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INTEGRATED DESIGN ANALYSIS

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State-of-the-art and Future Requirements for Vehicle Thermal Management Simulation

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Thermal Management Simulation
Key Applications

Design and Analysis of

State-of-the-art

future applications

I vehicle cooling systems

… to keep engine, oil and coolant below max. allowable temperatures

II engine warm-up

… to reduce friction to optimize fuel economy

III thermal reliability of underhood components

… to protect components from thermal damage

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Thermal Management Simulation
I. Vehicle Cooling Systems

… to keep engine, oil and coolant below max. allowable temperatures

State-of-the-art

Coolant temperatures and engine oil temperatures can be calculated for arbitrary stationary operating conditions as well as for arbitrary drive cycles.

Requirements:

Test data for engine heat fluxes to coolant and oil for various coolant and oil temperatures over load and speed.

Test data for heat transfer and flow resistance of heat exchangers.

3D CFD flow analysis for components of complex three dimensional flow.

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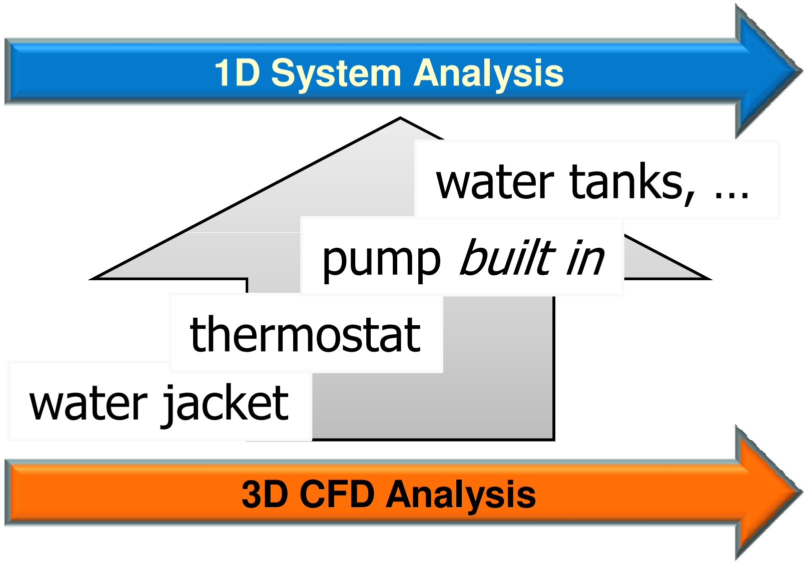
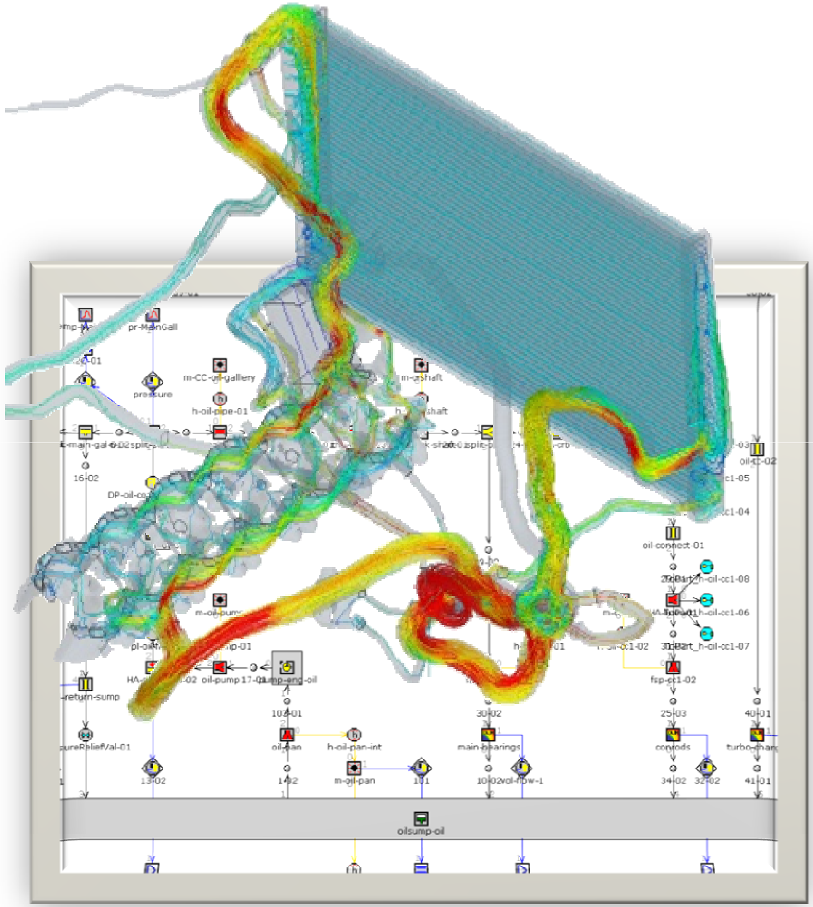
Thermal Management Simulation
I. Vehicle Cooling Systems

1D and 3D CFD analysis must interact throughout the development process.





Future Development:

Substitution of test data for engine heat fluxes through a predictive engine model with the integration of GT-POWER.

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Thermal Management Simulation
II. Engine Warm-Up

… to reduce friction to optimize fuel economy

Background information:

Fuel economy during warm-up is measured for specified drive cycles (NEDC, FTP75, …)

As the engine heats up, engine friction reduces - in general.

Basic design guidelines for rapid engine warm-up:

- warm up the engine oil first.
- warm up the structure close to frictional groups.
- do not get the coolant involved too early.
- do not involve the outer engine structure at all.

The **idea of thermal management** is to direct the waste heat from combustion to the oil and to the dominant frictional groups of the engine.

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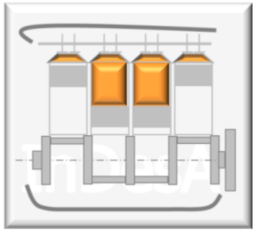
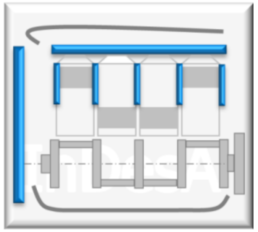
II. Engine Warm-Up

Modules for an engine warm-up simulation model

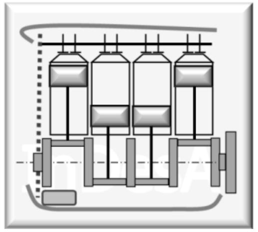
Combustion



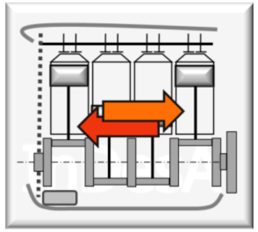
Coolant



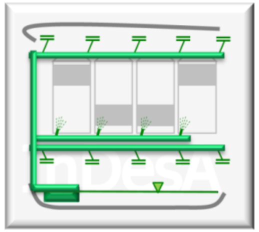
Structure



Friction



Oil



Vehicle

GT-POWER MeanValue engine model;
calculates
Heat Source
heat transfer coeficients and combustion temperatures in cylinder

Detailed engine water jacket, heat exchangers and thermostats;
calculates
thermal transport in coolant

Lumped masses and FE-cylinder models;
calculates
thermal transport in engine structure

prosesses maps from strip-down measurements;
calculates
frictional losses for different friction groups

simplified lubrication model;
calculates
thermal transport in oil

Vehicle and power train model
calculates
engine load and speed for vehicle drive cycle

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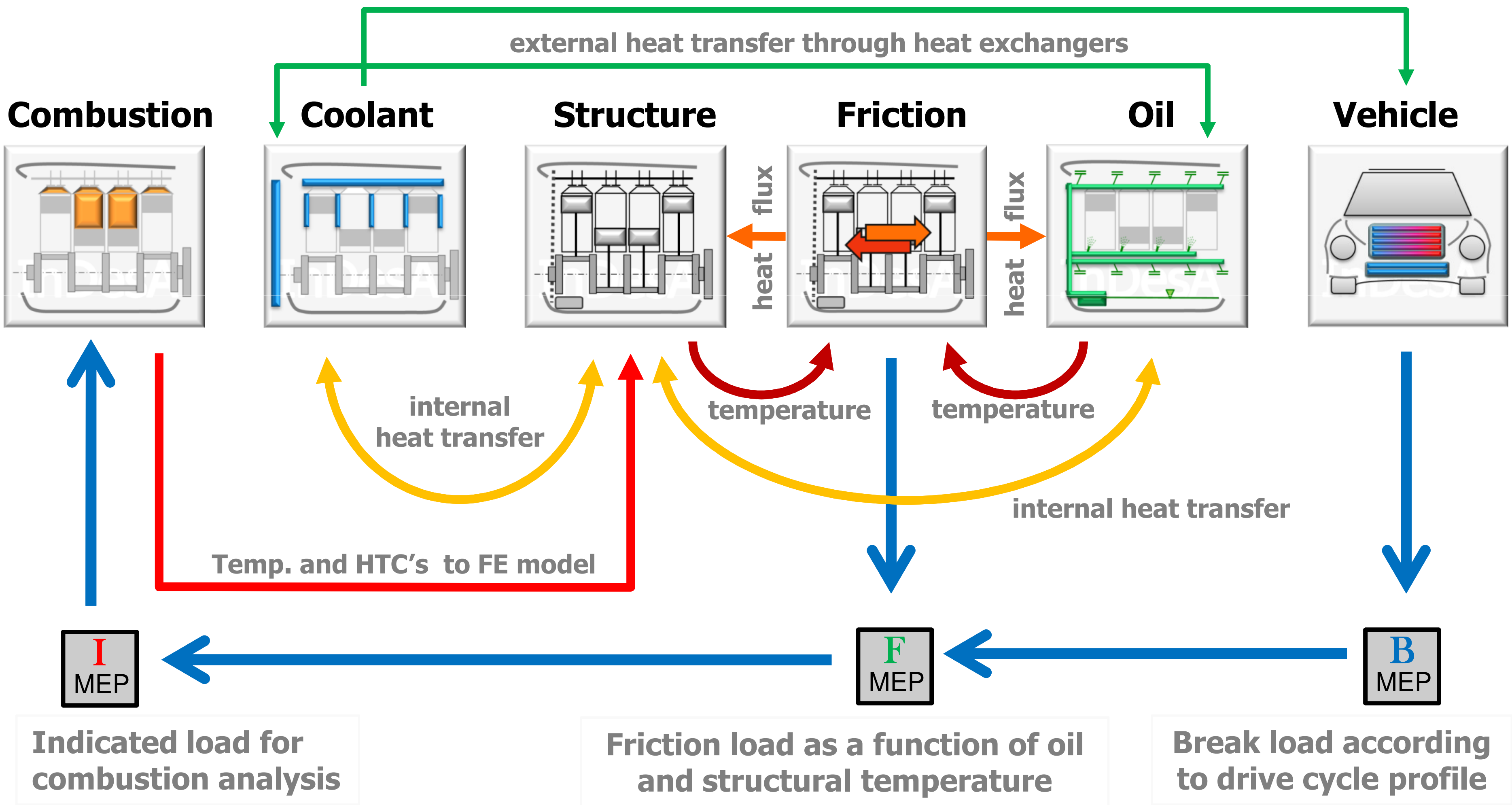
II. Engine Warm-Up

Interaction of Modules / Sub-Assemblies



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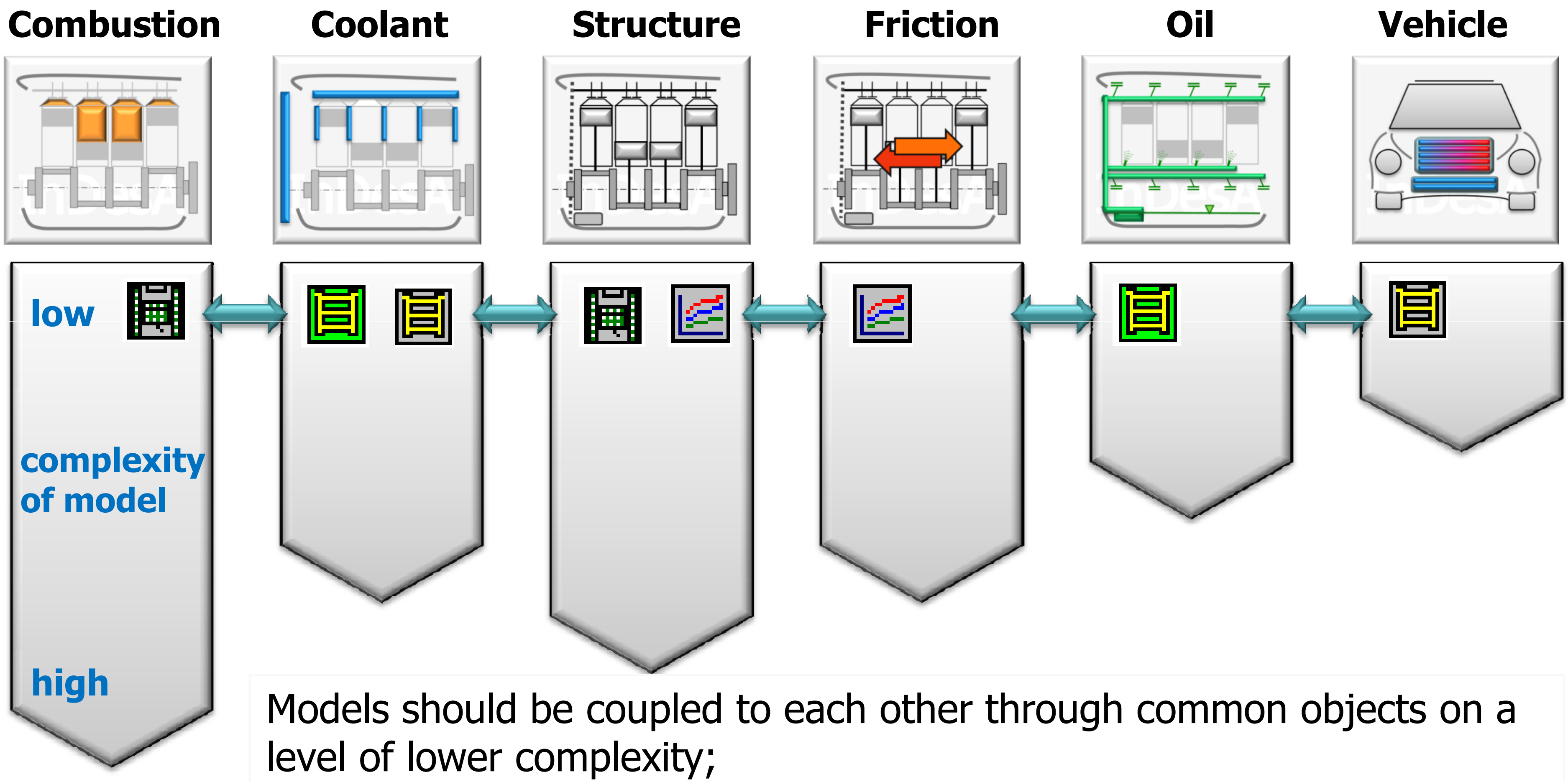
Thermal Management Simulation
II. Engine Warm-Up

Interaction of Modules / Sub-Assemblies

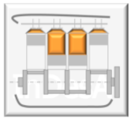


Models should be coupled to each other through common objects on a level of lower complexity;
⇨ reduces duplication of work and makes baseline data consistent
⇨ requires interdepartmental collaboration

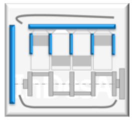
Thermal Management Simulation

II. Engine Warm-Up

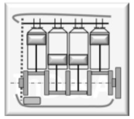
Major (critical) Requirements to build Modules:



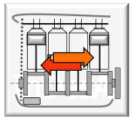
GT-POWER model must be calibrated for part load performance and MeanValue representation.



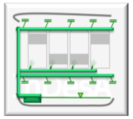
3D CFD calculation for the flow of the engine‘s waterjacket must be available to build detailed 1D model.



3D CFD/CHT or FEM thermal analysis calculation for the engine‘s structure must be available to model the major heat flux paths correctly in the 1D model.



Strip-down measurements must be available to obtain friction maps for the different friction groups as a function of structure/oil temperature over engine speed (zero load).



Oil pump performance, pump control, and consumer behavior must be known as a function of oil temperature.

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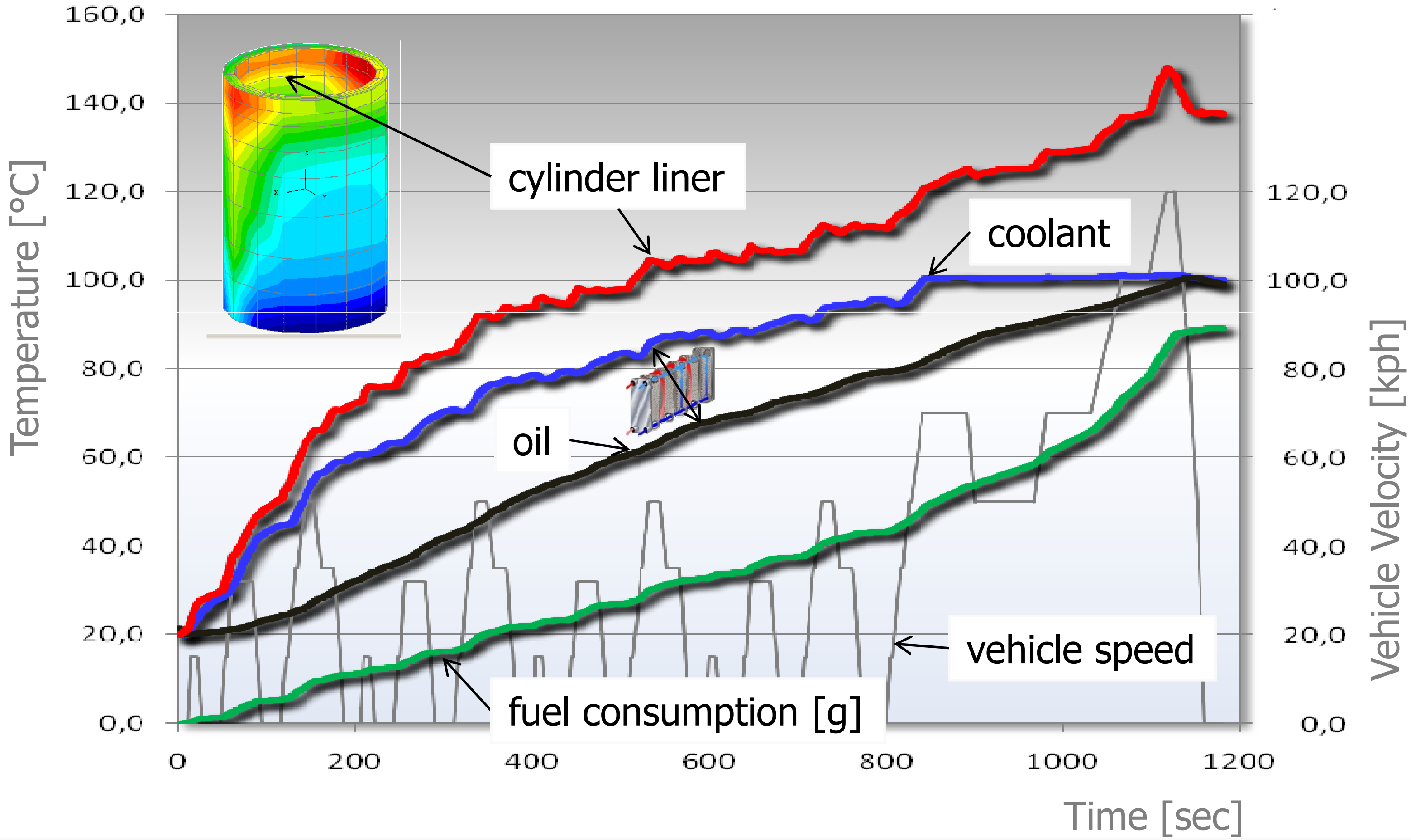
II. Engine Warm-Up

Example Results:
Temperatures for NEDC Drive Cycle



Temperature of oil and structure affect friction and fuel consumption

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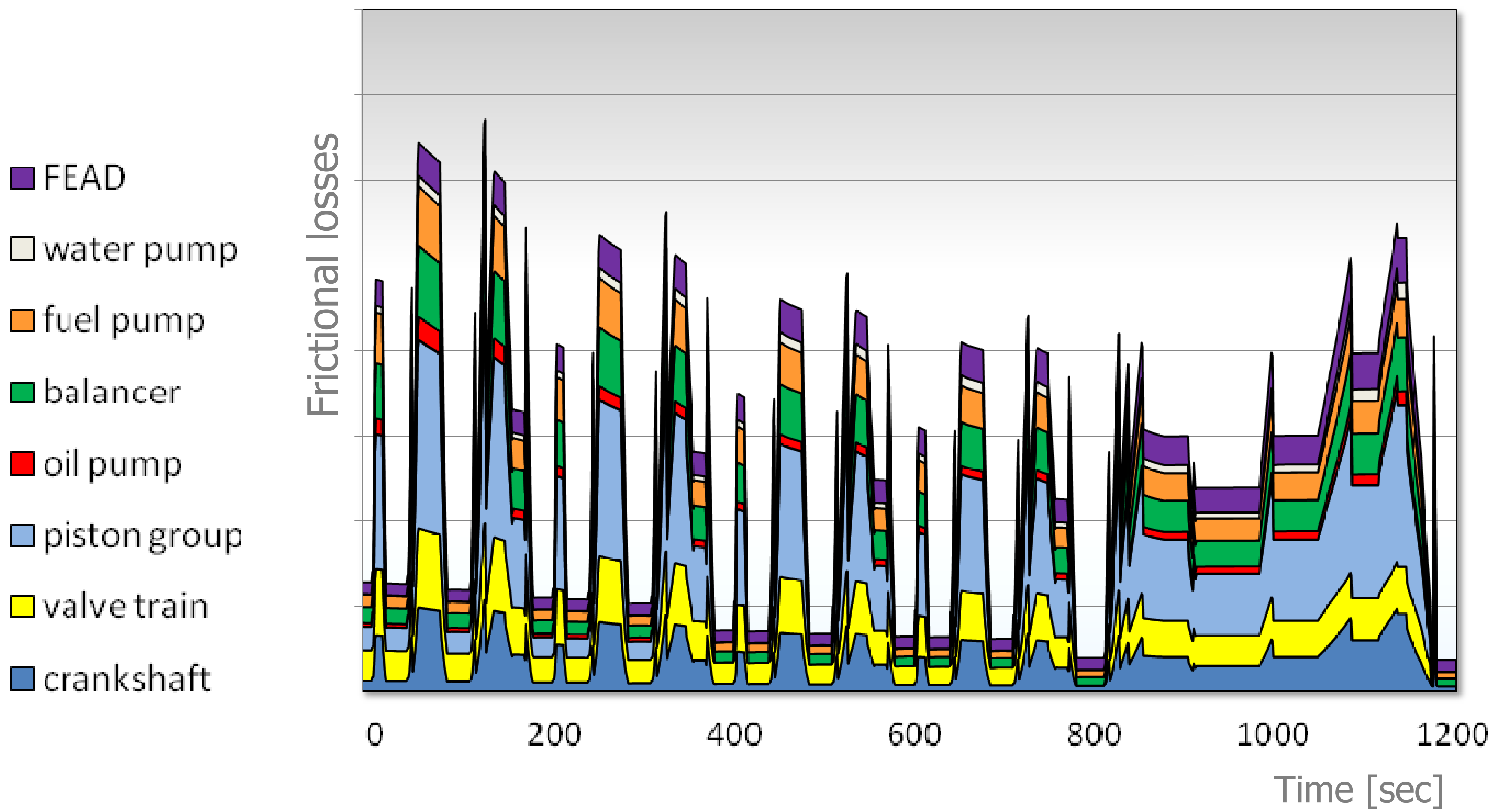
Example Results:
Frictional Losses for NEDC Drive Cycle



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Thermal Management Simulation
II. Engine Warm-Up

Future Development

- Extension of friction module to allow for load other than zero.

- Inclusion of control unit (ECU) to allow for the interaction of thermal management and combustion control

In future engine warm-up models will be used to predict the heat flux rates of the engine to the coolant and oil for the design of cooling systems (application I) and for general thermal management strategies.

Engine Warm-Up Model

⇨ **General Vehicle Thermal Management (VTM) Model**

⇨ **Vehicle Energy Management (VEM) Model**

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Thermal Management Simulation
III. Thermal Reliability

... to protect components from thermal damage

Background information:

Case of interest: **Thermal Soak**

Vehicle slows down from high speed cruise and comes to a complete stop; engine shut off.
(e.g stop at highway gas station or rest area)

⇨ The engine, turbo charger and exhaust system will cool down due to convection and radiation, but will heat up neighboring components with a possibility of thermal damage.

Time period of interest: up to 20 minutes after vehicle stops.

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Thermal Management Simulation

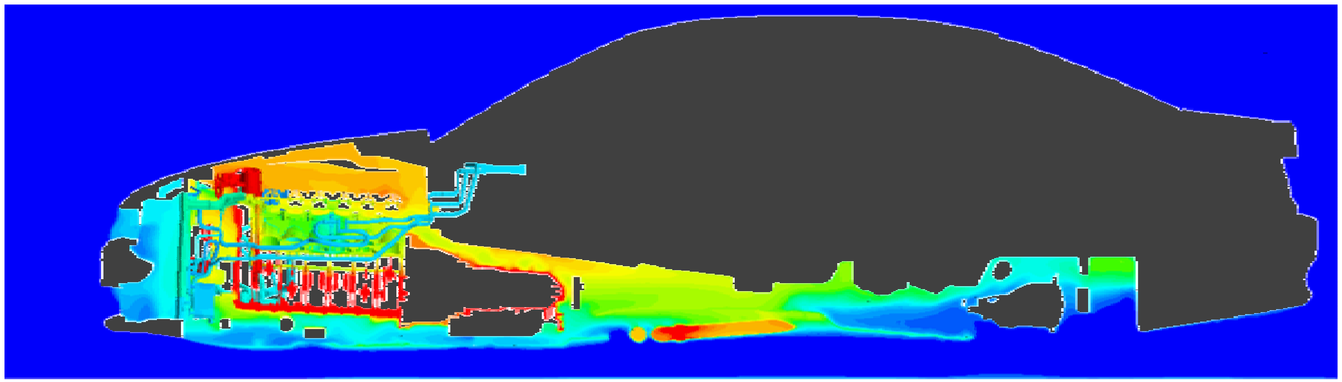
III. Thermal Reliability

Thermal Soak

State-of-the art:
Because of the complexity of the involved geometry the simulation model must capture 3D details.

⇨ 3D CFD/CHT* model for a full vehicle is needed.

Simulation must include:
Flow over vehicle and through engine compartment; complete coolant circuit, CHT engine model, CHT exhaust system model, and more **.



*) conjugate heat transfer

**) for details see our presentation at the Star Conference, Berlin 09.11.2009

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Thermal Management Simulation
III. Thermal Reliability

Thermal Soak

However ...

Consistent boundary conditions for such complex simulation models are hard to obtain if they are available at all!

Sample of boundary conditions needed:
BMEP, FMEP, IMEP, mass flow rates, temperatures and heat transfer coefficients in combustion chambers and exhaust system, waste gate position of TC, catalyst reaction, charge air temperature and mass-flux, heat transfer maps and porosities for heat exchangers, …

Consistent Boundary conditions can in principal be provided by 1D VTM System Simulation.

⇨ **GT-SUITE VTM System Simulation will serve as a backbone for complex 3D thermal underhood simulations.**

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Thermal Management Simulation
Conclusion - Outlook

Vehicle Thermal Management applications I, II, III will merge to one general application in future.
⇨ One GT-SUITE model will cover all applications

Modules are in principal available, but need to be further enhanced and calibrated by test data.
⇨ GT-POWER part load; frictional models for non zero load

Modules must be synchronized throughout the product development process and must use common objects.
⇨ requires interaction of different groups of competence

1D System Simulation must strongly interact with CFD analysis.
⇨ 3D enhances 1D Simulation
⇨ 1D Simulation provides backbone for complex 3D CFD simulation

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Thank you for your attention !