Forschungsinstitut für
Kraftfahrwesen und
Fahrzeugmotoren
Stuttgart

Thermal Management Investigations at FKFS: Experimental Measurements and Simulation with CFD and KULI

Overview:

1. FKFS – Experimental Test Facilities
   - Aeroacoustic Wind Tunnel
   - Roller Test Bench and Hot Climatic Wind Tunnel
2. Experimental Measurements
   - Air Flow
   - Thermal
3. Simulation with KULI
   - Resistance Matrix
   - Built-In Resistance
4. Summary

M. Genger
T. Kuthada
J. Wiedemann

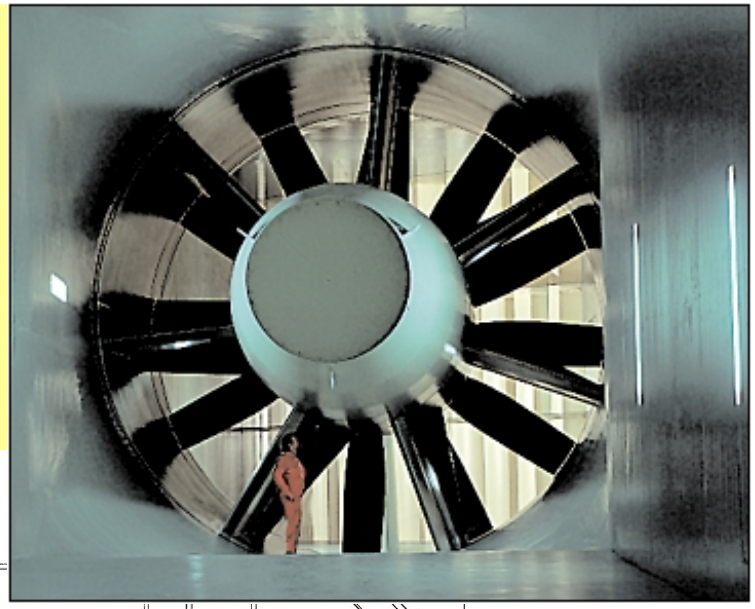
FKFS

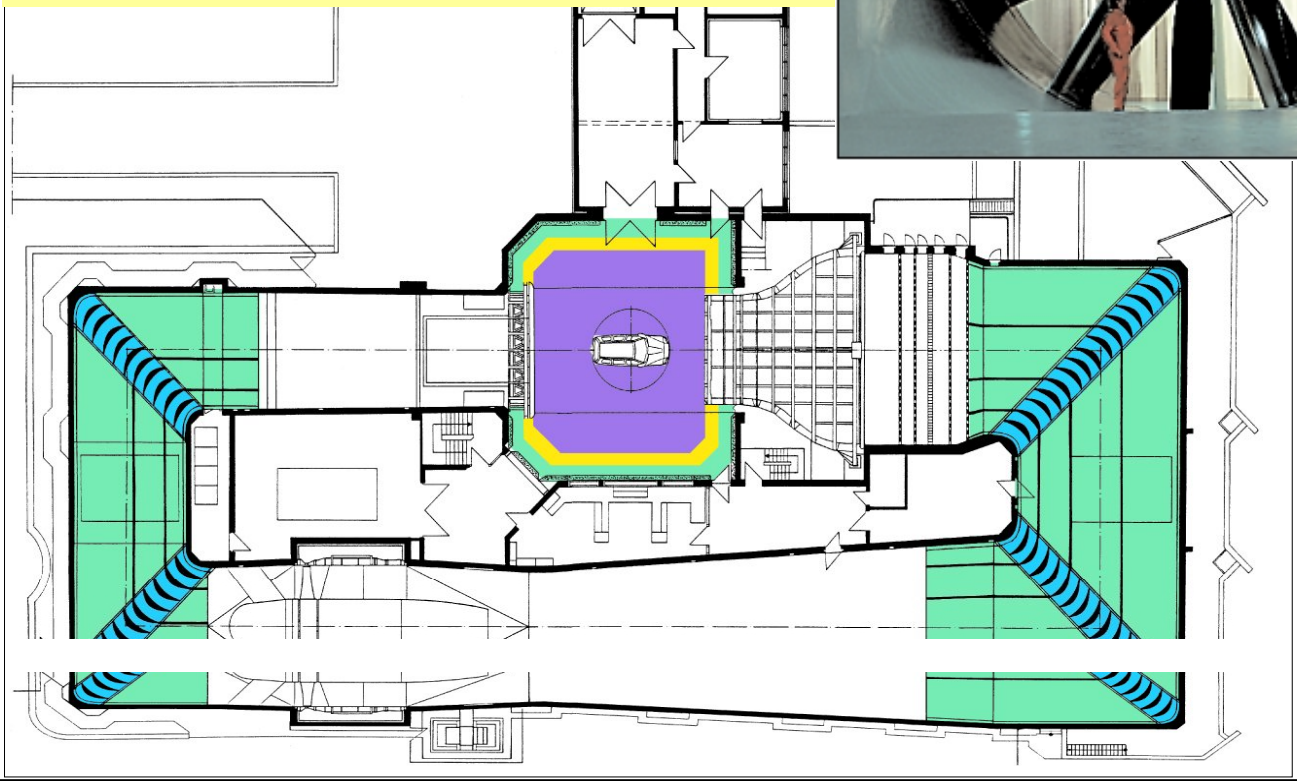
Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

1. **Experimental Test Facilities:**
   - Aeroacoustic Wind Tunnel
2. **Measurements**
3. **Simulation**

FKFS Full Scale Aeroacoustic Wind Tunnel with 5-Belt Road Simulation System

Nozzle Exit Area:	22,45 m^2
Test Section Length:	9,95 m
Fan Diameter:	7,1 m
Top Speed:	250 kph

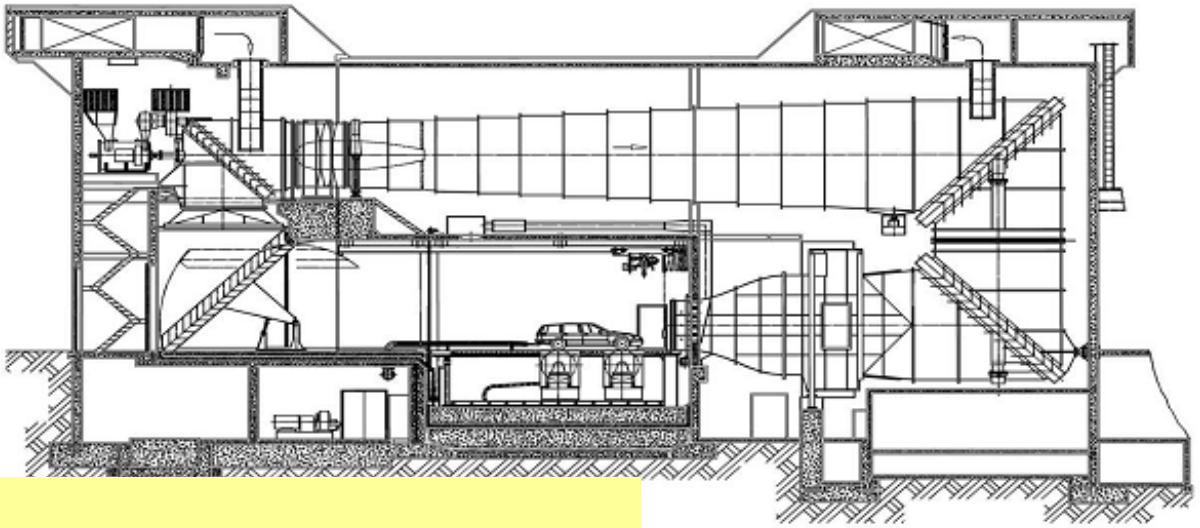




M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

FKFS Roller Test Bench and Hot Climatic Wind Tunnel



Technical Data:

Test Section (L/W/H): 15,8 m / 6,8 m / 5,5 m

Roller Diameter: 1,5 m

Roller Speed: max. 400 kph

Tractive Force during Braking: max. 14 kN

Air Flow Speed: max. 220 kph

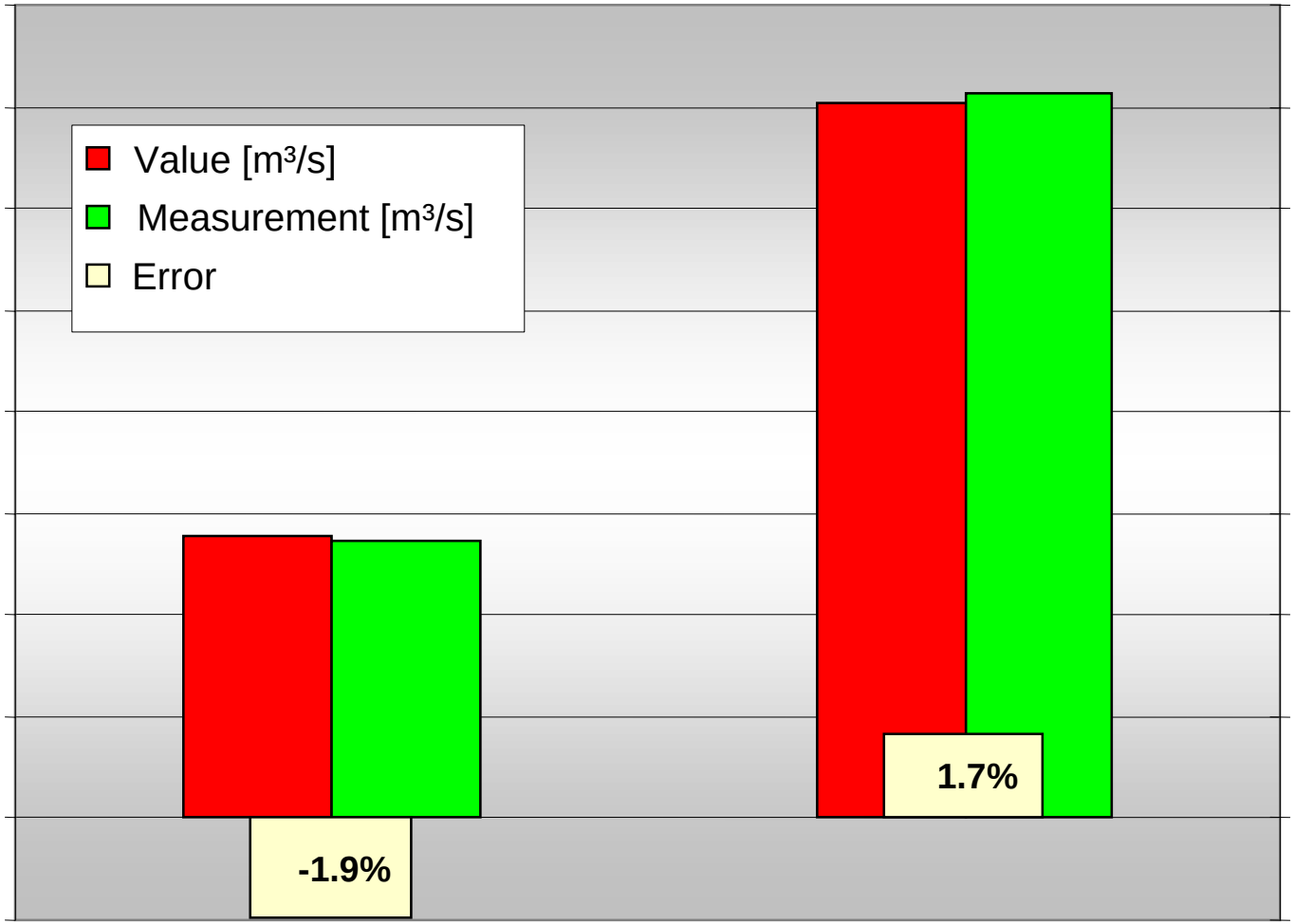
Nozzle Cross-Section: 6 m² (2,45 m x 2,45 m)

Input Power of Fan: max. 1000 kW

M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Measurements – Air Flow



➢ Unusual High Accuracy in Prediction of Cooling Air Volumeflow Rate

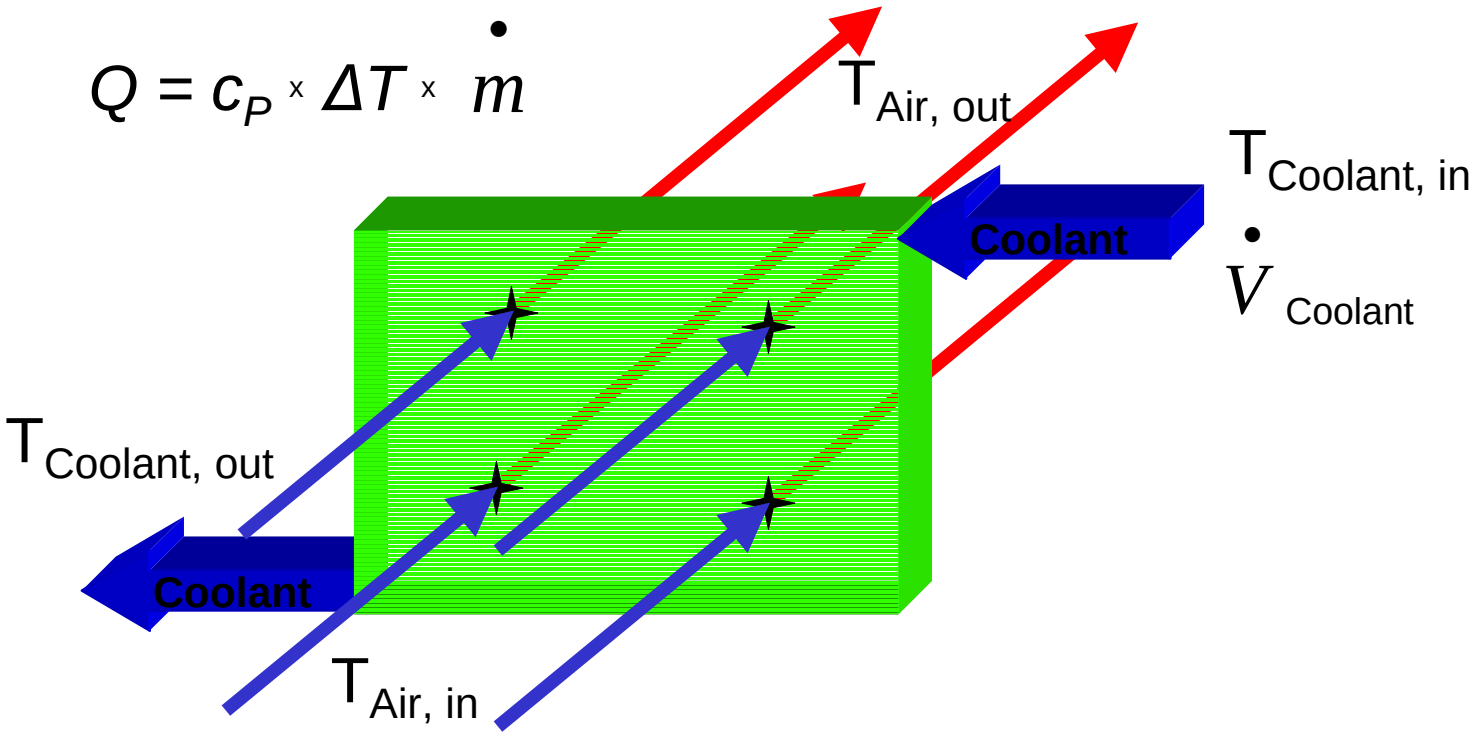
M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Measurements – Thermal

- Coolant and Air Temperatures at the Radiator Inlet and Outlet
- Volume Flow of Coolant through the Radiator
- Fan Rotational Speed and Power
- Ambient Conditions (Atmospheric Pressure, Temperature, Humidity)
- Power, Velocity and Traction Force of the Vehicle on the Roller

$$Q = c_P \times \Delta T \times \dot{m}$$



M. Genger
T. Kuthada
J. Wiedemann

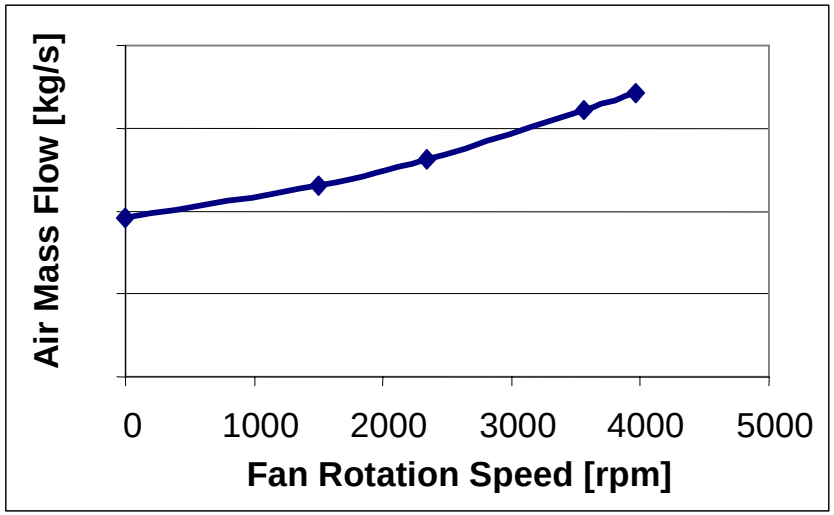
Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

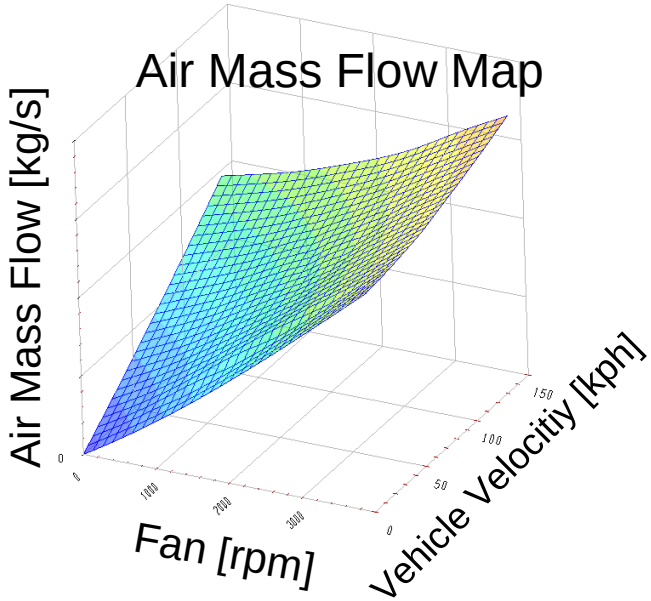
Measurements – Results

➡ **Heat Balance**
Air Side: Mass Flow and Temperature Rise
Coolant Side: Mass Flow and Temperature Drop

➡ **Cooling Performance:**
- of Reference Vehicle at different Driving Conditions
- at different Fan Speeds

➡ **Relation between Air Mass Flow and Temperatures of Coolant and Cooling Air at Full Load Operating Points**
➡ **Relation between Fan Speed and Air Mass Flow**



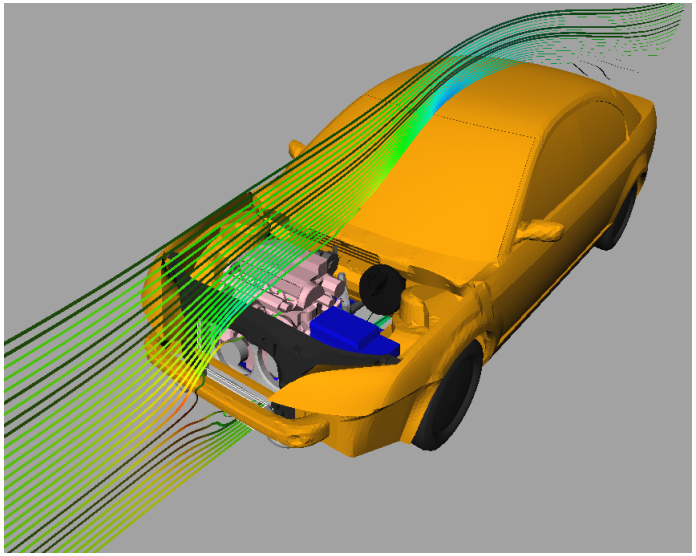


M. Genger
T. Kuthada
J. Wiedemann

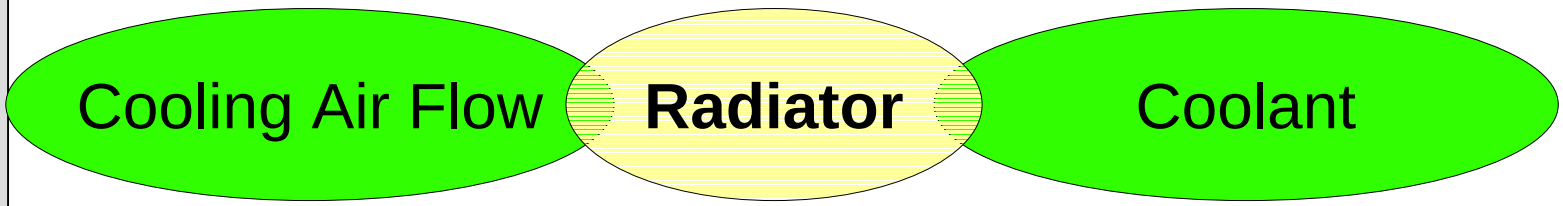
Forschungsinstitut für
Kraftfahrwesen und
Fahrzeugmotoren
Stuttgart

Simulation at FKFS

„Cold“: PowerFLOW



„Hot“: KULI

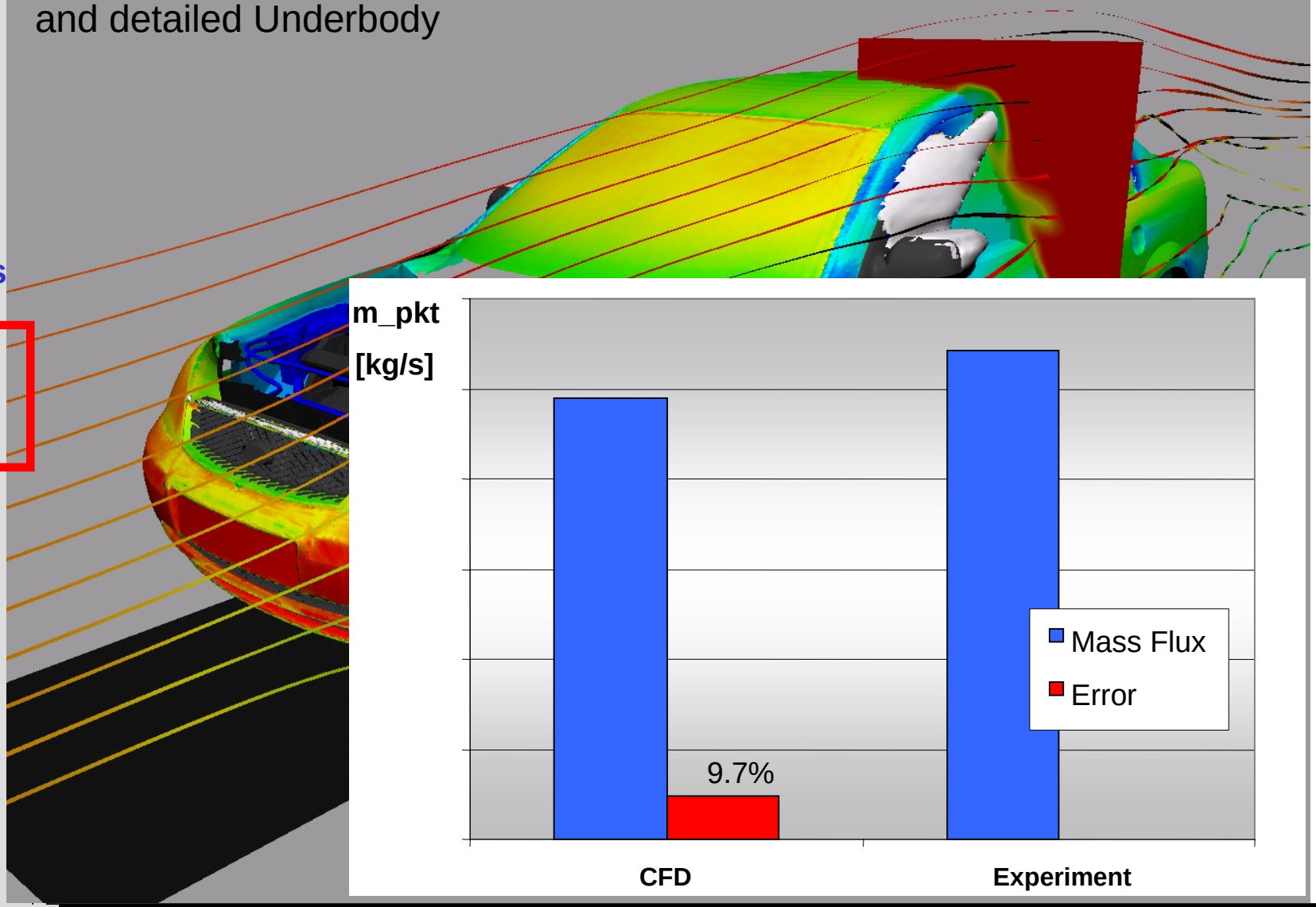


M. Genger
T. Kuthada
J. Wiedemann

CFD-Simulations using EXA PowerFLOW

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

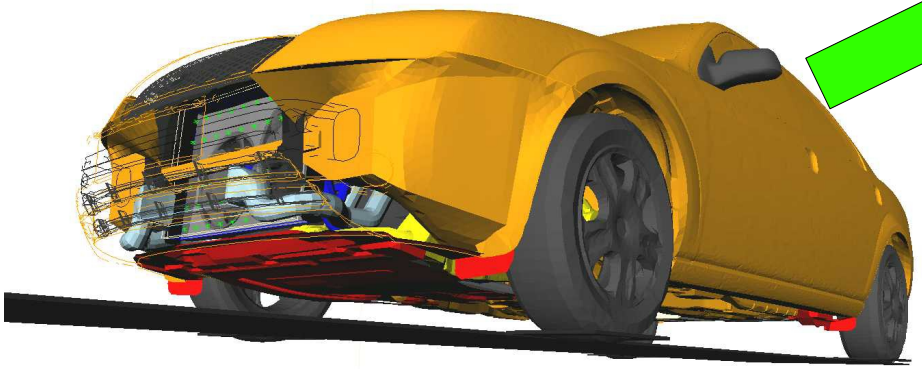
Fully resolved Engine Bay
and detailed Underbody



M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für
Kraftfahrwesen und
Fahrzeugmotoren
Stuttgart

Computational Results



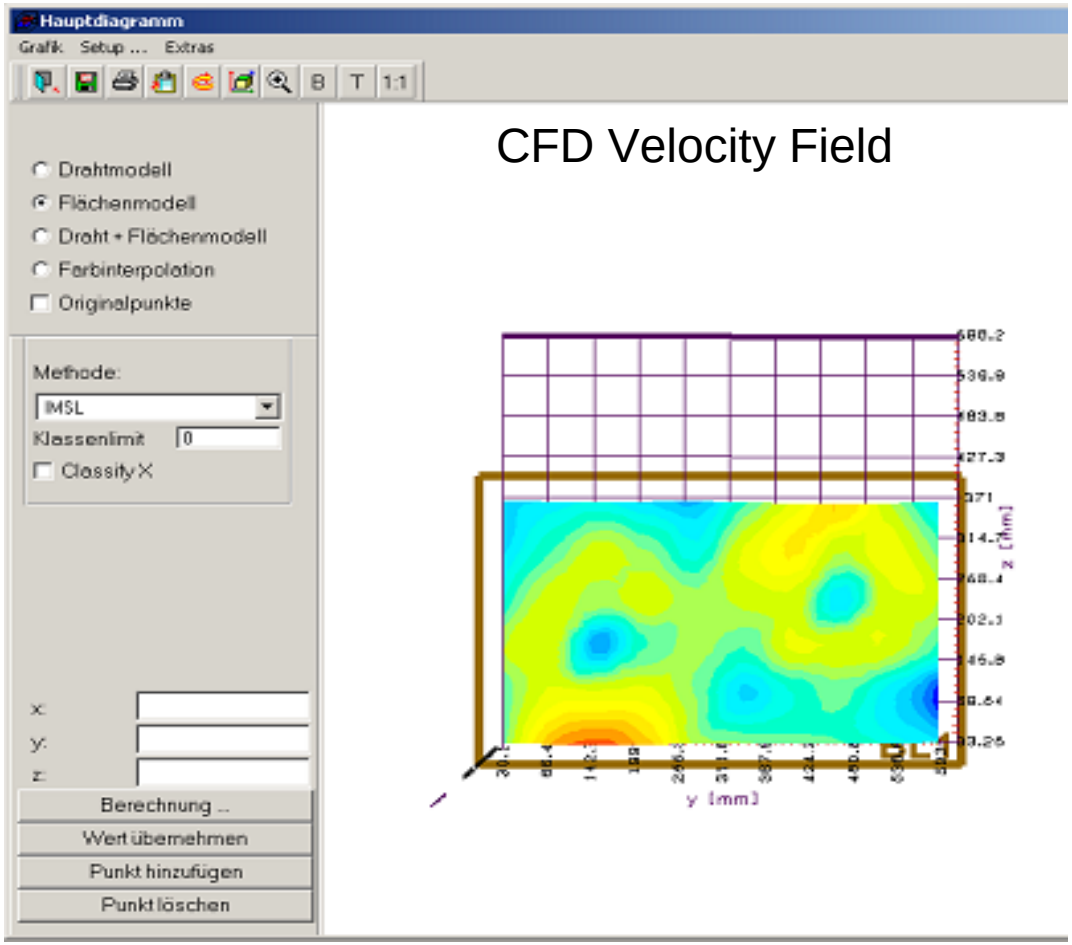
Input Values to KULI

M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für
Kraftfahrwesen und
Fahrzeugmotoren
Stuttgart

Simulation with a Resistance Matrix in KULI

Convertion of the Measured or Simulated (3D-CFD) Air Velocities in a Resistance Matrix in KULI:



M. Genger
T. Kuthada
J. Wiedemann

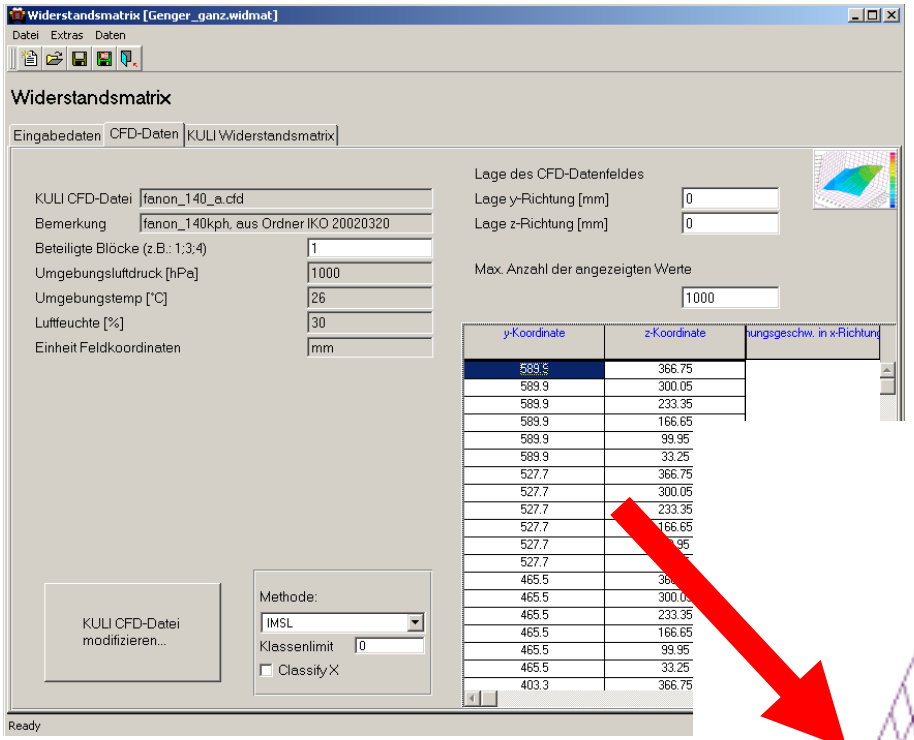
FKFS

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

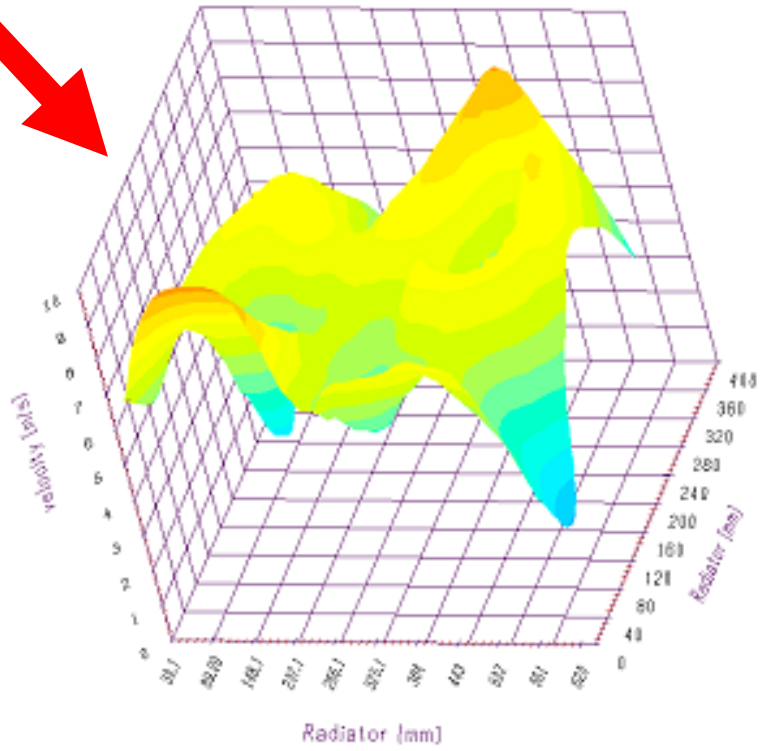
1. Experimental Test Facilities

2. Measurements

3. Simulation:
- KULI Resistance Matrix



CFD Velocity Field



11
M. Genger
T. Kuthada
J. Wiedemann

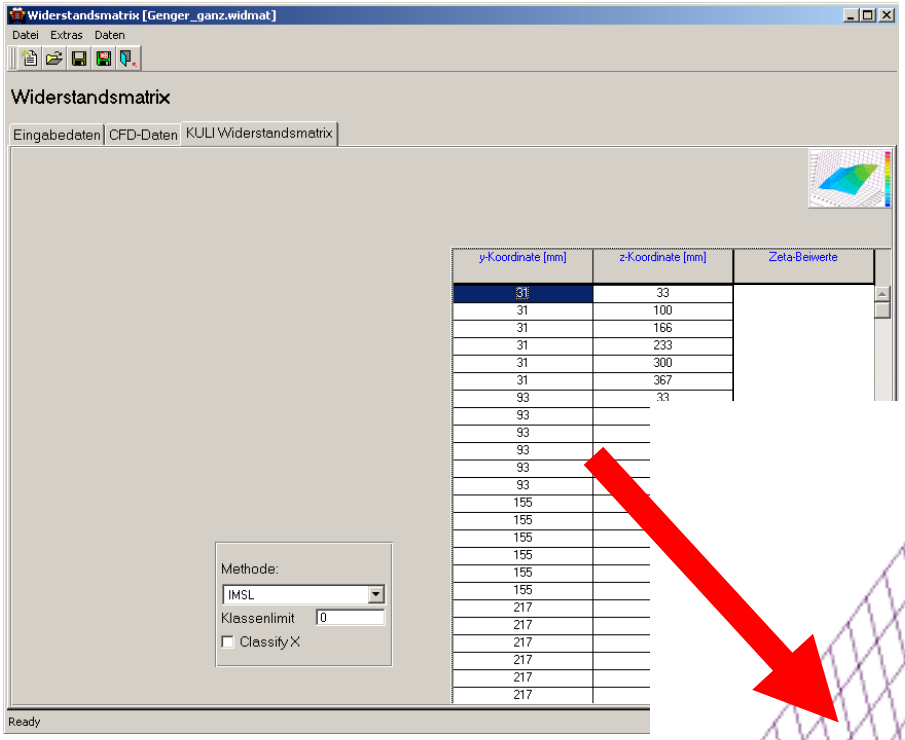
FKFS

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

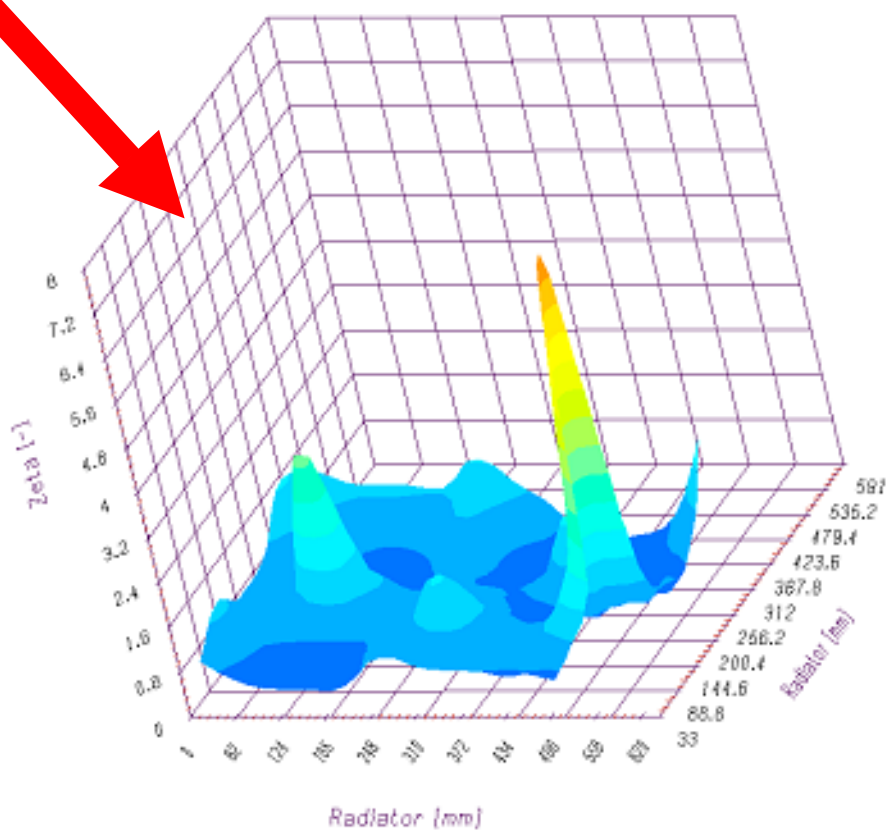
1. Experimental Test Facilities

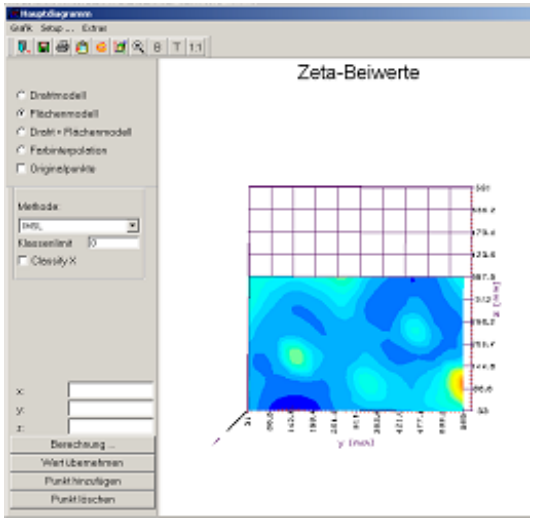
2. Measurements

3. Simulation:
- KULI Resistance Matrix



Zeta Values





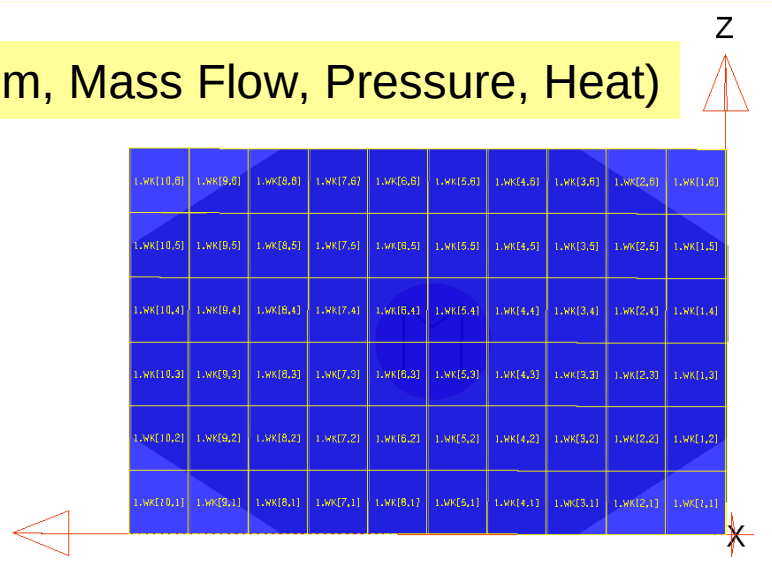
12
M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Creation of a KULI-*Matrixmodel*

with the following Components:

- Radiator
- Resistance Matrix
- Mass Flow Target
- Water Circuit (Medium, Mass Flow, Pressure, Heat)



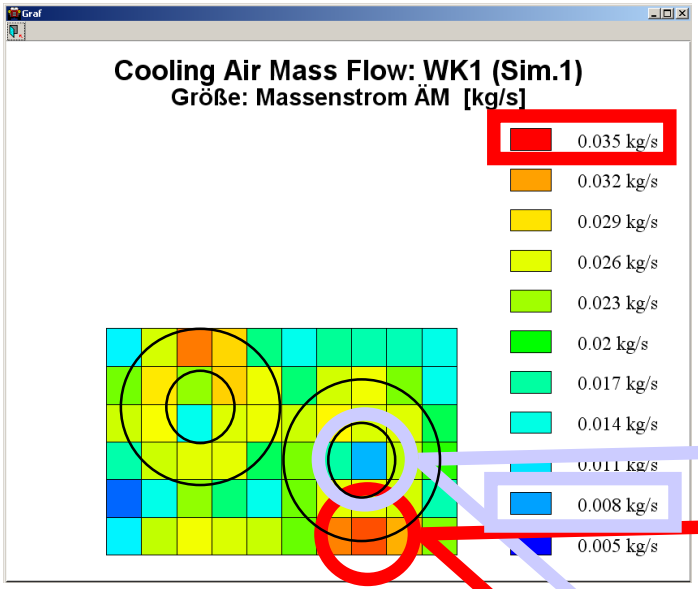
➡ **Better Knowledge of the Cooling Air Mass Flow and Coolant Temperatures over the Radiator**

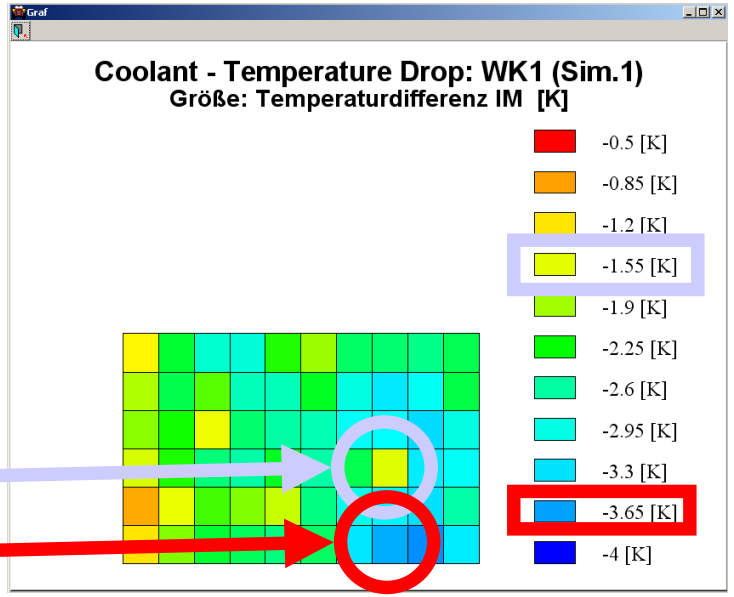
➡ **Resistance Matrix can be Used also at Other Operating Points**

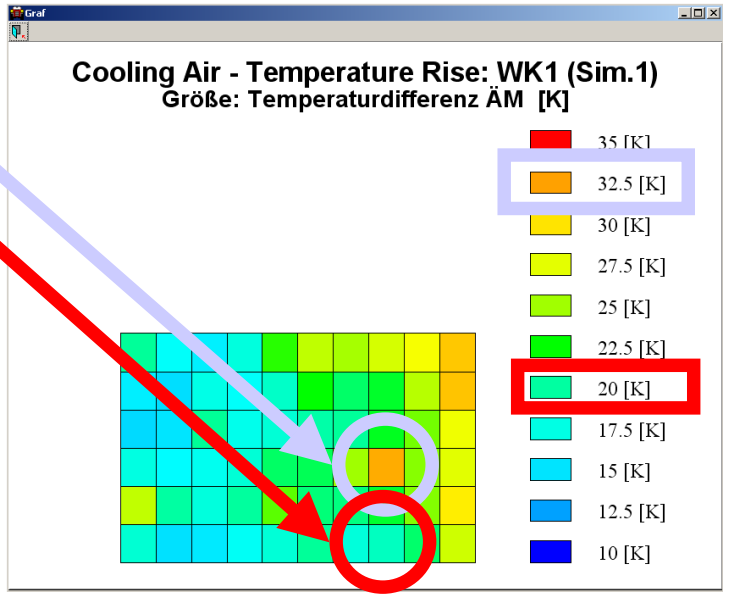
M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Simulation – Results of the *Matrixmodel*







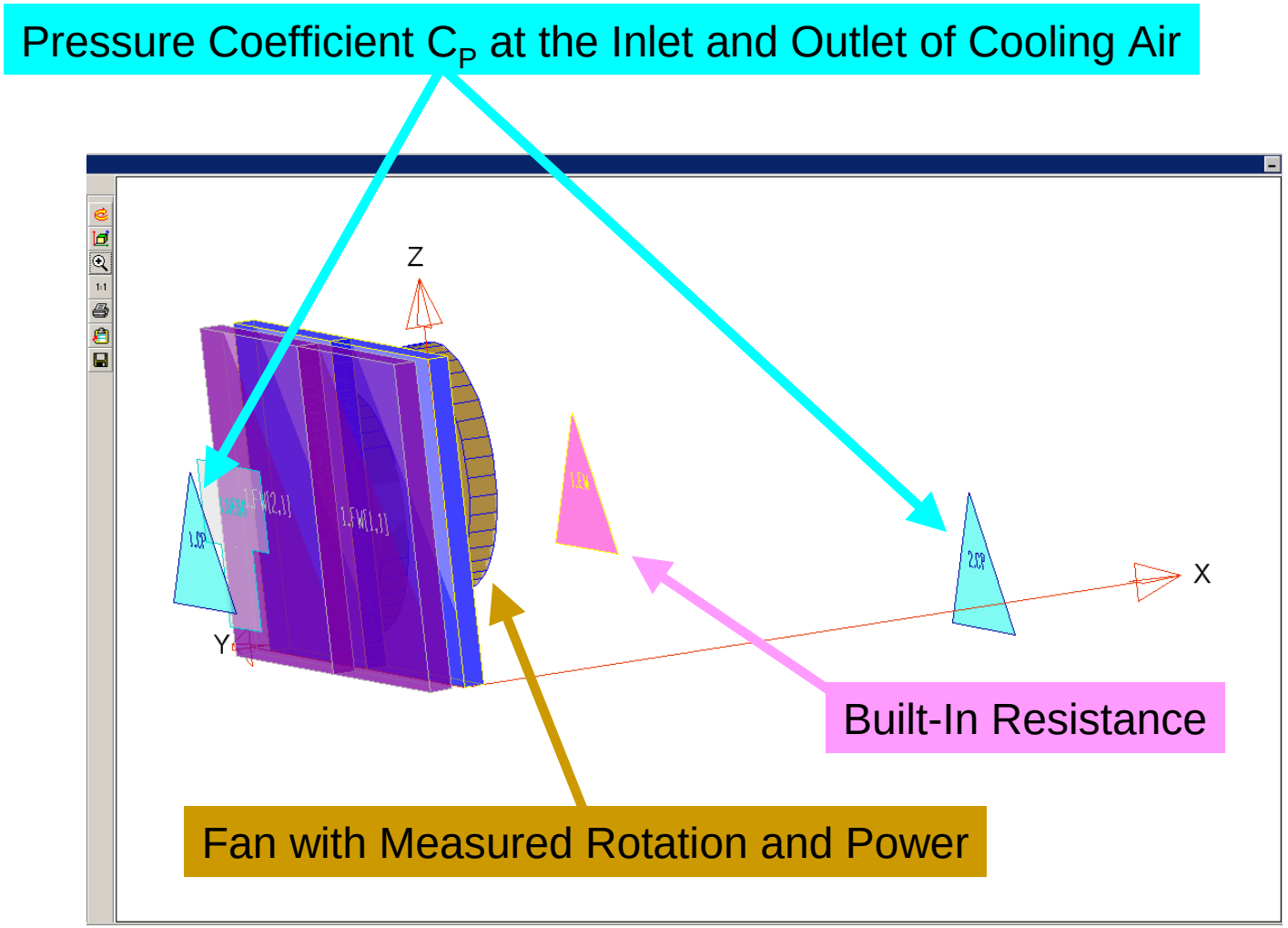
➡ **Detailed Analysis of Air Flow and its Effects is possible**

Difference of Simulated Coolant Temperatures to Exp. Measurements:
Coolant, in: +0.3%
Coolant, out: +1.3%

M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Substitution of the Resistance Matrix with:

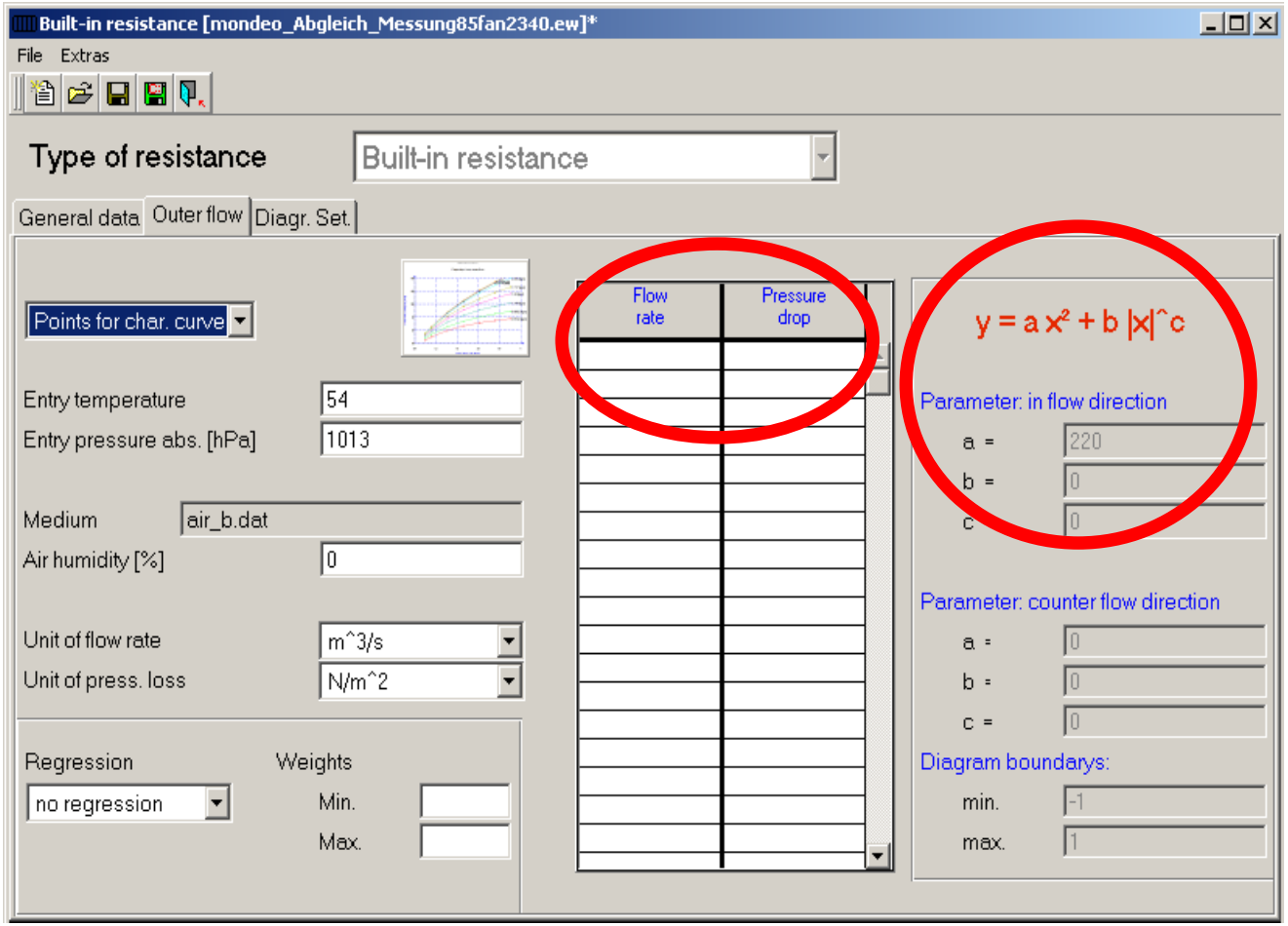


M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Determination of the Built-In Resistance – the Unknown Factor

➡ Vary the Pressure Drop Until the Air Flow Rate is Equal to the Experimental Value (or the *Matrixmodel* Result)

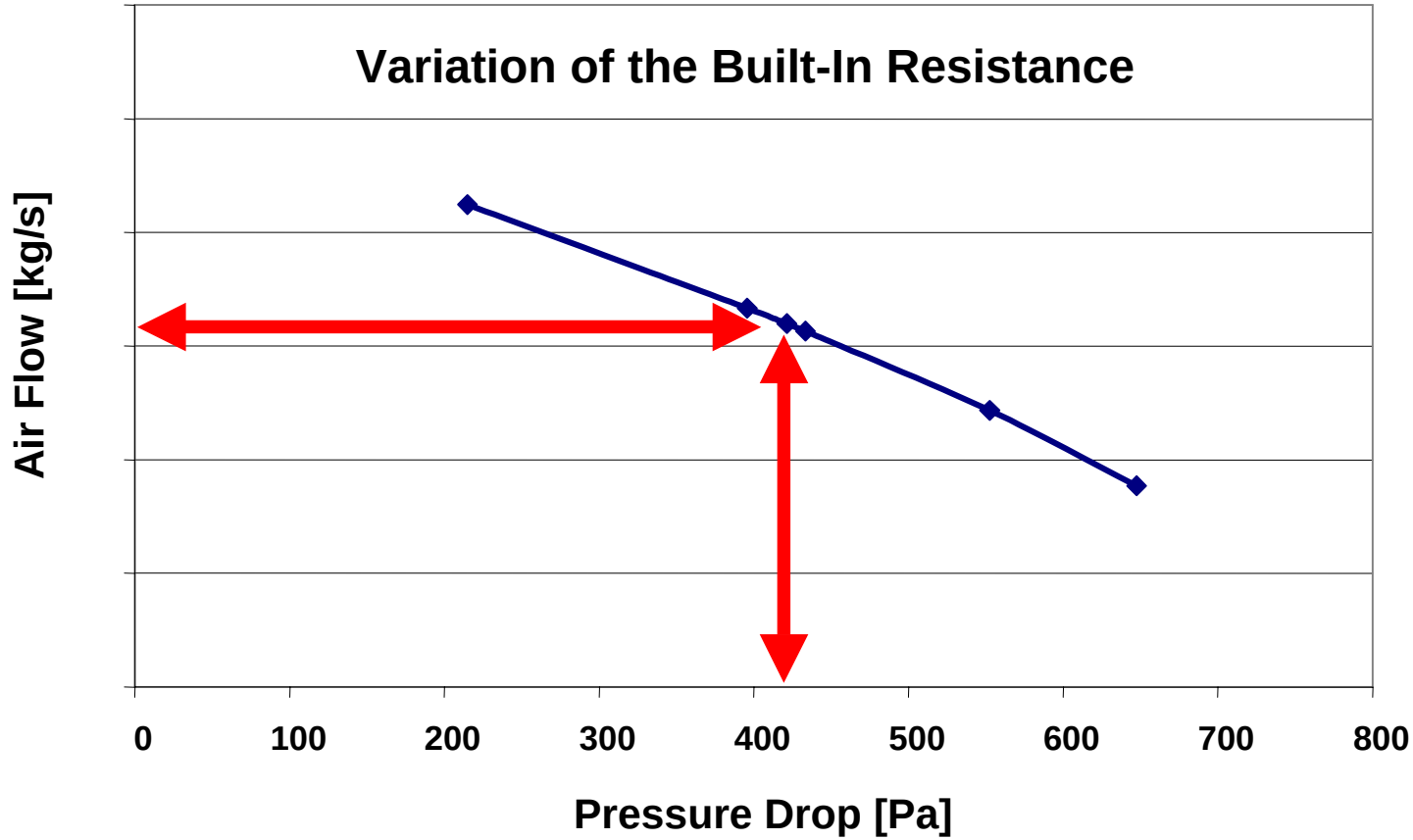


M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Determination of the Built-In Resistance – the Unknown Factor

Know: Mass Air Flow through the Radiator from Exp. Measurements
Want: Built-in Resistance at this Operating Point



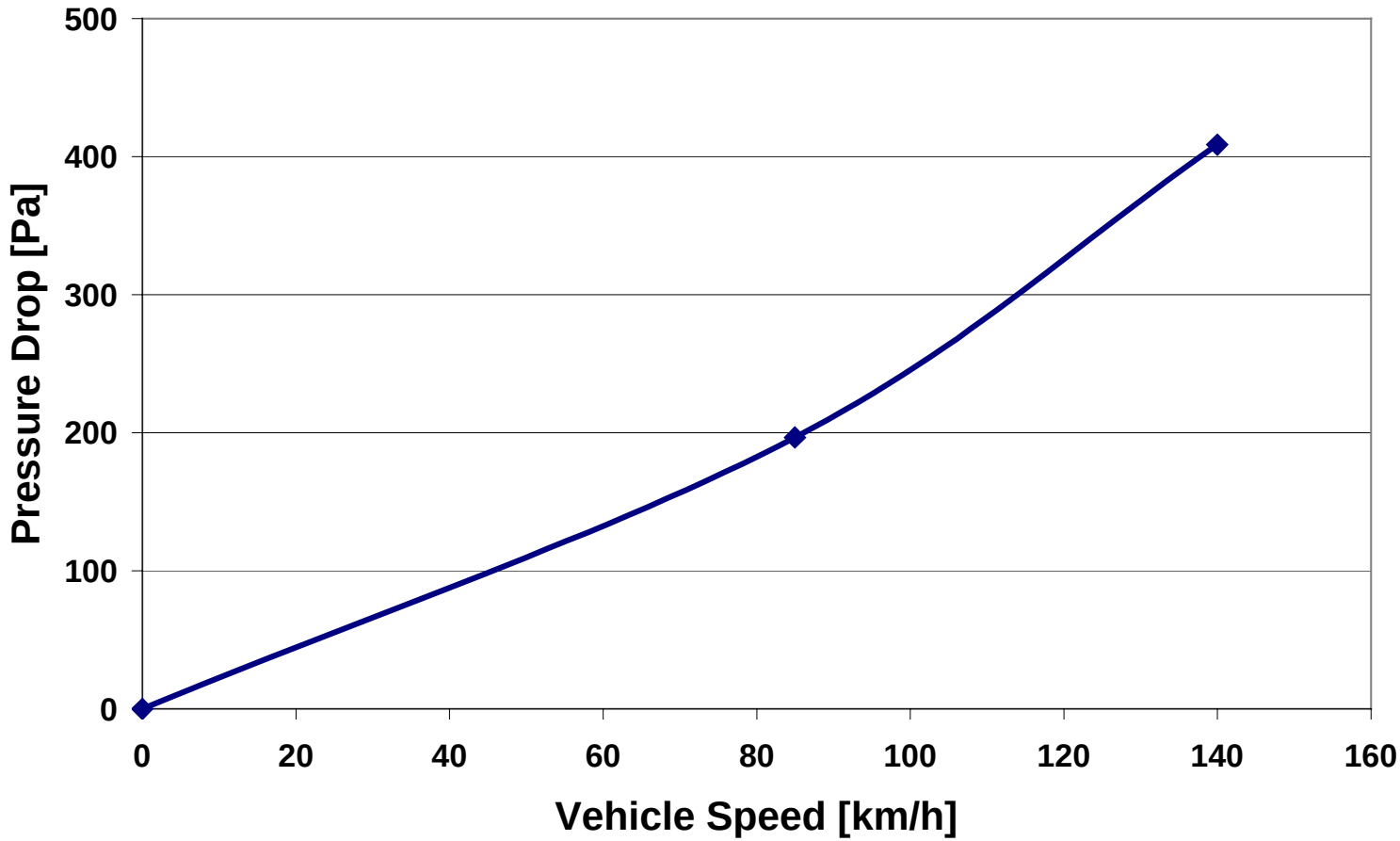
➡ **Built-In Resistance Pressure Drop: 422 Pa**

M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für
Kraftfahrwesen und
Fahrzeugmotoren
Stuttgart

Determination of the Built-In Resistance – the Unknown Factor

Pressure Drop at Different Driving Speeds



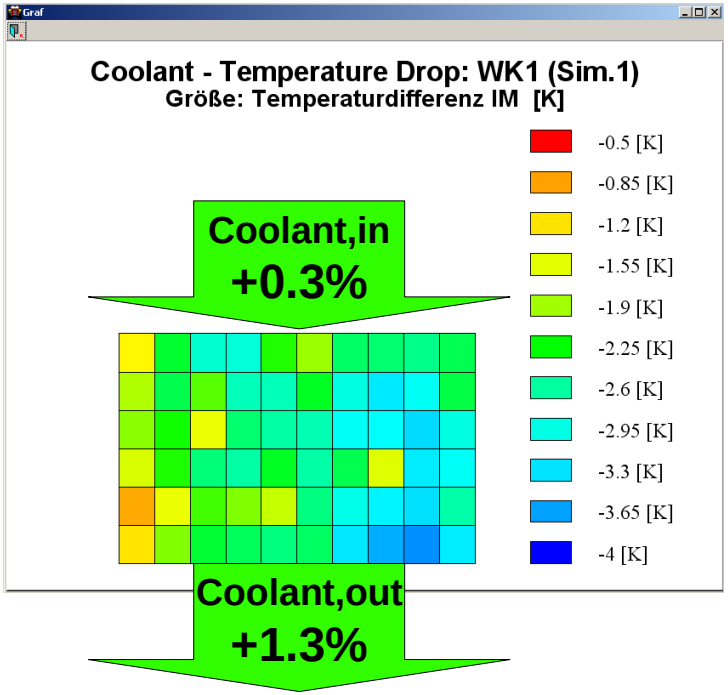
M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

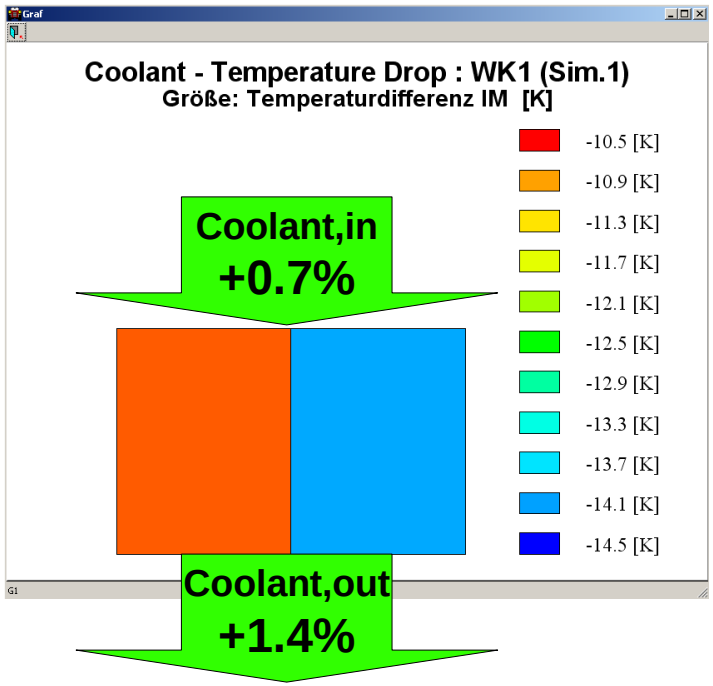
Comparison of the Simulation Results to the Experimental Measurements

Difference of Simulated Coolant Temperatures to Experimental Measurements:

Matrixmodel:



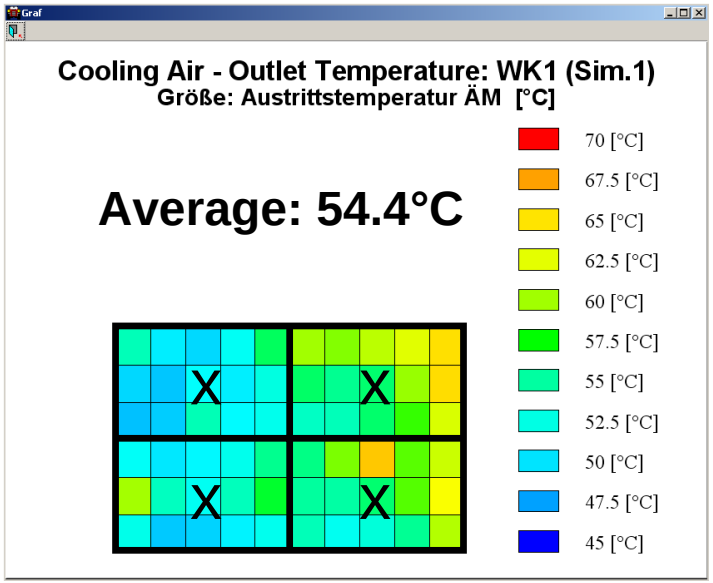
Model with Built-In Resistance:

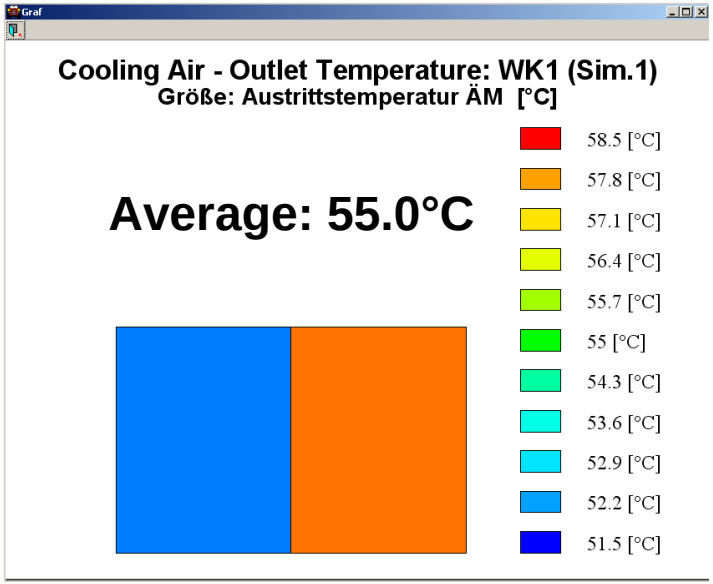


M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Simulation - Comparison of the Results





Measured Values

62°C	69°C
57°C	70°C

Average: 64.5°C

Heat Balance Error with Only 4 Sensors: ~15%

➡ **More Sensors Needed at Cooling Air Outlet**

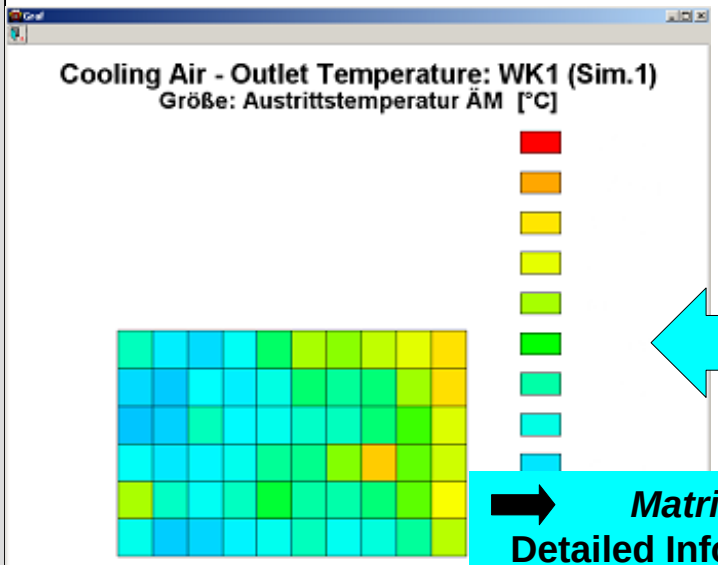
➡ **Recent Measurements with 8 Thermocouples: Approx. 5% Error**

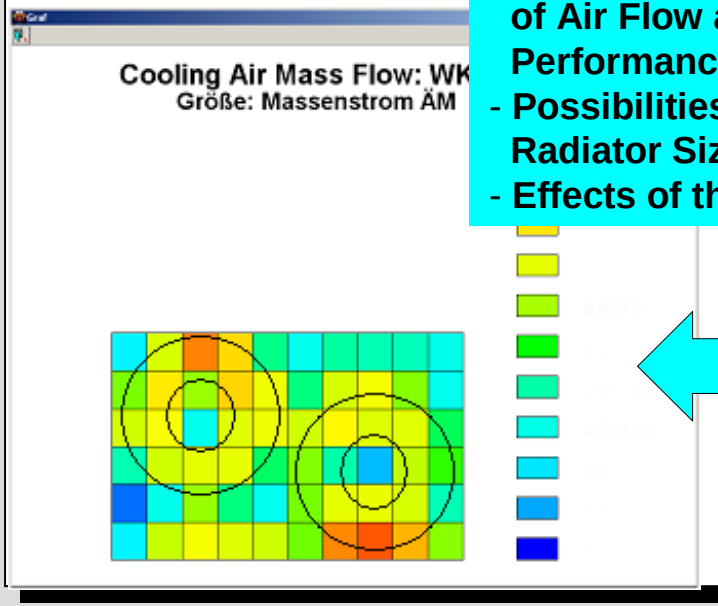
M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für
Kraftfahrwesen und
Fahrzeugmotoren
Stuttgart

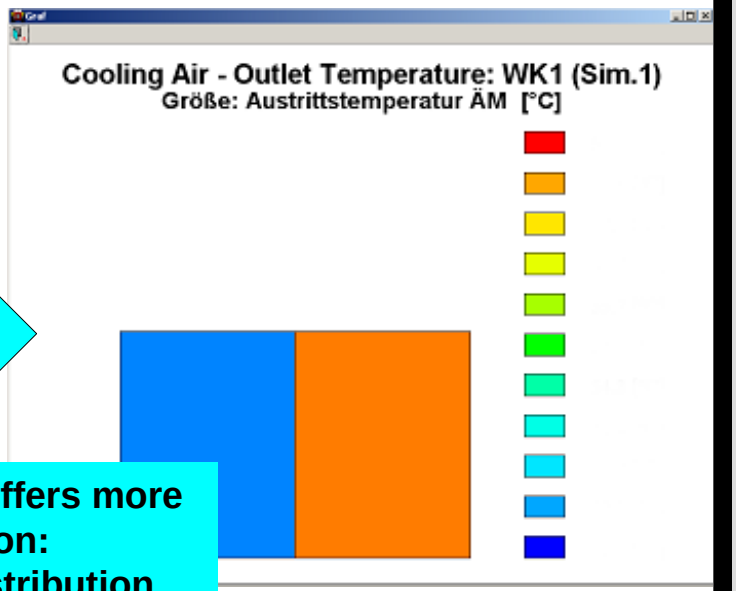
Simulation - Comparison of the Results

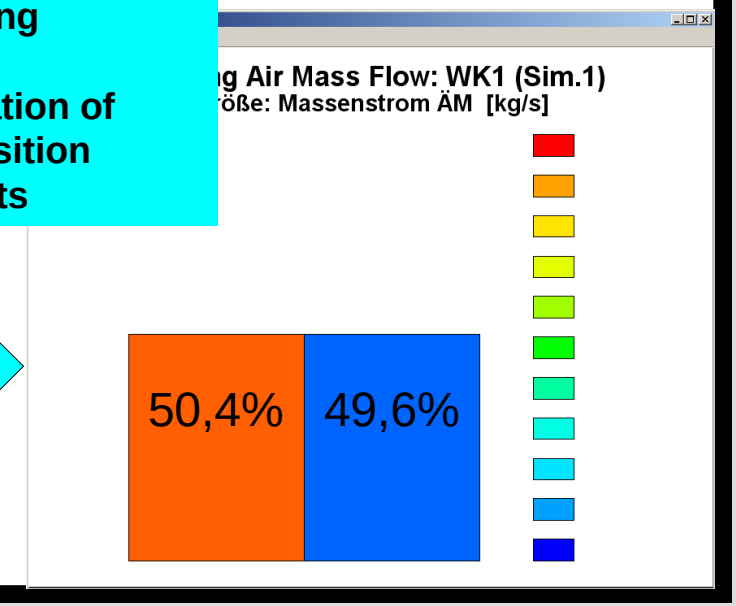
Matrixmodel:





Model with Built-In Resistance:





➡ ***Matrixmodel*** **Offers more Detailed Information on:**
- **Disturbances and Distribution of Air Flow and Cooling Performance**
- **Possibilities for Variation of Radiator Size and Position**
- **Effects of the Air Inlets**

M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

Summary

- **Simulation Results for the Coolant Temperatures Differ From Experimental Measurements by Less Than 1.5 %**
- **High Accuracy in the Cooling Air Flow Measurements**
- **The *Matrixmodel* Offers Detailed Information on the Air Flow through the Radiator and its Relation to Cooling Performance**
- **Knowledge of the Built-In Resistance from Air Flow Measurements**
- **It Has Been Shown that More Air Temperature Sensors at the Radiator Outlet Will Produce More Accurate Results**

M. Genger
T. Kuthada
J. Wiedemann

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

M. Genger
T. Kuthada
J. Wiedemann