Vehicle Thermal Management Systems Conference and Exhibition

Gaydon, UK   15-19 May 2011

A High-Resolution Warm-Up Simulation Model for a Gasoline Engine with Advanced Thermal Control

Dr. Gerald Seider, InDesA GmbH
Jan Mehring & Carsten Weber, FORD Werke GmbH

InDesA

Ford

A High-Resolution Warm-Up Simulation Model
Methodology

What is a High-Resolution Warm-Up Simulation Model ?

	low-resolution Model	**high-resolution Model**
engine structure represented by …	only few lumped masses (1-10 masses)	by Finite Element Models for area close to combustion chamber (liner, flame deck, piston, in/outlet ports) and lumped masses for outer structure.
coolant jacket represented by …	few pipes and flow splits with only few contact surfaces to structure for heat transfer	each cylinder segment resolved and split off for crankcase and cylinder head; calibrated by 3D CFD simulation
oil circuit represented by …	few pipes and flow splits with only few contact surfaces to structure for heat transfer	all pipes/drills and return flow passages included; flow consumers of same kind are grouped together (bearings)

A High-Resolution Warm-Up Simulation Model
Methodology

What is the Benefit of a High-Resolution Warm-Up Simulation Model ?

Due to the geometrical resolution of the simulation model temperatures of the engine structure, the oil and the coolant can be predicted adjacent to different frictional groups such as

- ➢ valve train
- ➢ chain drive
- ➢ piston assembly
- ➢ crank train
- ➢ auxiliary shafts

➔ **Prediction of frictional losses** (FMEP); based on motored strip measurements (zero load) as a function of oil and structural temperatures.

➔ **Prediction of fuel consumption** for different warm-up drive cycles; based on measured fuel consumption maps as a function of IMEP and engine speed.

A High-Resolution Warm-Up Simulation Model
Methodology

Who should use a High-Resolution Warm-Up Simulation Model ?

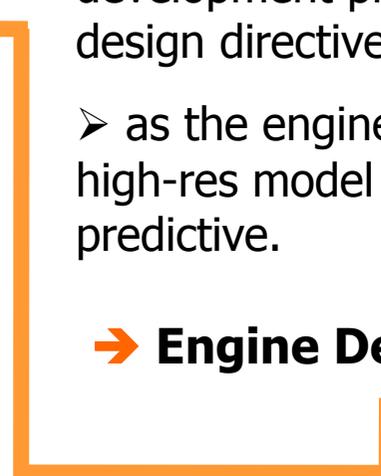| low-resolution Model	high-resolution Model

➢ generic model is calibrated after the engine/vehicle is available and tested on an engine test bench or roller dynamometer.

➢ model can be used for the design of coolant systems after the engine is available.

➢ model must be synchronized, build and calibrated within the engine creation process.

➢ model is available throughout development process and gives design directives.

➢ as the engine is developed the high-res model is becoming more predictive.

➔ **Cooling System Supplier**

➔ **Engine Developer (OEM)**

A High-Resolution Warm-Up Simulation Model
Investigated Prototype Engine
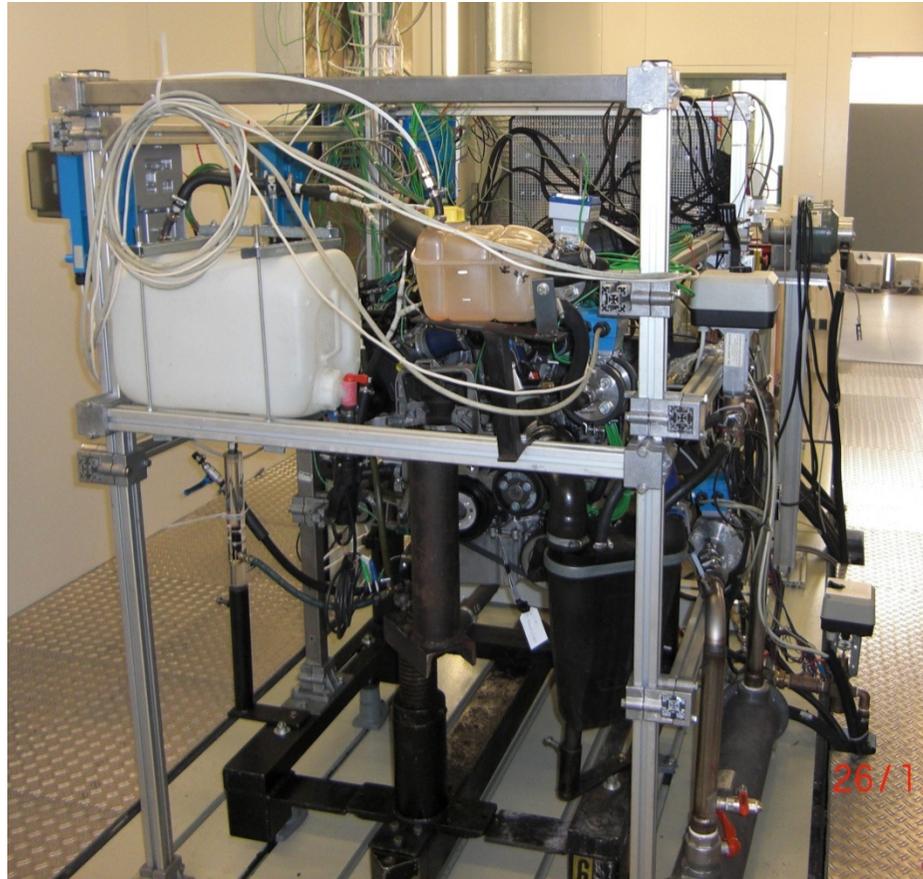
The Engine:

➢ turbo charged
➢ 3 cylinders
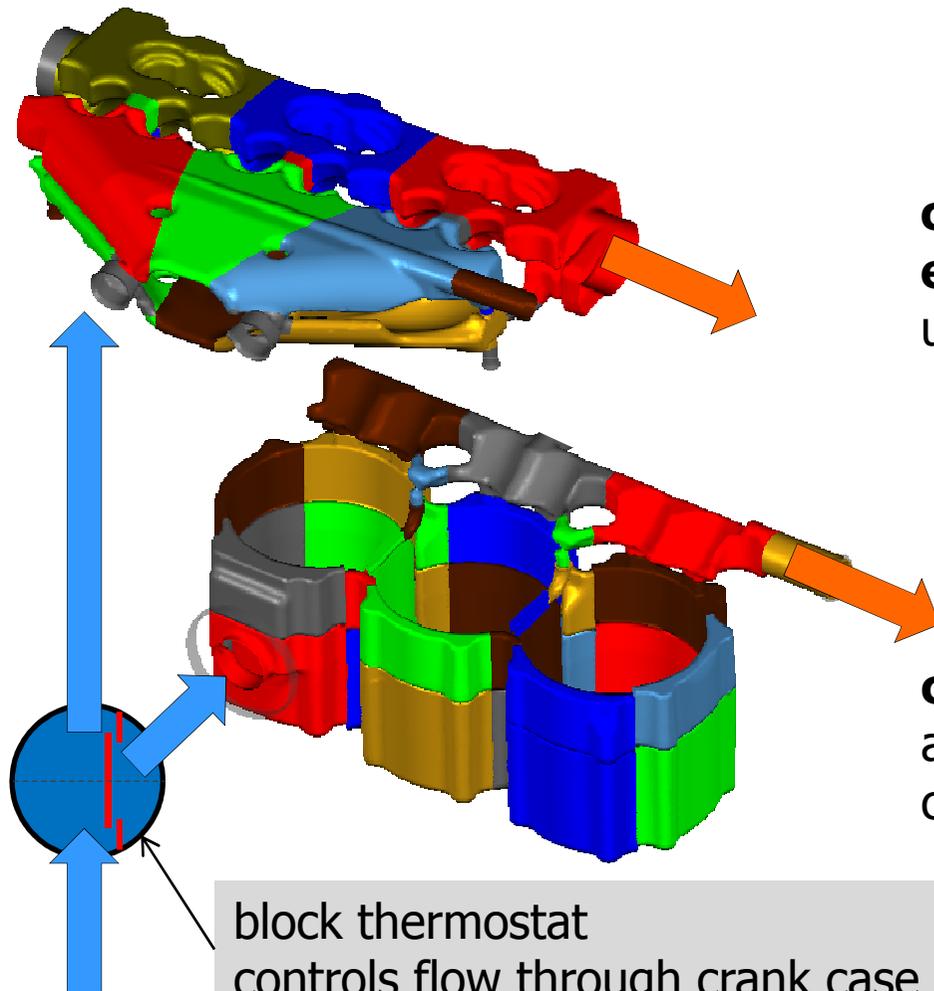➢ gasoline DI
➢ 1 Liter displacement

The Cooling System:

➢ split-cooling concept
➢ water-cooled exhaust manifold
➢ controlled thermostat

What is the benefit of Split-Cooling with respect to fuel consumption ?

A High-Resolution Warm-Up Simulation Model
The Split Cooling Concept - Waterjacket

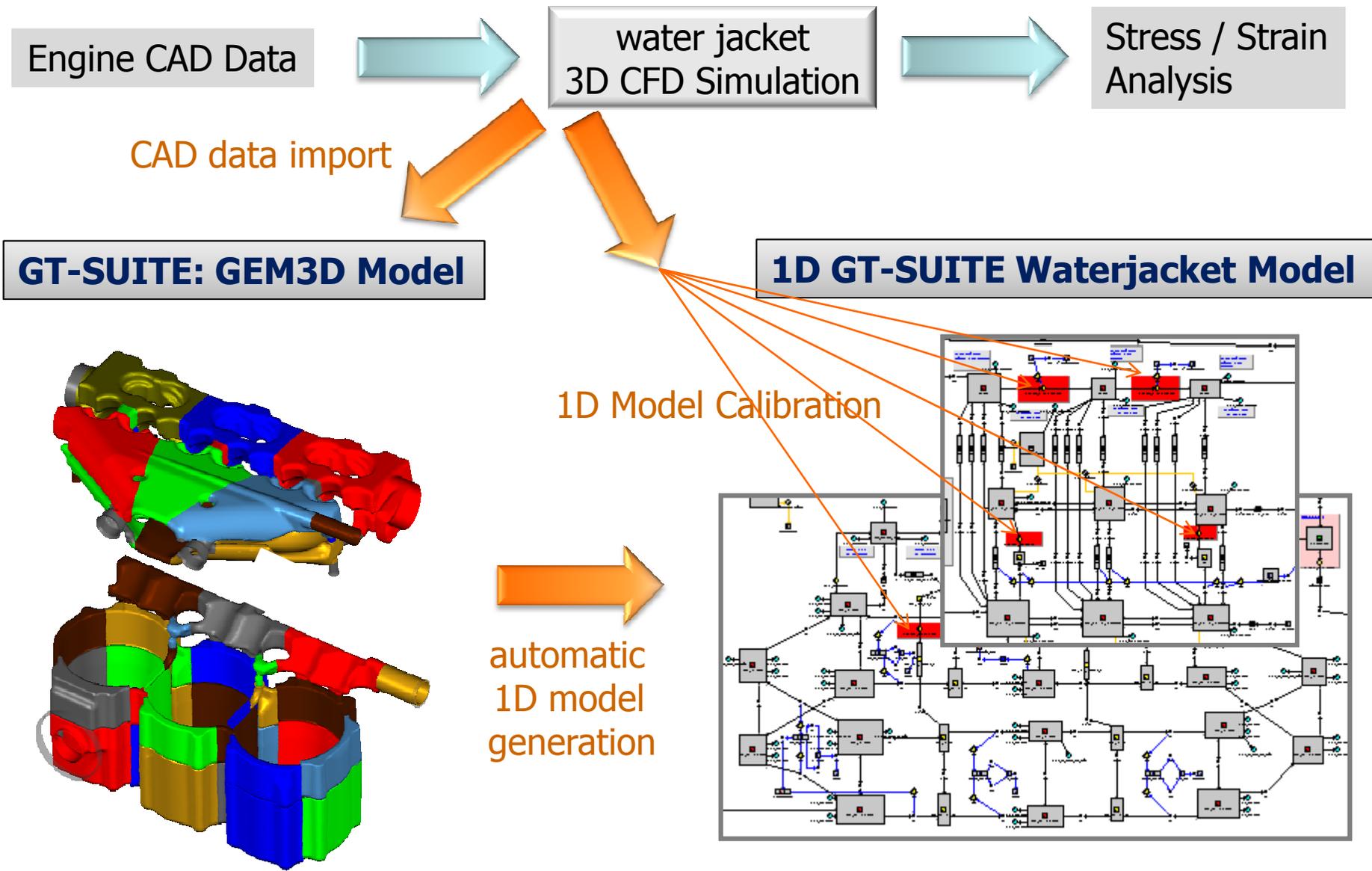**cylinder head and exhaust manifold:** unblocked; permanent flow

crankcase : coolant stagnant at beginning of warm-up; inlet to crankcase blocked by thermostat

block thermostat controls flow through crank case

A High-Resolution Warm-Up Simulation Model
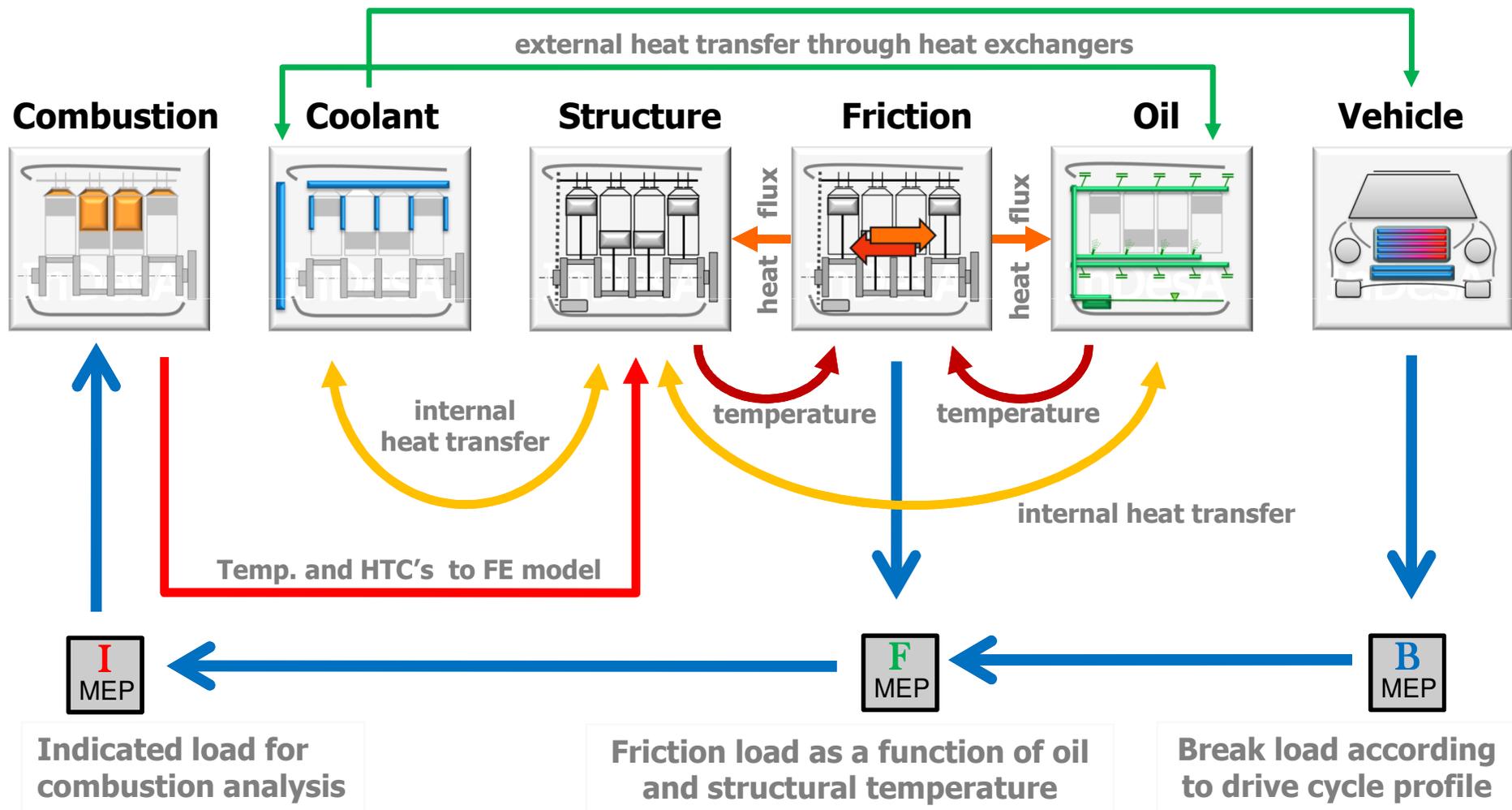## Work Flow to set up the Simulation Model

Engine CAD Data → water jacket 3D CFD Simulation → Stress / Strain Analysis

CAD data import

GT-SUITE: GEM3D Model

1D GT-SUITE Waterjacket Model

1D Model Calibration

automatic 1D model generation

A High-Resolution Warm-Up Simulation Model
Architecture of GT-SUITE Simulation Model

Interaction of Modules / Sub-Assemblies

external heat transfer through heat exchangers

Combustion   **Coolant**   **Structure**   **Friction**   **Oil**   **Vehicle**

heat flux

heat flux

internal heat transfer

temperature   temperature

internal heat transfer

Temp. and HTC's to FE model

I MEP   **F** MEP   **B** MEP

Indicated load for combustion analysis   **Friction load as a function of oil and structural temperature**   **Break load according to drive cycle profile**

A High-Resolution Warm-Up Simulation Model
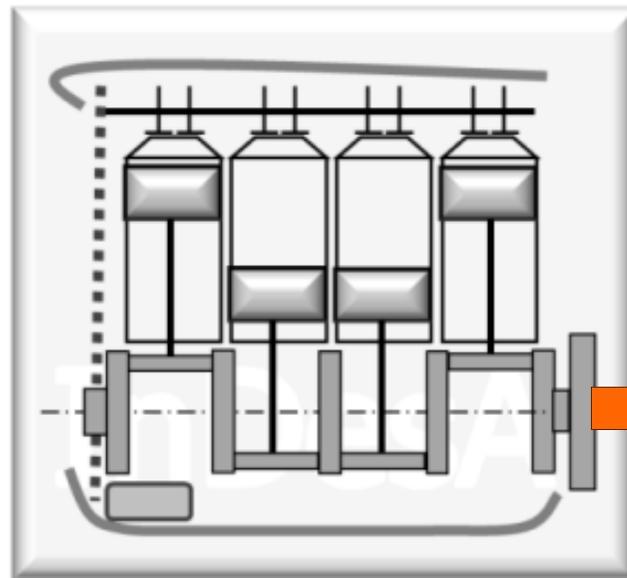## Methodology of Engine Strip Measurements

- engine motored by electric motor ⇨ zero load
- coolant and oil temperatures held constant
- frictional torque is measured

- investigation starts with complete engine
- engine assembly groups are progressively disassembled
to identify the contribution of different frictional groups:

Coolant
30, 60, 90 °C

Oil
30, 60, 90 °C
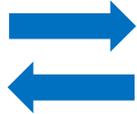
Electric Motor

➢ piston/liner assembly
➢ crankshaft
➢ valve train
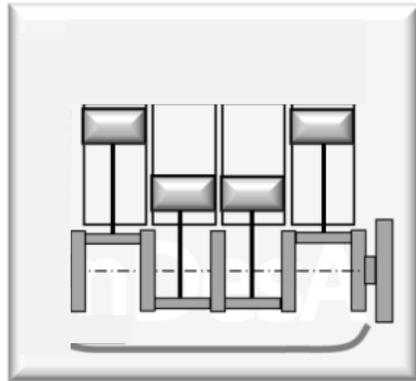➢ chain/belt drive
➢ balancer module, etc.

InDesA

Ford

A High-Resolution Warm-Up Simulation Model
Methodology of Engine Strip Measurements

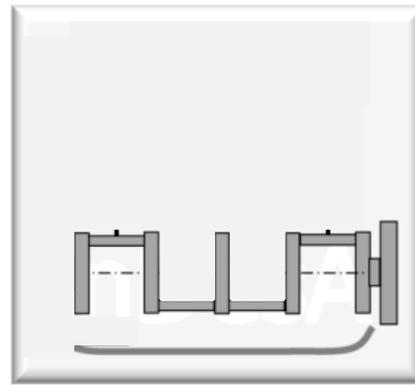### Investigation of frictional torque for the piston assembly

crank train
- open gas room
- liner water cooled

crank shaft
- with master weights

piston/liner and conrods

friction dependent on **oil and coolant** temperature

friction dependent only on **oil** temperature

friction of liner/piston dependent on **coolant** temperature

friction of conrod bearing dependent on **oil** temperature

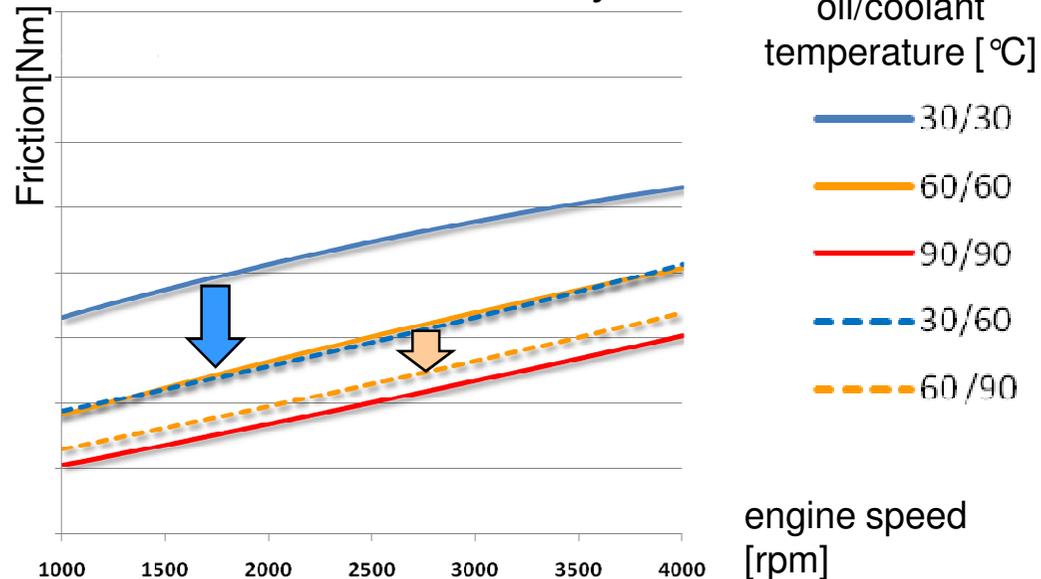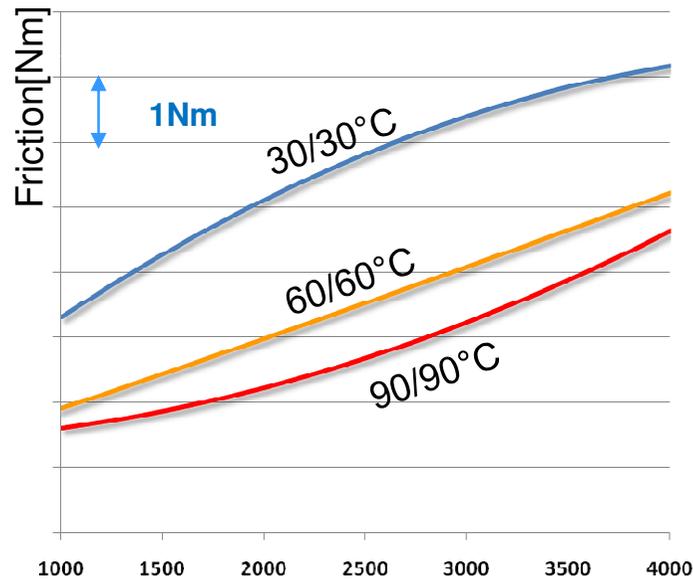**InDesA**

A High-Resolution Warm-Up Simulation Model
Frictional Torque for Engine and Piston Assembly

coolant T [°C]

	30	60	90
30	x		
60		x	
90			x

oil T [°C]

Complete Engine

coolant T [°C]

	30	60	90
30	x	x	
60		x	x
90			x

oil T [°C]

Piston Assembly

Friction[Nm]

1Nm

30/30°C

60/60°C

90/90°C

Friction[Nm]

oil/coolant
temperature [°C]
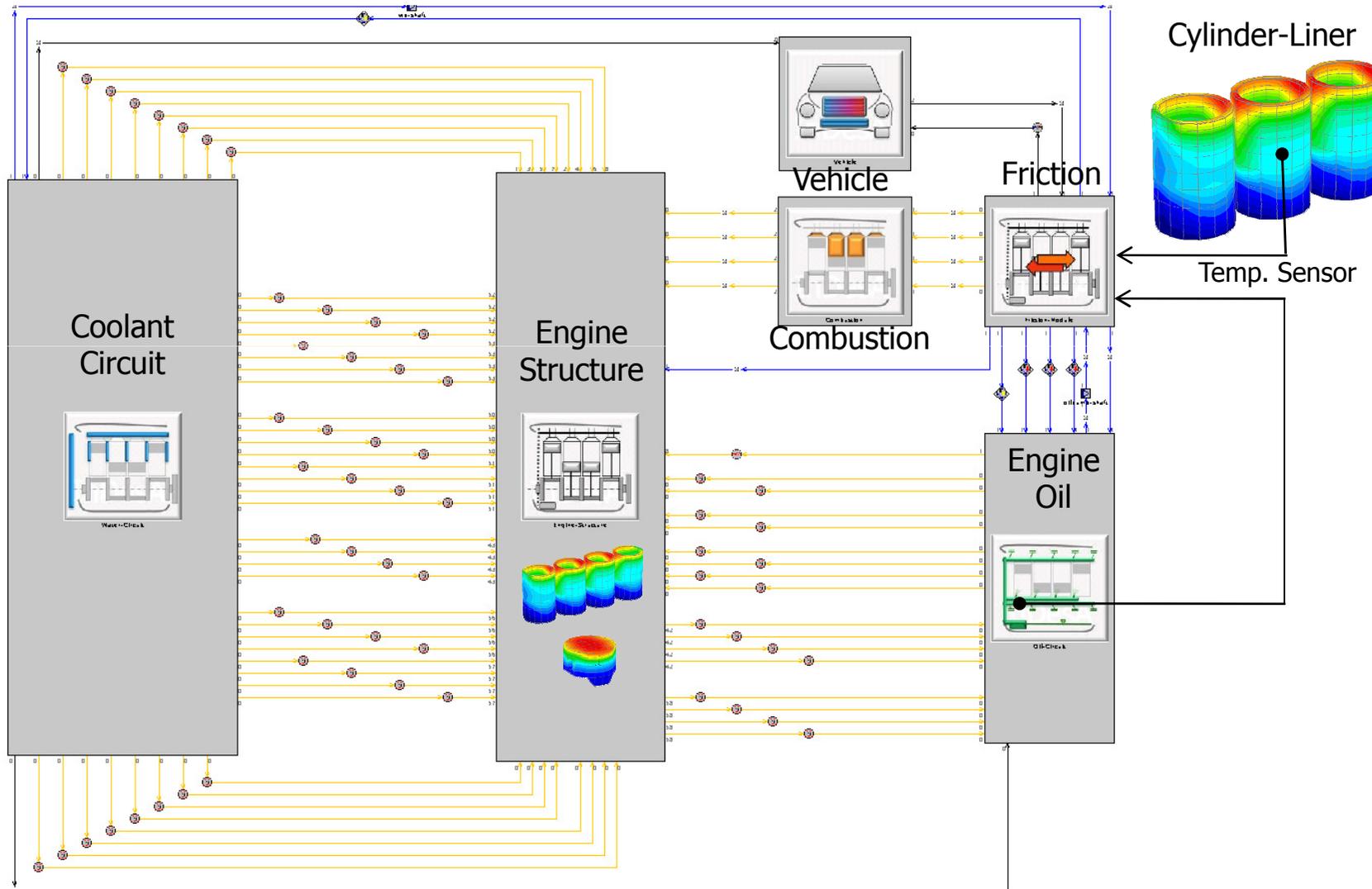
— 30/30
— 60/60
— 90/90
---- 30/60
---- 60 /90

engine speed
[rpm]

➢ piston assembly friction depends mainly on coolant temperature
➢ if coolant heat transfer coefficient is high ⇨ coolant Temp. = liner Temp.

A High-Resolution Warm-Up Simulation Model
GT-SUITE Warm-Up Simulation Model

Cylinder-Liner

Vehicle

Friction

Temp. Sensor

Coolant
Circuit

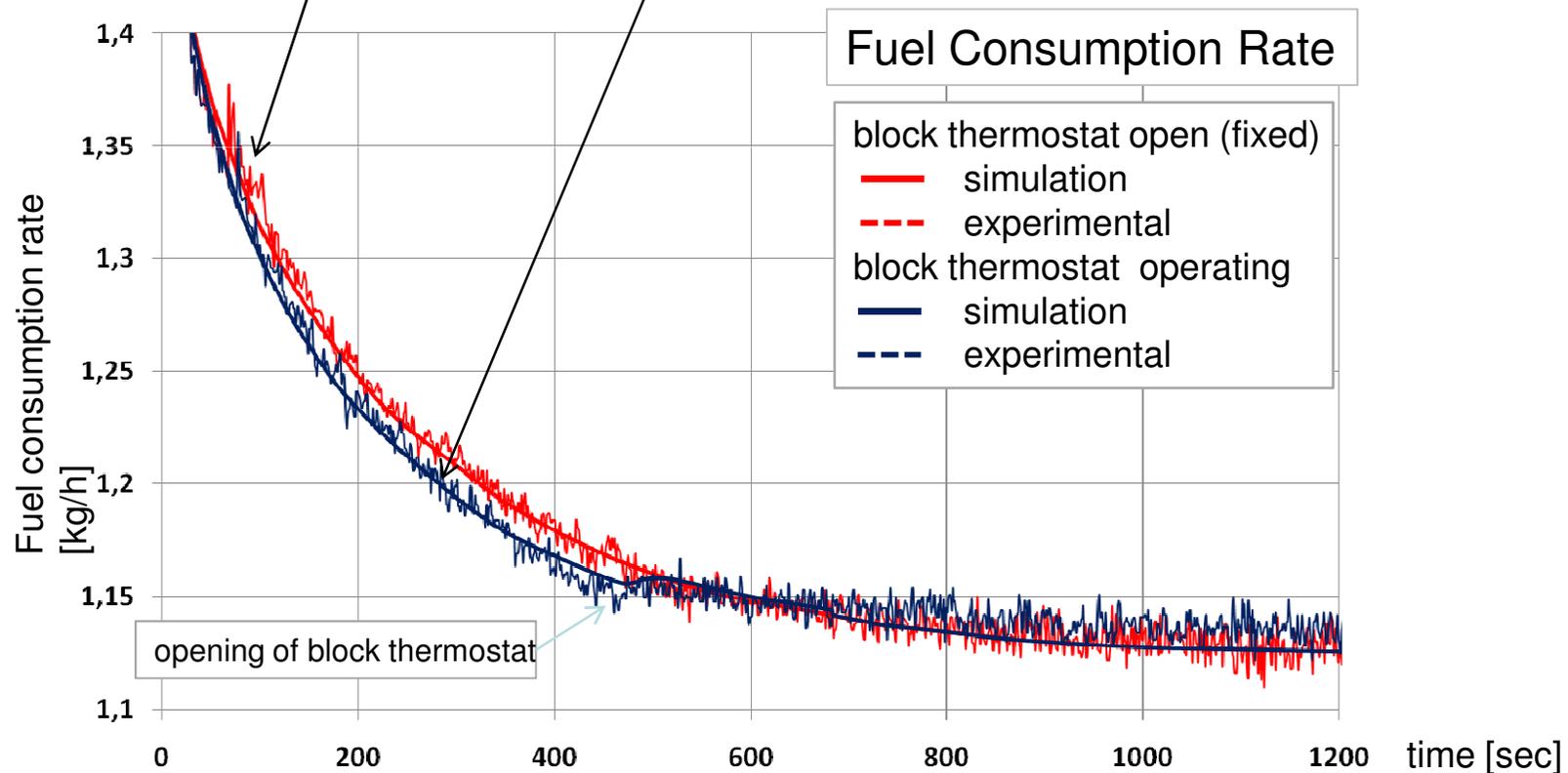Engine
Structure

Combustion

Engine
Oil

A High-Resolution Warm-Up Simulation Model
Warm-Up for Constant Brake Load

results **calibrated** for warm-up <u>without</u> split cooling

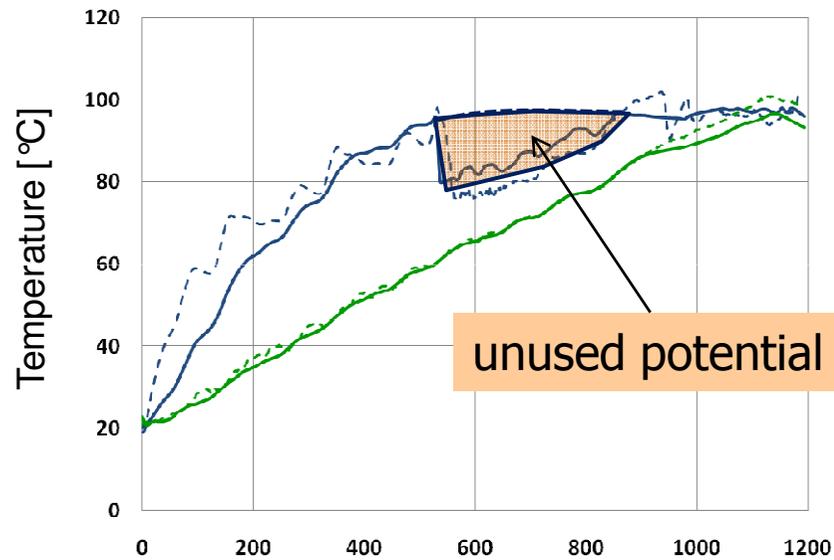results **predicted** for warm-up <u>with</u> split cooling

A High-Resolution Warm-Up Simulation Model
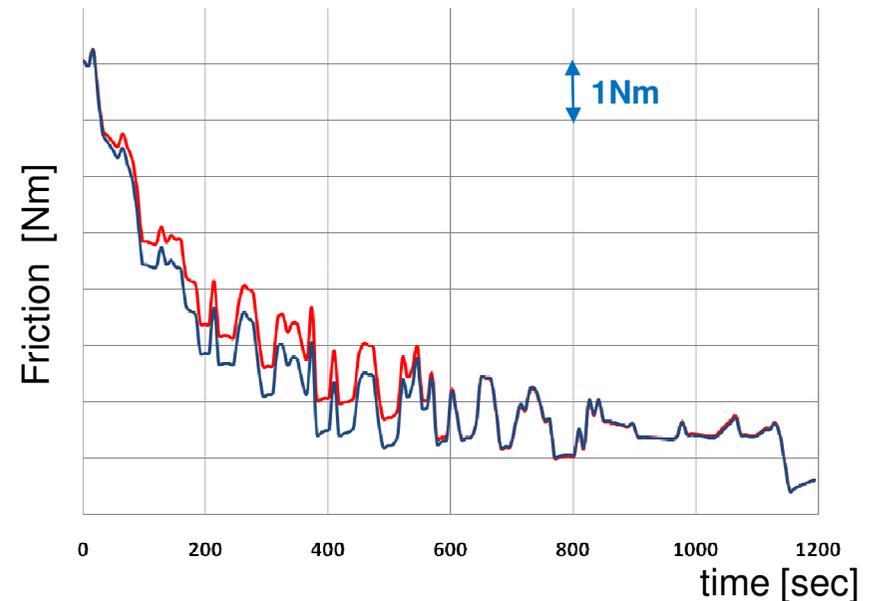## Warm-Up for NEDC Drive Cycle

Coolant and Oil Temperature

Friction Torque

unused potential

1Nm

Coolant temp. in water jacket of cyl 2
—— simulation (spatial averaged)
- - - experimental
Oil temperature in oil pan
—— simulation
- - - experimental

Simulation with block thermostat
—— a) open (fixed)
—— b) operating (Split Cooling)

A High-Resolution Warm-Up Simulation Model
Summary

A High-Resolution Warm-Up Simulation Model
was developed and used to predict and assess the potential
of advanced thermal concepts (Split-Cooling) with respect to

⇨ **frictional losses** for the complete engine and its frictional groups
⇨ **fuel consumption** for different warm-up drive cycles,

utilizing the following measurements for calibration:

❑ Engine Strip Measurements
❑ Thermal Measurements
❑ Fuel Consumption Measurements

Future development:
Full integration of GT-POWER to predict gas exchange losses
and account for full energy conservation.

Thank you for your attention !

www.InDesA.de