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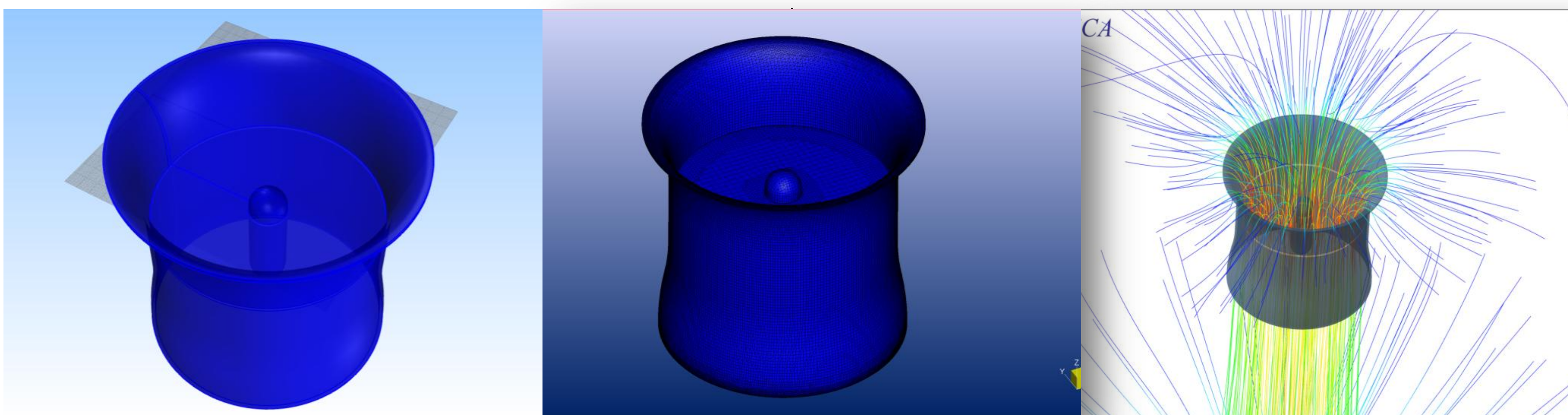
COMPOSITE

Feasibility Study Athena V2
Diffusor-Outlet

For Neva Aerospace Ltd.



Content

1. Specifications

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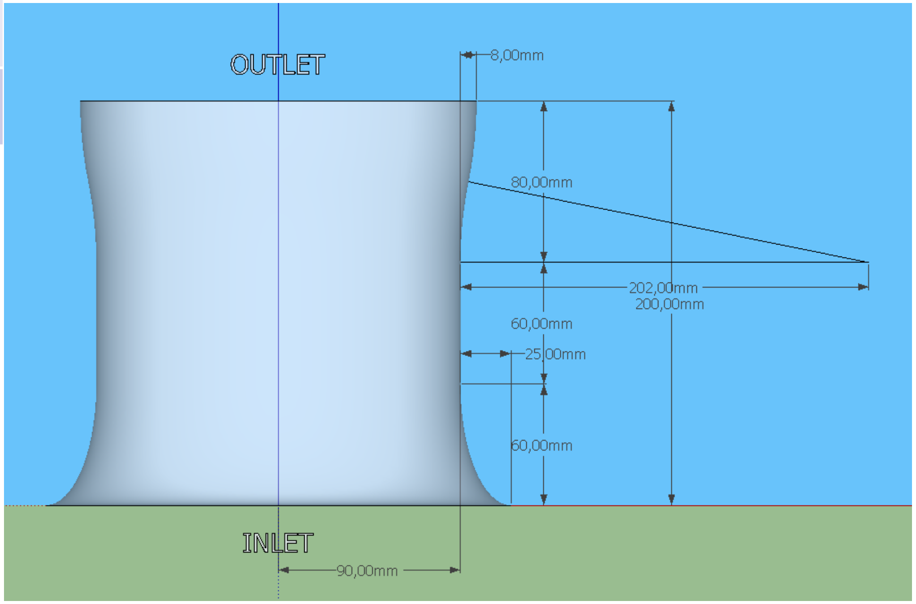
	Athena V2
Density [kg/m³]	1,25
Shroud Diameter [mm]	180
Hub Diameter [mm]	30
v0 [m/s]	0
Thrust [N]	~40 N



2. Analytical Approach

Where is the Lift generated?

- Momentum change

$$I = mv$$

$$T = \dot{I} = \frac{dm}{dt} v = \dot{m} v$$

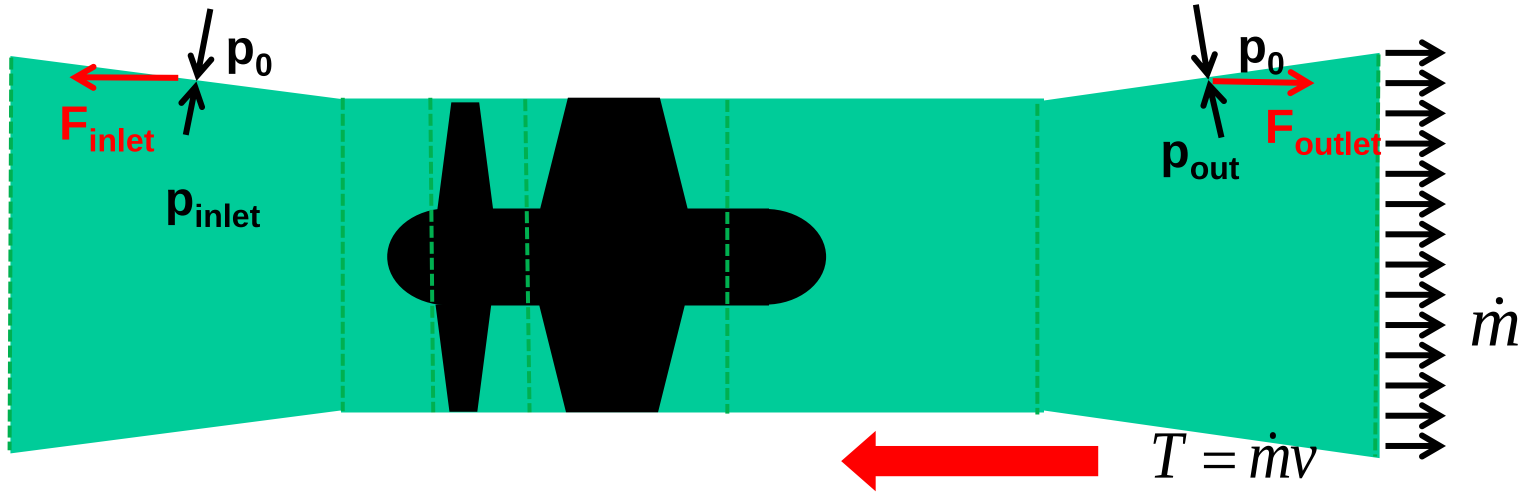
OR

- Thrust due to pressure distribution and viscous stress on solids

$$T = \int_{A_{solid}} p \cdot \vec{n} \cdot dA_{solid} + \int_{A_{solid}} \tau_{viscous} dA_{solid}$$

2. Analytical Approach

Effects on Thrust in Inlet and Outlet



- $p_0 > p_{inlet} \rightarrow T_{P,Inlet} > 0 \rightarrow$ **positive Thrust**
- $p_0 < p_{out} \rightarrow T_{P,Out} < 0 \rightarrow$ **negative Thrust**

2. Analytical Approach

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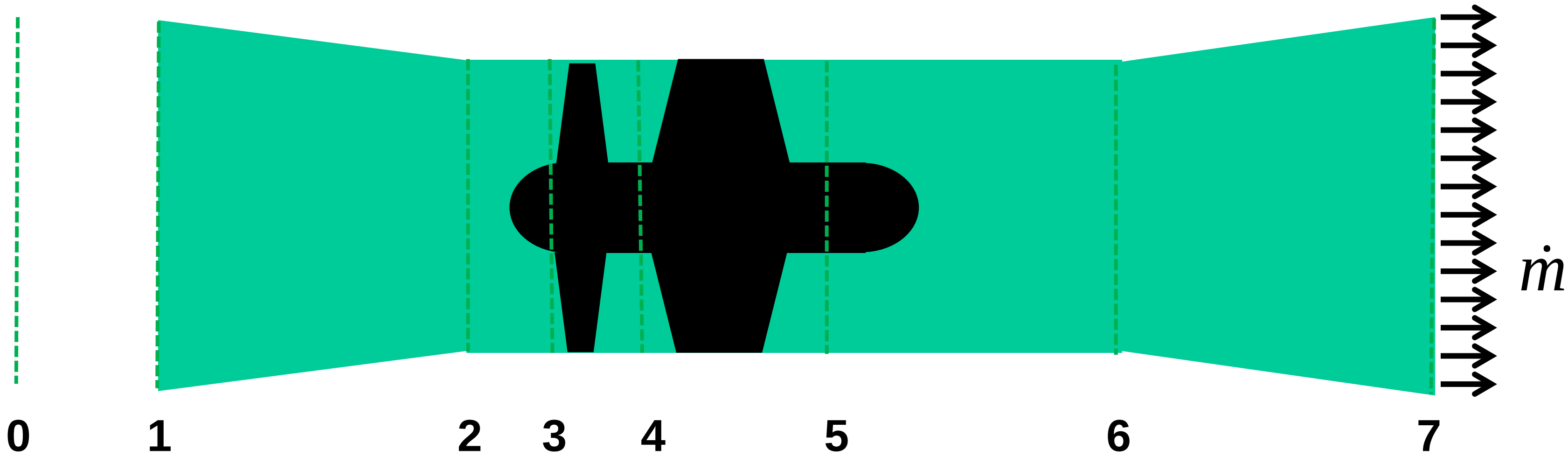
Effect in widening the outlet



- Windening the outlet will reduce the outlet velocity and
- reduce the backpressure on plane 5
- Thrust is reduced to the square of the velocity while
- Power ist reduced to the cube

$$T = \dot{m} v_7 = \rho A_7 \cdot v_7^2$$

$$P = \Delta p_{total} \cdot \dot{V} = \Delta p_{total} \cdot A_7 v_7$$

$$\Delta p_{total} = p_7 - p_0 = (p_0 + \tfrac{1}{2} \rho v_7^2) - p_0 = \tfrac{1}{2} \rho v_7^2$$

$$P \propto v_7^3 \qquad T \propto v_7^2 \qquad \Rightarrow \frac{T}{P} \propto v_7^{-1} \propto A_7^{-1}$$

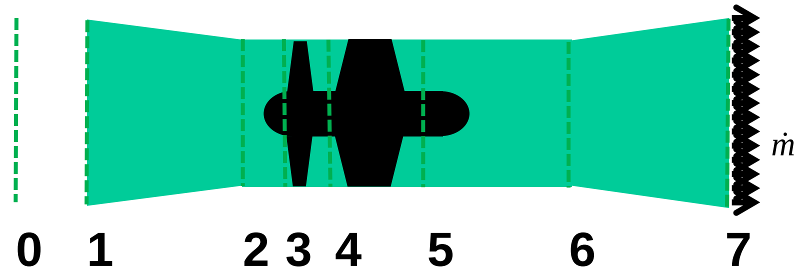
2. Analytical Approach

Calculated improvement on Thrust-Power Ratio

$$A_{7,straight} = 254{,}5cm^2$$

$$A_{7,\text{expanding}} = 301{,}7cm^2$$

$$\frac{T}{P} \propto \frac{1}{\left(A_{7,straight} / A_{7,\text{expanding}}\right)} = \frac{301{,}7}{254{,}5} = 1{,}185$$



- **18,5% higher Thrust-Power-Ratio**

Losses in widening the outlet

- **The outlet diffusor produces pressure losses depending on the diffusor angle and length**
- **Difficult to estimate**

$$\Delta p_{diffusor} = \zeta \cdot \frac{\rho}{2} \cdot v_7^2$$

$$\zeta : \text{Re}\,sis\,\tan ce - Coefficien\,t$$

$$\zeta \approx 0{,}01 - 0{,}2$$

2. Analytical Approach

Unlimited Thrust?

- In Theory, yes
- Until the diffusor losses are bigger than the Thrust increase
- Reducing the outlet velocity means loss of agility
- What are the limits for the diffusor?

3. CFD-Simulations

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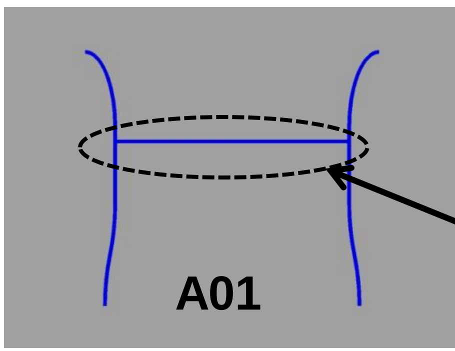
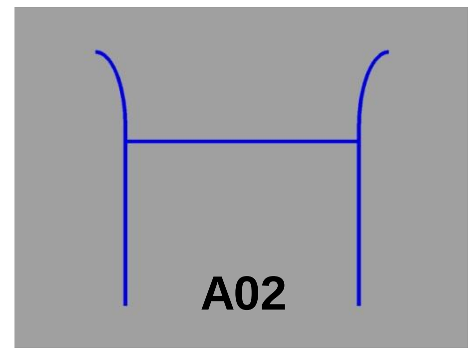
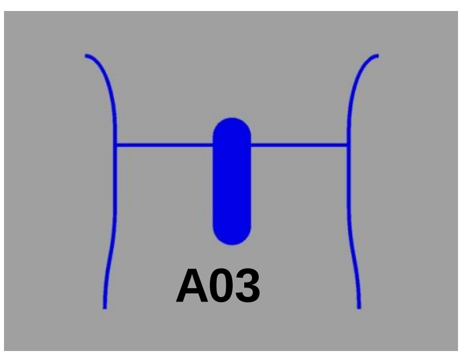
Geometry:

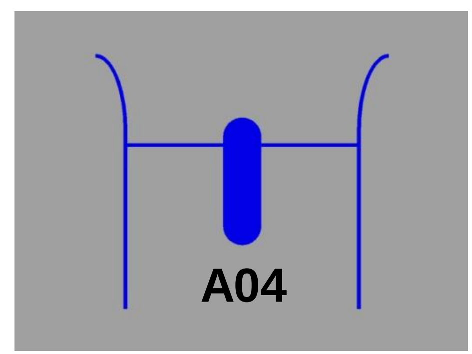
- **4 Geometries calculated**
- **With hub and without hub**
- **With expanding nozzle and without**



Actuator Disc:
-Outlet at upper side
-Inlet at lower side
-same massflow







3. CFD-Simulations

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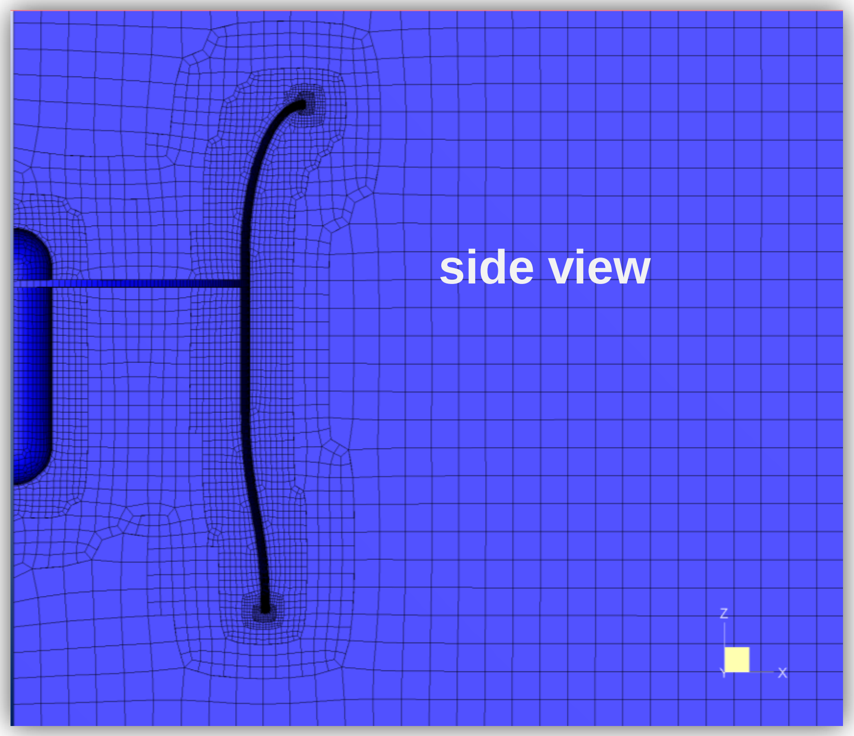
Mesh

- Multigrid unstructured hexaedron mesh
- Fully resoluted boudary layer
- ¼ of complete geometry with symmetric boundary conditions
- Total number of nodes: ~ 550.000



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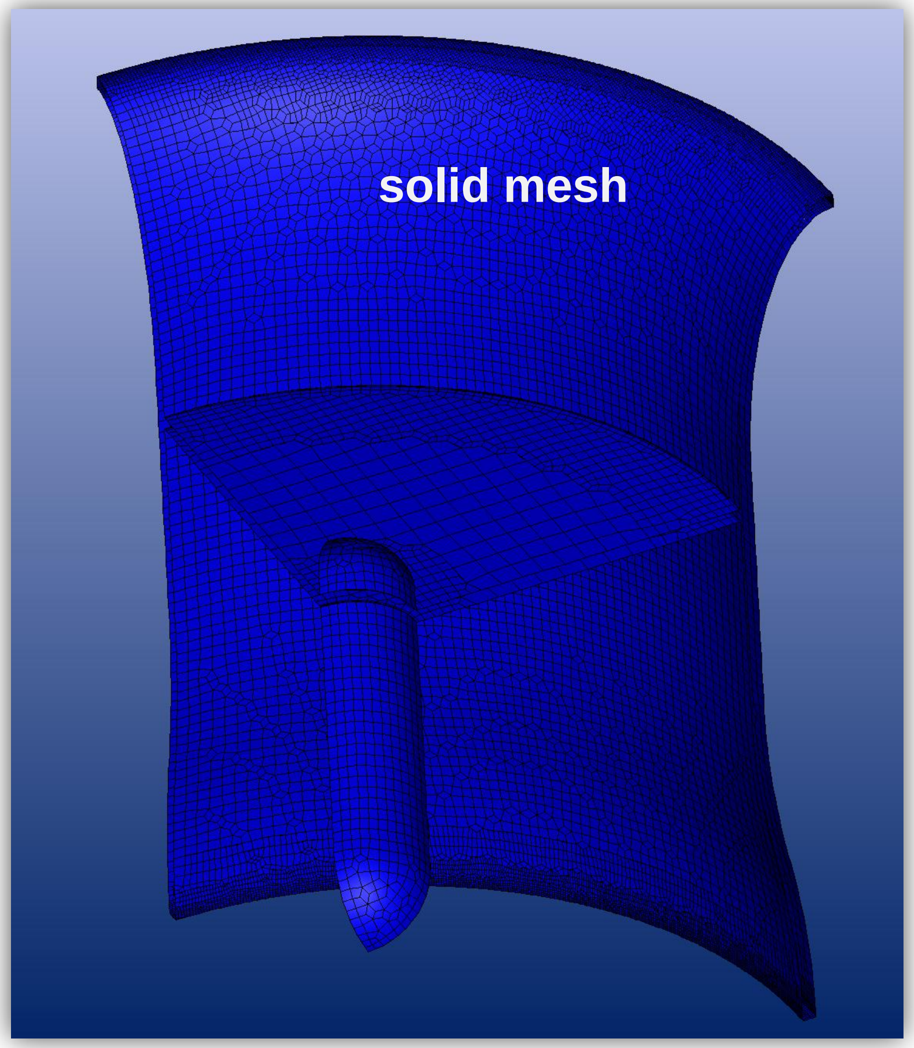
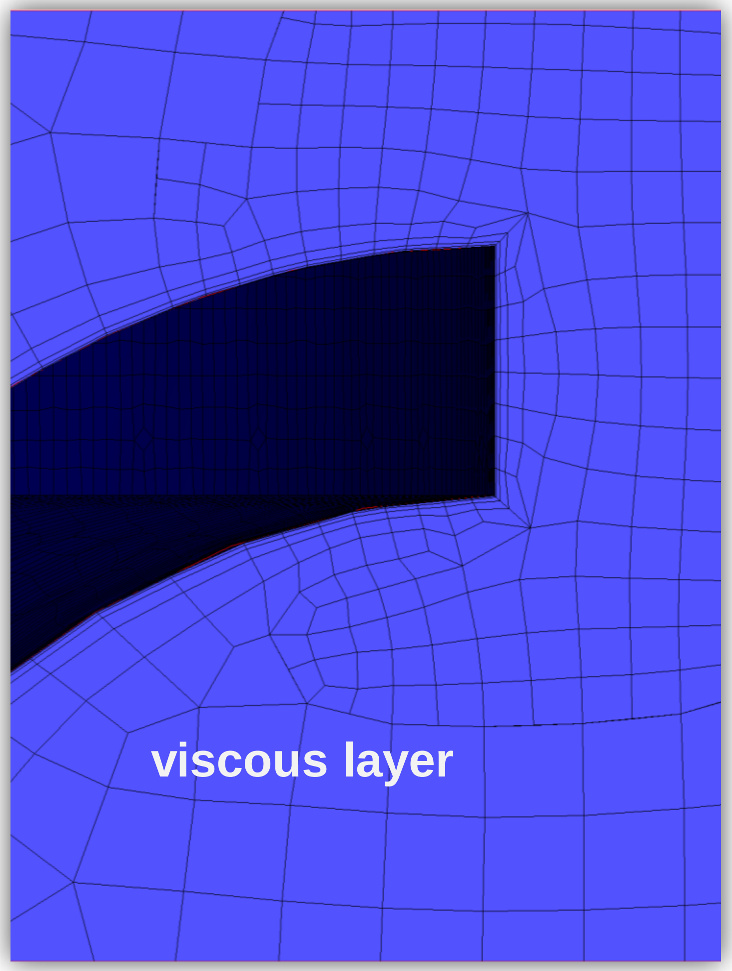
Mesh





3. CFD-Simulations

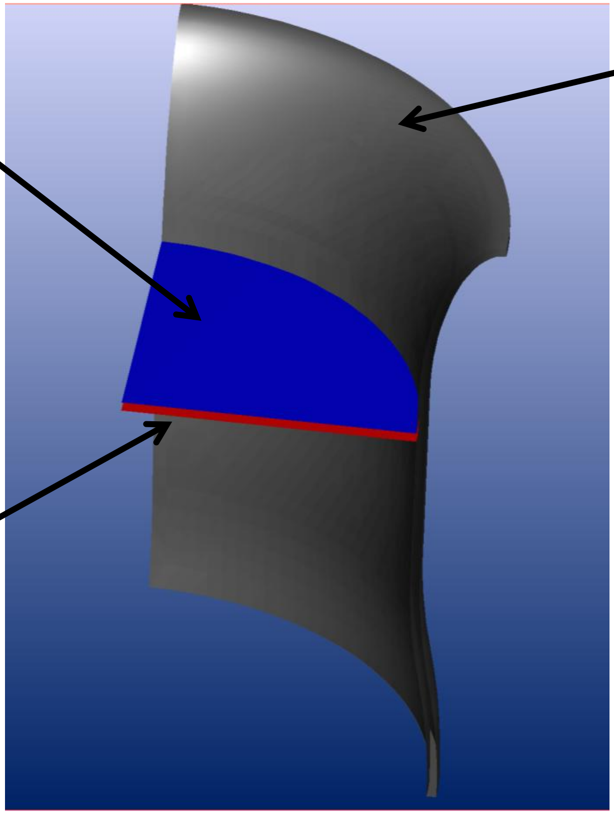
Solver Setting

- **Compressible fluid model „Air Perfect“**
- **Mathemetical model: Navier Stokes**
- **Spalart Almaras turbulence model**
- **CFL number: 3**
- **Steady state**

3. CFD-Simulations

Boundary Conditions

Outlet:
1,049 kg/s



Solids:
smooth Wall

Inlet:
1,049 kg/s

Externals:
v=0 m/s
p=102325
T=288,15 K

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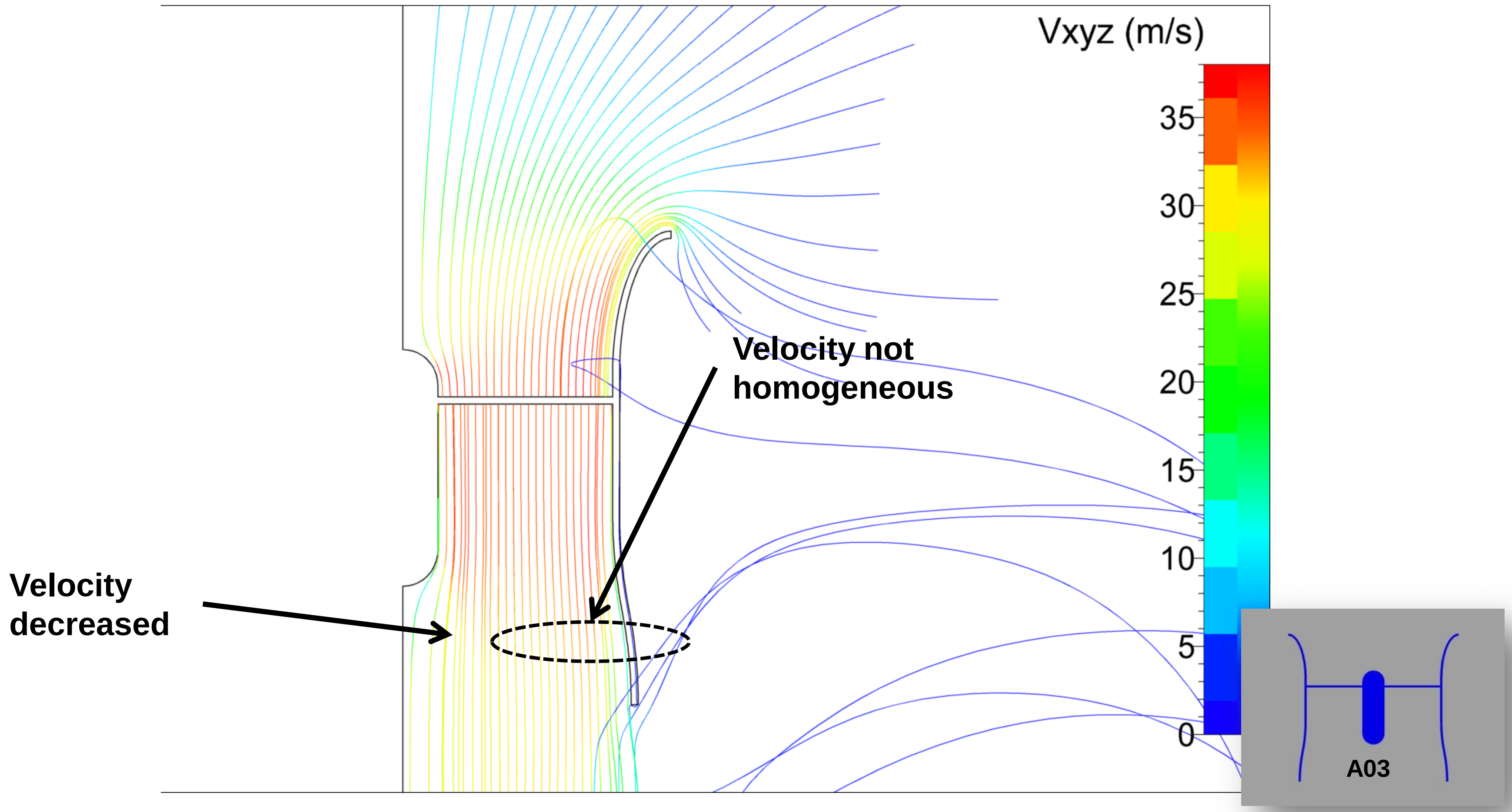
Results: Streamlines A03



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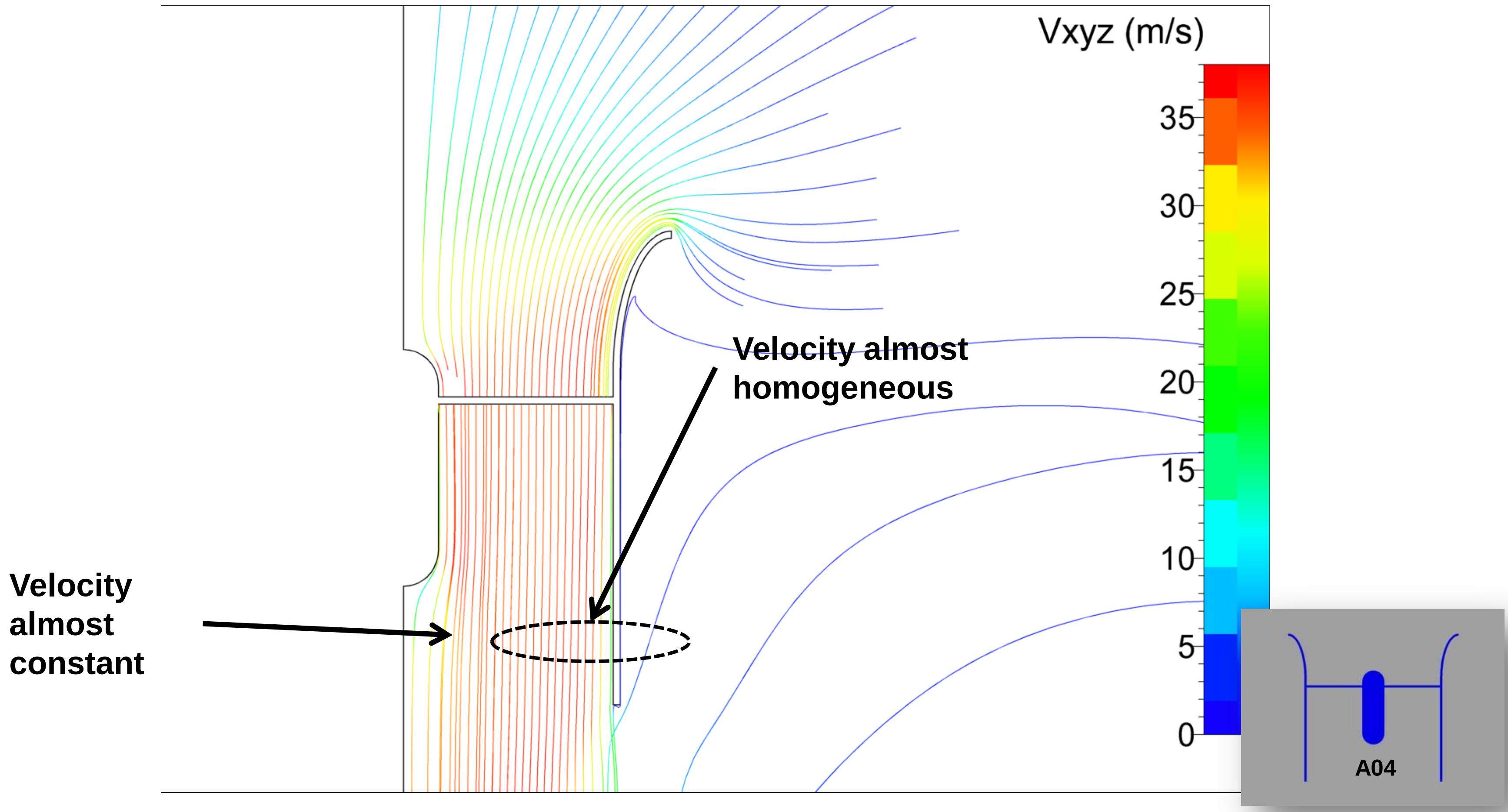
Results: Streamlines A04



3. CFD-Simulations

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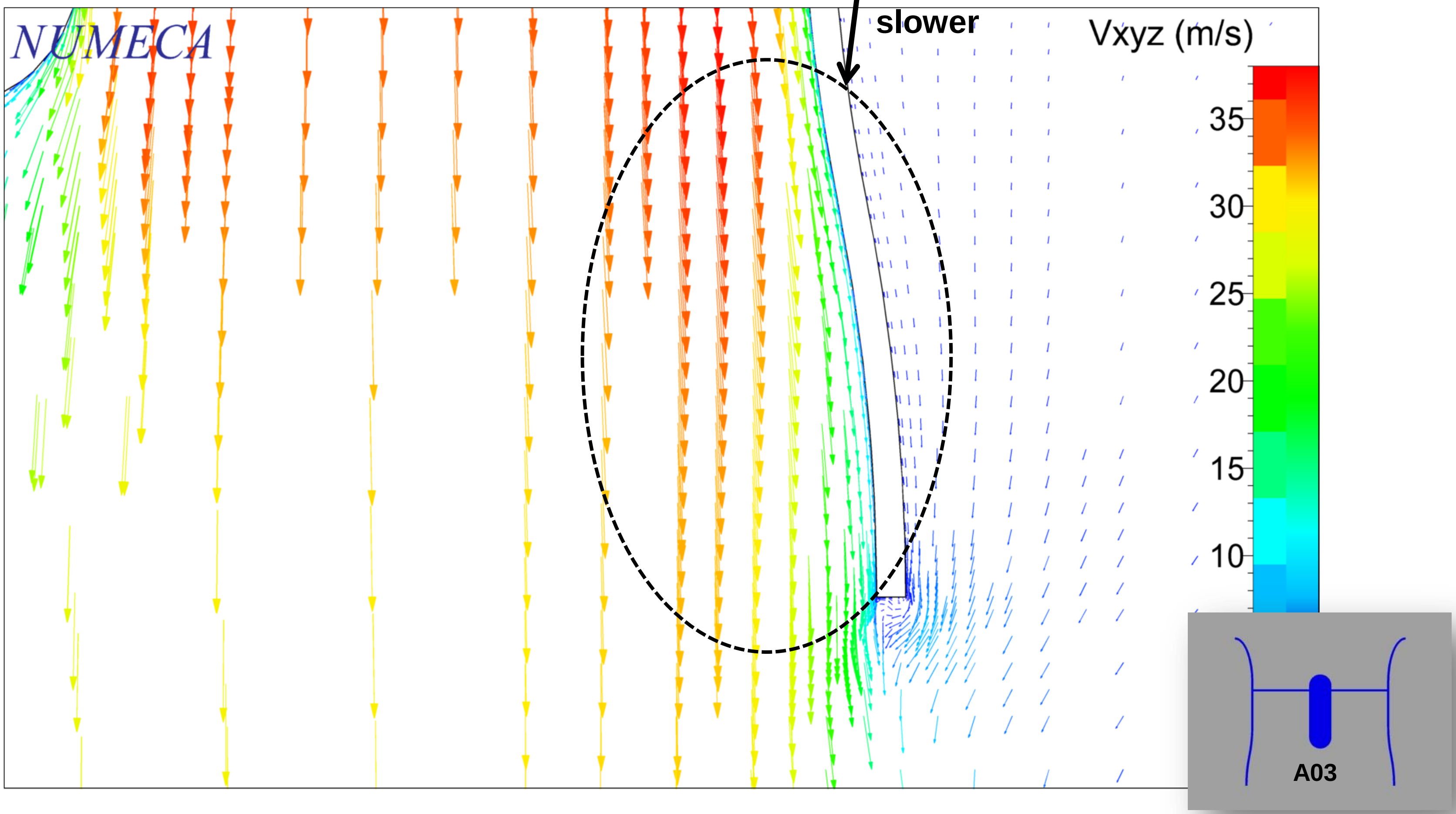
Results: Detailed Velocity Field A03

In the diffusor, the near wall stream is much slower



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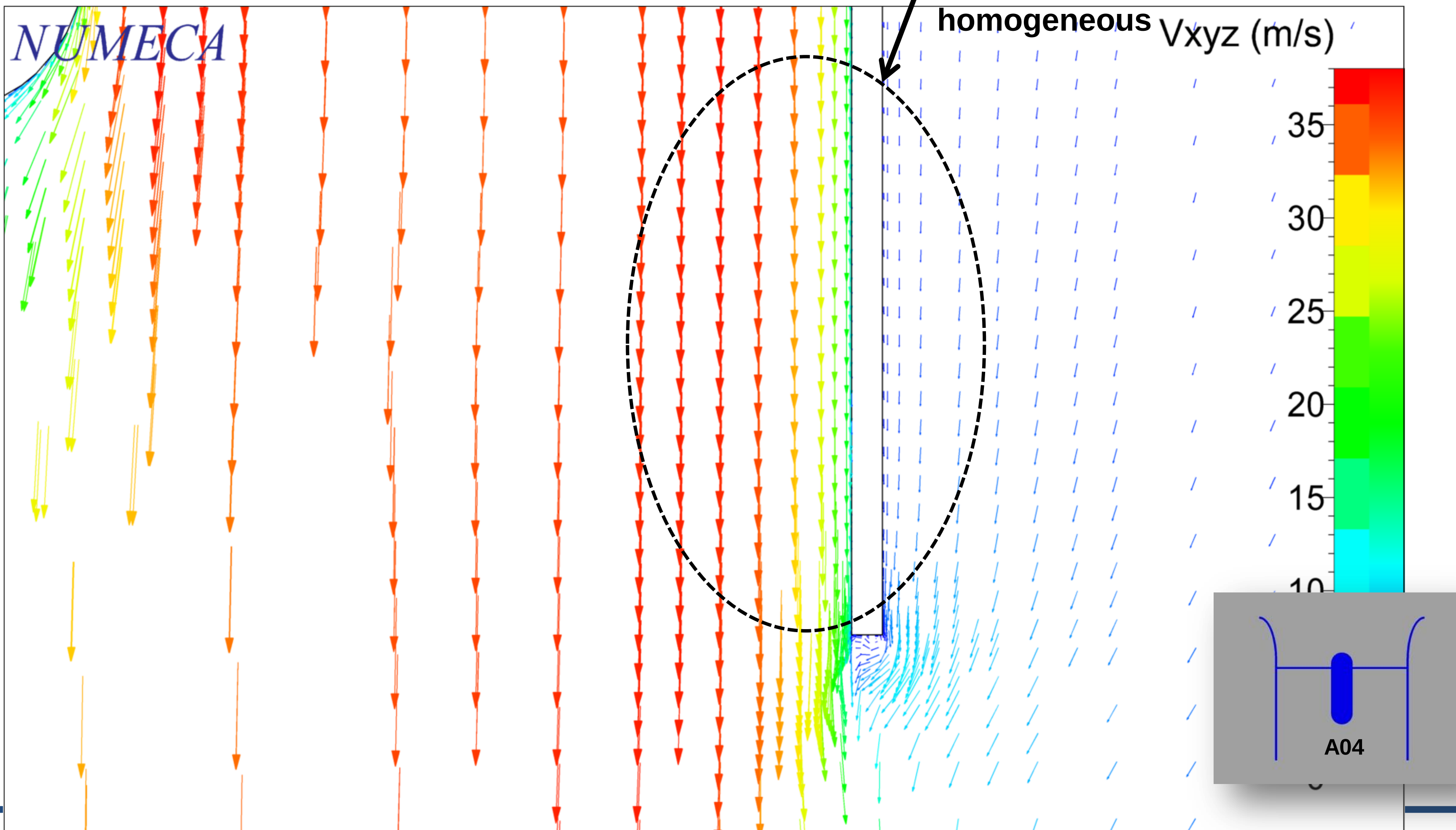
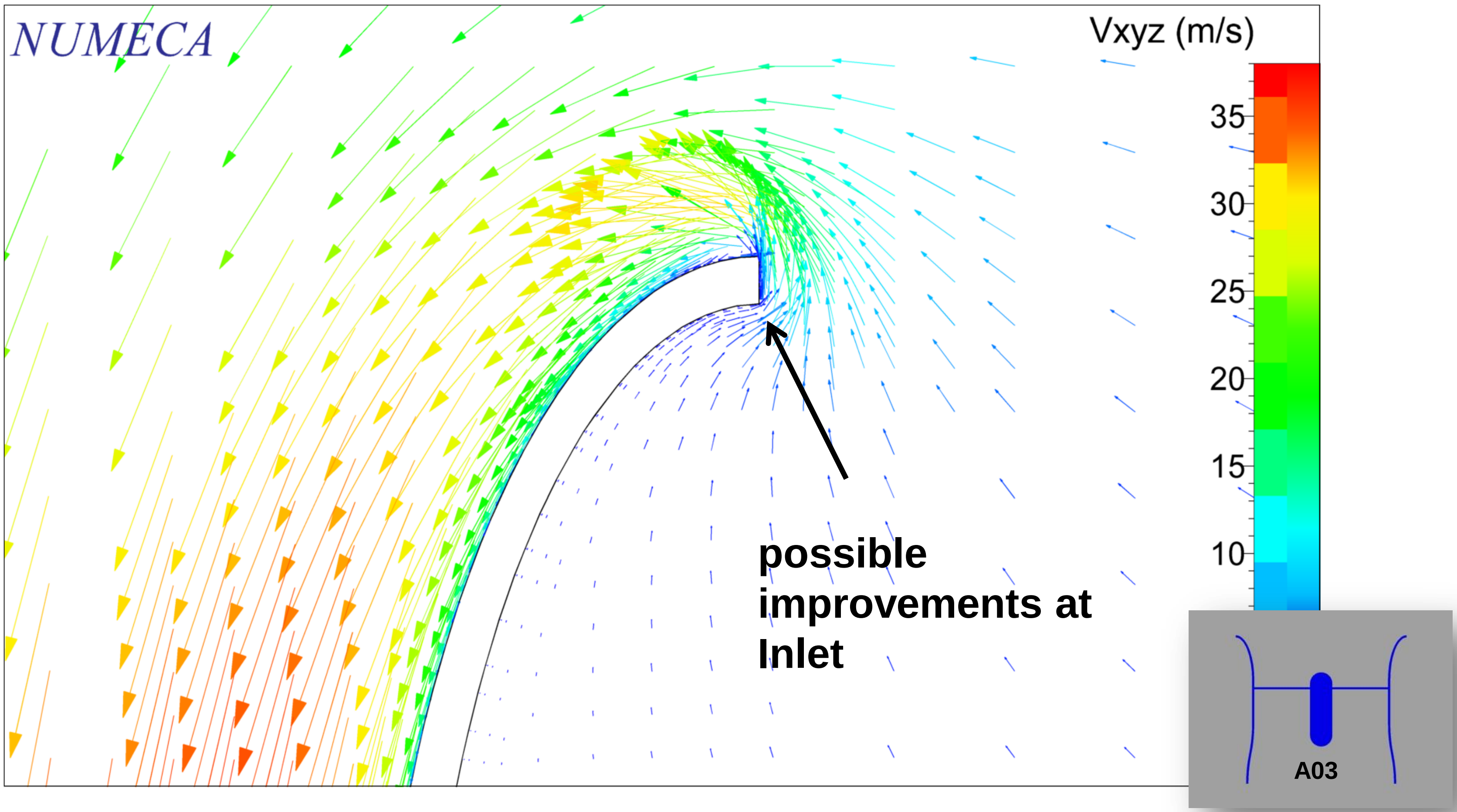
Results: Detailes Velocity Field A04

Without diffusor the stream is more homogeneous



3. CFD-Simulations

Results: Detailed Velocity Vectors Inlet A03



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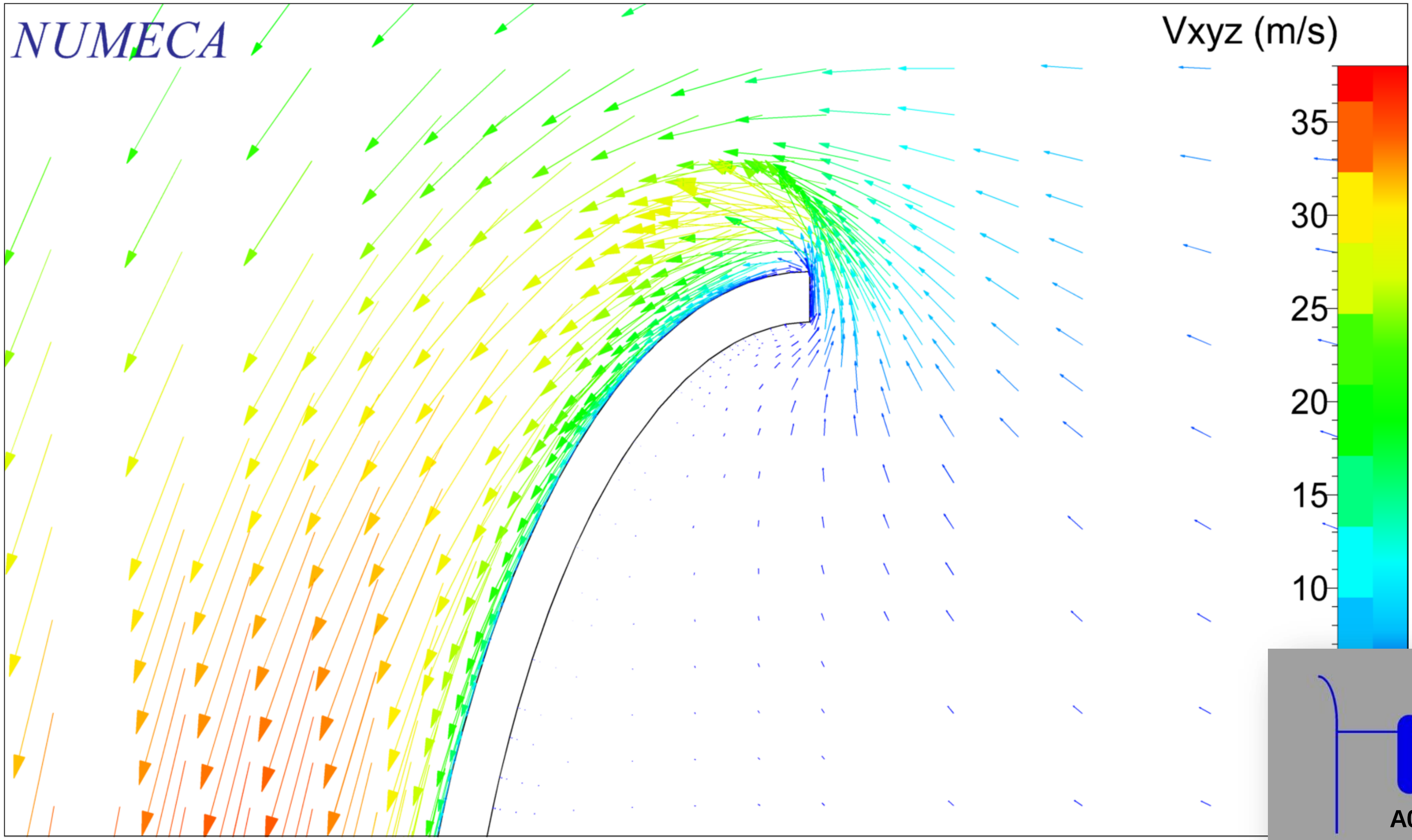
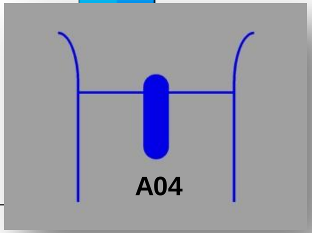
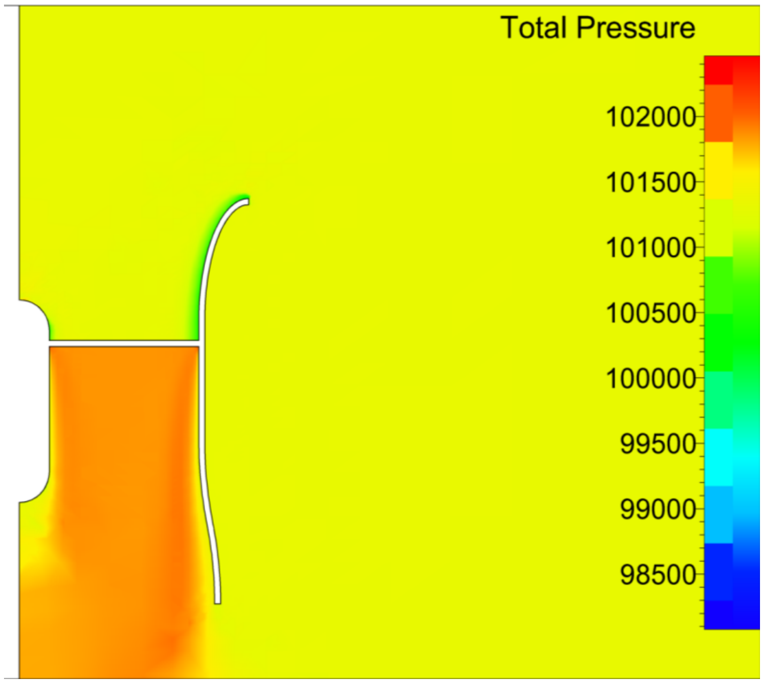
Results: Detailed Velocity Vectors Inlet A04

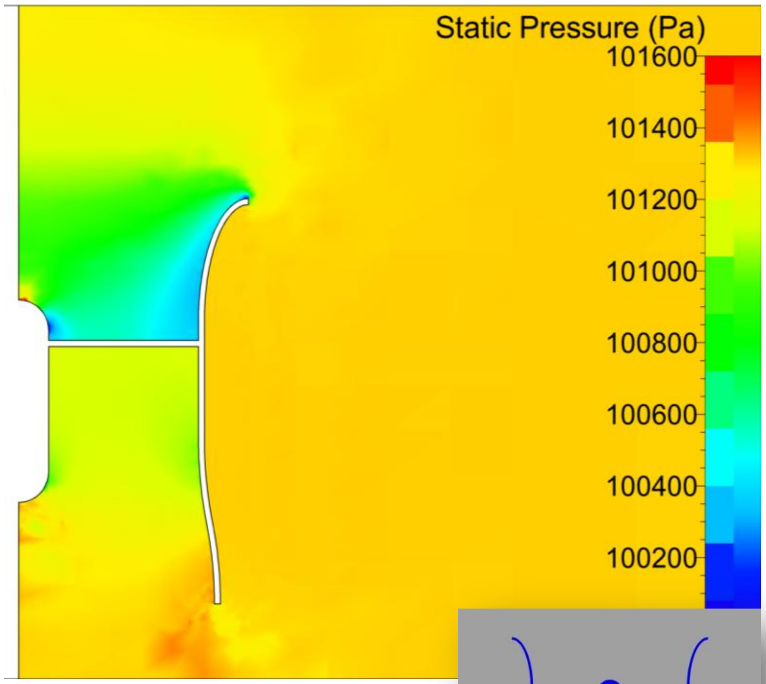


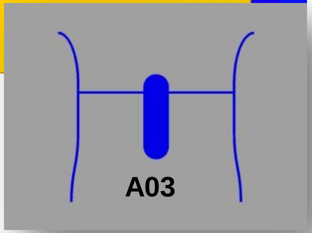


3. CFD-Simulations

Results: Total and Static Pressure A03







3. CFD-Simulations

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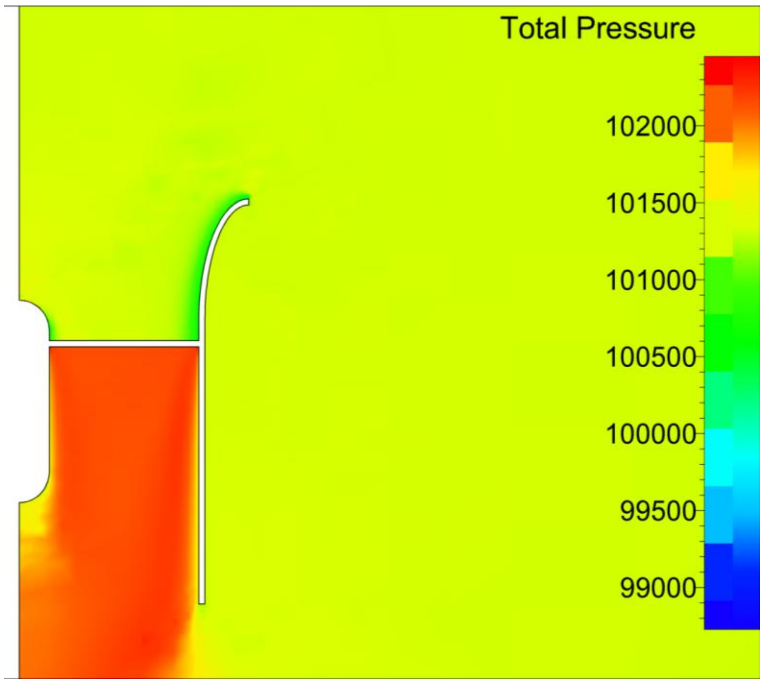
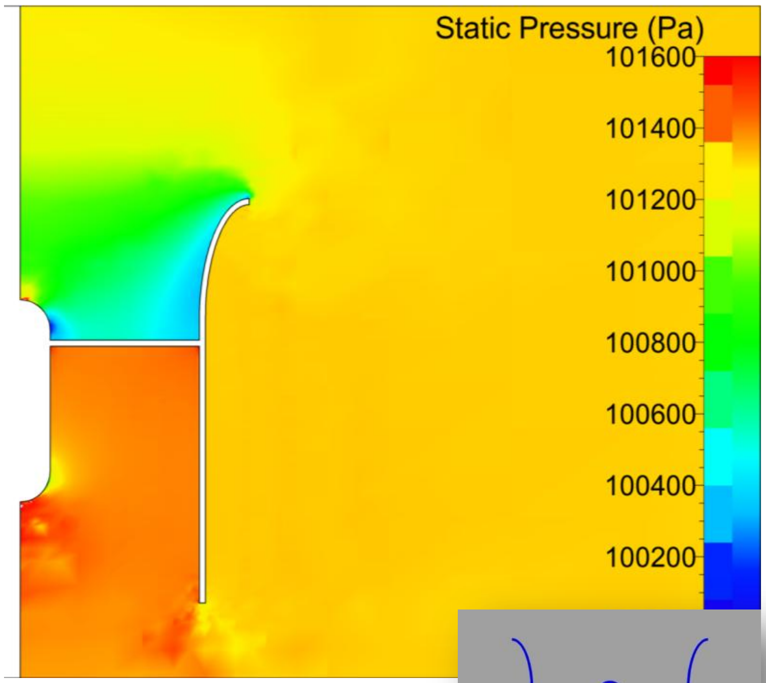
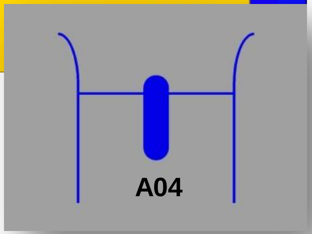
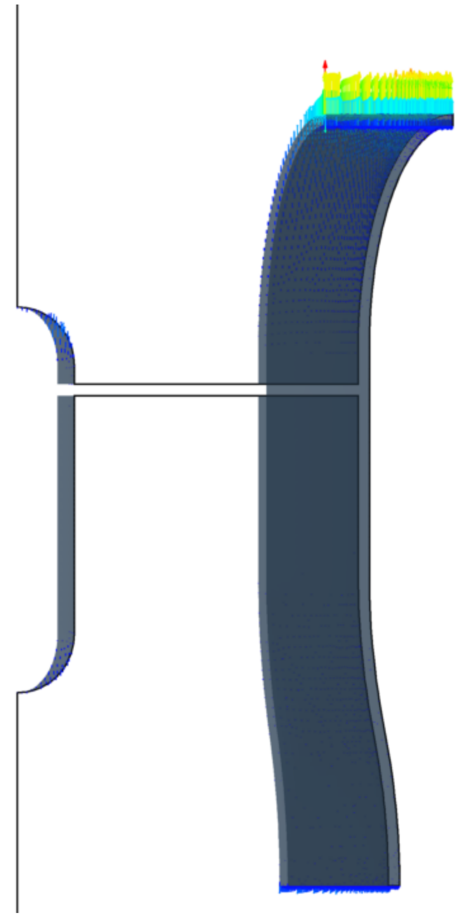
Results: Total and Static Pressure A04

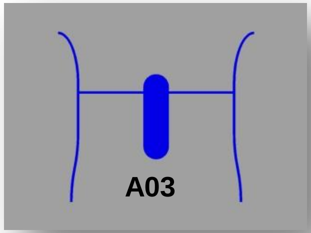






Results: Visualization of the Pressure Forces in Z-Direction A03





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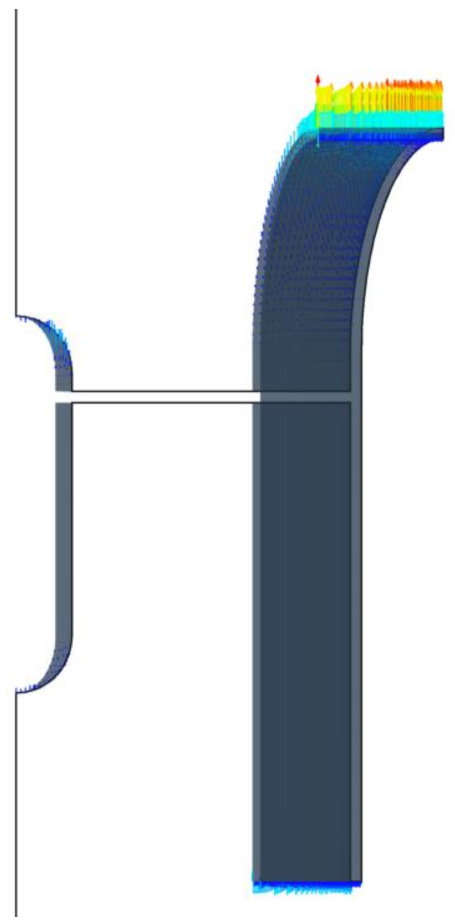
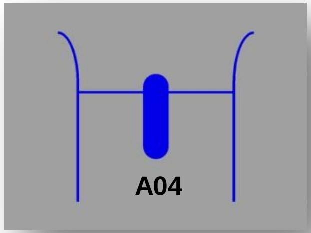
Results: Visualization of the Pressure Forces in Z-Direction A04





3. CFD-Simulations

Results: Comparsion

	T[N] Momentum change (mf*v)	vf[m³/s]	$p_{tot,3}$ [Pa]	$p_{tot,5}$ [Pa]	Δp [Pa]	P_{hydr} [W]	T/P_{hydr} [N/kW]
A03	30,45	0,856	101220	101867	647	553,8	**54,9**
A04	35,88	0,855	101220	102160	940	803,9	**44,6**

- The diffusor outlet has 23% better Thrust-Power-ratio
- Analytically only 18% ... ?
- Only the **hydraulical Power** is considerated, no fan, nor motor efficiency
- To achieve this improvement, the aerodynamic rotor has to be optimized for each case. (Optimum rotor for A03 is other than A04)
- The improvement works only for static thrust

4. Conclusions

Outlook

- It may be interesting to push the diffusor to the limits
- Find the optimum diffusor in trems of diameter, length and shape
- Investigate how the diffusor behaves at other power setting
- Perform a complete CFD-Calculation including the complete rotating fan