INTEGRATED DESIGN ANALYSIS GmbH InDesA

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On the Performance Prediction of Automotive Cooling Fans and Coolant Pumps

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Company Profile

INTEGRATED DESIGN ANALYSIS GmbH **InDesA**

Consulting- &
Engineering Services

Simulation and Analysis
of complex fluid flow and heat transfer systems
for engineering and industrial applications

- **Vehicle Thermal Management**
- **Engine Thermal Management**
- **Electronics & Battery Thermal Management**
- **Heat Exchanger Thermal Analysis**
- **Turbomachinery Flow and Thermal Analysis**

  and more …

3D CFD/CHT Analysis

STAR-CCM+

1D System Analysis

GT-SUITE

InDesA Virtual Test Center

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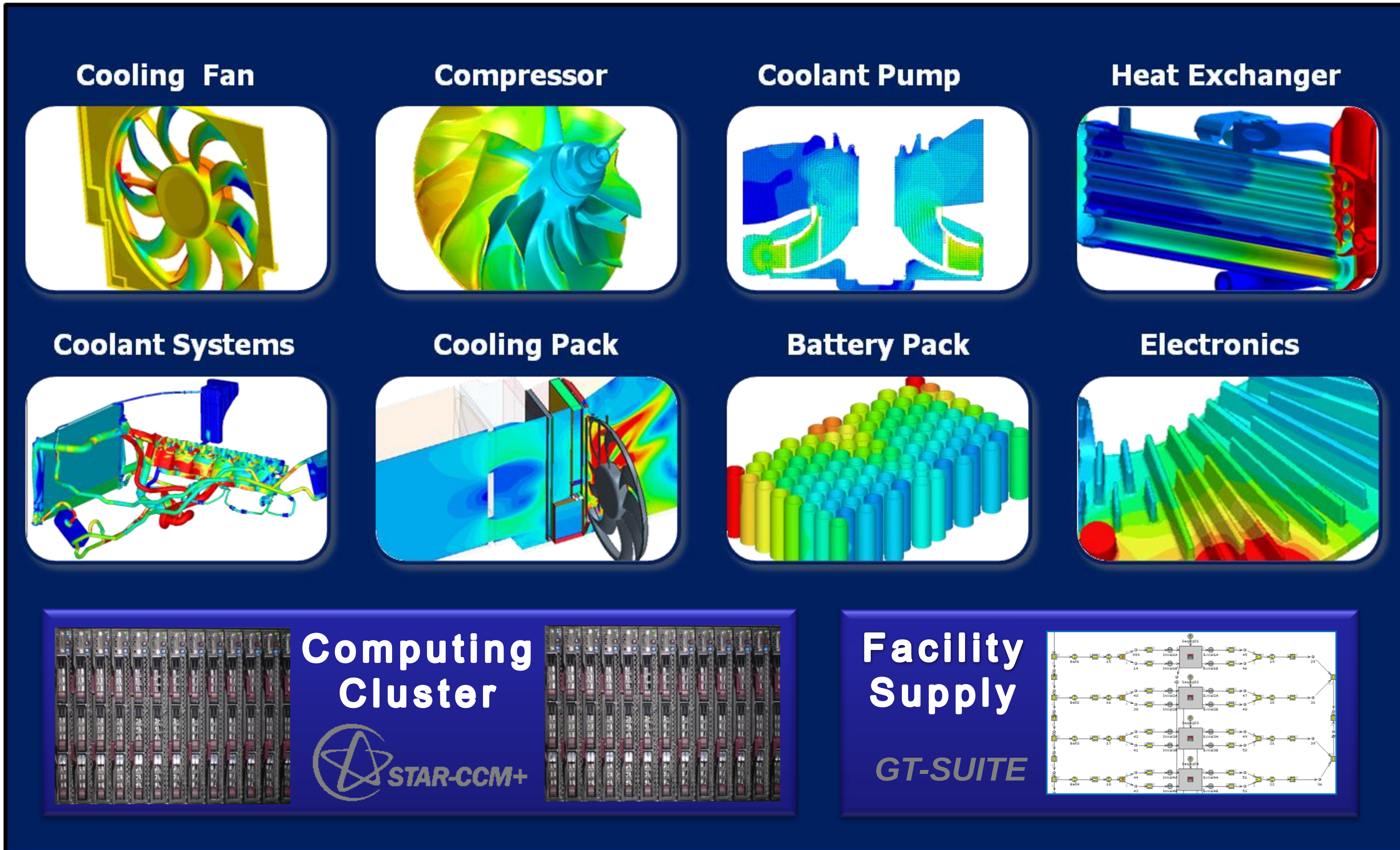
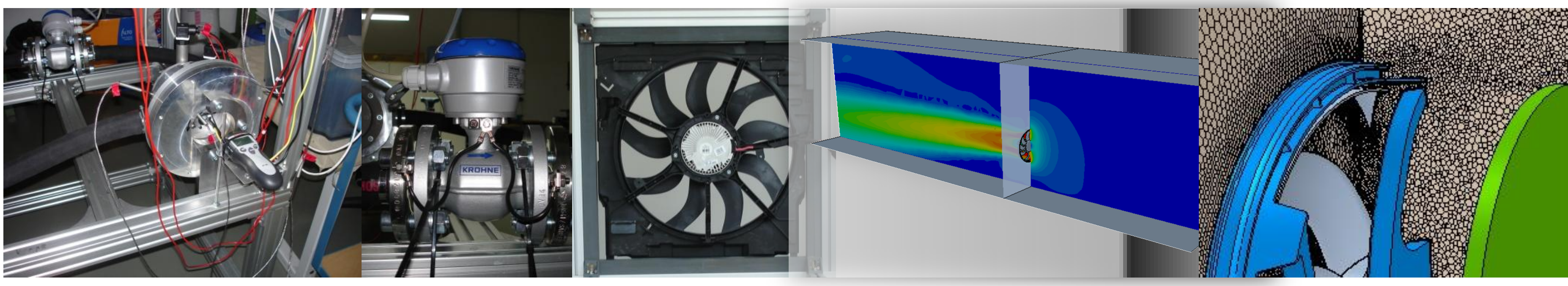
Virtual Test Bench
InDesA Virtual Test Facility Center



Virtual Test Bench

Motivation



Test Bench:

High technical level/equipment
Large amount of space
Prototypes (high costs)
Time Scheduling (low flexibility)
Accuracy in planning
Shortly unavailable after dismounting

Measurement of physical entity
Restricted (Bench) Conditions

Virtual Test Bench:

High technical level/knowledge
Computing resources
CAD Designs (low costs)
Short Time Scheduling (high flexibility)
Supplementary analysis possible
Shortly available every time

Simulation of virtual entity
Easley upgrade to “real” operation

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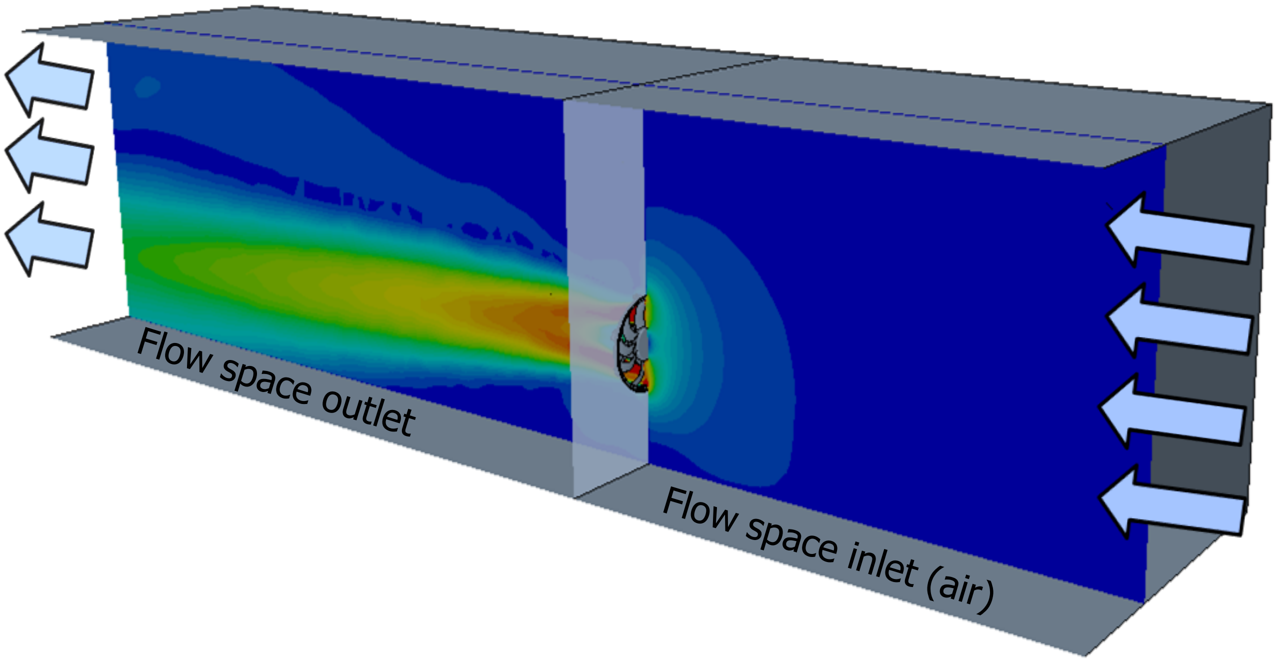
Virtual Test Bench
Geometry of Cooling Fan Test Bench



Geometry
- Fan is integrated in standardized frame within virtual test bench
- 3 simulation setups have been considered in order to investigate the influence of the fan on total pressure

Case Definition and Boundary Conditions
- 5 simulations for each geometric setup have been performed
- Rotational speed of fan varies from 2391 – 3055 rpm as the volumetric mass flow rate through the wind tunnel covers the range of 0.334 - 2.482 m^3/s
- Total pressure is mass flow averaged at inlet and outlet surface planes of the virtual test bench

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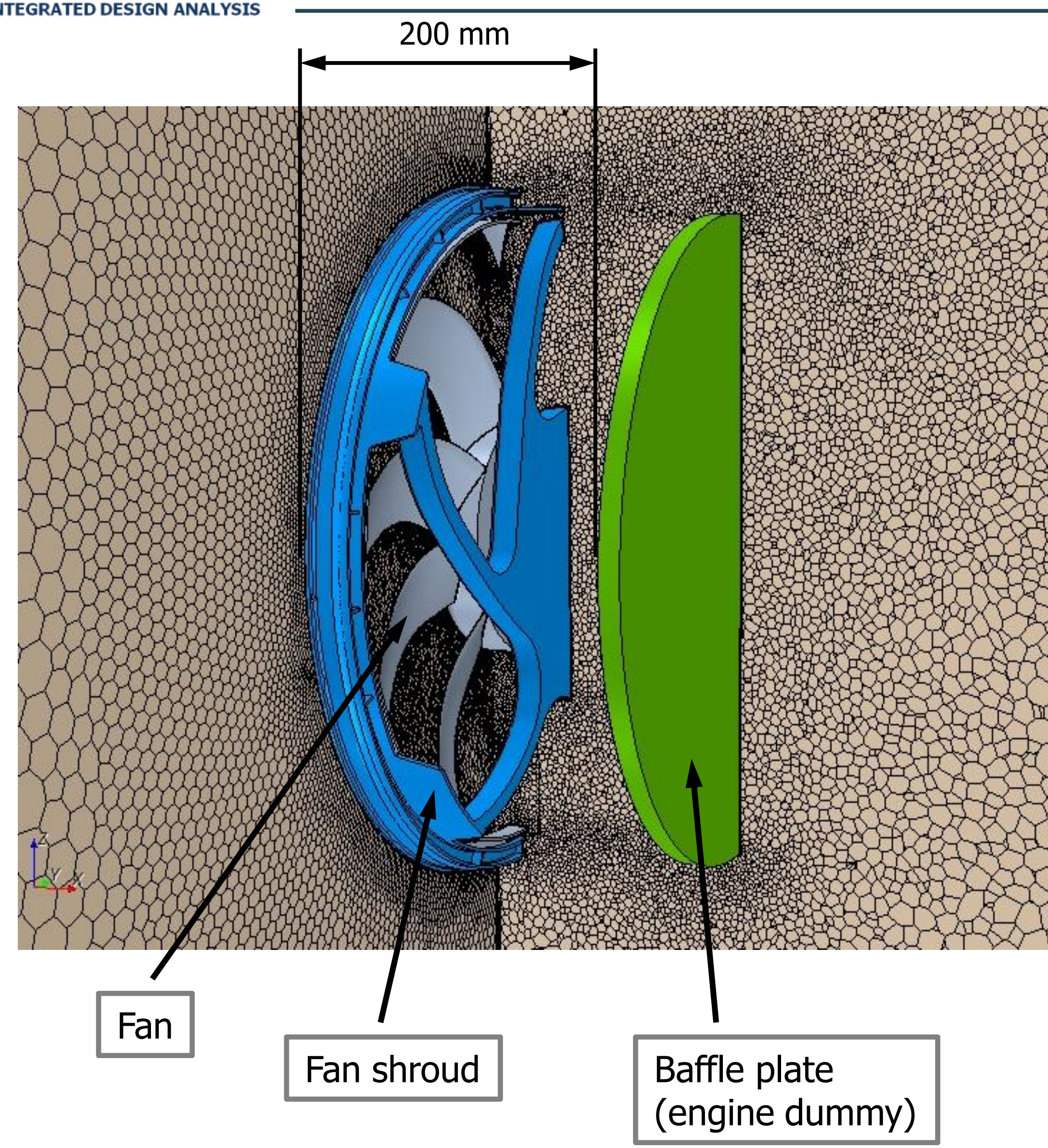
Virtual Test Bench
Fan Geometry and Baffle Position



Geometry
3 simulation setups have been considered:
i) No obstacle is placed behind fan
ii) A baffle plate is placed 200mm behind fan (as shown here)
iii) A baffle plate is placed 150mm behind fan

Mesh
- ➢ Unstructured Polyhedral mesh with wall Prism Layers
- ➢ $3.3 – 3.8 \cdot 10^6$ Volume Cells

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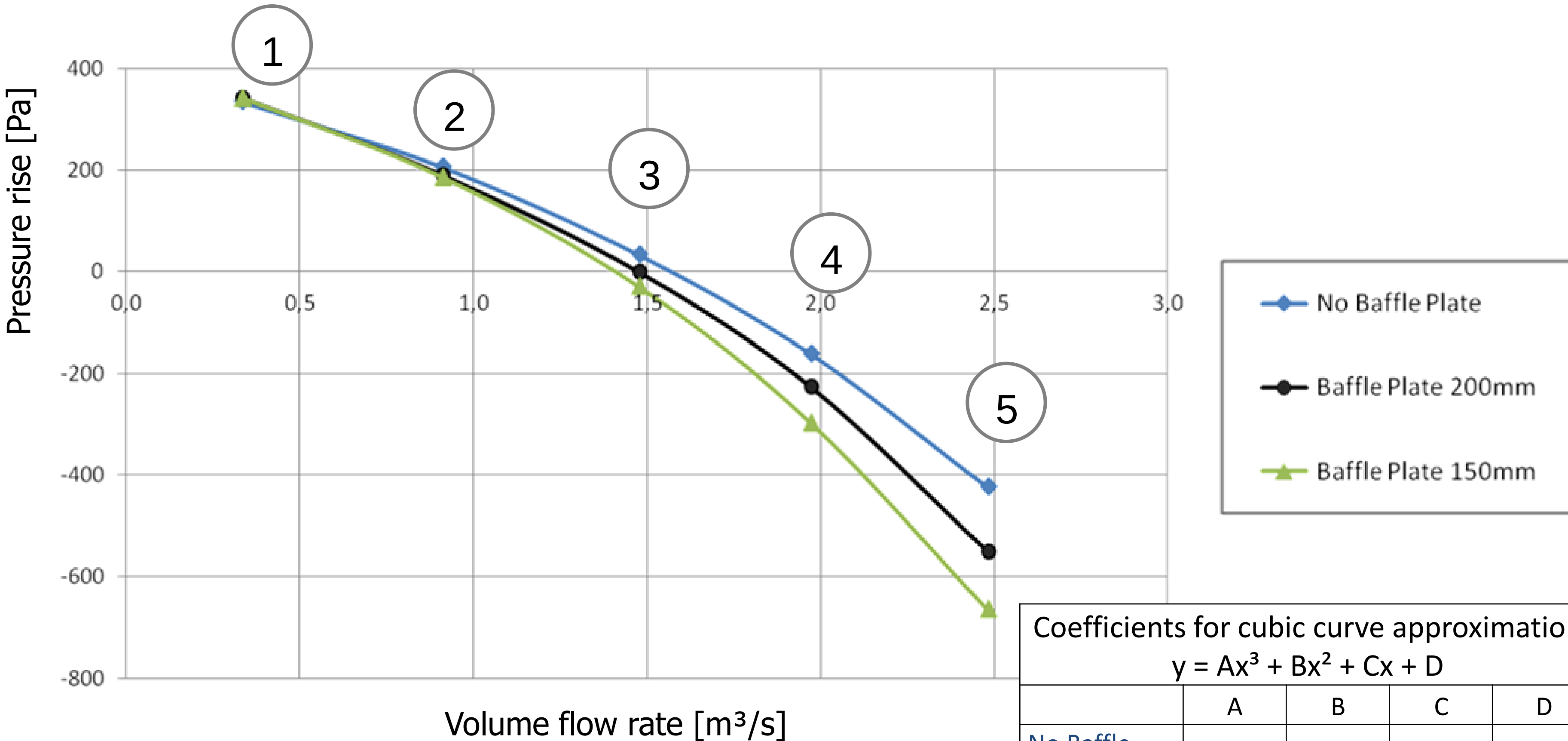
Virtual Test Bench
Fan Characteristics



Coefficients for cubic curve approximation
$y = Ax^3 + Bx^2 + Cx + D$

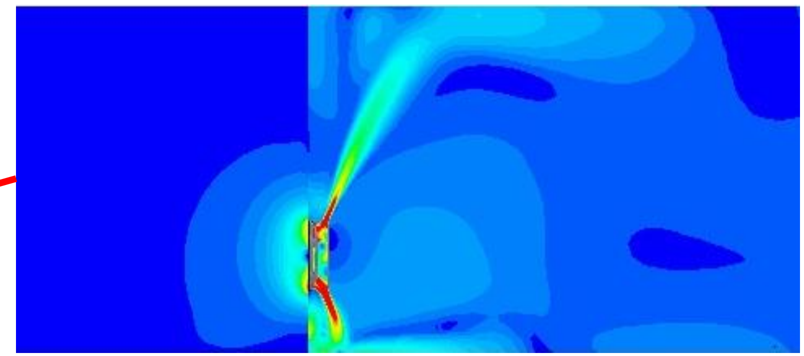
	A	B	C	D
No Baffle Plate	-14.382	-28.809	-169.6	394.61
Baffle Plate 200mm	-34.915	34.099	-263.34	426.61
Baffle Plate 150mm	-26.297	-29.442	-199.19	412.66
Test Rig	-46.91	-81.22	-99.571	462.15

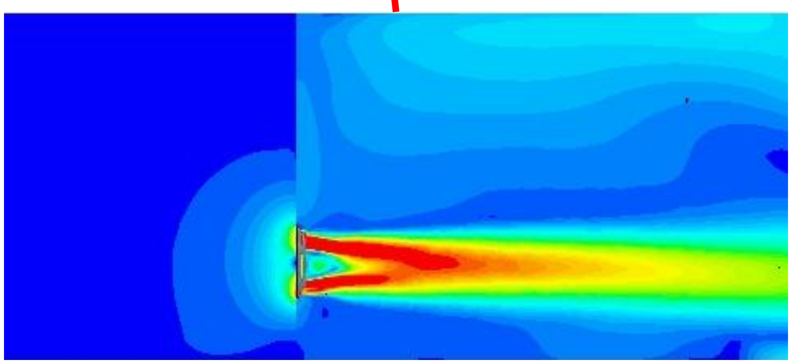
Virtual Test Bench

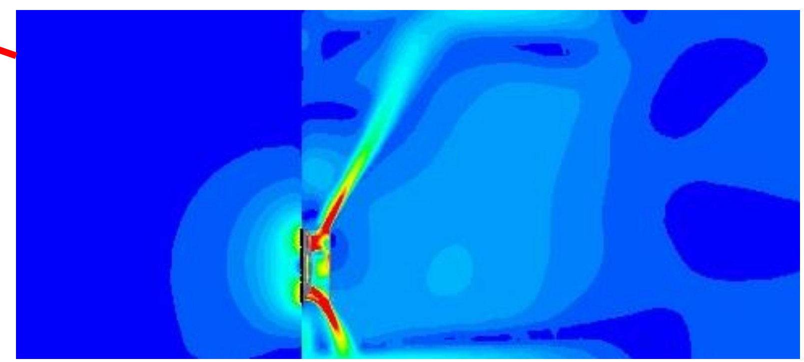
Results: Flow Field for Case 5

	Volumetric Flow Rate	Rotation Rate	No Baffle Plate	Baffle Plate 200mm	Baffle Plate 150mm	Test Rig
Case	[m^3 / s]	[rpm]	[Pa]	[Pa]	[Pa]	[Pa]
1	0.334	2391	334	341	342	420
2	0.912	2535	206	189	186	260
3	1.478	2736	33	-2	-30	0
4	1.972	2859	-161	-227	-297	-420
5	2.482	3055	-424	-551	-665	-1000

Vertical section of flow field in case of an overflowed fan







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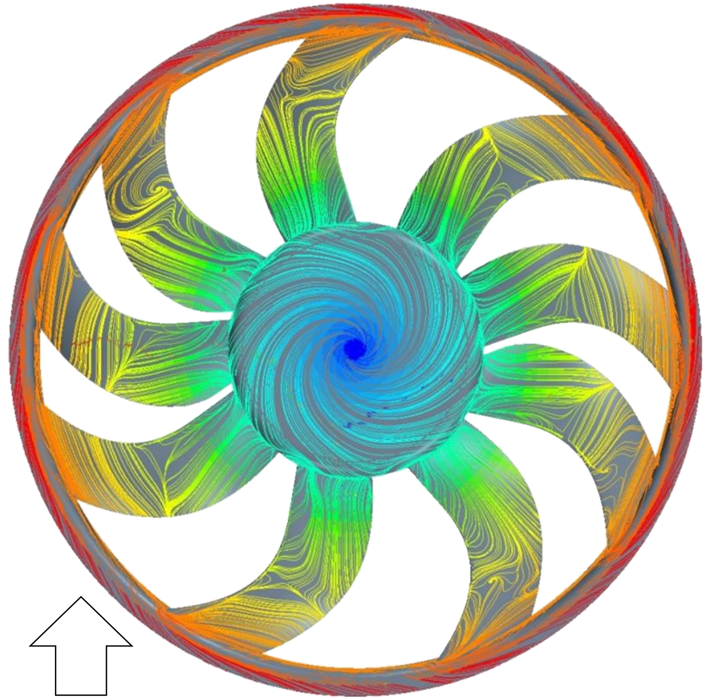
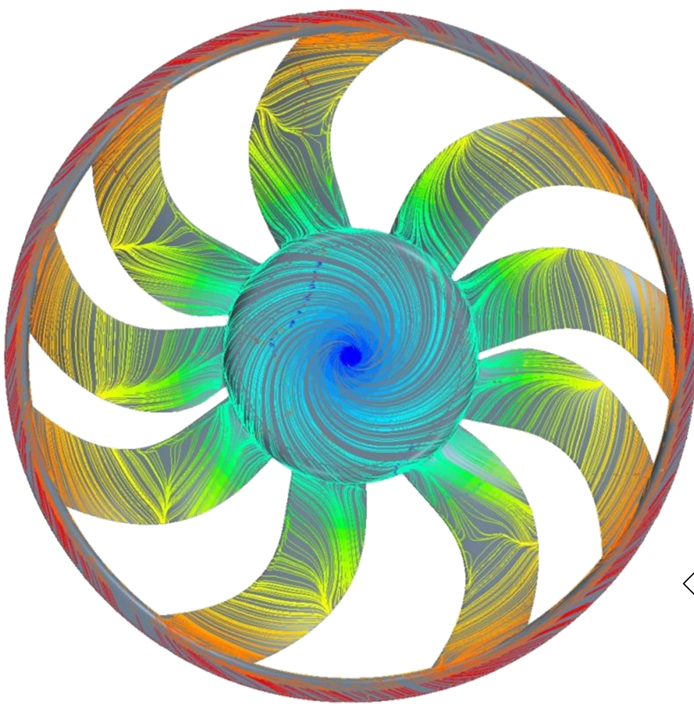
Virtual Test Bench
Results: Constrained Streamlines on Fan

	Volumetric Flow Rate	Rotation Rate	No Baffle Plate	Baffle Plate 200mm	Baffle Plate 150mm	Test Rig
Case	[m³ / s]	[rpm]	[Pa]	[Pa]	[Pa]	[Pa]
1	0.334	2391	334	341	342	420
2	0.912	2535	206	189	186	260
3	1.478	2736	33	-2	-30	0
4	1.972	2859	-161	-227	-297	-420
5	2.482	3055	-424	-551	-665	-1000



Constrained streamlines on the front of the fan indicates a severe stall of flow in particular in cases of low fan efficiency (e.g. case 1)



In cases of higher fan efficiency, the constrained streamlines show less stall (e.g. case 2)

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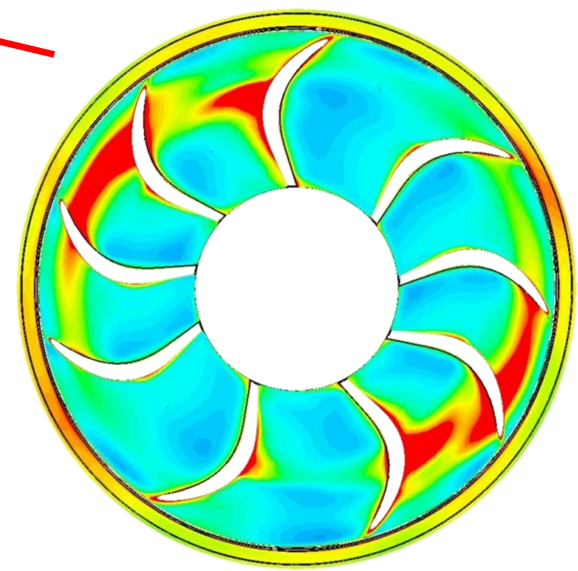
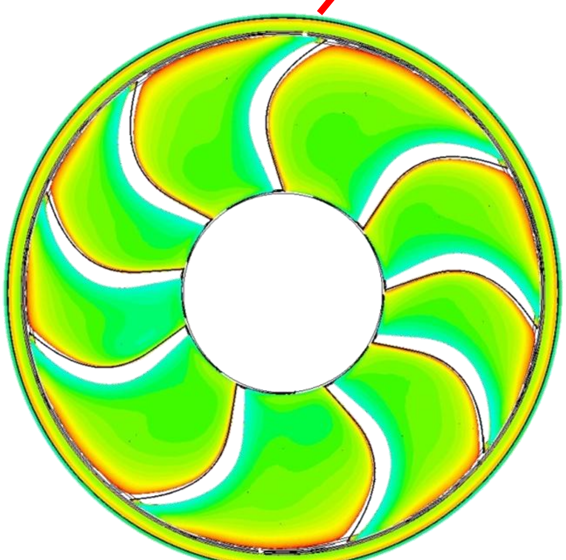
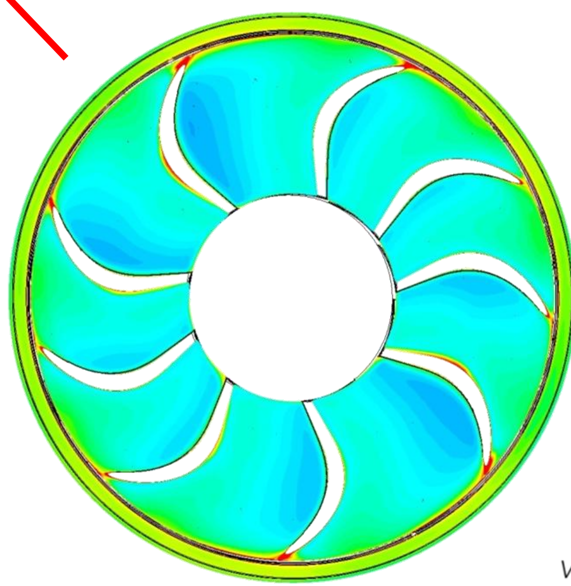
Virtual Test Bench
Results: Flow Field

	Volumetric Flow Rate	Rotation Rate	No Baffle Plate	Baffle Plate 200mm	Baffle Plate 150mm	Test Rig
Case	[m³ / s]	[rpm]	[Pa]	[Pa]	[Pa]	[Pa]
1	0.334	2391	334	341	342	420
2	0.912	2535	206	189	186	260
3	1.478	2736	33	-2	-30	0
4	1.972	2859	-161	-227	-297	-420
5	2.482	3055	-424	-551	-665	-1000

Vertical section of flow field through the fan shows the stalled flow in case 1, whereas higher fan efficiency (case 2) and high mass flow rate (case 5) leads to a more uniform flow field







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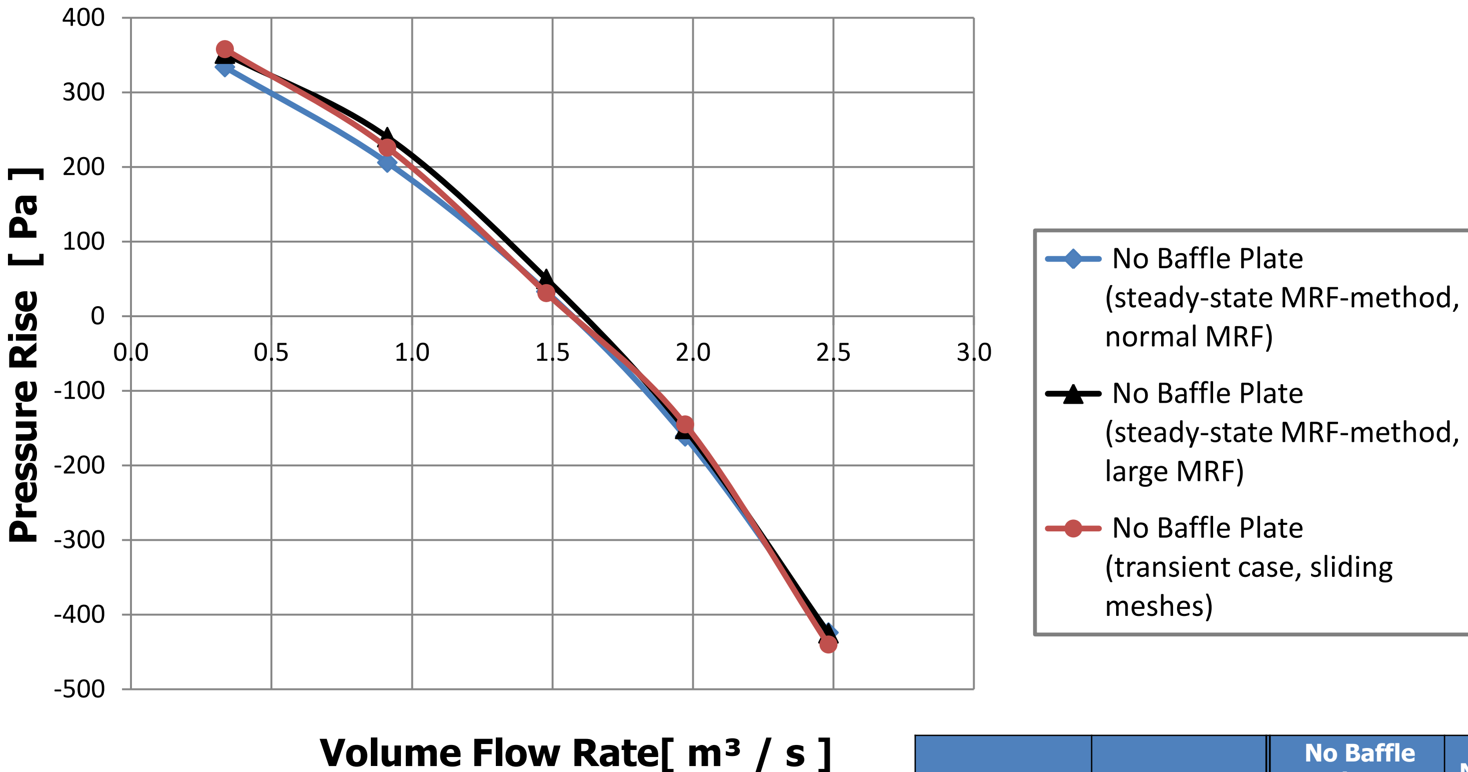
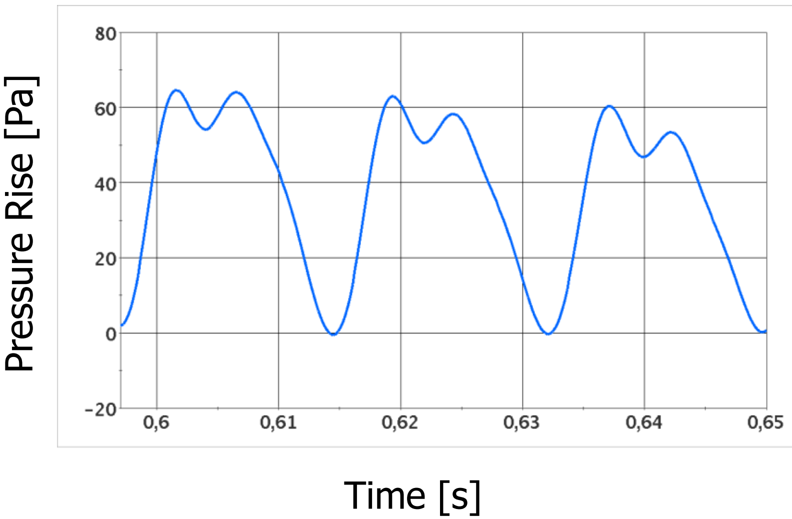
Virtual Test Bench
Comparison between methods

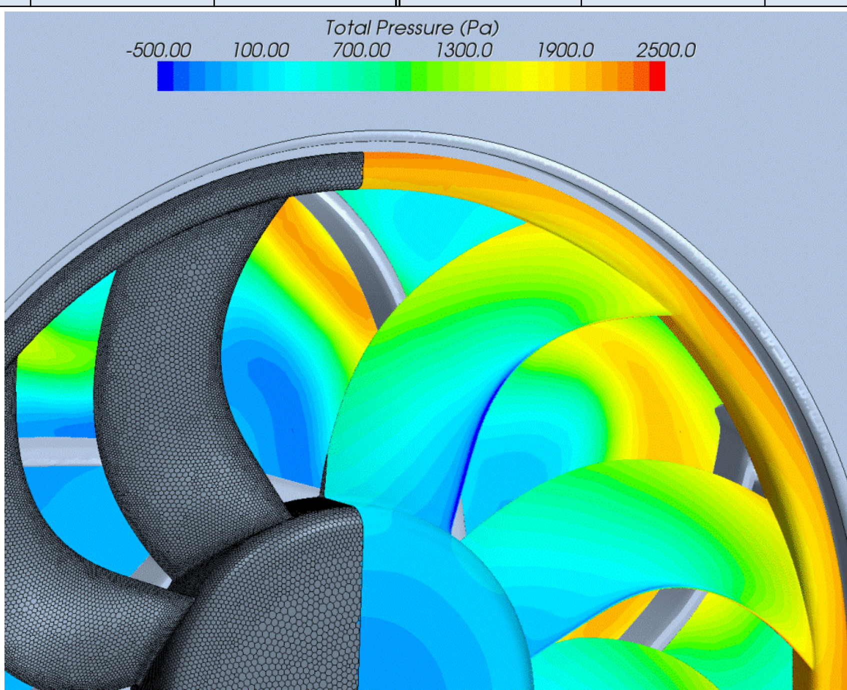


	Volumetric Flow Rate	Rotation Rate	No Baffle Plate (steady-state MRF-method, normal MRF)	No Baffle Plate (steady-state MRF-method, large MRF	No Baffle Plate (transient case, sliding meshes)
Case	[m³ / s]	[rpm]	[Pa]	[Pa]	[Pa]
1	0.334	2391	334	352	358
2	0.912	2535	206	240	226
3	1.478	2736	33	50	31
4	1.972	2859	-161	-151	-145
5	2.482	3055	-424	-425	-440

Virtual Test Bench
Fan characteristics

	Volumetric Flow Rate	Rotation Rate	No Baffle Plate (steady-state MRF-method)	No Baffle Plate (transient case, sliding meshes)	Test Rig
Case	[m³ / s]	[rpm]	[Pa]	[Pa]	[Pa]
1	0.334	2391	334	358	420
2	0.912	2535	206	226	260
3	1.478	2736	33	31	0
4	1.972	2859	-161	-145	-420
5	2.482	3055	-424	-440	-1000





- Unsteady calculations with sliding meshes delivers fluctuating characteristics for the pressure rise; corresponding pressure-values are averaged here.
- The averaged pressure rise with sliding meshes compared to the steady-state calculations is larger in case of pressure build up (case 1).
- In the transit case (case 3) the results of both methods are similar.
- In case of an overblown fan (case 5) the pressure drop with sliding meshes slightly increases.
- In conclusion, the much more costly method with a truly moving fan provides slightly different fan characteristics than the steady-state MRF-method.
- Results with sliding meshes are supposably of higher quality, especially in case of pressure build-up.

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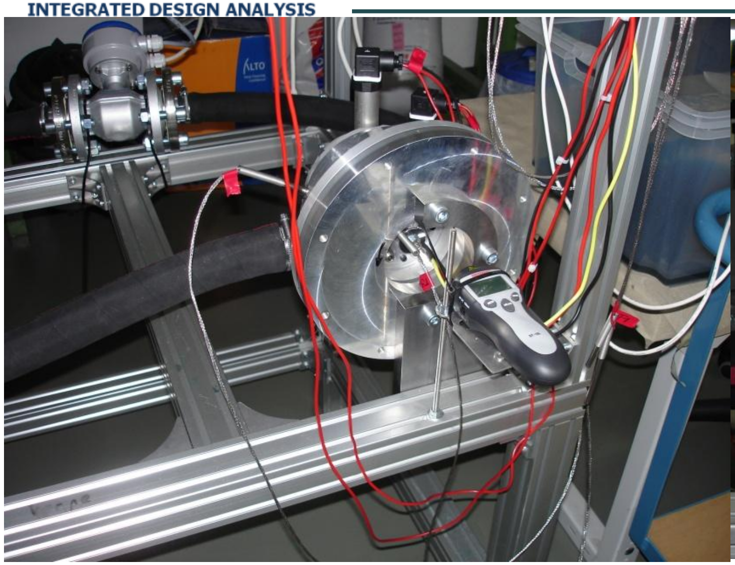
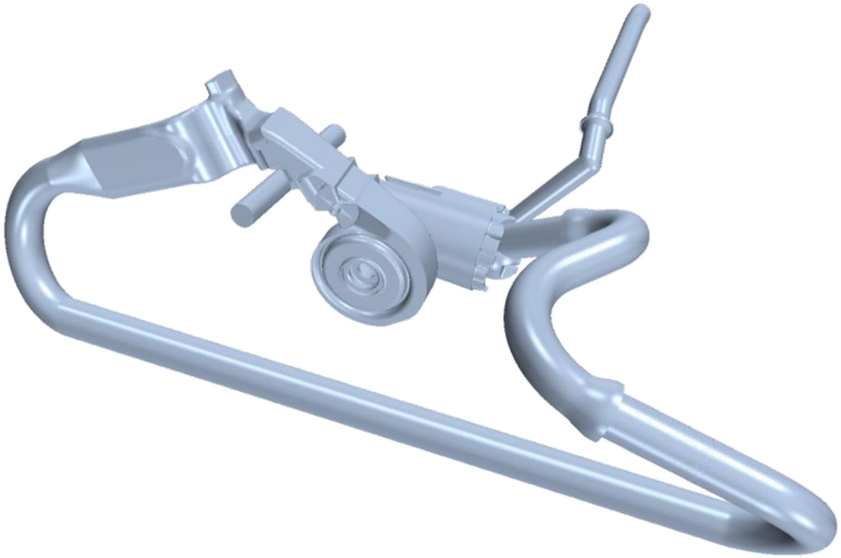
Virtual Test Bench
Water Pump Test Bench





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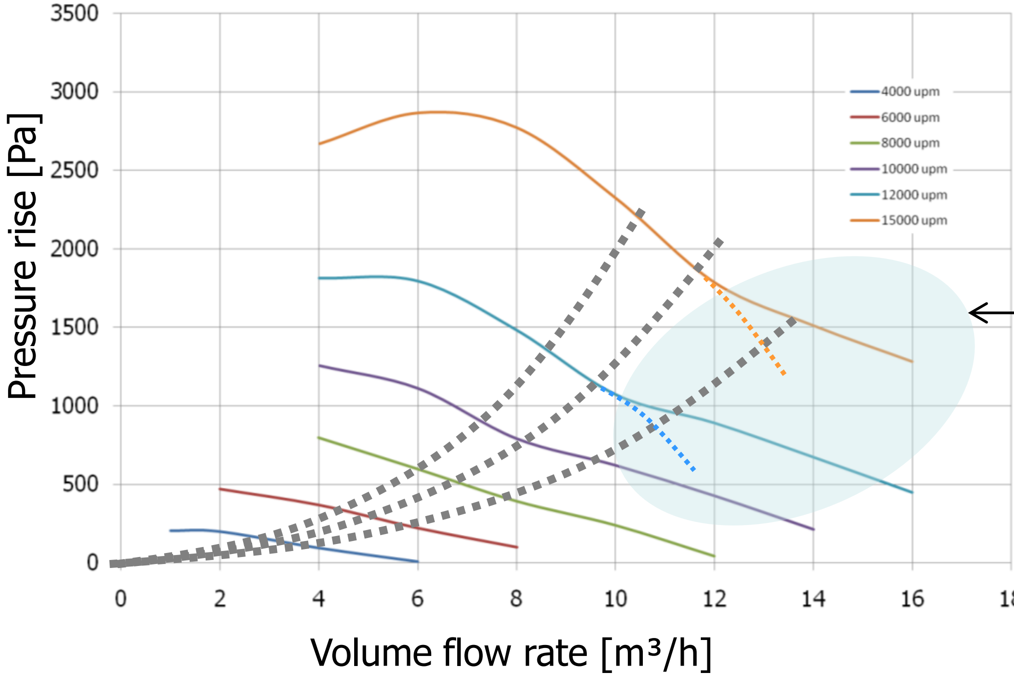
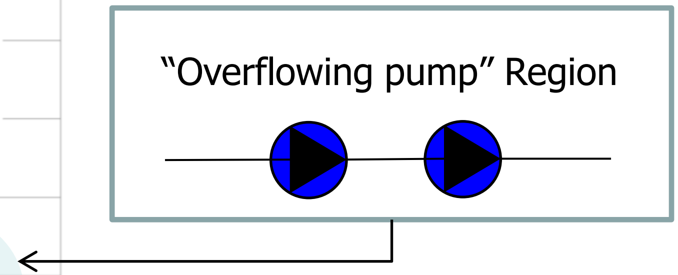
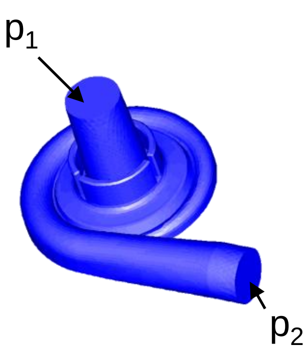
Virtual Test Bench
Pump Operating Field

Tipical calculated operation field





System Characteristic



Several Measured the intersection between System-Resistence and Pump-Characteristic

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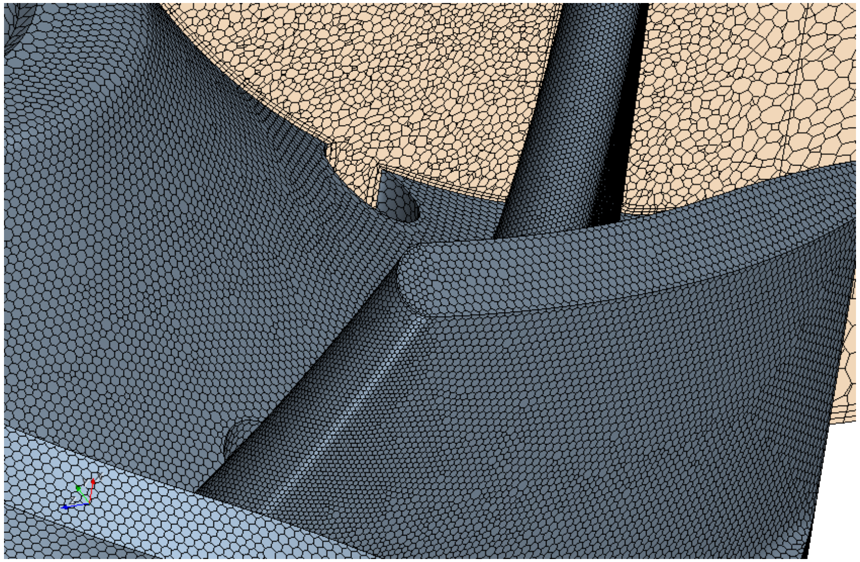
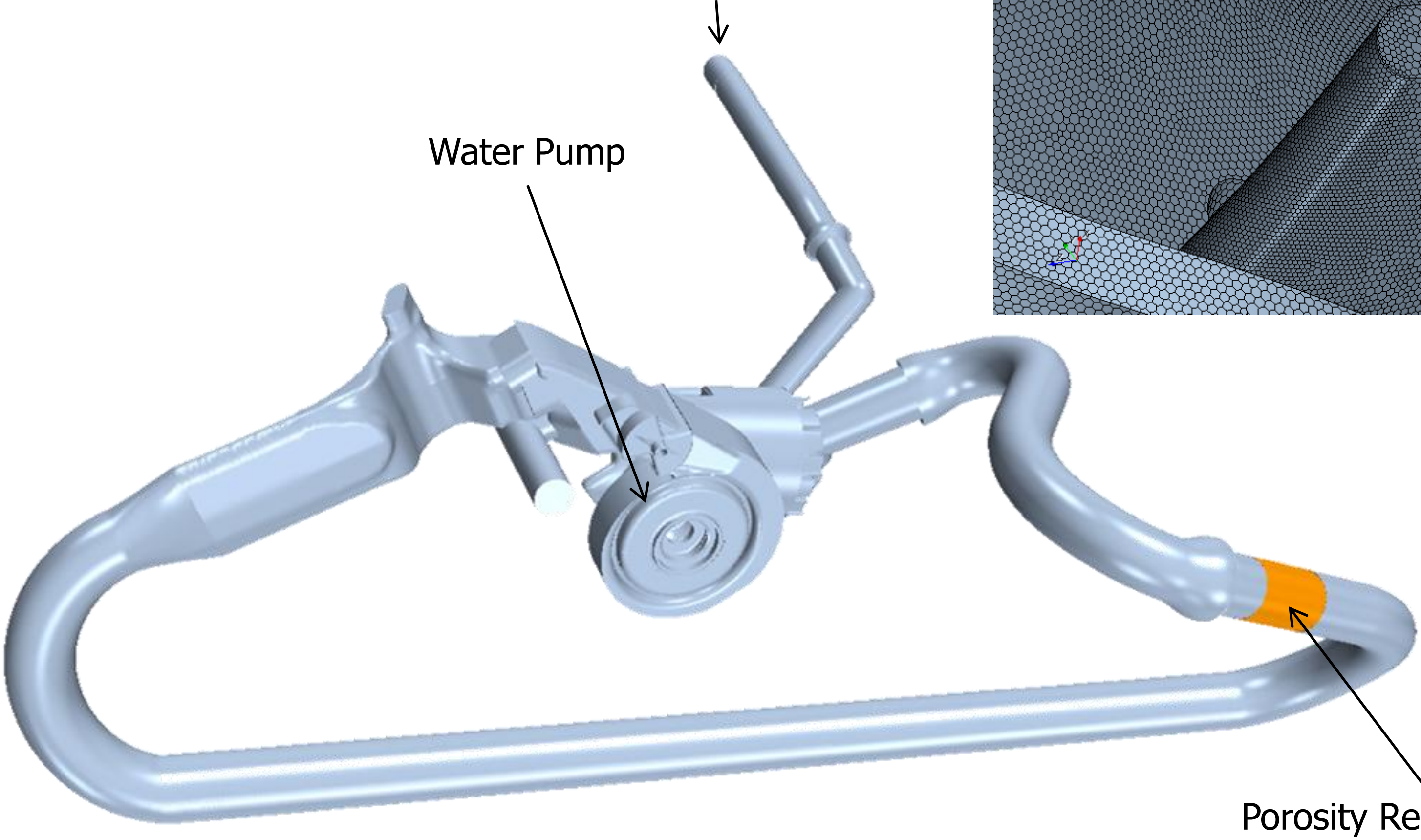
Virtual Test Bench
Water Pump Geometry and Mesh Detail





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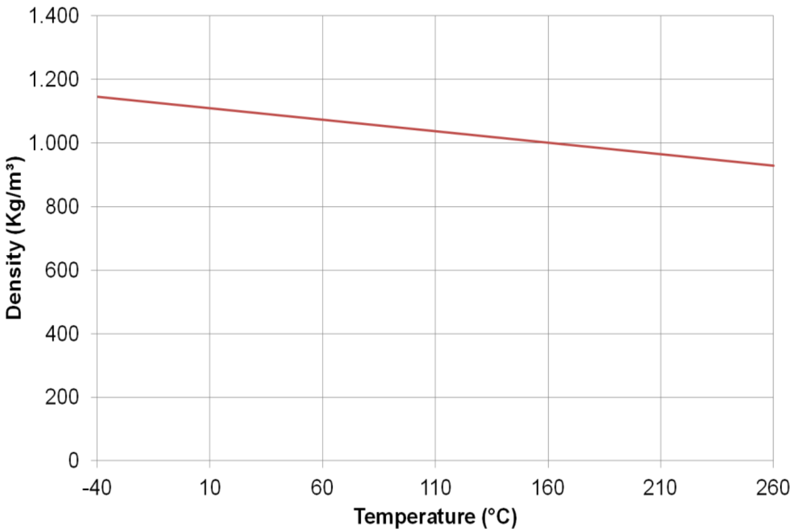
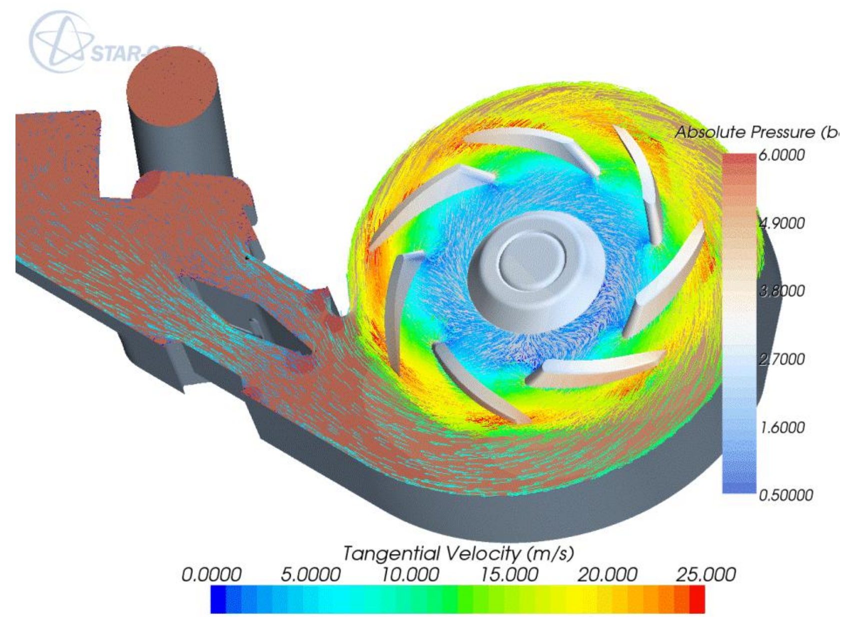
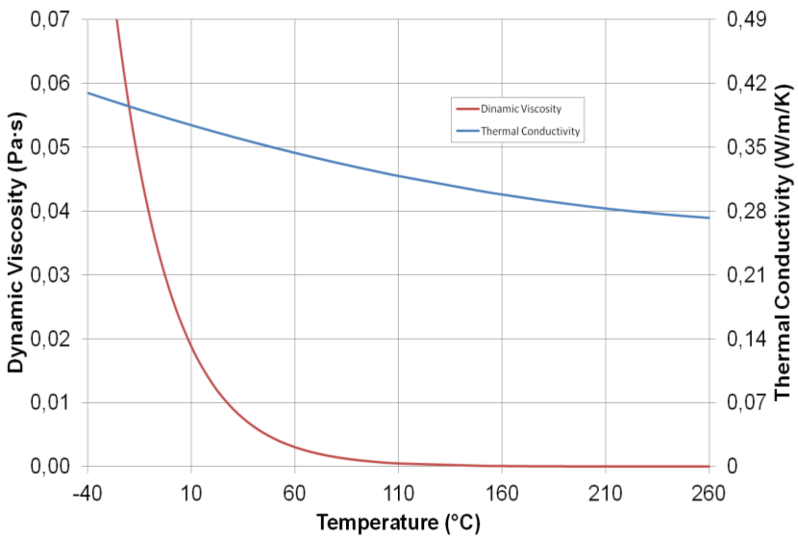
Physics and Boundary Conditions







Density: $\rho = 1312.82 - 0.7215 \cdot T$

Viscosity: $\nu = 554.68 \cdot e^{(-0.0365 \cdot T)}$

Thermal conductivity: $\lambda = 0.6388 - 1.221 \cdot 10^{-3} \cdot T + 1 \cdot 10^{-6} \cdot T^2$

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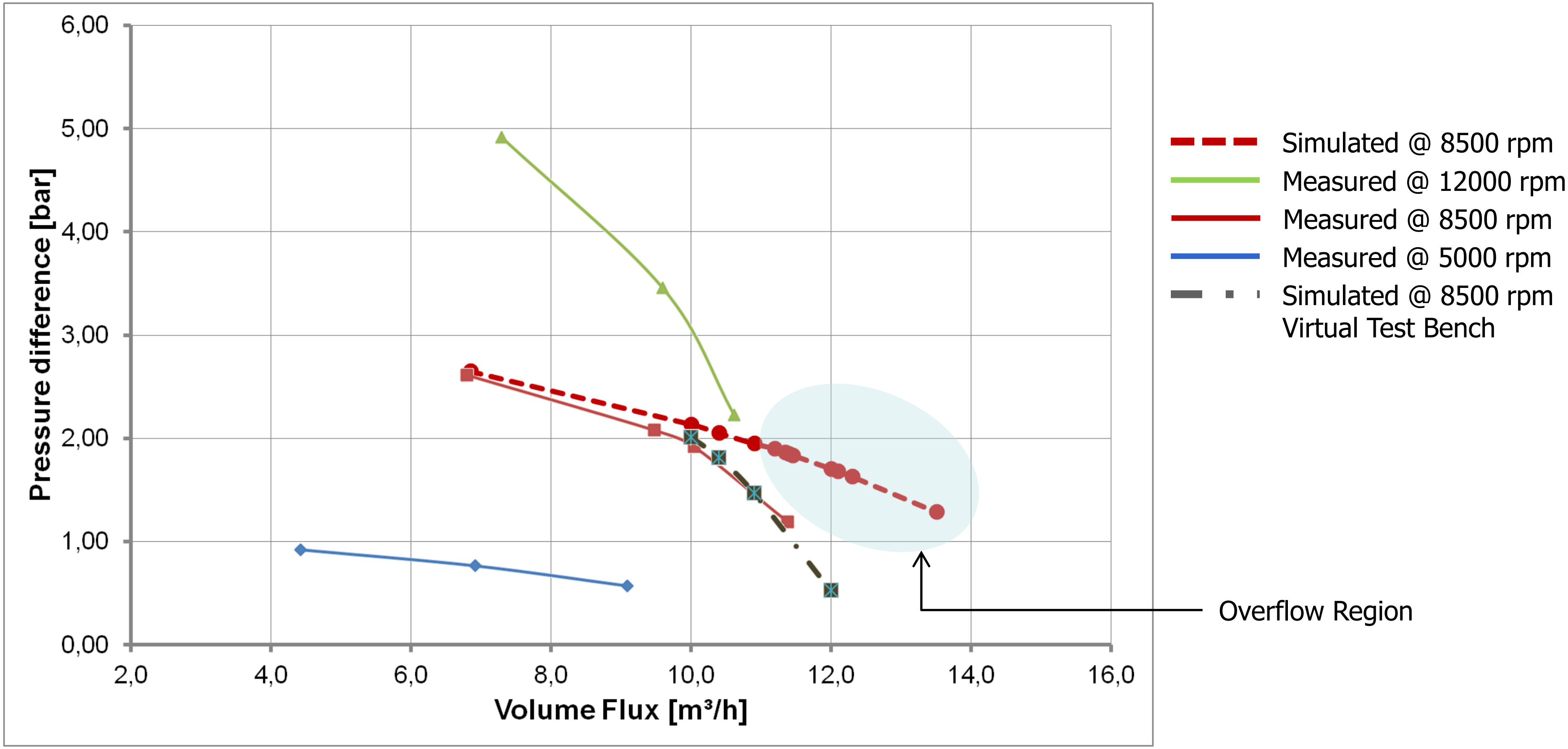
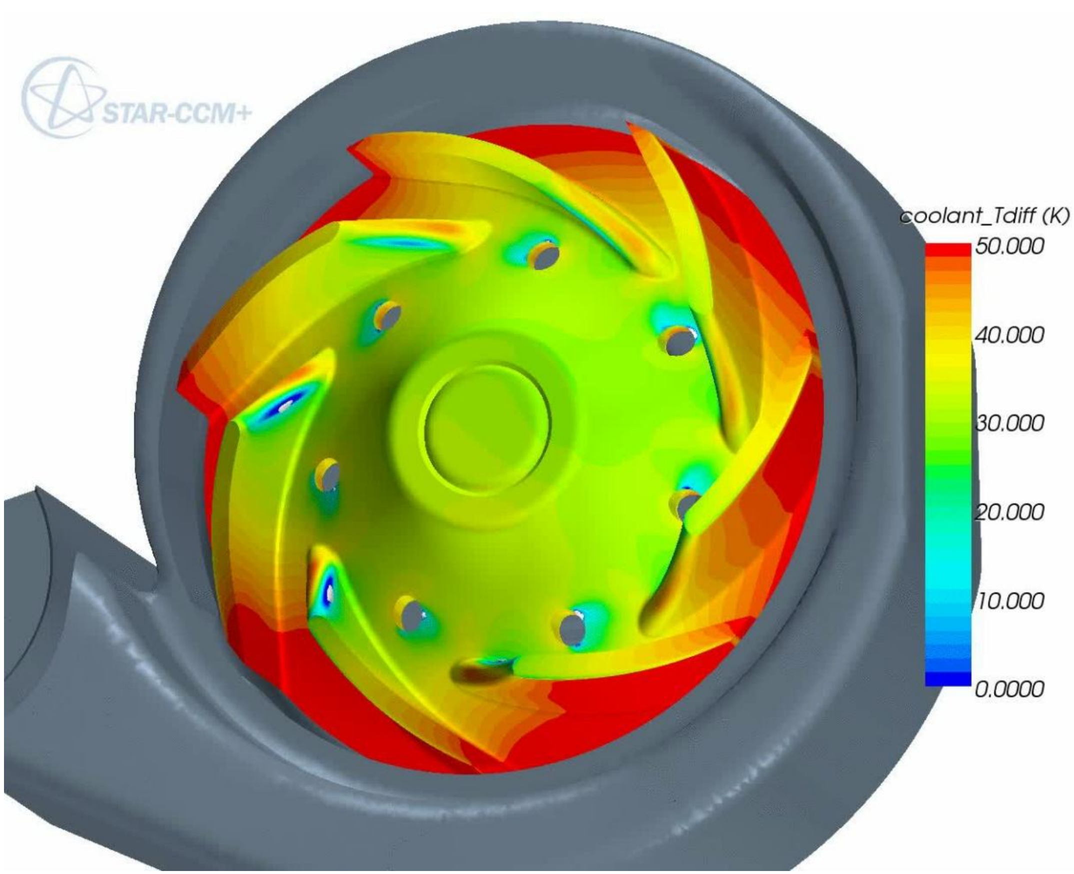
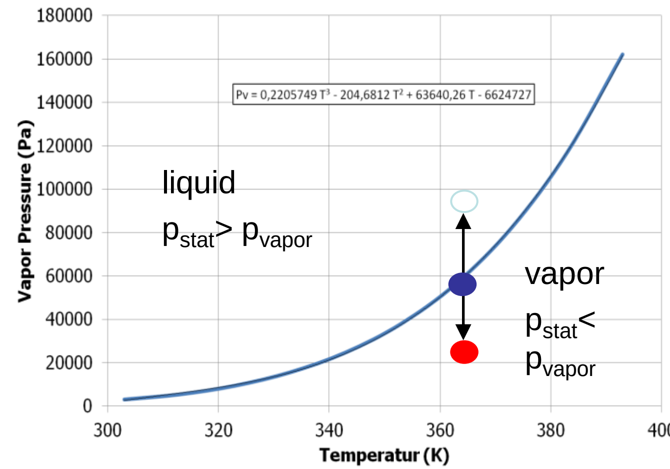
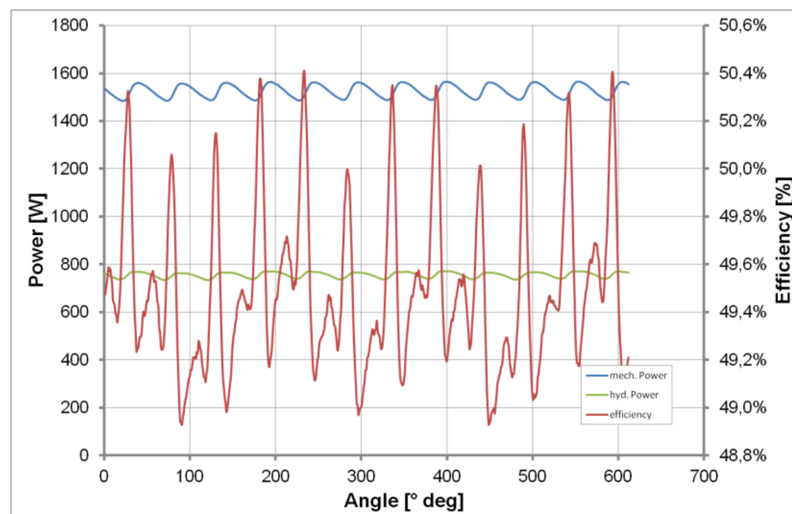
Virtual Test Bench
Characteristic Curves



Virtual Test Bench
Cavitation







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