WHY coupling KULI to CFD?

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3rd KULI User Meeting USA
07.04.2006, Troy, Michigan

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Why coupling KULI to CFD?

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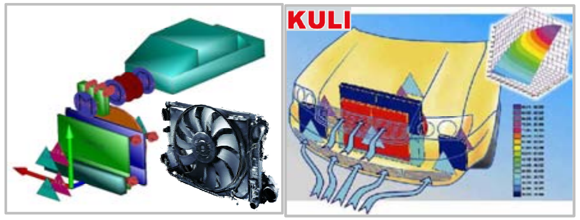
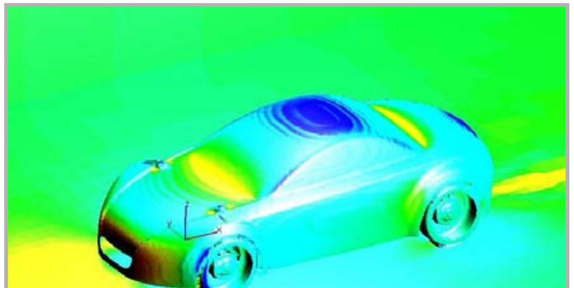
- Conclusions

Thermal Development - Simulation

Thermal Calculation / Computational Fluid Dynamics

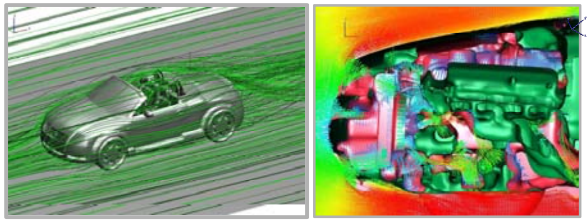
Engine Cooling and HVAC System 1D

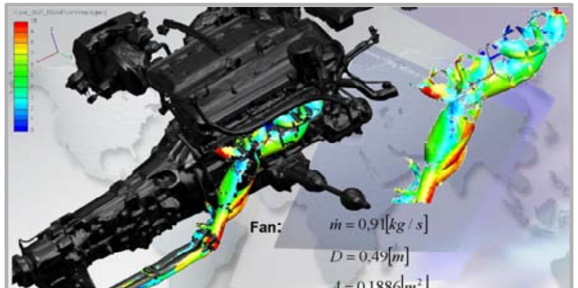




simulated pressure distribution

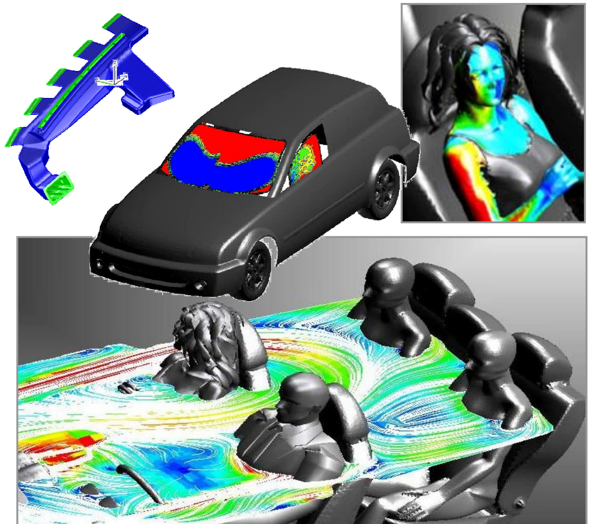
Aerodynamics Engine Compartment Heat Protection 3D





simulated thermal radiation

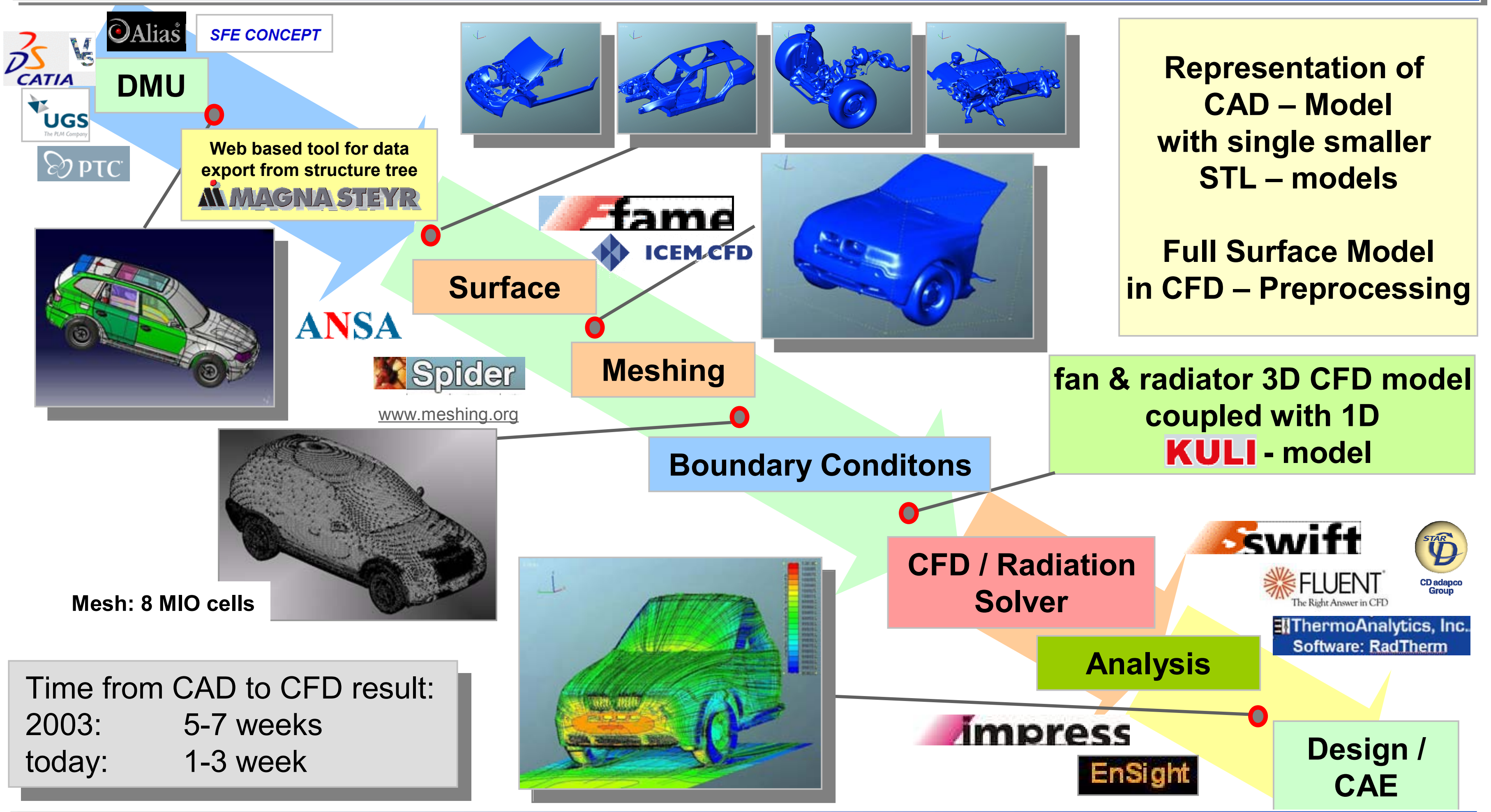
Channel Flow De-Icing Thermal Comfort 3D



simulated A/C comfort

Data - Acquisition

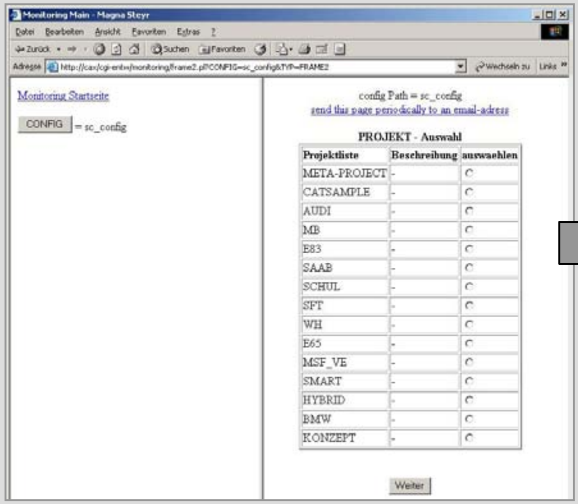
Workflow CAD – CFD (plus 1D coupling)



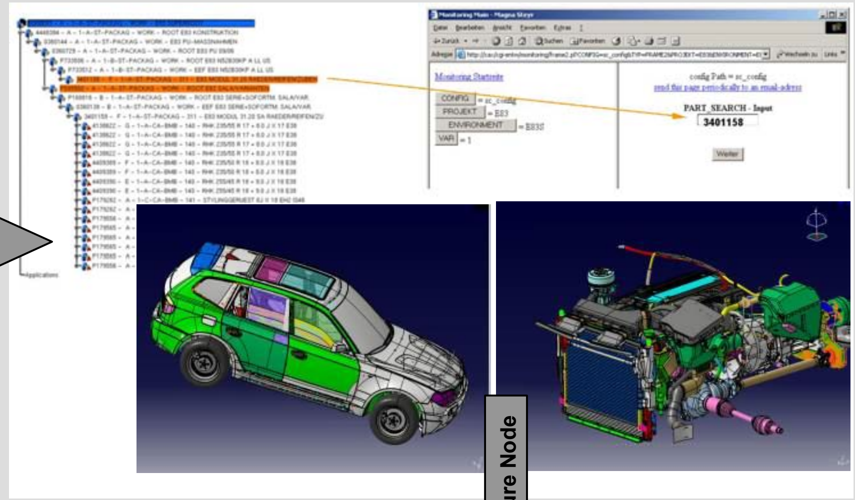
Time from CAD to CFD result:
2003: 5-7 weeks
today: 1-3 week

Data - Acquisition

Web based tool for data export from vehicle structure tree



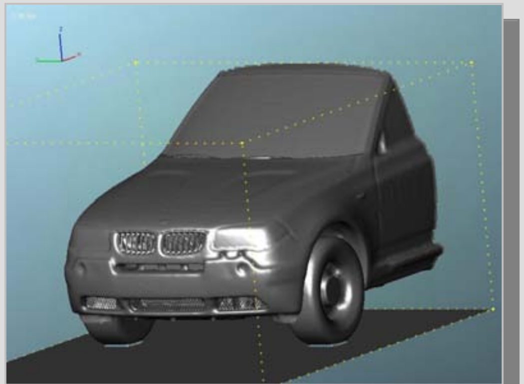
Project



Structure Node

GRID PILOT
Max. 40 Rechner
(IBM AIX CAD Workstation)

Export to CFD



• Introduction • Workflow/Validation • Scope of Work • Model Setup • Results • Optimization • Conclusions

Tools and Validation

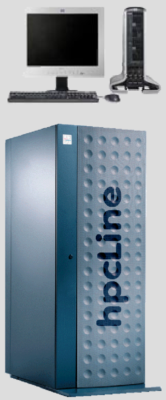
Hardware/Software Tools and Virtual Methods

HARDWARE:

- Linux Cluster (48 CPUs, 100 GB MEM, 64bit)
- HP Itanium II (2 CPUs, 12 GB MEM, 64bit)
- HP PC WS (2 CPUs, 4 GB MEM, 32bit)
- Opteron PC WS (2 CPUs, 8 GB MEM, 64bit)

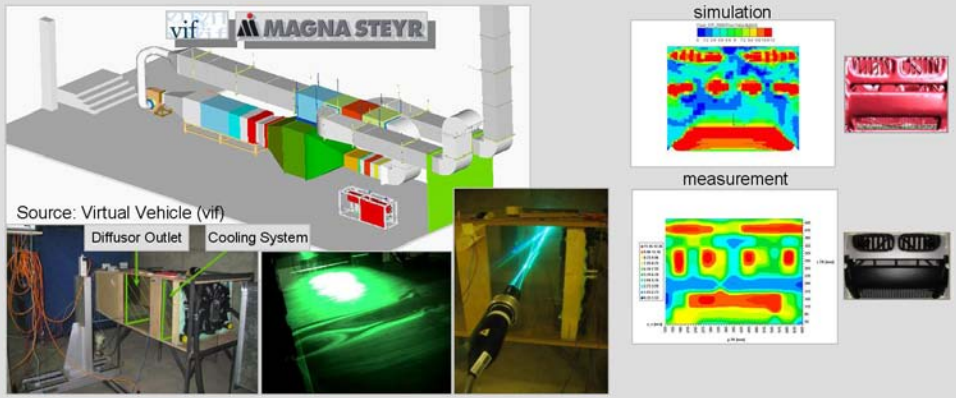
SOFTWARE:

- Catia v5 DMU Navigator
- SWIFT (StarCD, FLUENT)
- KULI
- RadTherm / INKA / TILL
- Spider, CFDWM



MODEL VALIDATION:

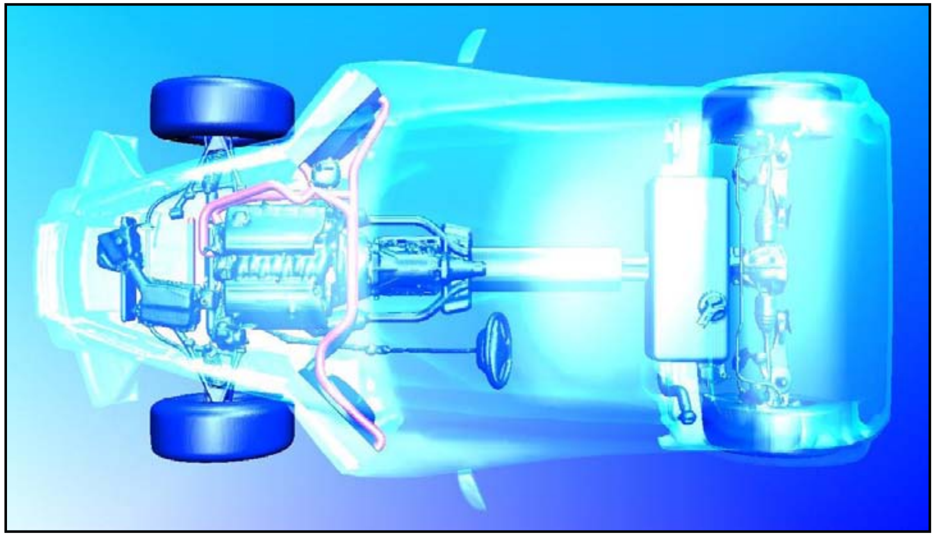
- Component Wind Tunnel with Laser Doppler Anemometry (LDA) for Cooling Components
- Thermal material data measurements

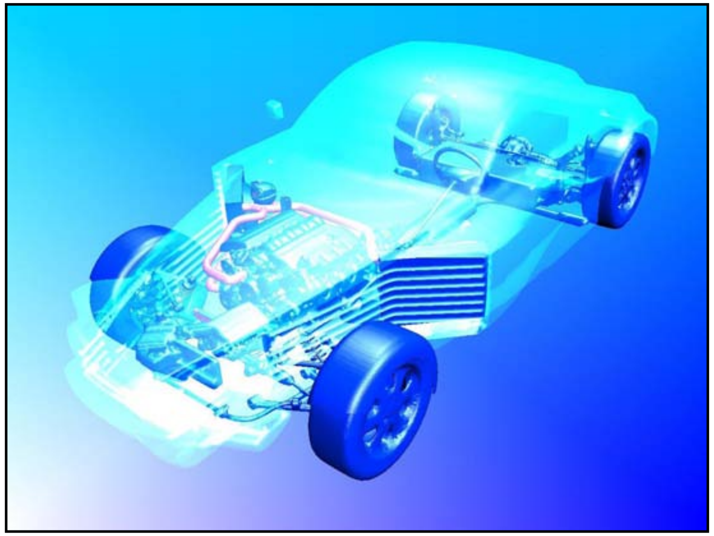


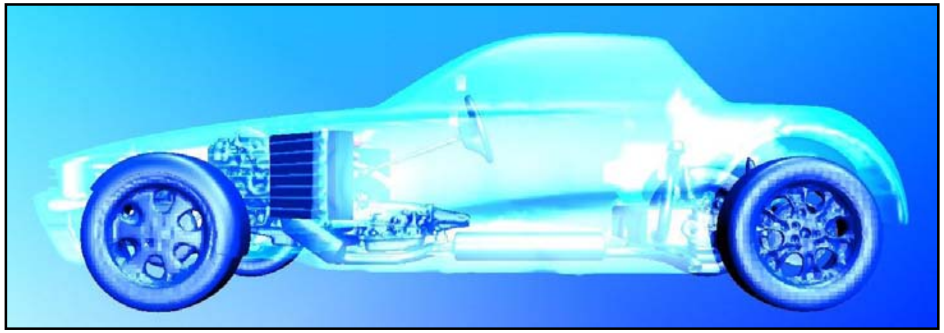
- Testing of cooling system performance
- Validation of simulation models (Radiator, Fan, …)
- Detection of emissivity / absorptivity coefficients

Scope of Work

Concept Car: Feasibility Study







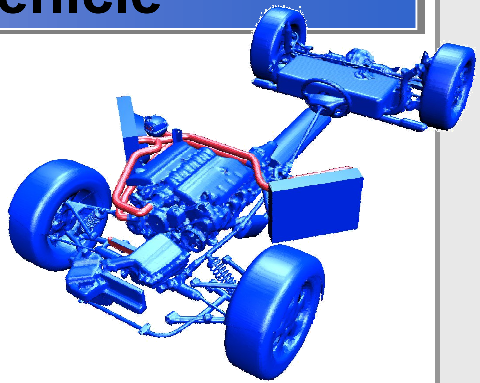
Design a cooling system for

- V8 Engine Power: 295 kW
- Maximum Speed: 240 kmph

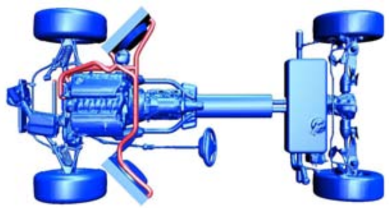
with radiators on the sides

Cooling System Behavior

Problems expected due to configuration of the vehicle



- Too less airflow through the radiator to guarantee adequate efficiency of the cooling system.
- In order to reach an adequate cooling of the system, a cp-pressure of at least 0.5 has to be reached, together with an air mass flow through the radiator of at least 1.5 kg/sec.



- possible backflows out of the underhood due to negative pressure differences between the inside and the outside of the radiator and a low-pressure field behind the tire at high speeds which would negatively influence the flow field in front of the radiator.

- Very high thermal loads to reach top-speed due to a high drag-coefficient.

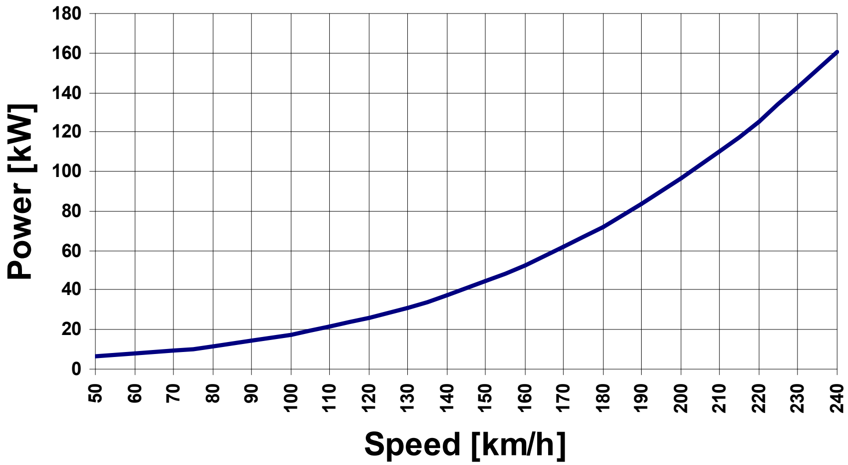
Cooling System Behavior

Boundary conditions of the cooling system

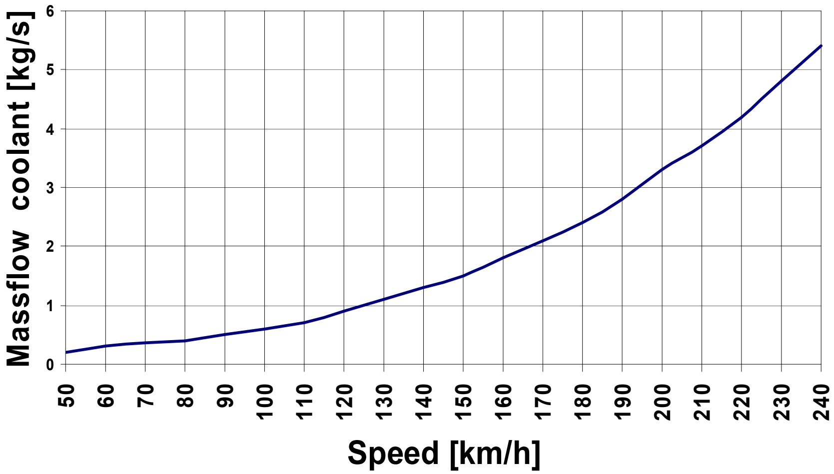
In order to calculate the efficiency of the cooling-system, the following radiator-sizes were chosen:

- radiators: two times, each with an area of at least 16 dm²
- condenser: area at least 29 dm²

heat-quantities dependent on the driving speed



necessary mass-flow of the cooling fluid dependent on the driving velocity

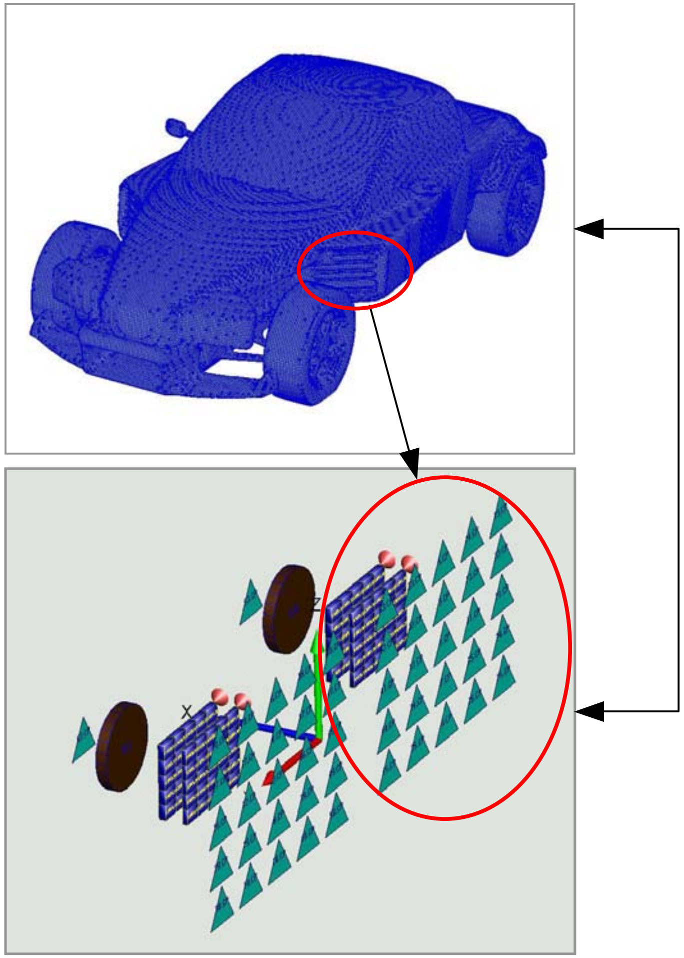


Model Setup

Simulation Model, Load Cases

Load Cases

- Hill, 60 km/h without trailer, 35°C ambient temperature
- Hill, 60 km/h with trailer, 35°C ambient temperature
- Hill, 90 km/h without trailer, 35°C ambient temperature
- Hill, 90 km/h with trailer, 35°C ambient temperature
- Vmax without trailer, 240 km/h, 45°C ambient temperature
- Vmax with trailer, 180 km/h, 45°C ambient temperature



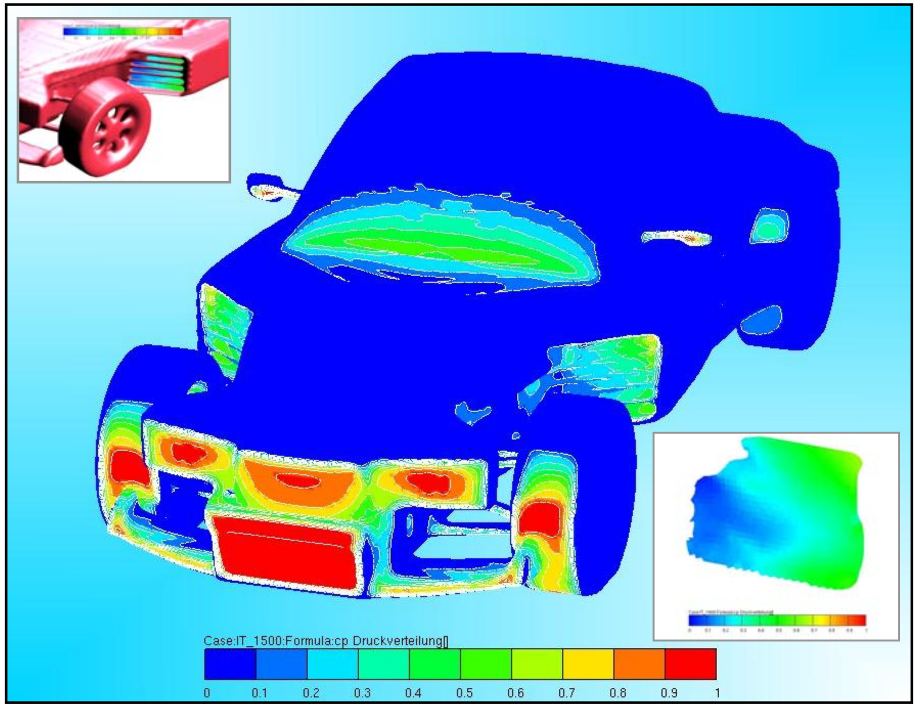
Coupling of CFD and KULI via a c_p-Matrix

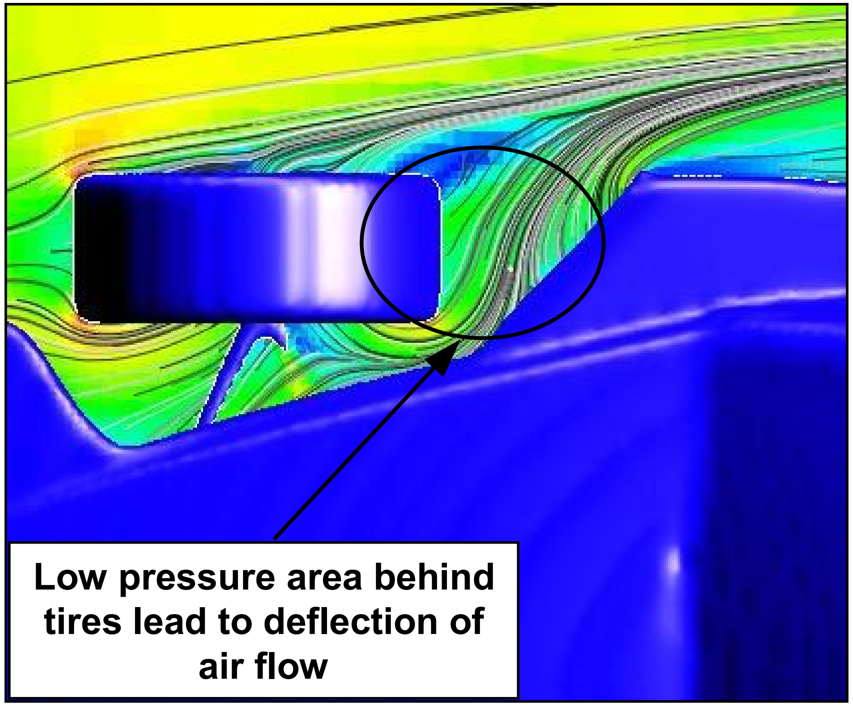
CFD Results Base Version (A)

c_p distribution and streamlines

c_p-distribution over vehicle, 3D calculation

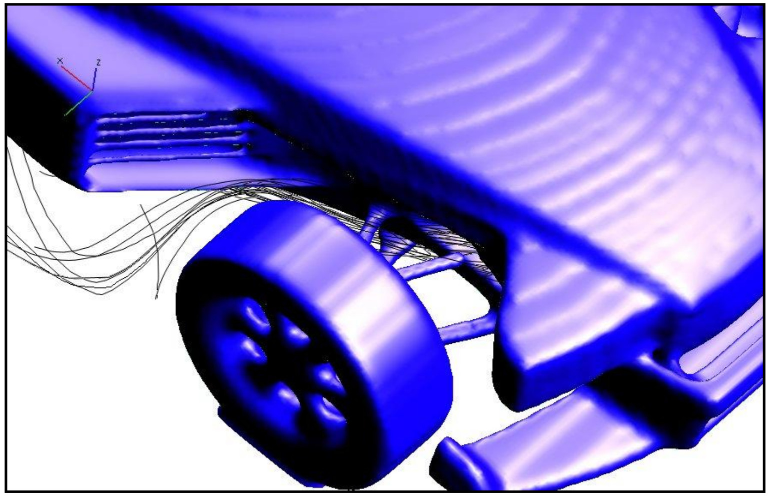
stream lines showing the air-flow behind the tire

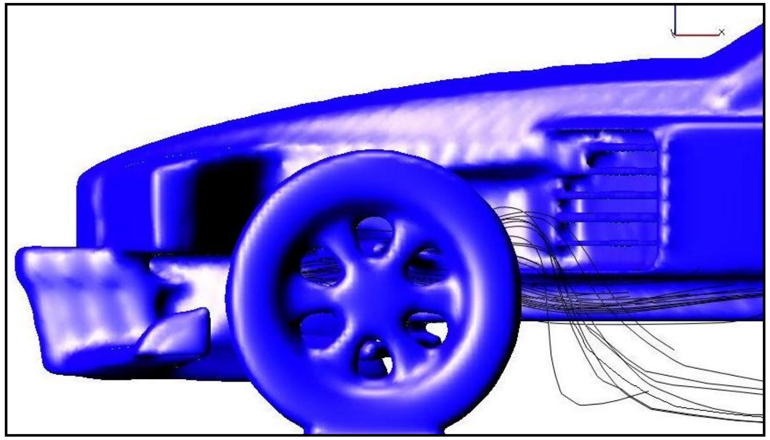


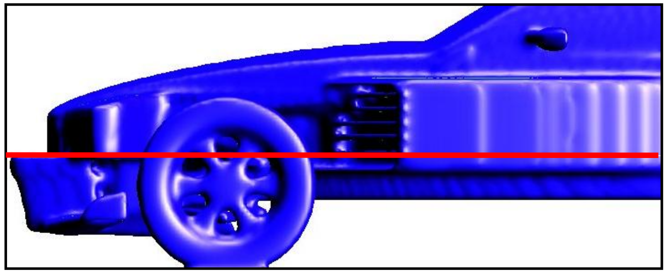


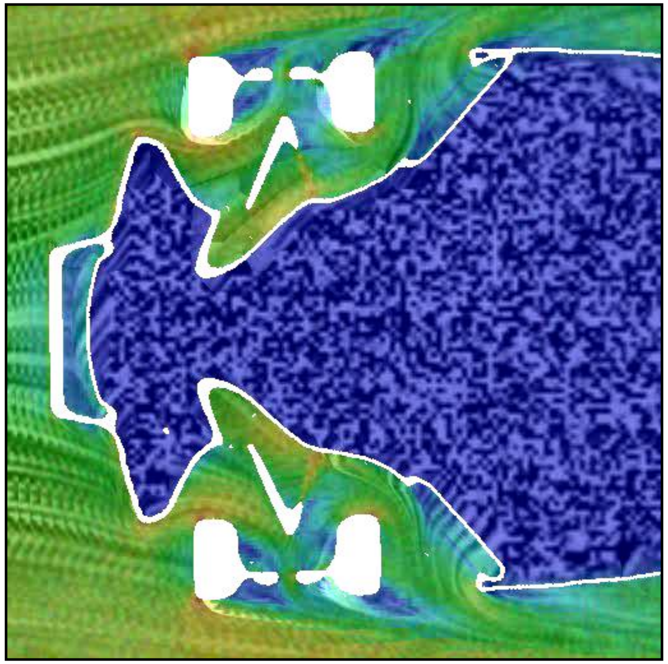
CFD Results Base Version (A)

Streamlines and velocities



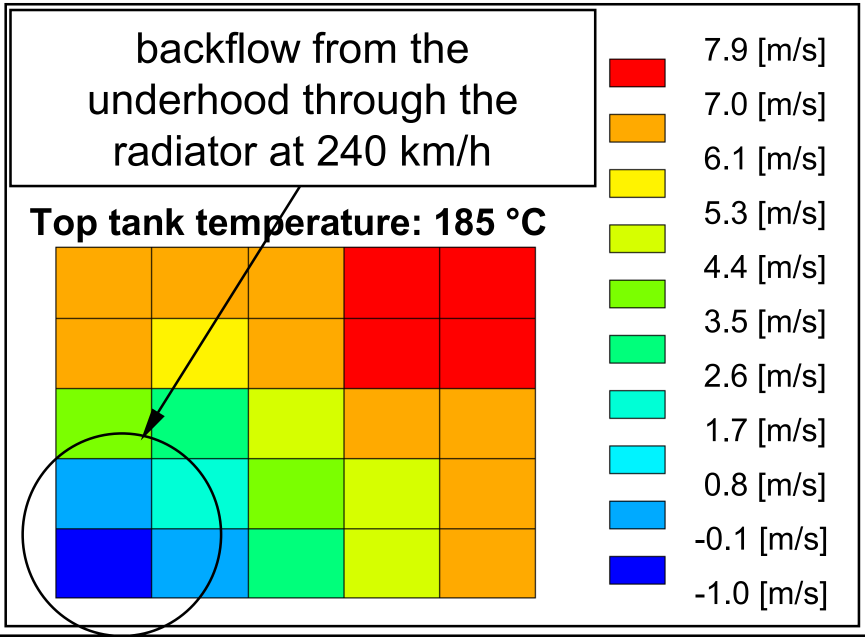


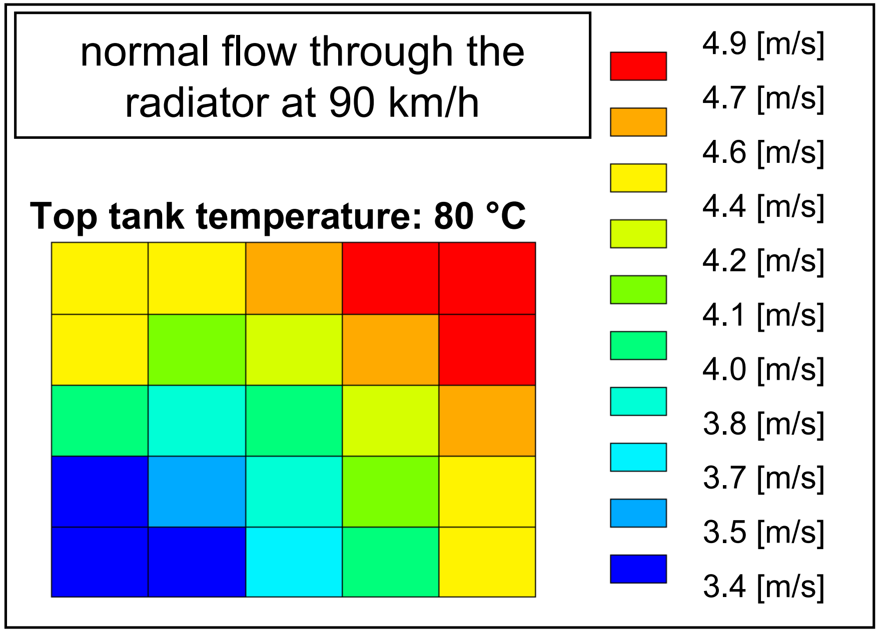


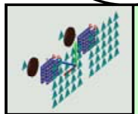


KULI Results Base Version (A)

Air Massflow





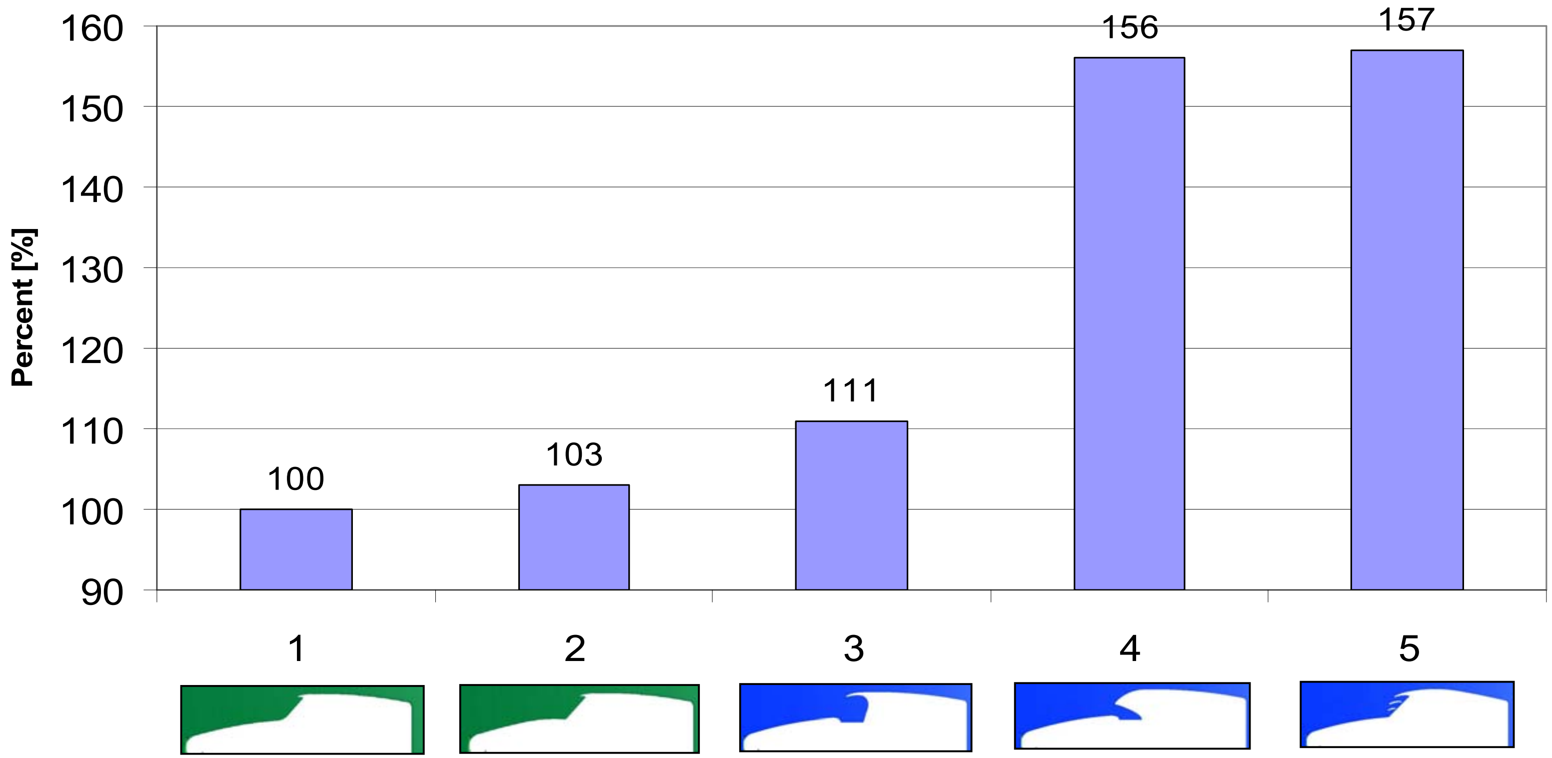


KULI Simulation		450W Electrical Fan							
		responsible for modelling	Idle 1000 RPM outside: 45°C Limit: 115°C	Hill 7% with 60 km/h outside: 35°C Limit: 105°C	Hill 7% with 60 km/h and trailer outside: 35°C Limit: 115°C	Hill 6% with 60 km/h outside: 35°C Limit: 105°C	Hill 6% with 90 km/h and trailer outside: 35°C Limit: 115°C	Vmax 240 km/h outside: 45°C Limit: 113°C	Vmax with trailer 180 km/h outside: 45°C Limit: 115°C
A	Base version without any measures	Christian Kussmann	max. heat 54 kW	57.1	67.4	65.3	78.9	181.2	118.1

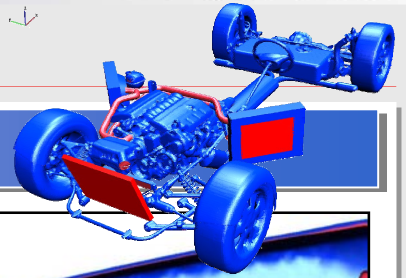
Optimization

2D study

In order to find an optimised air inlet geometry, different situations have been calculated in 2D. The optimal variant concerning c_p was then chosen to be modelled in 3D.

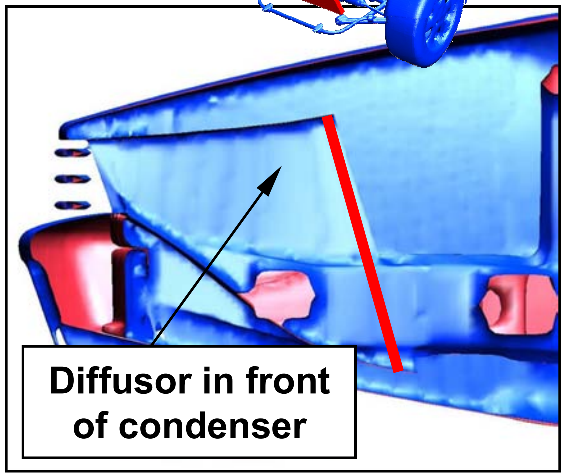


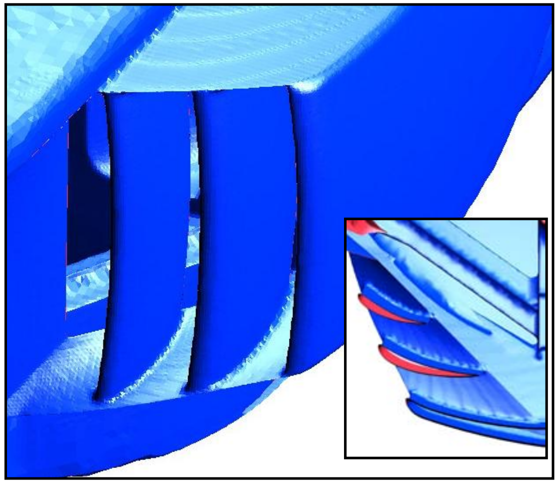
Optimization 2nd Version (C)



Aerodynamic Improvements

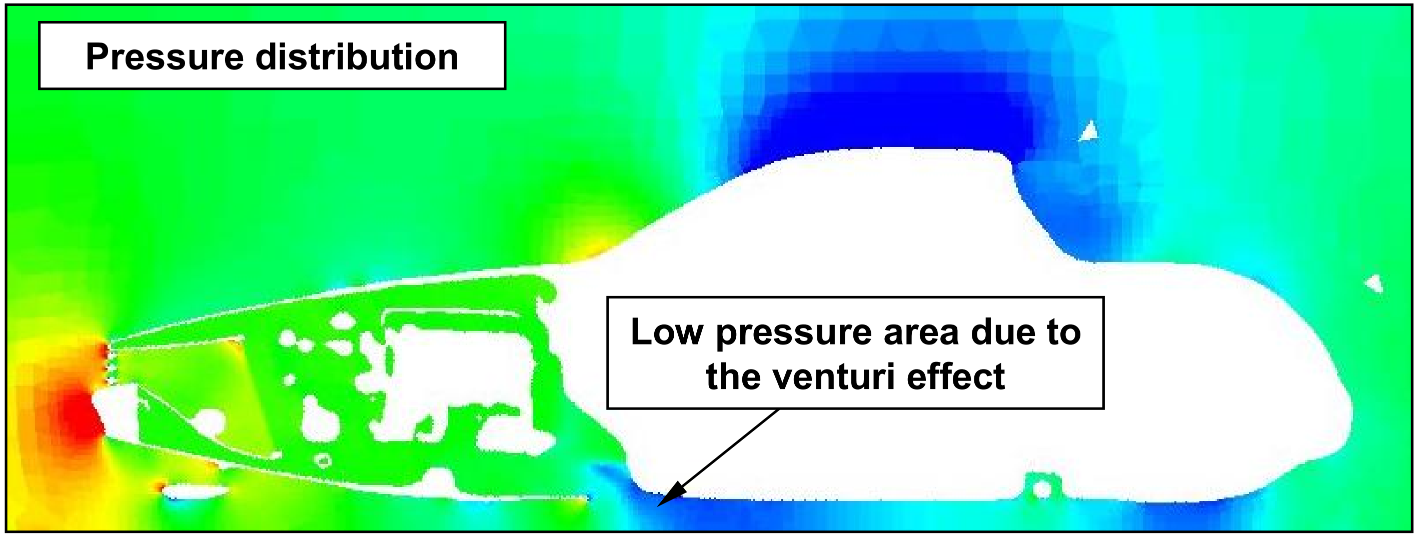
- the underbody has been shaped like a venturi nozzle to generate a low pressure area below the car in order to improve the cp-difference. In the centre of this area, the air could leave the underhood and join the surrounding air.
- The climate condenser has been moved to the front of the car in order to function like an air restrictor to prevent high pressures to be produced in the underhood. To intensify this effect, the air duct in front of the condenser has been shaped to function as a diffuser.The second main effect of the movement of the condenser is the uneffected air flow through the radiator, as there is no resistor in front of it anymore.
- vertical vanes have been designed in order to guide the air directly to the surface of the radiator. The fins of this guidance system have been shaped to form a diffuser system as well.

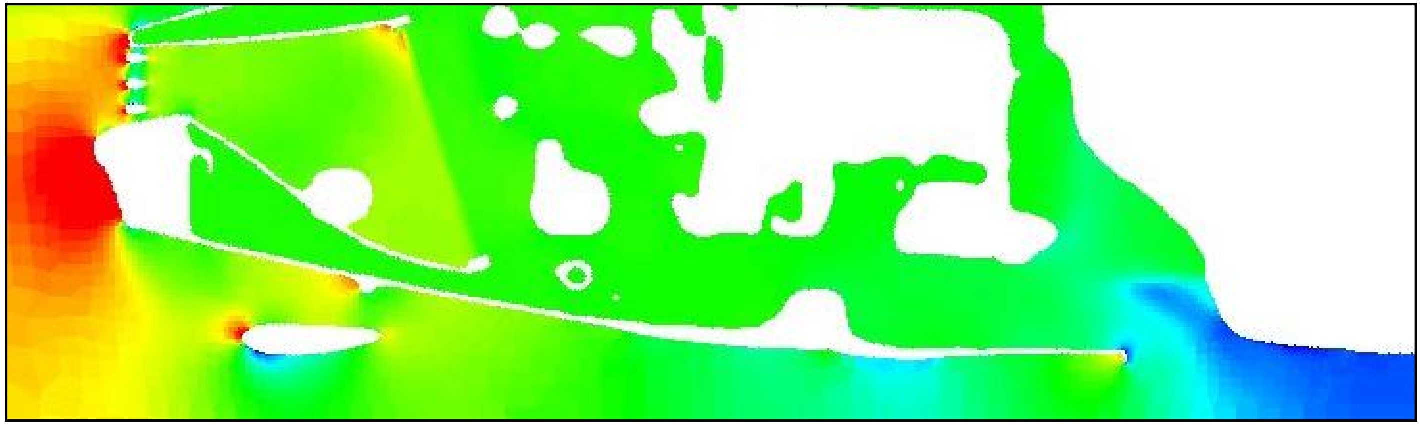




CFD Results Optimization 2nd Version (C)

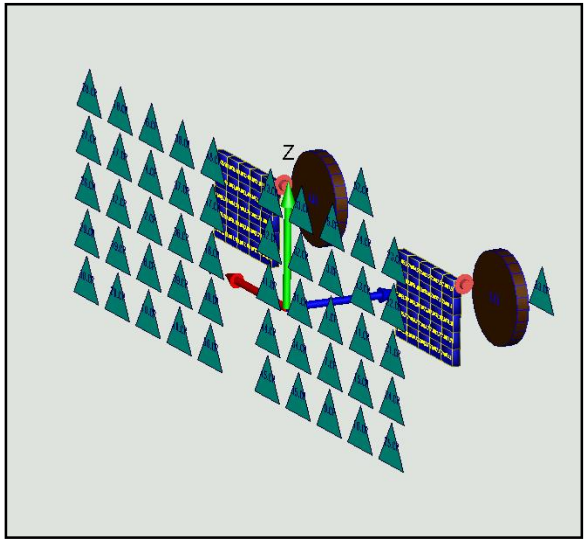
Pressure Distribution

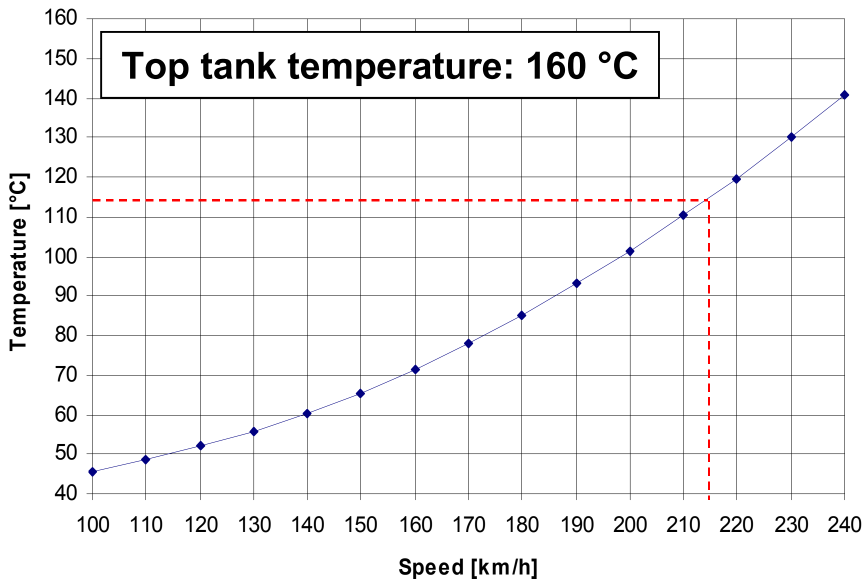




KULI Results Optimization 2nd Version (C)

Cooling Performance (Top Tank Temperature)





KULI Simulation		450W Electrical Fan							
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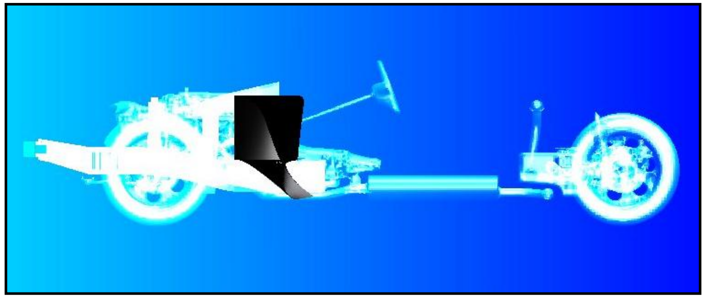
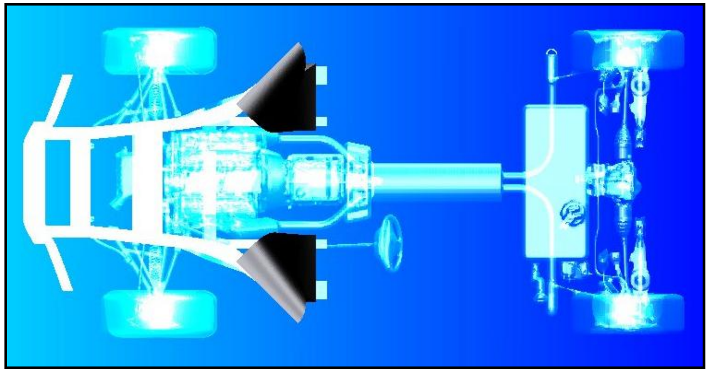
A	Base version without any measures	Christian Kussmann	max. heat 54 kW	57.1	67.4	65.3	78.9	181.2	118.1
C	New underhood with diffusor, condenser in front and vertical inlet fins	Christian Kussmann	max. heat 64 kW	50.7	59.6	58.3	70.1	159.9	106.3

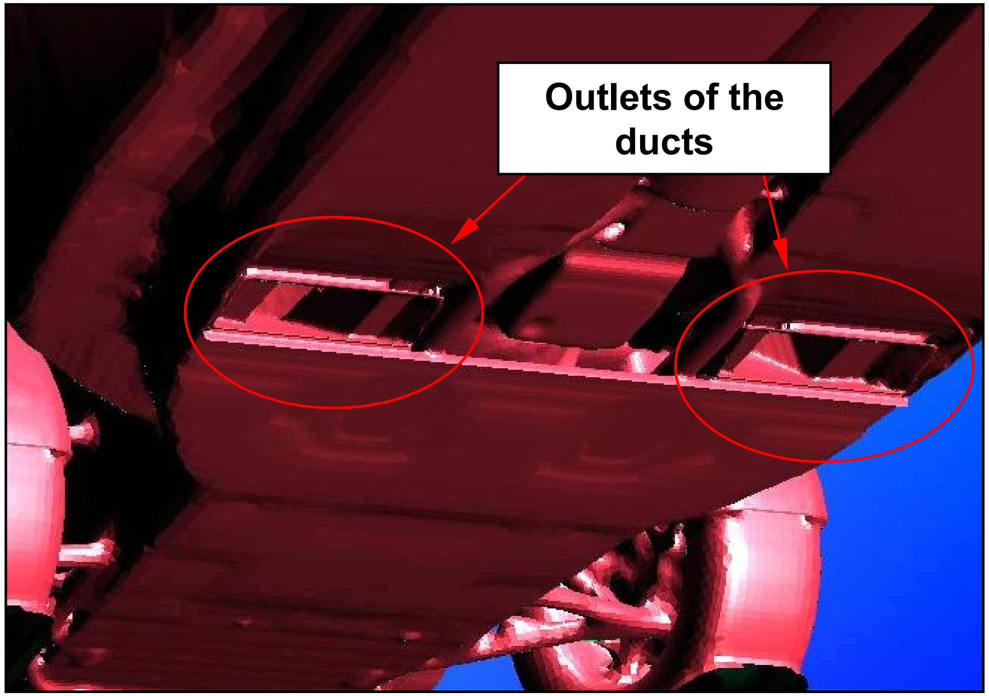
Optimization 3rd Version (R)

Geometry Improvements

- In order to maximize the cp-difference between radiator front and cooling-package outlet, a duct was implemented. This construction connects the radiator directly with the low pressure area at the underbody of the car.

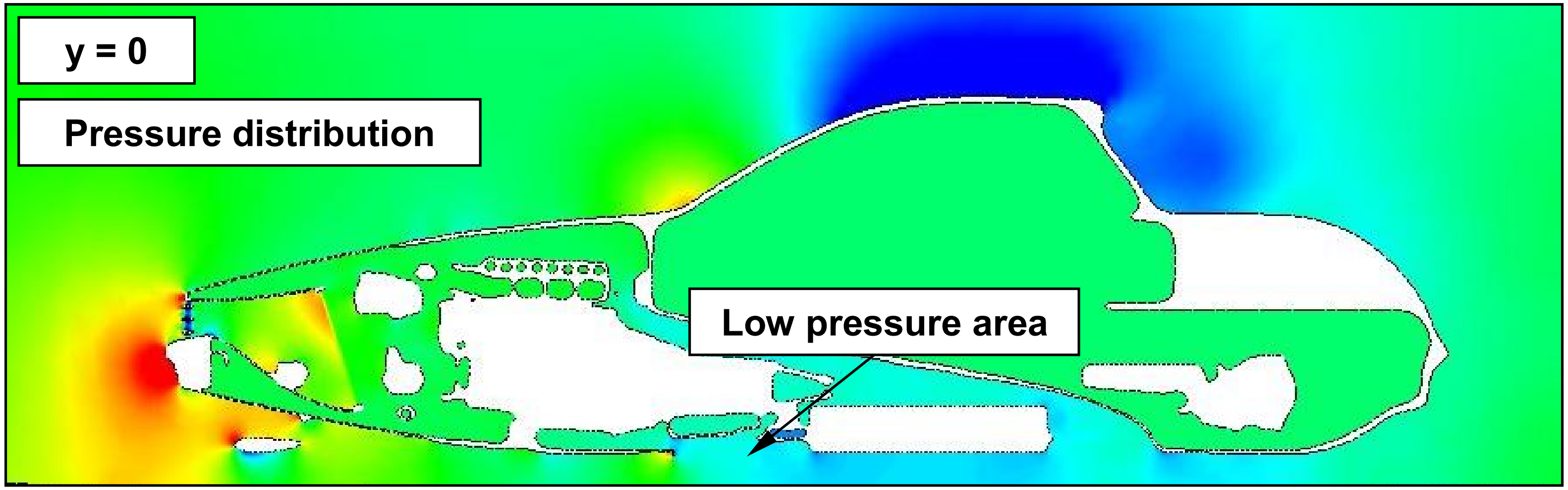


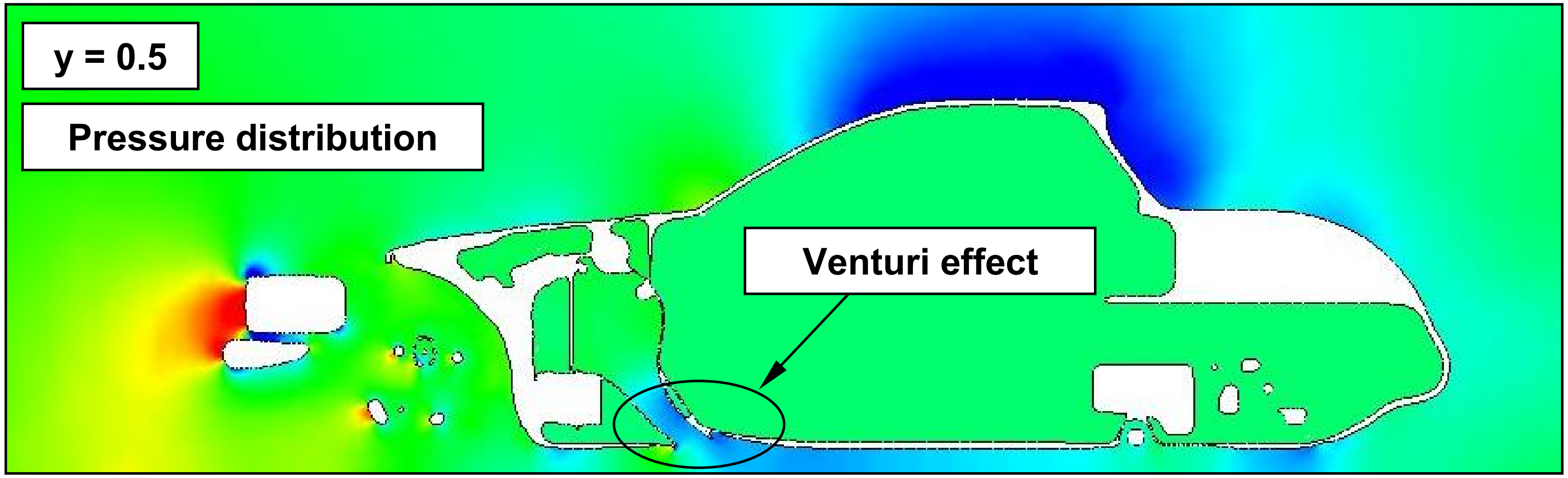




CFD Results Optimization 3rd Version (R)

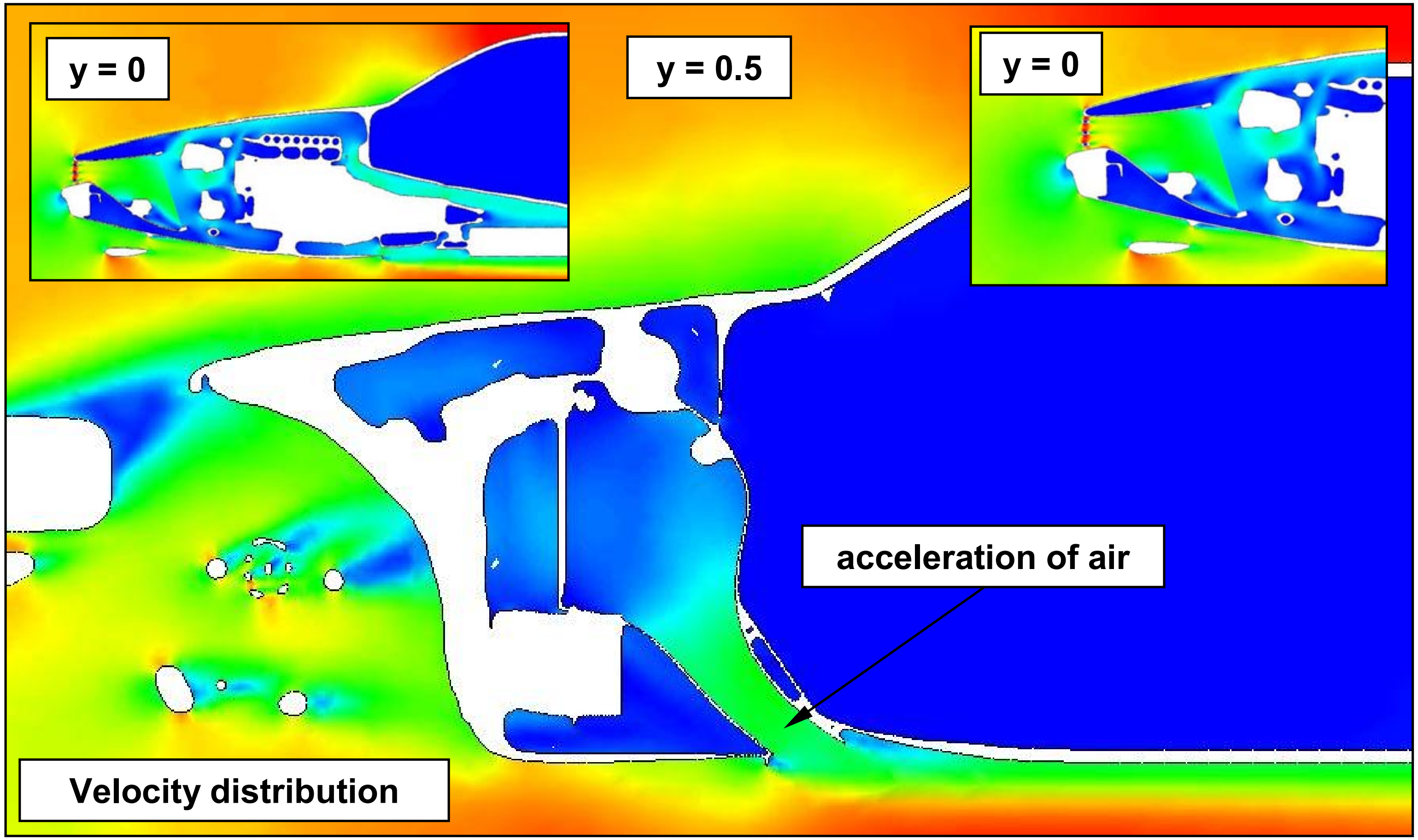
Pressure Distribution





CFD Results Optimization 3rd Version (R)

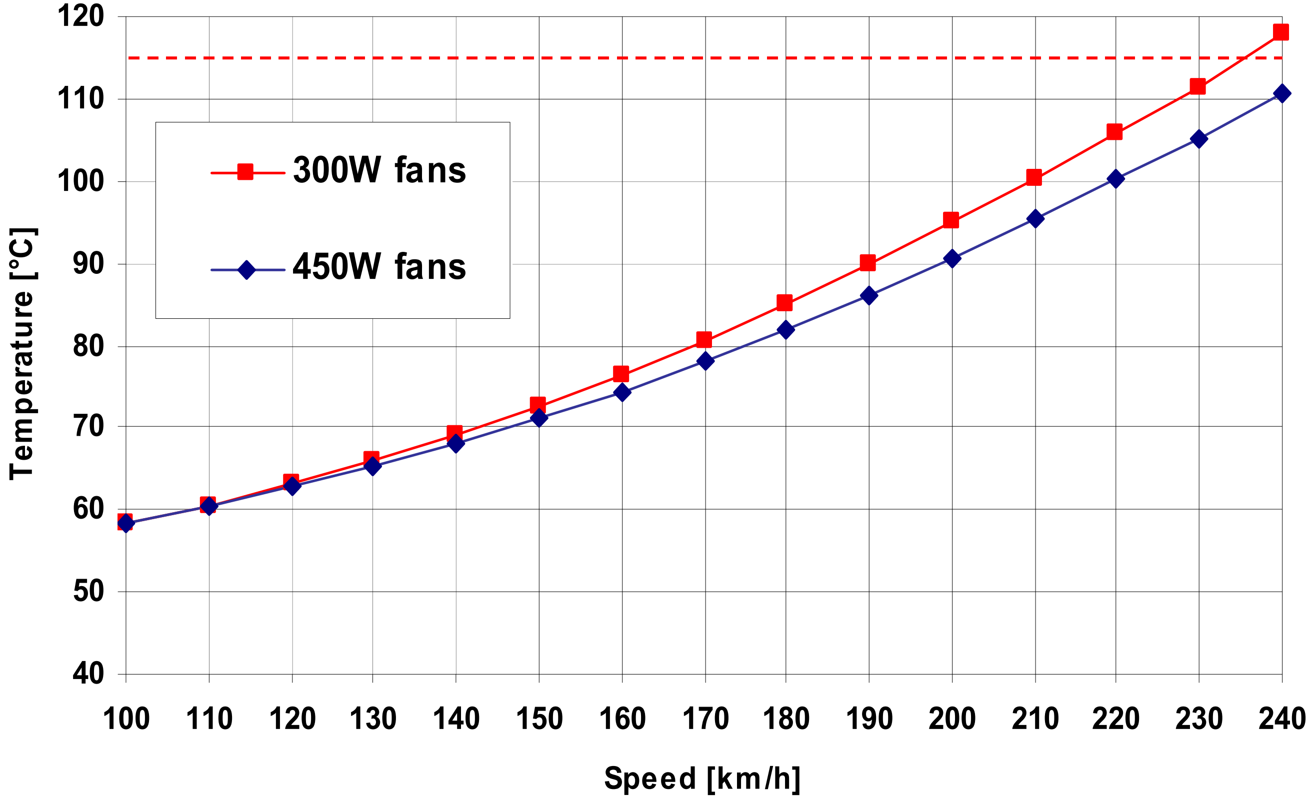
Velocity Distribution

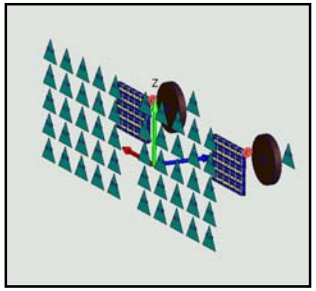


KULI Results Optimization 3rd Version (R)

Cooling Performance (Top Tank Temperature)

1D simulation results calculated with 450 W and 300 W fans, 45°C ambient temperature and a radiator with 32mm depth.

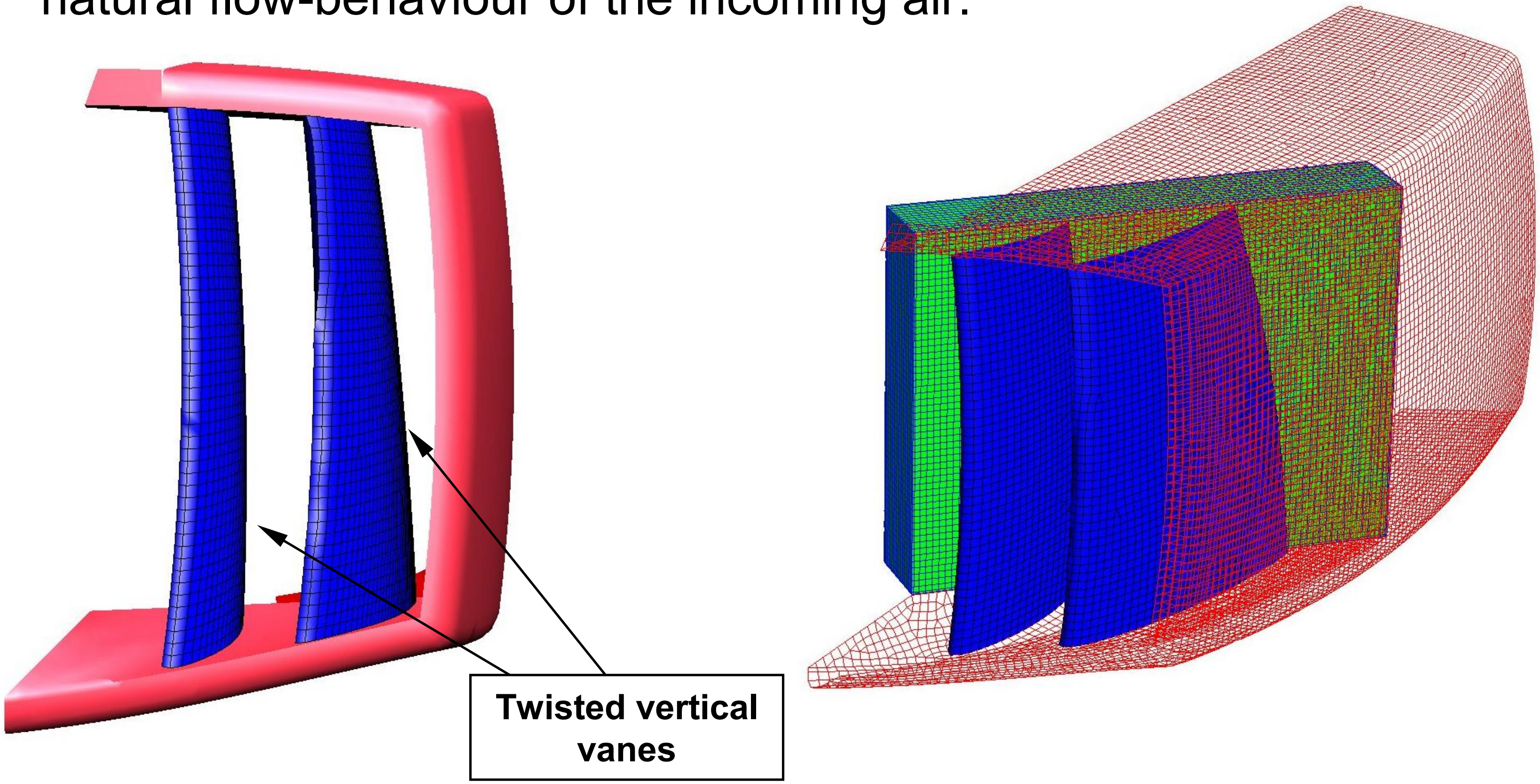




Optimization 4th Version (S)

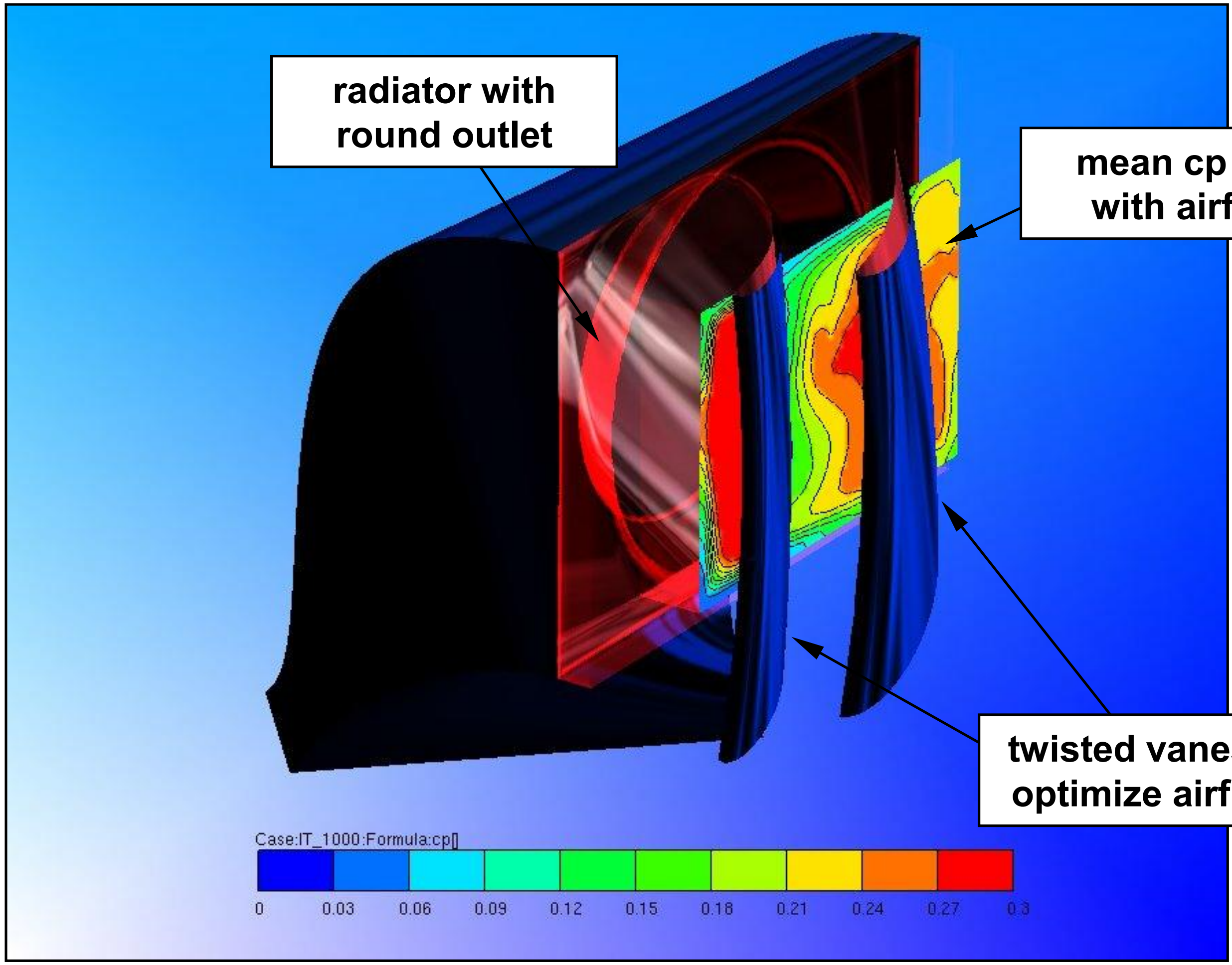
Geometry Improvements

- A further improvement was to turn the vertical vanes regarding to the natural flow-behaviour of the incoming air.



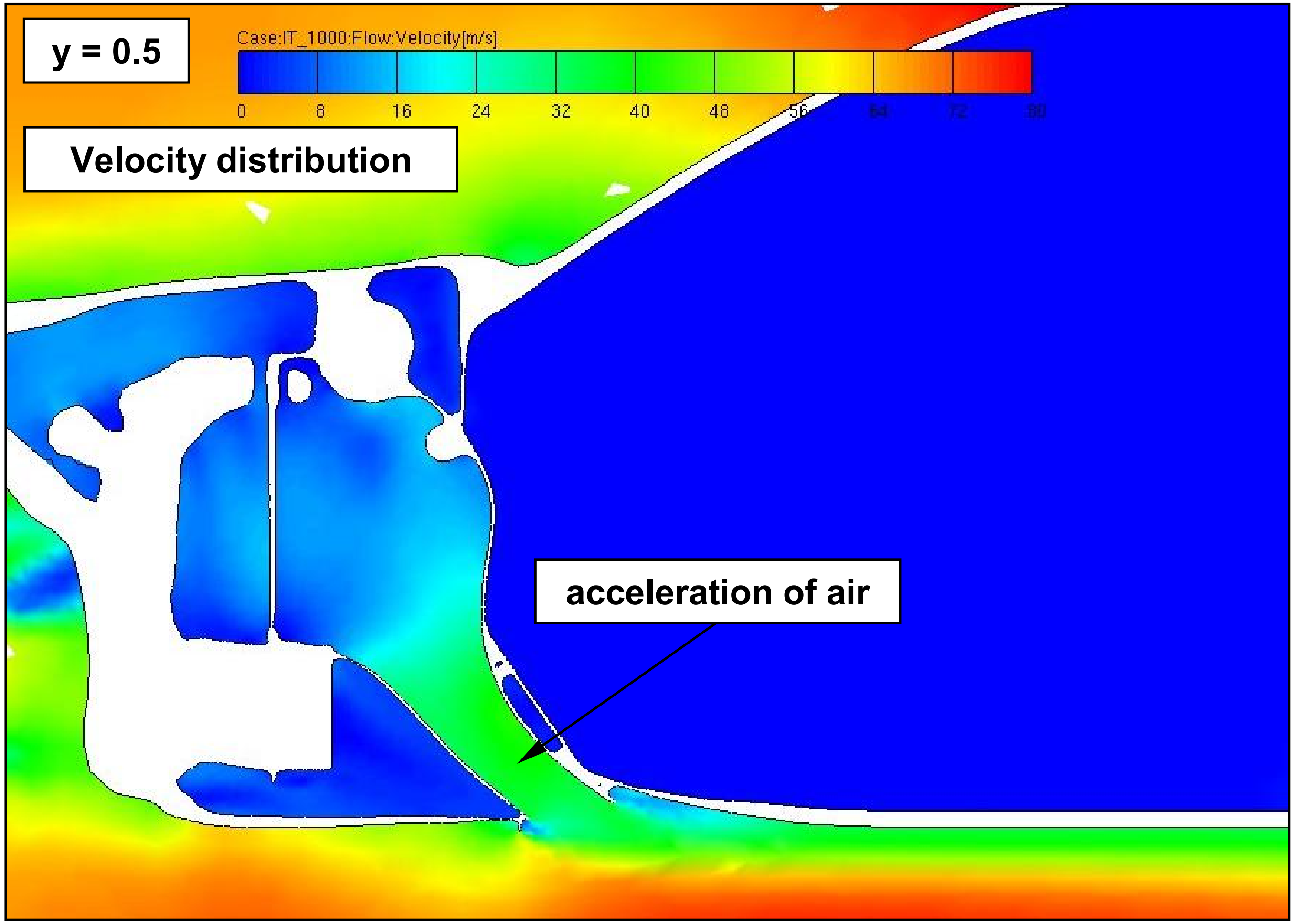
CFD Results Optimization 4th Version (S)

c_p Distribution



CFD Results Optimization 4th Version (S)

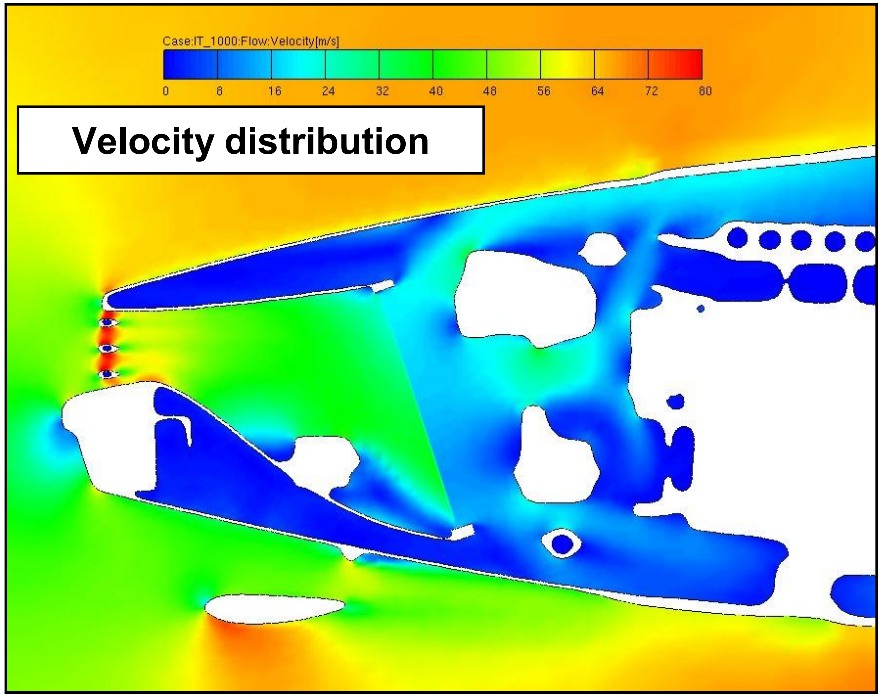
Velocity Distribution



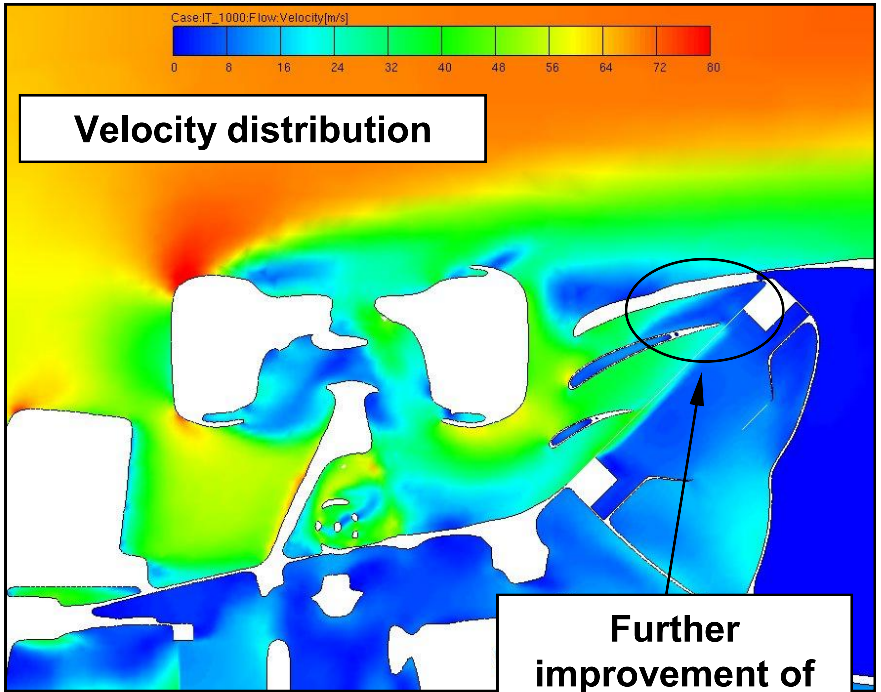
CFD Results Optimization 4th Version (S)

Velocity Distribution

y = 0



z = 0.9

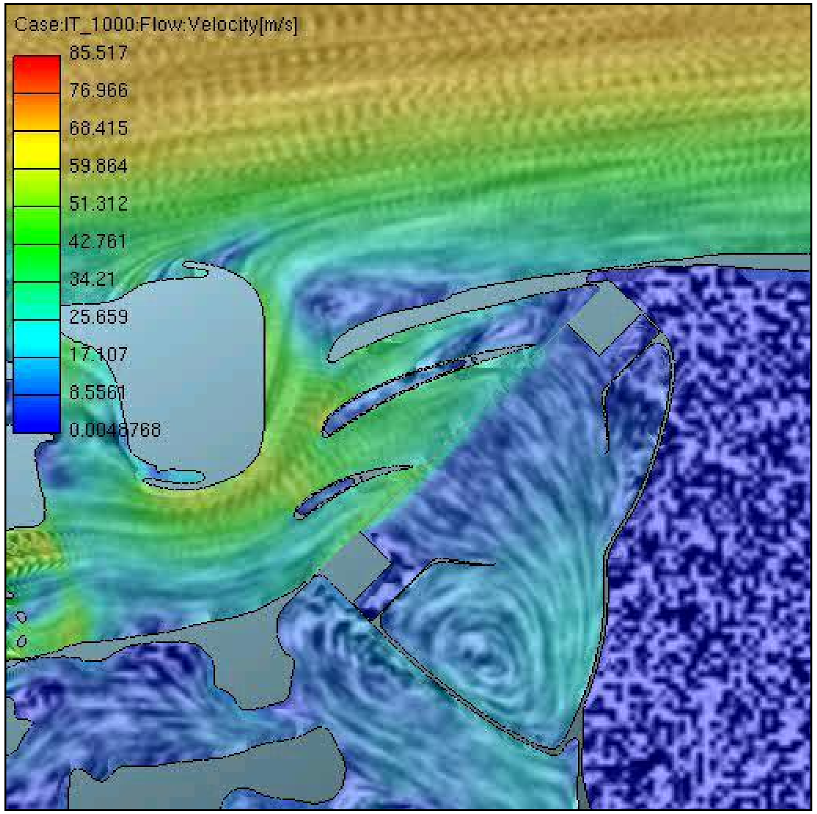


Further improvement of airflow due to twisted vanes

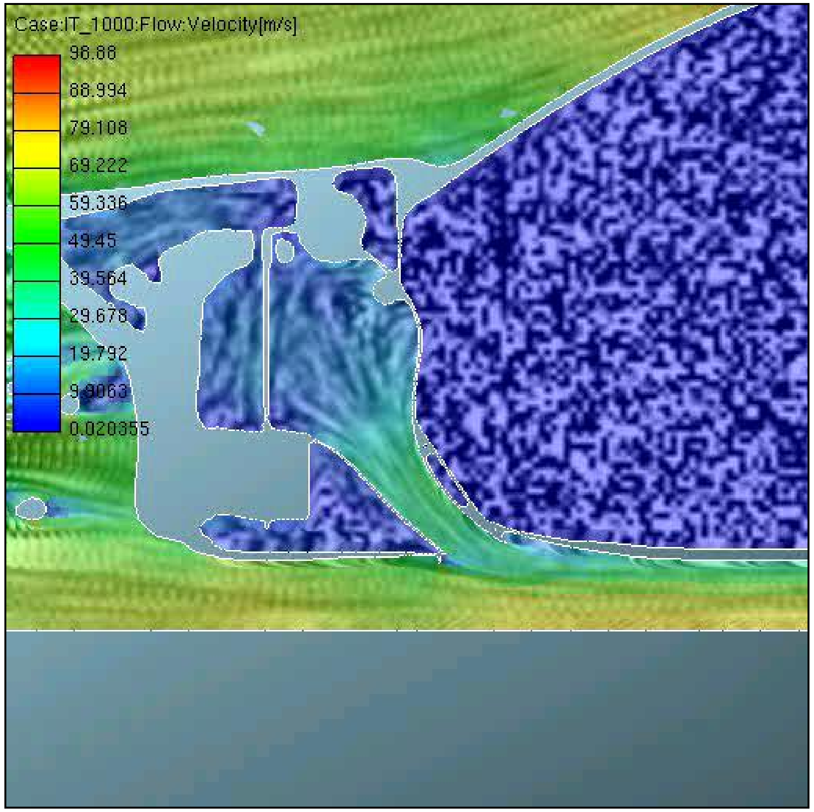
CFD Results Optimization 4th Version (S)

Videos

Flow around the vanes



Low pressure area underbody / venturi effect



KULI Results Optimization 4th Version (S)

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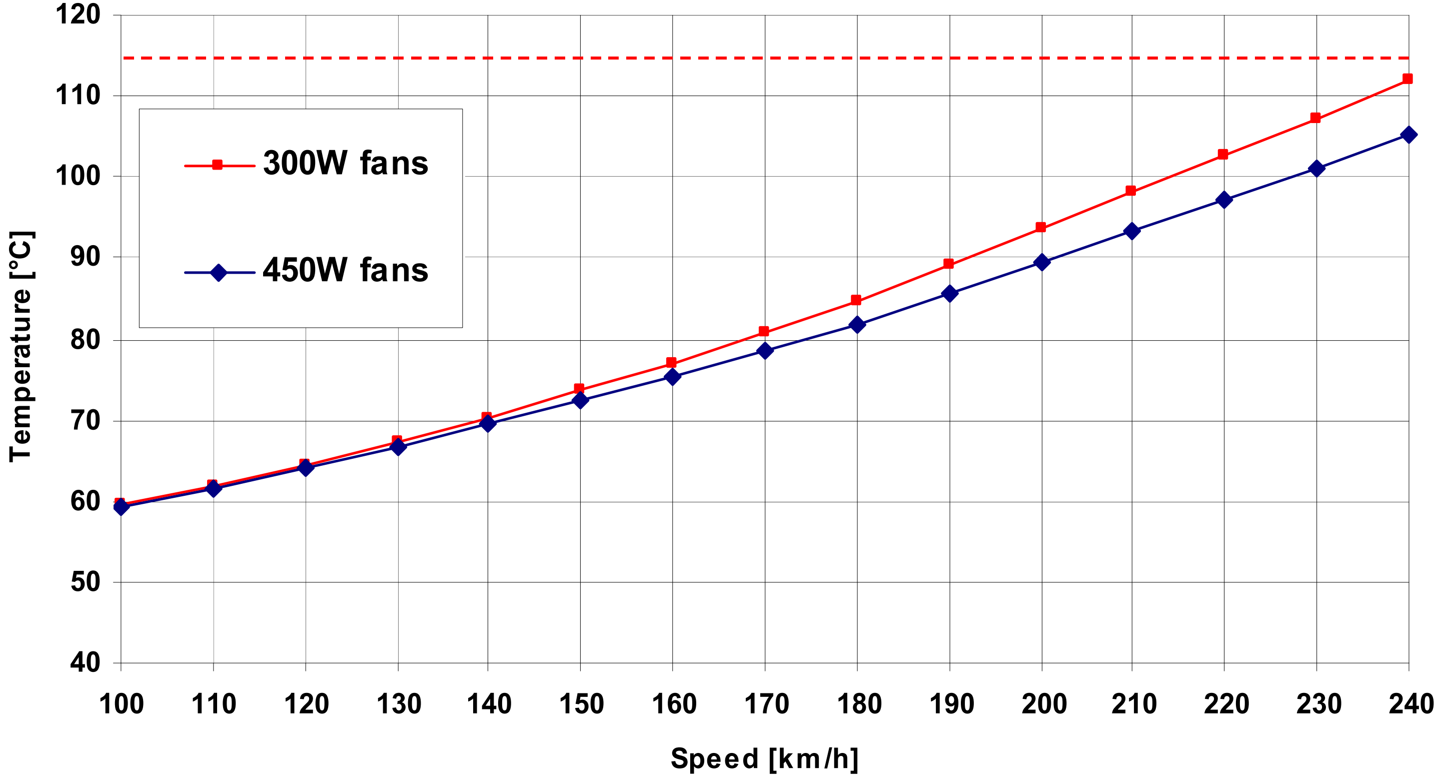

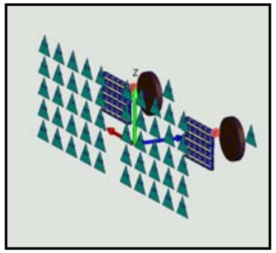

KULI Results Optimization 4th Version (S)

Cooling Performance, Summary 1D-Calculation

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R	New underhood with diffusor, condenser in front and vertical inlet fins and duct	Christian Kussmann	max. heat 64 kW	54.2	65.5	60	72.9	107.1	89.5
S	New underhood with diffusor, condenser in front and modified vertical inlet fins and duct	Christian Kussmann	max. heat 64 kW	54.1	65.2	59.6	72.2	105.4	88.4

KULI Simulation		responsible for modelling	300W Electrical Fan: Idle 1000 RPM outside: 45°C Limit: 115°C	Hill 7% with 60 km/h outside: 35°C Limit: 105°C	Hill 7% with 60 km/h and trailer outside: 35°C Limit: 115°C	Hill 6% with 60 km/h outside: 35°C Limit: 105°C	Hill 6% with 90 km/h and trailer outside: 35°C Limit: 115°C	Vmax 240 km/h outside: 45°C Limit: 113°C	Vmax with trailer 180 km/h outside: 45°C Limit: 115°C
A	Base version without any measures	Christian Kussmann	max. heat 50 kW	59.3	70.7	68	82.8	186.2	123.7
C	New underhood with diffusor, condenser in front and vertical inlet fins	Christian Kussmann	max. heat 61 kW	51.8	61.4	59.8	72.7	164.6	110.4
R	New underhood with diffusor, condenser in front and vertical inlet fins and duct	Christian Kussmann	max. heat 61 kW	51.5	61.1	57.8	69.4	113.9	91.5
S	New underhood with diffusor, condenser in front and modified vertical inlet fins and duct	Christian Kussmann	max. heat 61 kW	51.4	61	57.5	69	111.9	90.6

Conclusions

Why coupling KULI to CFD?

- For new cooling concepts it is essential to couple KULI to CFD to get feasible results.
- Without the coupling it would not have been possible to show what is necessary to fulfill the requirements and to optimize the system in the very early stage.
- With the c_p matrix coupling, it was possible to represent 3D flow effects in the KULI model and even back flow is shown.
- Finally, version 4 seems to be a feasible solution for this vehicle.
- The final results show, that with a better air guidance even with 300 W fans a sufficient cooling of the system is achieved.

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