

Reliable and Robust Design of Cooling Systems in an Early Stage of the Development Process

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Diese Arbeit wurde im
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gefördert aus Mitteln
des K plus Kompetenzzentren-Programm,
des Landes Steiermark,
der Steirischen Wirtschaftsförderungsgesellschaft mbH und
der Stadt Graz

Kplus
Kompetenzzentren-Programm

Stadt **GRAZ** Wissenschaft



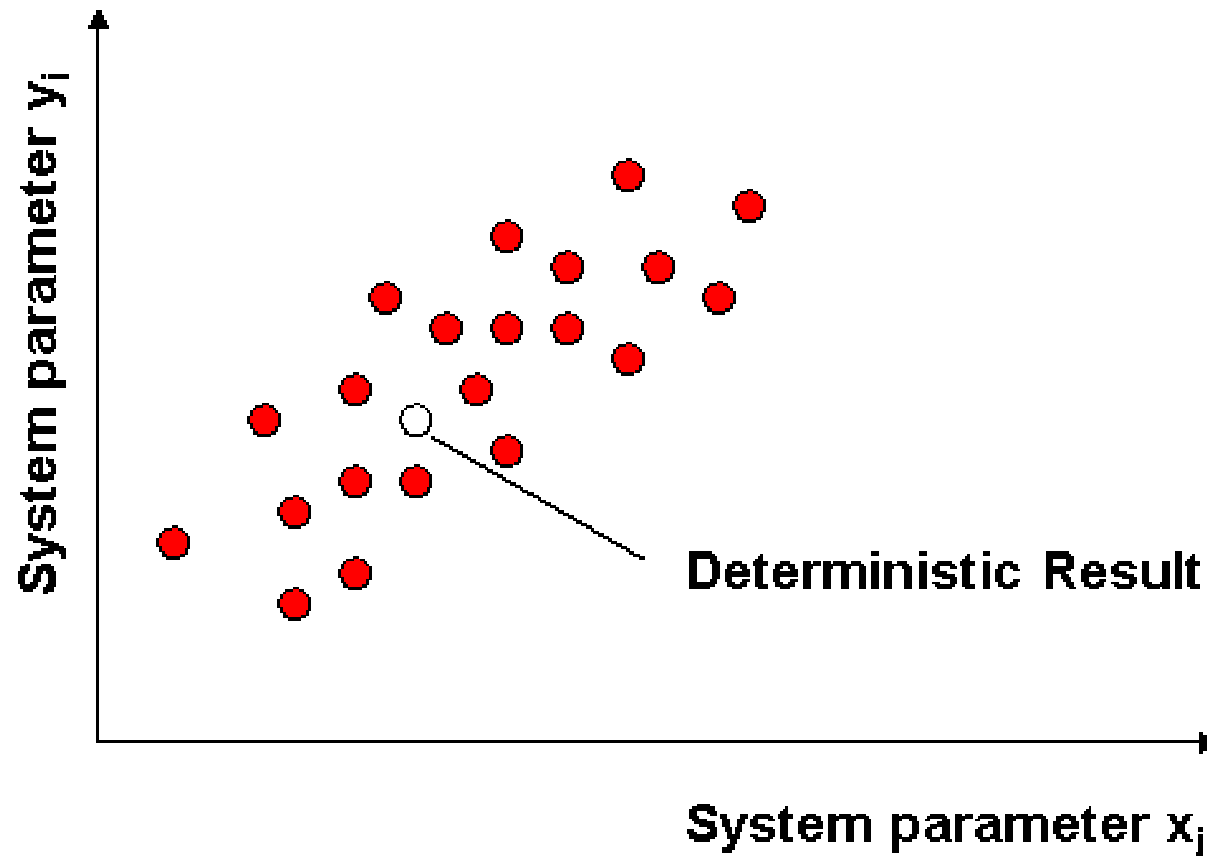
AGENDA

- Motivation – Robust Cooling
- Method - Strategy
- Simulation Model
- Test Bench Measurement
- Deterministic Results
- Stochastic Model
- MRC Model Application
- Conclusion and Outlook

MOTIVATION

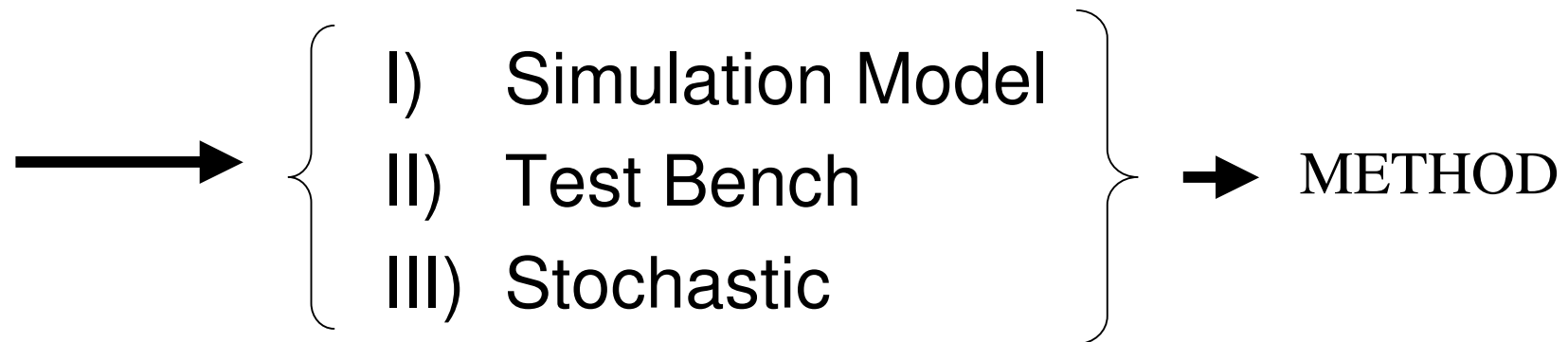
- Provide robust and reliable simulation results
- Simulations have to deal with physical uncertainty and numerical errors
- These uncertainty influences the results
- Impact of uncertainty must be evaluated
- Getting a better understanding of the sensitivity of the model
- More information in the early development

MOTIVATION



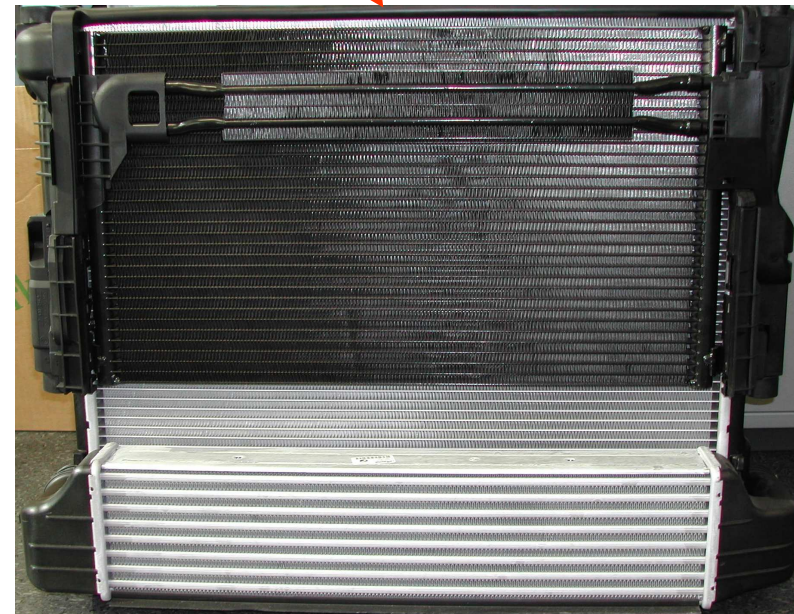
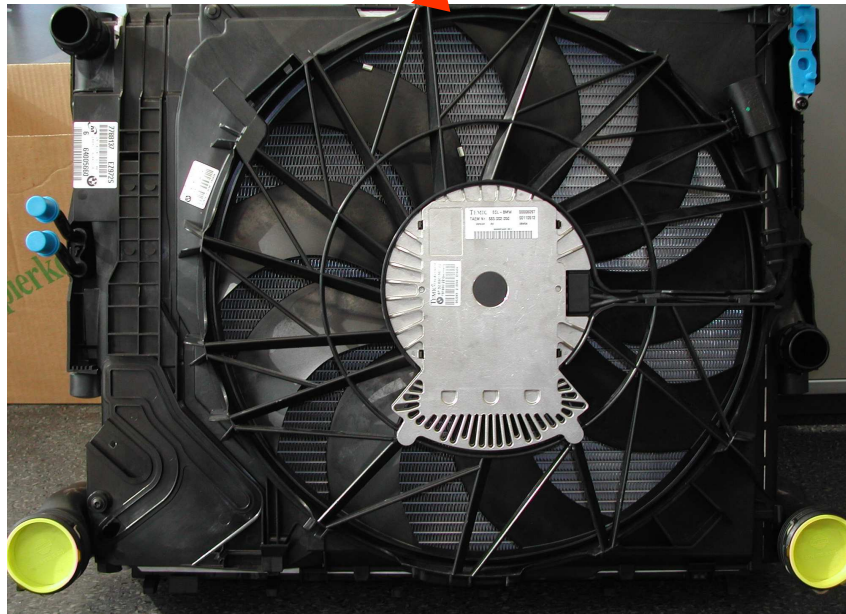
METHOD - STRATEGY

- CASE: Deterministic Result – Measurements
- CASE: Stochastic CFD Case, Resistance Matrix



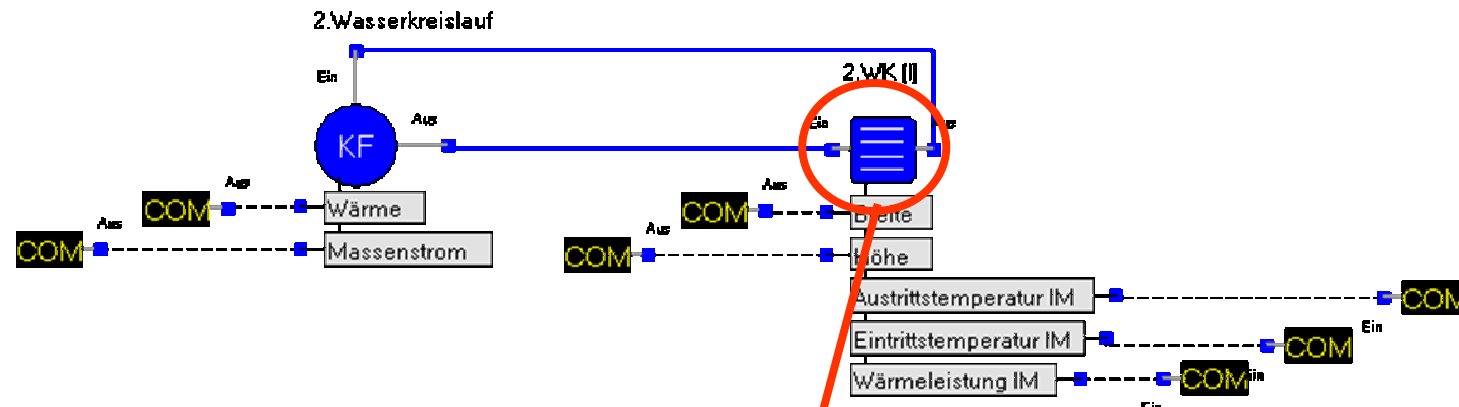
SIMULATION MODELL

- Cooling Package

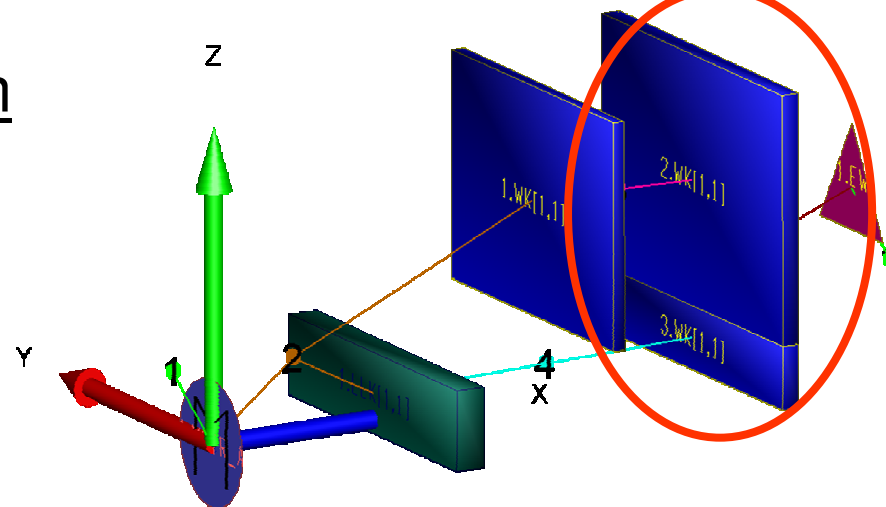


SIMULATION MODELL

- Inner Circuit

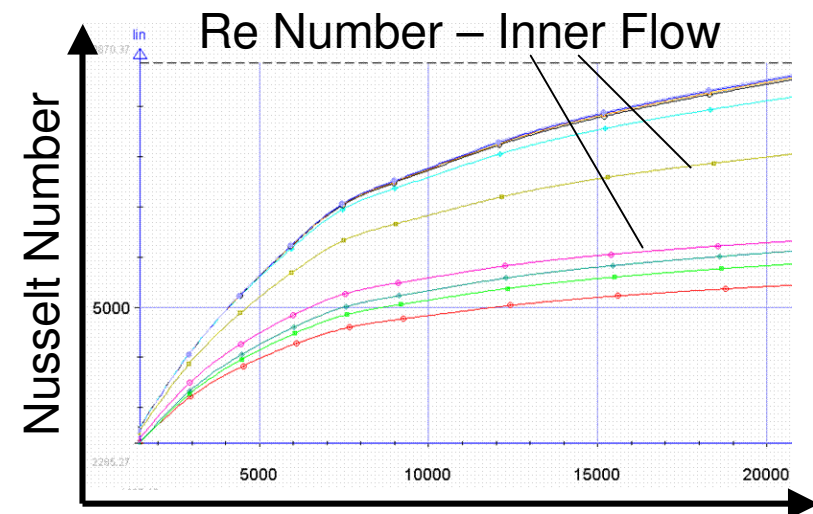
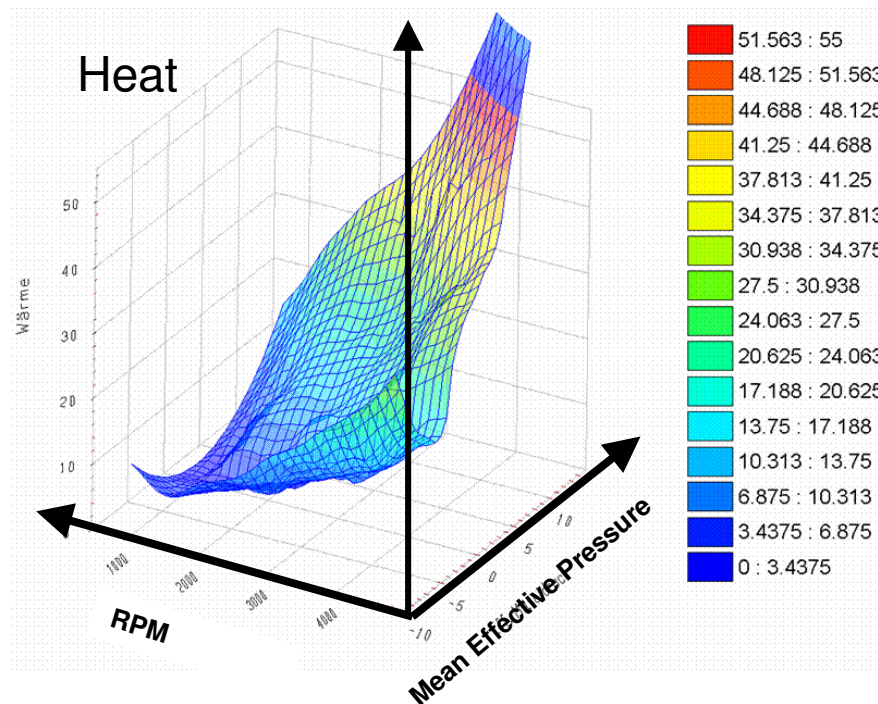
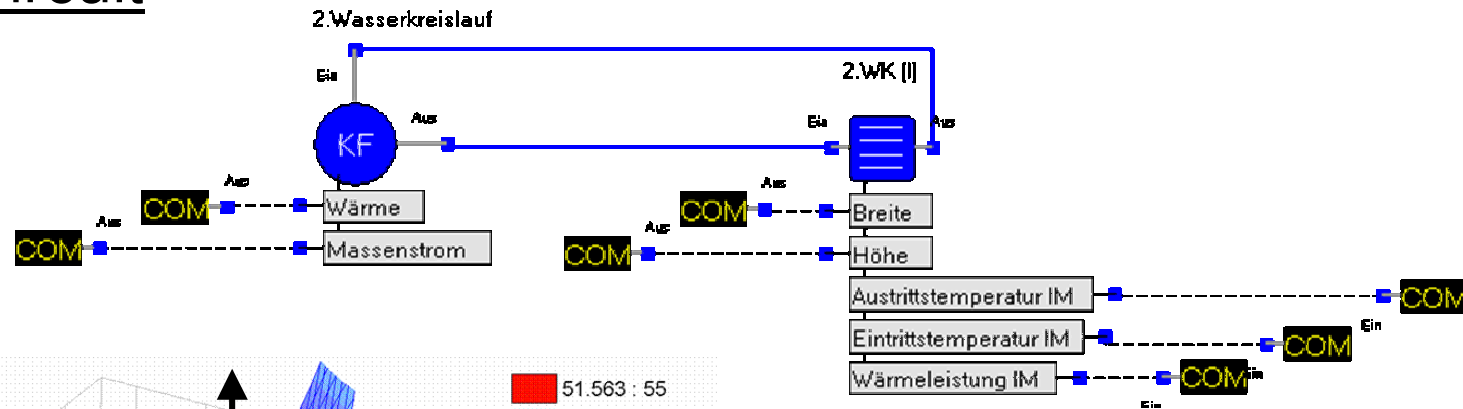


- Air Path



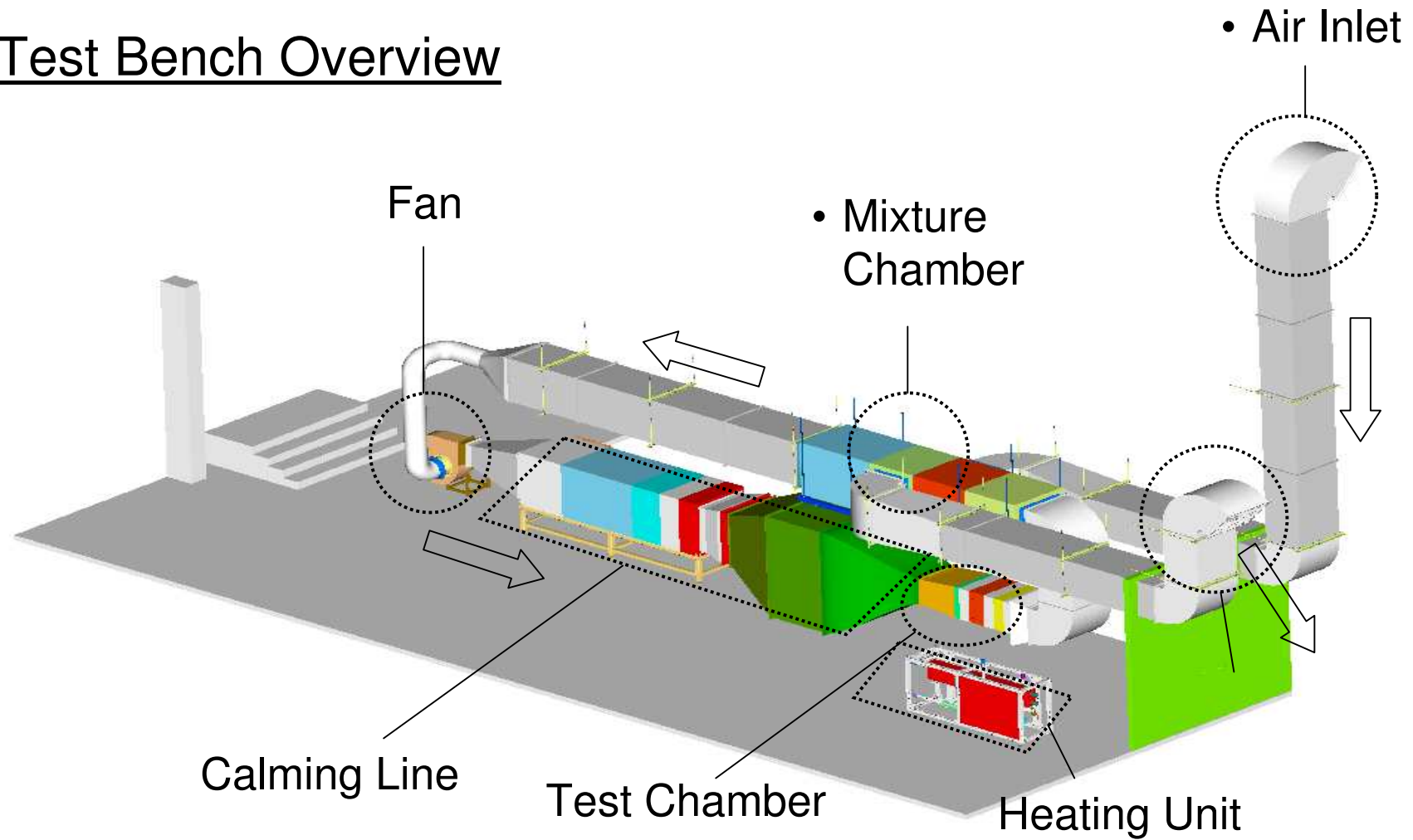
SIMULATION MODELL

• Inner Circuit



TEST BENCH MEASUREMENTS

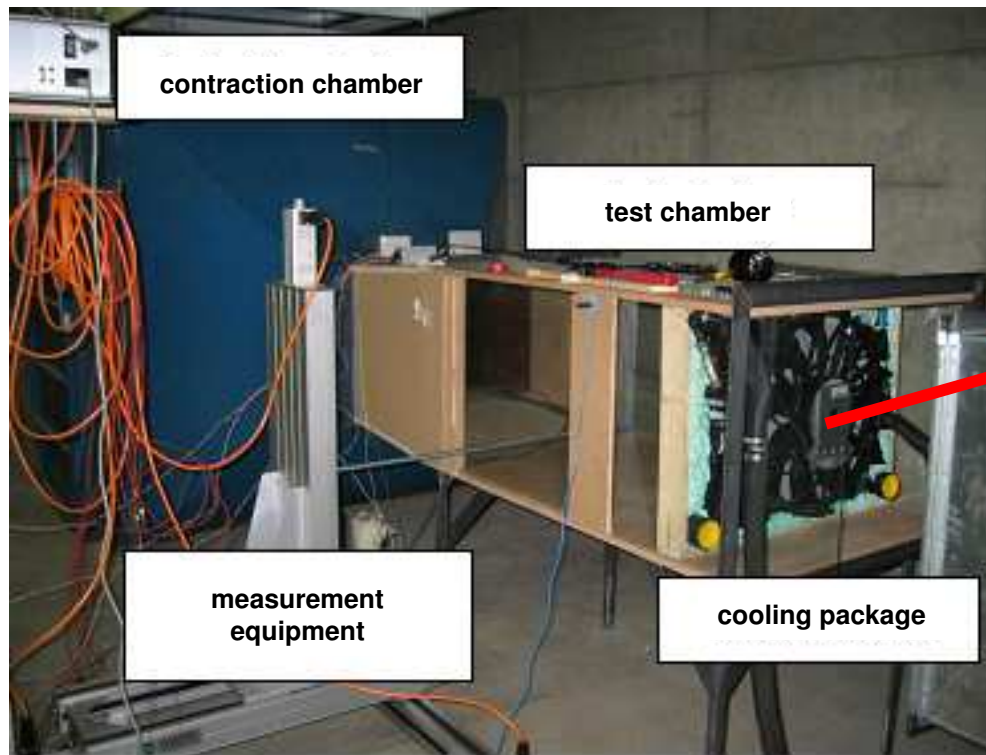
- Test Bench Overview



TEST BENCH MEASUREMENTS

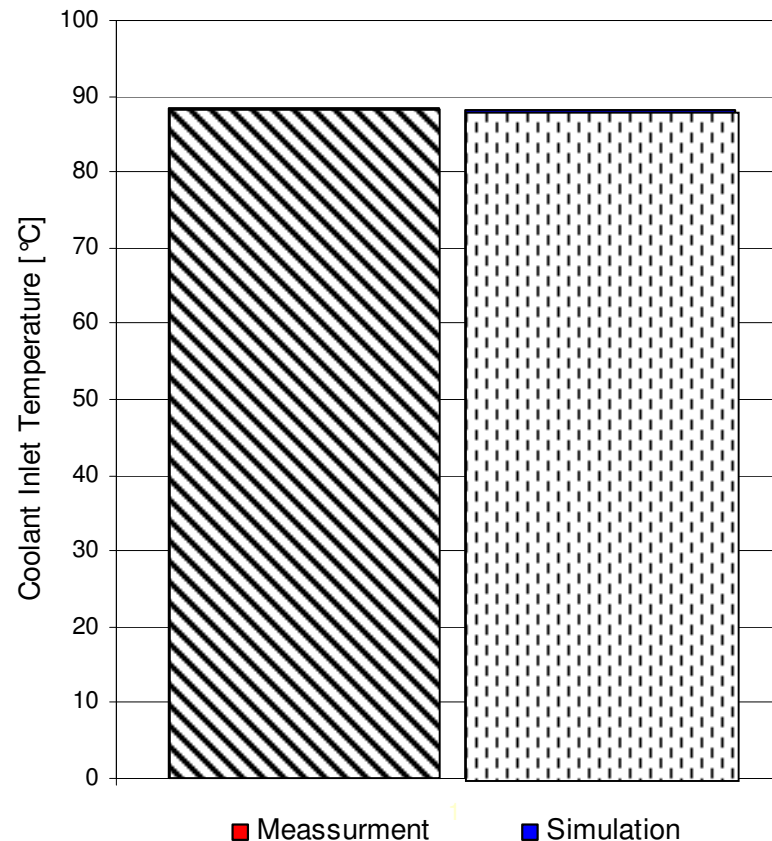
- Test Chamber

- Front Grill

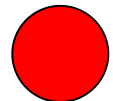


COMPARISON

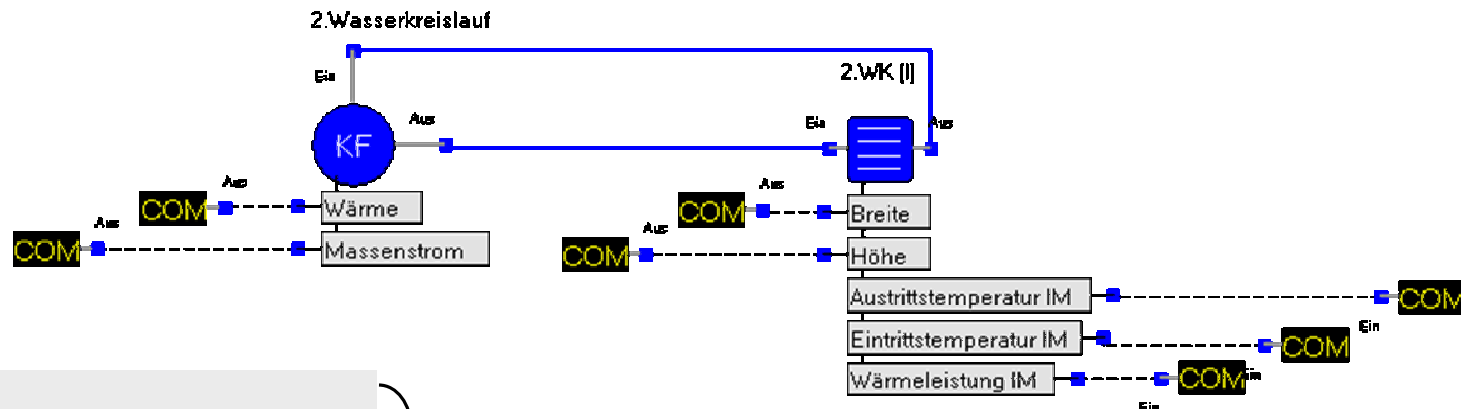
- Deterministic Result - Measurements



- Validation of the Physical Model
- Good Correlation
- No Information About Behavior



SIMULATION METHOD



- Heat Release
- Mass Flow Coolant
- Mass Flow Air
- Geometry
- Ambient Conditions

SOLVER
KULI

Coolant Entry
Temperature

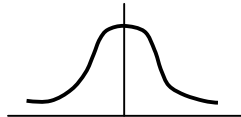
COM IN

EXCEL CONTROL

COM OUT

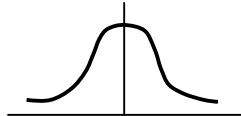
STOCHASTIC METHOD

➤ Heat Release



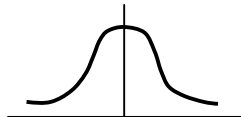
• Deviation 3 %

➤ Mass Flow Coolant



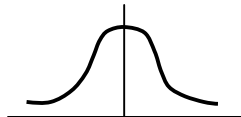
• Deviation 3 %

➤ Mass Flow Air



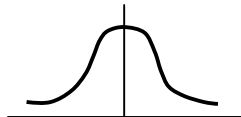
• Deviation 3 %

➤ Geometry

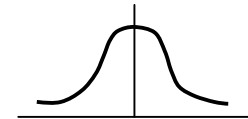


• +/- 10 mm

➤ Ambient Conditions



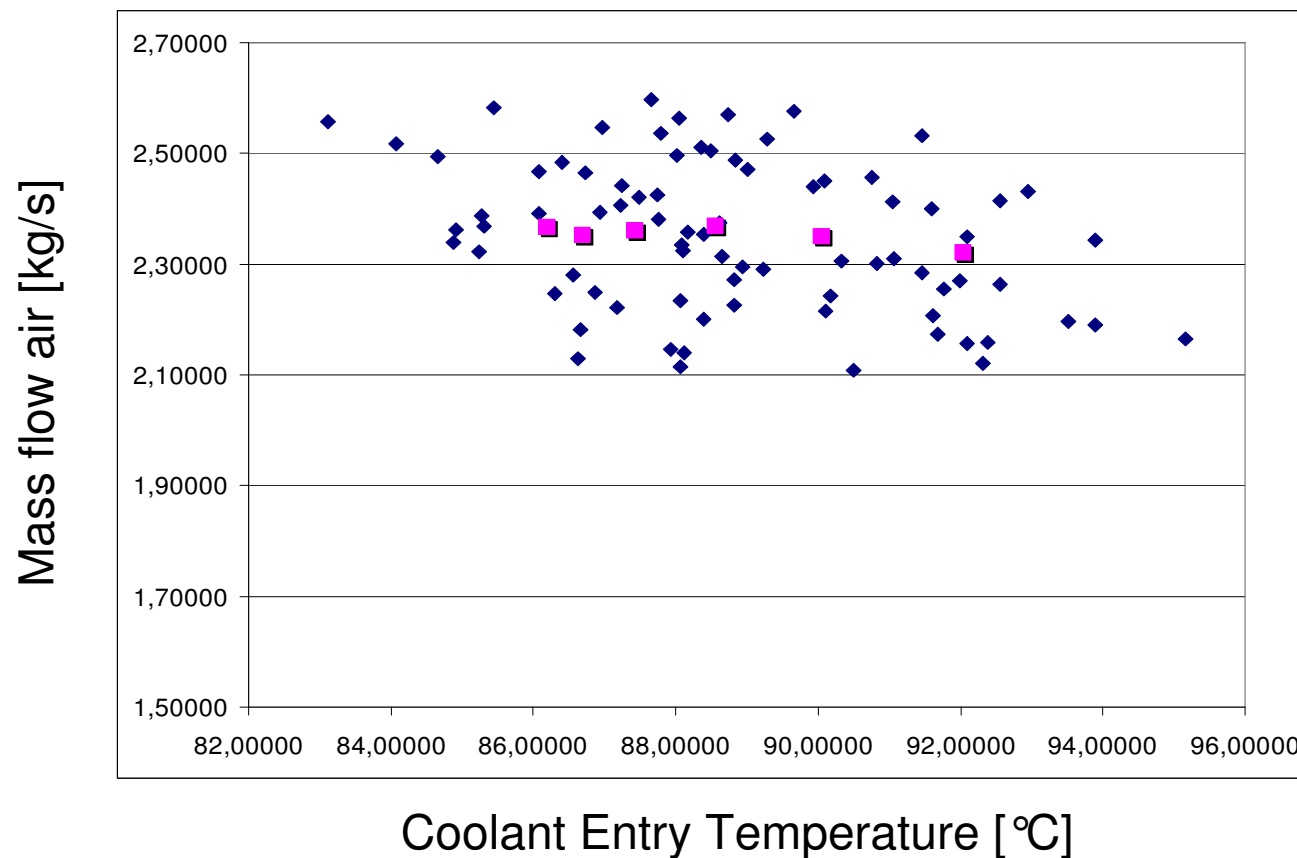
• +/- 2 K



• Coolant Entry Temperature
(statistical distribution)

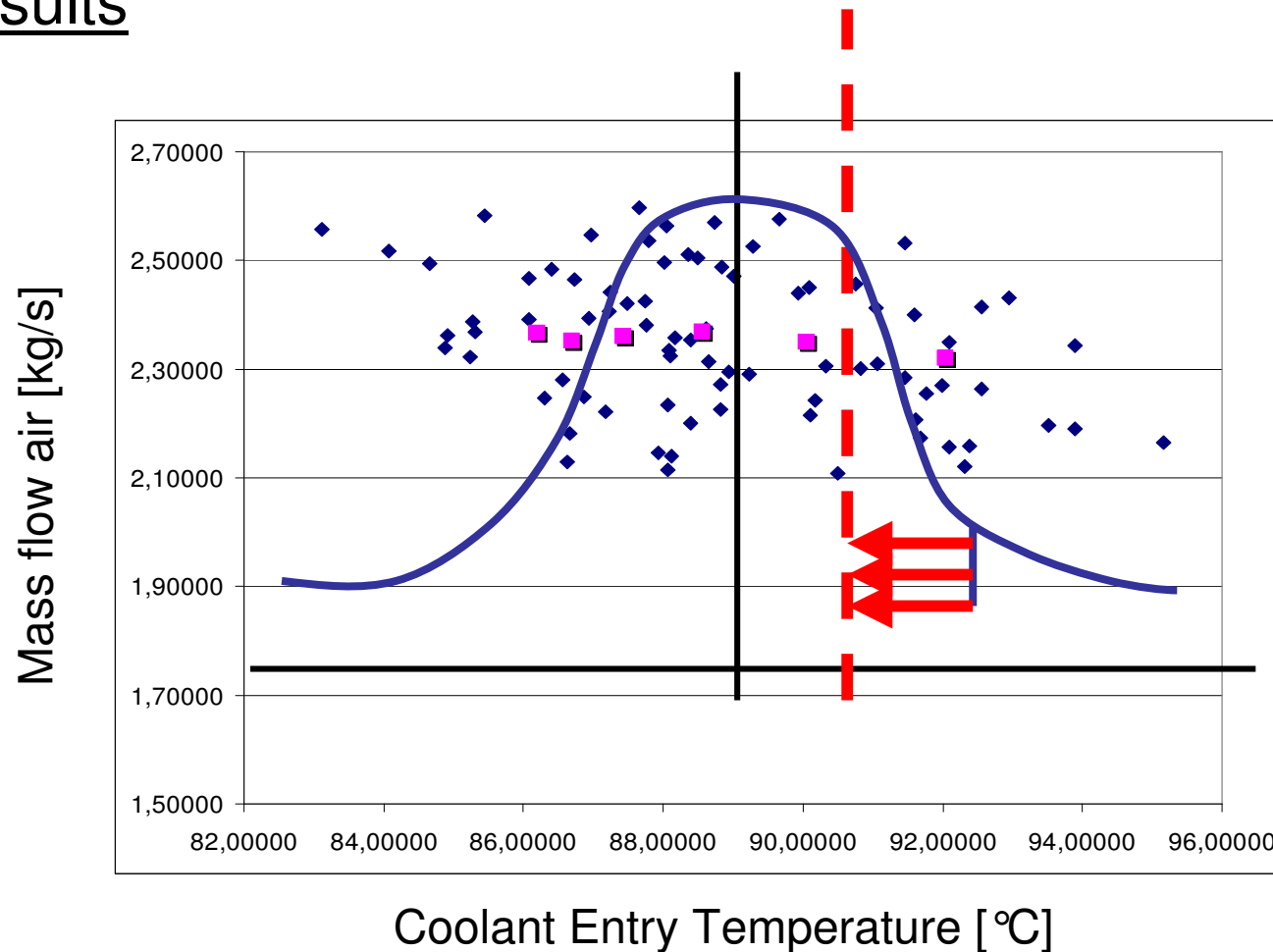
RESULTS

- Influence on the Cooler Entry Temperature – Stochastic Results



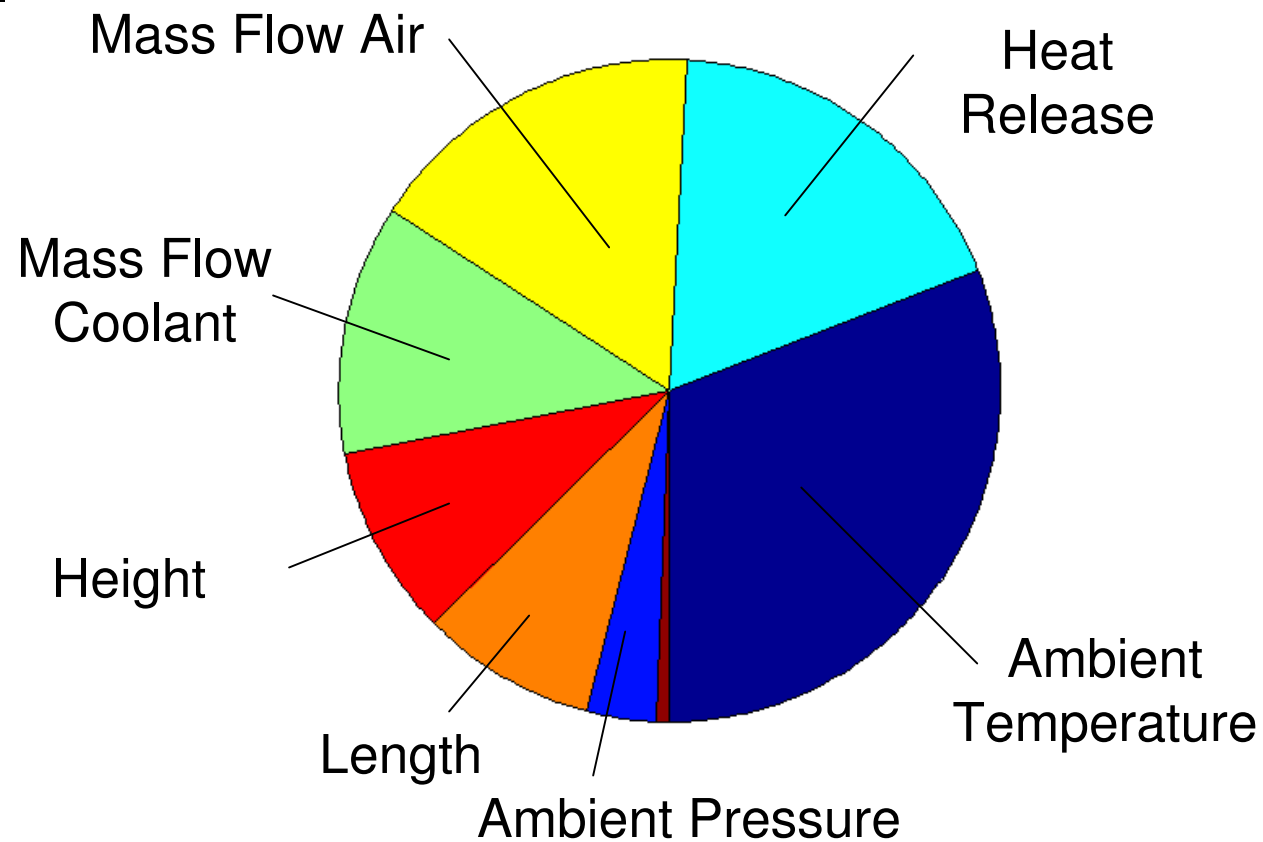
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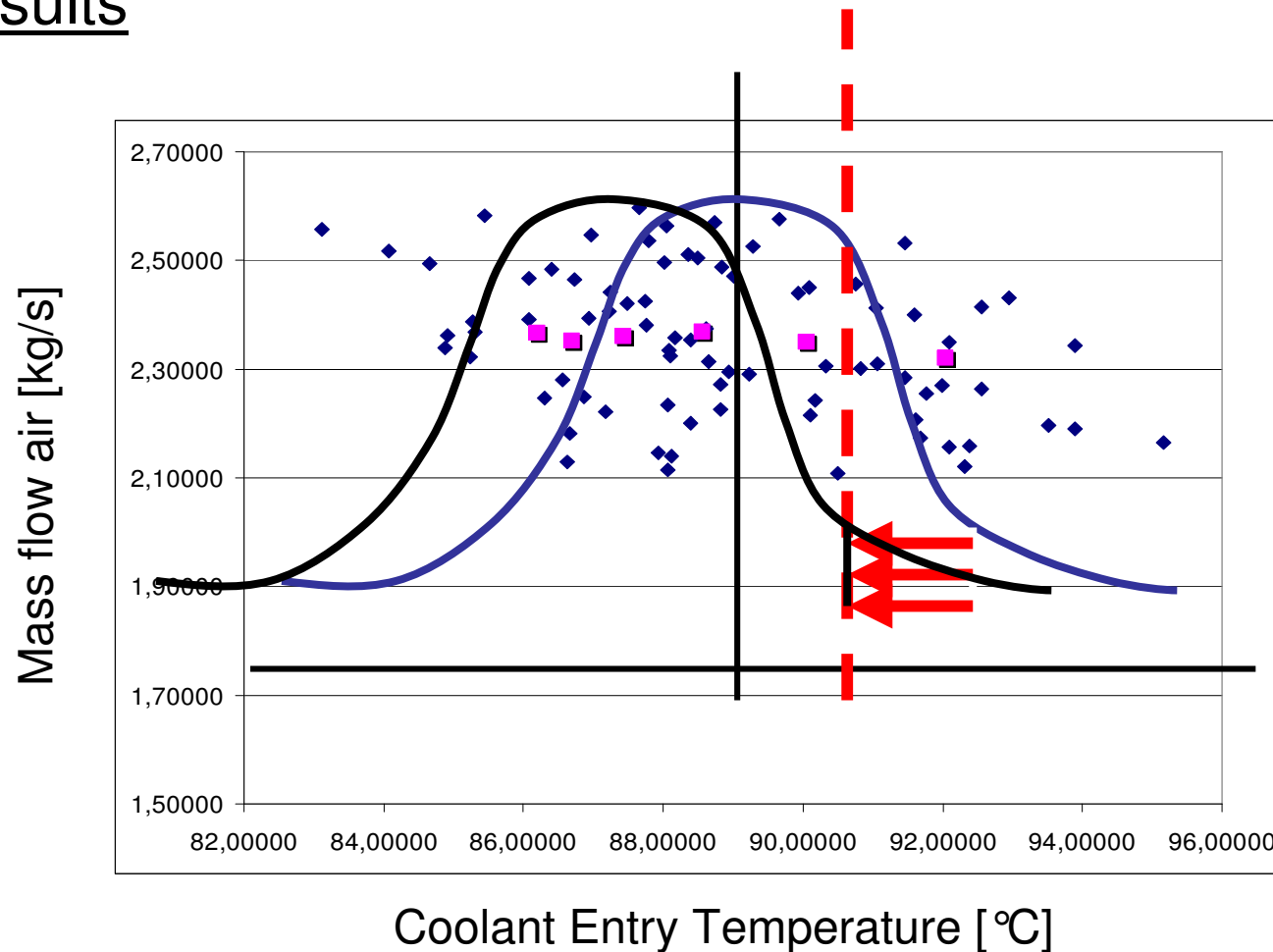
RESULTS

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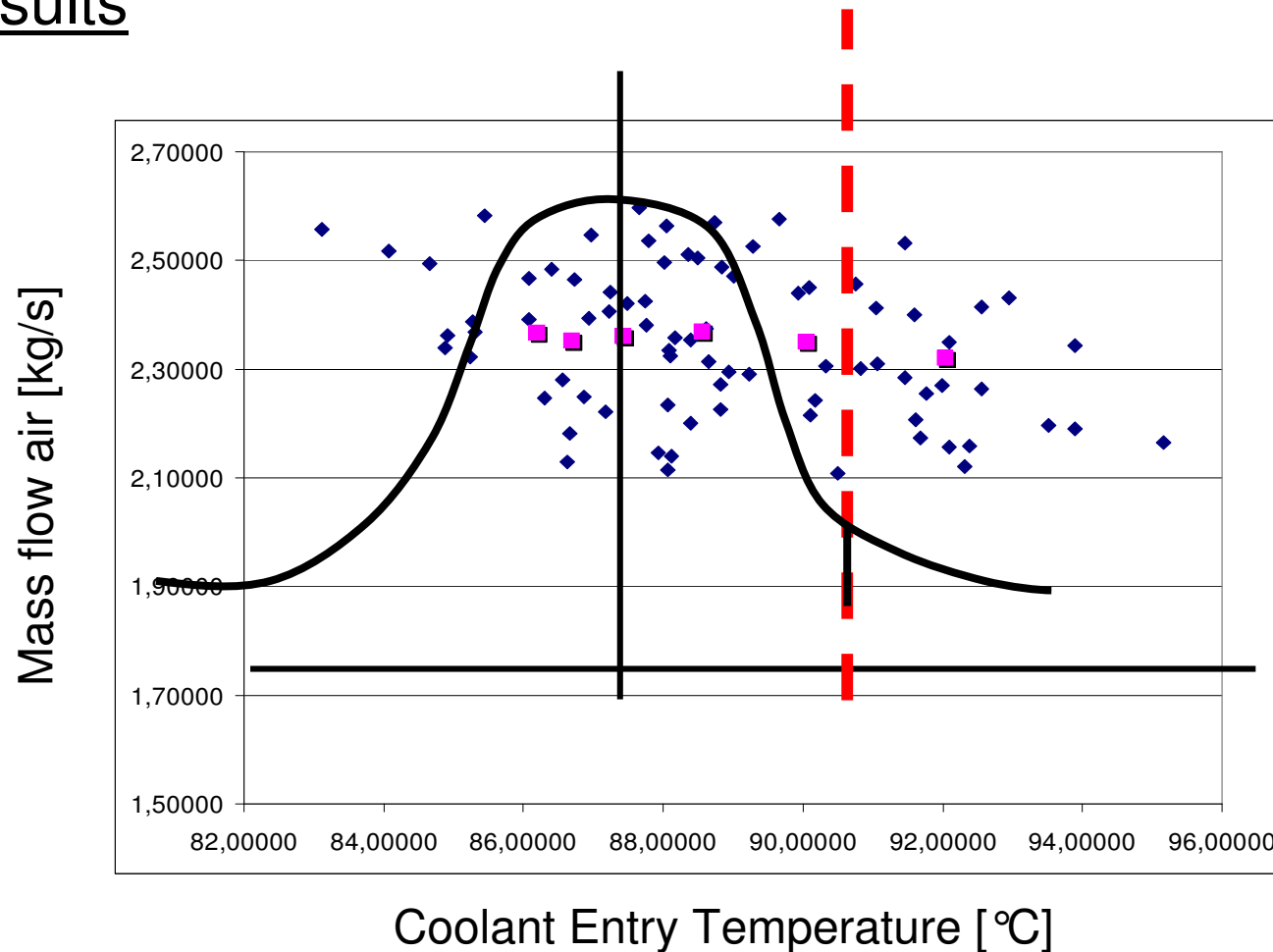
RESULTS

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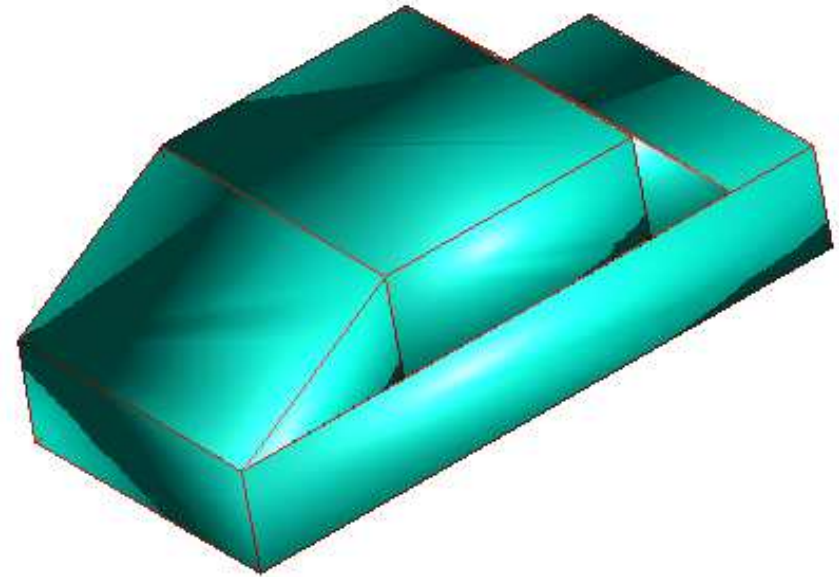
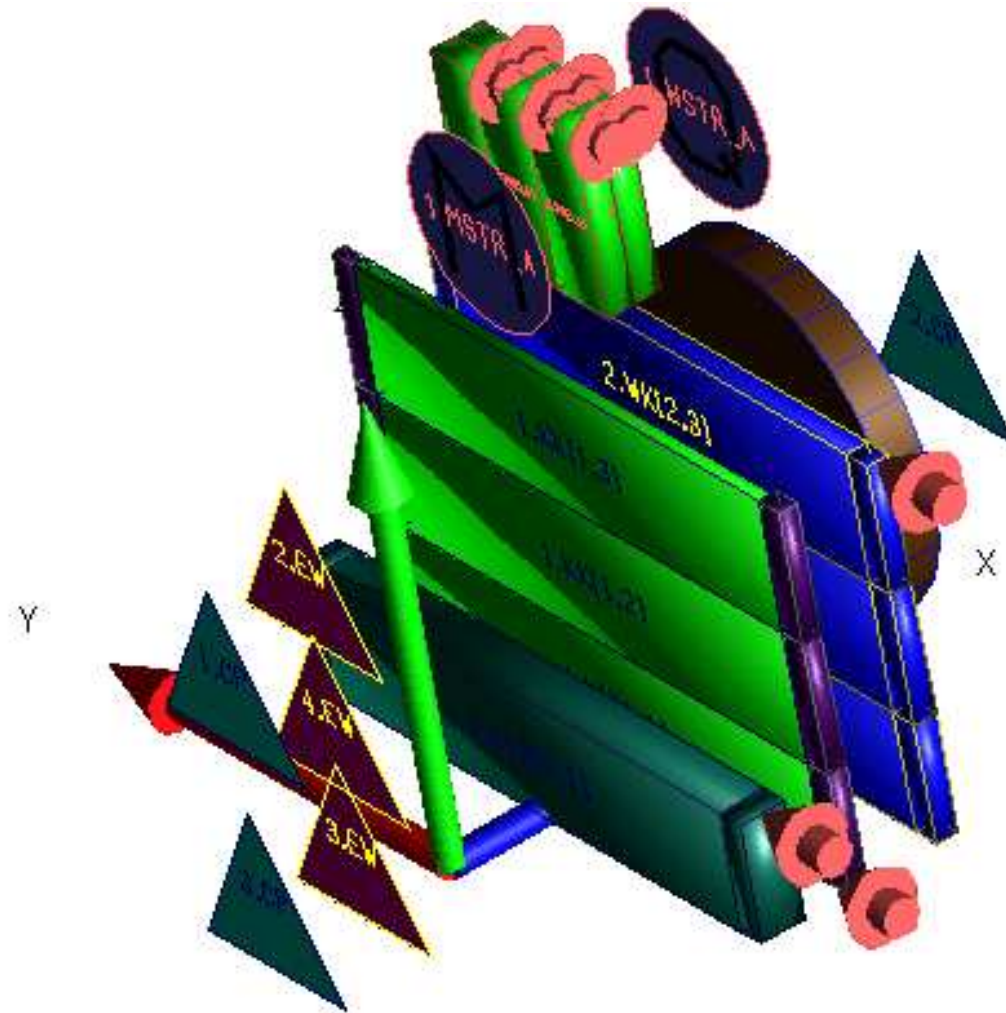
RESULTS

- Influence on the Cooler Entry Temperature – Stochastic Results

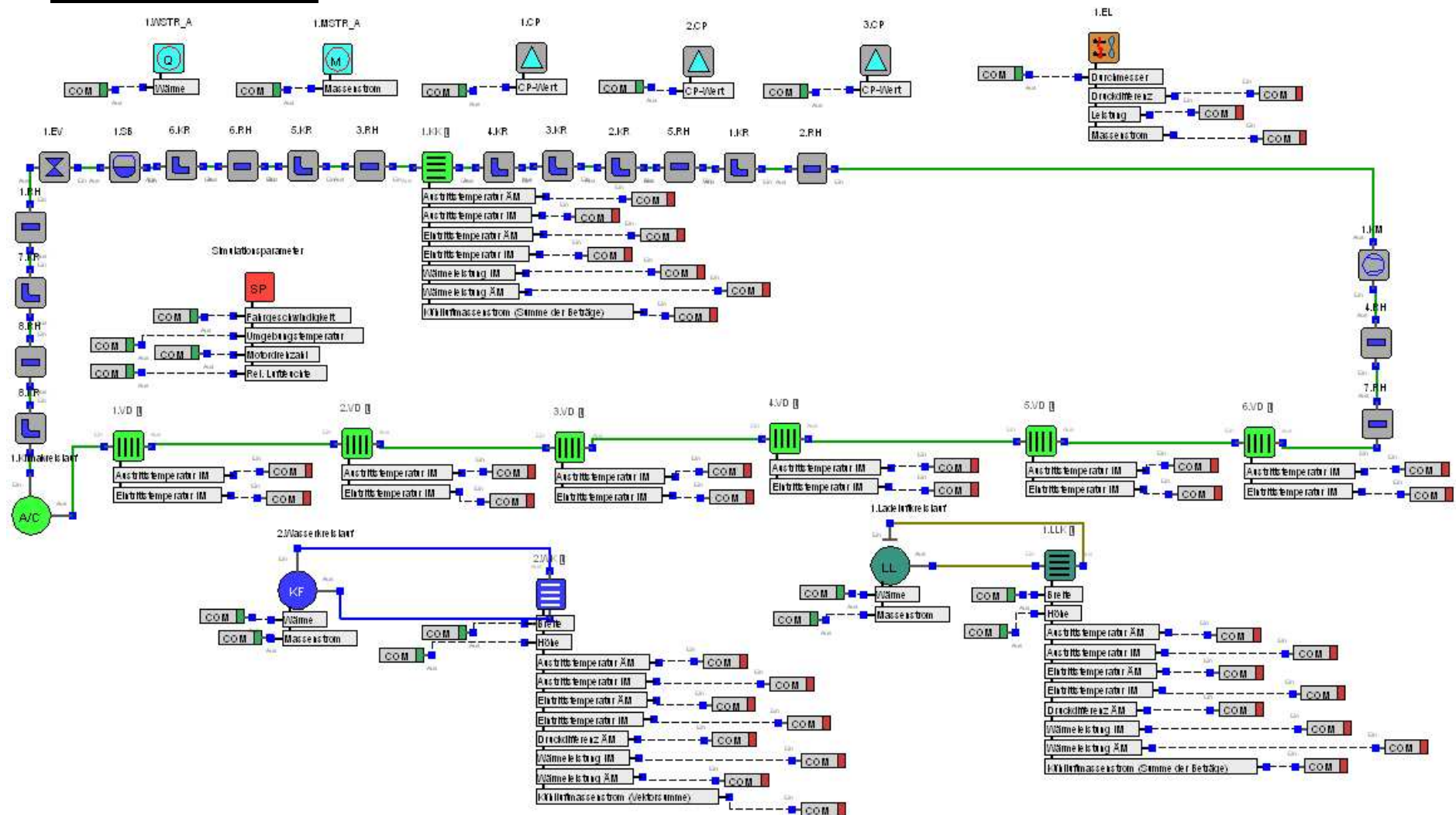


MRC MODELL

- Air Side



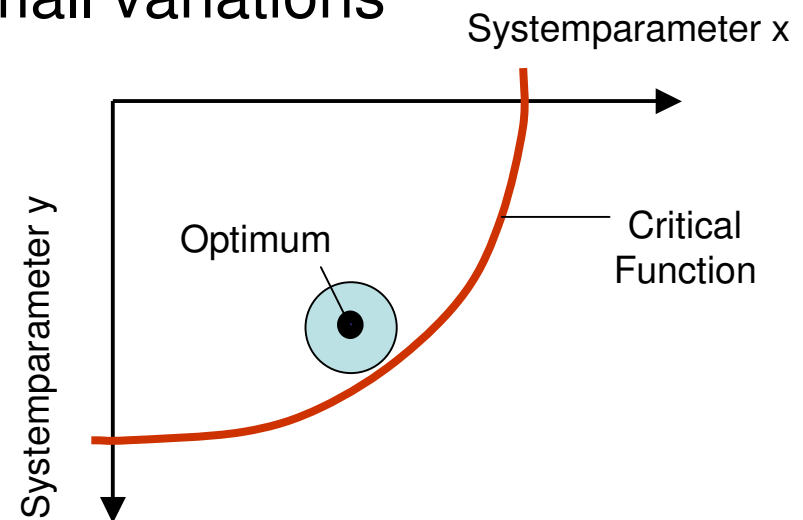
- Inner Circuit



MRC MODELL

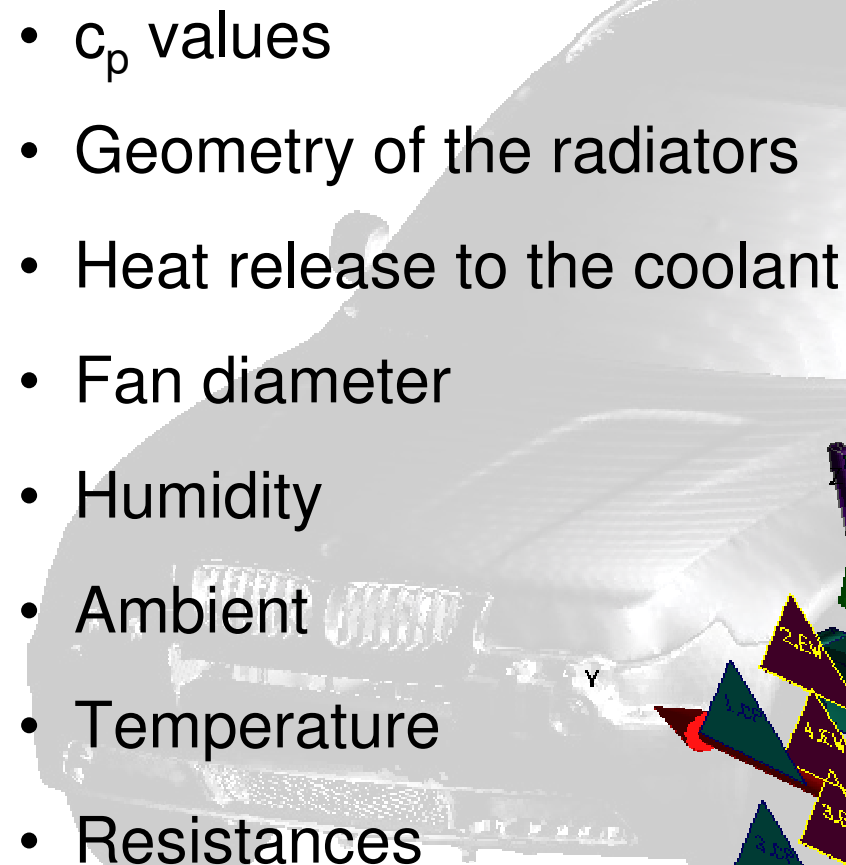
- Development Task

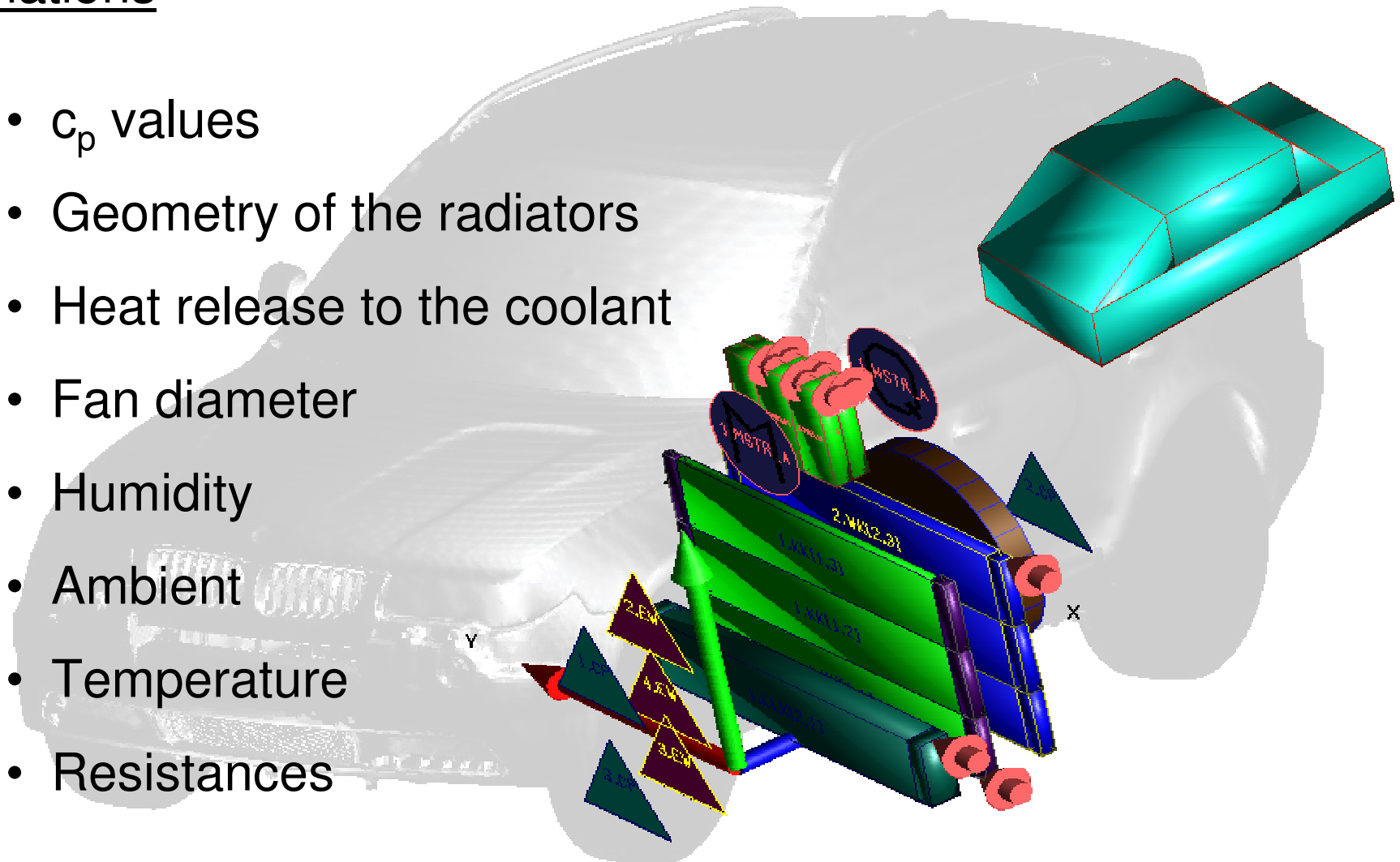
- Performance checks of the cooling and HVAC system in the early development phase
- Robust and Reliable Design for all critical driving conditions (e.g. hill with trailer, fast hill, $v_{\max}$)
- Behaviour of the system on small variations



MRC MODELL

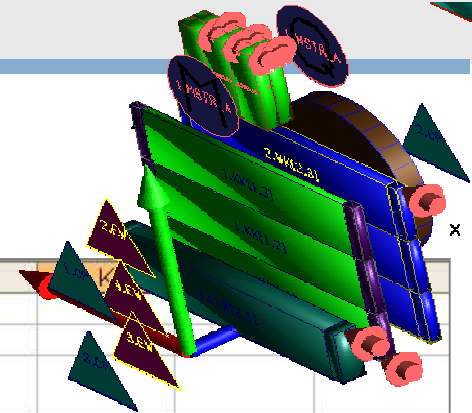
- Variations

- 
- c_p values
 - Geometry of the radiators
 - Heat release to the coolant
 - Fan diameter
 - Humidity
 - Ambient
 - Temperature
 - Resistances



MRC MODELL

- Excel Sheet

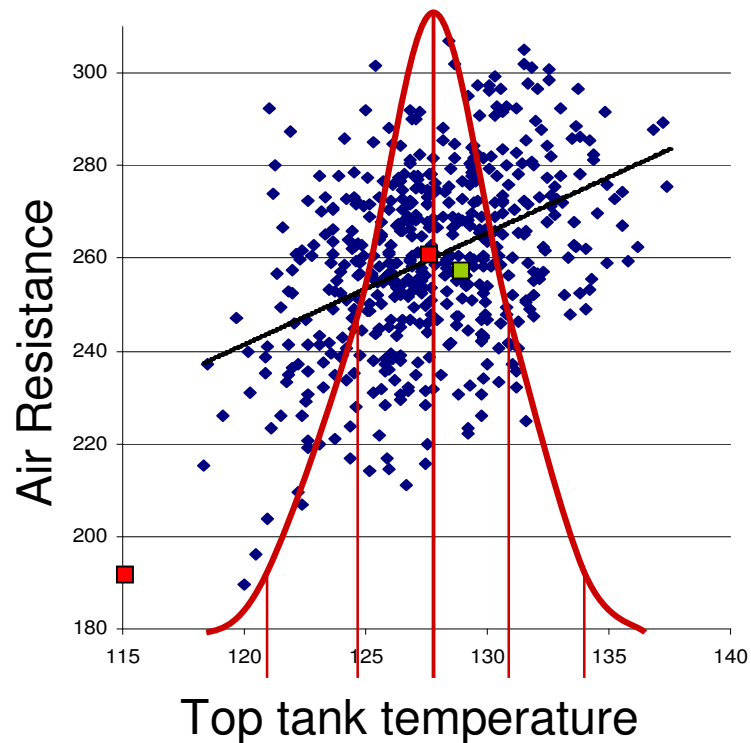
[illegible]

MRC MODELL

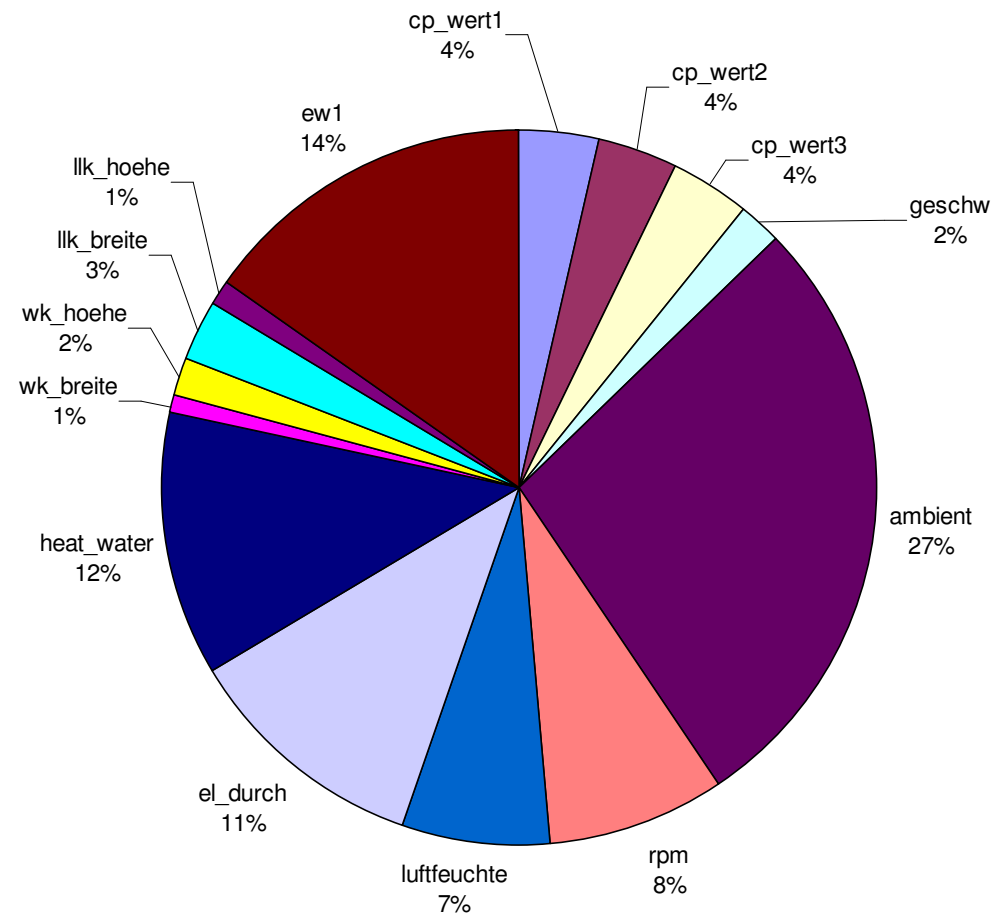
• Results

Statistical Distribution of the Top Tank Temperature

Mean:127,7 St. Deviation: 3,5



Influence on the Top Tank Temperature



CONCLUSION

What we achieved ...

- ... Robust and reliable simulation results
- ... Simulation method for the early phase of the development process
- ... A better understanding of the sensitivity of the system concerning variations
- ... Basis for decisions and first risk estimations concerning robustness of the cooling system

OUTLOOK

What is on the roadmap ...

... Hybrid Multidimensional Optimization

... Grid Solution for KULI on a
64 bit Opteron Cluster

... Multidisciplinary Optimization by Coupling