Part and Perspective of KULI in the Virtual Vehicle Development at Audi AG

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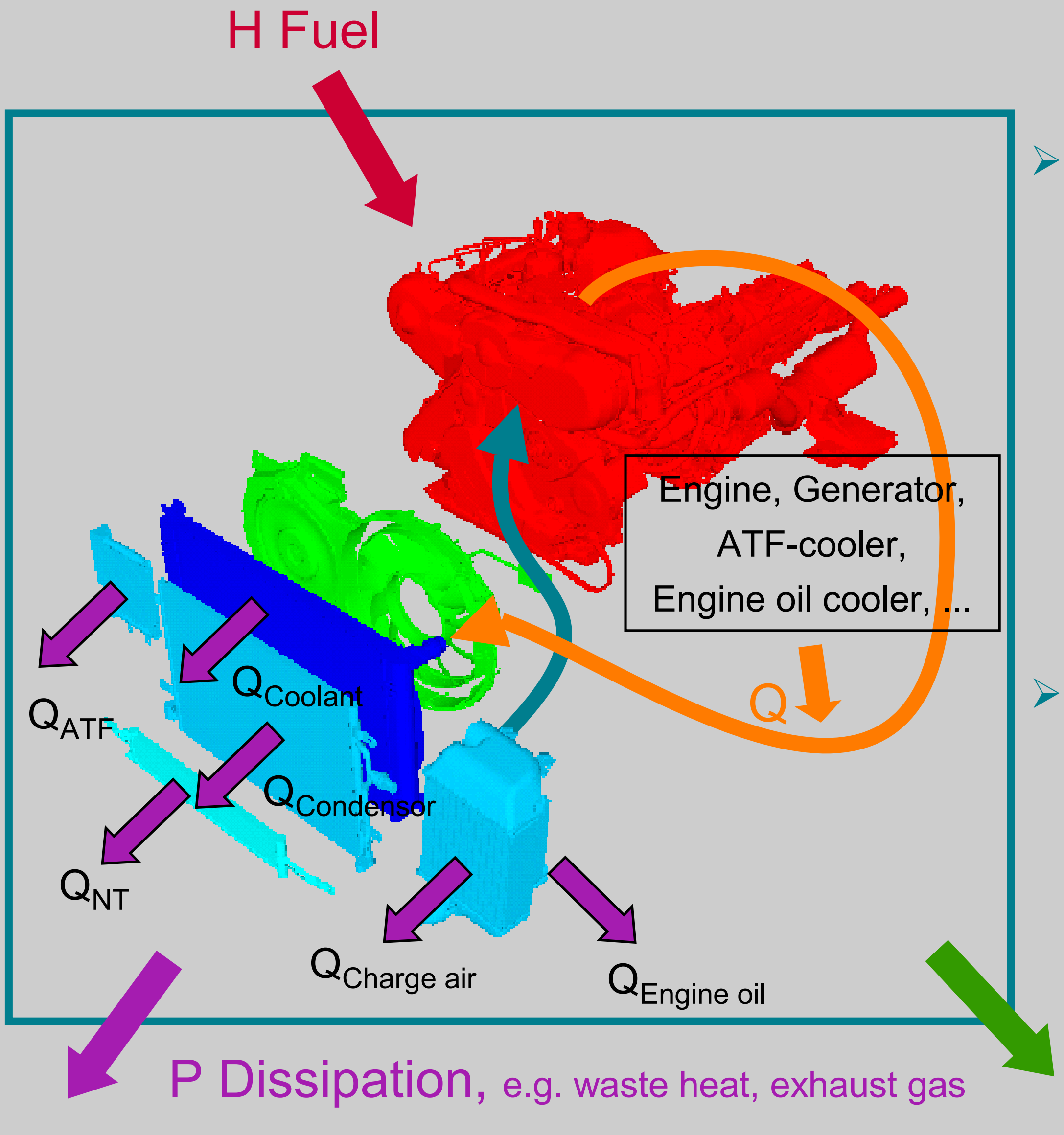
Overview

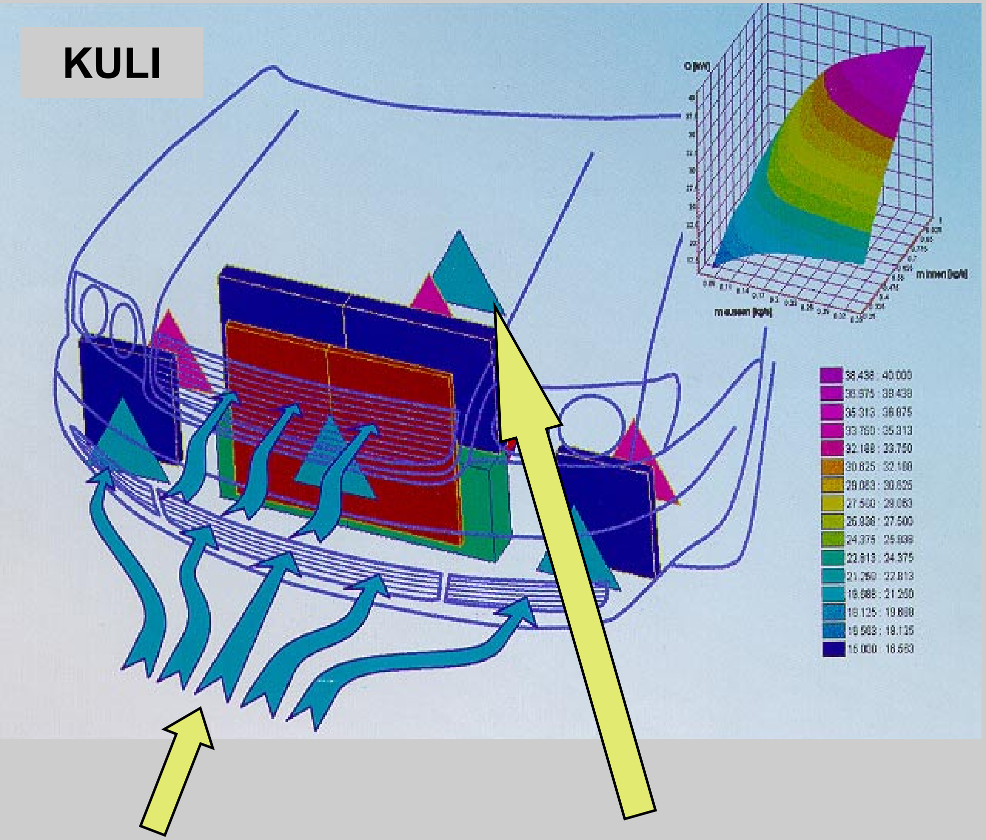
- Historical evolution of the application of KULI in the development of cooling systems
- Extensions in the last years
- Discussion of potentials in view of fundamental design and thermal heat management

Primary Application - Development of Cooling Systems



- **Transfer** of the heat fluxes to the **Cooling air** at **stationary** extremal operating conditions, guaranty for the limiting temperatures for
  - Cooling water
  - Charge air
  - ATF oil
  - Engine oil
  - Fuel (Diesel)
  - Hydraulic(Servo) oil
- Quantitative evaluation of **variants** in a very early stage of development referring to
  - Cooling performance, occupied space, costs
  - In parallel to tests in the stage of serial development

1D - Concept Development in a very early Stage of Development, Organization of Cooling Areas



Simplified description of the cooling air in- and outflow and the cooling air drag in the engine compartment, as known from a predecessor vehicle

Concept decisions for the entire engine pallet

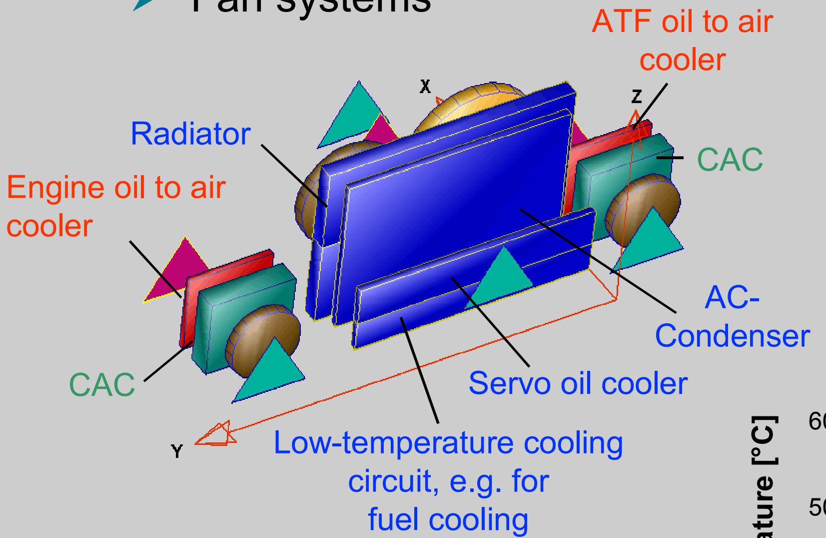
- Media-air-HE-applications
- Media-air-HE-geometries
- Fan systems

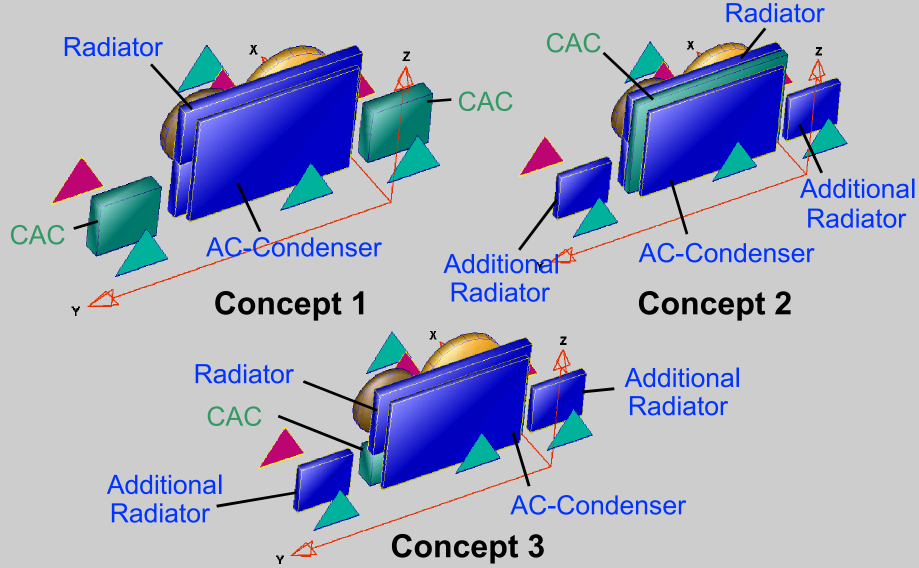
Vehicle - Concept decisions

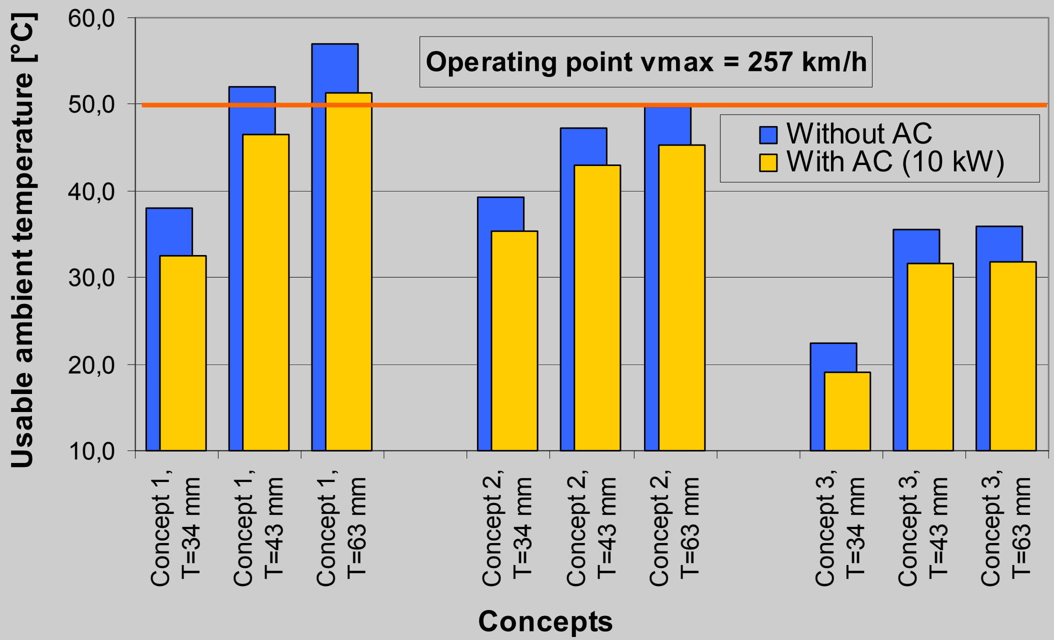
- Location and area of the cooling air inlets, integration of the whole engine pallet

Variants of Cooling Systems - Concept Decision

Concept decision for
- Media-air-HE-applications
- Media-air-HE-geometries
- Fan systems



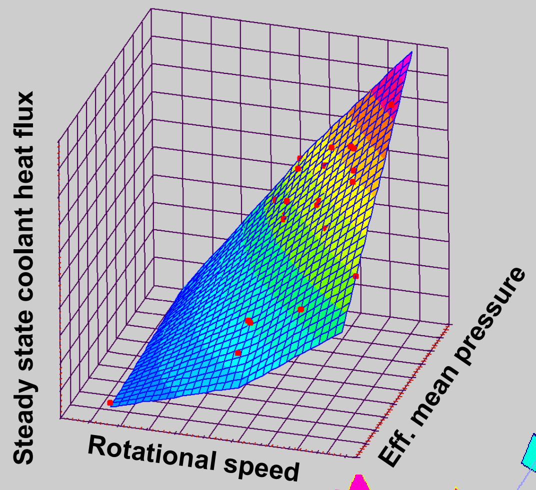


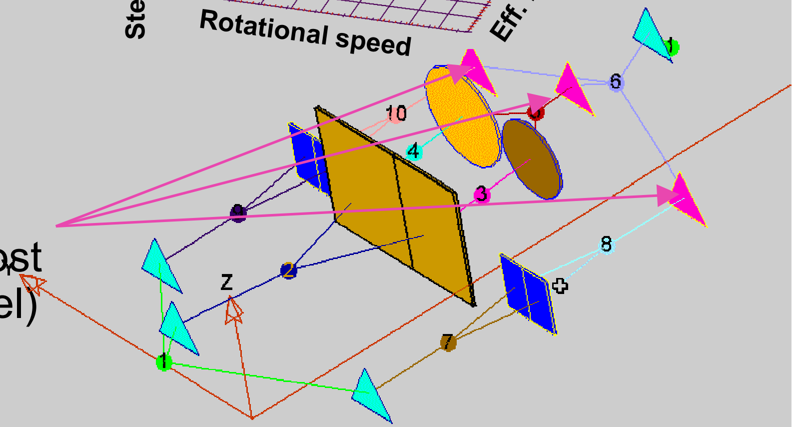


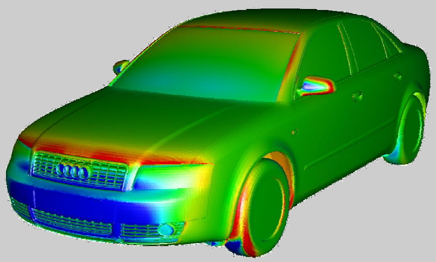
Variants of Cooling Systems - Concept Decision - Prerequisites

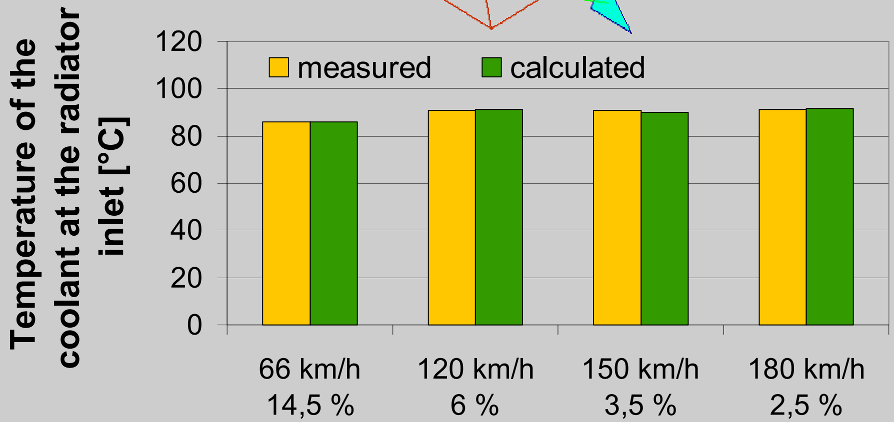
Prerequisites

- Project demands
- Packaging
- Heat fluxes of the aggregates at all relevant operating conditions
  - Engine
  - Gearbox
  - Generator
- Media mass fluxes
- Component know how
  - Fan
  - Radiator
- Air resistances in the cooling air flow paths (in most cases known from a calibrated predecessor model)
- cp-distribution at the new vehicle









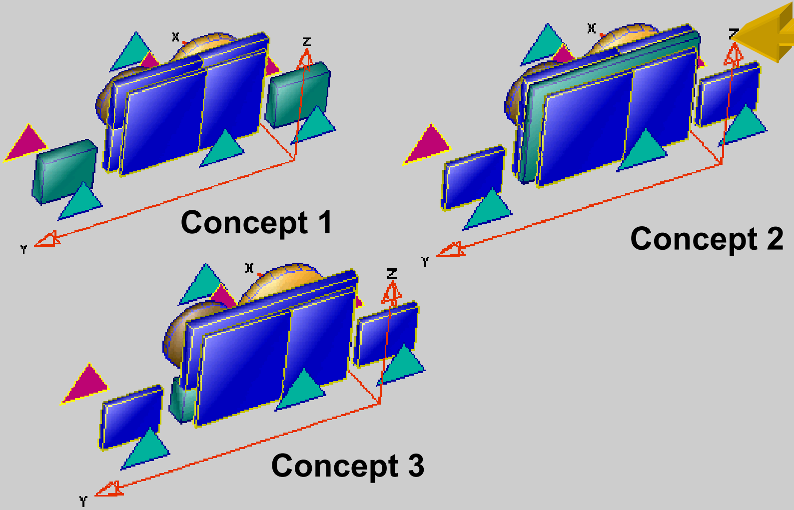
Coupling of KULI and FLOWMASTER

Simultaneous calculation of the coolant flow and the heat transfer at the radiator
4-arm-ECM for the calculation of the heat transfer within the coolant flow circuit

KULI ***FLOWMASTER***

KULI

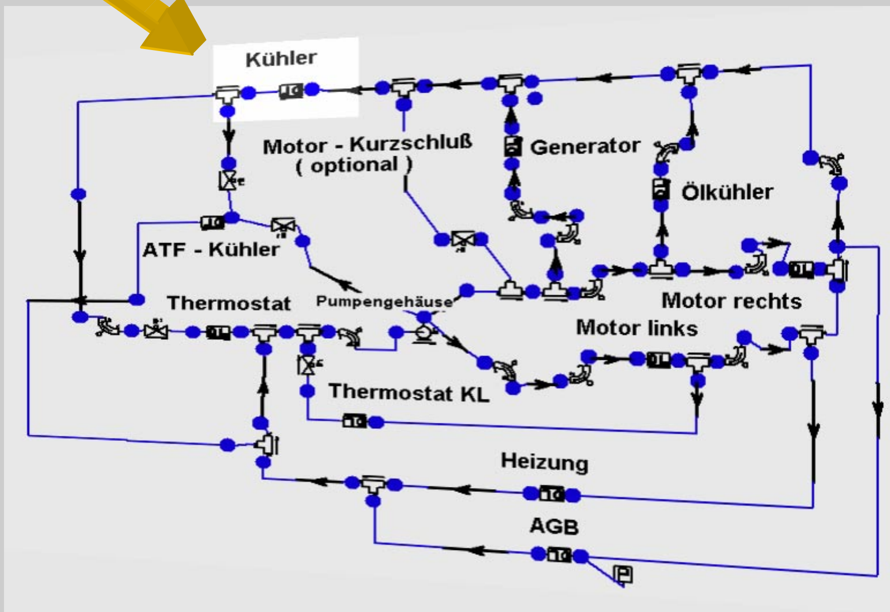
- Thermal flow calculation at the cooling components with integration of experimental experience
- Concept development and comparison of cooling systems for steady state operating conditions



- Assessment of the influence of the cooling air inlet area and of cp-distributions on the cooling rate

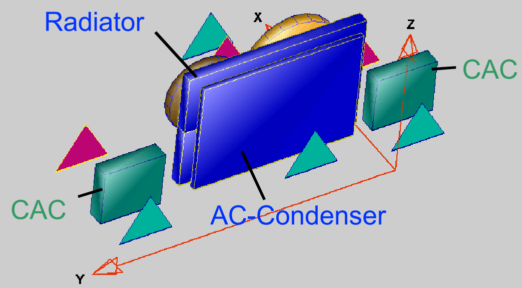
FLOWMASTER

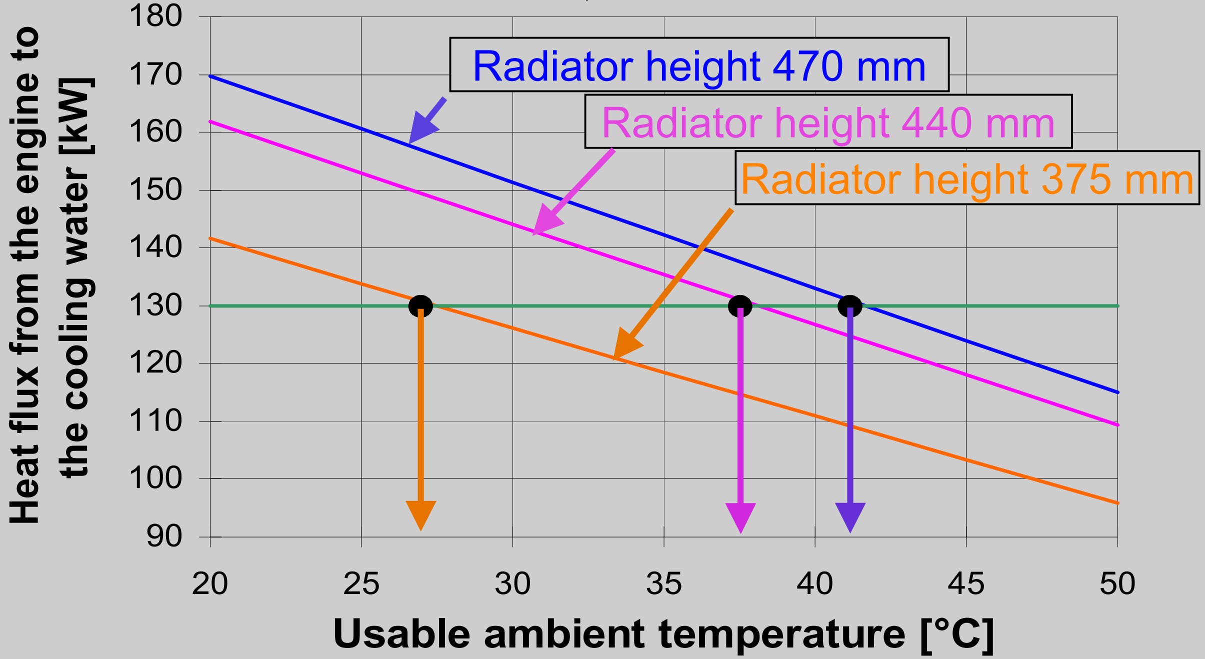
- Calculation of the cooling water flow rate distribution
- Development of component flow rates
- Design and evaluation of variants
- Layout of the operating point of the water pump
- Development basing on existing systems, close coupling to experiments



Routines for Optimization and Postprocessing

e.g. operating point vmax, constant radiator width and depth, fan arrangement and rotational speed, AC performance, maximum coolant temperature, condition short before drop of AC





Parametric simulation of the parameters

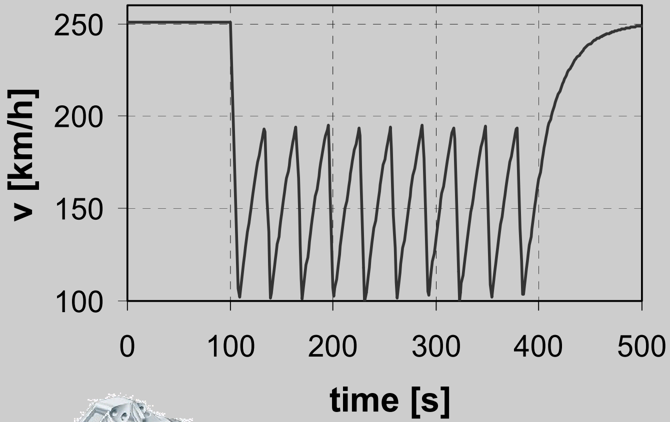
- Radiator with and depth
- Vehicle speed
- cp in and cp out
- Areas and built in resistances
- Cooling air inlet areas, when a mean cp-value is valid
- Cooling water flow rate
- Fan system
- Upflow heat exchangers

Analogous procedure

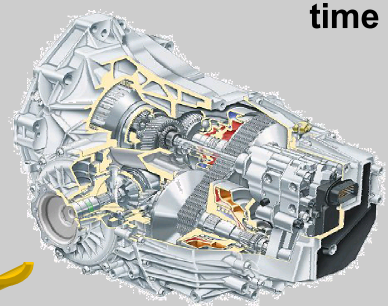
- Charge air cooling, engine oil to air cooling
- Other water-air-HE, e.g. fuel cooling, water-charge-air-HE

Improvement II: Transient Module and Driving Simulation

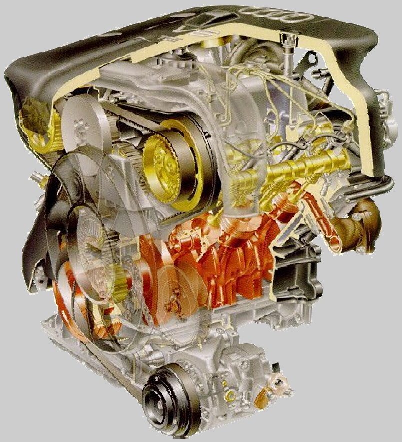
Velocity profile
Velocity / time
Road level profile



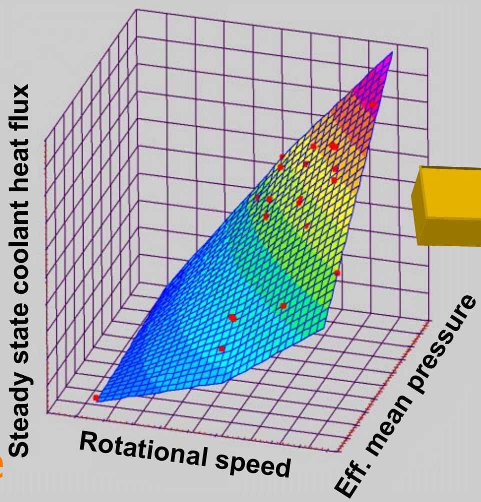
Vehicle
Mass
Road resistance
Inertia moments

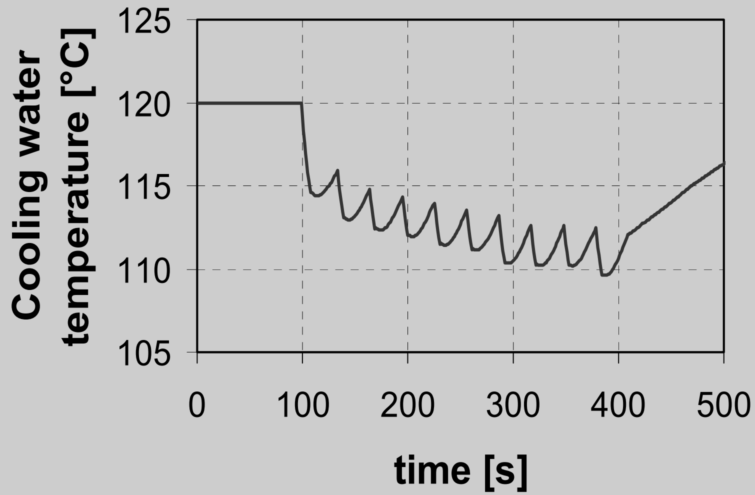


Gearbox
Gear ratios
Efficiency rates,
Gear shifting strategy



Engine model
Rot.speed / mean pressure





Improvement III: Integration of Pressure- and Resistance Relationships from 3D CFD-Calculations

Audi

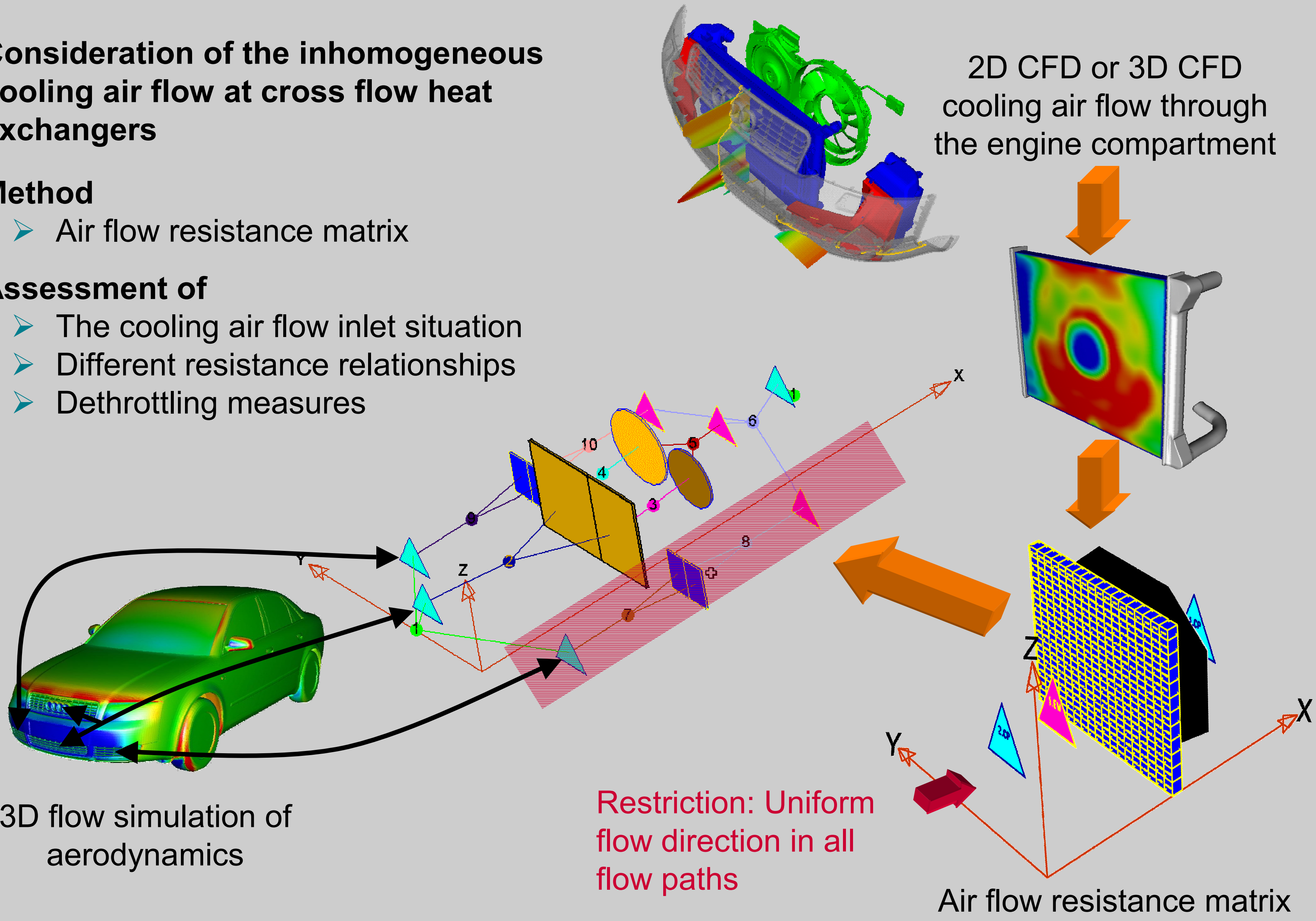
Consideration of the inhomogeneous cooling air flow at cross flow heat exchangers

Method

- Air flow resistance matrix

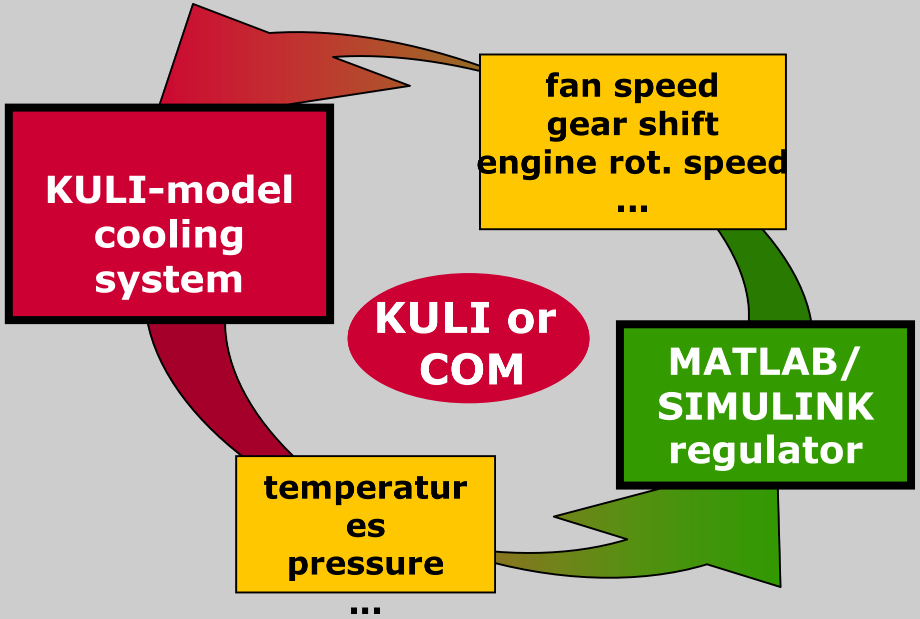
Assessment of

- The cooling air flow inlet situation
- Different resistance relationships
- Dethrottling measures

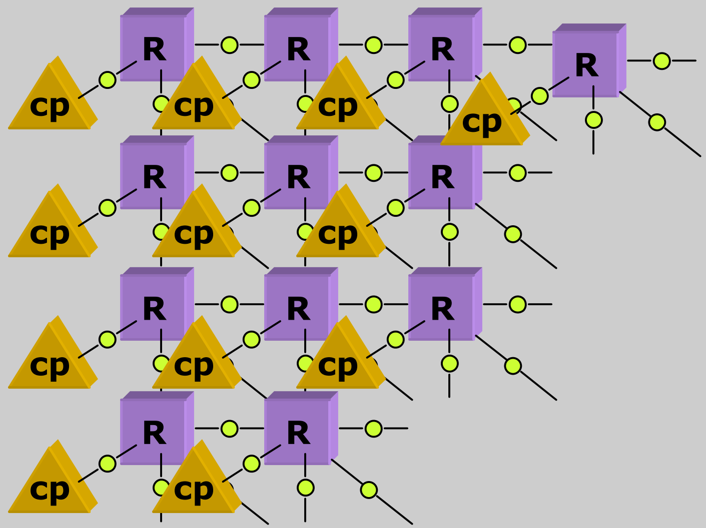


Further Improvements - Regulation Tasks and Accuracy of the Model

1. **Sensors and actuators**
    1. Components, air and water
    2. GUI in KULI
    3. Up to 6 input values, 1 output
    4. Also transient
    5. COM-interface
2. **SIMULINK regulator**
3. **Improved optimization**
    1. Multiple parameters
    2. Goal: Min, max or value



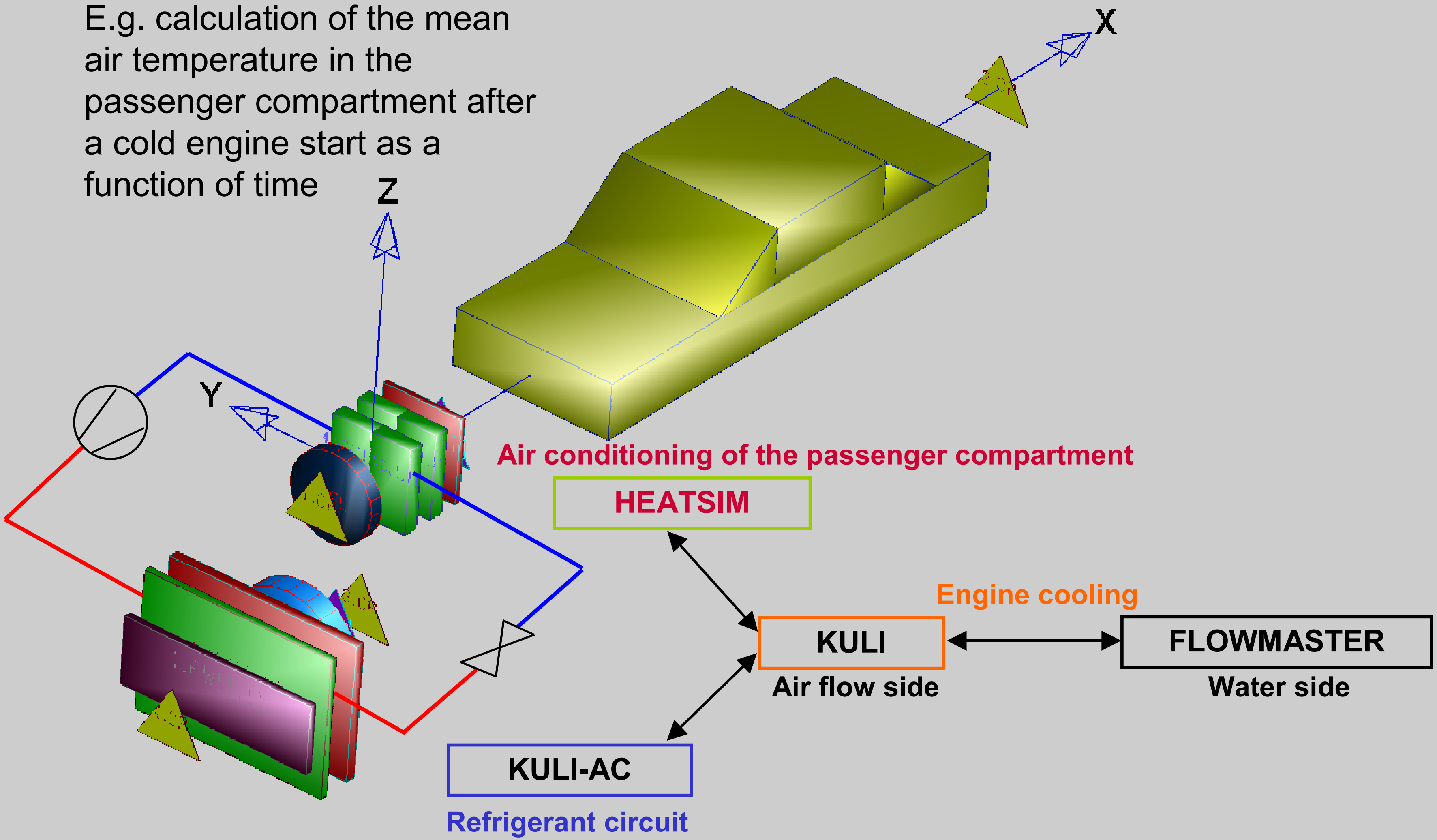
1. **Cp-value and resistance matrix**
    1. With consideration of recirculations



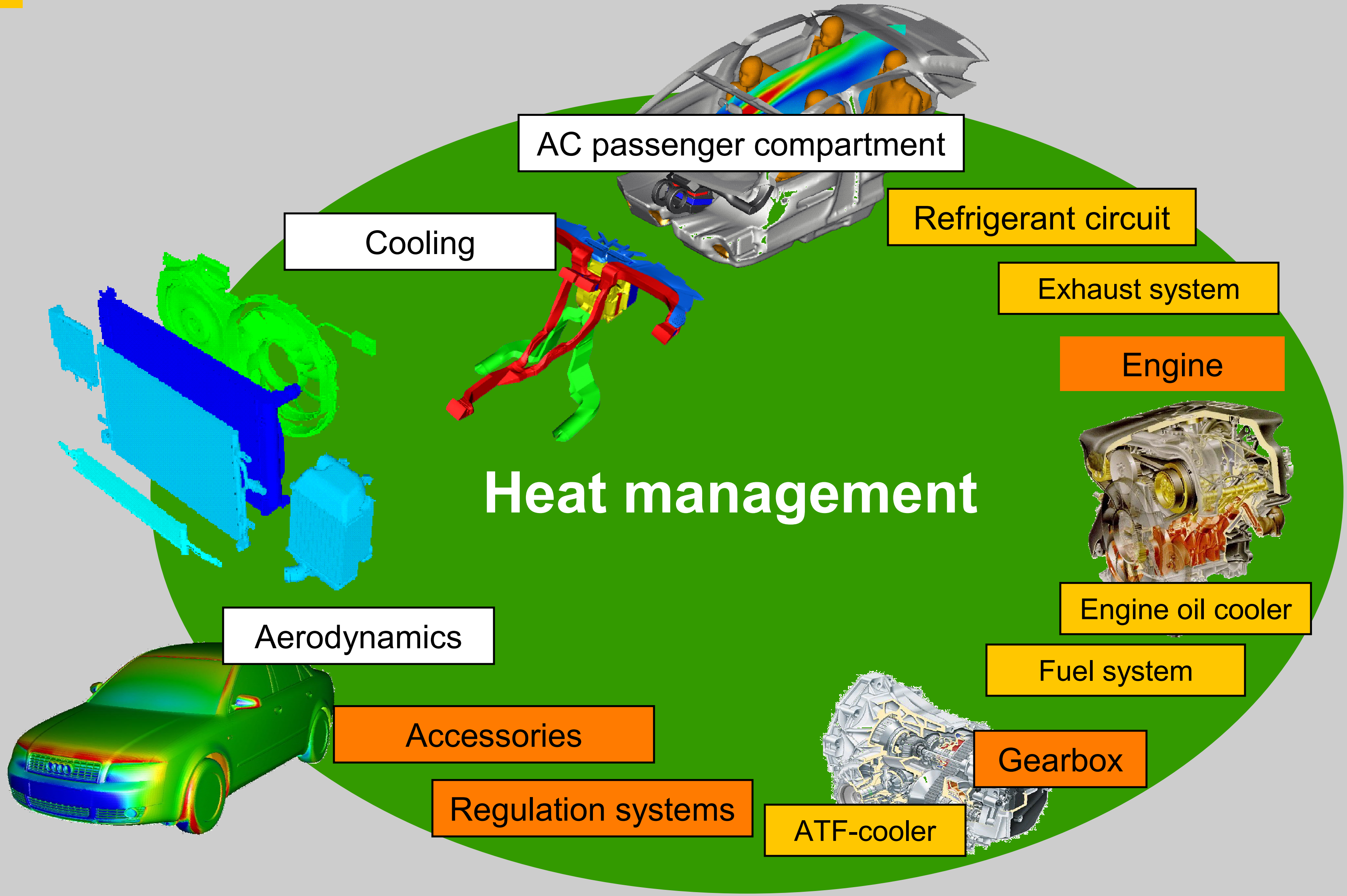
1. **Fan parameters**
    1. Geometry of the air box
    2. Distance between fan and radiator
    3. Dependencies on the hub and gap
    4. ...

Coupling to HEATSIM

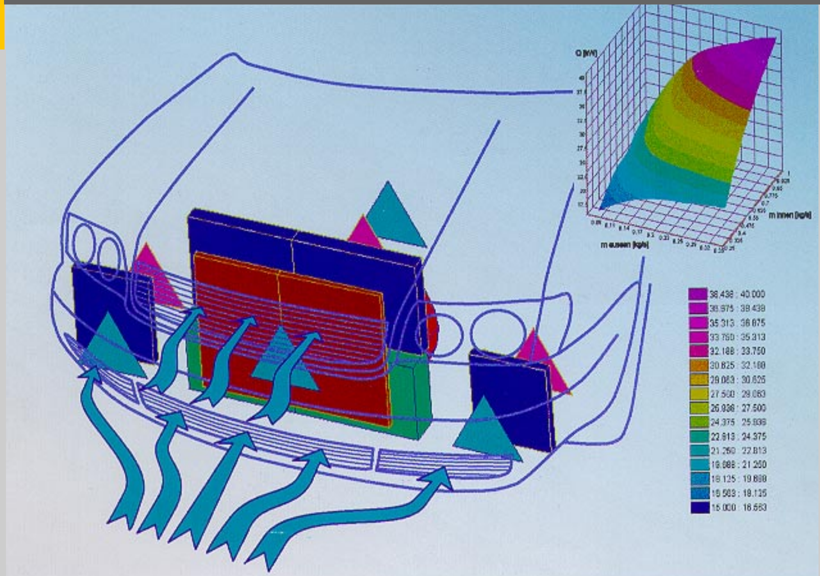
E.g. calculation of the mean air temperature in the passenger compartment after a cold engine start as a function of time



Heat Management in a Vehicle

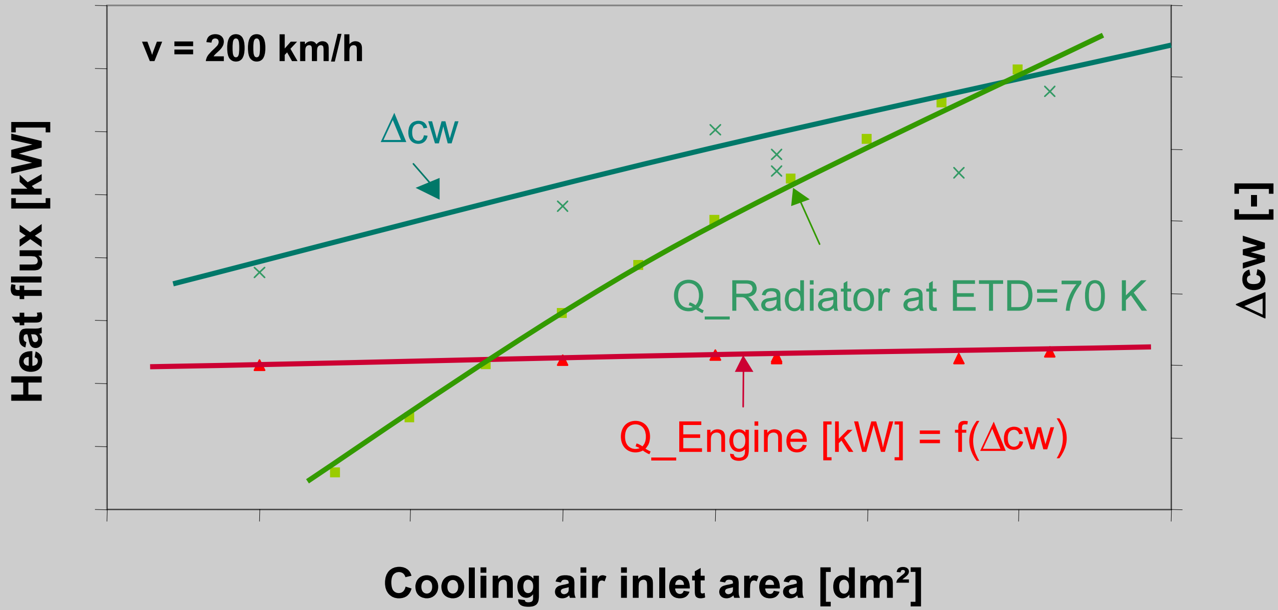


Example I of Heat Management in Vehicles

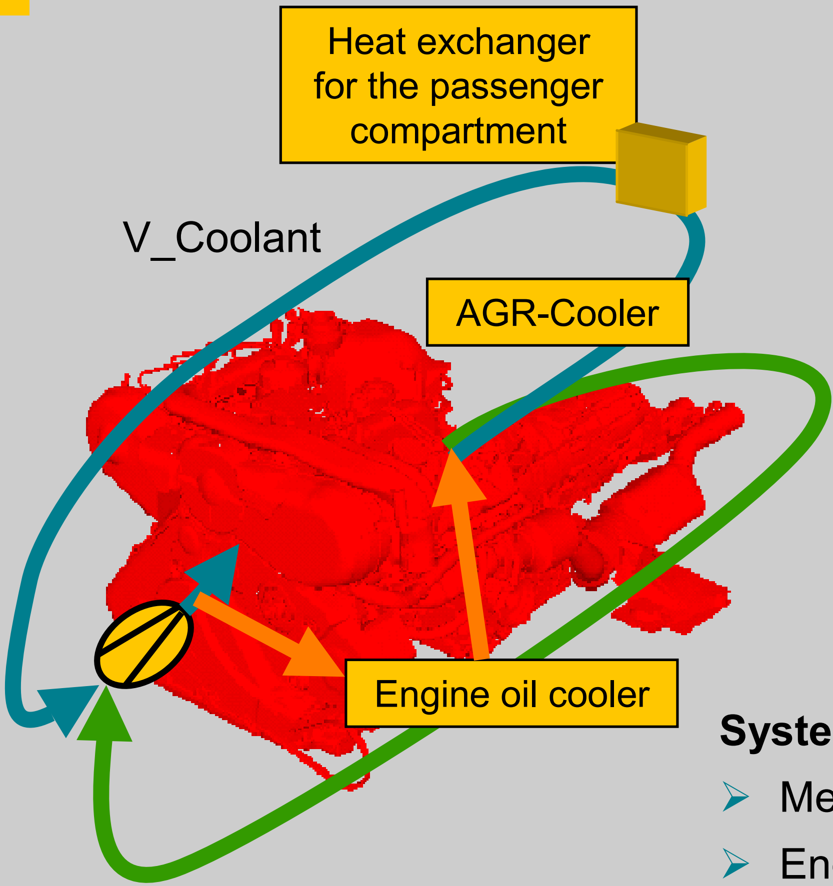


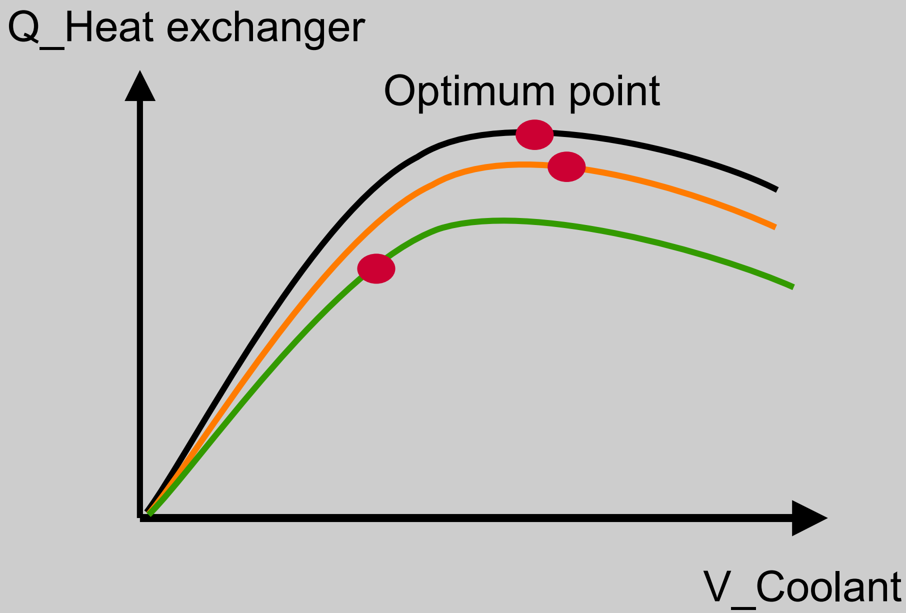
Coupling between aerodynamics and
engine cooling

1. E.g. size of the cooling air inlet



Example II of Heat Management in Vehicles





System qualities

- Mean temperature of the passenger compartment
- Engine oil temperature (Inner friction, fuel economy)

Prerequisites for the simulation and assessment

- Functional knowledge of the heat sources and losses
- Engine oil temperature with and without heat transfer at the engine oil cooler
- Dependence between heat transfer and frictional power (fuel consumption)

Perspectives in Heat Management

Control and regulation of all functions, which are part of the heat transfer processes in a way that stationary and non-stationary partial and global qualities of the vehicle are optimized

Examples

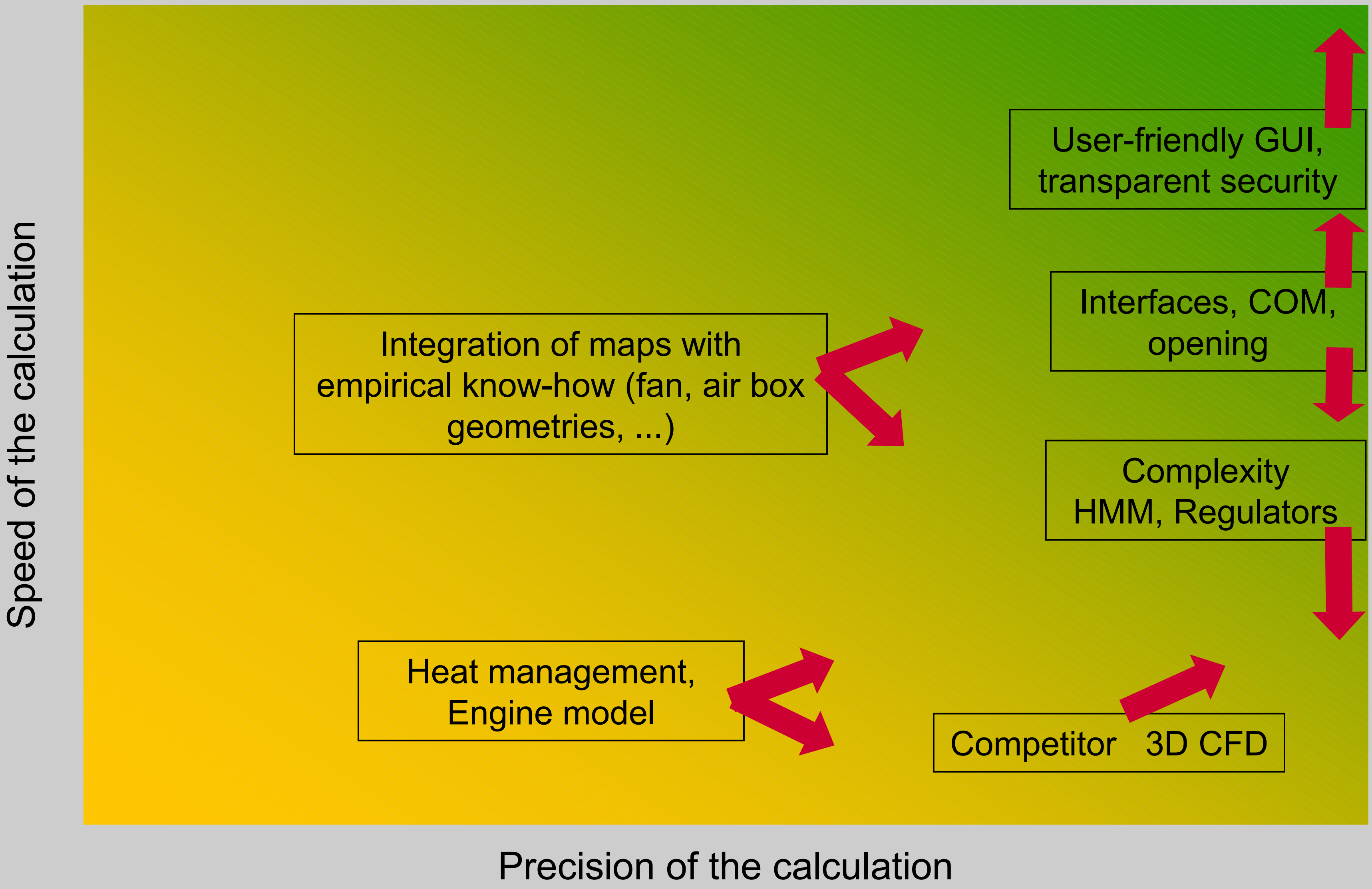
- **Maximization** of the comfort of the passenger compartment
- **Maximization** of the transmission efficiency
- **Minimization** of the exhaust emissions and of the fuel consumptions
- **Minimization** of the vehicle weight
- Regulation of the flow of the energy transferring media
    - Cooling water
    - Air for the passenger compartment
    - Cooling air

- Reluctant objectives, optimization job

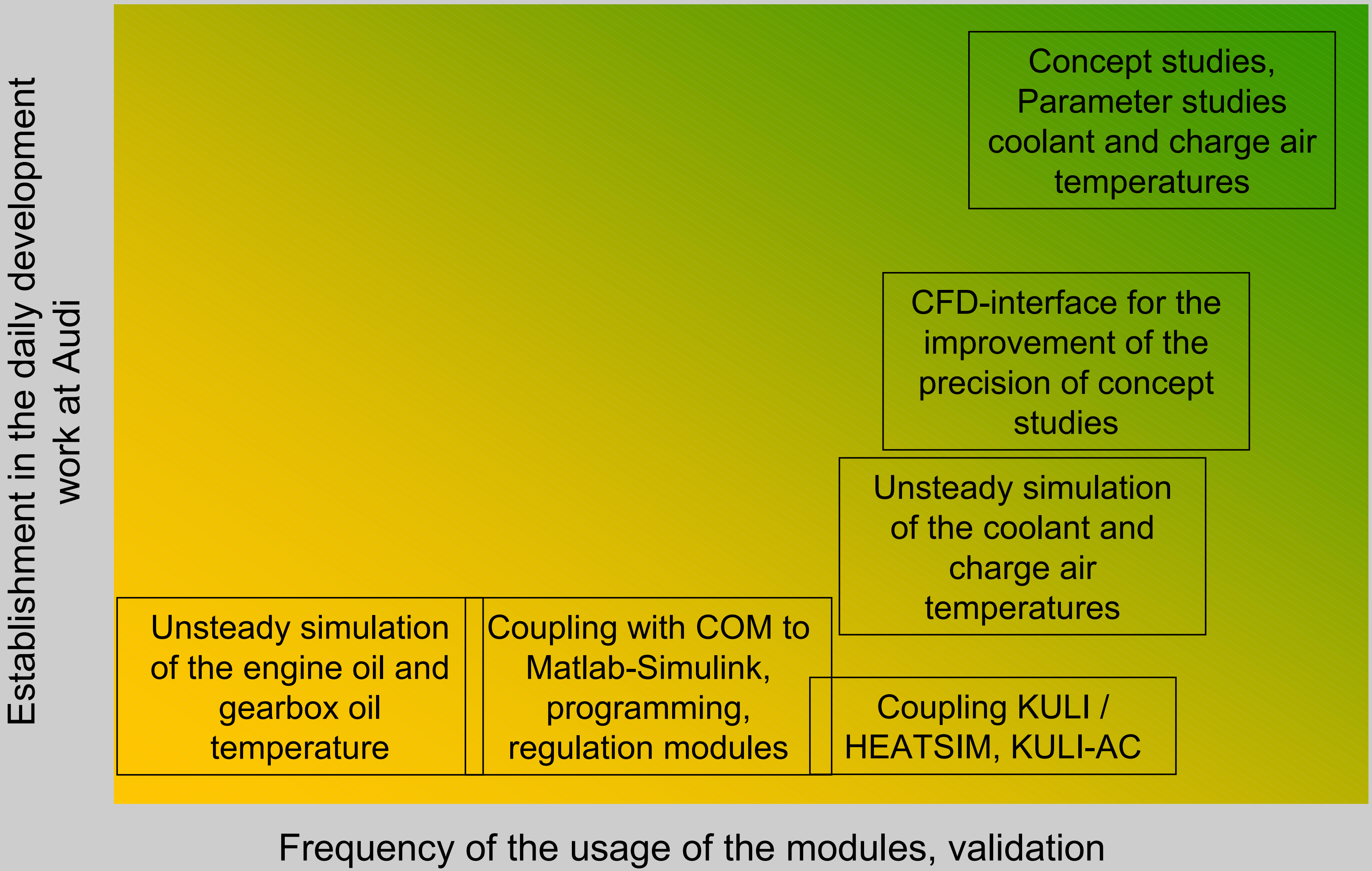
- Possible part of a simulation tool: Analysis and assessment of a complex technical system

- **Realization of heat management** = Knowledge and understanding of all concerned factors + strategy + tool + conversion

Orientation of Future Modules



Usage of the Modules in the Development Process



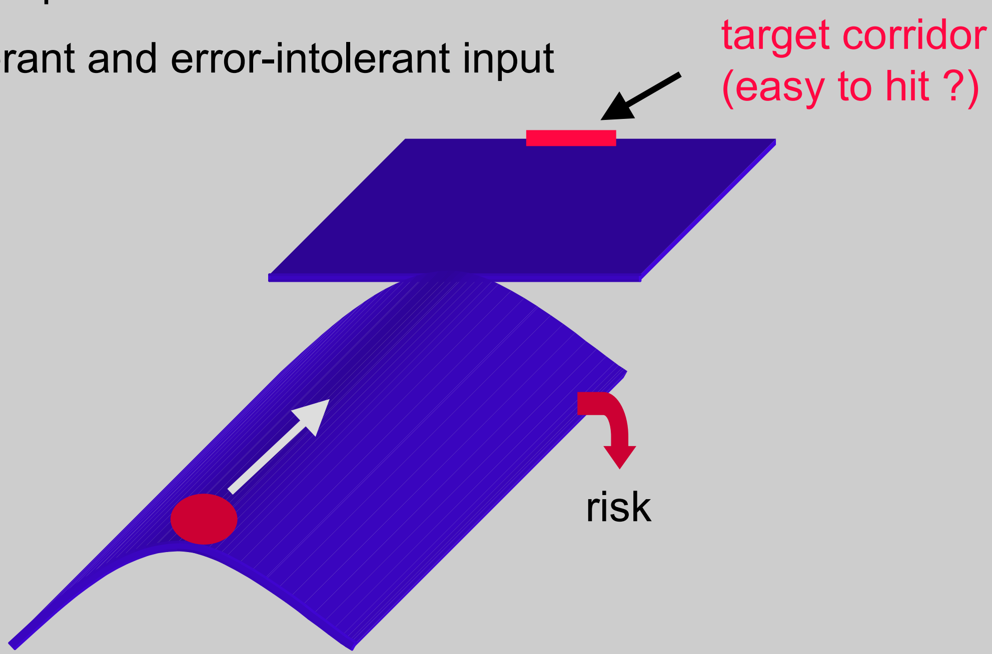
Quality Management

In ancient KULI

$$ETD = \frac{Q_{Aggregate}}{\Phi_{Radiator}}$$

Error analysis for integrating and complex processes is highly desirable

- Consideration of the error reproduction
- Transparency of error-tolerant and error-intolerant input data
- E.g. Mars probe
- E.g. way of a ball



Vision of Future Development

e.g. $T_{Coolant}$

$Q_{Pass.Compart}$ *after x* sec

$T_{Charge\,air}$

$T_{Engine\,oil}$

$P_{Hydraulic}$

$Q_{Ambient}$

Fuel consumption

$$\frac{P_{Hydraulic}}{Colling\ efficiency}$$

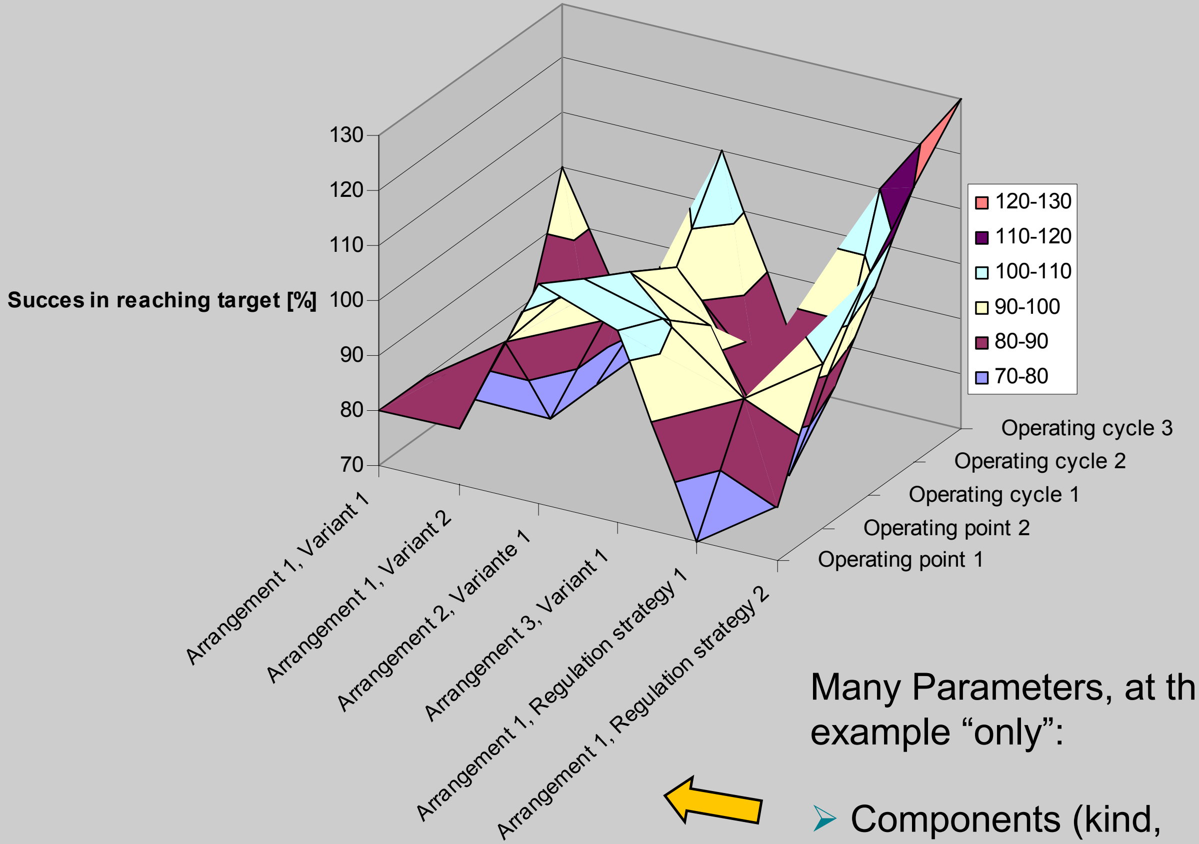
$$\frac{Colling\ efficiency}{Costs}$$

$$\frac{Colling\ efficiency}{weight}$$

time until AC off

time until coolant hot

...



Many Parameters, at this example "only":

- Components (kind, geometry, connection)
- Coolant flow

Automatical extraction of technical solutions, when criteria are given by the user, transparent depiction of the development levers and results

Thank you very much

Dr.-Ing. Johann Betz, **KULI** User Meeting 2001,

17.10.-18.10.2001, Steyr