System modelling and transient KULI simulation
– System Supplier Demands –

KULI User Meeting 2005

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Outline

- Motivation and objective
- Steady state vs. transient KULI model
- Simulation example (Truck)
- Transient model description
- Necessary input to adapt transient model
- Results of transient simulations
- Conclusion
- Outlook

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Motivation and objective

Why transient KULI simulation ?

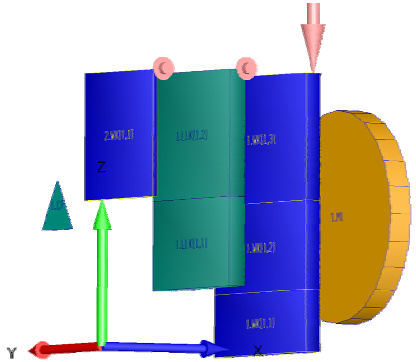
- Increased system responsibility for cooling module supplier
  - Transient effects (system control, e.g. fan, thermostat)
  - Warm up
  - Influence of cooling system on fuel consumption
- Load input for durability tasks (testing and simulation)
- Enhanced evaluation of system configurations

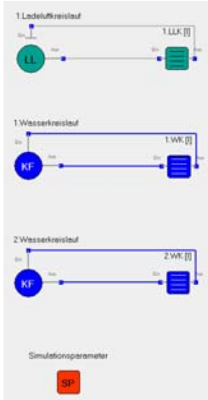
Objective

Simulation of transient conditions:

- Warm up phase of the cooling system
- Transient driving situations
- Consideration of non-continuous retarder/fan operation

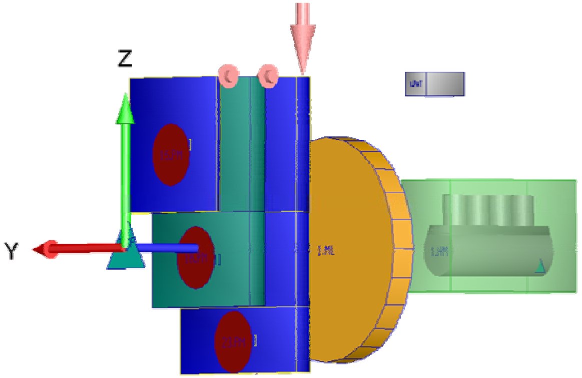
Steady state vs. transient KULI model



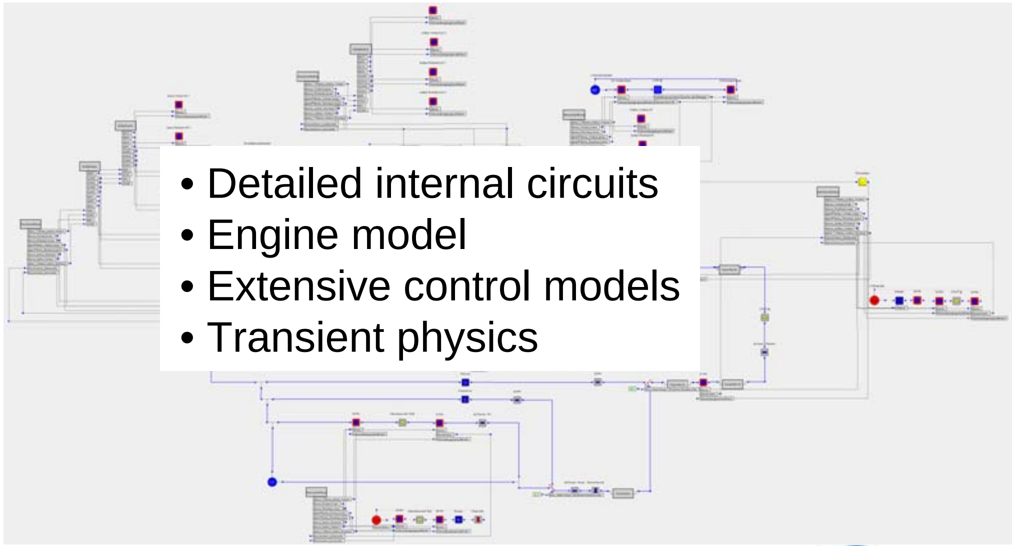


Steady state model

- Simplified model of internal circuits



Transient model



- Detailed internal circuits
- Engine model
- Extensive control models
- Transient physics

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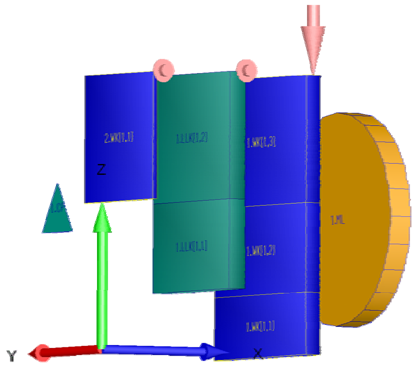
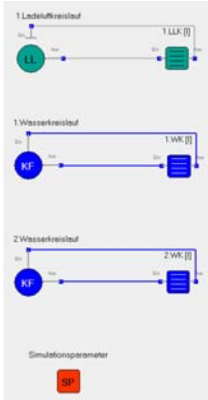
Steady state vs. transient KULI model

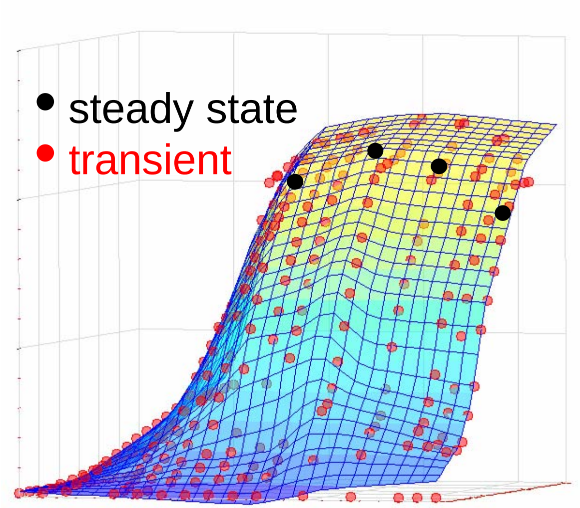




Steady state model

Simulation of single operating points

- Flow rates
- Pressures
- Temperatures
- Heat loads



Transient model

System data	• Transient measurement data • Thermal masses • Volumes • Heat losses to ambient • Pressure drops
Engine data	• Heat load distribution • Power and torque • Fuel consumption • Warm up curves

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Simulation example

Truck- model

Vehicle data:

- Engine power: 294 kW
- Gear unit offering 12 gears
- Weight: 44t (tractor with semitrailer)

Cooling components

- Condenser of AC-circuit
- Charge air cooler
- Radiator
- Retarder-heat exchanger
- Oil-heat exchanger
- Mechanical driven fan

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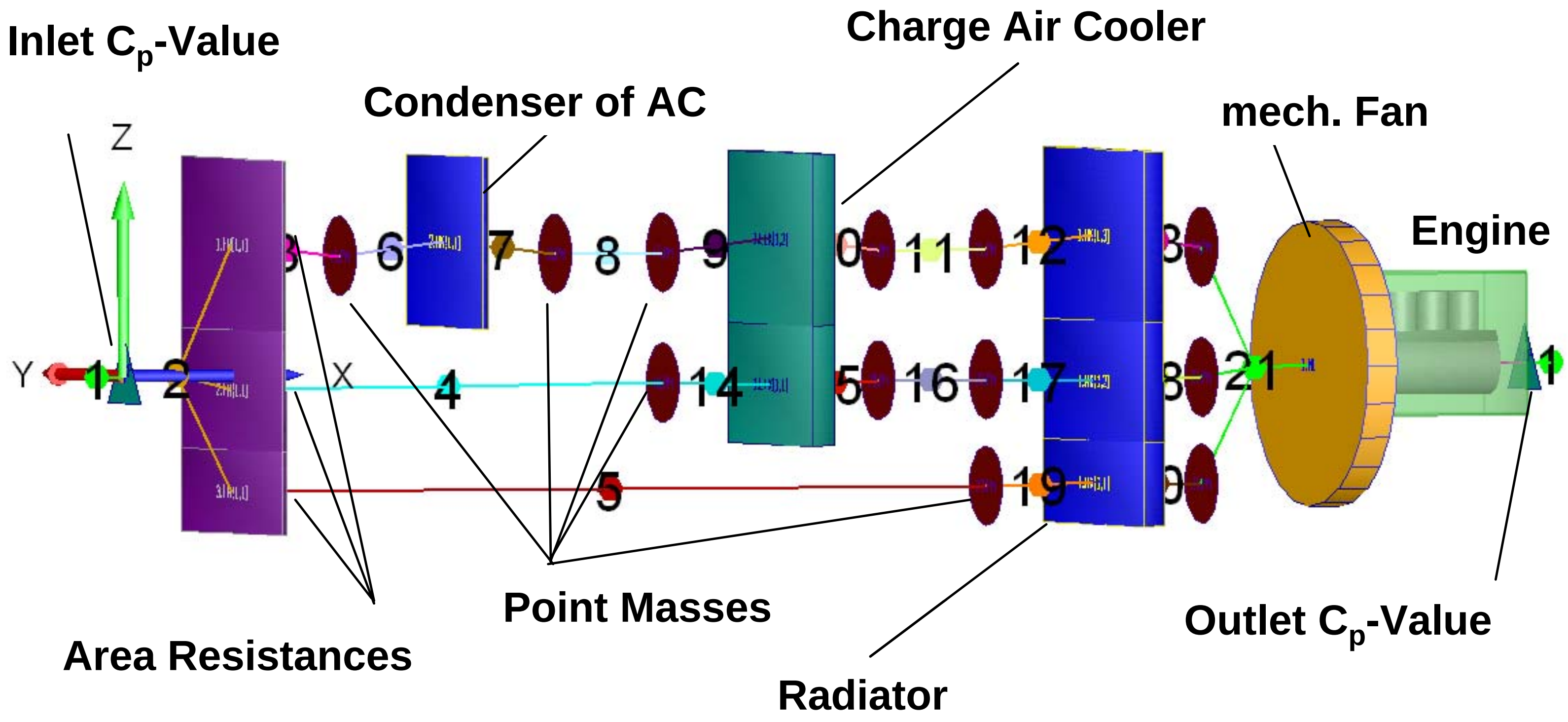
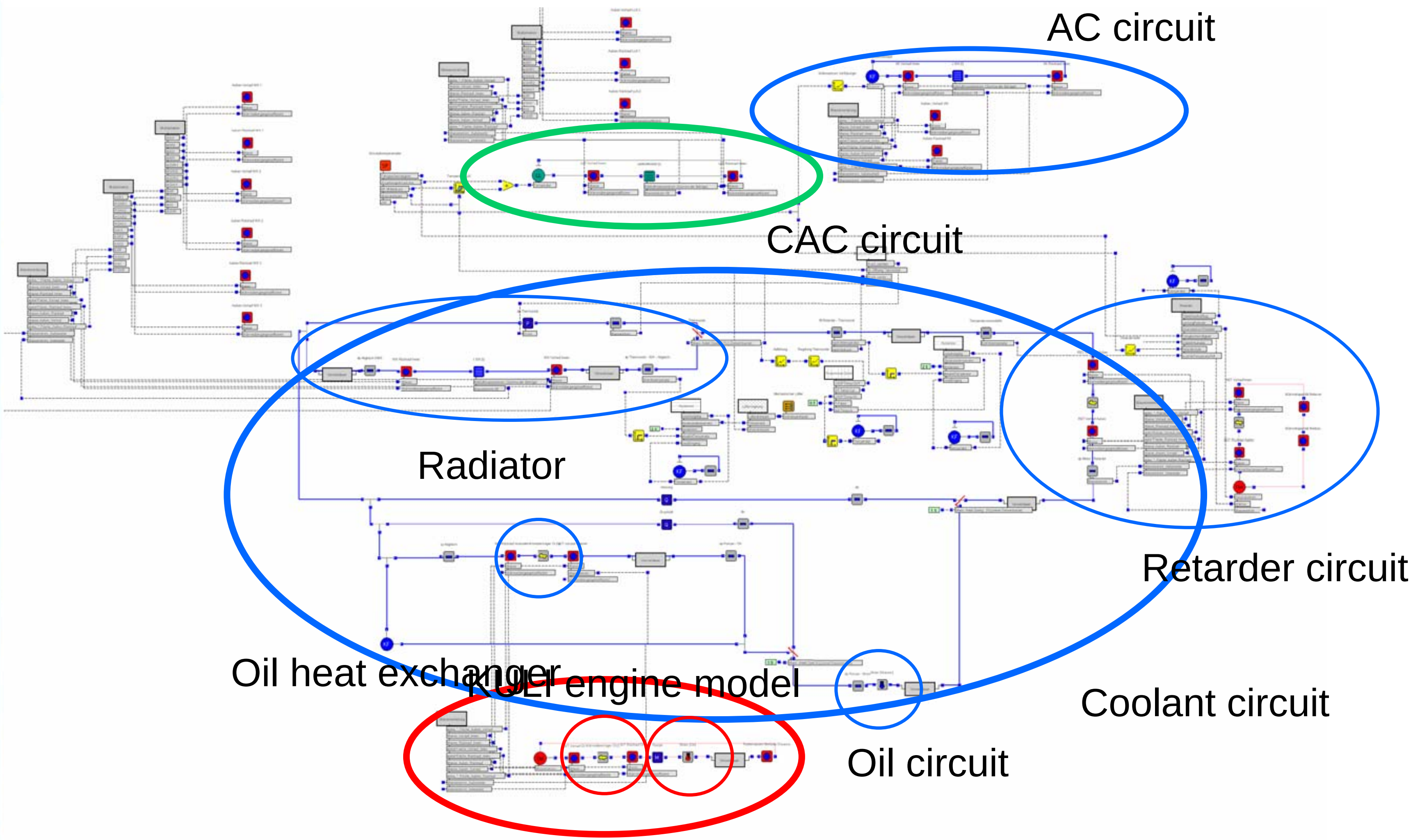
Transient model description – Air flow network



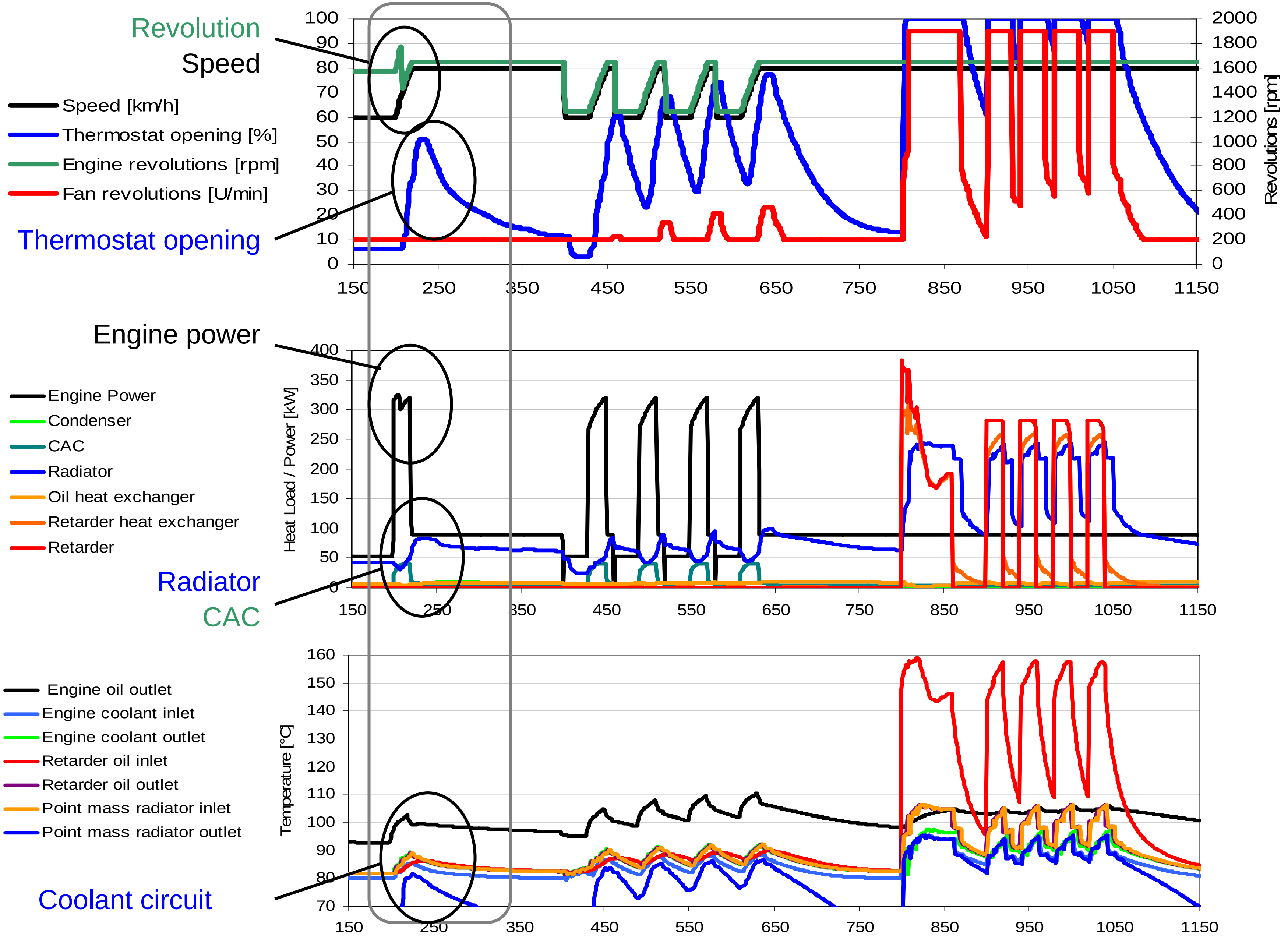
Transient model description – Inner circuits



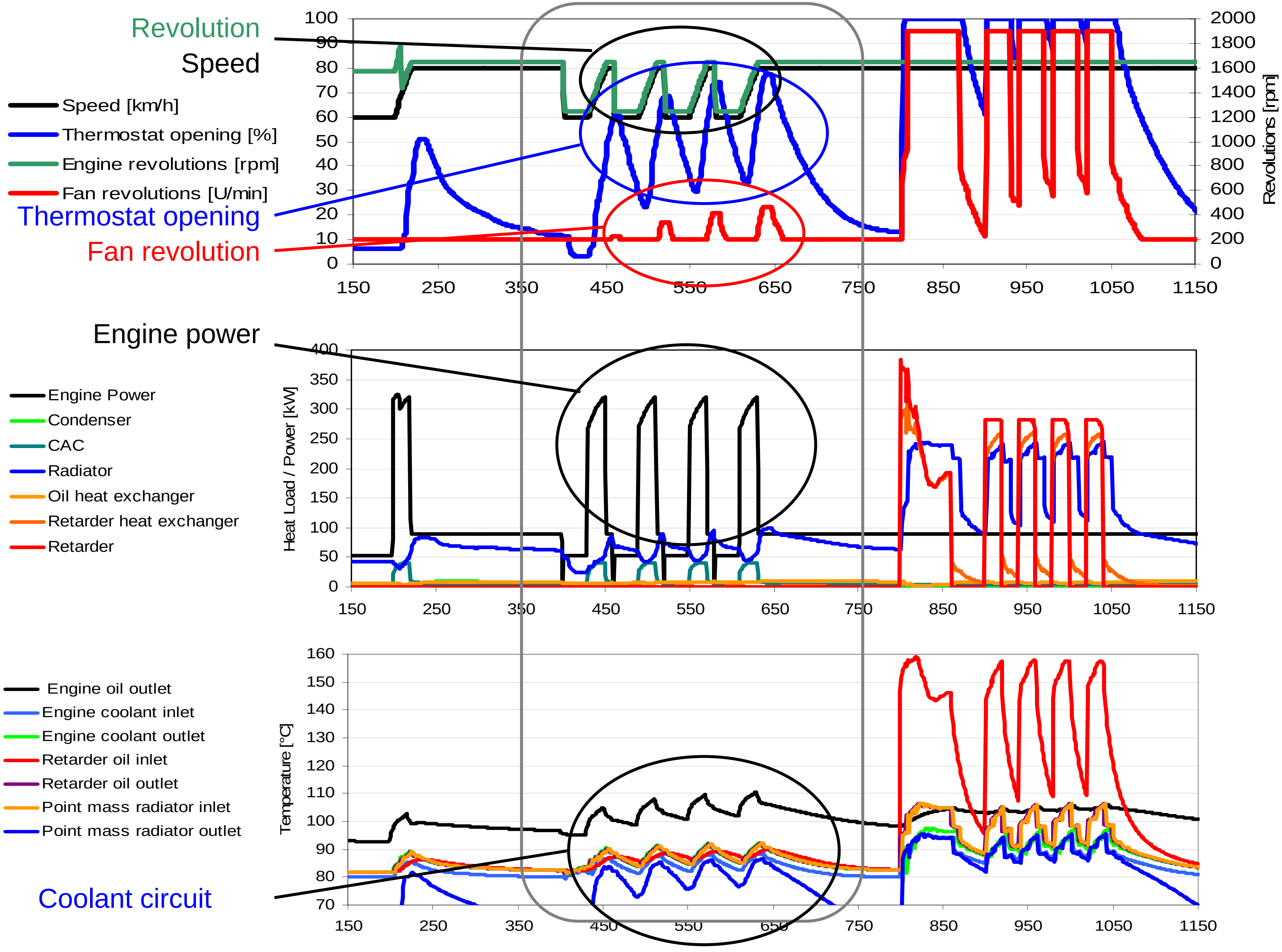
Necessary input to adapt transient model

Necessary Input	Steady state model	Transient model	Availability for this study	Data from
Characteristics of charge air circuit	X	X	✓	OEM
Volume of coolant circuit		X	✓	OEM
Characteristics of coolant pump		X	✓	OEM/supplier
Pressure drops in coolant circuit		X	✓	OEM/CWT
Volume of oil circuit		X	✓	OEM
Characteristics of oil pump		X	**assumption**	OEM/supplier
Pressure drops of oil circuit		X	**assumption**	CWT/OEM
Control of mechanical fan		X	✓	OEM/supplier
Characteristics of thermostat (flow distribution, temperature)		X	✓	OEM/supplier
Characteristics of engine (Power, Torque)	X	X	✓	OEM
Gear ratio		X	✓	OEM
Heat distribution from engine to circuits		X	**assumption**	CWT
Coolant flow distribution in system		X	**assumption**	CWT
Air flow distribution	X	X	✓	CWT/CFD
Heat up of engine		X	**assumption**	CWT
Characteristic map of fuel consumption		X	**assumption**	OEM

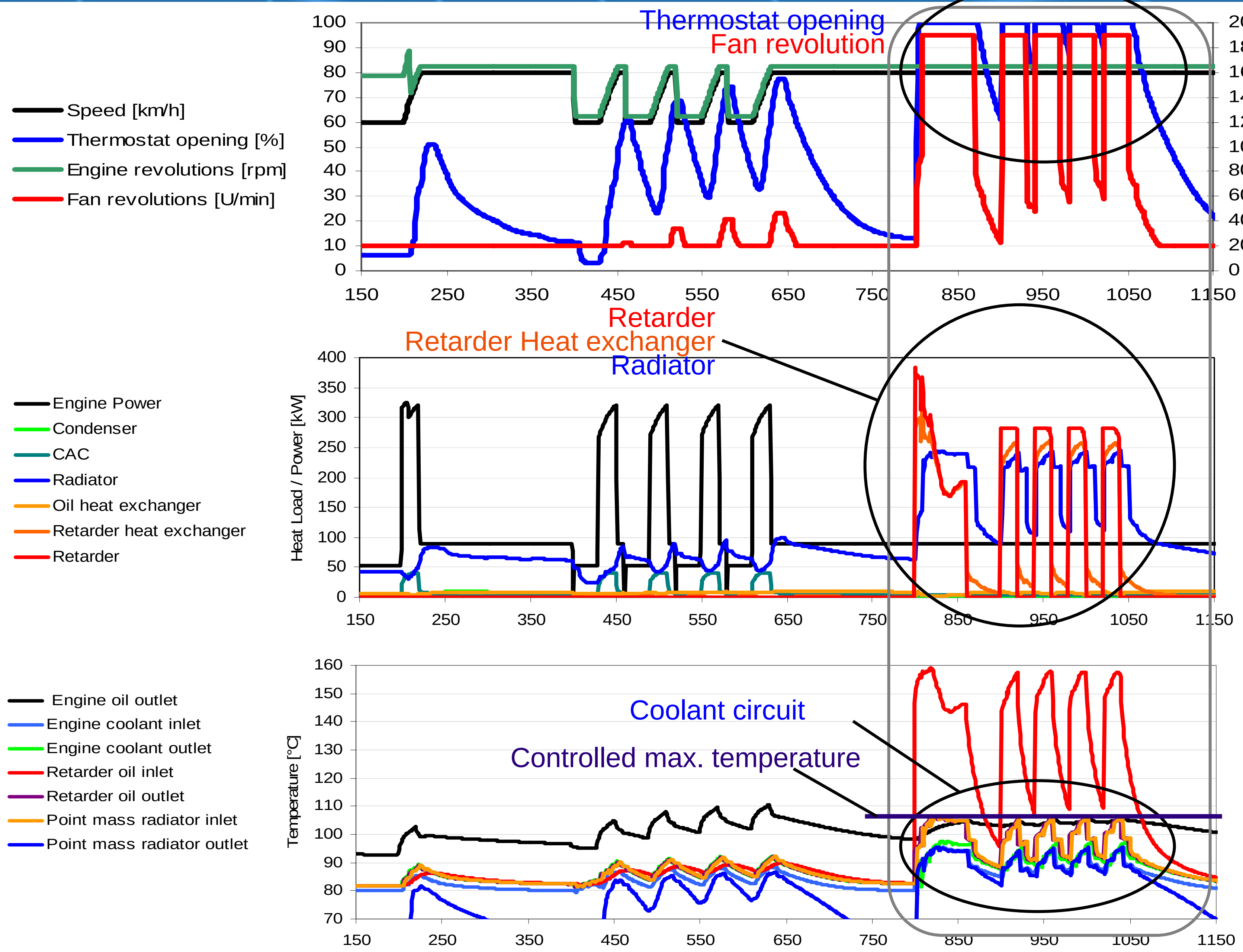
Results of transient simulations



Results of transient simulations



Results of transient simulations



Conclusion

- Transient model has been built based on existing measurement data
- Thermal masses and retention periods have been implemented
- Control models were created to define the reaction of the cooling system to transient conditions
- Adaptation of the model to steady-state operating points

➔ **Transient model shows qualitatively same behaviour as vehicle**

➔ **Improvement of transient model necessary to get closer to absolute numbers**

➔ **Transient model allows focusing on single components of the cooling system**

Outlook

- **Own measurements in wind tunnel (no engine test rig)**
    - Each heat exchanger instrumented completely
    - Steady state measurement of different operating points incl. heat up data
- **Characteristics of pumps**
- **Influence of masses on load variation (CAC, RAD, etc.)**

- **Needs**
    - Transient behaviour of components

      retention period inside components
      transient temperature distribution in components
      direct/indirect mass of cooling components
    - Time and iteration information for external components
    - Encrypted components and submodels