WOST 2018

# Optimization of a Radial Pump using CFturbo, TCFD & optiSLang

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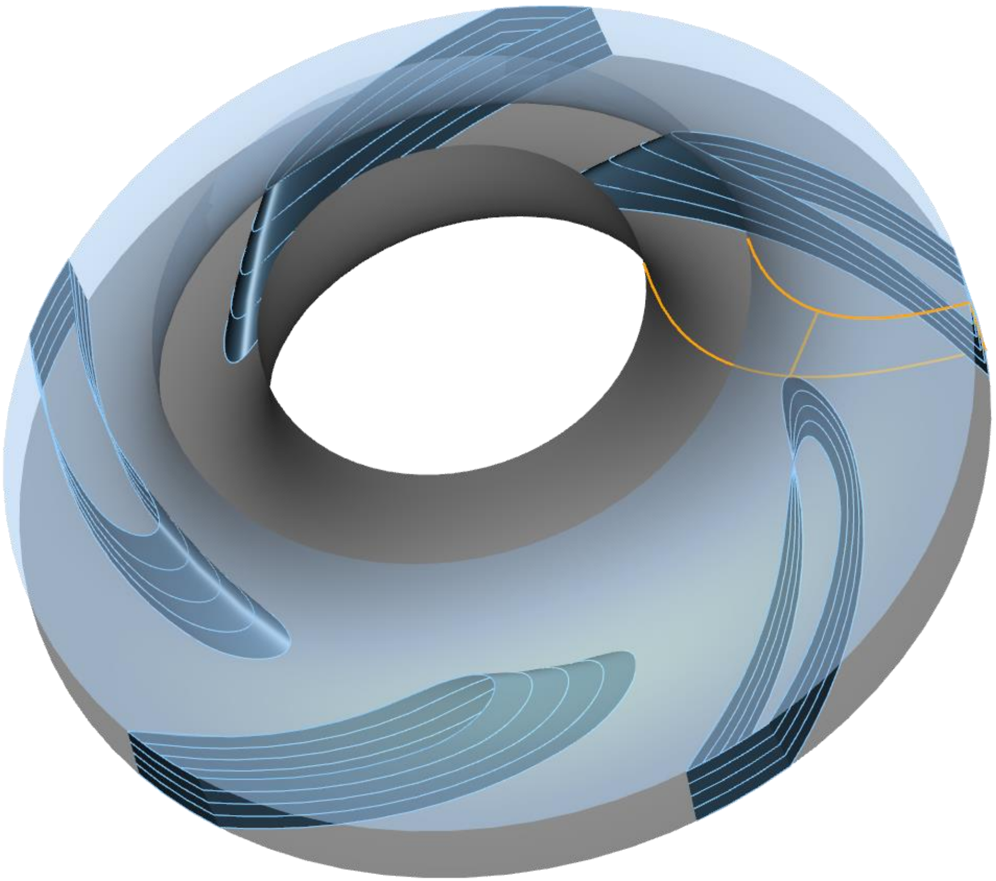
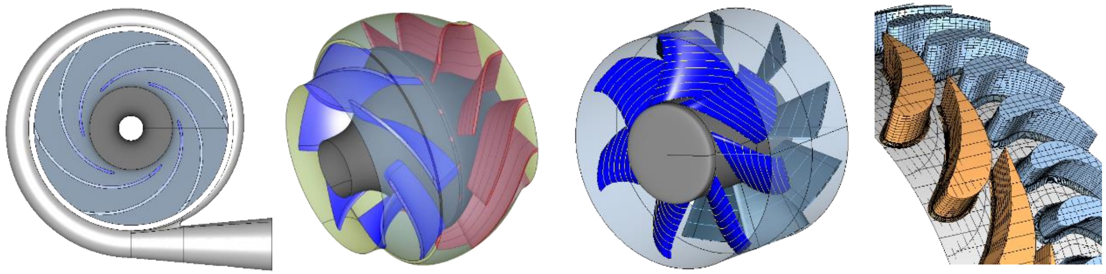
CFturbo®

# Content



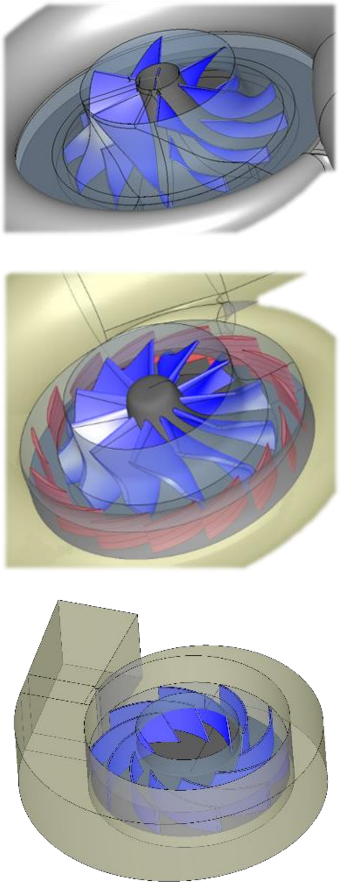


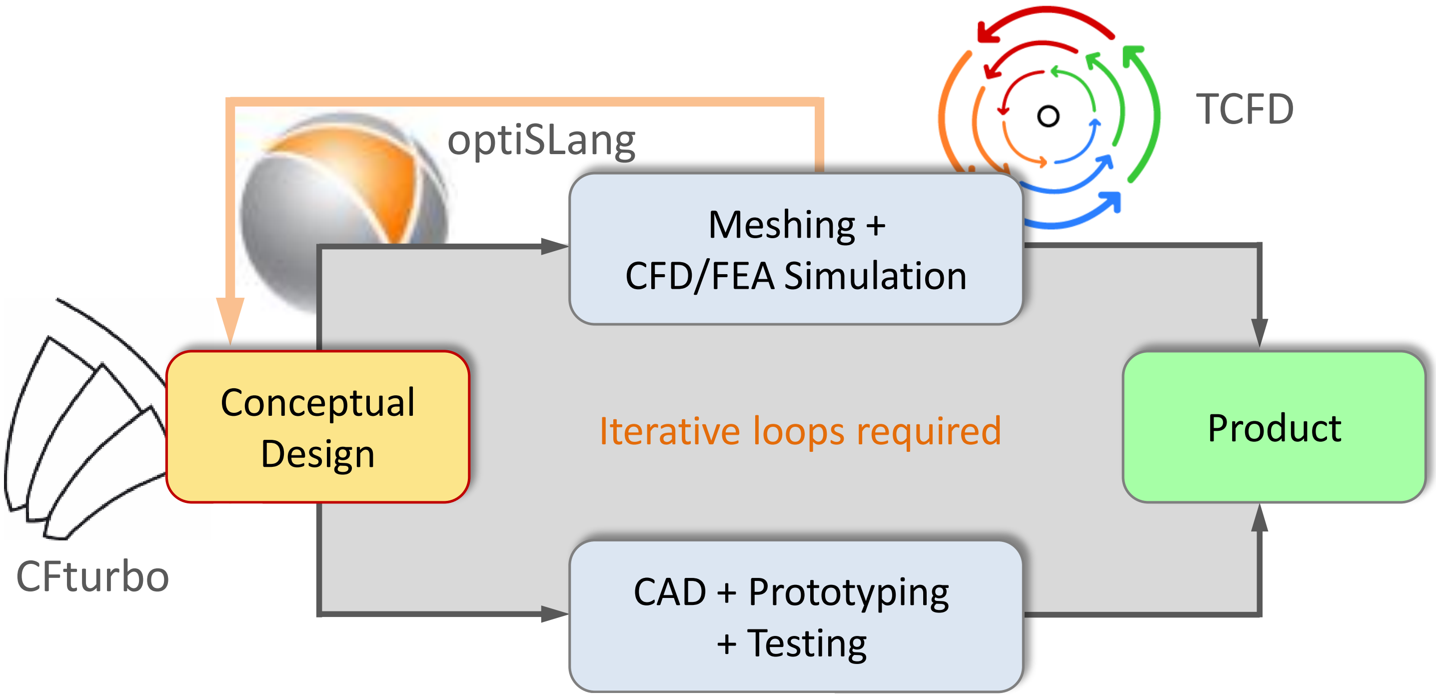
# 1. Motivation



Turbomachinery design is

- Complex
- Time-consuming
- Expensive

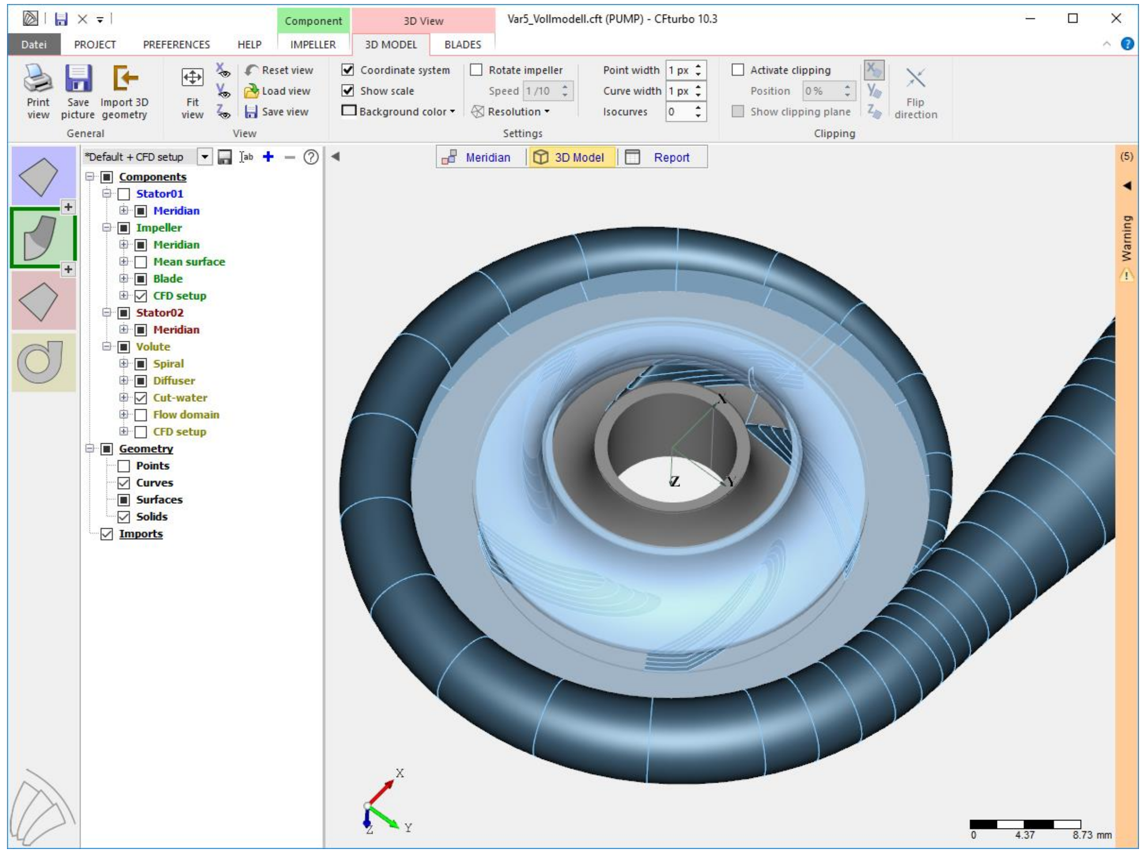




# 2. Software tools a) CFturbo

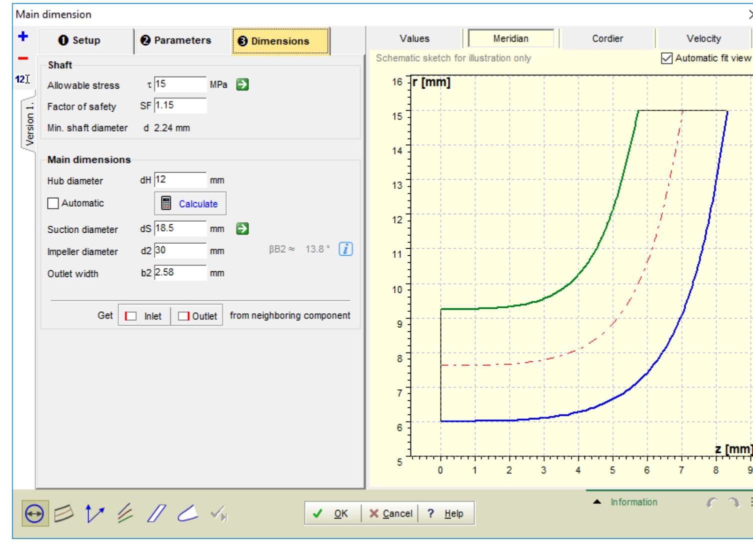
- Modern turbomachinery design software for
  - ✓ Pumps
  - ✓ Ventilators
  - ✓ Compressors
  - ✓ Turbines
- Covers all major types:
  - ✓ Radial
  - ✓ Mixed-flow
  - ✓ Axial
- Available components:
  - ✓ Impeller
  - ✓ Volute
  - ✓ Vaned/vaneless stators
- Analytical design theory & empirical correlations

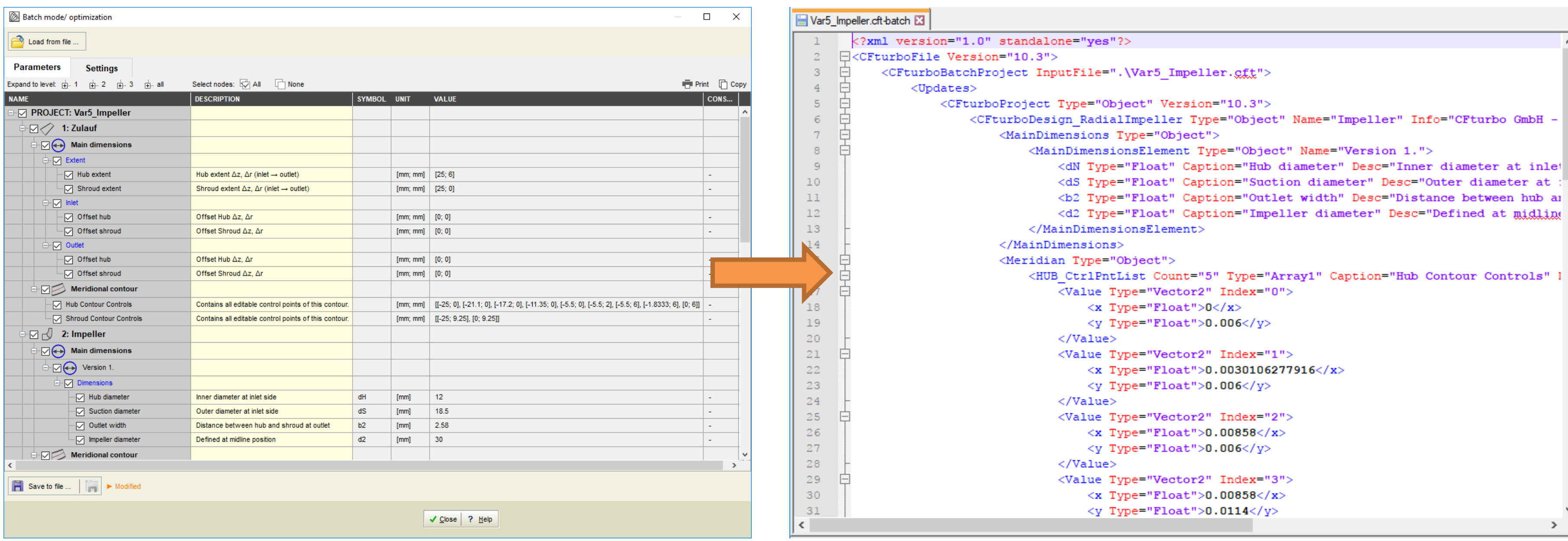



→ Fully parametric geometry model of machines

# 2. Software tools a) CFturbo

- Several design steps from design point to 3D geometry
- All parameters can be accessed via batch mode per XML file
- optiSLang integration available

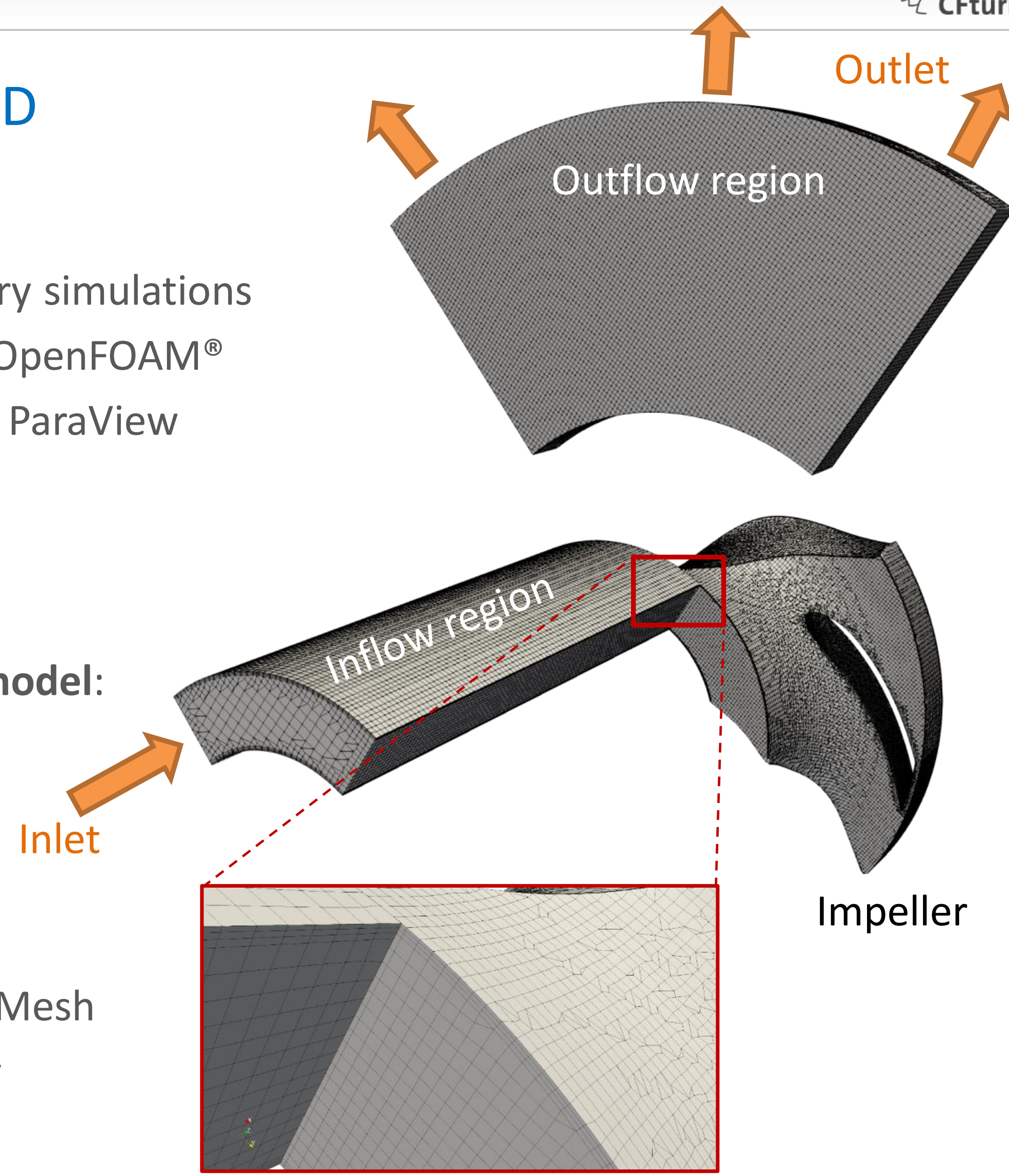


# 2. Software tools b) TCFD

- **TCFD® = Turbomachinery CFD**
- CFD workflow for turbomachinery simulations
- Commercial software based on OpenFOAM®
- Graphical user interface (GUI) in ParaView
- Developed by CFD Support s.r.o.

**Geometry model**:



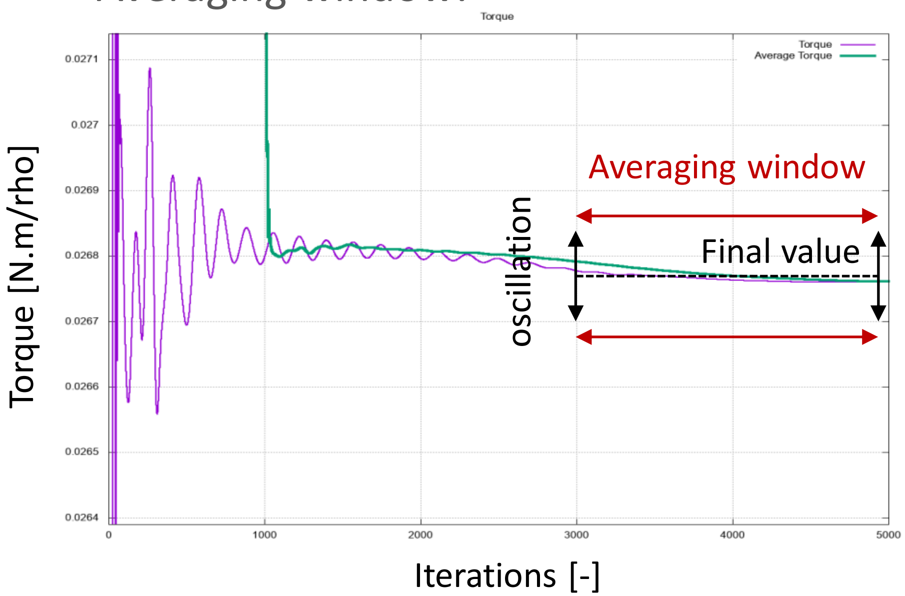

**Mesh density**:

- 270 000 cells
- Created with snappyHexMesh
- Solver speed ⇆ accuracy

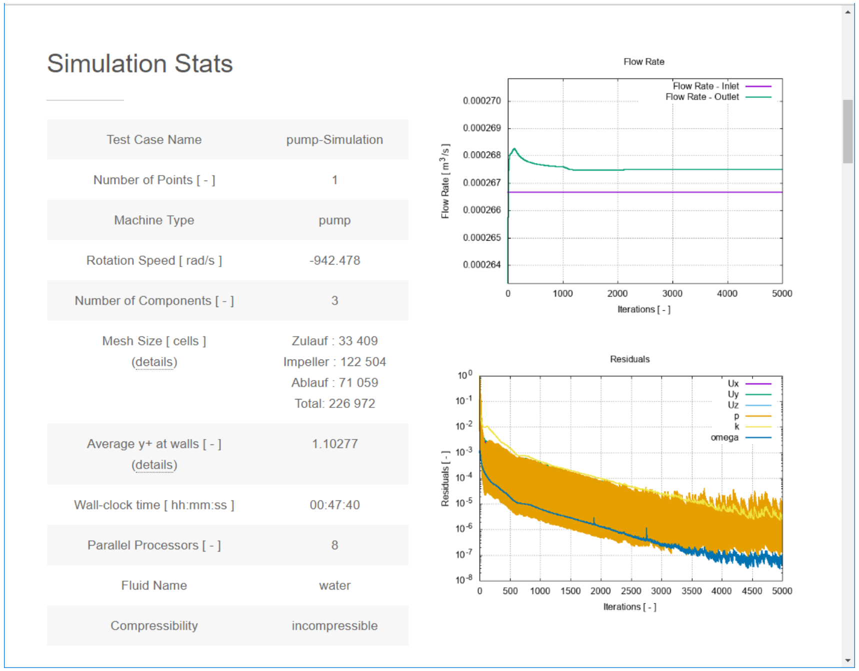
  

# 2. Software tools b) TCFD

## Averaging window:



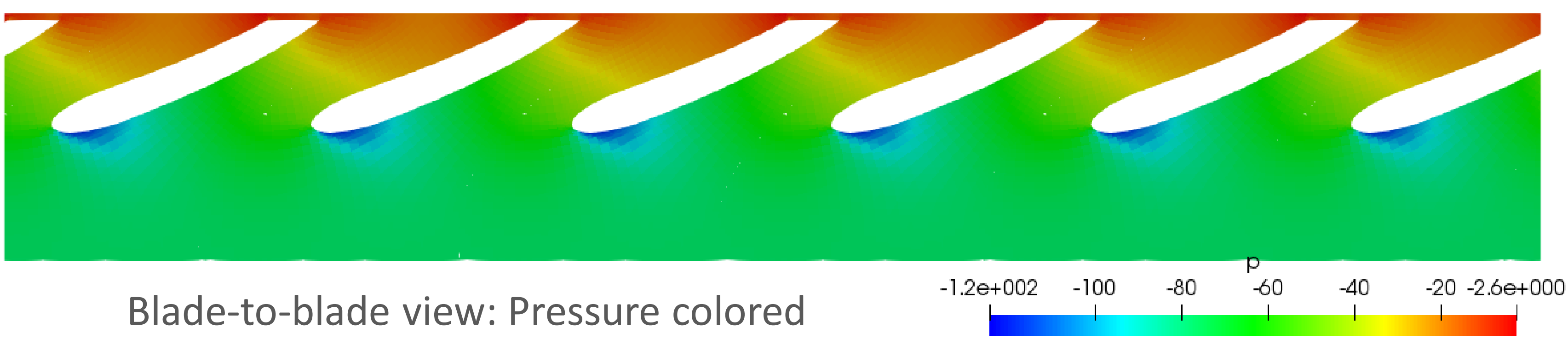

## HTML Report:



Simulation Stats

| | |
|---|---|
| Test Case Name | pump-Simulation |
| Number of Points [ - ] | 1 |
| Machine Type | pump |
| Rotation Speed [ rad/s ] | -942.478 |
| Number of Components [ - ] | 3 |
| Mesh Size [ cells ] (details) | Zulauf : 33 409<br>Impeller : 122 504<br>Ablauf : 71 059<br>Total: 226 972 |
| Average y+ at walls [ - ] (details) | 1.10277 |
| Wall-clock time [ hh:mm:ss ] | 00:47:40 |
| Parallel Processors [ - ] | 8 |
| Fluid Name | water |
| Compressibility | incompressible |



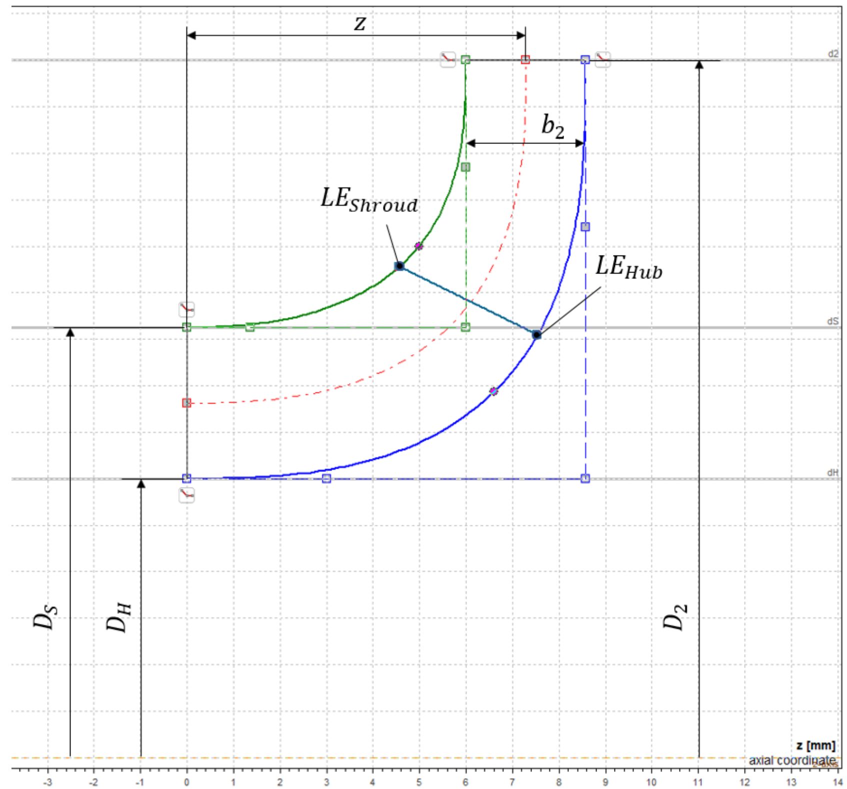



Blade-to-blade view: Pressure colored

# 3. Parameters

- Overall 12 parameters are used

| | # | Parameter | Reference | Minimum | Maximum |
|---|---|---|---|---|---|
| Main dimensions | 1 | $D_H$ [mm] | 12.0 | 9.6 | 14.4 |
| | 2 | $D_S$ [mm] | 18.5 | 14.8 | 22.2 |
| | 3 | $b_2$ [mm] | 2.58 | 2.064 | 3.096 |
| | 4 | $D_2$ [mm] | 30 | 24 | 32 |
| Meridional contour | 5 | z [mm] | 7.29 | 5.832 | 8.748 |
| | 6 | $LE_{Hub}$ [%] | 58.63 | 53.1 | 64.9 |
| | 7 | $LE_{Shroud}$ [%] | 50.16 | 45 | 55 |

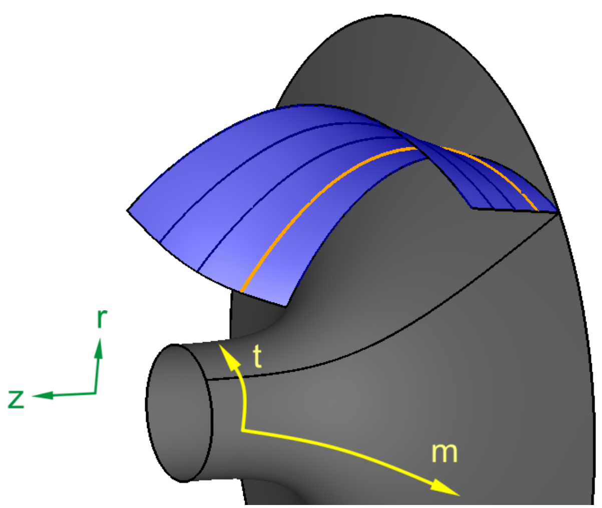


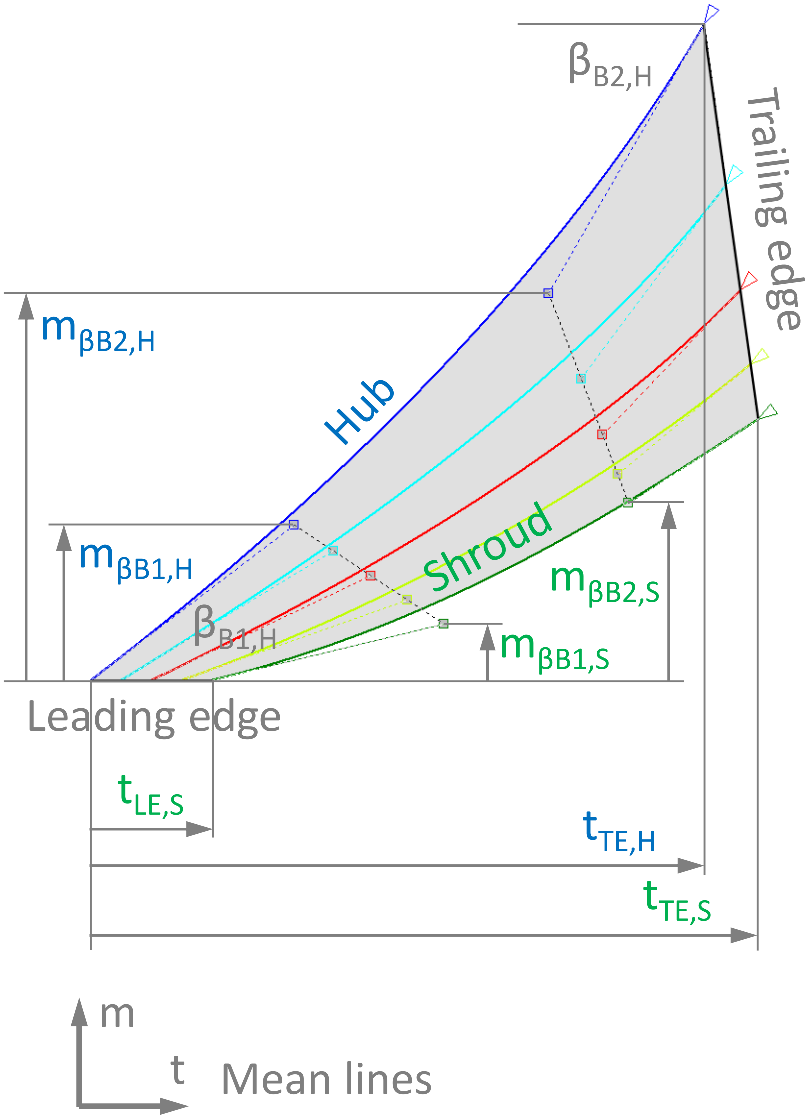

- Minimum / Maximum values: ± 10 … 20 %
- Maximum $D_2$ limited by available space

# 3. Parameters

| | # | Parameter | Reference | Minimum | Maximum |
|---|---|---|---|---|---|
| Blade properties | 8 | $n_{Bl}$ [-] | 5 | 3 | 7 |
| | 9 | $\beta_{B1,H}$ [°] | 19.65 | 15.72 | 23.58 |
| | 10 | $\beta_{B2,H}$ [°] | 28.0 | 22.40 | 33.60 |
| Mean lines | 11 | $m_{\beta B1,H}$ [%] | 36.15 | 20 | 40 |
| | 12 | $m_{\beta B2,H}$ [%] | 66.62 | 60 | 70 |



# 4. Optimization workflow

## Design point

- Flow rate Q = 0.96 $m^3/h$
- Total pressure difference $\Delta p_t$ = 0.87 bar (H = 8.885 m)
- Rotational speed = 9000 /min
- Water, no pre-swirl

## Objective

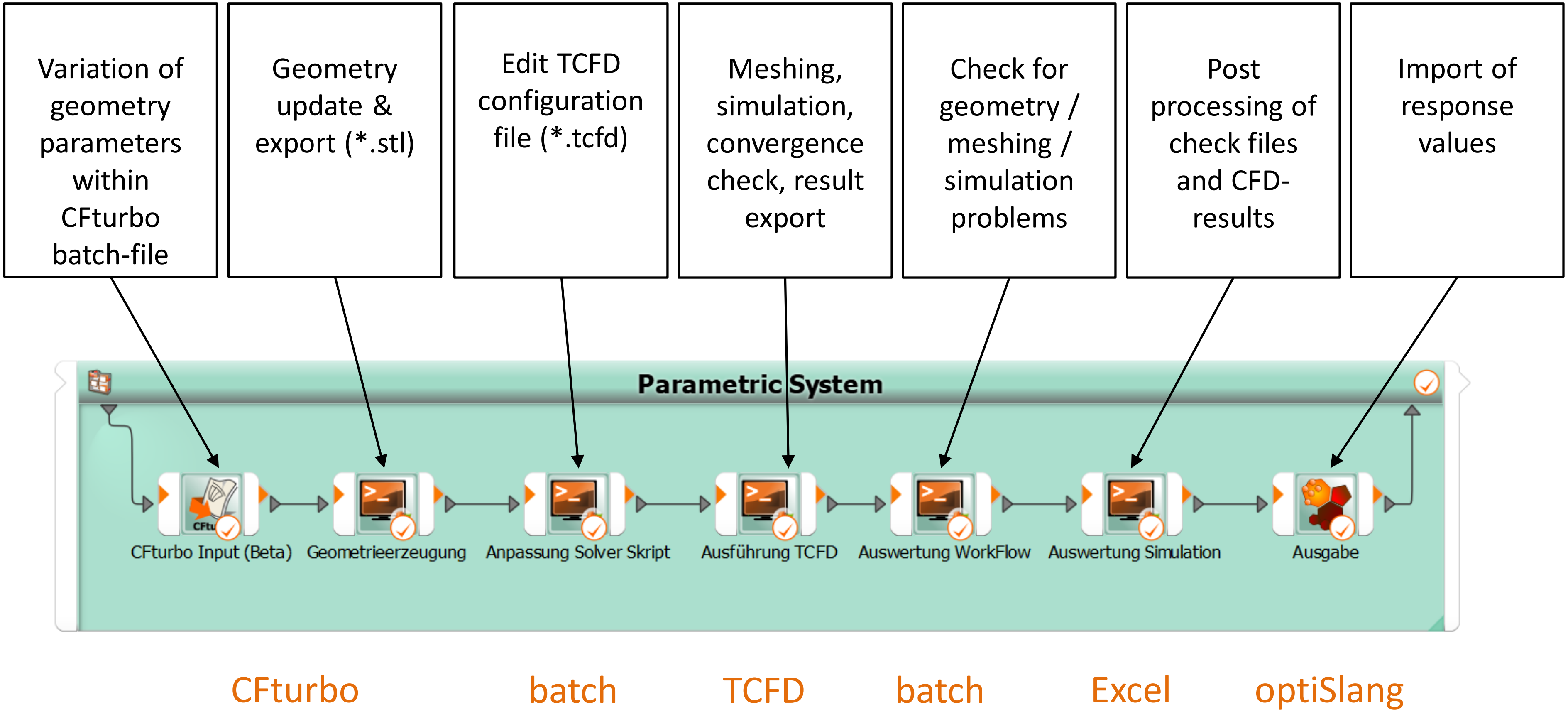
- Max. hydraulic efficiency $\eta_{hydr}$

## Constraints

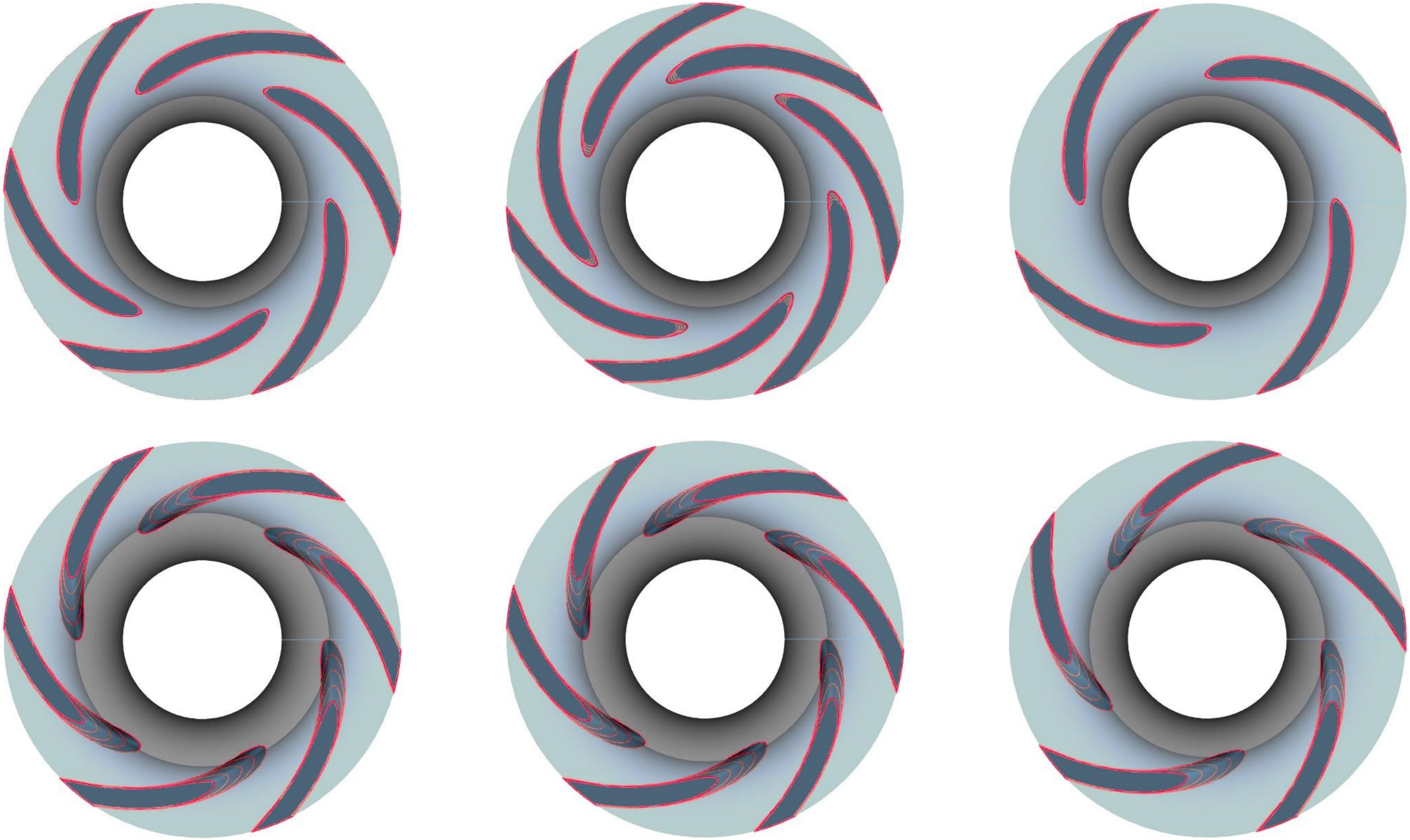
- $P_{hydr} < 30$ W
- Variation of total pressure difference $\Delta p_t \pm 10\%$

# 4. Optimization workflow



# 5. Results – Some geometry examples



# 5. Results – Sensitivity analysis / Number of samples

Advanced Latin Hypercube Sampling

| | | Samples 100 |
|---|---|---|
| Failed | Geometry | 10 |
| | Meshing | 7 |
| | Simulation | 20 |
| Valid | samples | 63 |
| Constraints | Valid | 19 |
| | Not valid | 44 |
| CoP | $\Delta p_t$ | 95.7 % |
| | $P_{hydr}$ | 96.6 % |
| | $\eta_{hydr}$ | 94.2 % |

**High variation of results**

- 61,27% ≤ $\eta_{hydr}$ ≤ 91,15%
- 36 samples with low $\eta_{hydr}$
- Reduction of samples to calculate CoP not possible

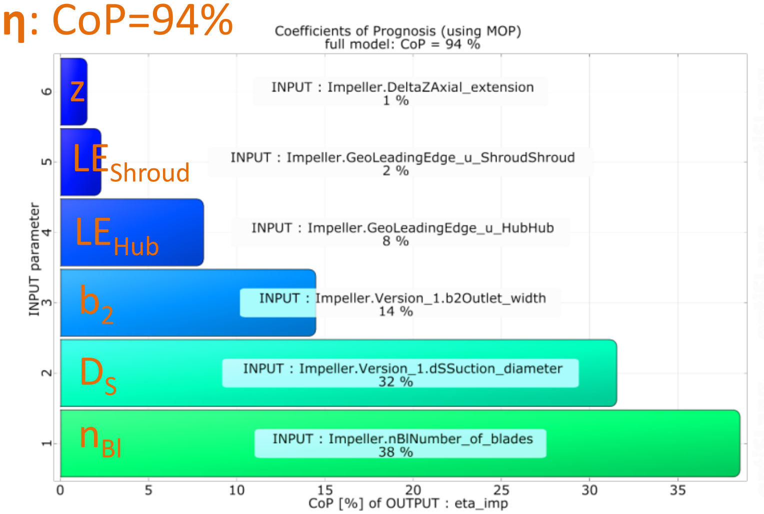
# 5. Results – Sensitivity analysis / Coefficient of Prognosis CoP

η hydraulic efficiency (objective)

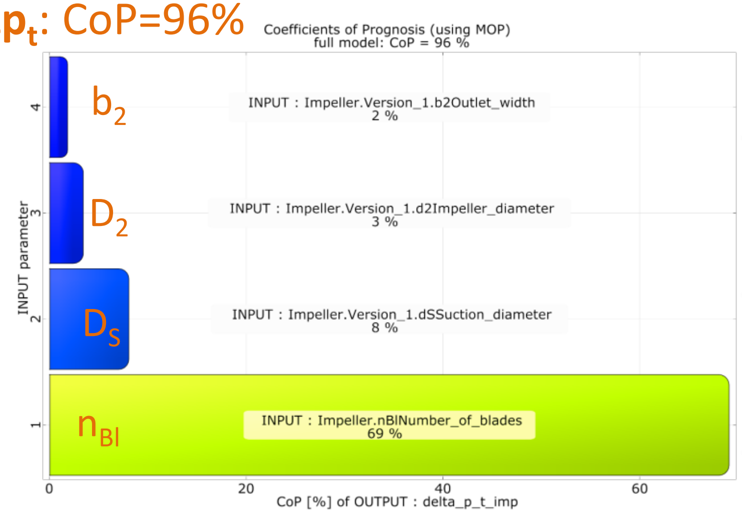
$$\eta = \frac{Q \cdot \Delta p_t}{P}$$

| | |
|---|---|
| Q | Flow rate |
| $\Delta p_t$ | Total pressure difference |
| P | Power consumption |

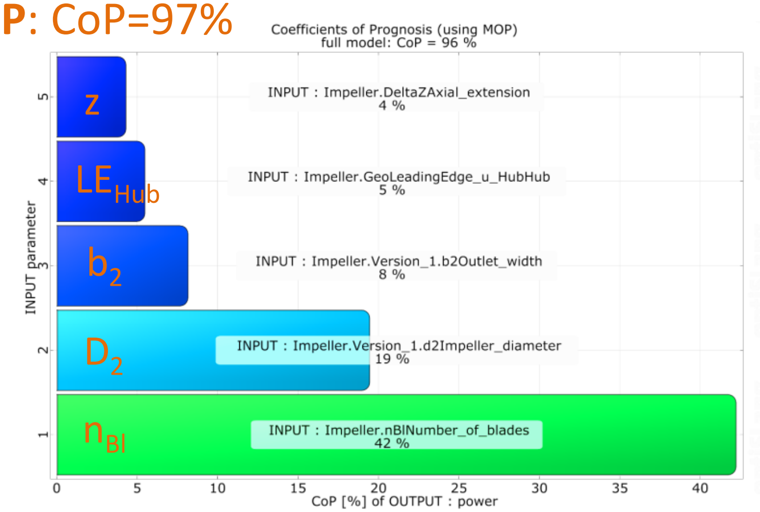
η: CoP=94%



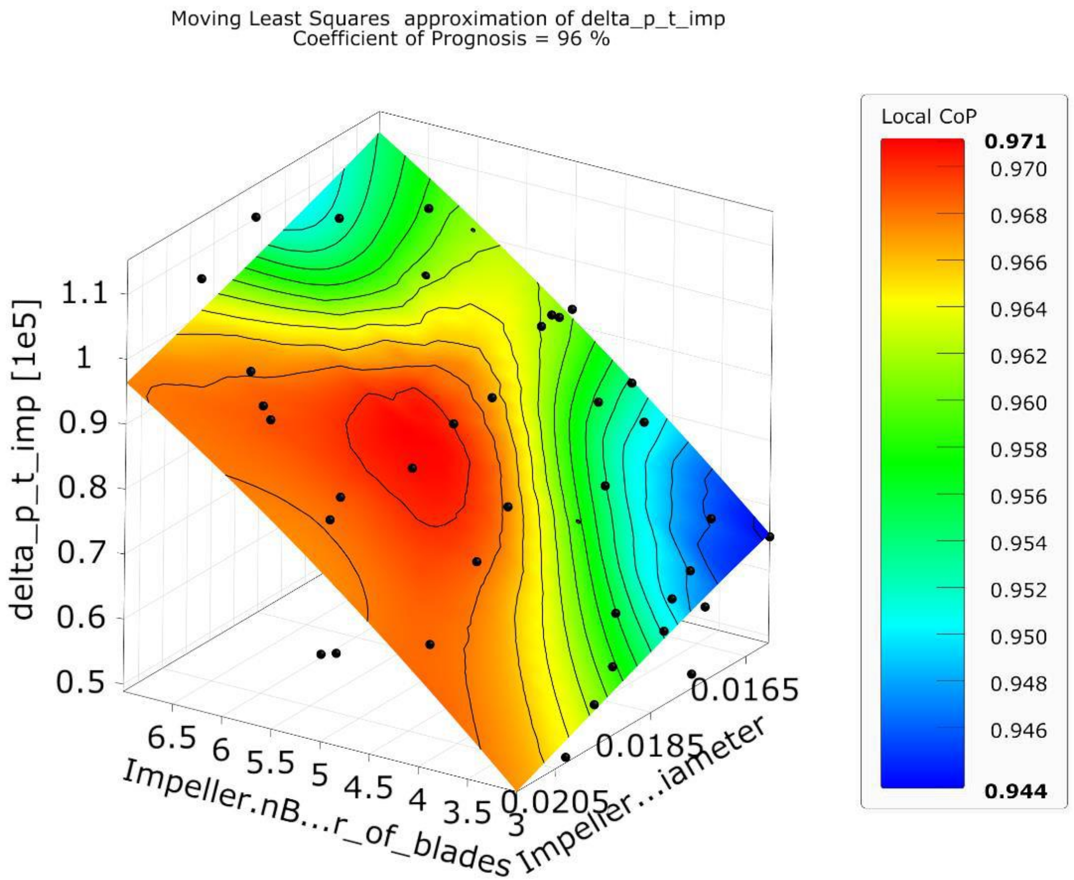

$\Delta p_t$: CoP=96%




P: CoP=97%



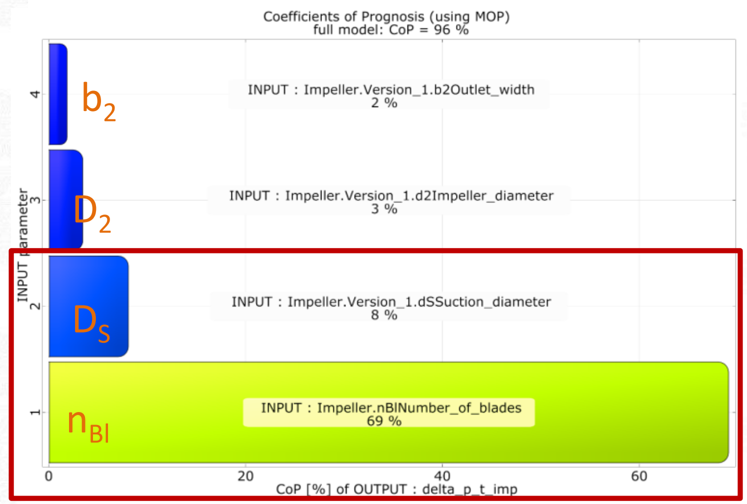
# 5. Results – Sensitivity analysis / Metamodel of Optimal Prognosis MOP



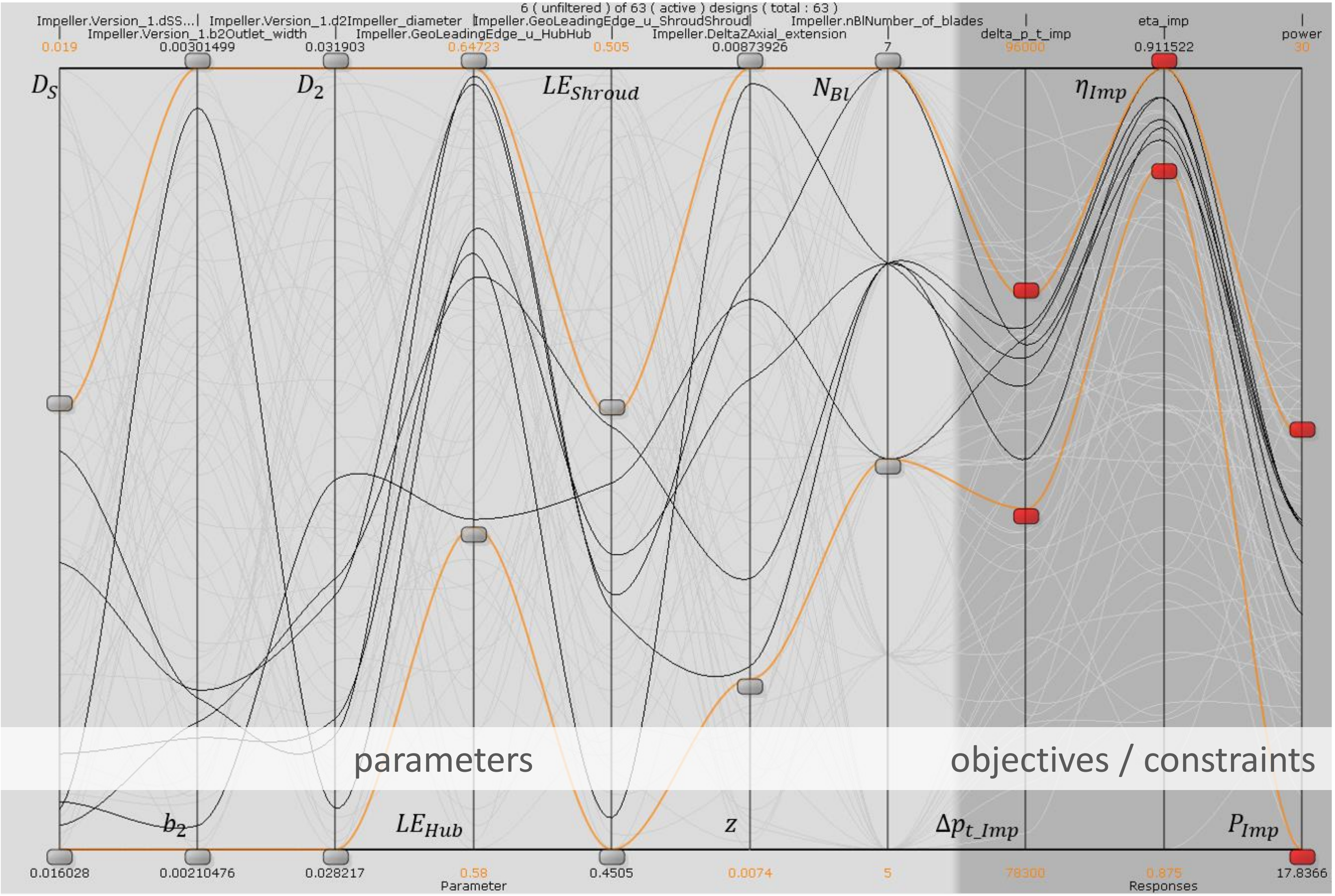

Response surface for

$\Delta p_t = f(n_{Bl}, D_s)$

**$\Delta p_t$**: CoP=96%



# 5. Results – Sensitivity analysis / Parallel coordinate plot



# 5. Results – Optimization

| Algorithm | Samples | Simulation time | Simulation time/ sample | $\eta_{hydr}$ |
|---|---|---|---|---|
| **EA** Evolutionary Algorithm | 400 | ≈ 235 h * | ≈ 35 min | 92.2 % + 10.2 % |
| **ARSM** Adaptive Response Surface Method | 260 | ≈ 255 h ** | ≈ 60 min | 92.2 % + 10.2 % |

compared to initial design

* Desktop PC

- 2 x Intel Xeon 3.30 GHz, 8 cores
- 128 GB RAM

** Desktop PC

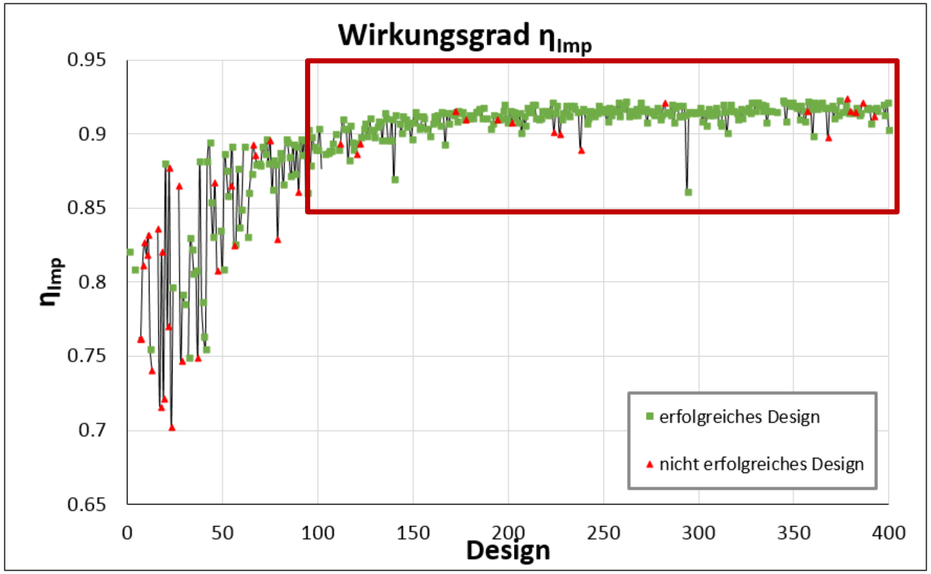
- 2 x Intel Xeon 3.07 GHz, 6 cores
- 32 GB RAM

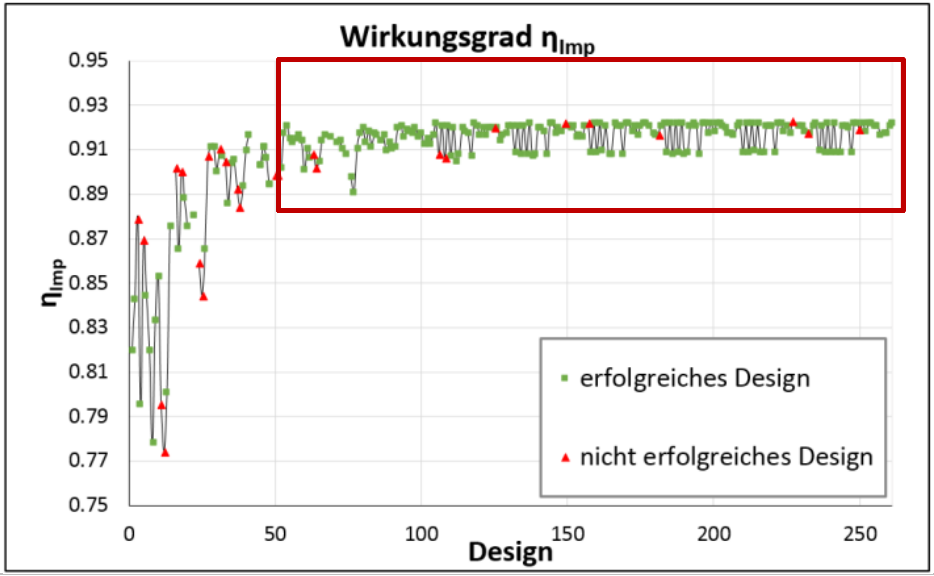
# 5. Results – Optimization

| | $D_H$ [mm] | $D_S$ [mm] | $D_2$ [mm] | $n_{Bl}$ [mm] | z [mm] | $\beta_{B1,H}$ [°] | $\beta_{B2,H}$ [°] | $\Delta p_t$ [bar] | P [ W] | $\eta_{hydr}$ [%] |
|---|---|---|---|---|---|---|---|---|---|---|
| **EA** | 12.12 | 15.98 | 29.71 | 6 | 7.28 | 18.51 | 23.73 | 0.897 | 25.94 | 92.2 |
| **ARSM** | 12.00 | 15.95 | 30.00 | 5 | 7.09 | 19.65 | 28.00 | 0.904 | 26.15 | 92.2 |

**EA:**



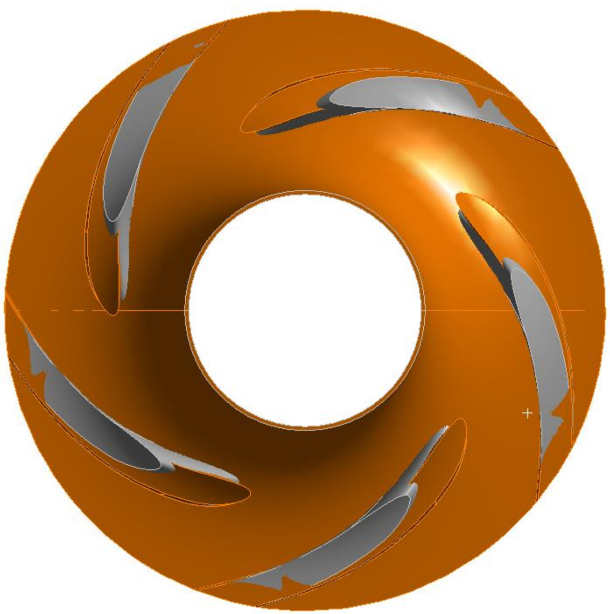

**ARSM:**



# 5. Results – Optimization

Reference
ARSM



Reference
EA

ARSM
EA

# 6. Conclusion, outlook

- Optimization process CFturbo + TCFD + optiSLang successfully tested
- CFturbo initial design can be used as very reasonable starting point („pre-optimized“) to save optimization time
- Geometry simplifications necessary to save optimization time
  → segment model
- High CoP of efficiency due to high variation of results
- Different geometric designs as result of EA and ARSM
  → more than 1 optimum with similar efficiency
- Next steps:
  - Use metamodel for indirect optimization
  - Optimization of other components (volute, diffusor) of pump with optimized impeller

Thanks to Dynardo (optiSLang) and CFD Support (TCFD) for licenses and support!