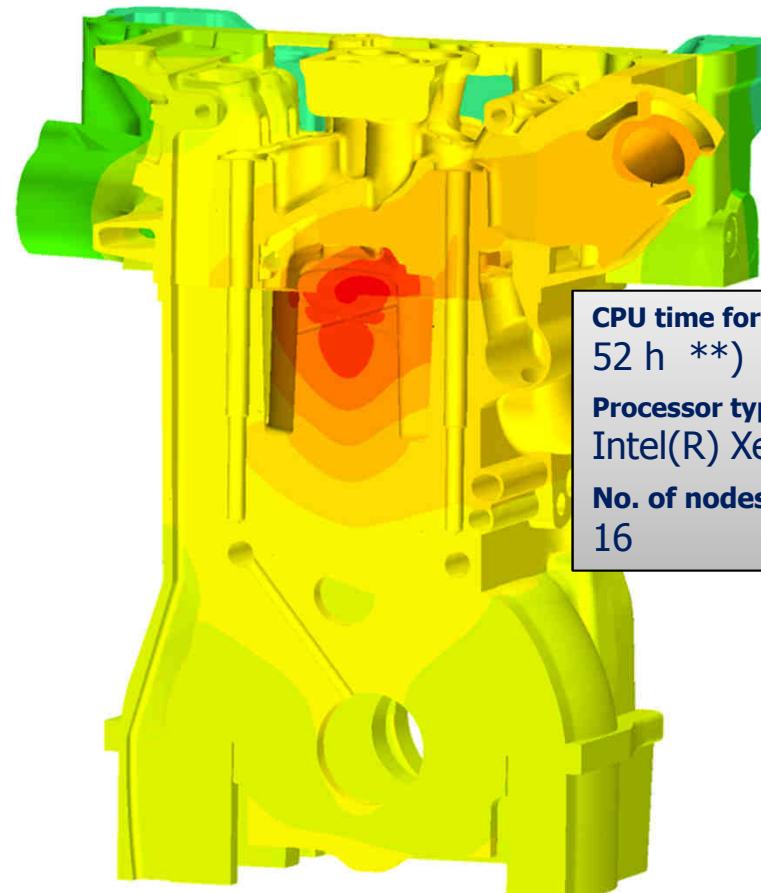
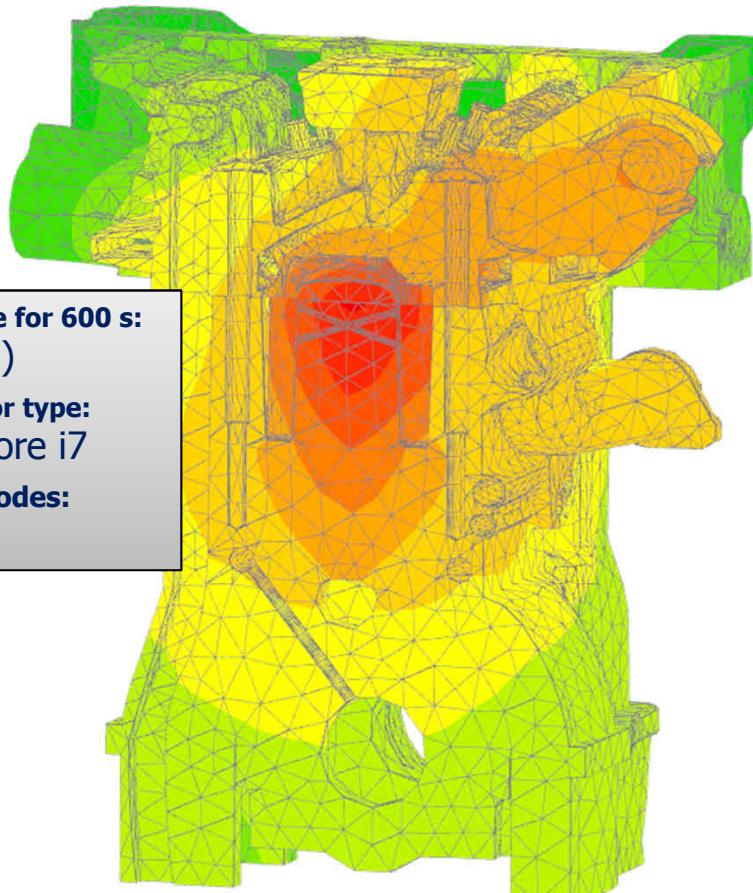
Engine Structure Temperature after 600 sec



Customized FE v2016



3D CFD/CHT



*) complete warm-up model

**) CFD/CHT head and block

Customized FE Cylinder Structure Objects

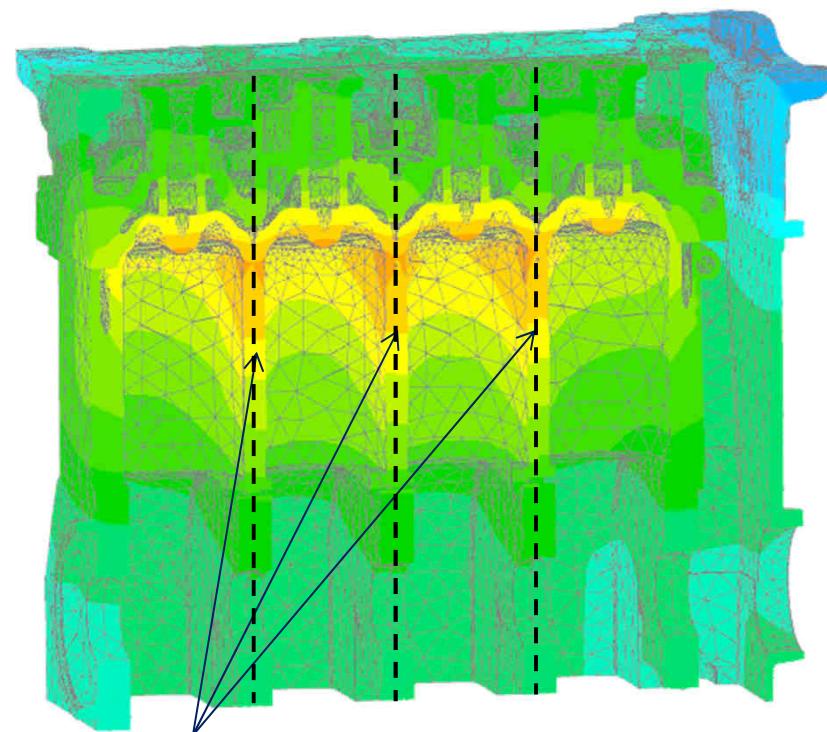
Engine Structure Temperature after 400 sec



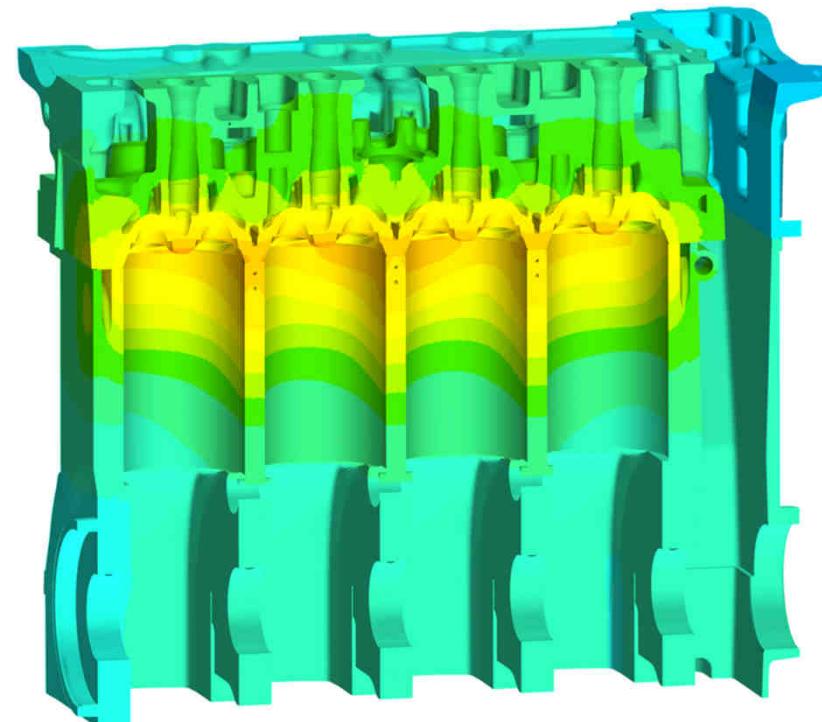
Customized FE v2016



3D CFD/CHT

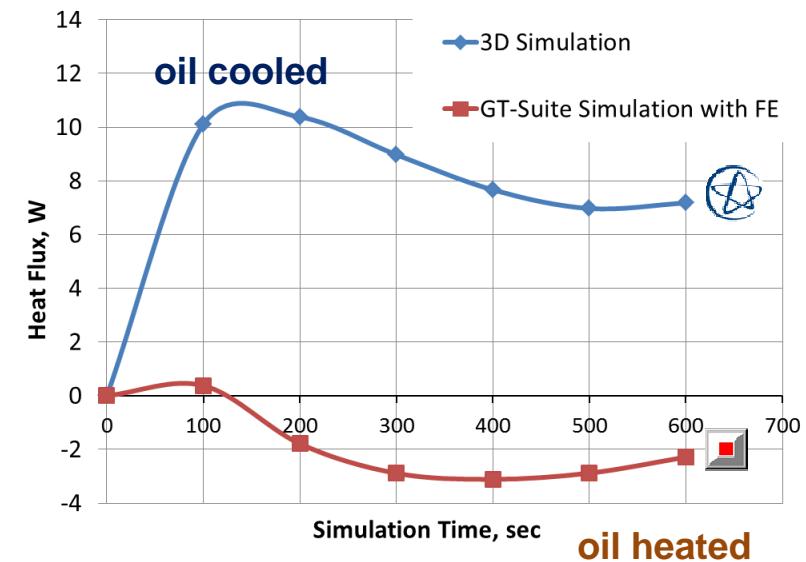
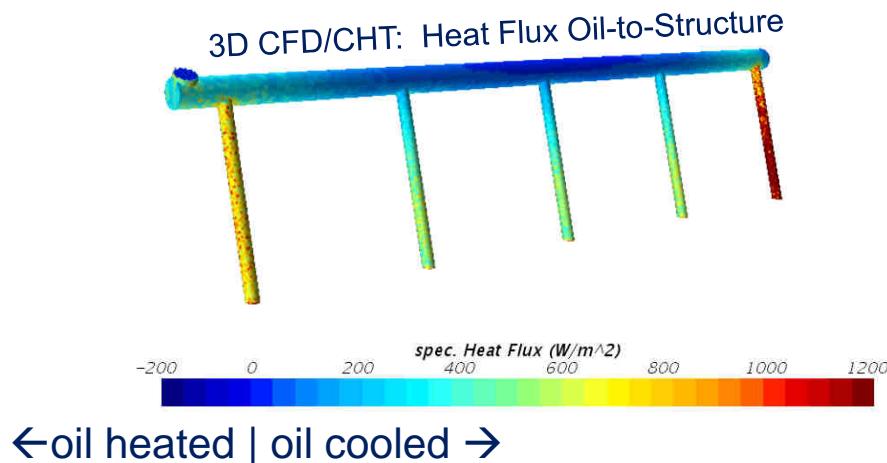


Cylinder segments w/o
thermal connection at
interface to keep size of
solution matrix small



Customized FE Cylinder Structure Objects Heat Flux for Main Oil Gallery with MB Feed

During engine warm-up oil is heated through engine oil cooler before entering the engine, but can be cooled down by the colder engine structure in the main oil gallery and main bearing feeds.



Differences are not significant for Fuel Economy prediction.

Customized FE Cylinder Structure Objects

Comparison Customized FE vs. Full CFD/CHT

Good overall agreement !

... for the purpose of fuel economy prediction for warm-up drive cycles.

Local differences in temperature are mainly due to different treatment of engine coolant jacket.

- ⌚ 3D CFD/CHT treats coolant flow as 3D (Navier-Stokes-Eq.) with cell-to-cell connection to solid ⇒ **high** resolution for fluid and solid

- ▣ GT-SUITE Customized FE treats coolant as 1D, with average HTC's calibrated with respect to 3D CFD/CHT solution (↳ see page 12).
 - ⇒ **mid** resolution for solid
 - ⇒ **low** resolution for coolant

Customized FE Cylinder Structure Objects

Conclusion

v2016 Customized FE Cylinder Structure Objects

- ⇒ Significant step towards higher accuracy engine warm-up model.
- ⇒ Faster model built compared to lumped mass approach.
- ⇒ Reasonable run times for typical fuel consumption drive cycle analysis.

Standard engine thermal analysis can be extended to ...

- ⇒ warm-up and cool-down simulation with internal and external thermal encapsulation.
- ⇒ more complicated engine geometries, e.g. with integrated exhaust manifold.

Thank you for your attention!

