STAR Global Conference 2015
San Diego March 16–18

INTEGRATED DESIGN ANALYSIS GmbH InDesA

Virtual Approach to Predict Heat Rejection of Combustion Engines

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San Diego, March 17, 2015

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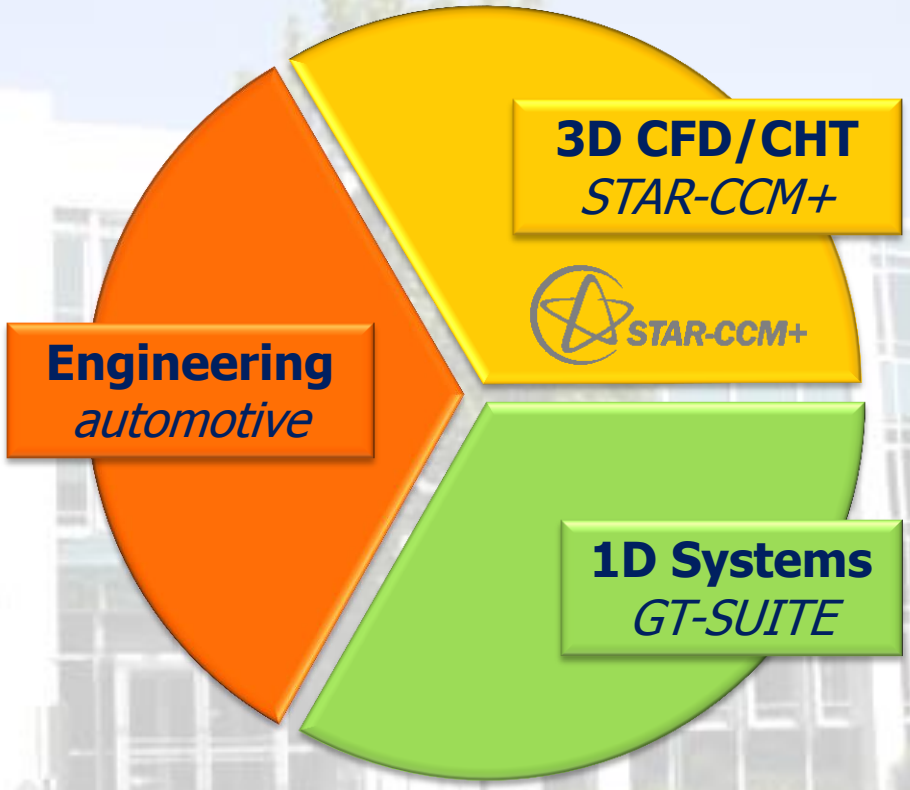
Company Profile
Fields of Competence

INTEGRATED DESIGN ANALYSIS GmbH **InDesA**

Consulting, Engineering Services & Virtual Test Center

- Simulation and Analysis of complex fluid flow and heat transfer systems for engineering and industrial applications
- Virtual Performance Testing for automotive accessory units
- **Virtual Heat Rejection Testing of combustion engines**



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Heat Rejection of Combustion Engines

Why to Predict Heat Rejection of Combustion Engines ?

Knowledge of engine heat rejection is basic for

- **Engine thermal design**
  - **Exhaust system design**
    - **Cooling system design**
      - **Underhood thermal management**

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♦ Thermal Stress Analysis

♦ Integration of Thermal Management Technologies

- ➢ Split Cooling
- ➢ Water Cooled Exhaust Manifold
- ➢ Controlled Water Pump
- ➢ Controlled Thermostats
- ➢ Thermal Encapsulation

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♦ Vehicle Integration

- ➢ Layout of coolant network
- ➢ Layout of Heat Exchangers and Water Pumps
- ➢ Layout of Thermostats and Valves
- ➢ Layout of Control Strategies

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Heat Rejection of Combustion Engines
Heat Rejection Measurement

A common approach to measure heat rejection:

Take prototype engine with first available and stable combustion application.
… often with safety application e.g. rich combustion, restrictions for speed and torque, etc.

Instrument engine with

- pressure indicators → IMEP → predict FMEP (friction)
- temperature sensors (thermocouples) → control temperature limits
- Coolant and Oil conditioning appliance → predict heat rejection

Dilemma:
Heat Rejection must be known at the early stage of the development process **but** the engine application (combustion & exhaust) is often not sufficient mature to allow for accurate heat rejection evaluation.

Idea:
Design a virtual approach to use standard testing procedures at OEM and combine with 1D and 3D simulation techniques to overcome restrictions due to the current engine built and application.

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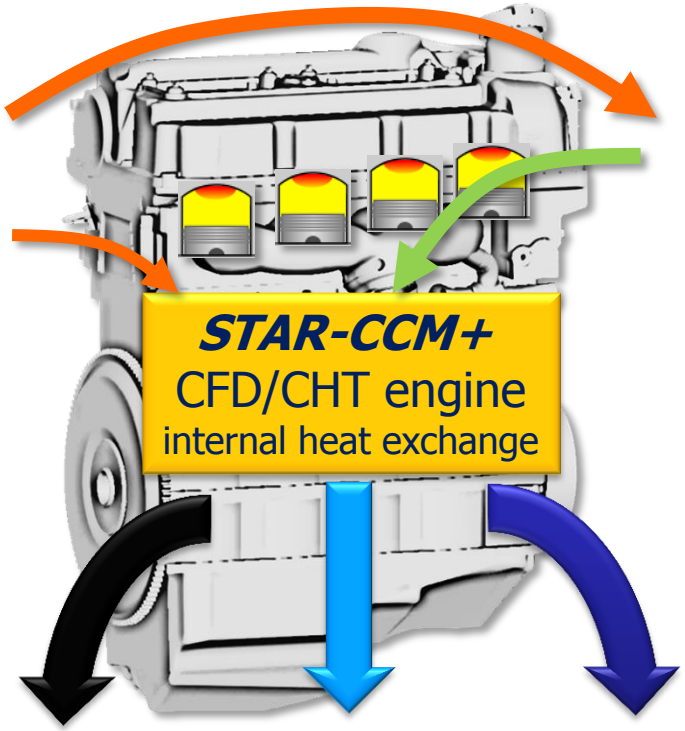
Heat Rejection of Combustion Engines
Virtual Approach to Predict Heat Rejection

… with Backup from Standard Testing @ OEM

heat sources: • combustion • friction

Testing (OEM)
- pressure indication
- engine temperatures
- engine tear down
- fuel consumption
- HX thermal maps
- …



GT-SUITE
- engine performance
- combustion
- intake air & exhaust
- heat transfer
- friction
- engine structure
- lubrication
- coolant

heat release to: • engine oil • ambient • coolant

STAR-CCM+
CFD/CHT Vehicle Underhood

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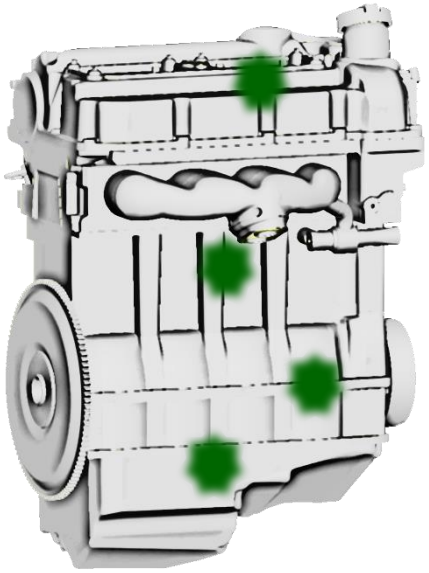
Heat Rejection of Combustion Engines
Engine Tear Down (Strip) Measurement

- Engine is motored, i.e. no load on piston applied & no combustion
- Engine is torn down, i.e. dismounted step by step to measure friction of different friction groups:

- Complete engine
- Valve drive
- Piston group (piston and con rods)
- Crankshaft
- Mass balancer drive
- Oil pump
- Water pump
- Fuel & Vacuum pump
- Generator (unloaded)
- Compressor (unloaded)

} „thermal friction groups“



- To measure friction for different temperatures the engine oil and coolant temperature is preconditioned typically at 30°C, 60°C, 90°C, 120°C.

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Heat Rejection of Combustion Engines
Pressure Indication Measurement

- Engine is fired i.e. load on piston and combustion
- Commonly operated hot
- Indicated (IMEP) and brake mean effective (BMEP) pressure are measured.
- Engine friction for the complete engine (FMEP) is calculated from IMEP – BMEP
- Load factors can be derived to be multiplied with FMEP for friction groups from teardown measurements.

For the hot engine:

Σ (FMEP $_{teardown}$ * *load factor)* = FMEP $_{indicated}$ must match!

Other Useful parameters to feed into system simulation:

- Fuel consumption
- Basic engine operation parameters
- Mass flow rates, pressure, temperature in air induction and exhaust system
- Mass flow rates, pressure, temperature in air coolant and lubrication system
- Temperatures in and on engine structure (good for calibration of CFD/CHT model)
- …

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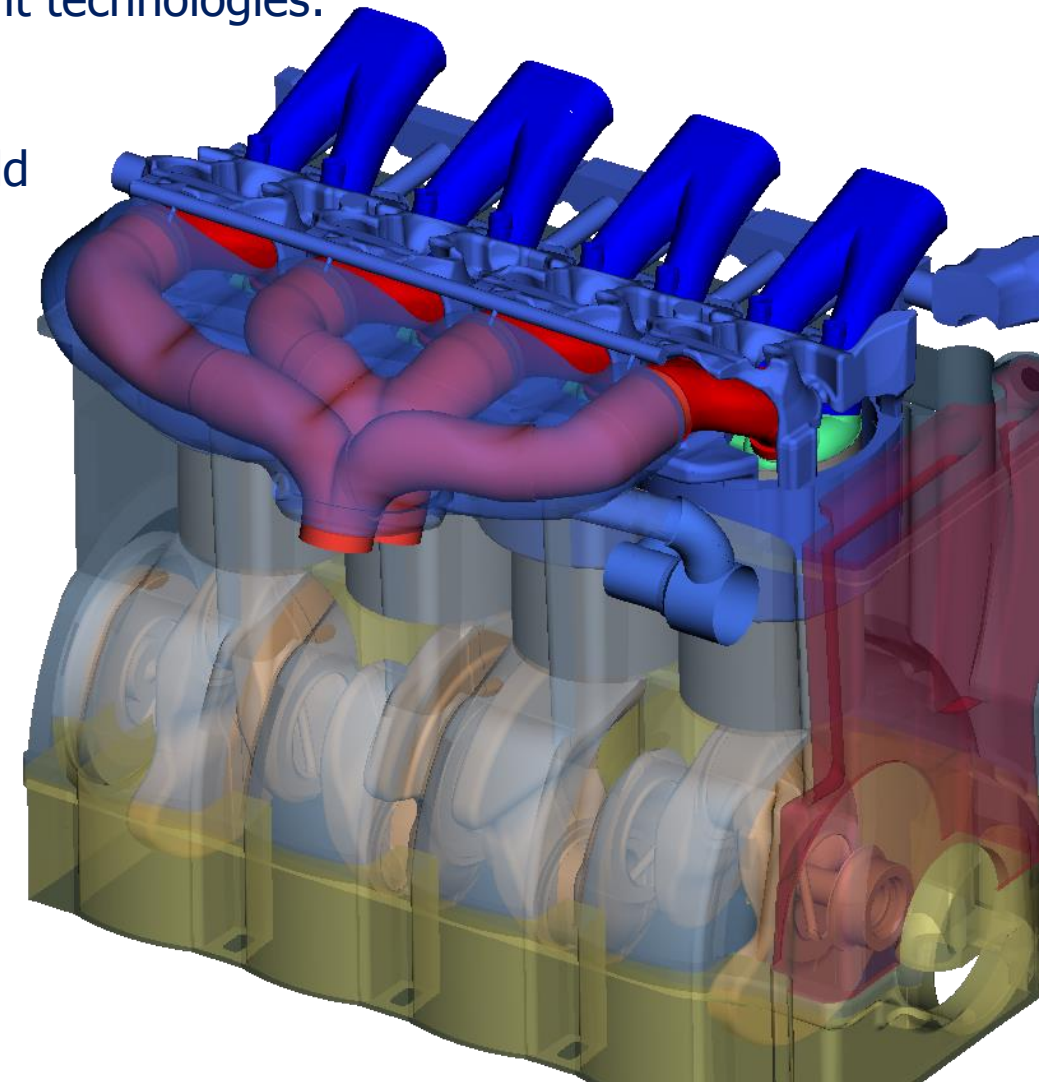
Heat Rejection of Combustion Engines
InDesA's Virtual Engine GTDI4 2.0L

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

- Split Cooling
- Water Cooled Exhaust Manifold
- Engine oil Cooler
- Thermal Encapsulation

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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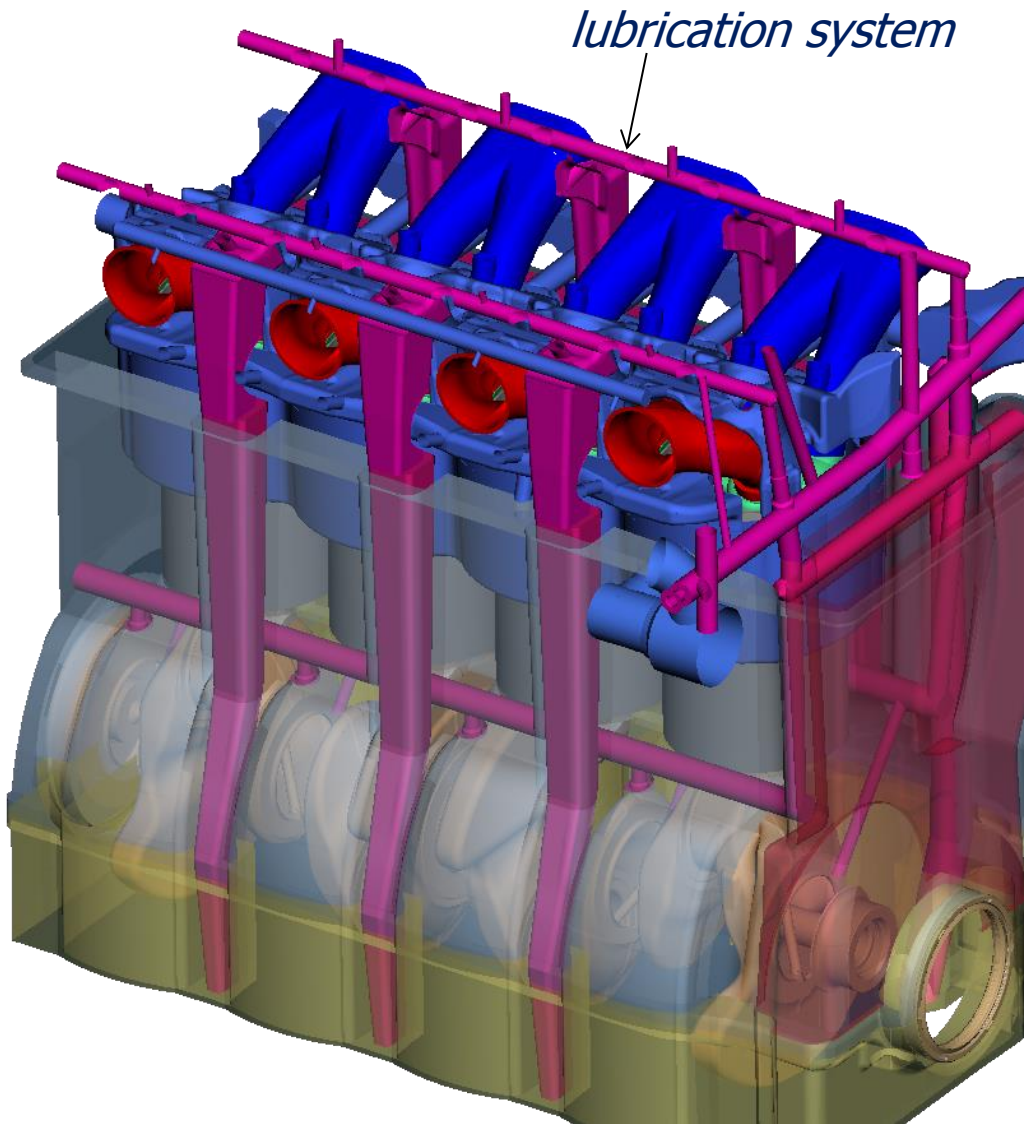
Heat Rejection of Combustion Engines
InDesA's Virtual Engine GTDI4 2.0L

Design is filled with "life",
i.e. with relevant physical models
in GT-SUITE:

- engine performance
- combustion
- intake & exhaust
- heat transfer
- engine structure
- lubrication circuit
- coolant circuit



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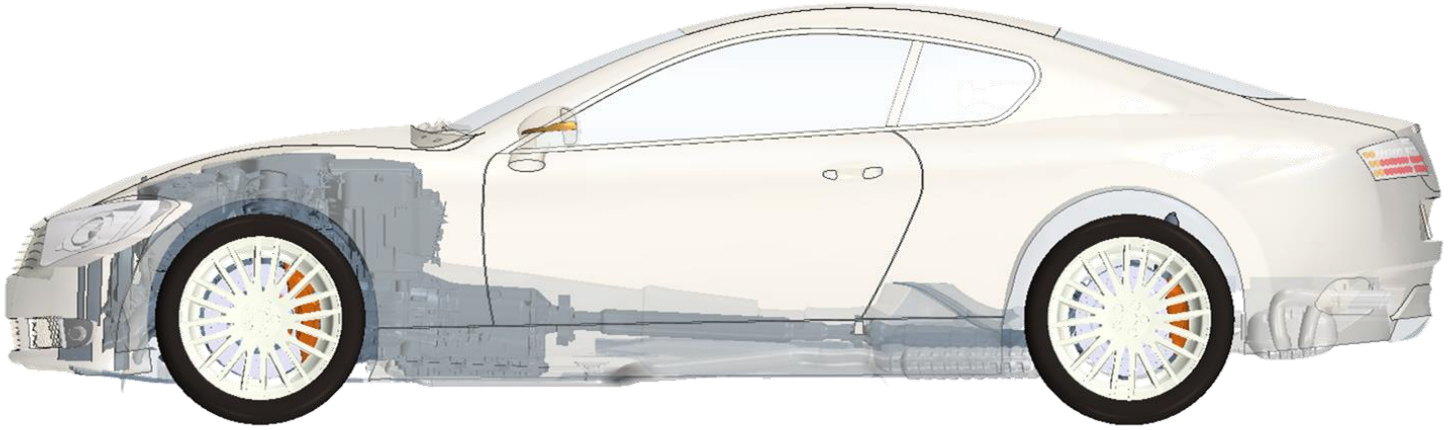
Heat Rejection of Combustion Engines
InDesA's Virtual CAR "Pandora MY14"



.. to simulate a realistic engine environment with heat transfer to the ambient.

- Air flow through engine compartment in accordance with vehicle speed and cooling fan performance.
- Air flow temperature in accordance with heat release from radiator module in front of engine.

GT-SUITE modules:
- vehicle
- drive train
- road and environment

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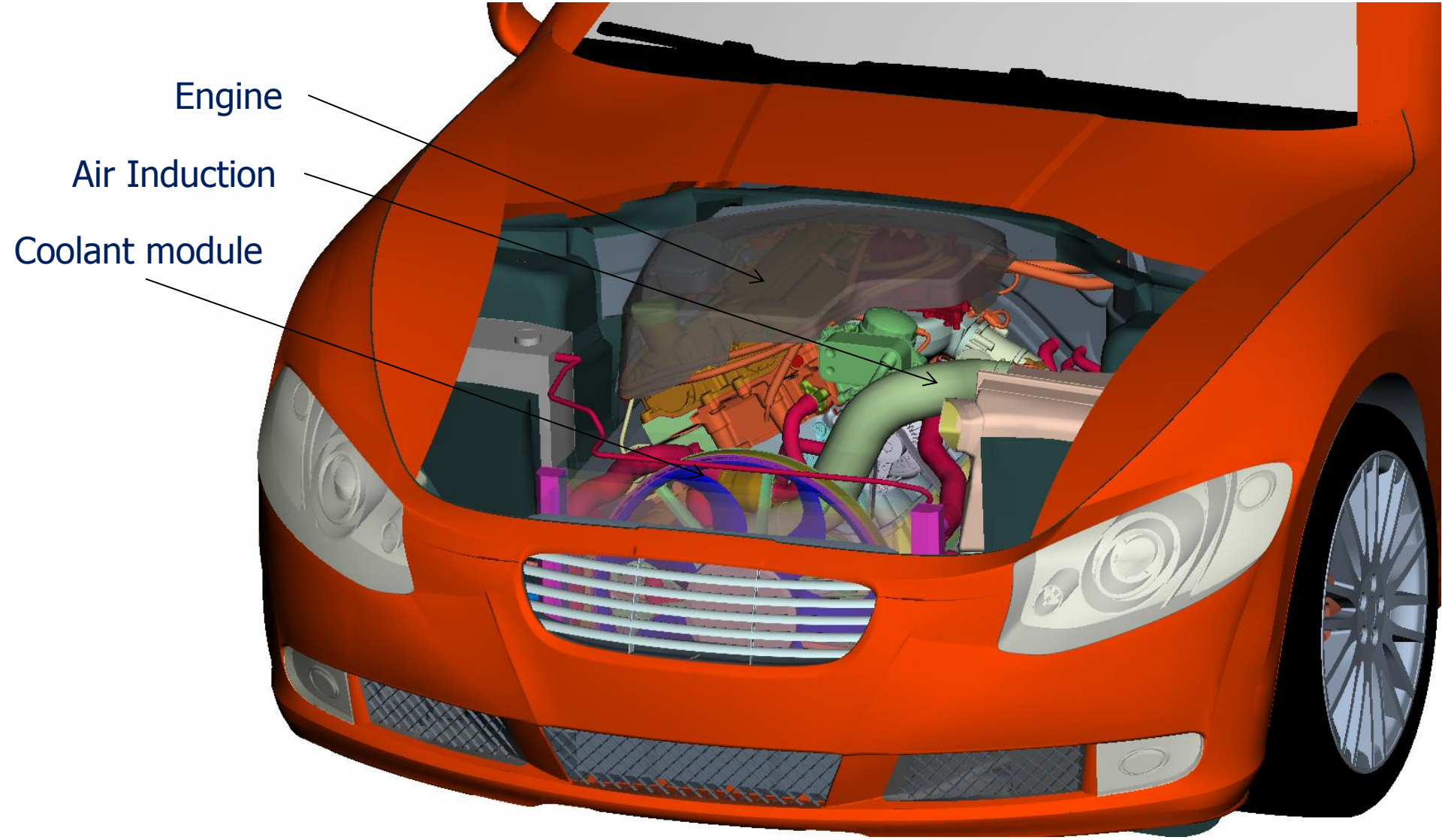
Heat Rejection of Combustion Engines
Engine Installation in "Pandora MY14"



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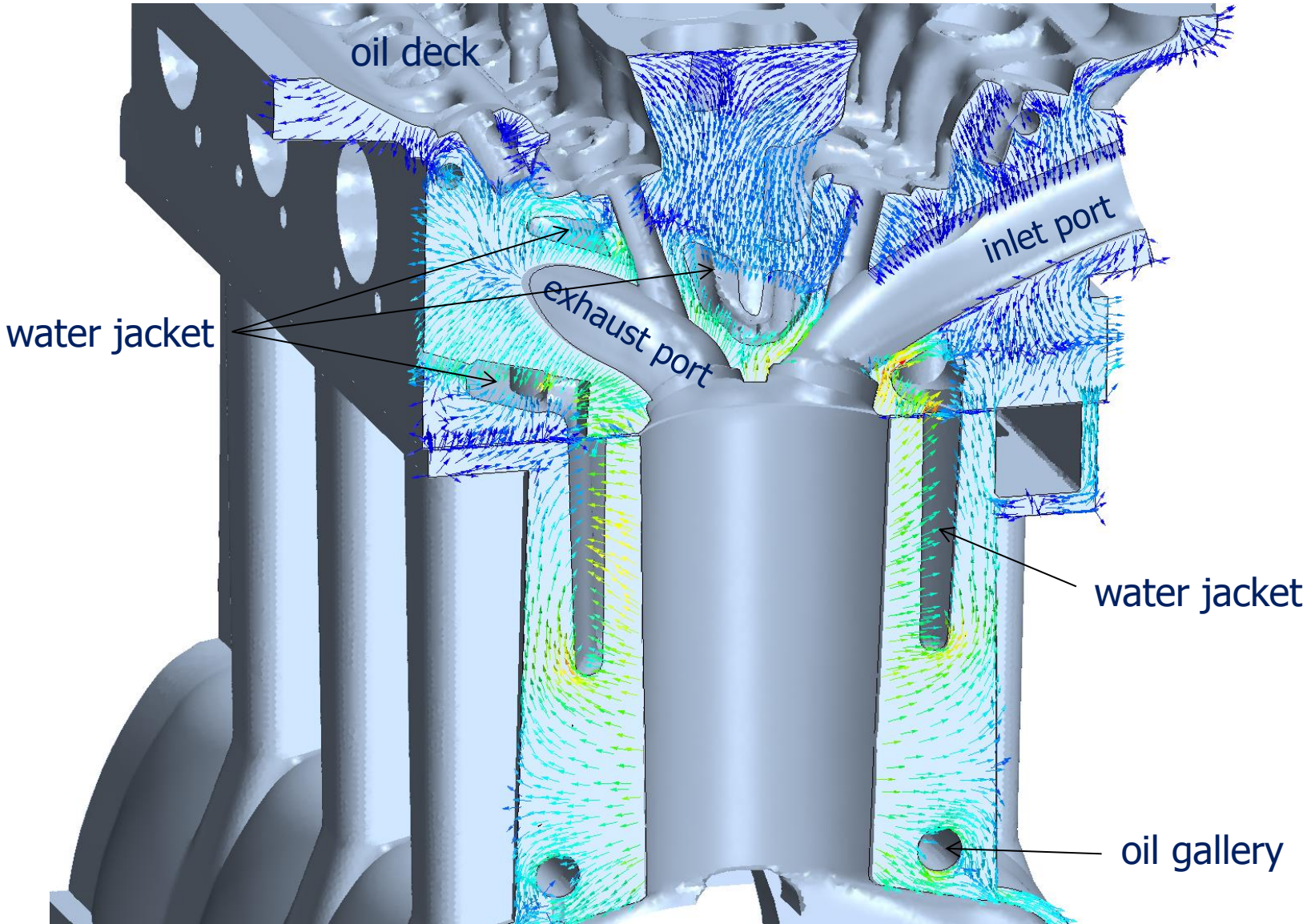
Heat Rejection of Combustion Engines
Heat Flux Vectors in Engine Structure



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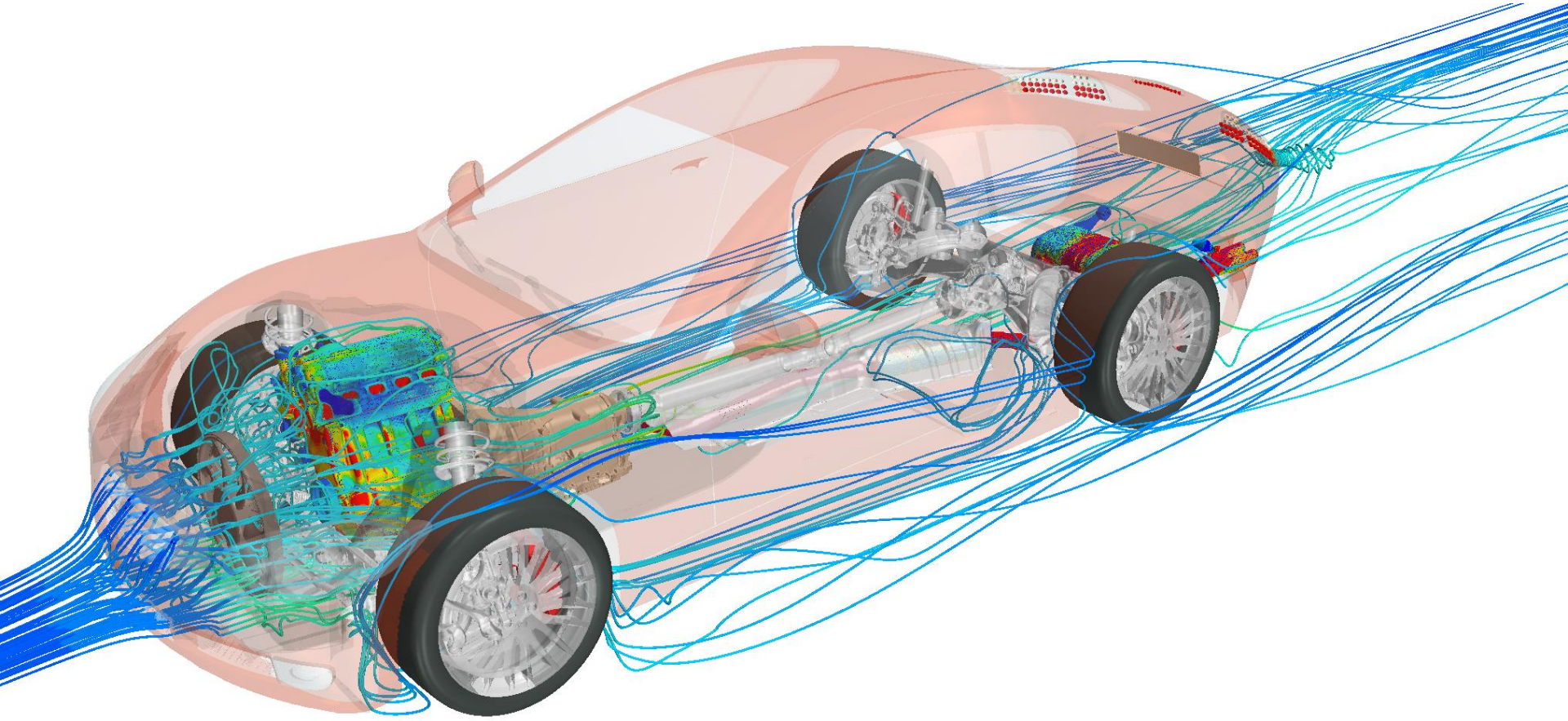
Heat Rejection of Combustion Engines

Heat Flux from Engine Surface & Streamlines



240 kph; 135 kW

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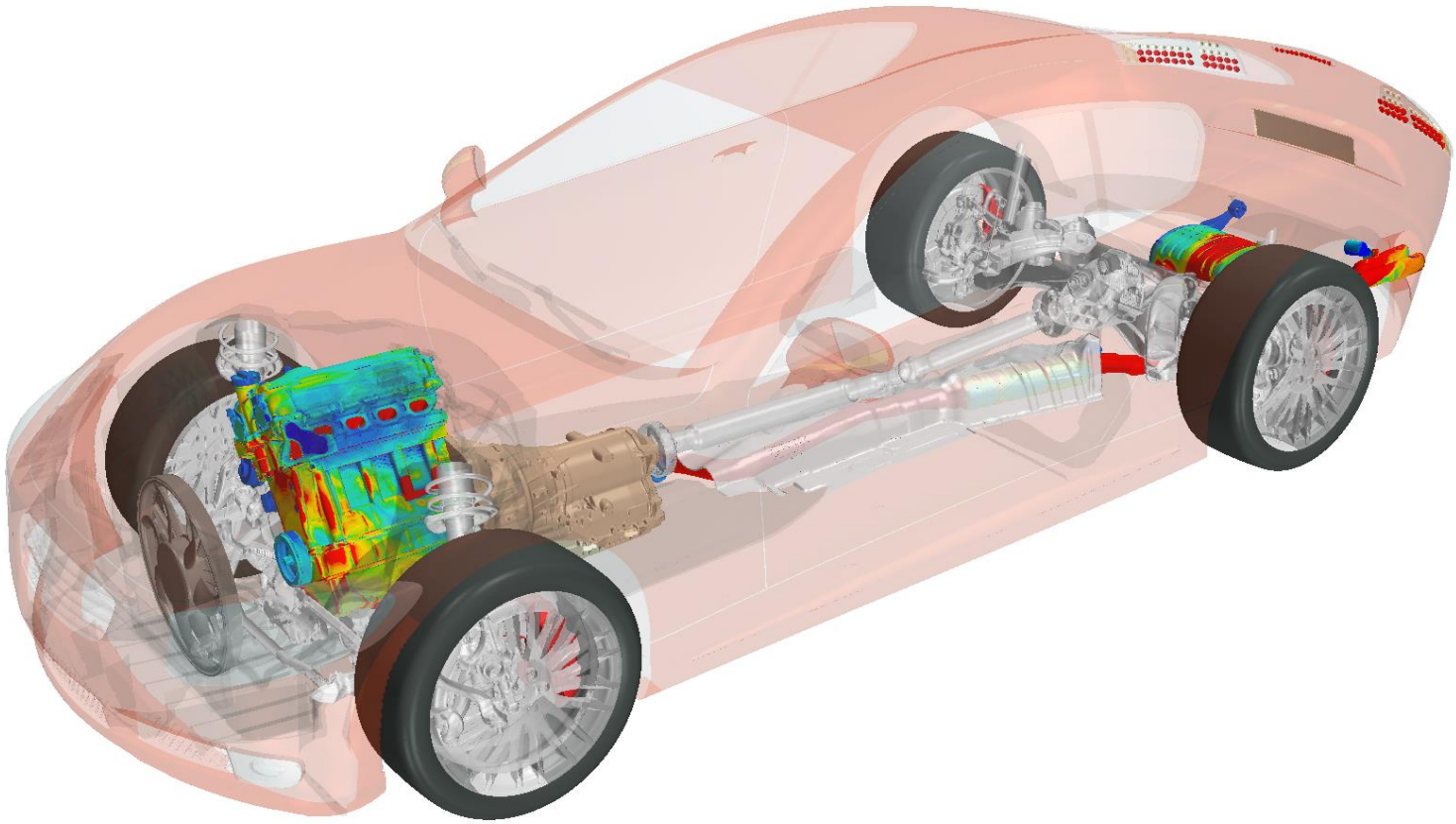
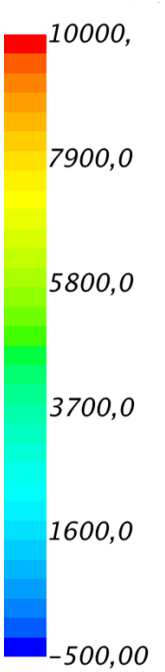
Heat Rejection of Combustion Engines

Heat Flux from Engine Surface to Ambient





240 kph; 135 kW

Boundary Heat Flux [W/m²]

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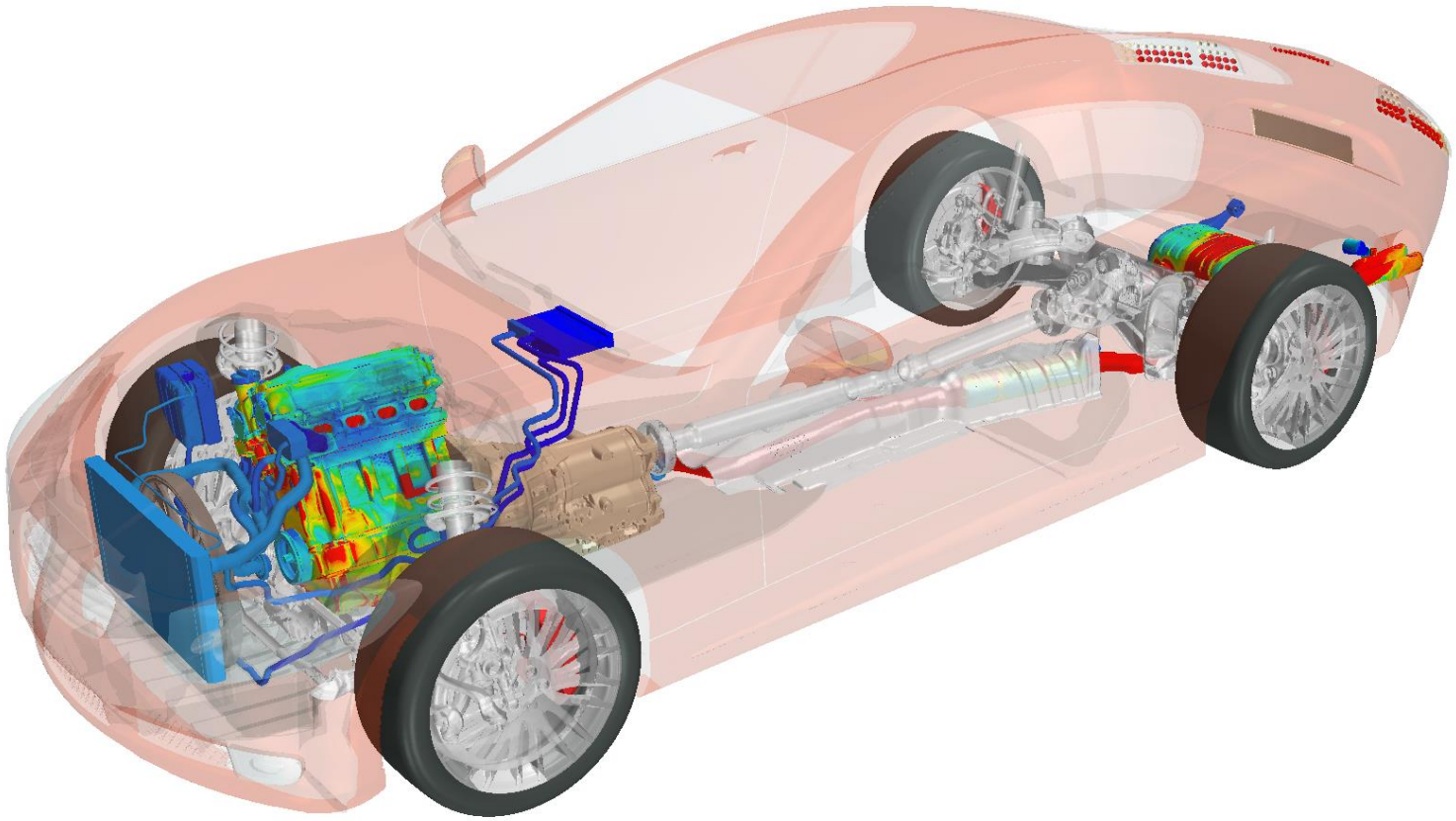
Heat Rejection of Combustion Engines
Engine Combined with Cooling System



240 kph; 135 kW

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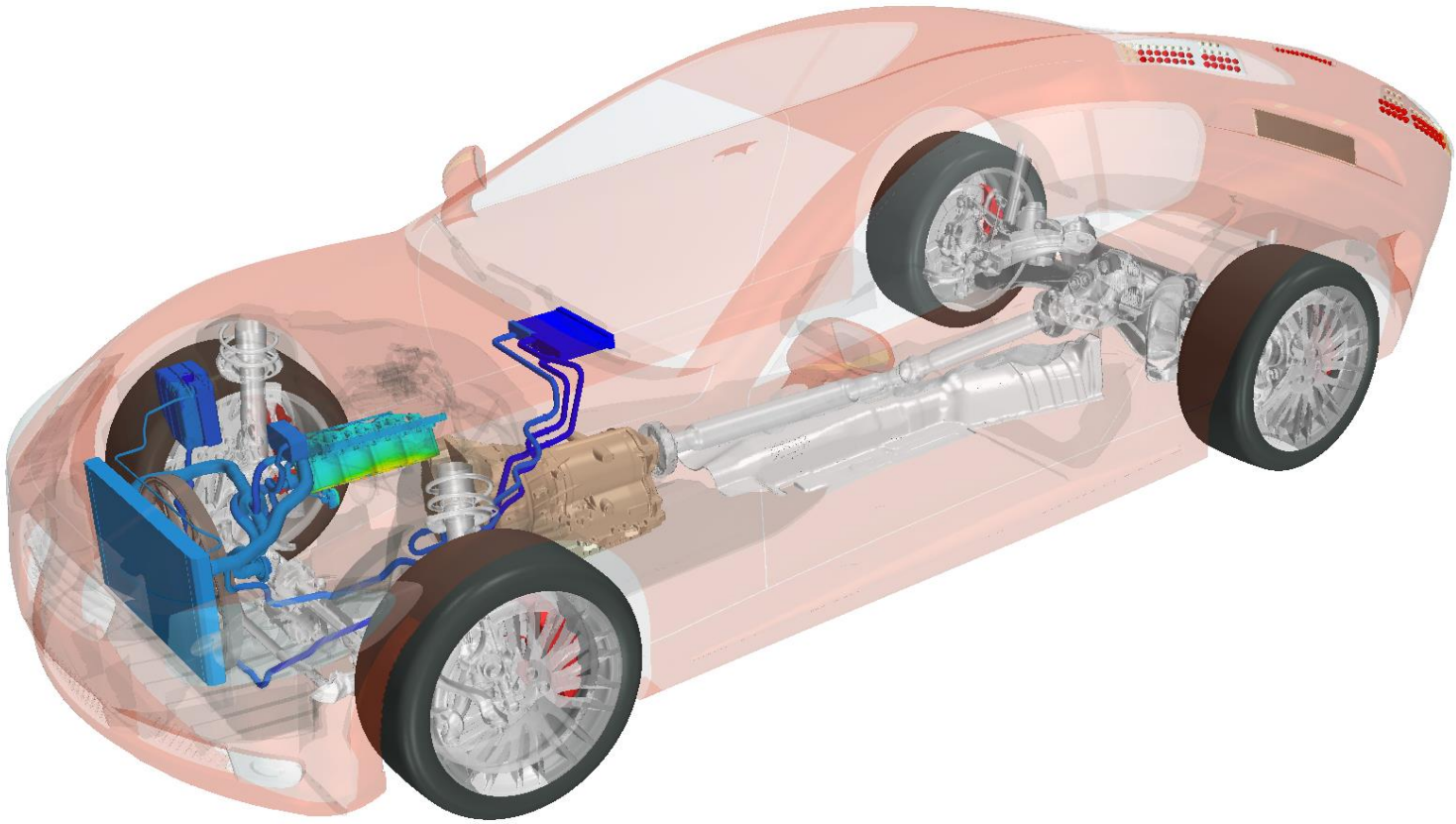
Heat Rejection of Combustion Engines
Cooling System



240 kph; 135 kW

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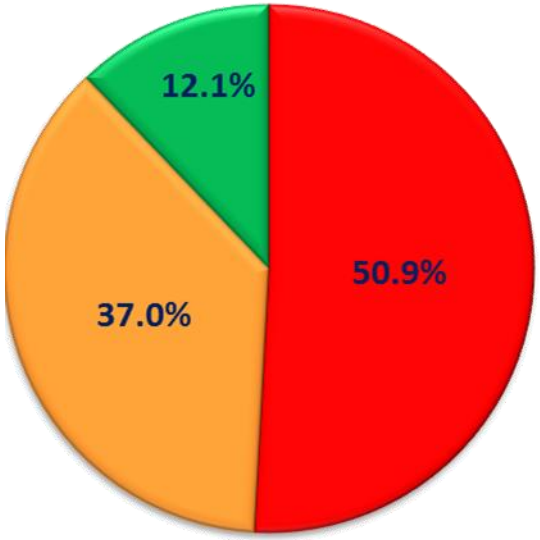
Heat Rejection of Combustion Engines
Heat Rejection and Temperatures

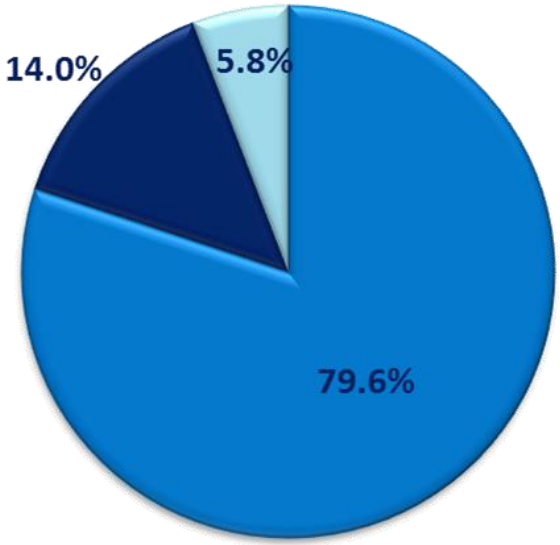
heat sources:

- combustion chamber *)
- exhaust manifold *)
- engine friction
  (FMEP=1.2 bar assumed)



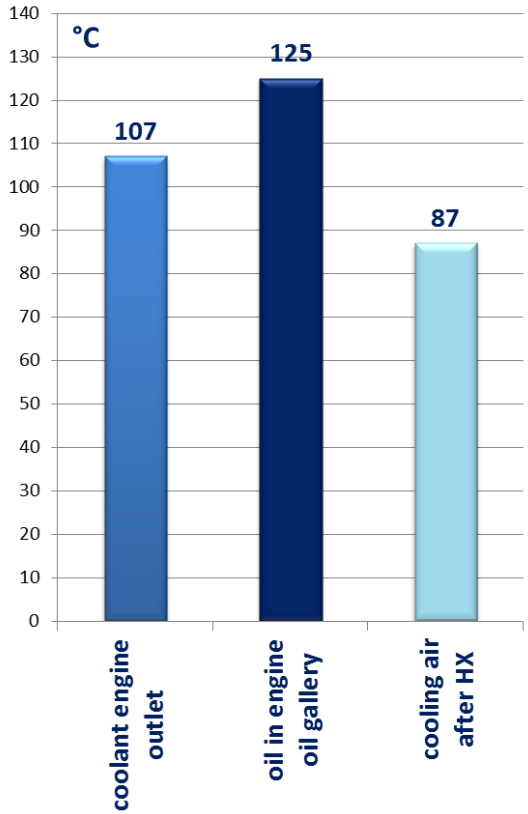
heat release to:

- engine oil
- ambient
- coolant



*) heat transfer gas to structure

fluid temperatures:



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Heat Rejection of Combustion Engines
Summary

Virtual Approach to Predict Heat Rejection of Combustion Engines

- based on standard testing procedures at OEM
- combined with 1D and 3D simulation techniques

Approach includes:

- Heat transfer from combustion/exhaust to liner, piston, flame deck, exhaust port, exhaust manifold
- Dissipated heat from different friction groups to structure and oil
- Internal heat transfer in engine with 3D CFD/CHT approach in STAR-CCM+
- Heat Release to ambient through engine surface and radiator.

Approach can be used in combination with a heat rejection test bench:

- to predict heat rejection in early development stage beyond the capabilities of a prototype engine and application.

Approach has the potential:

- to substitute heat rejection bench testing.

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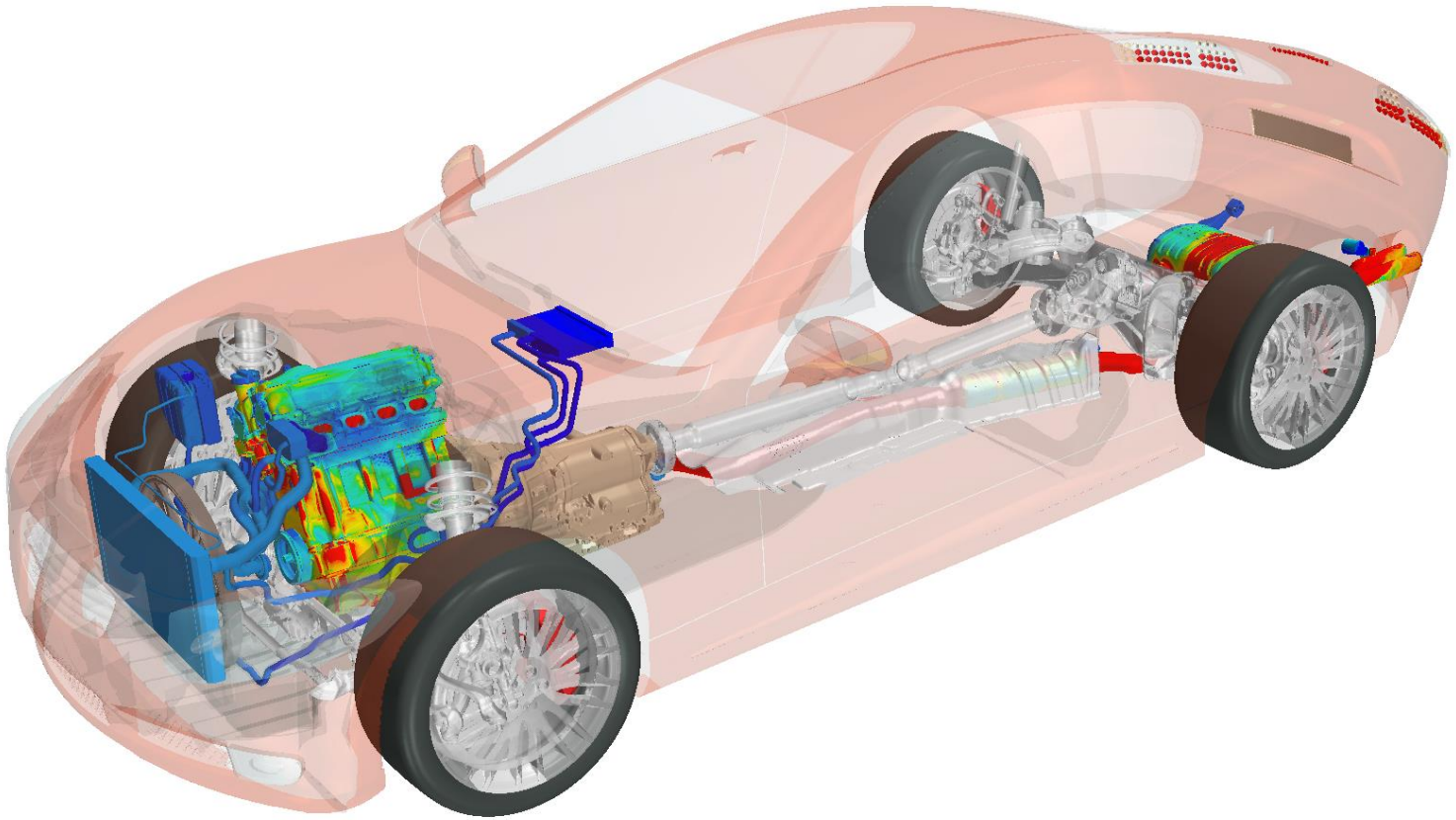

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