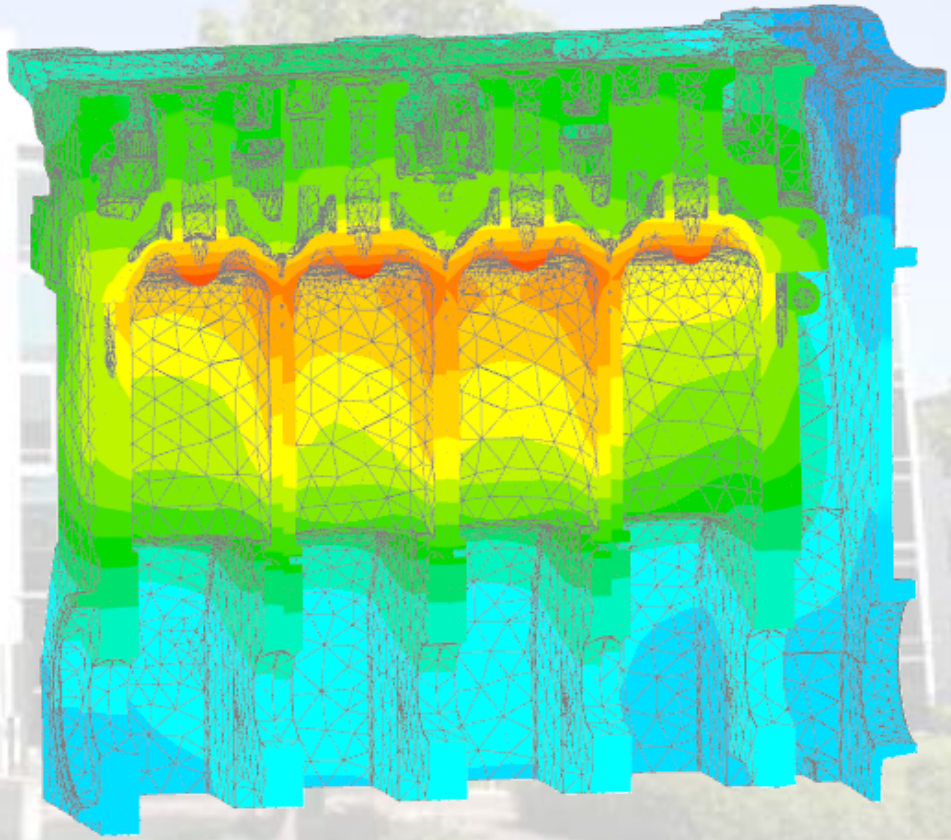
Prediction of Engine Warm-up and Fuel Economy utilizing GT's Customized FE Cylinder Structure Objects

Uliana Bryakina
Gerald Seider

Frankfurt, October 16, 2016



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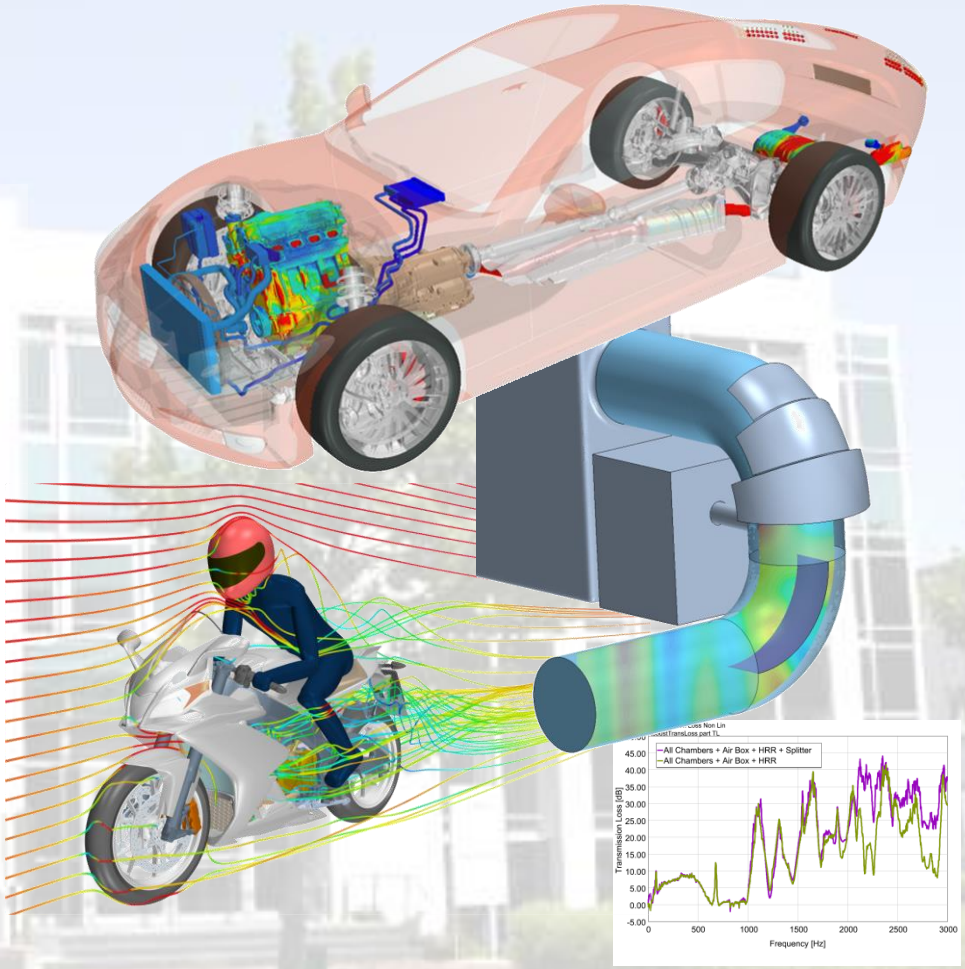
  - heat transfer, thermal management
  - air-borne acoustics, sound design



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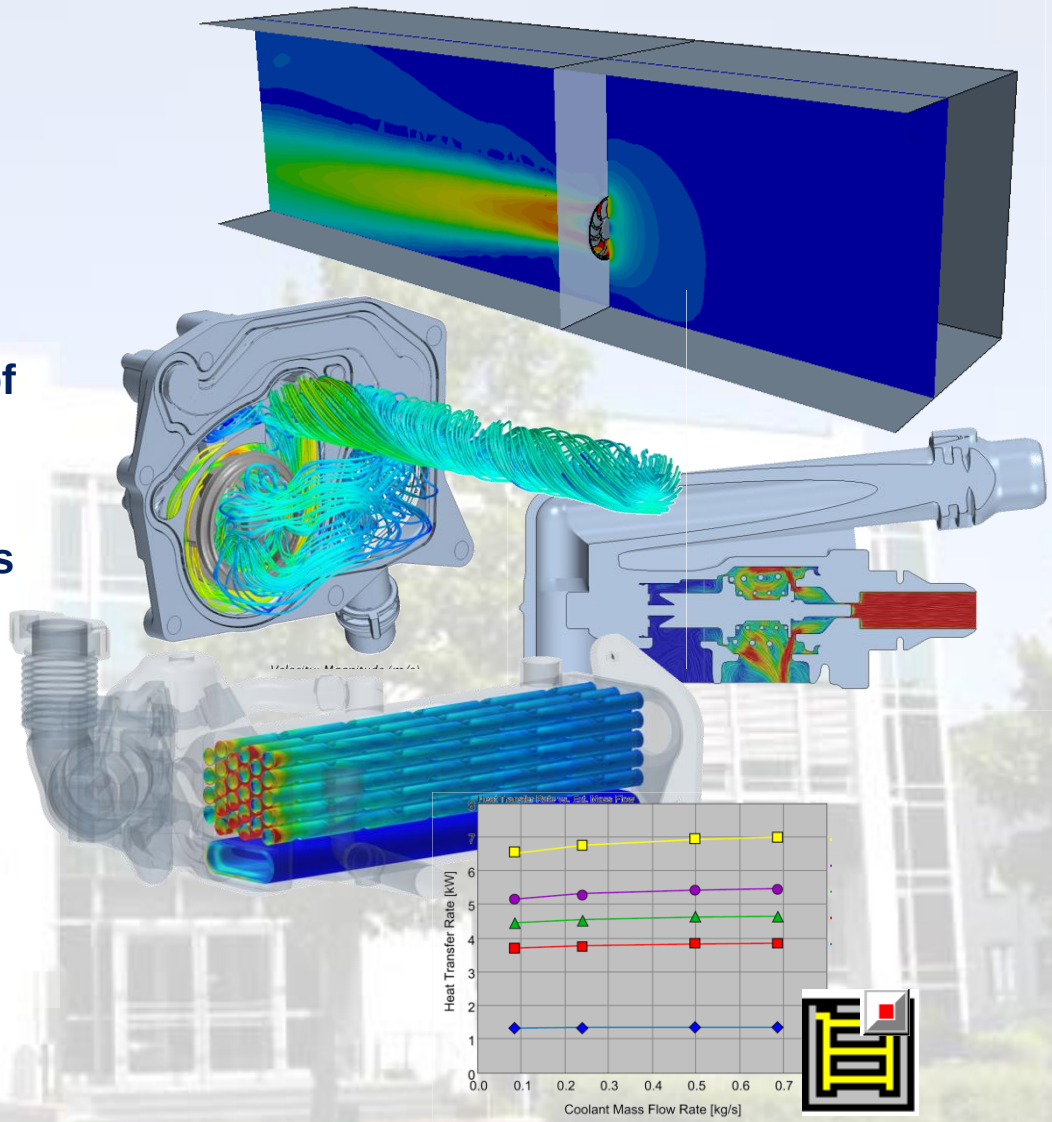
- Virtual Performance and Functional Testing for automotive accessory units



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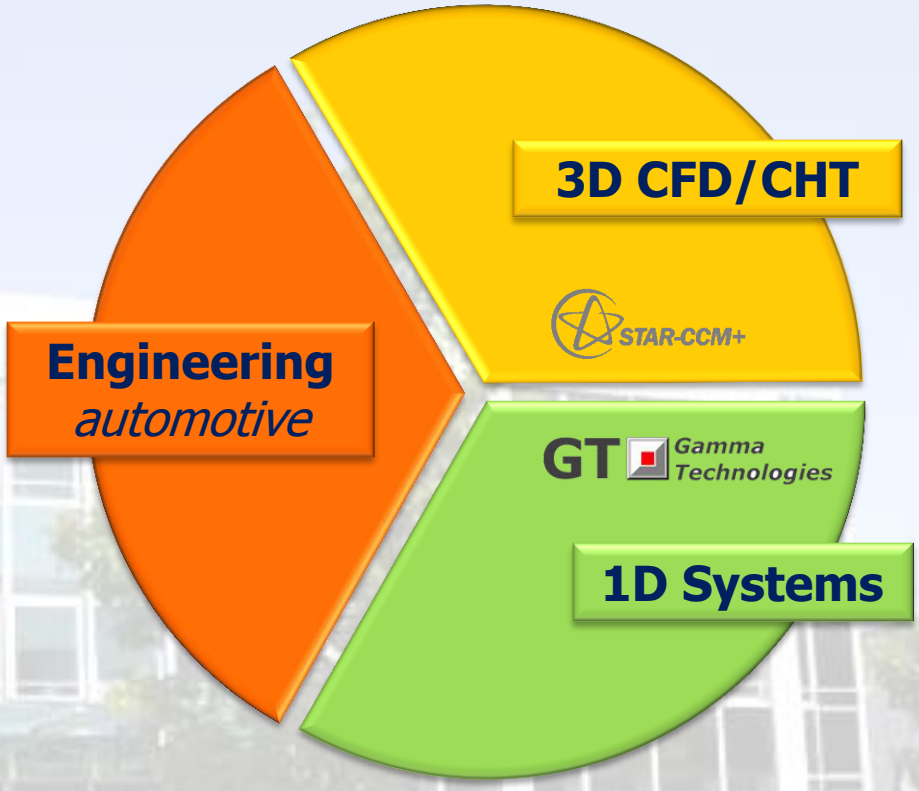
- Virtual Heat Rejection Testing of combustion engines



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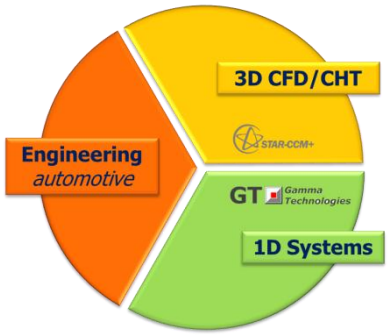
Customized FE Cylinder Structure Objects
Presentation Overview

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.

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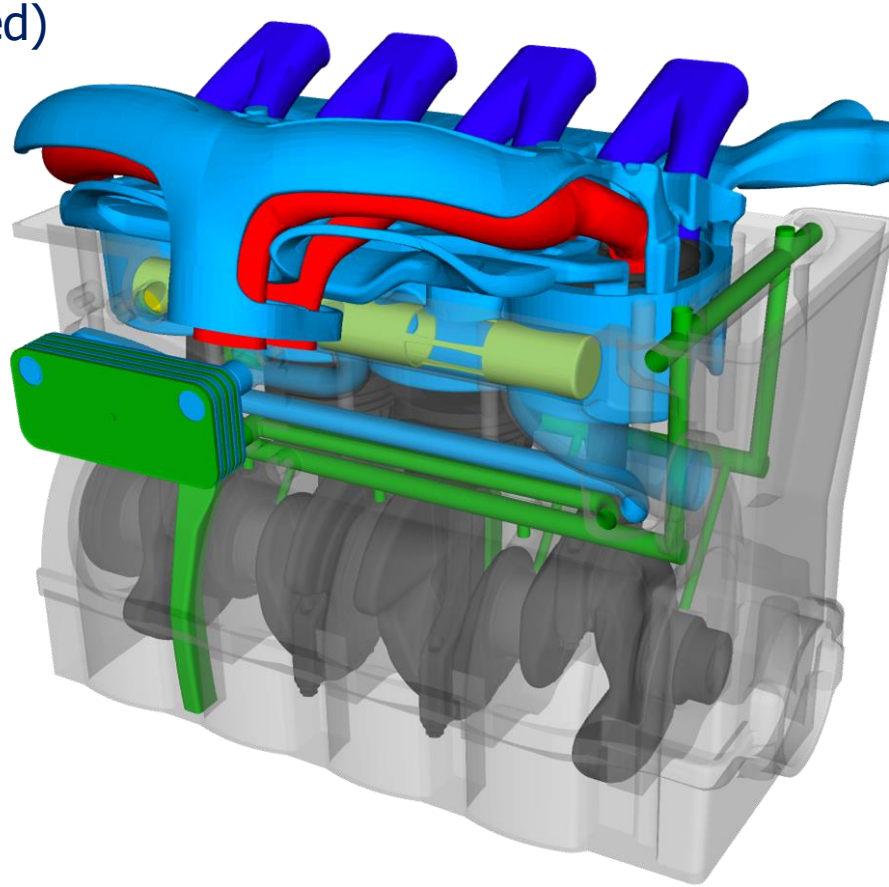
Customized FE Cylinder Structure Objects
InDesA's Virtual Internal Combustion Engine

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.



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

Warm-up control phases:

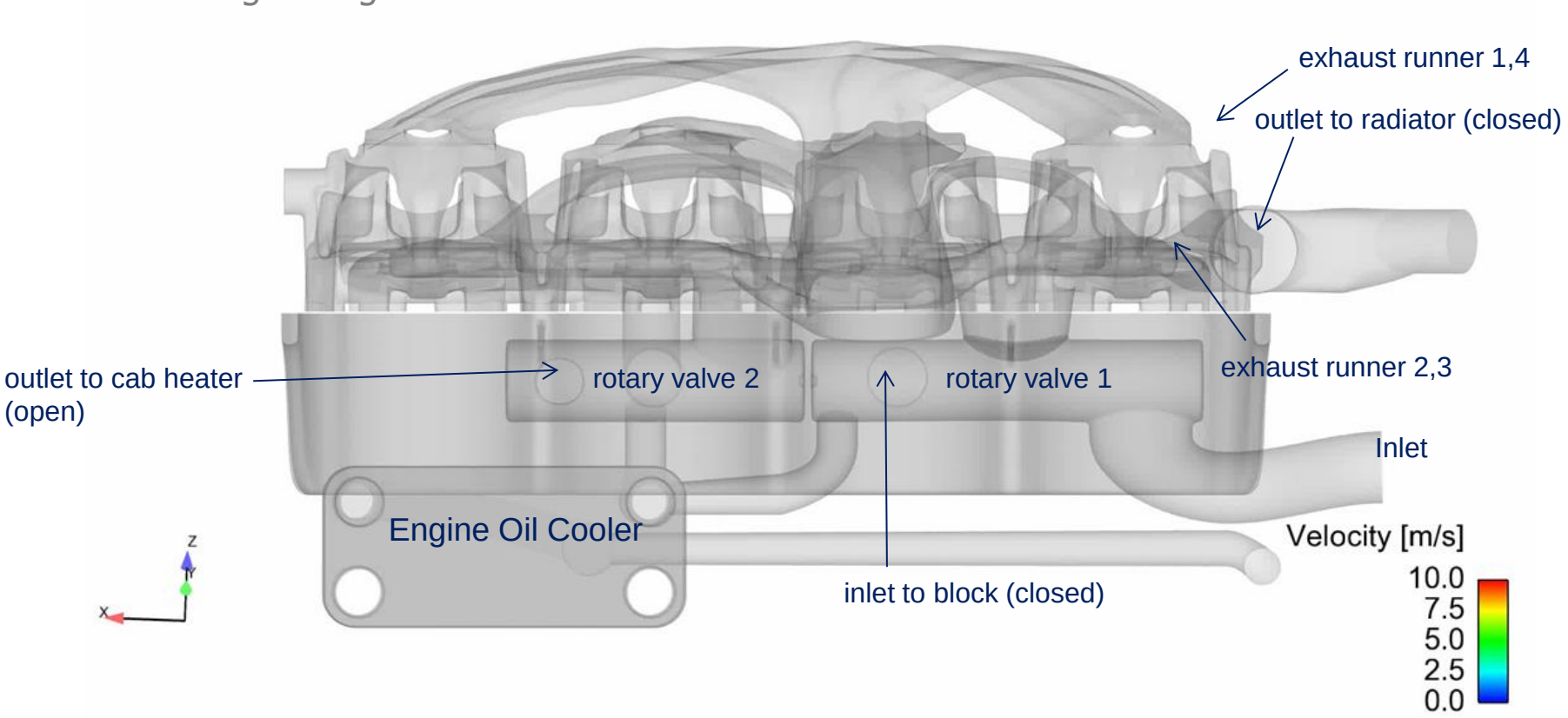
I water pump shut off

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



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Customized FE Cylinder Structure Objects
1D System Simulation of Engine Warm-Up

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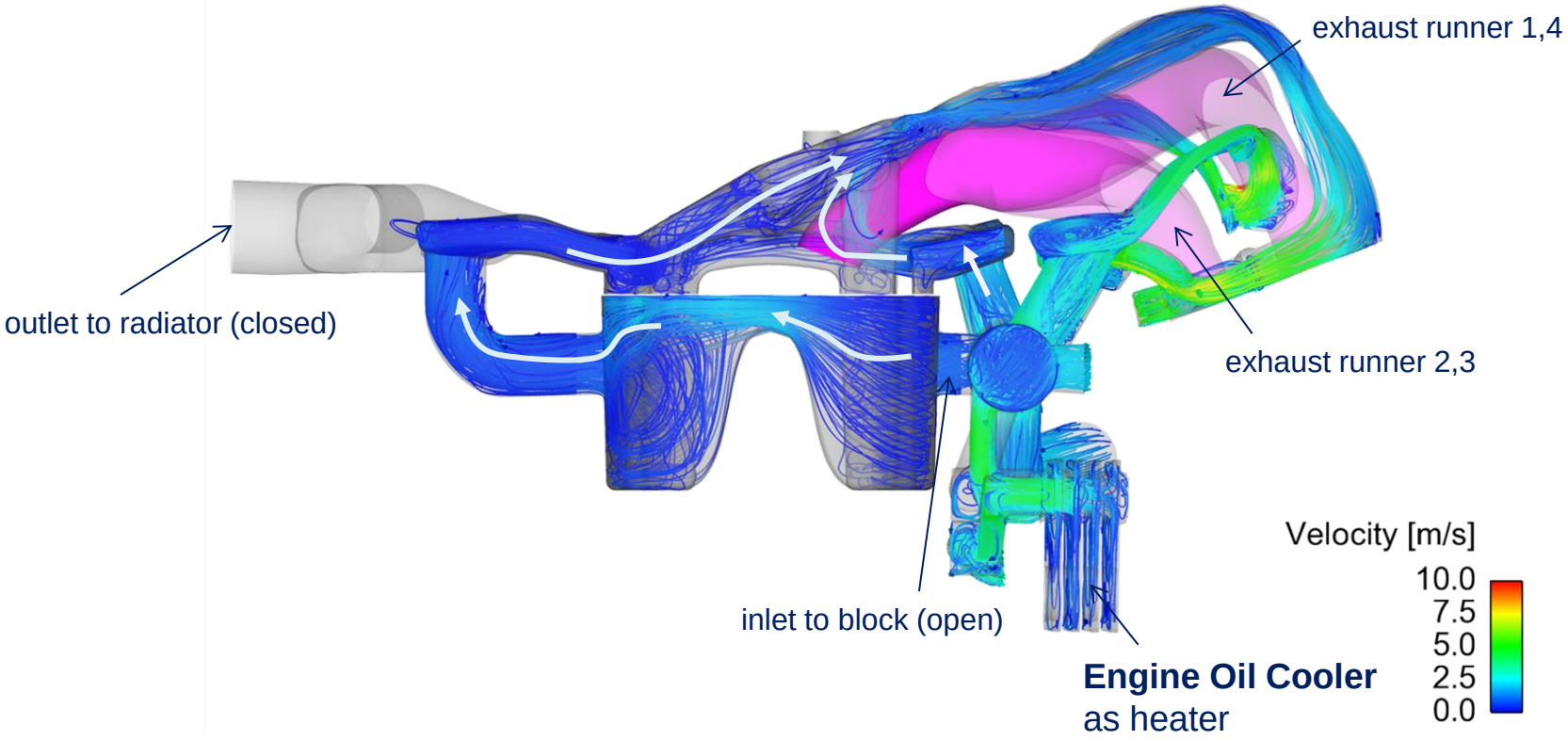

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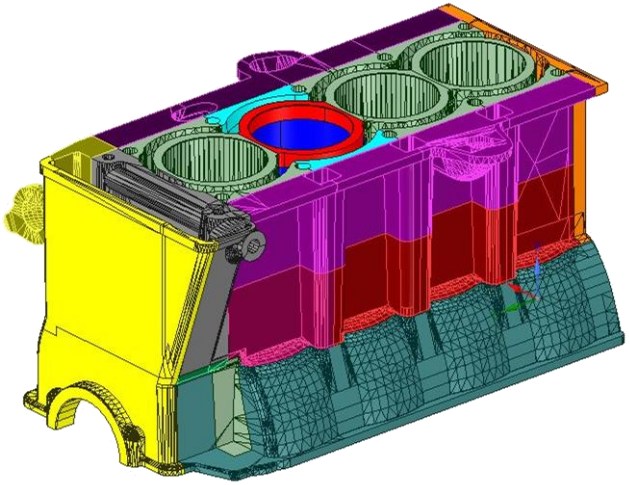
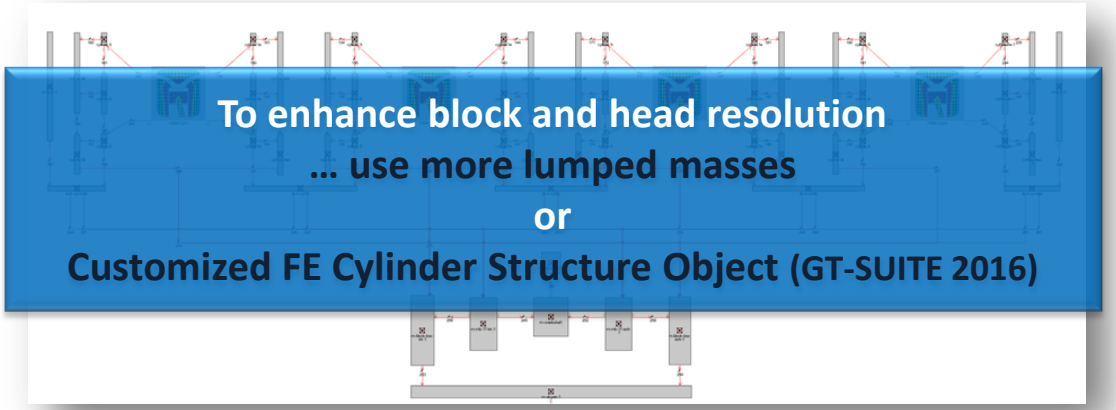
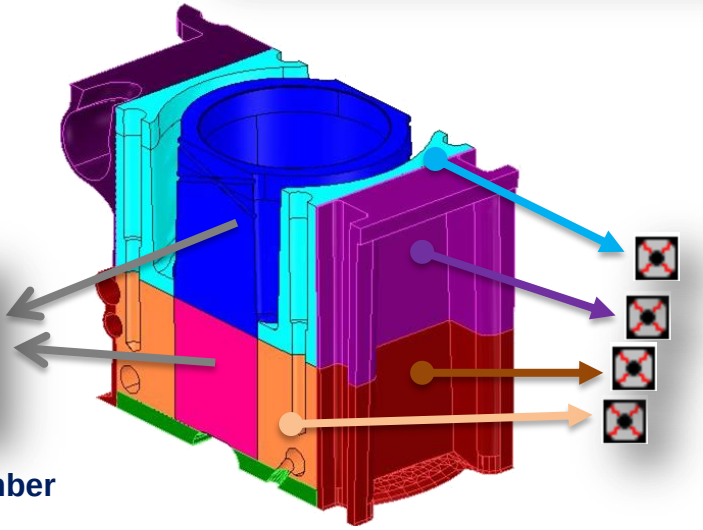
1D System Simulation of Engine Warm-Up

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







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

Outer engine structure
converted to lumped masses
and be connected to
- coolant
- oil
- ambient

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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.

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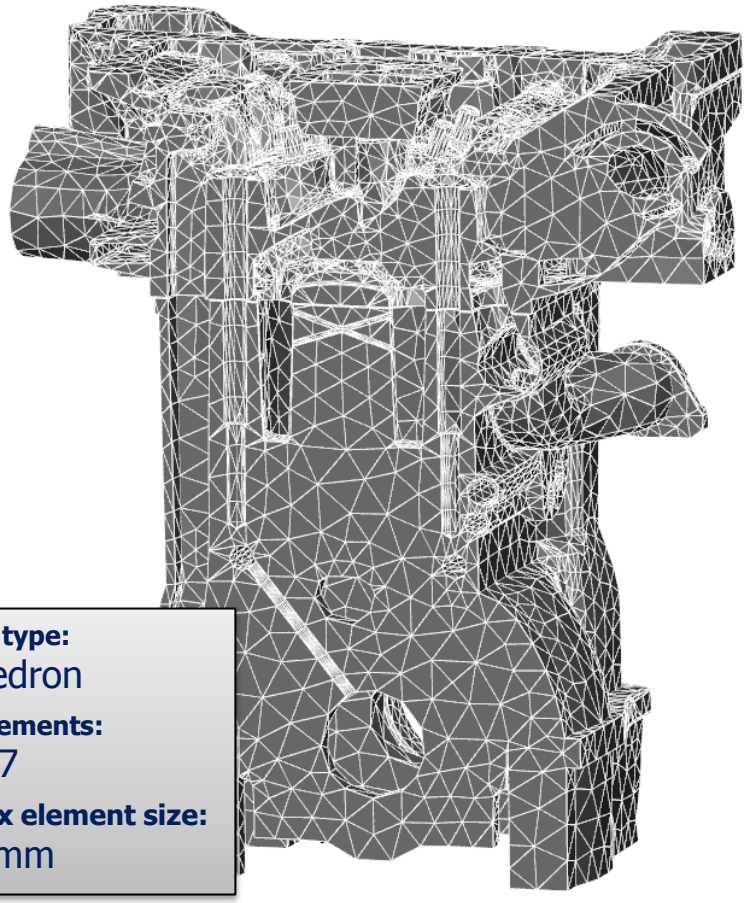
Customized FE Cylinder Structure Objects
3D Mesh Generation

Customized FE v2016

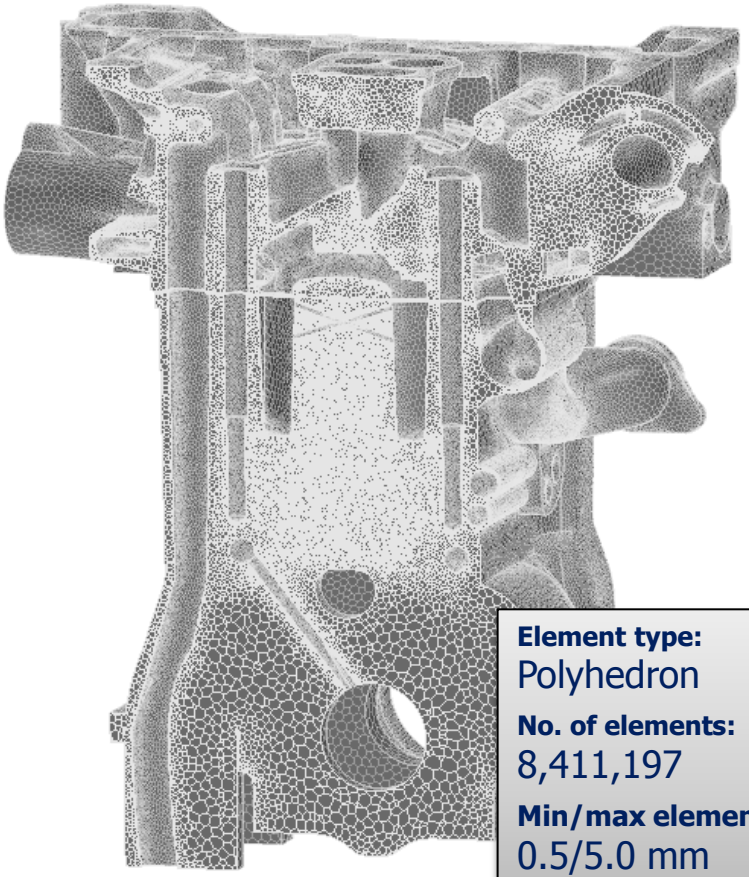


Element type:
Tetrahedron

No. of elements:
506,047

Min/max element size:
10/20 mm

3D CFD/CHT



Element type:
Polyhedron

No. of elements:
8,411,197

Min/max element size:
0.5/5.0 mm

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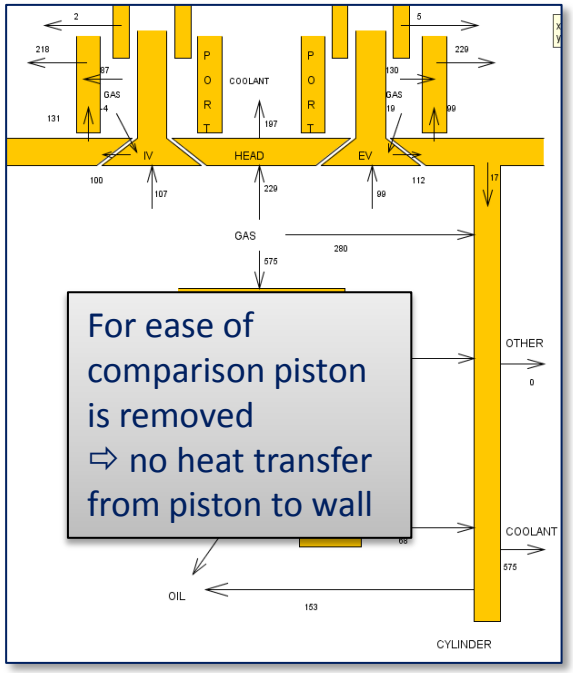
Customized FE Cylinder Structure Objects
Deriving BC's for Combustion Chamber

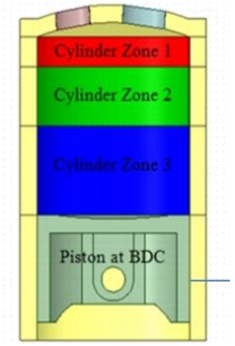
GT-POWER heat transfer analysis

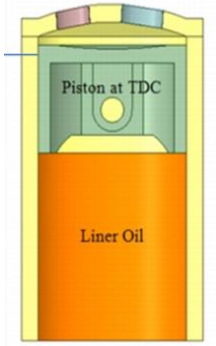


Gas temperatures and HTC's for GT Customized FE model and STAR-CCM+ model are identical.

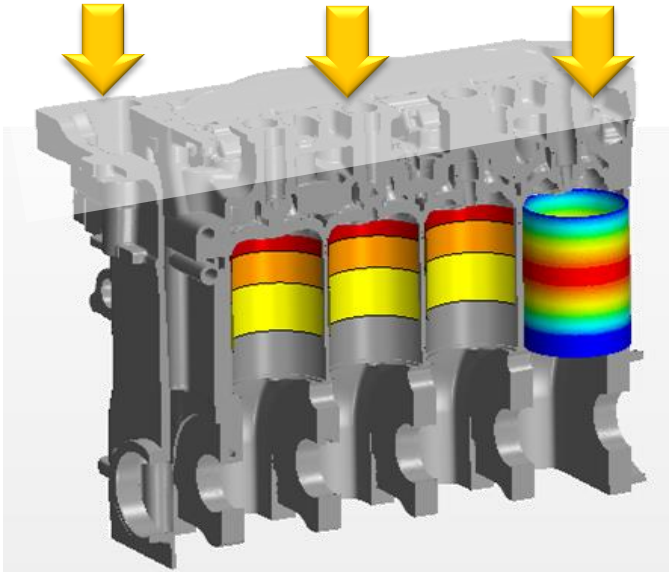
Gas Temperature Zones

Cylinder Oil Zone





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



Customized FE v2016

3D CFD/CHT

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Customized FE Cylinder Structure Objects
Deriving BC's for Coolant Water Jacket

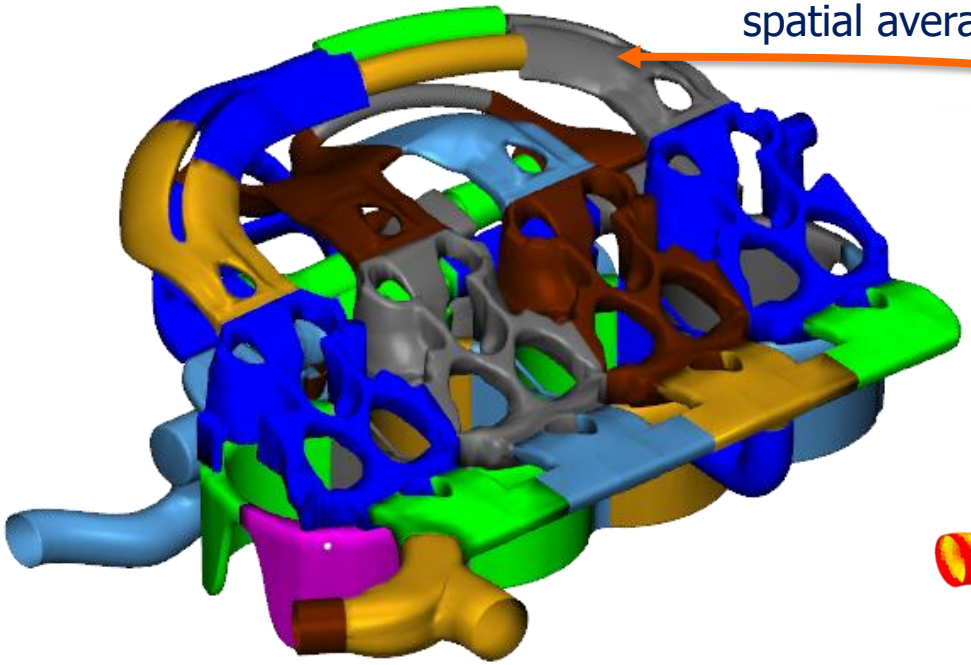
Customized FE v2016

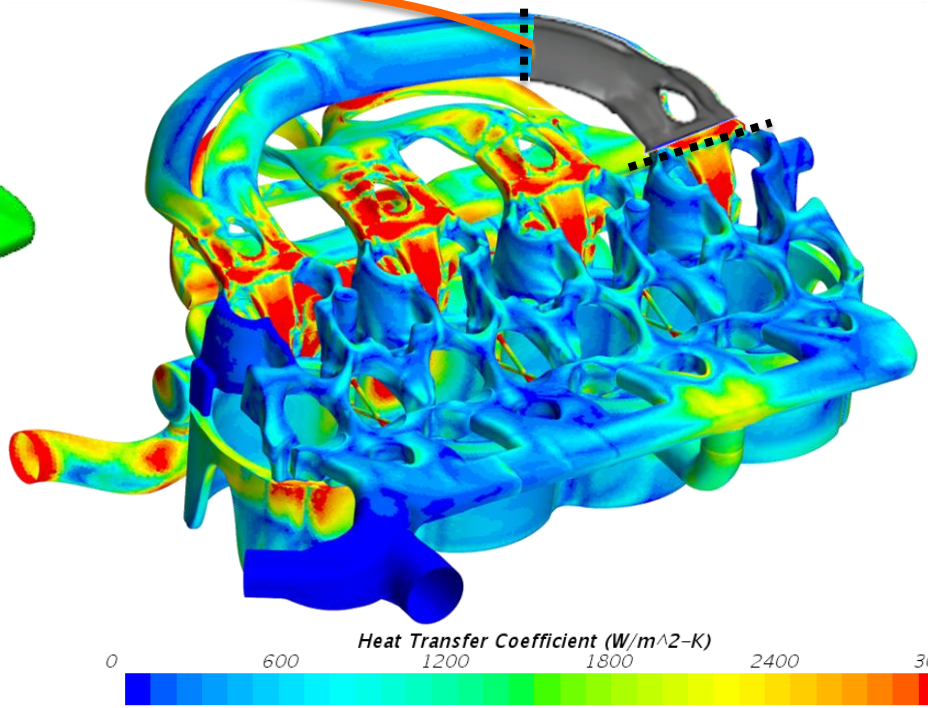
- Water jacket split into segments with GEM3D
- Each segment represented by a flow split

3D CFD/CHT

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

spatial average HTC's mapped onto flow splits





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

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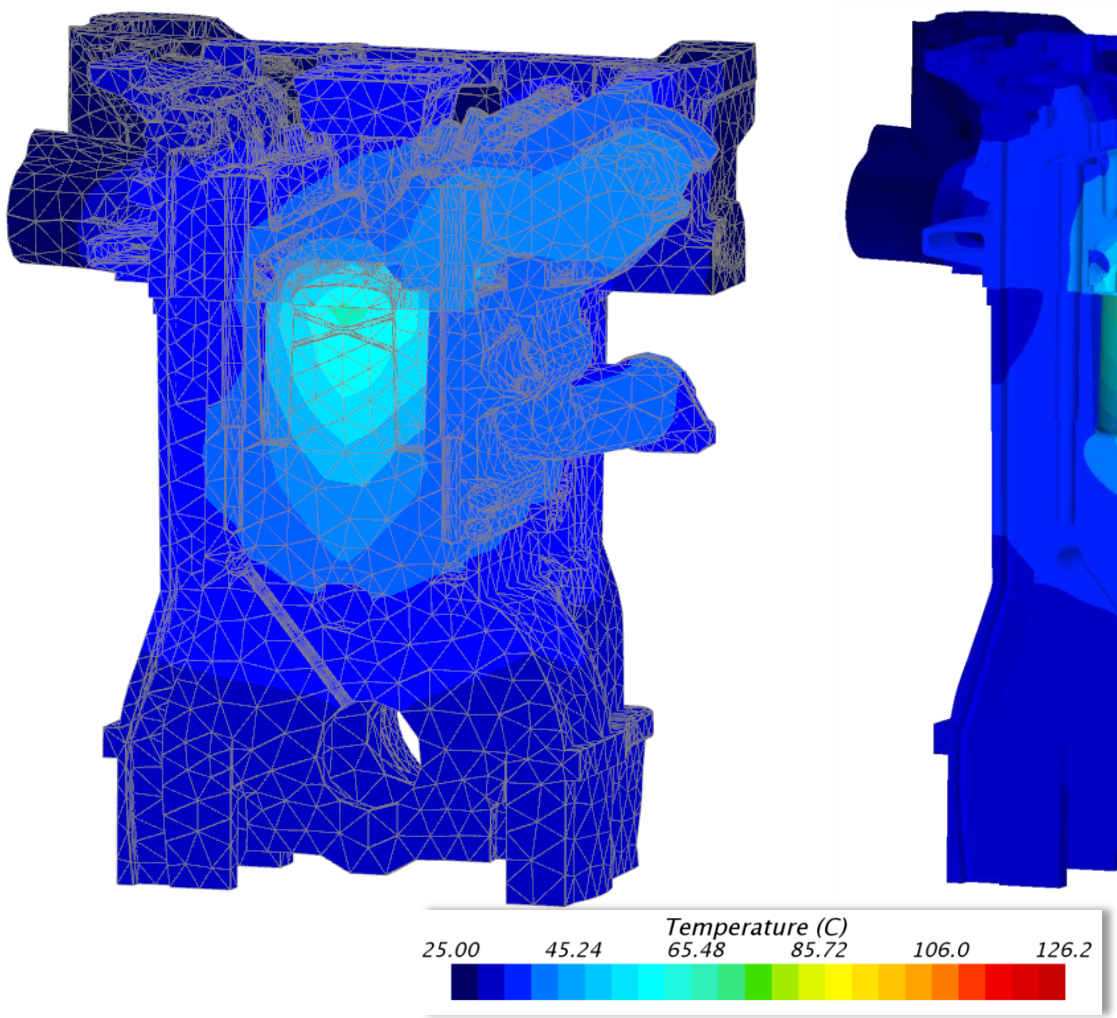
Customized FE Cylinder Structure Objects
Engine Structure Temperature after 100 sec

Customized FE v2016

3D CFD/CHT



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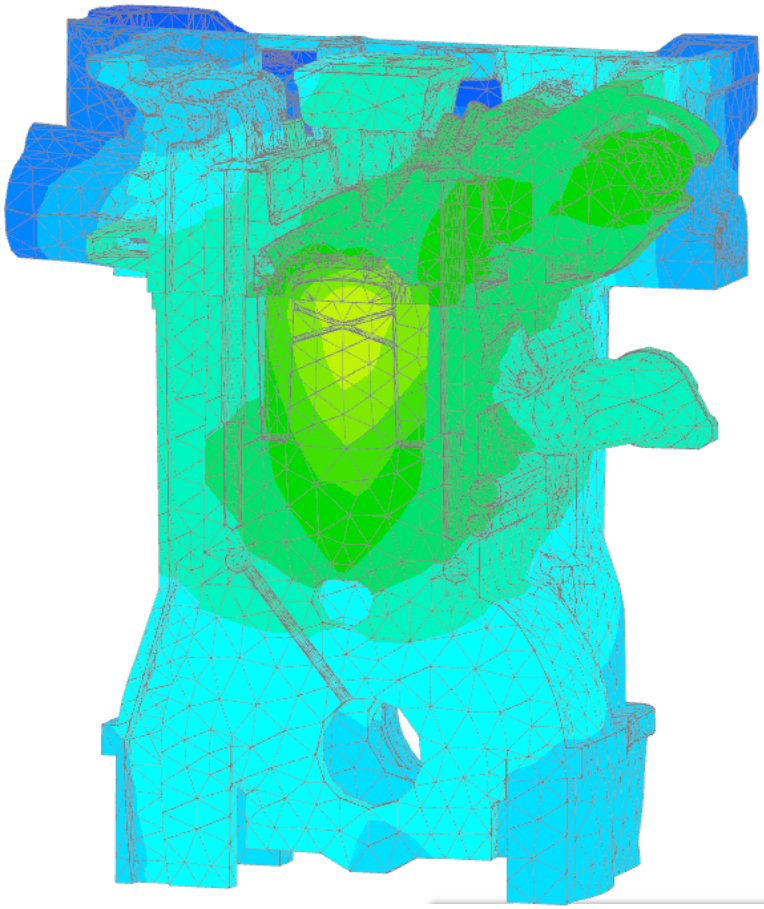
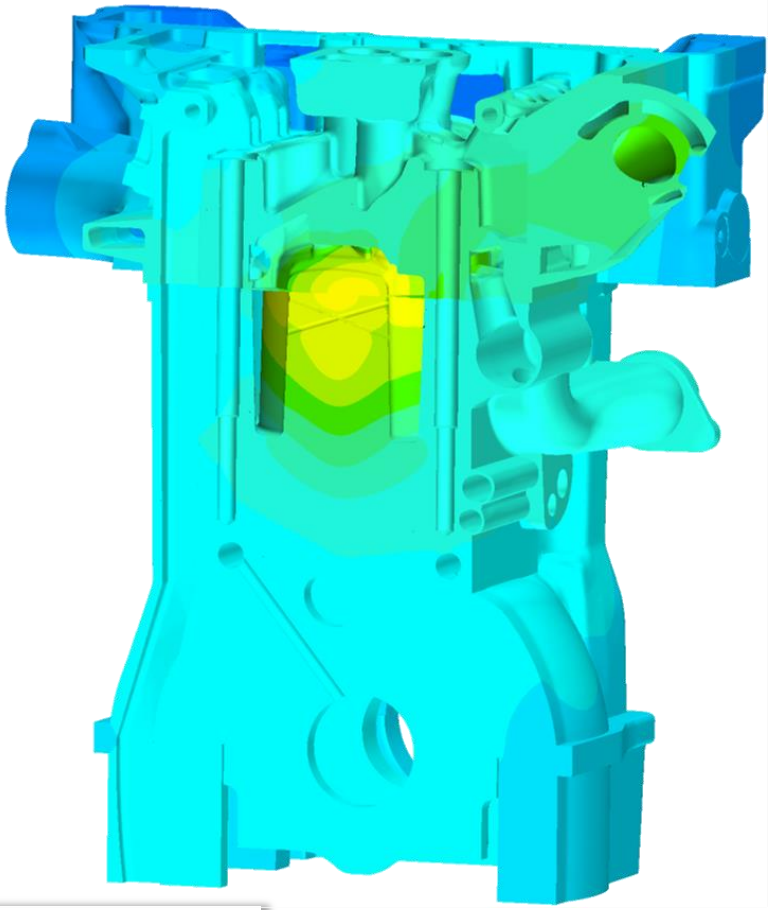
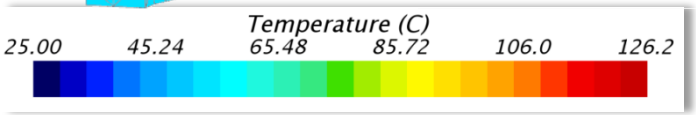
Customized FE Cylinder Structure Objects
Engine Structure Temperature after 300 sec

Customized FE v2016



3D CFD/CHT





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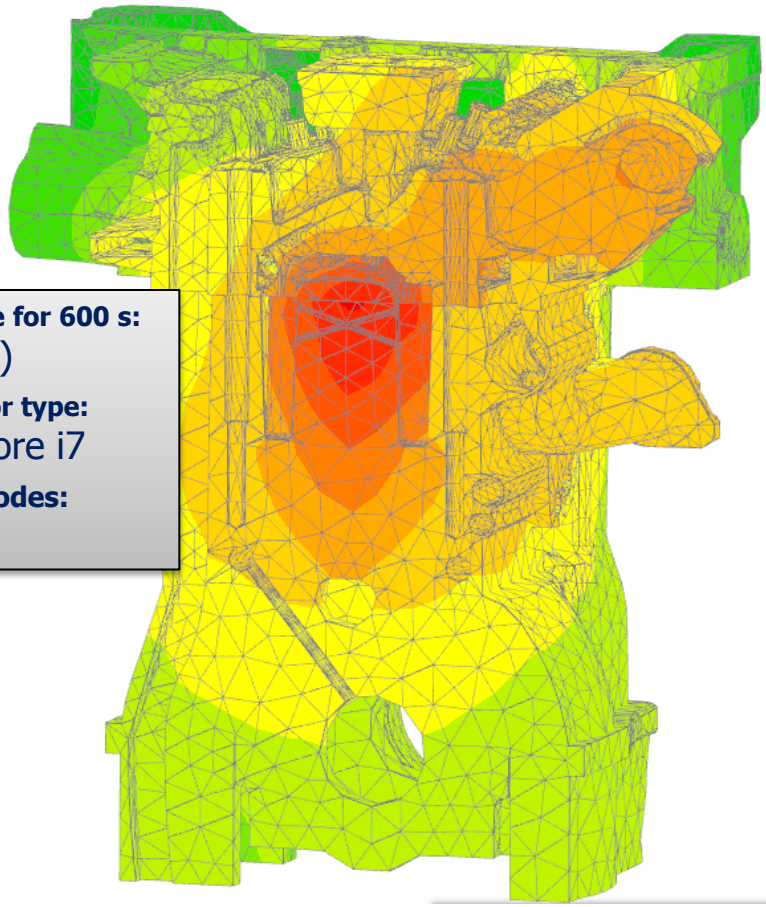
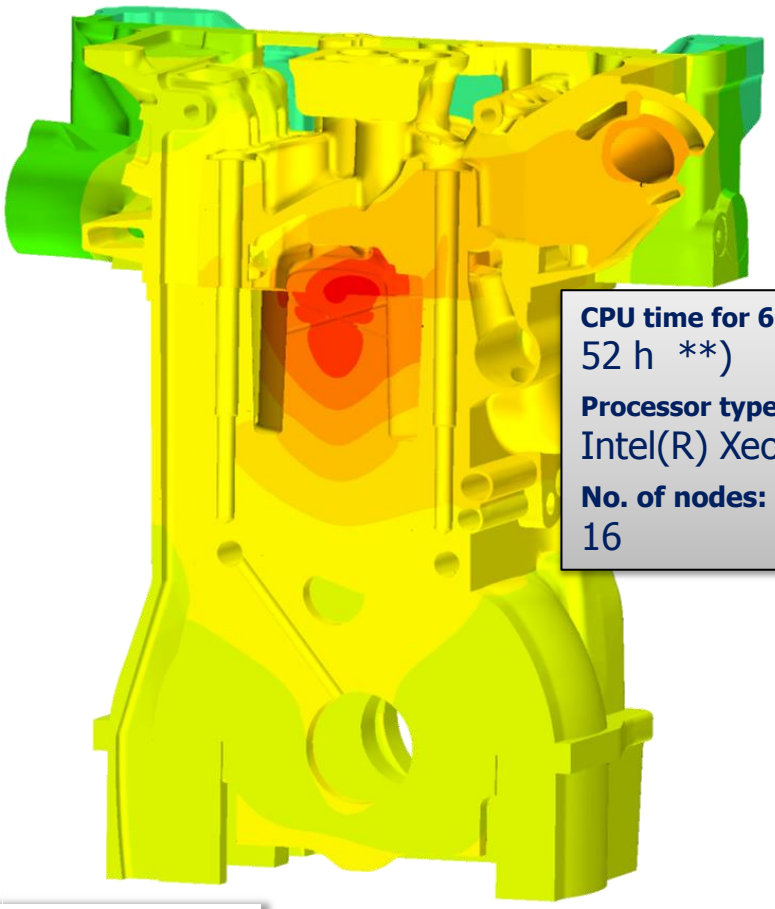
Customized FE Cylinder Structure Objects
Engine Structure Temperature after 600 sec

Customized FE v2016

CPU time for 600 s:
1.9 h *)
Processor type:
Intel Core i7
No. of nodes:
1





3D CFD/CHT

CPU time for 600 s:
52 h **)
Processor type:
Intel(R) Xeon(R)
No. of nodes:
16

*) complete warm-up model

**) CFD/CHT head and block

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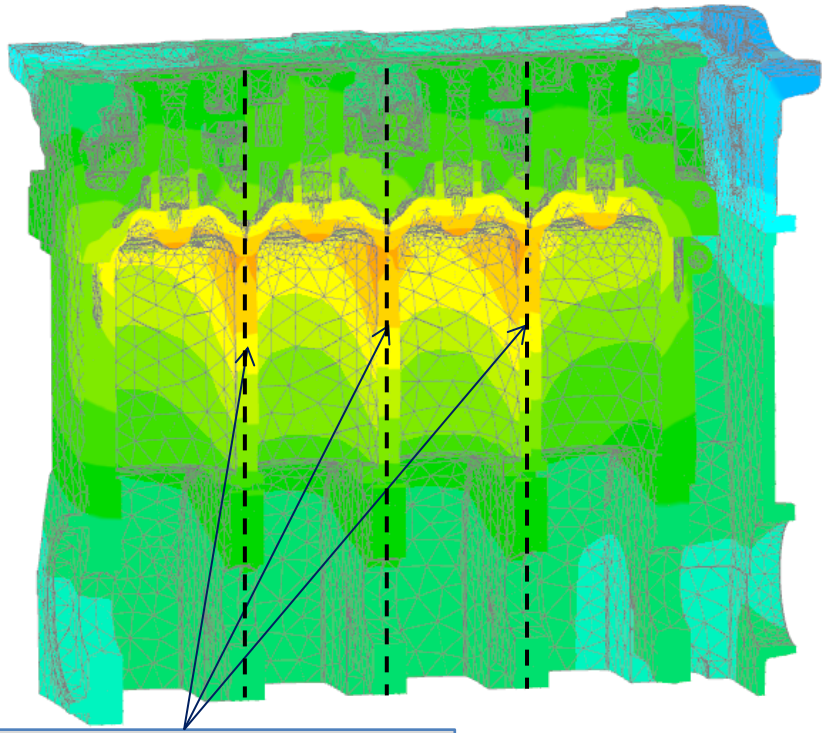
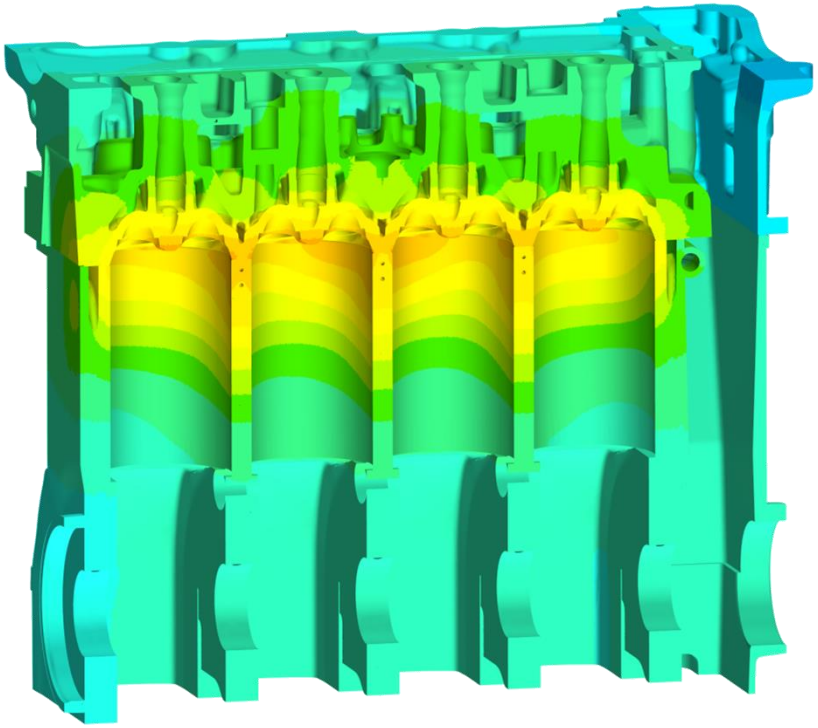
Customized FE Cylinder Structure Objects
Engine Structure Temperature after 400 sec

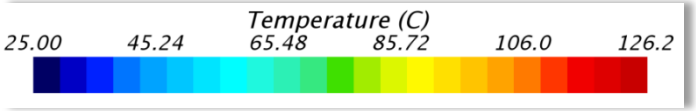
Customized FE v2016



3D CFD/CHT



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



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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

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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!