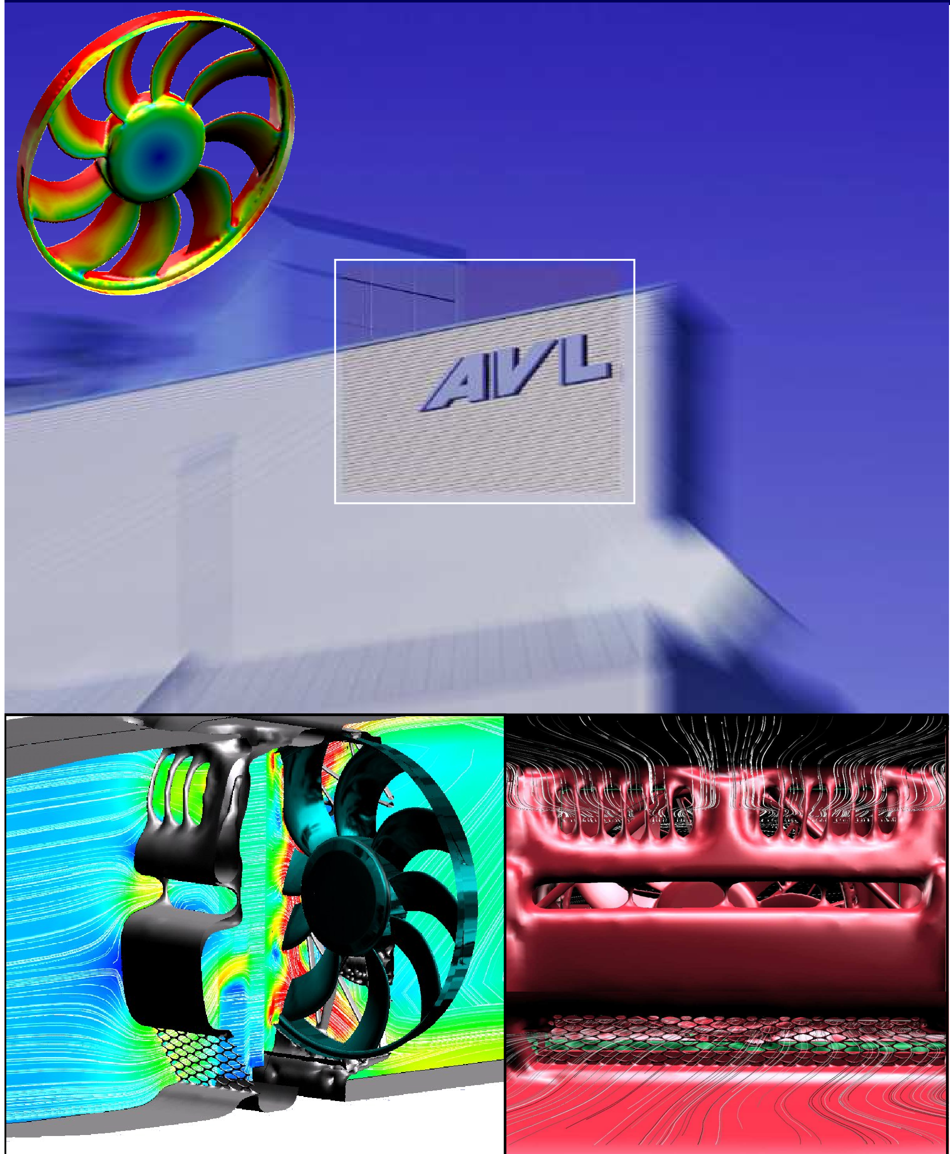
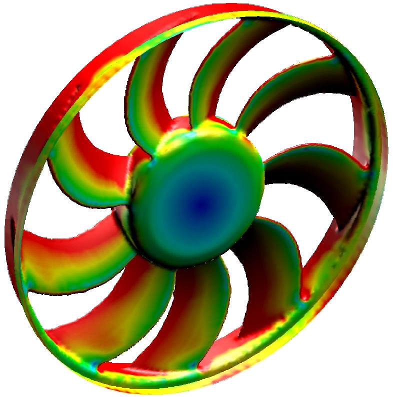


Influence of the 3D-CFD Fan Modeling Depth onto the coupled 1D-3D Simulation of a Cooling Package

H. Petutschnig	AVL, ViF
T. Hörmann	ViF
A. Bregant	AVL
A. Ennemoser	AVL
T. Moshammer	MSF

Agenda

- **Cooperation „Virtual Vehicle“ and AVL**
- **Motivation**
- **Measurements in the Test Bench**
- **Approaches for Fan Modeling in 3D-CFD**
- **CFD Simulation Model**
- **KULI Simulation Model**
- **Results and Conclusions**
- **Outlook**



Diese Arbeit wurde im
Kompetenzzentrum - Das virtuelle Fahrzeug Forschungsgesellschaft mbH abgewickelt,
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
vif

The Virtual Vehicle - ViF

Center of Competence „The Virtual Vehicle“

Business manager
Dr. J. Bernasch

Scientific head
Prof. W. Hirschberg

Founded in 2002 by:

TUG – Technische Universität Graz	52 %
Magna Steyr	19 %
AVL - List	19 %
Joanneum Research	10 %

Research Areas:

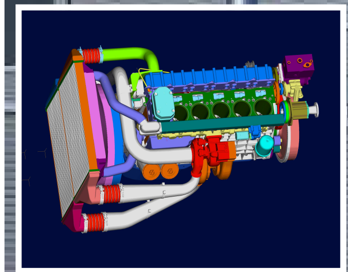
- **Mechanics (Vehicle Safety, Structural Analysis,...)**
- **Thermal Management and Fluid Dynamics**
- **Virtual Engineering**
- **Virtual Manufacturing**

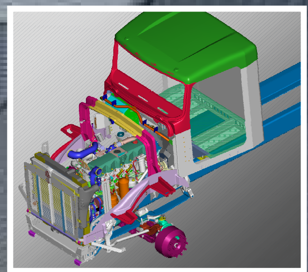
~ 60 employees

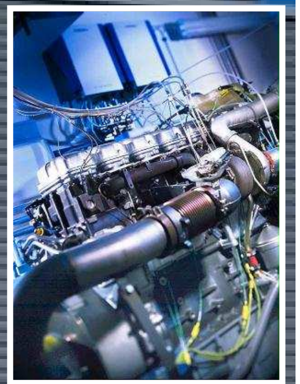
Cooperation AVL - ViF

AVL ⟷ Cooperation ⟷ vif

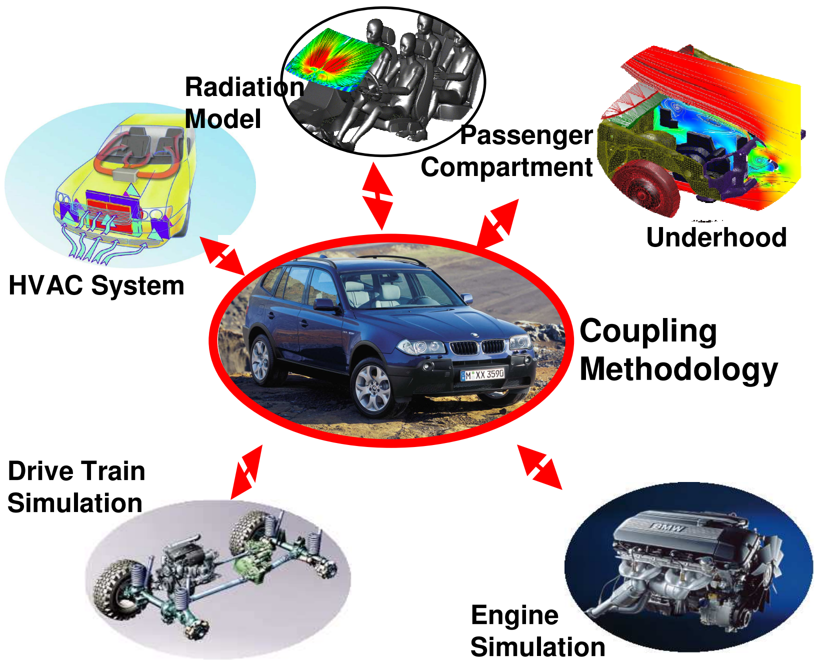
- Fundamental R&D outsourced to potential partners with strong affinity to university (TU-Graz)
- Integration of the developped methods and models into the product development process of AVL
- Industrial application of the integrated methods
- Advanced methods applied in the Engineering Process







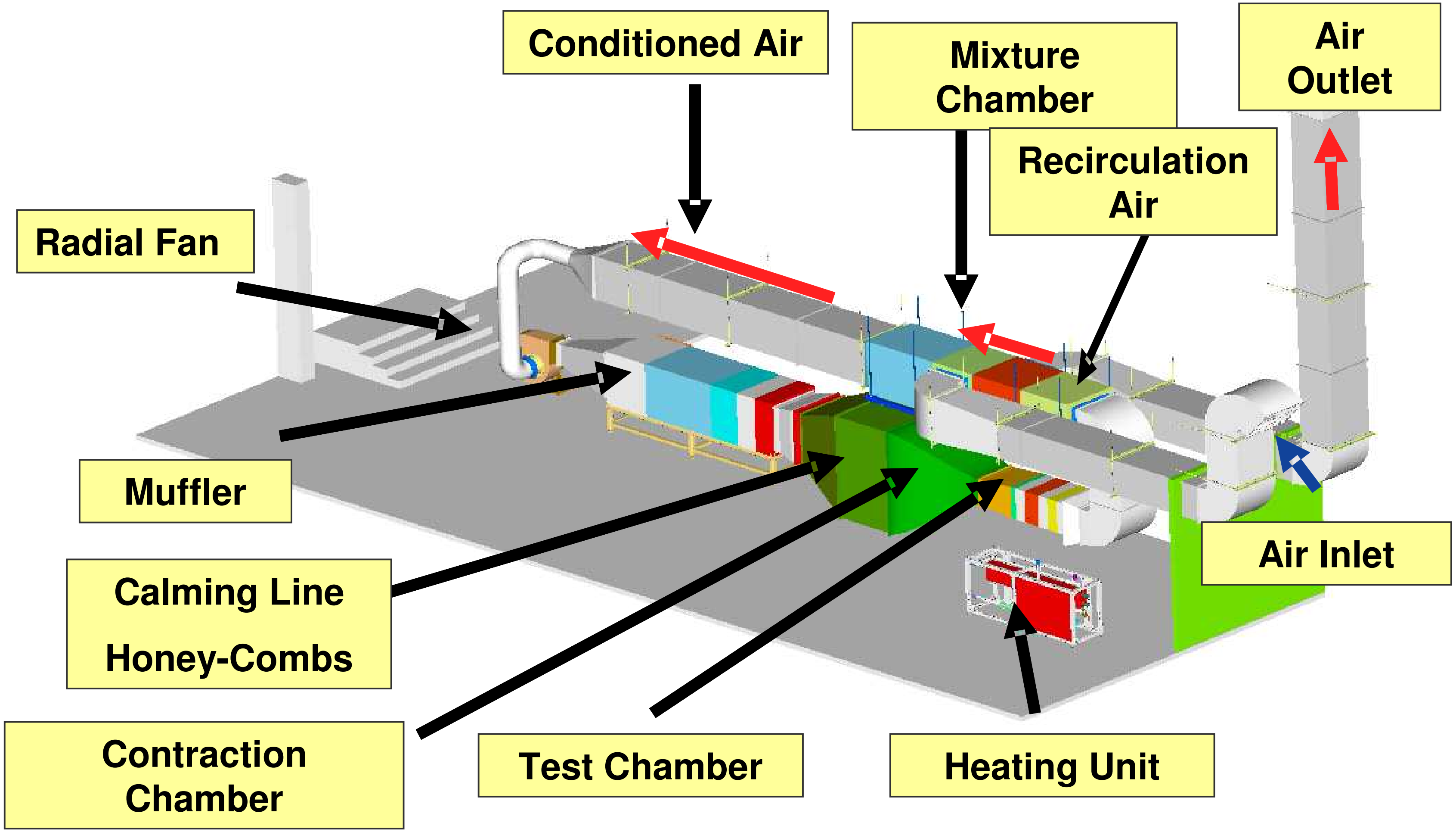
- Fundamental and Applied Research
- Method Development
- Benchmarks
- Engineering Services



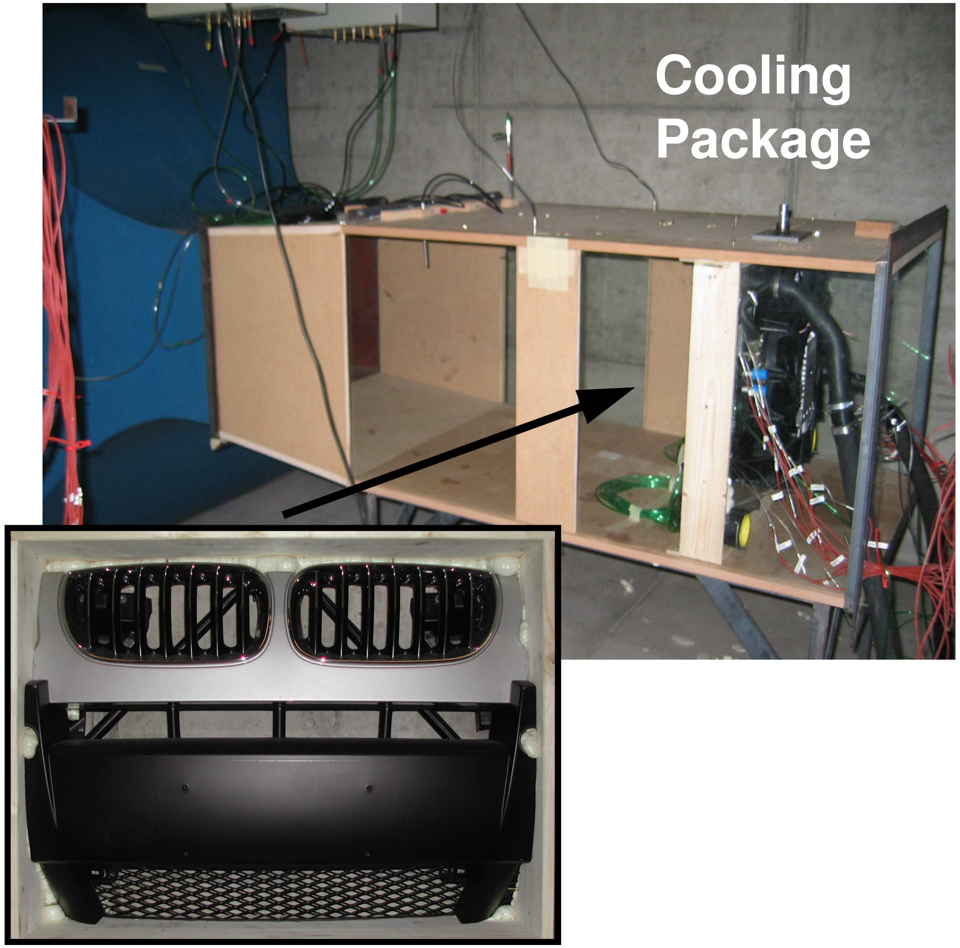
Motivation

- **Enforced integration of numerical development tools in the vehicle development process**
- **Request for increased accuracy in simulation results**
- **Accuracy of simulation results highly depend on quality of prescribed input and boundary conditions**
- **Coupled thermal analysis**
- **Sensitive boundary conditions for 1D cooling circuit analysis**
  - Investigation of fan driven cooling conditions
  - Sensitivity of inhomogeneous flow field onto heat transfer at the radiators
  - Integration of 3D-CFD analysis for fan driven flow field
  - Investigation of different approaches for 3D-CFD fan modeling and its impact on the resulting heat rejection

For Validation of Simulation Models and Results:



Test Bench: Characteristic Figures



Front End

Test Chamber

- 0.78 m x 0.57 m x 2 m
- Side Walls are glas made for LDA-measurements

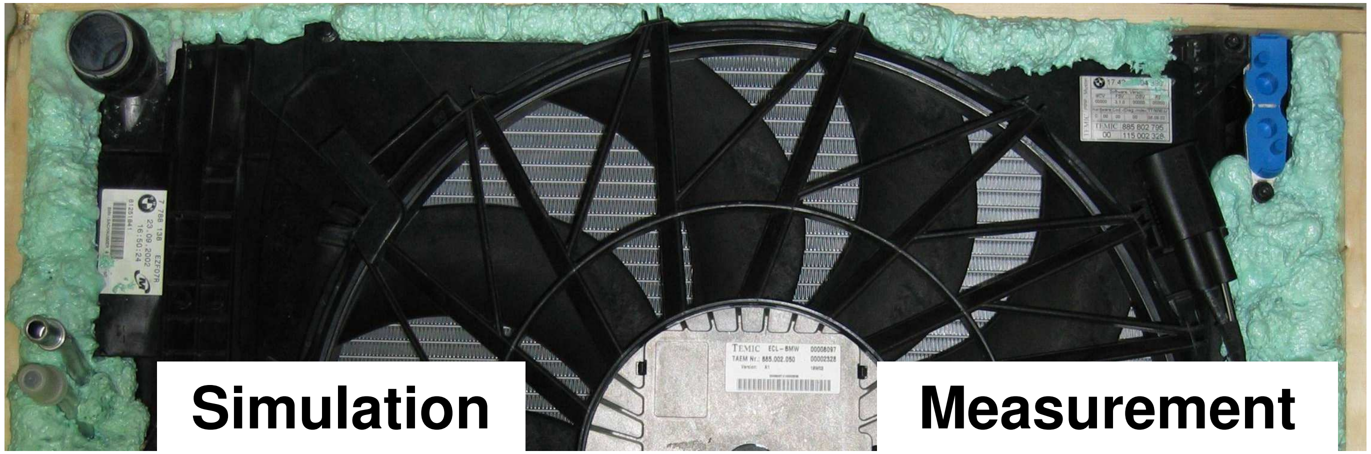
Coolant-Side

- Coolant flow up to 10.000 l/h
- Temperature 110 °C (~ 70 kW)

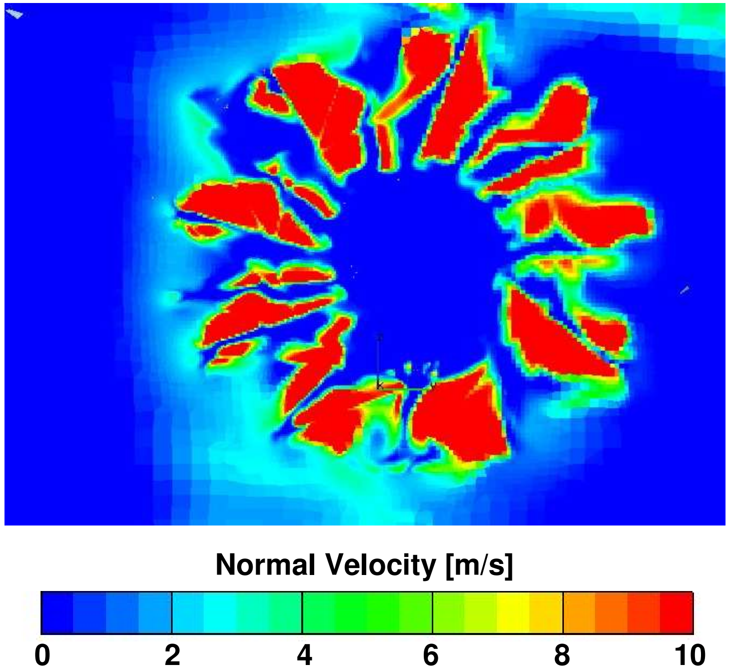
Air -Side

- Cooling Airflow up to 3 kg/s
- Air Temperature up to 50 °C
- Very low Turbulent Rate

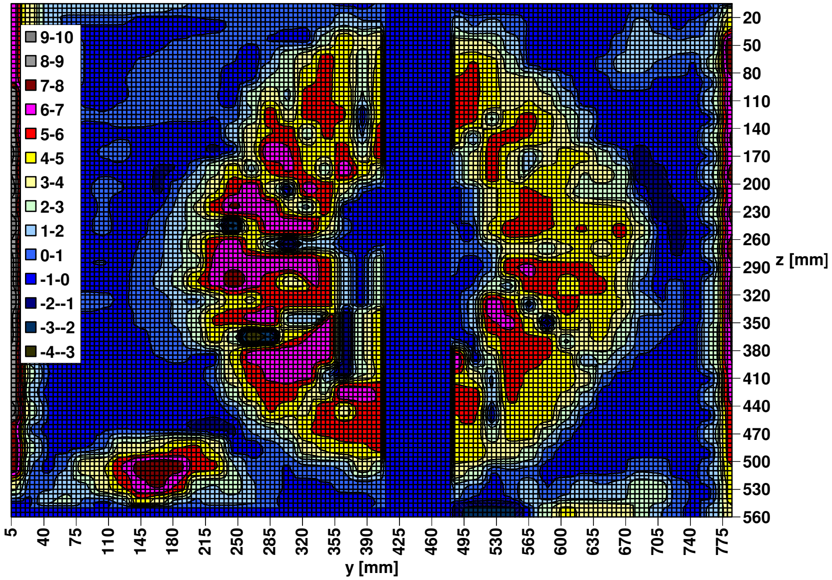
Validation of 3D-CFD Simulation



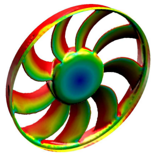
Simulation

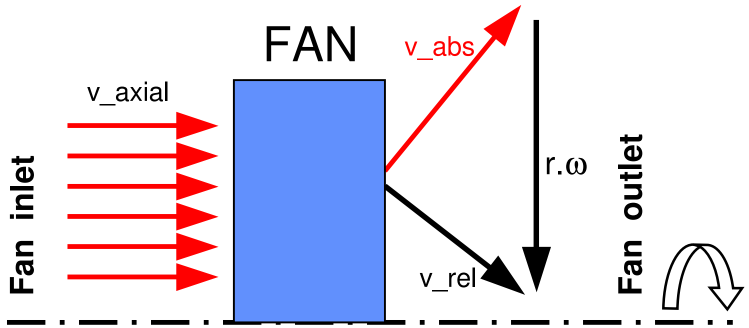


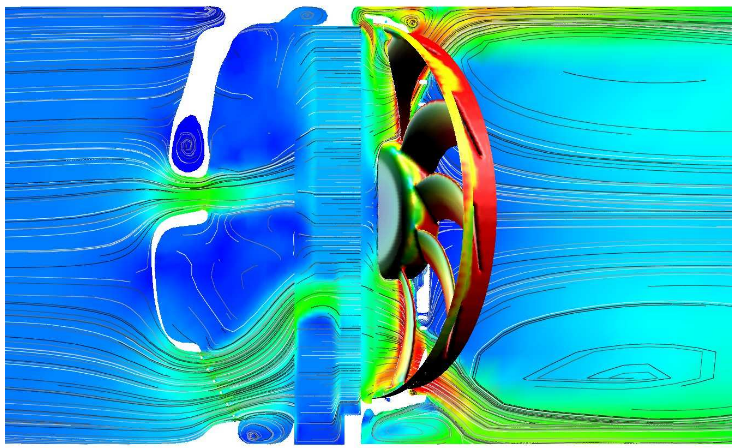
Measurement



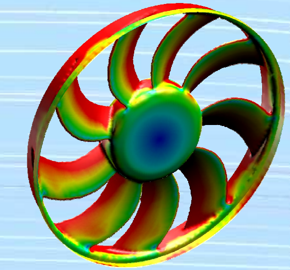
FAN - Modeling

	Fan Meshing	Numerical Treatment
User Function	Not required	Axial inflow assumption Velocity Triangles at the outlet
Multiple Frame of Reference	Yes	Stationary frame and rotating reference frame
Sliding Mesh	Yes	Sliding mesh is used in order to model the motion of the blades

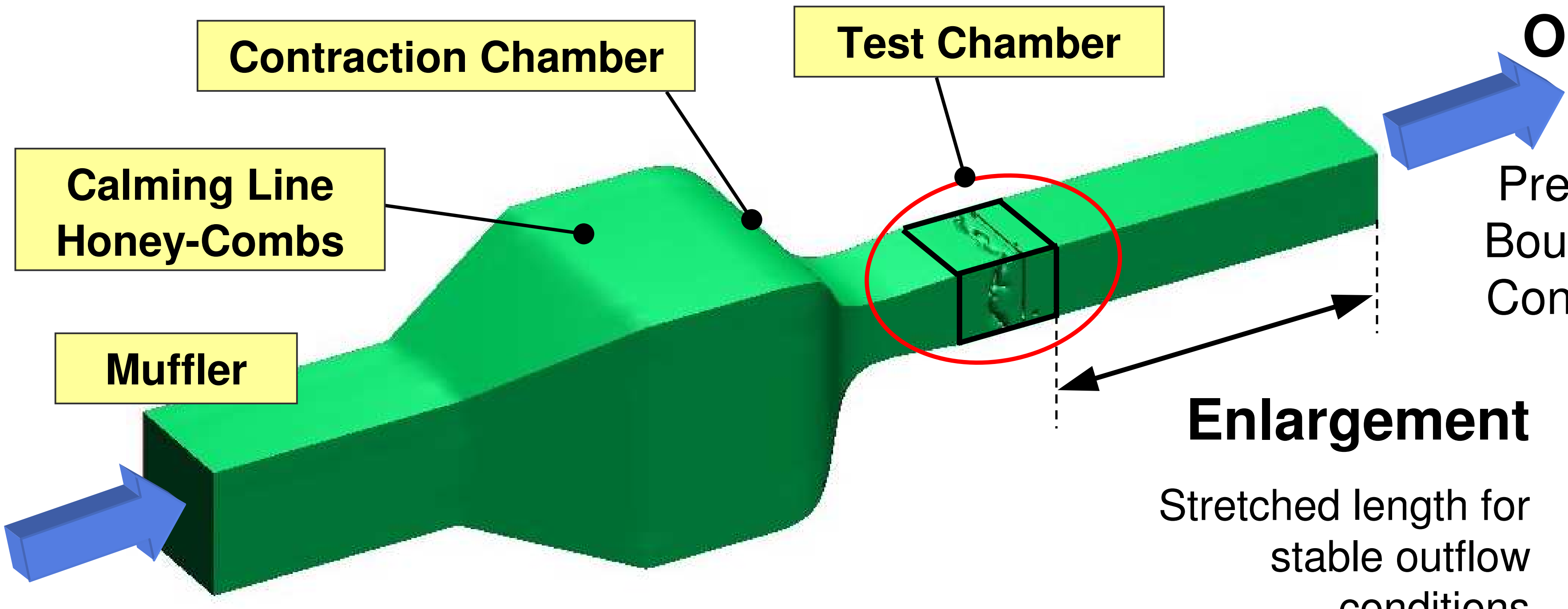




FAN - Modeling

	Preprocessing Costs	Solver Costs (CPU, memory, time)	Run Mode
User Function	Low	Low	Steady state
Multiple Frame of Reference	High	Medium	Steady state
Sliding Mesh	High	High	Transient

CFD – The Mesh



Outlet

Static
Pressure
Boundary
Condition

Enlargement

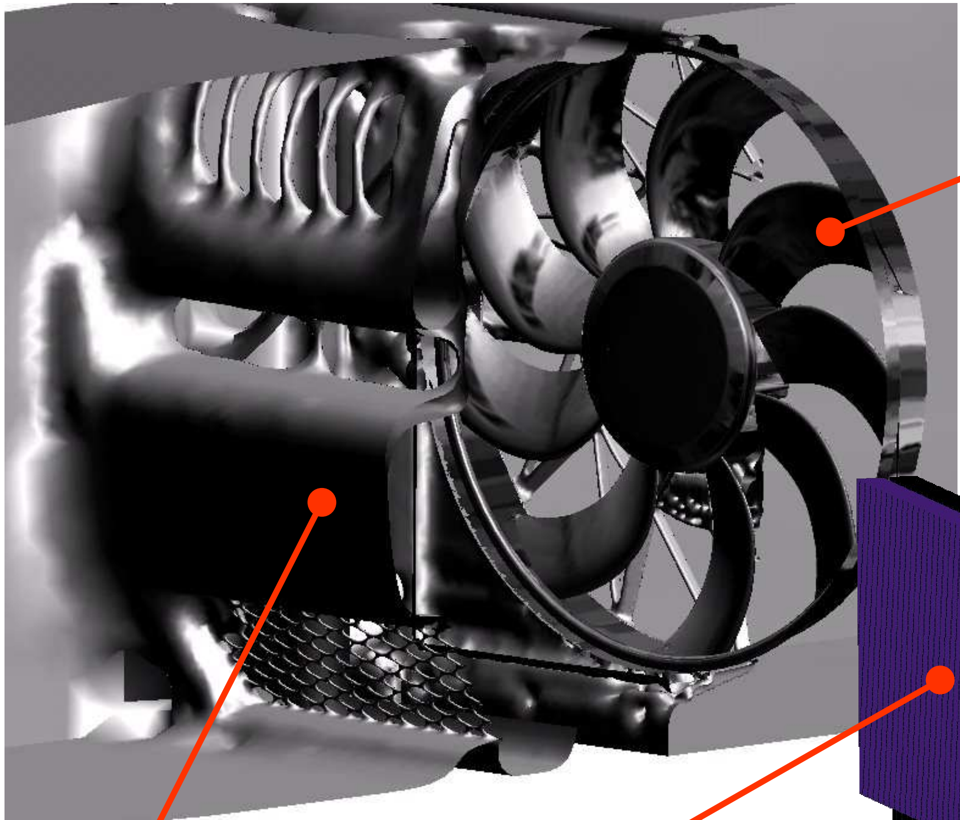
Stretched length for
stable outflow
conditions

Inlet

Mass Flow Boundary Condition

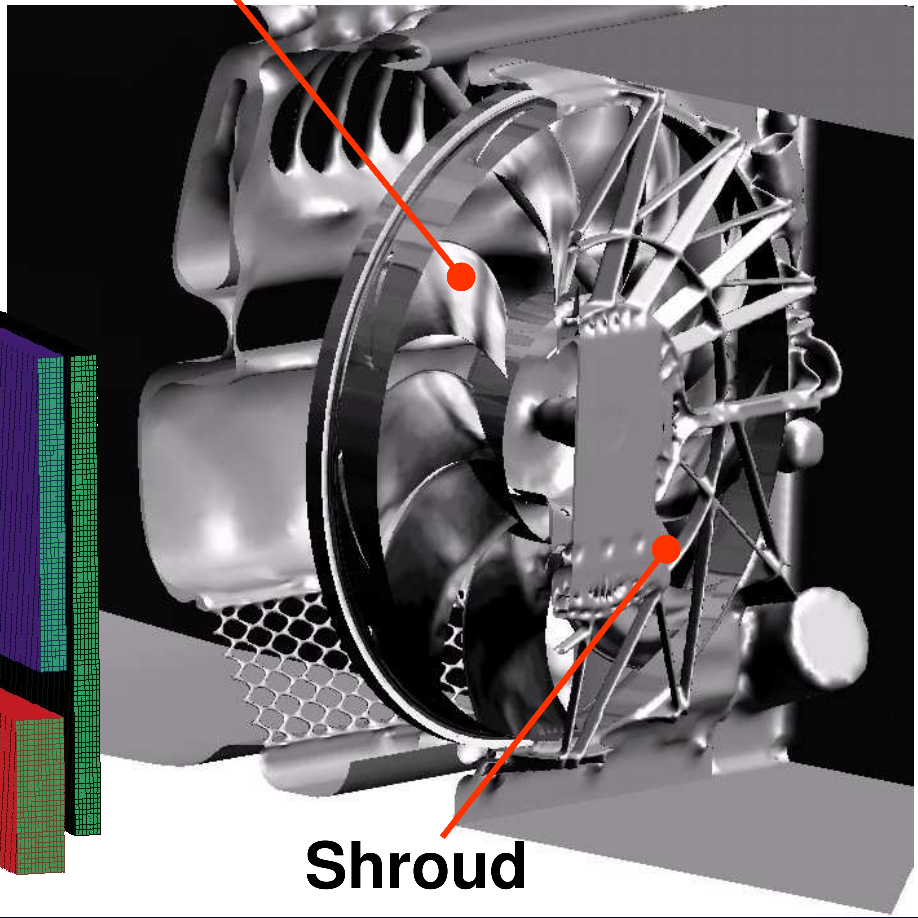
CFD – The Mesh

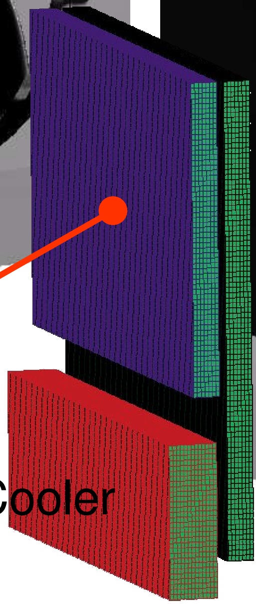
Front View



Fan

Rear View





Front End

- Air Inlets
- Grill
- Bottom Fence

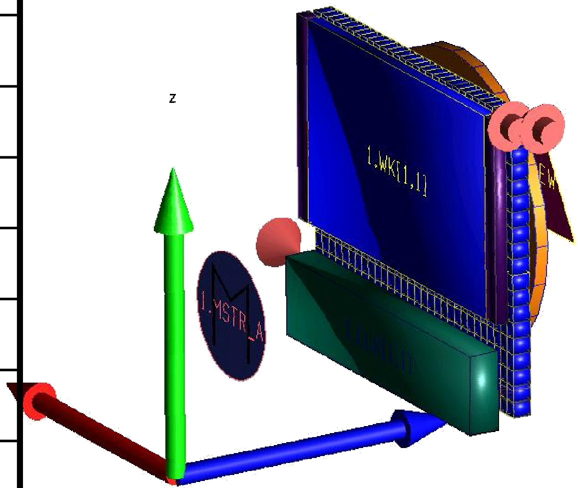
Porosities

- Charge Air Cooler
- Condenser
- Radiator

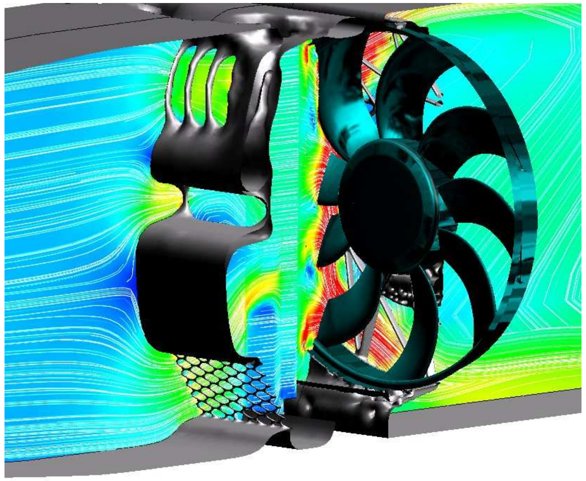
Shroud

Investigated Operating Points

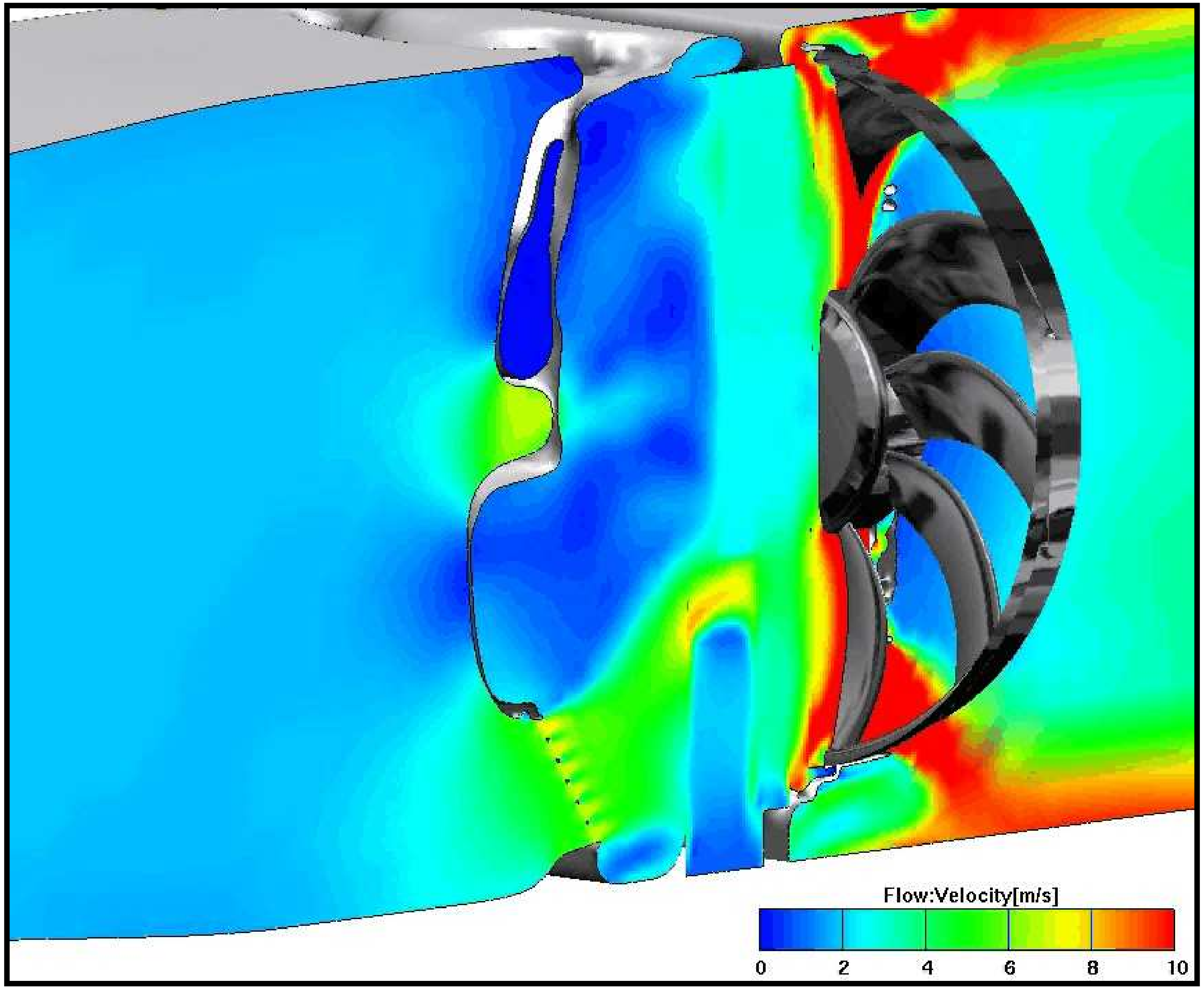
Investigated OPERATING POINTS			
	Point A	**Point B**	
Inlet Air Mass Flow	0.855	0.600	kg/s
Inlet Air Temperature	27	27	°C
Fan Speed	1960	980	rpm
Coolant Mass Flow	1.200	1.200	kg/s
Coolant Inlet Temperature	99.5	99.5	°C
ETD	72.5	72.5	°C



Investigated FAN MODELING TECHNIQUES		
	Point A	**Point B**
User Function	x	x
Blocked Fan	x	x
MRF (Multiple Frame of Reference)	x	x
Sliding Mesh	-	-



Vertical Cut: Velocity Scan



Point A:

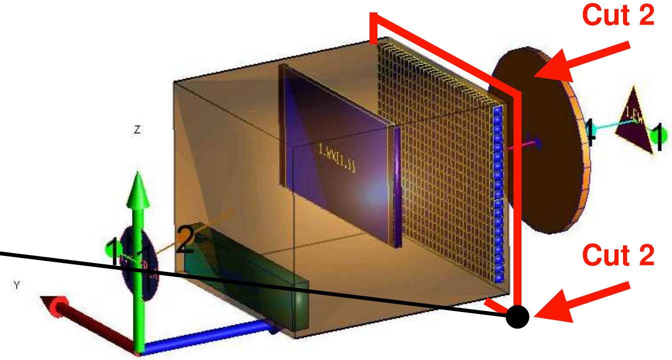
m_{air} = 0.855 kg/s
Fan: 1960 rpm
CFD Model: MRF

AVL

Point A:

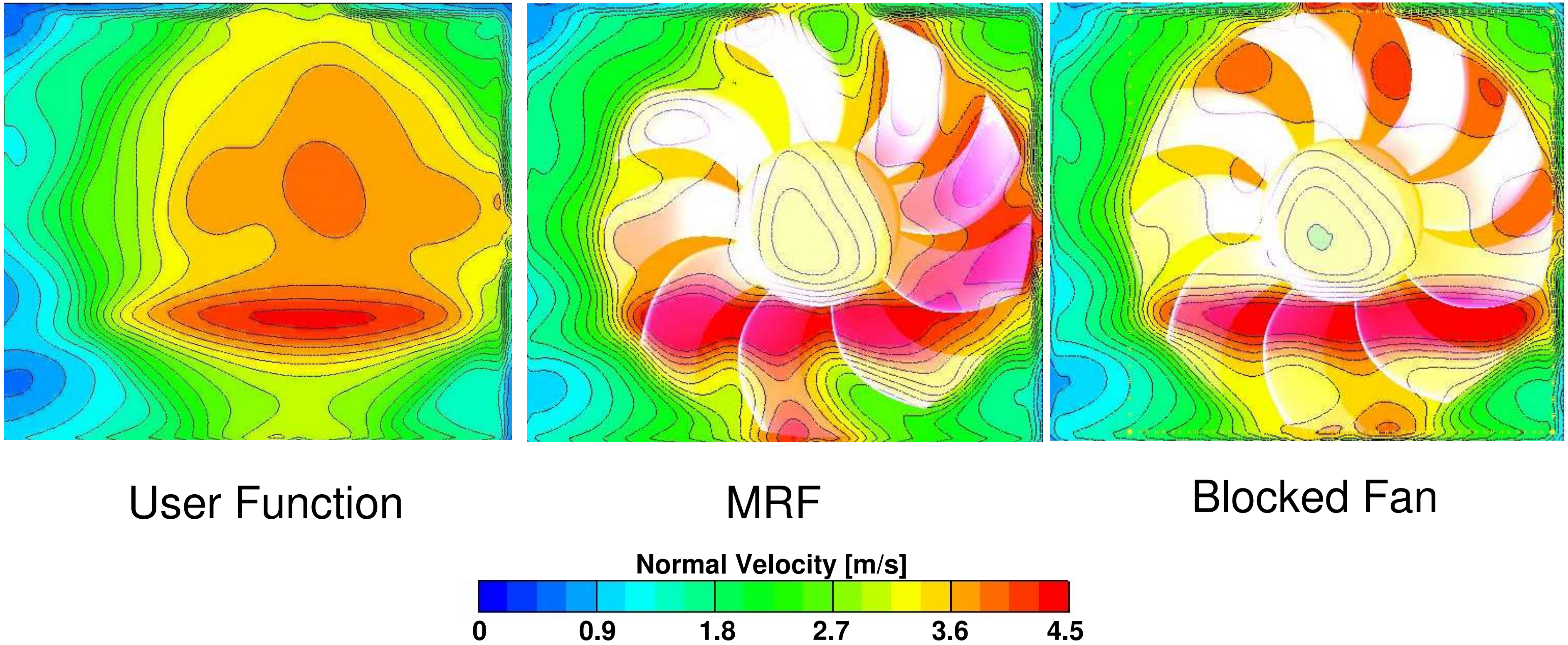
Constant Mass Flow = 0.855 kg/s

Vertical Plane Cut between Fan and Radiator ("Cut 2")



Fan 1960 rpm

Fan 1960 rpm

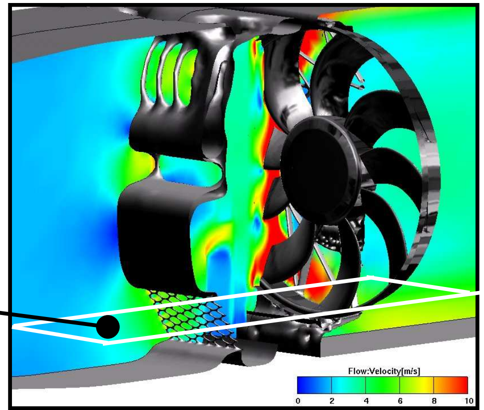


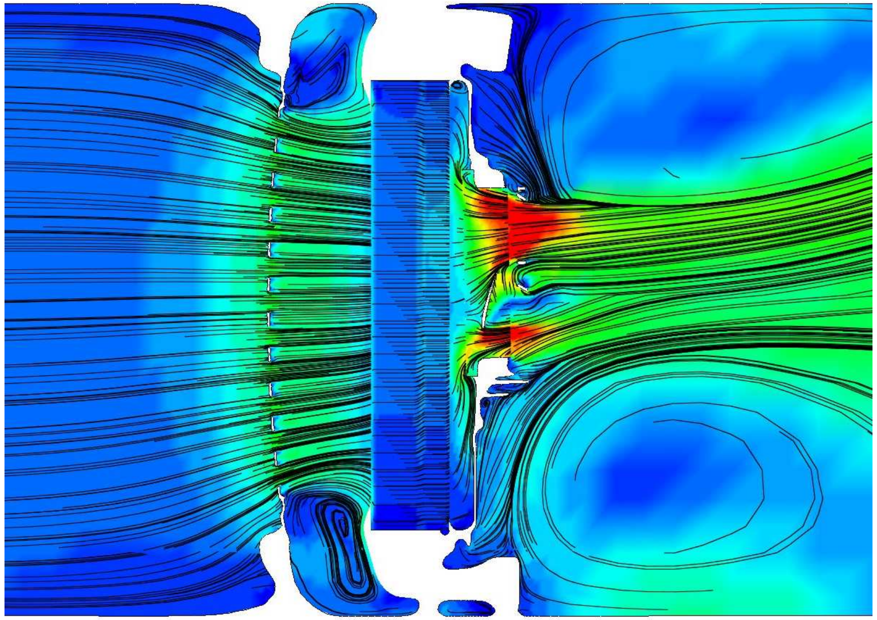
Velocity Distribution: Horizontal Cut

Point A:

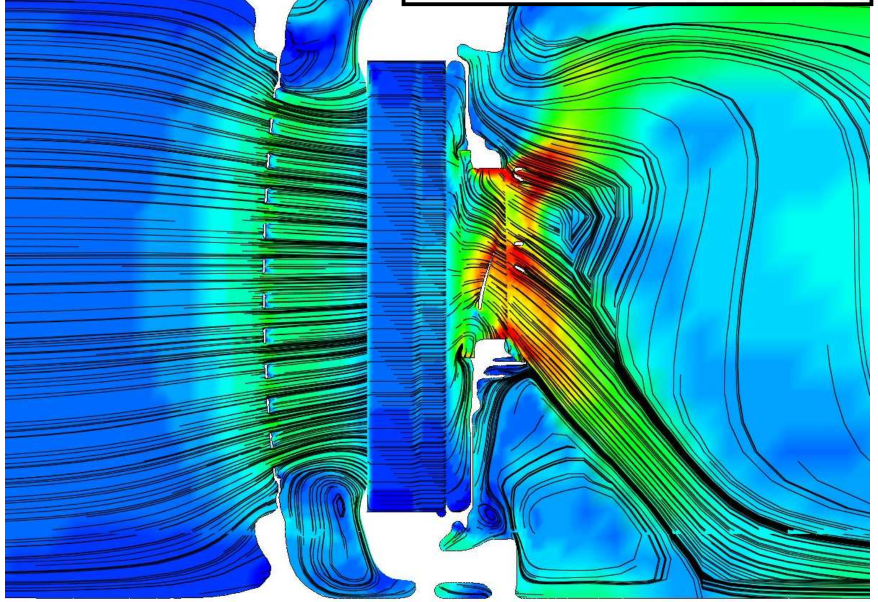
Constant Mass Flow = 0.855 kg/s

Horizontal Plane Cut through Bottom Inlet Grill





Blocked Fan



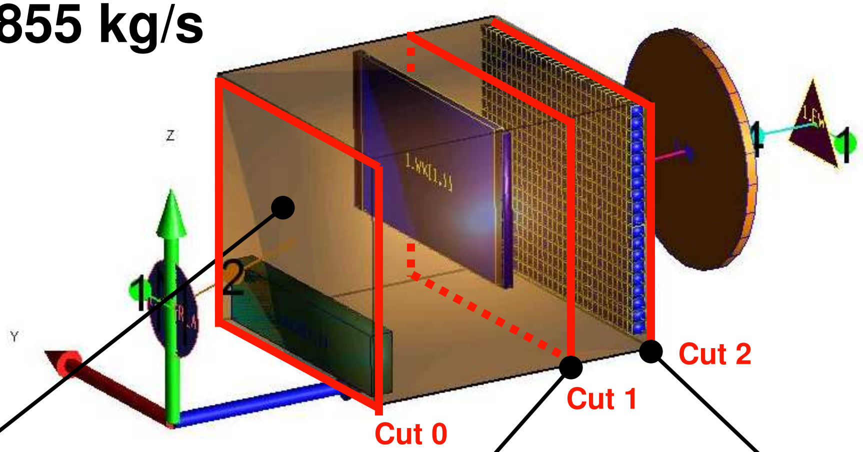
MRF 1960 rpm

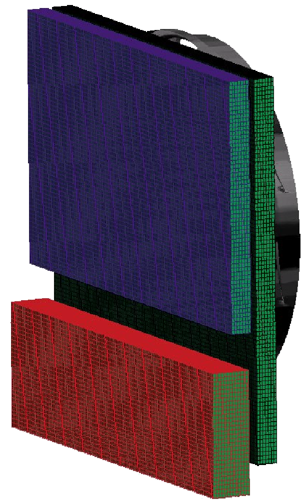
Velocity Profile: Cooling Package

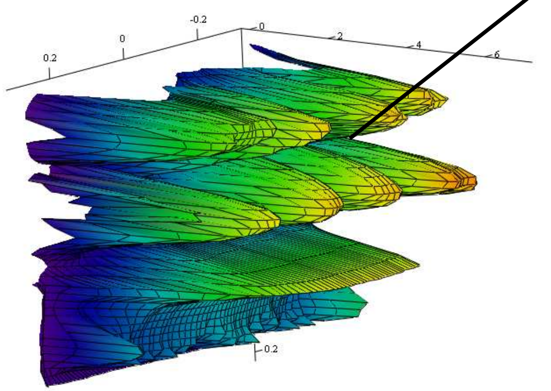
Point A:

Constant Mass Flow = 0.855 kg/s

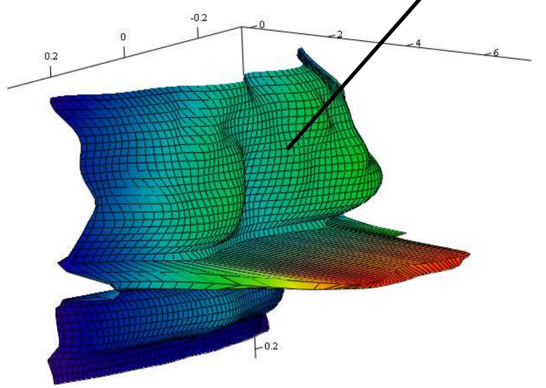
MRF 1960rpm



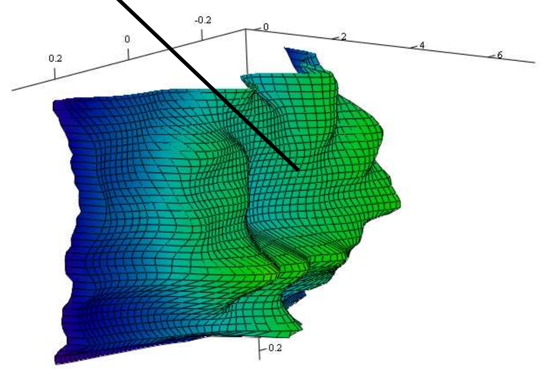




Cut 0: 10mm in front of charge air cooler

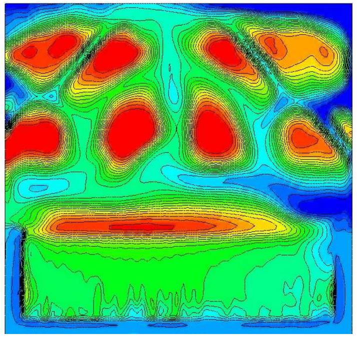
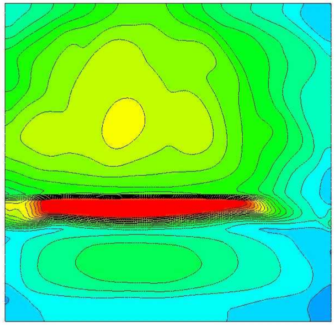
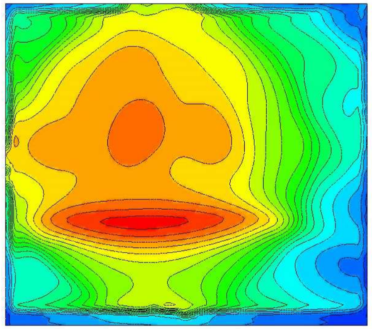
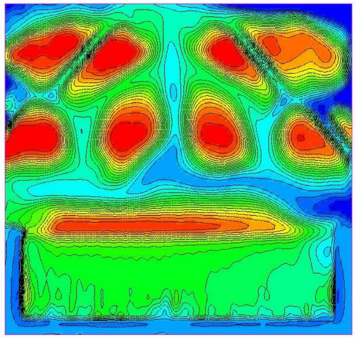
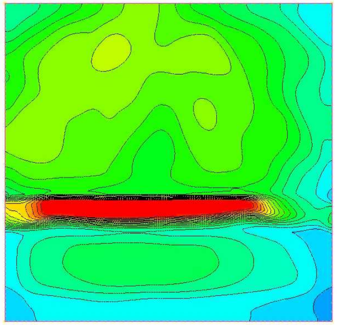
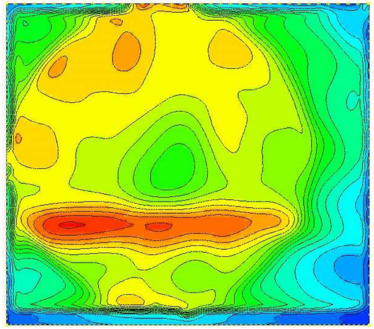
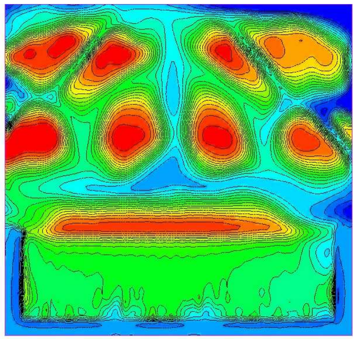
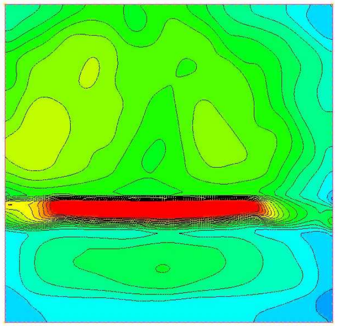
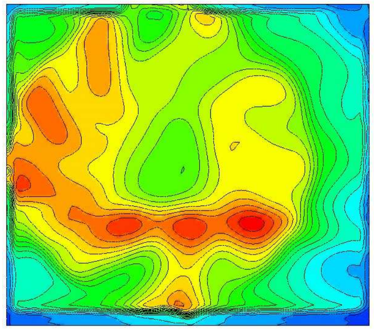


Cut 1: in between condenser and radiator



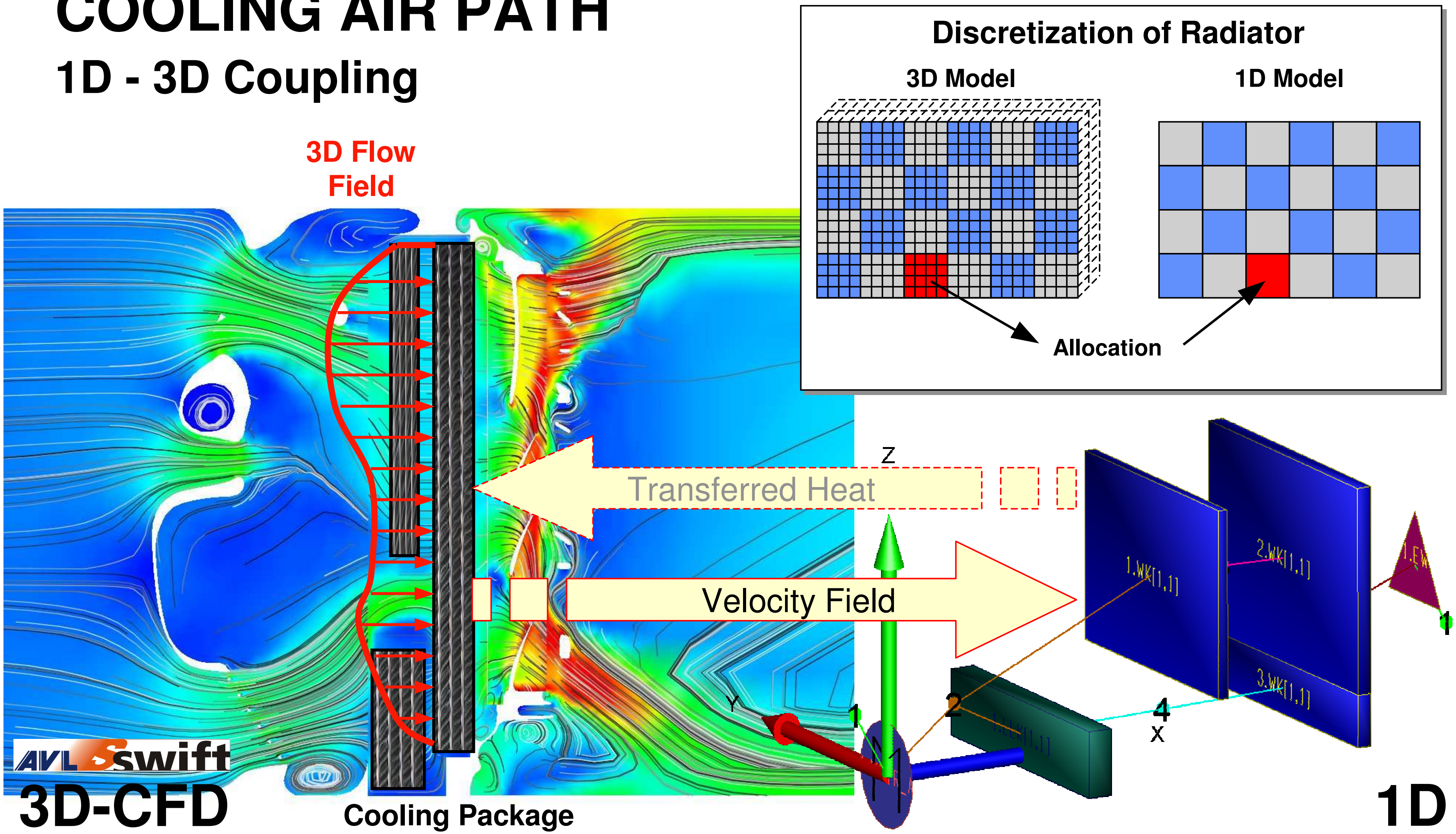
Cut 2: 10 mm behind of radiator

Velocity Profiles: CFD Fan Modeling

	Front of Cooling Package	Front of Radiator	Behind Radiator
User Function			
Blocked Fan			
MRF			

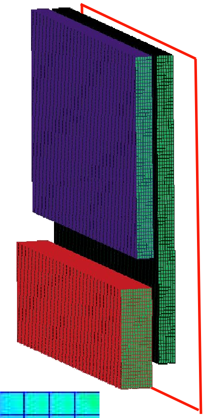
COOLING AIR PATH

1D - 3D Coupling

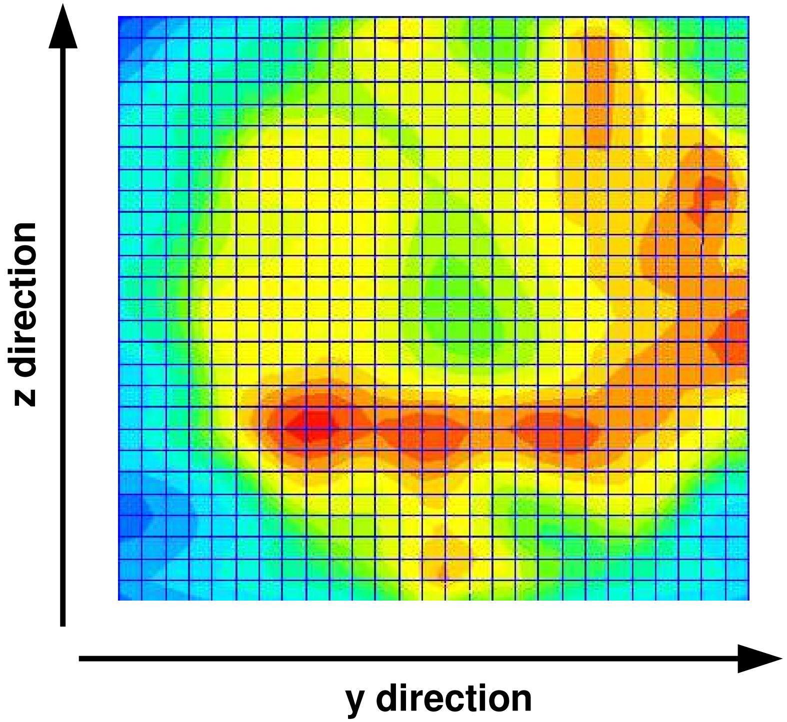


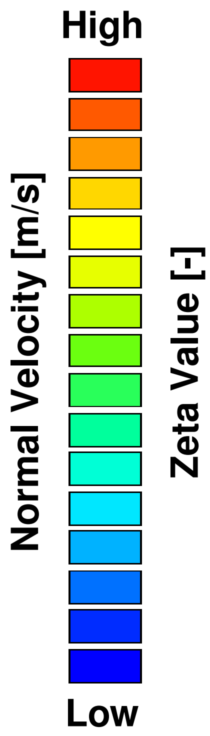
Resistance Matrix in KULI

1D-3D Interface: Cross Section at Radiator Outlet

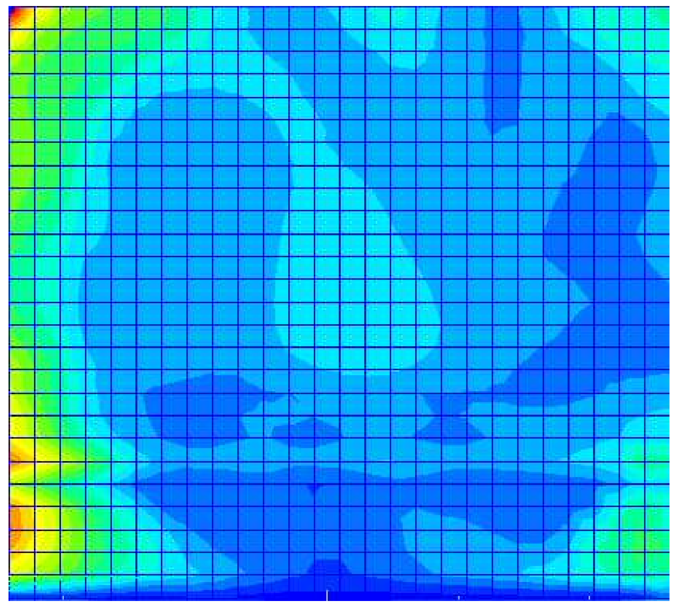


- 3D Flow Field from CFD





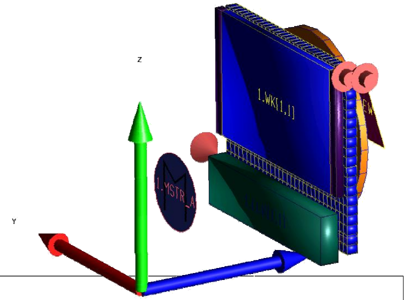
- Resistance Matrix in KULI

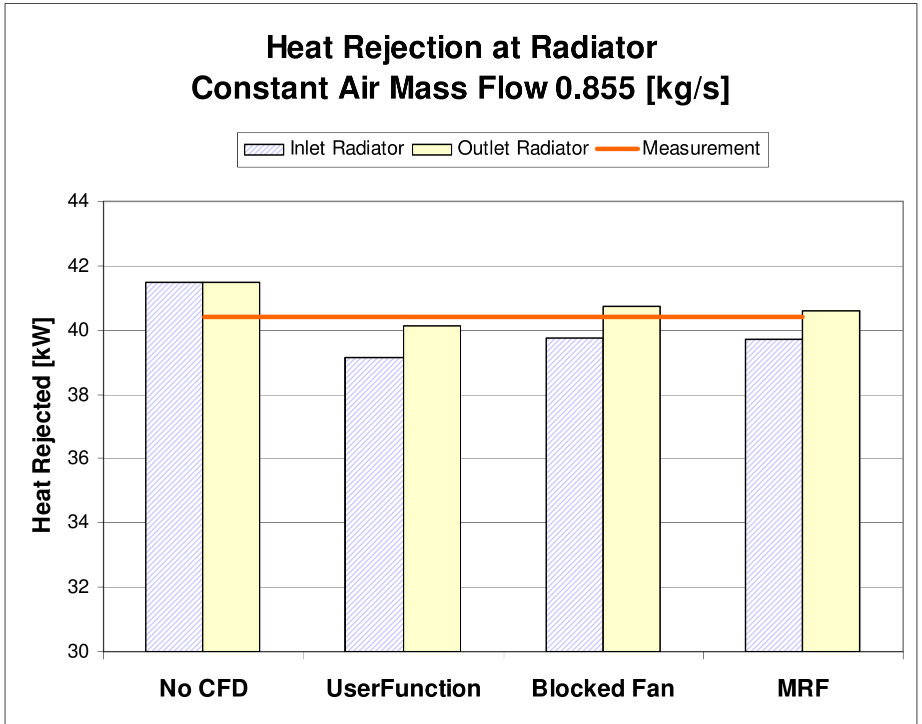


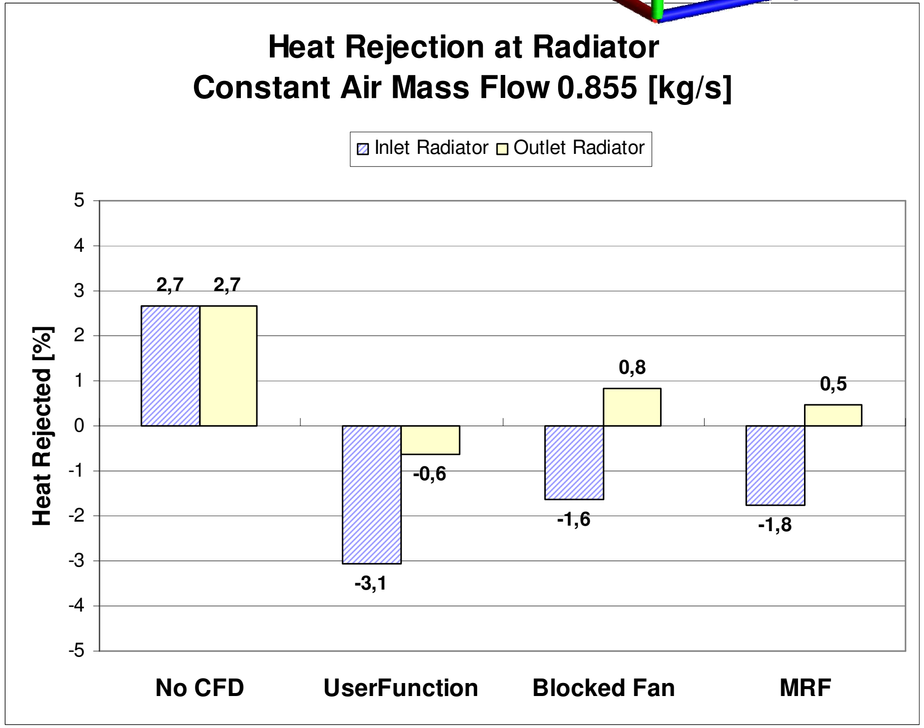
Heat Rejection in Dependency of Velocity Profile

Point A:

Fan Speed: 1960 rpm
Constant Mass Flow: 0.855 kg/s





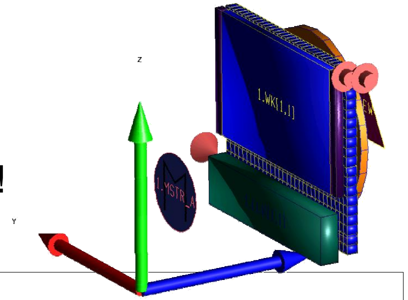


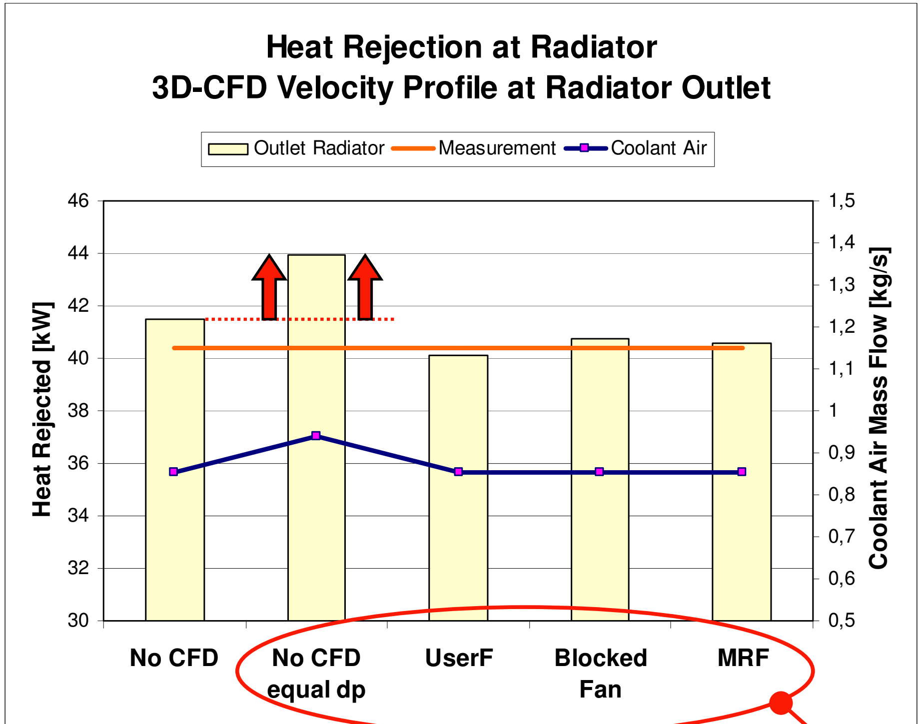
Heat Rejection in Dependency of Velocity Profile & Equal Delta p

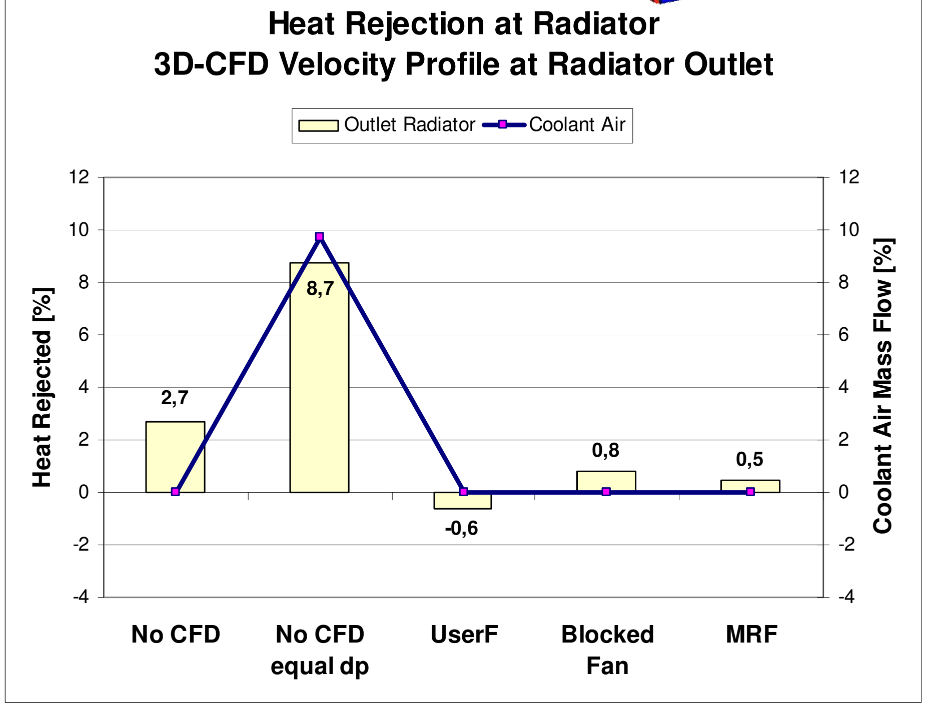
Point A:

Fan Speed: 1960 rpm

Air mass flow in KULI adapted according to air side pressure loss from MRF calculation !







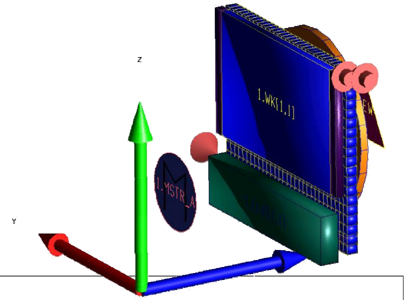
Air Side Pressure Loss Cooling Package [Pa]				
125	135	132	133	135

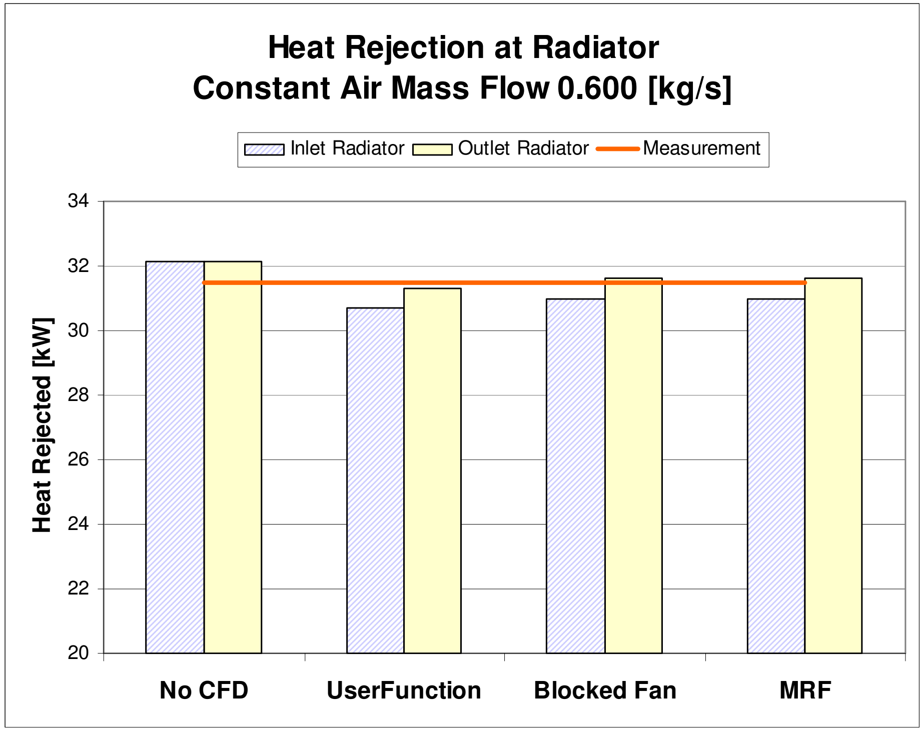
equal pressure loss

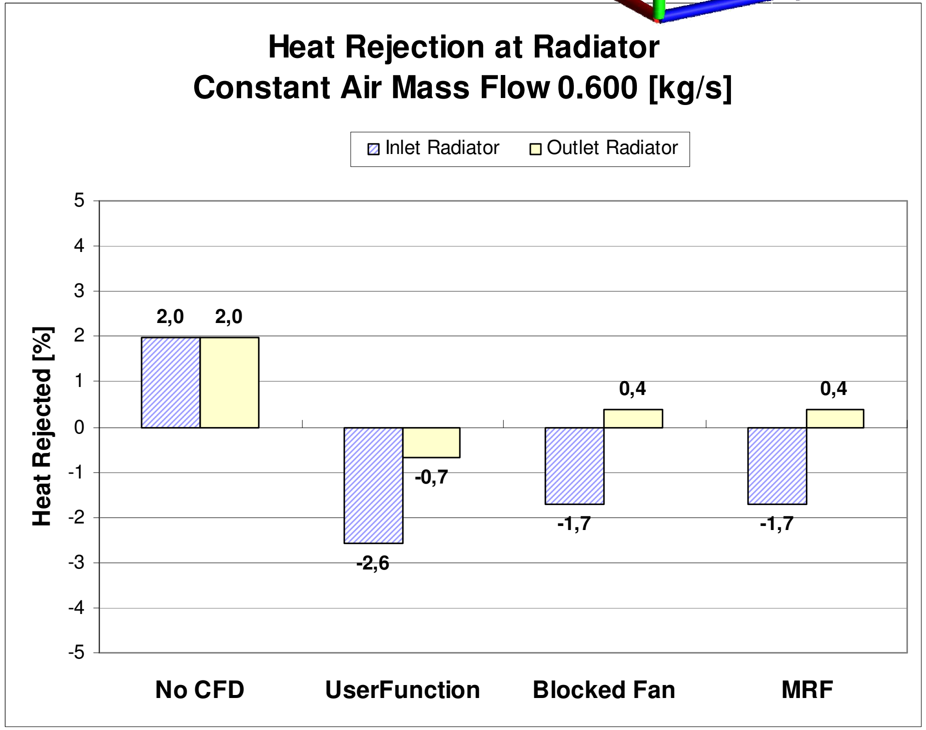
Heat Rejection in Dependency of Velocity Profile

Point B:

Fan Speed: 980 rpm
Constant Mass Flow: 0.600 kg/s







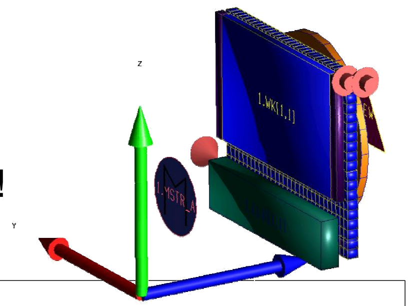
Heat Rejection in Dependency of Velocity Profile & Equal Delta p

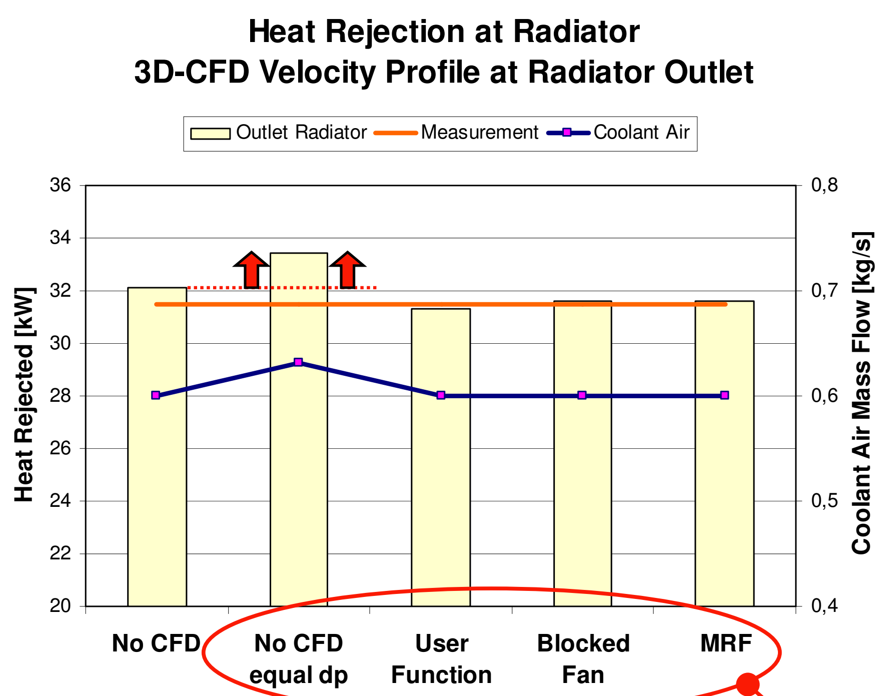
AVL

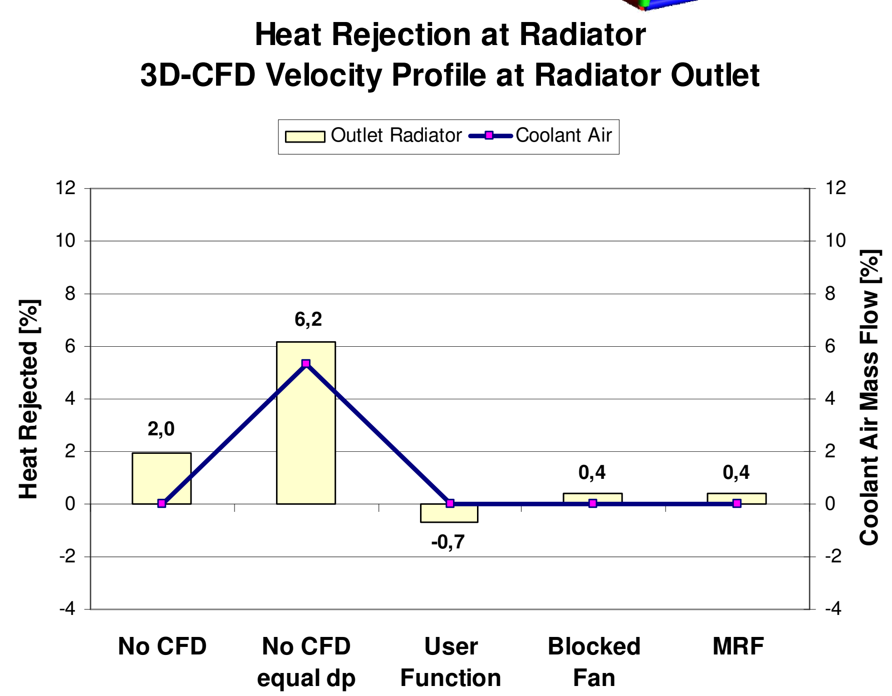
Point B:

Fan Speed: 980 rpm

Air mass flow in KULI adapted according to air side pressure loss from MRF calculation !







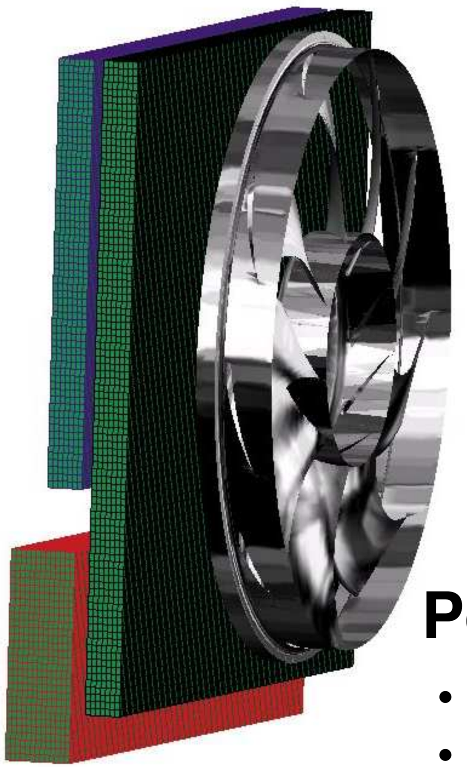
Air Side Pressure Loss Cooling Package [Pa]				
71	**80**	79	80	**80**

equal pressure loss

Sensitivity Analysis:

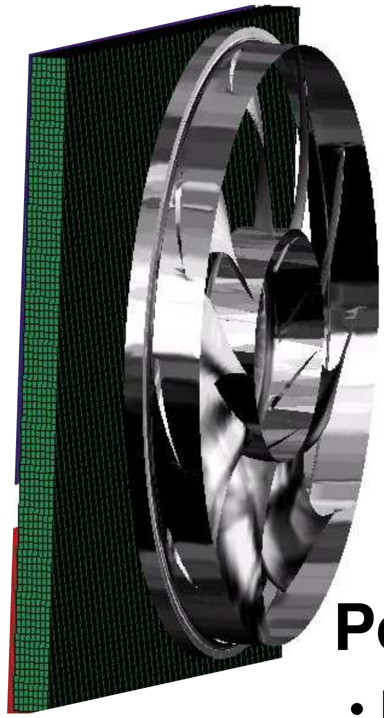
Blocking influence in the upstream direction of the fan

Fan Speed: 1960 rpm



Porosities

- Charge Air Cooler
- Condenser
- Radiator

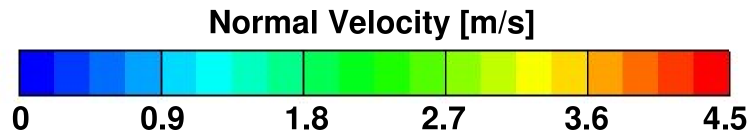


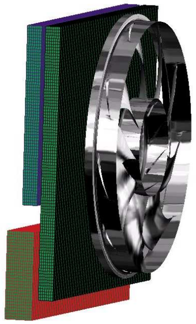
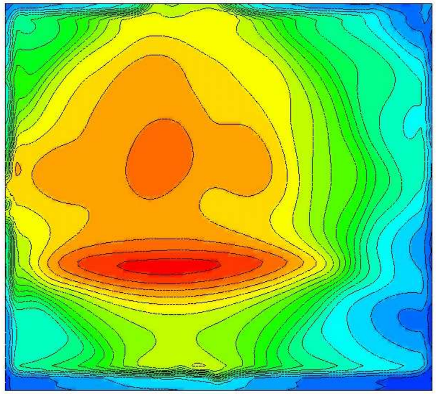
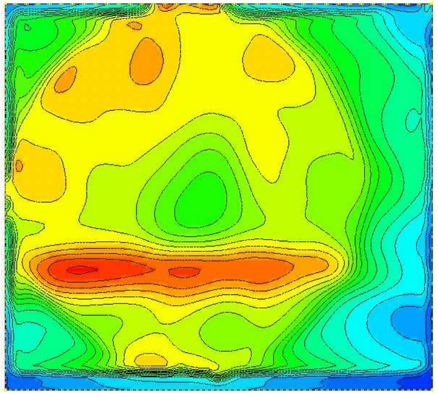
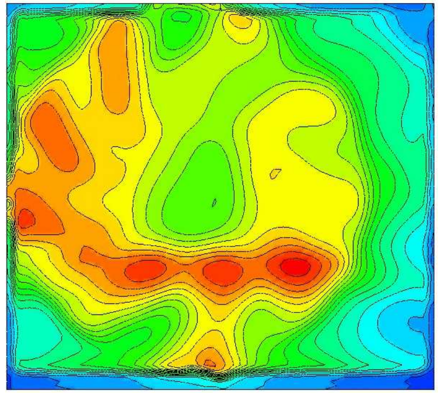
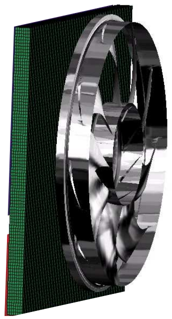
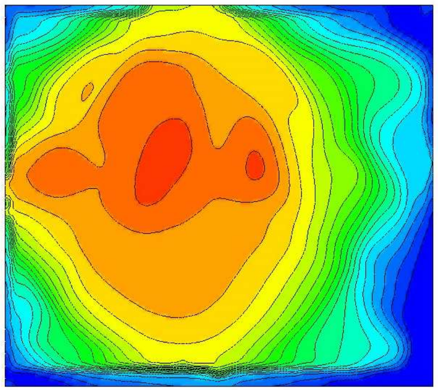
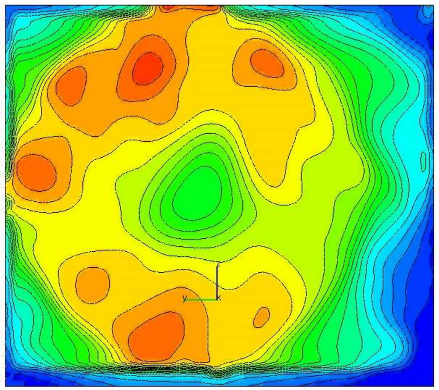
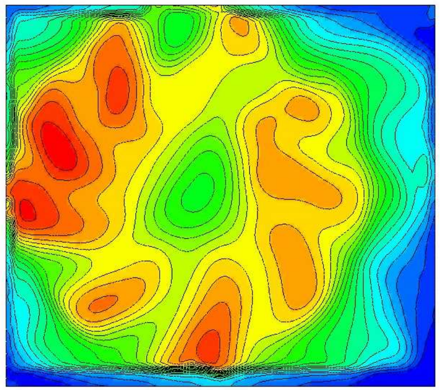
Porosities

- Radiator only

Blocking Influence: Velocity Profile

Point A:
Constant Mass Flow = 0.855 kg/s

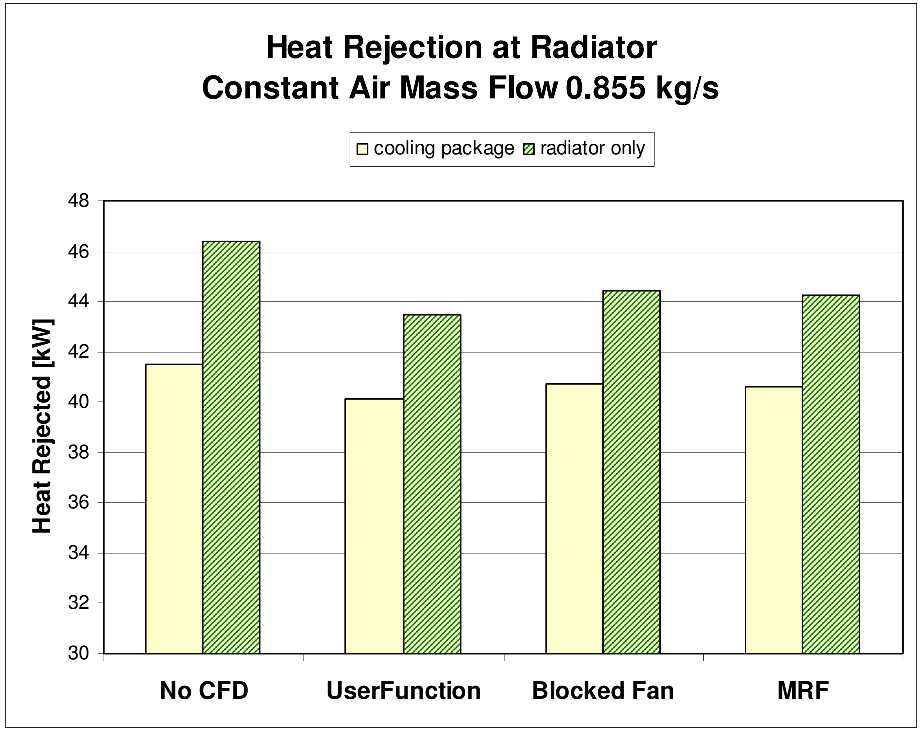


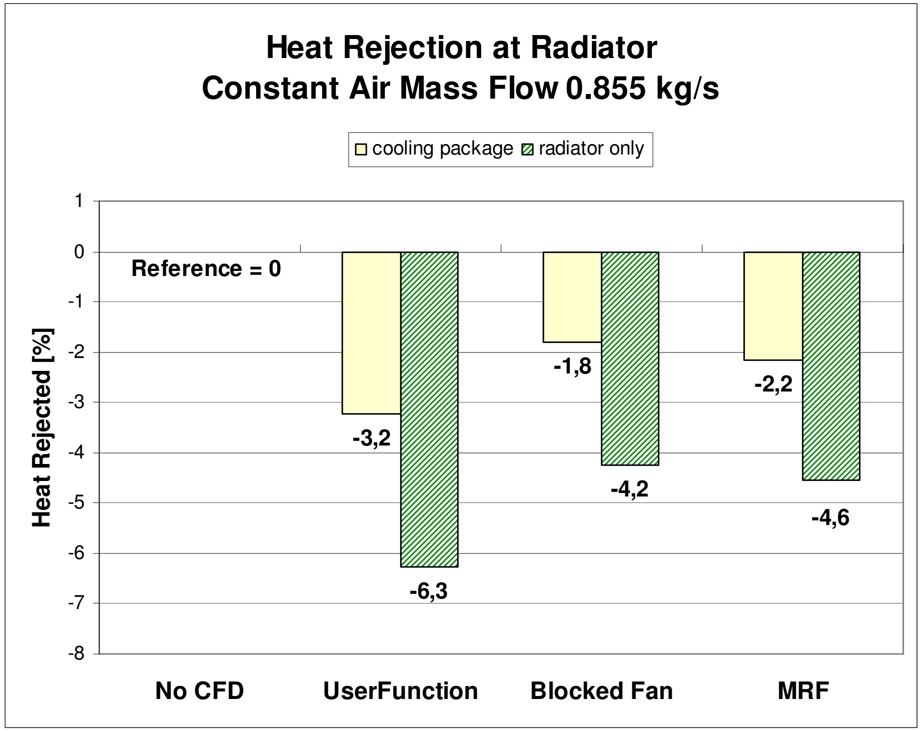
	User Function	Blocked Fan	MRF
 Cooling Package			
 Radiator Only			

Blocking Influence: Heat Rejection

Point A:

Constant Mass Flow = 0.855 kg/s





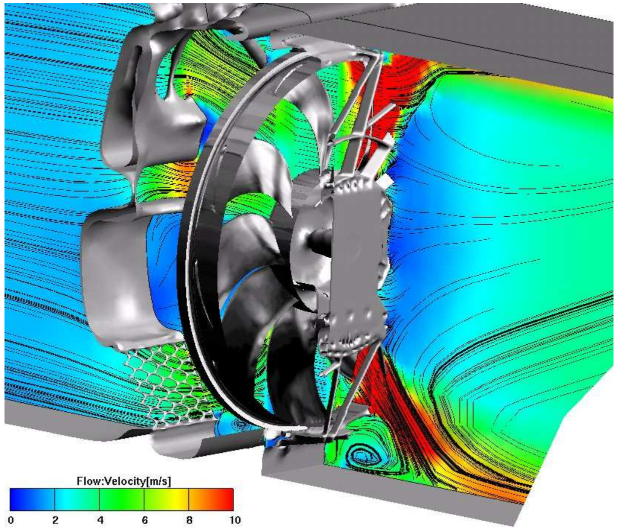
No upstream blocking → Stronger influence of the fan driven velocity profile

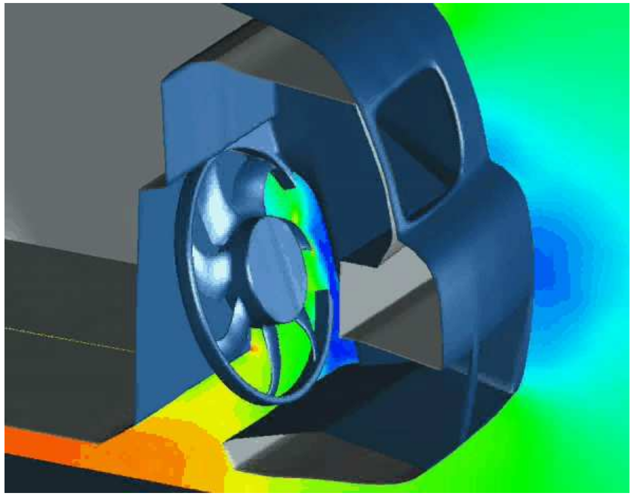
Summary and Conclusions

- Inhomogeneous flow situation leads to higher pressure drop → lower air mass flow → less heat rejection (up to ~10%)
- For a given air mass flow the differences in heat rejection, due to pure inhomogeneity, are of less importance!
- For real life application, where the mass flow is unknown, the integration of CFD is highly recommended to determine accurate predictions for mass flow and heat rejection!
- MRF resolves fan geometry and leads to realistic flow conditions at acceptable computing costs
- Downstream influence of fan driven effects much more significant than upstream → important for under hood analysis

Outlook

- **Prediction of the coolant air mass flow and its achievable accuracy**
  - total and static pressure boundary conditions
  - comparison among fan modeling techniques
- **Sliding mesh technique**
  - achievable benefits
- **Effects of downstream blocking and its predictability by CFD fan models**
  - modeling of engine block and other flow obstacles under the hood






Thank you for your attention!