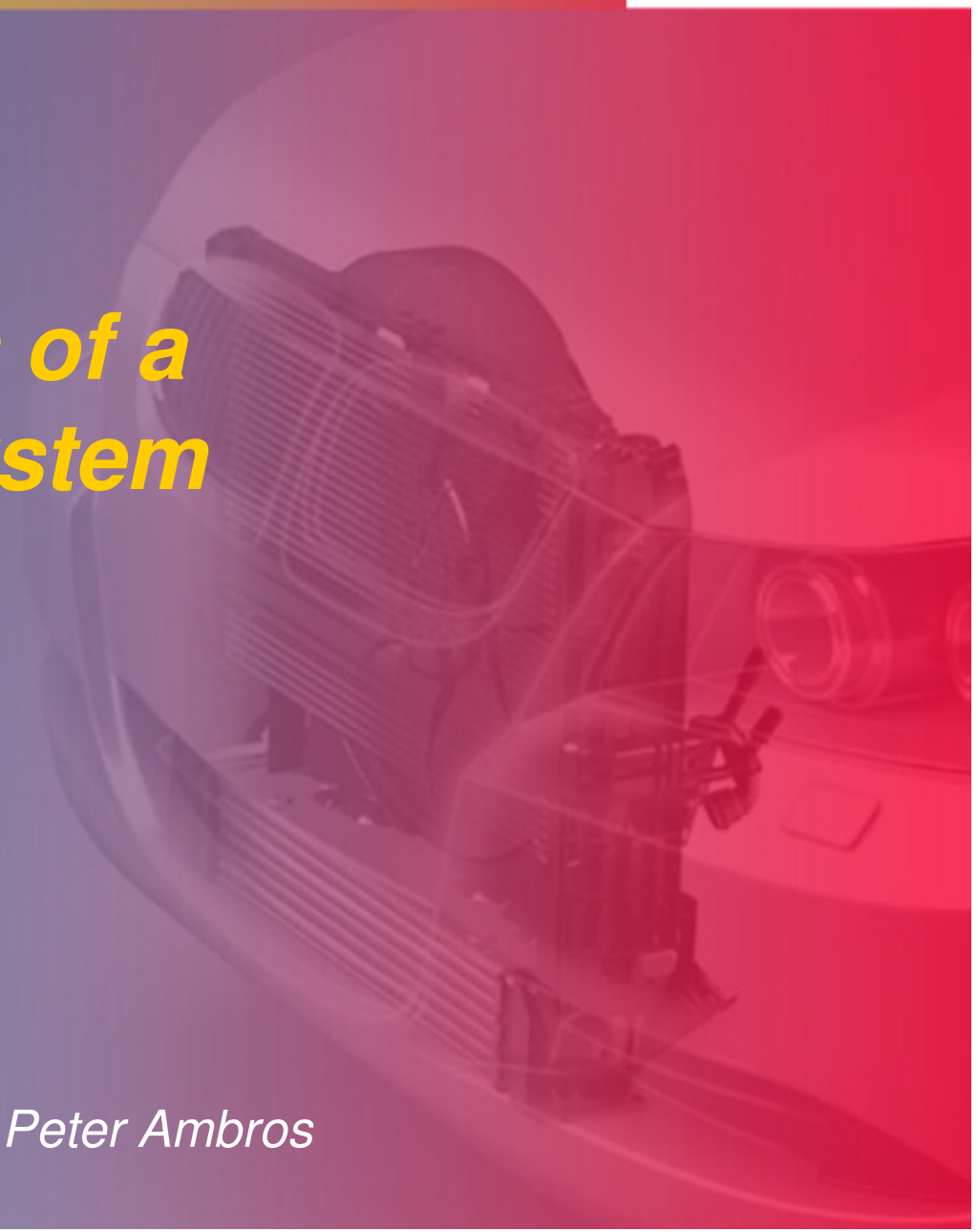
Thermal Analysis of a Truck Cooling System

KULI User Meeting
June 14, 2007



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Overview

1. **Motivation & Objective**

2. **Approach**

3. **Wind Tunnel Measurements**
   - Test Vehicle & Measurement Program
   - Measurement equipment

4. **Simulation**
   - Thermal Vehicle Simulation Model
   - Results

5. **Summary**

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Motivation for development of enhanced simulation model

- Quantify the potential advantage of new cooling system concept on:
  - fuel consumption
  - Cold start and warm-up phase
- increasing complexity of cooling systems
- control of auxiliary units

Objectives

Enhancement of measurement equipment for vehicle tests

Enhancement of Modine simulation tools

Approach

Objective 1: Enhancement of measurement equipment

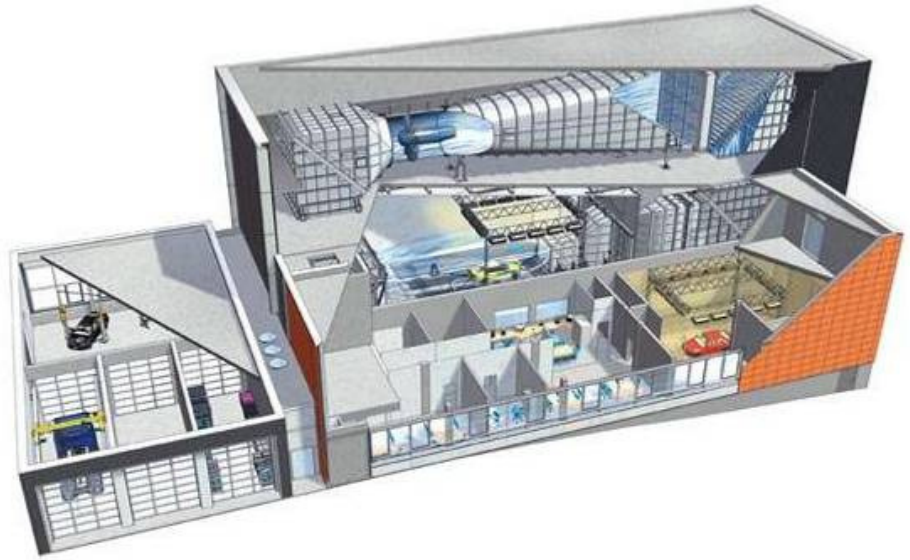
- Equip a test vehicle with measurement instrumentation
- Qualify new measurement equipment in wind-tunnel tests

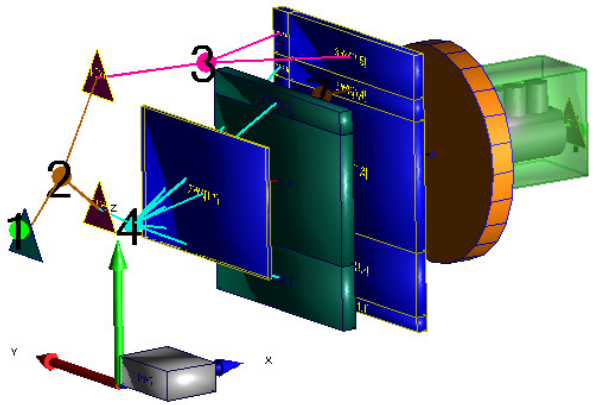
Measurement

Objective 2: Enhancement of simulation tools

- Develop an enhanced thermal vehicle simulation model
- Compare simulation results of enhanced model to wind-tunnel measurement

Simulation





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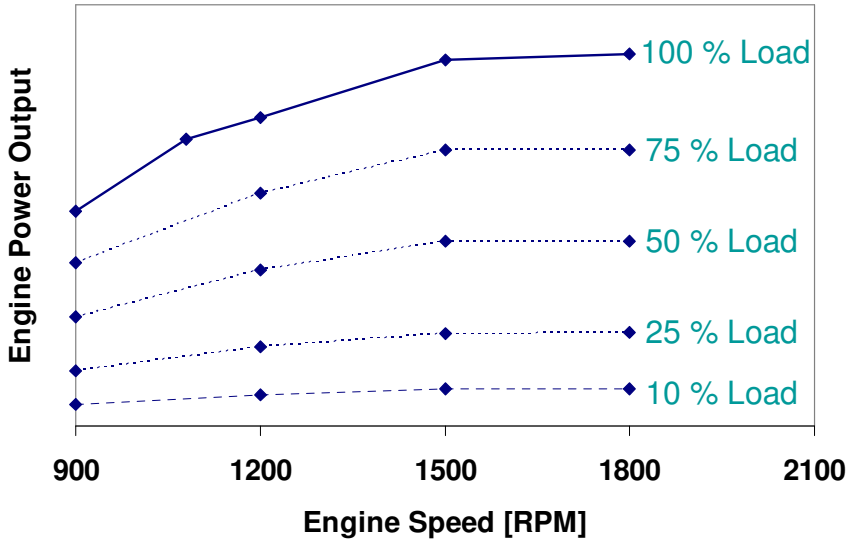
Wind Tunnel Measurements

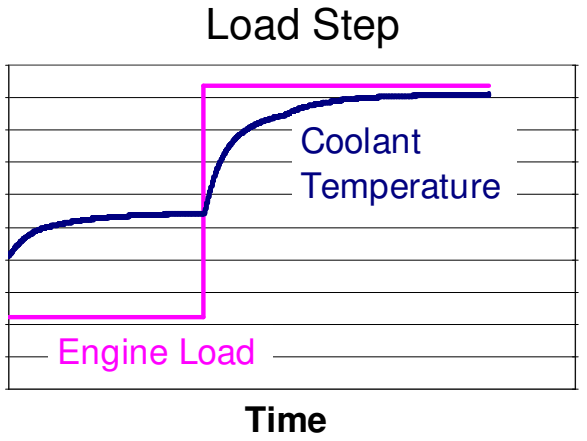
Test Vehicle

- Truck, V8-engine, 570 hp
- thermostat blocked (open position)
- locked fan clutch

Measurement program

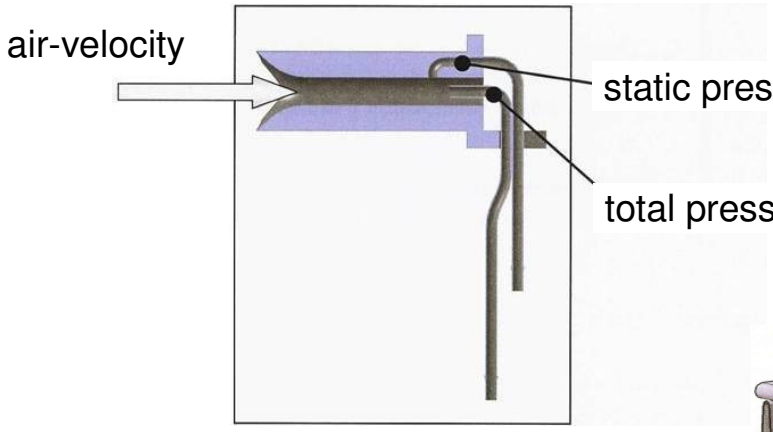
- steady-state operating points
  T_amb=25°C, wind speed 0…135 km/h
- Load step



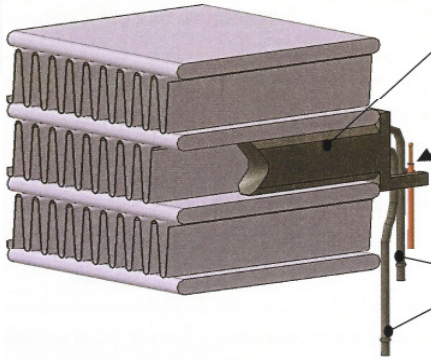


Wind Tunnel Measurements

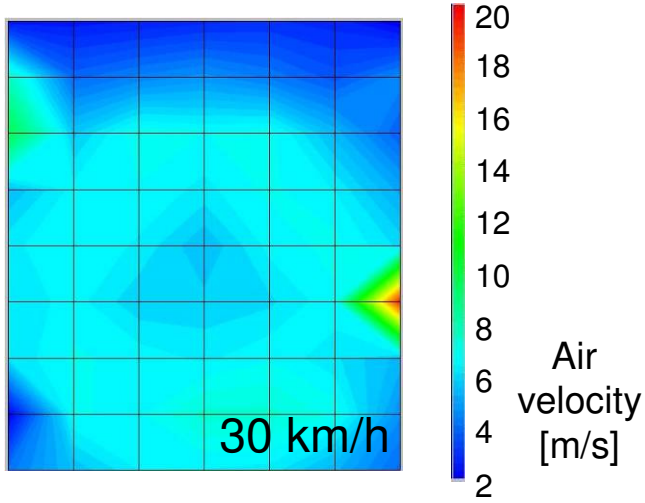
Measurement of cooling air mass flow rate



Micro-Probe



Installation in core



Radiator equipped with 63 Micro-Probes

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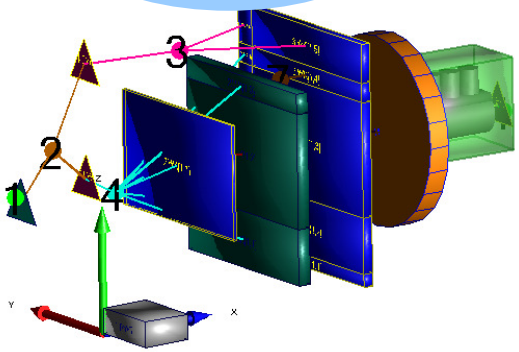
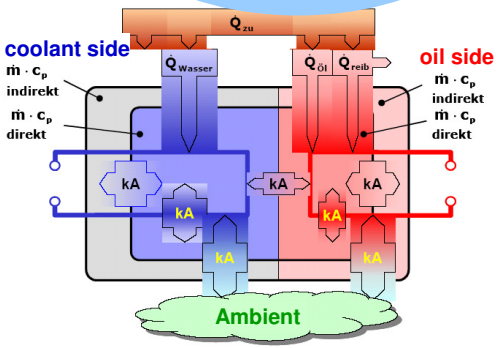
Enhanced Simulation Model

Charge Air
KULI

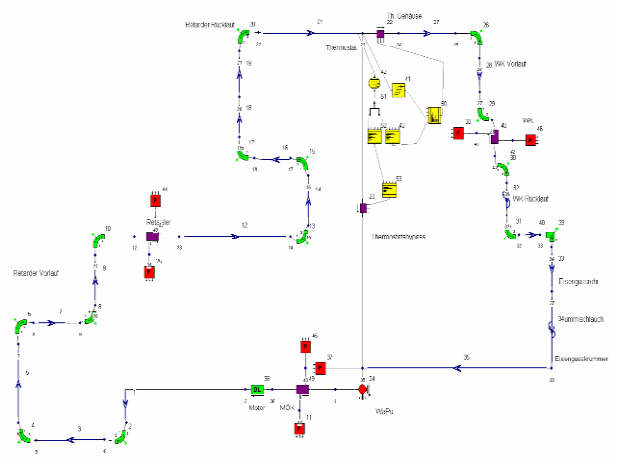
Cooling Air Duct
KULI

Engine
KULI





Master
Matlab/Simulink

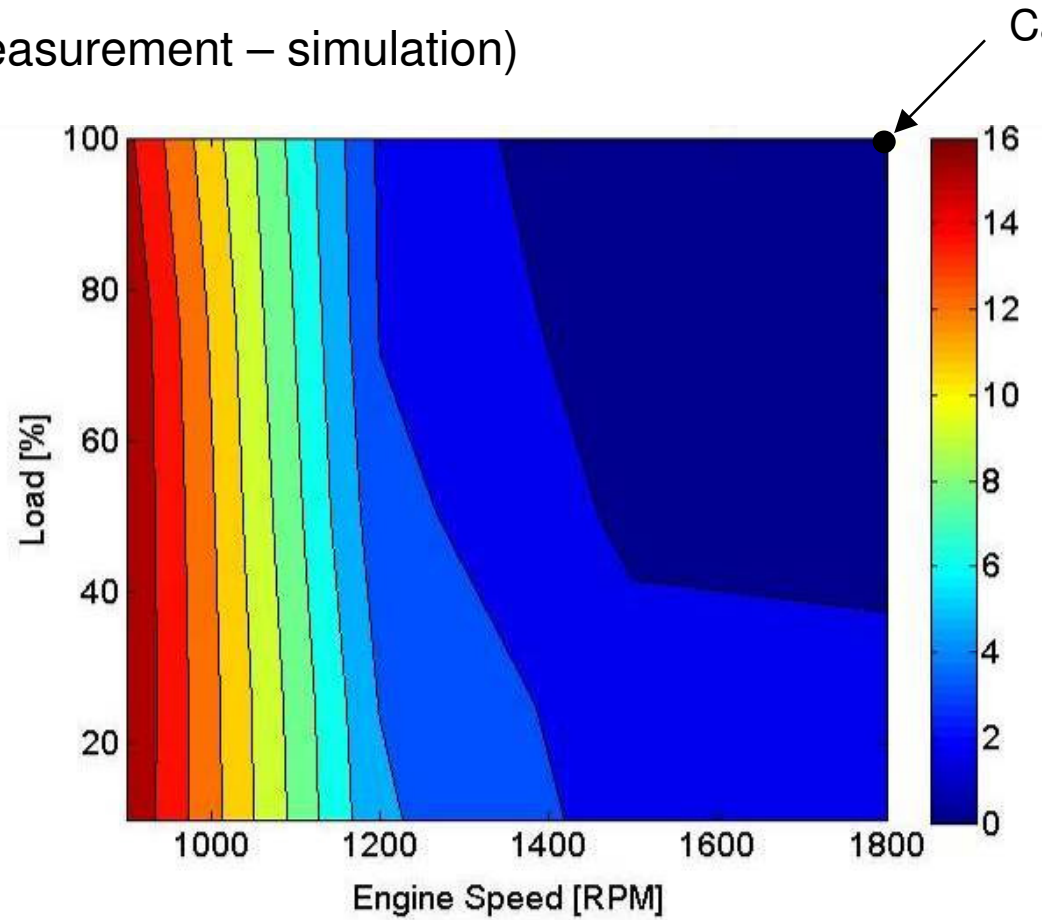


Powertrain & Driving Cycle
(future)

Coolant Circuit
Flowmaster

Coolant: Accuracy of flow rate simulation

Deviation (measurement – simulation)



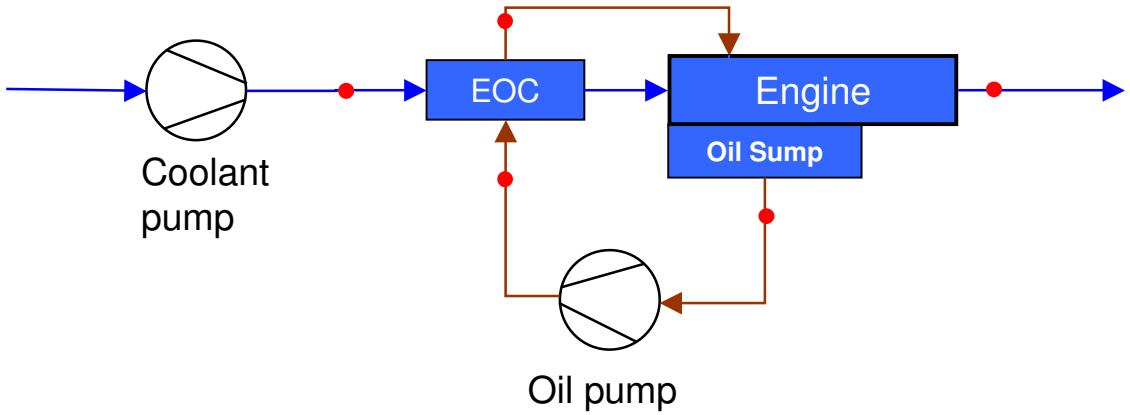
Deviation in coolant flow rate (radiator) [%]

⇨ deviation < 5% for usual operating range of a truck

⇨ higher deviation at engine speeds lower than 1200 RPM due to extrapolation in pump characteristic

Data for Engine Model

Measurement of coolant and oil temperature

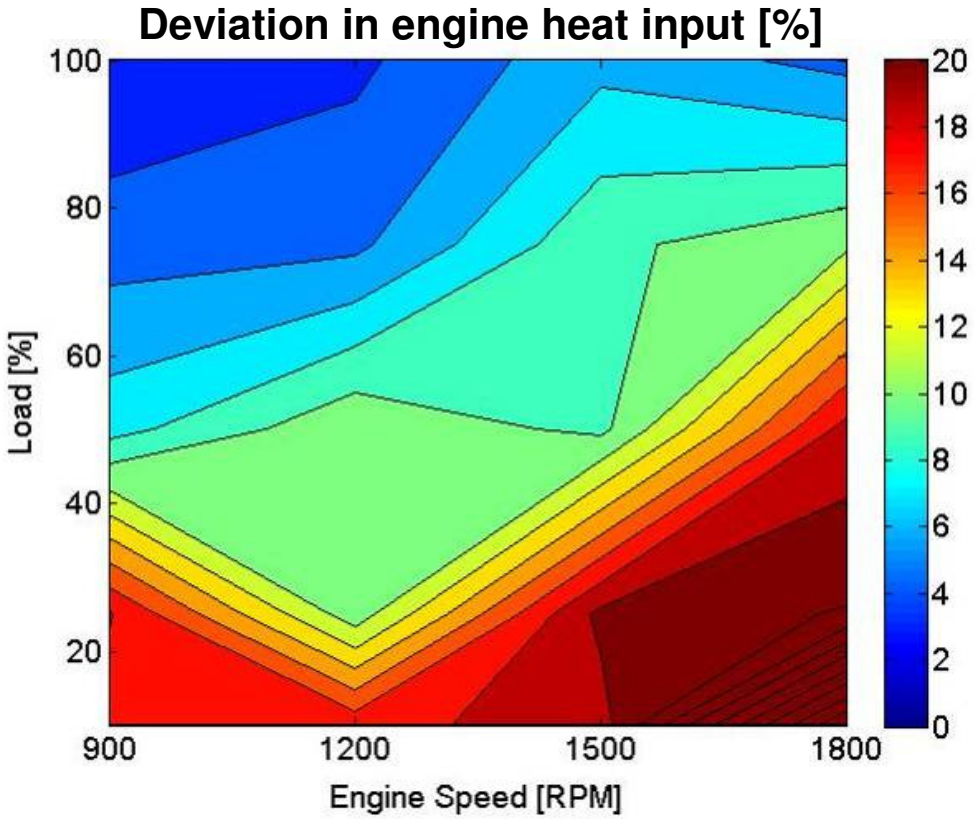


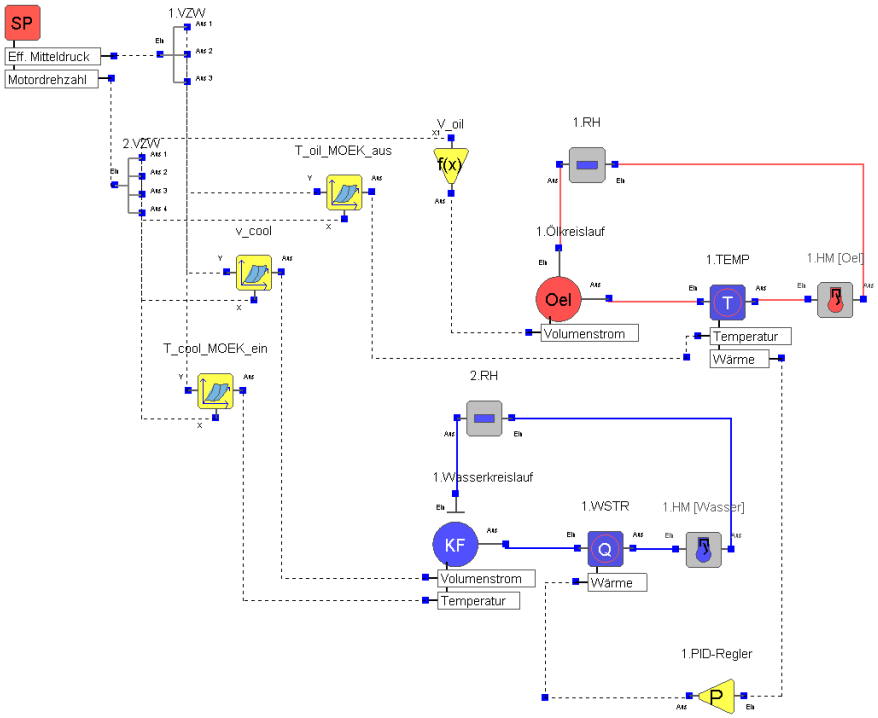
Coolant temperature between engine and engine oil cooler (EOC) could not be measured

⇨ Determination of temperature from heat balance at EOC

Engine: Accuracy of heat input

Deviation (measurement – simulation); KULI-engine model built by Magna Powertrain





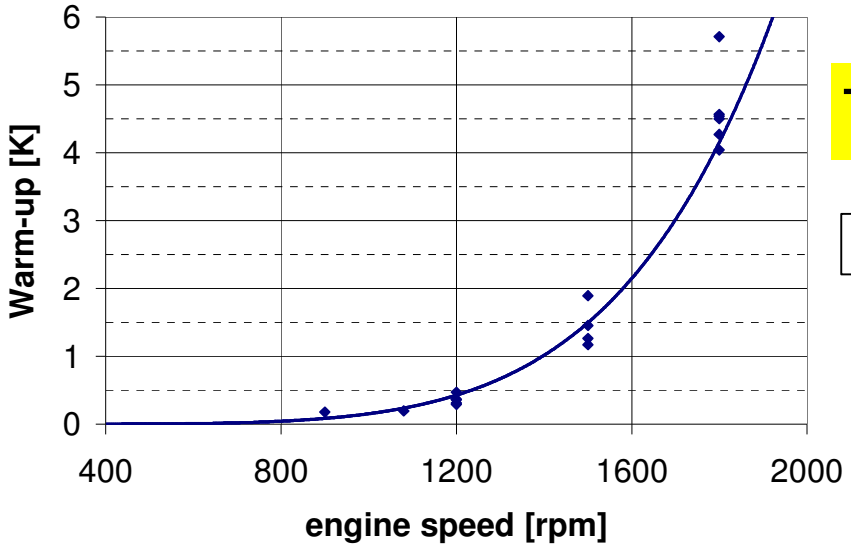
⇨ deviation < 14% for usual operating range of a truck

⇨ maximum deviation 17% (i.e. 0.7 K difference in coolant temperature)

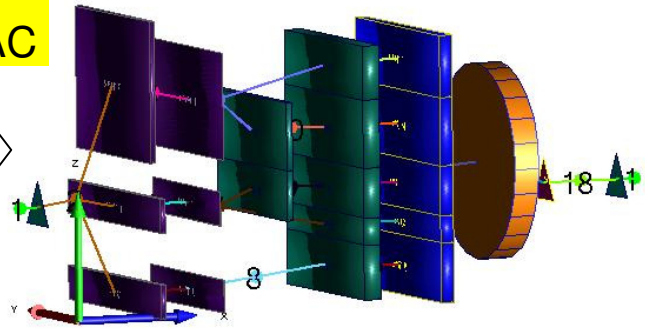
Measured cooling air temperature increase resulting from air recirculation @ full load

Wind speed 30 km/h

T_{amb}



$T_{ave,CAC}$



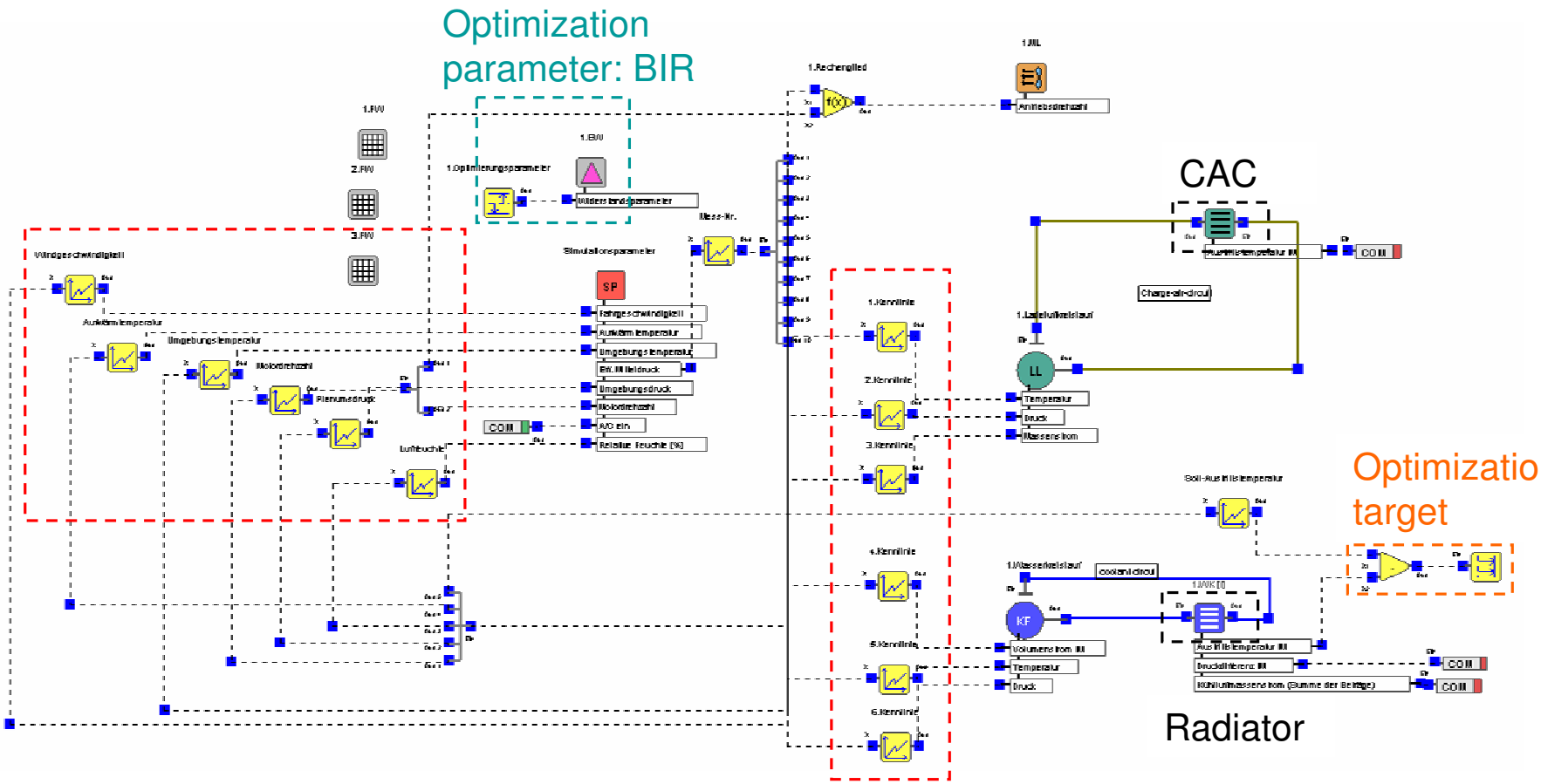
Warm-up = $T_{ave,CAC} - T_{amb}$

⇨ strong influence of fan speed

⇨ warm-up temperature 4.5 K at 2340 RPM fan speed (=1800 RPM engine speed)

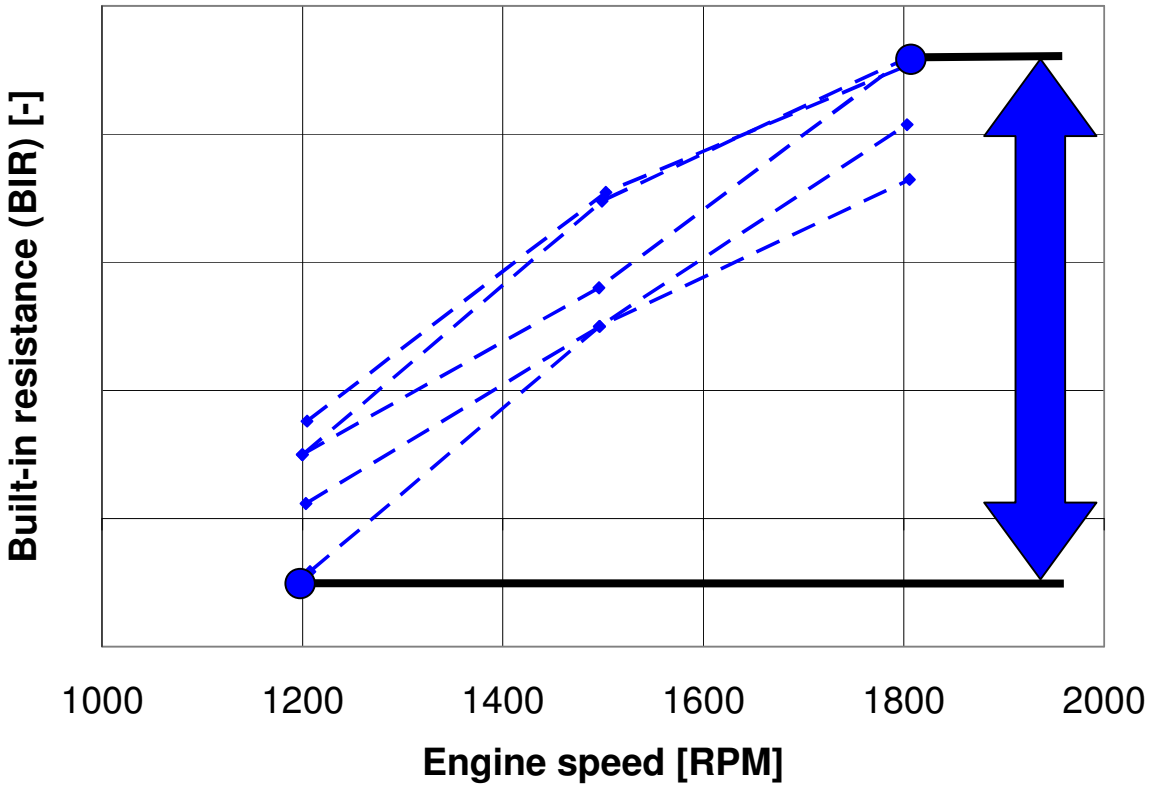
Enhanced Simulation Model

Calibration of simulation model

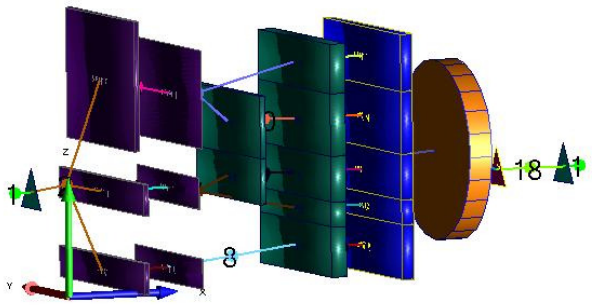


⇨ Result: Appropriate built-in resistances for each operating point

Enhanced Simulation Model

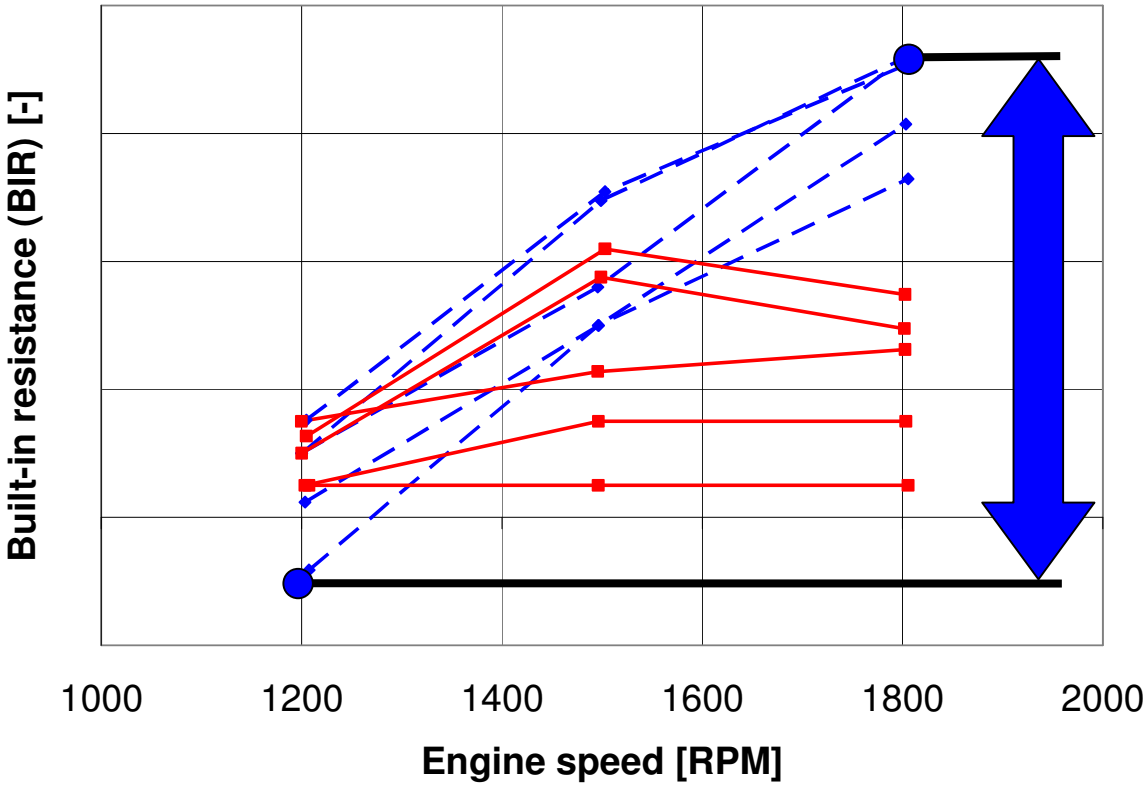


No air recirculation (no preheating)



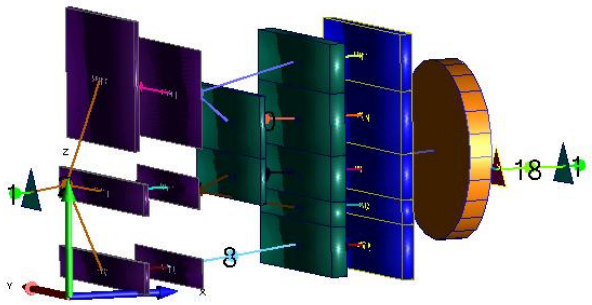
BIR = drag coefficient of cooling air flow through the engine compartment

Enhanced Simulation Model



No air recirculation (no preheating)

With air recirculation (with preheating)



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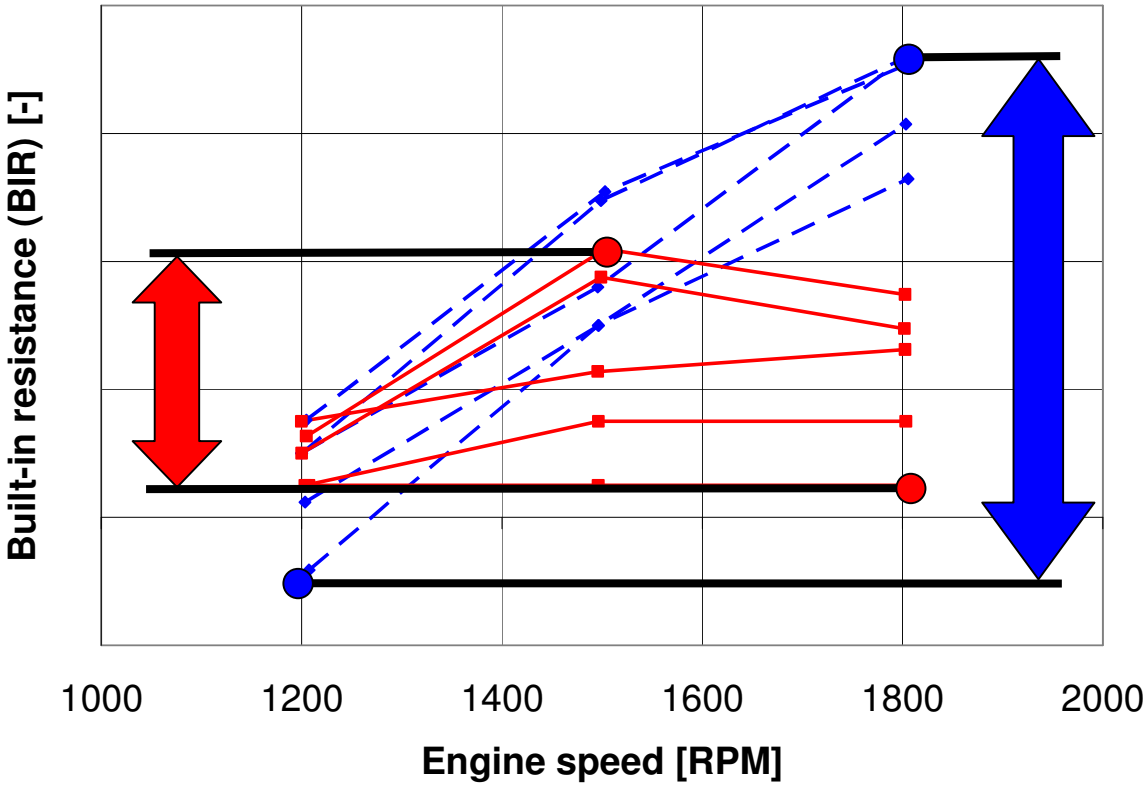
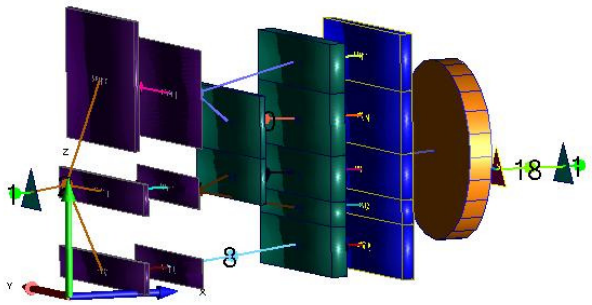


No air recirculation (no preheating)

With air recirculation (with preheating)



BIR = drag coefficient of cooling air flow through the engine compartment

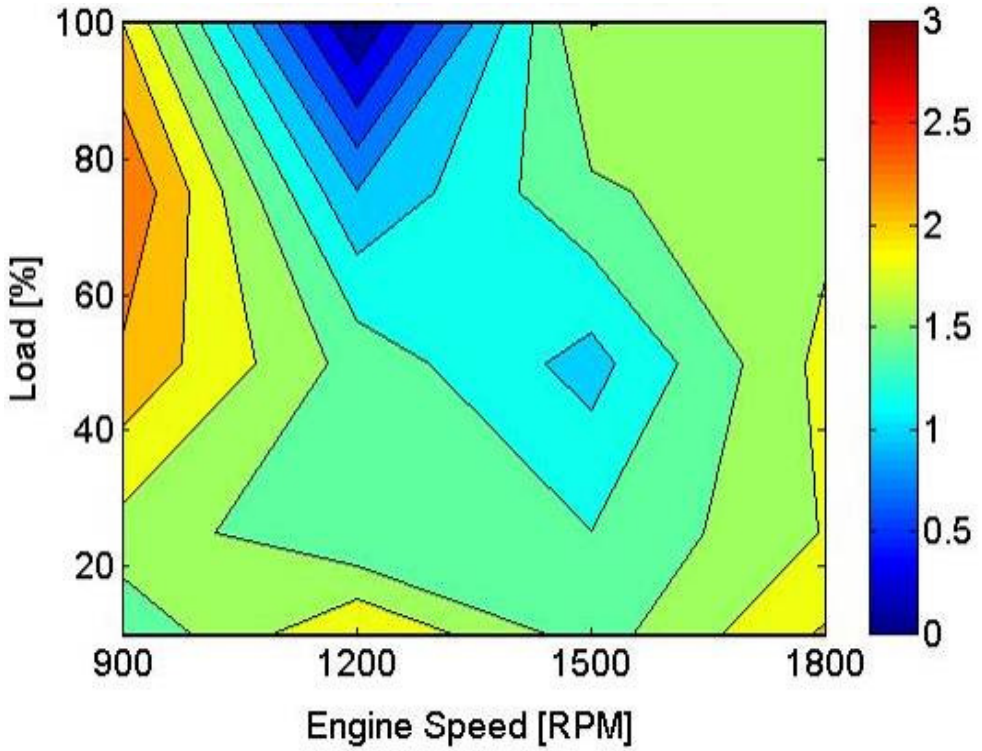
With air recirculation:

⇨ Smaller range of BIR

⇨ Significantly lower deviation of simulation results in case only average BIR is available

Coolant: Accuracy of temperature simulation

Deviation (measurement – simulation)



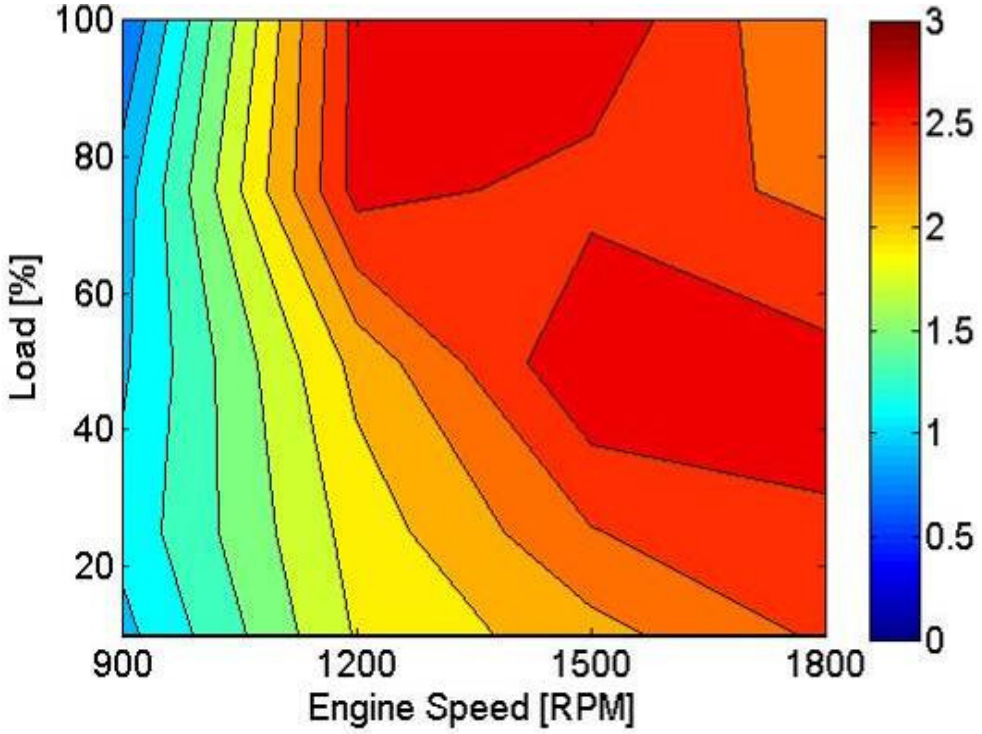
Temperature deviation [K]

Deviation in flow rate, engine heat input and cooling air side summarized in coolant temperature:

- ⇨ Deviation in coolant temperature < 2.5 K
- ⇨ Deviation in coolant temperature < 1.5 K for usual operating range of a truck

Charge-Air: Accuracy of temperature simulation

Deviation (measurement – simulation)



Temperature deviation [K]

- ⇨ Charge-Air temperature not calibrated to measurement
- ⇨ Deviation in Charge-Air temperature shows accuracy of model
- ⇨ Deviation in Charge-Air temperature < 3K !

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Measurement

- Qualification of new measurement technique
- Quantification of pre-heating of cooling-air determined: up to 5 K

Thermal vehicle simulation model

- Simulation model built up to handle interactions between engine heat load, coolant flow, charge air and cooling air flow
- Complete vehicle operating range can be simulated
- Improvement of simulation accuracy by consideration of hot air-recirculation
- Accuracy of charge-air and coolant temperature simulation better than 3 K for complete operation range

Overall

- Measurement technique and simulation model in use for research & application projects

Thank you!