WOST 2016

Optimization of an Axial Pump using CFturbo, PumpLinx & optiSLang

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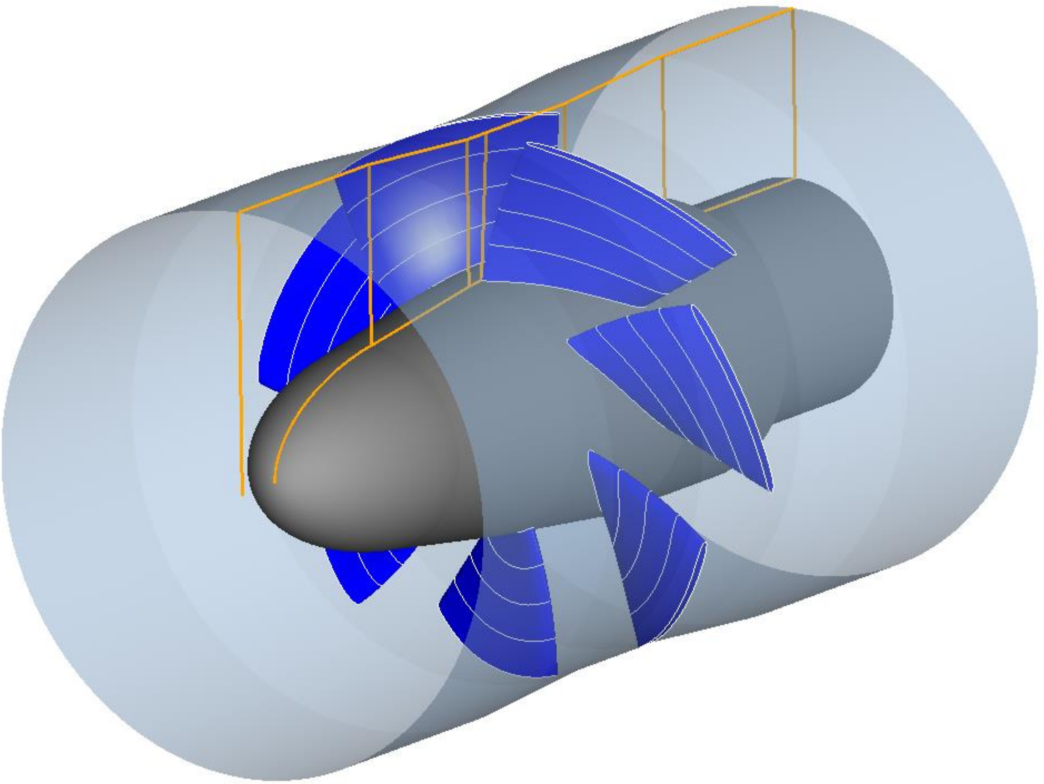
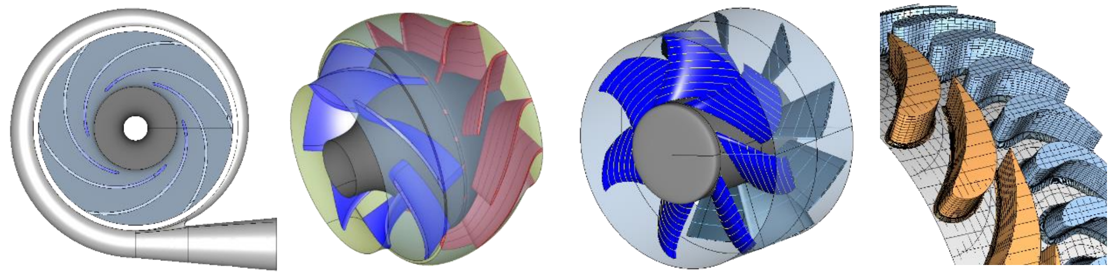
CFturbo®

Content

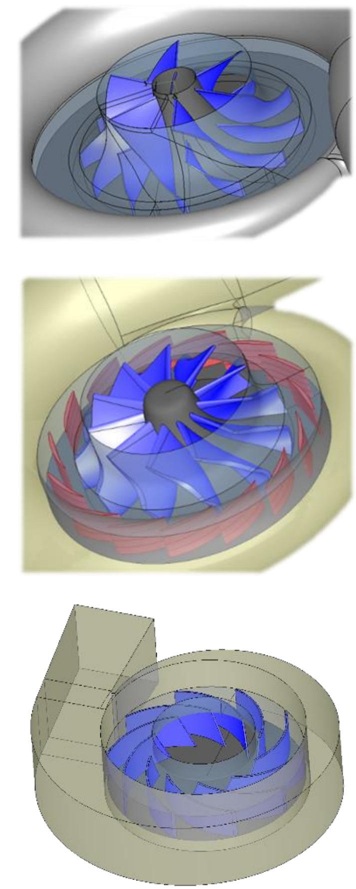


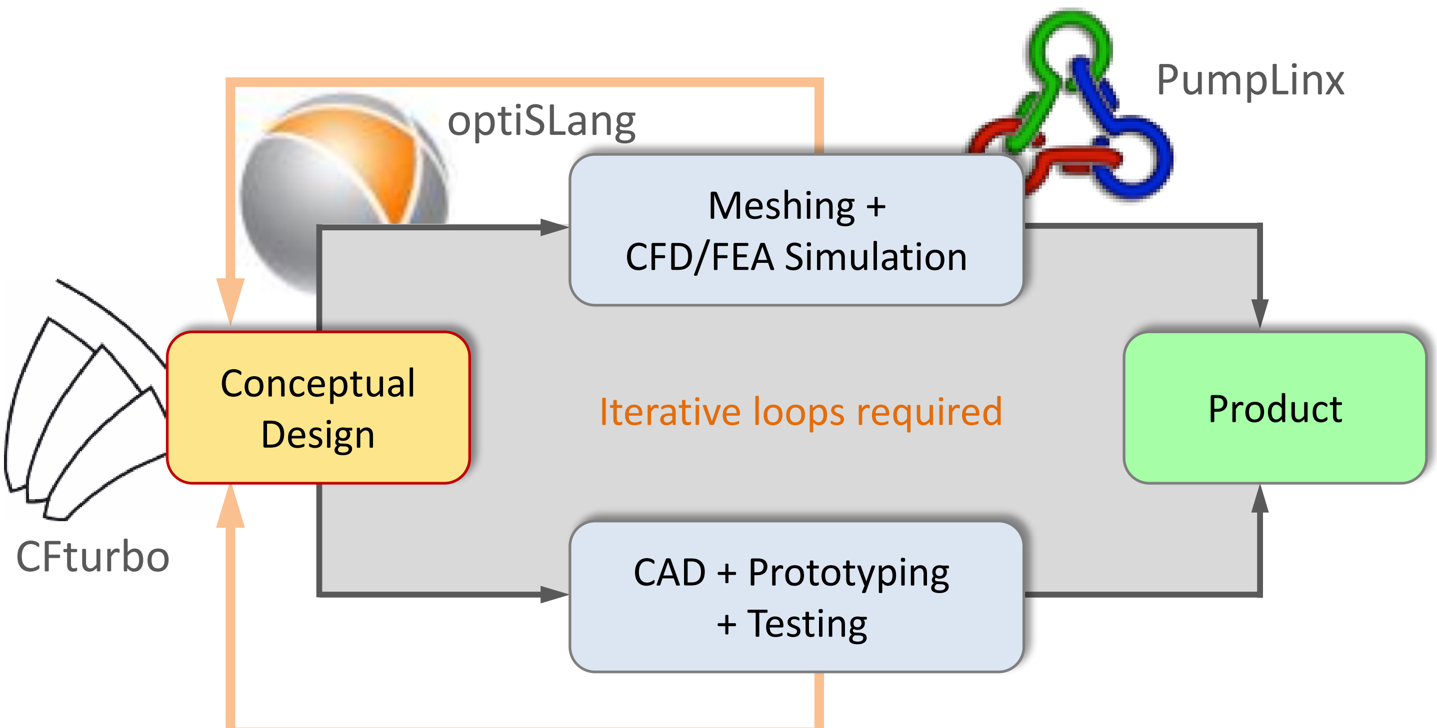
1. Motivation



Turbomachinery design is

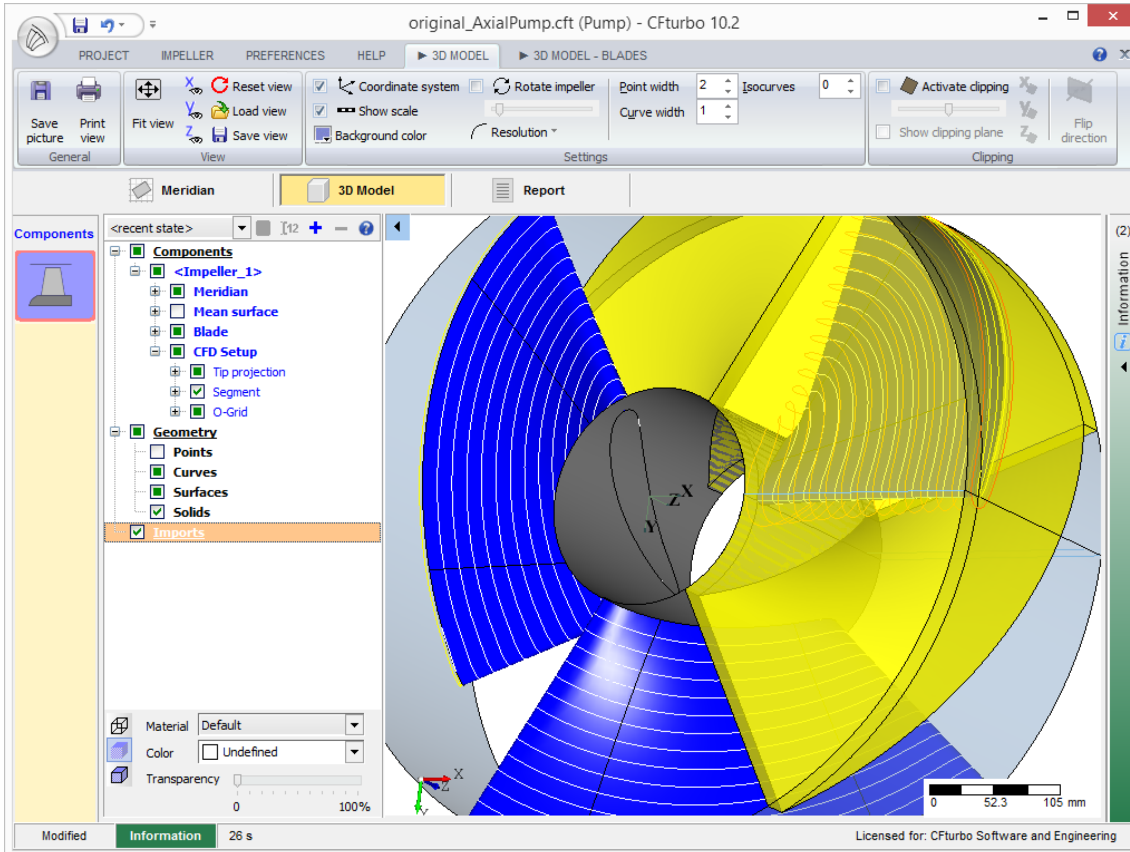
- Complex
- Time-consuming
- Expensive





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

original_AxialPump.cft-batch

```xml
<?xml version="1.0" standalone="yes"?>
<CFturboFile Version="10">
    <CFturboBatchProject InputFile="K:\jakisch\1_WOST_Gero\CFt_files\original_Axi
        <Updates>
            <CFturboProject Type="Object">
                <CFturboDesign_AxialImpeller Type="Object" Name="&lt;Impeller_1&g
                    <MainDimensions Type="Object" Desc="Main dimensions">
                        <MainDimensionsElement Type="Object" Name="Version 1." De
                            <xTip Type="Float" Desc="Tip clearance">0.003</xTip>
                        </MainDimensionsElement>
                    </MainDimensions>
                    <Meridian Type="Object" Desc="Meridian">
                        <TgrMer_AImp Type="Object" Desc="Meridional contour">
                            <Bezier4MerLE Type="Object" Name="GeoLeadingEdge" Des
                                <Points Type="Points" Count="5" Desc="Control poi
                                    <Point Type="Point" Index="0">
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                                        <y Type="Float">0.0876</y>
                                    </Point>
                                    <Point Type="Point" Index="1">
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                                    <Point Type="Point" Index="2">
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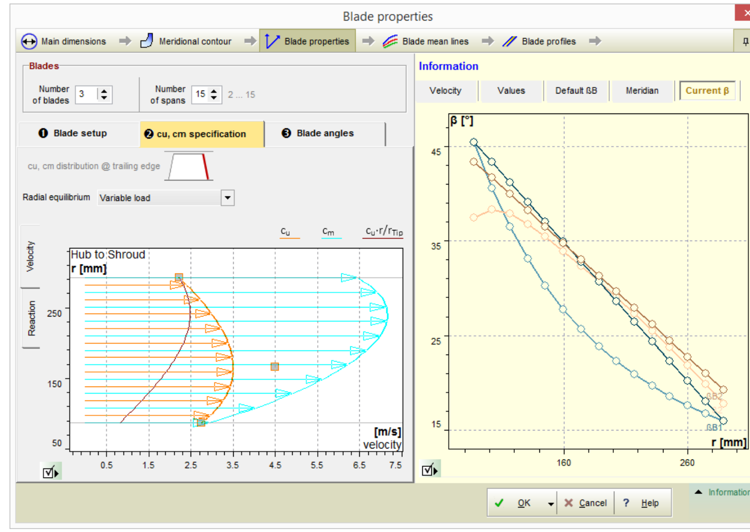
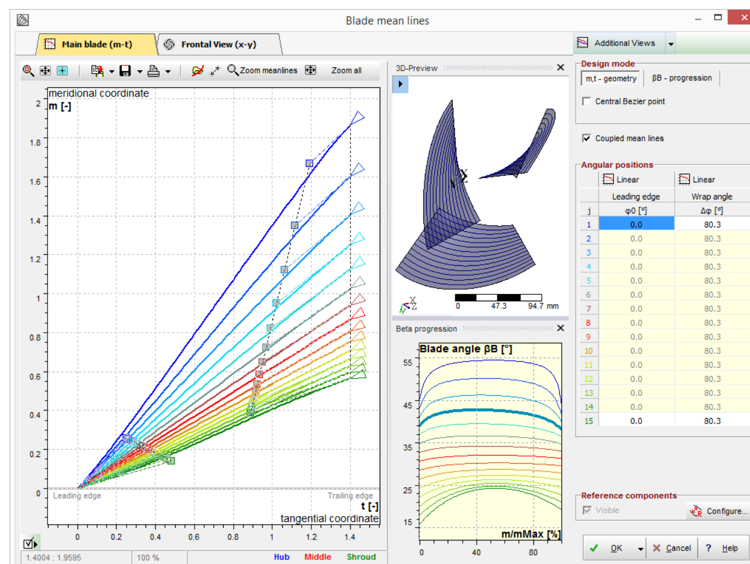
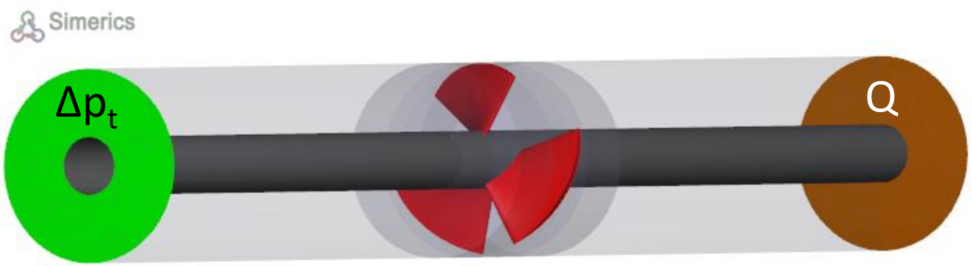




2. Software tools b) PumpLinx

CFD system with high solver speed, especially for fluid systems with rotating/ sliding components

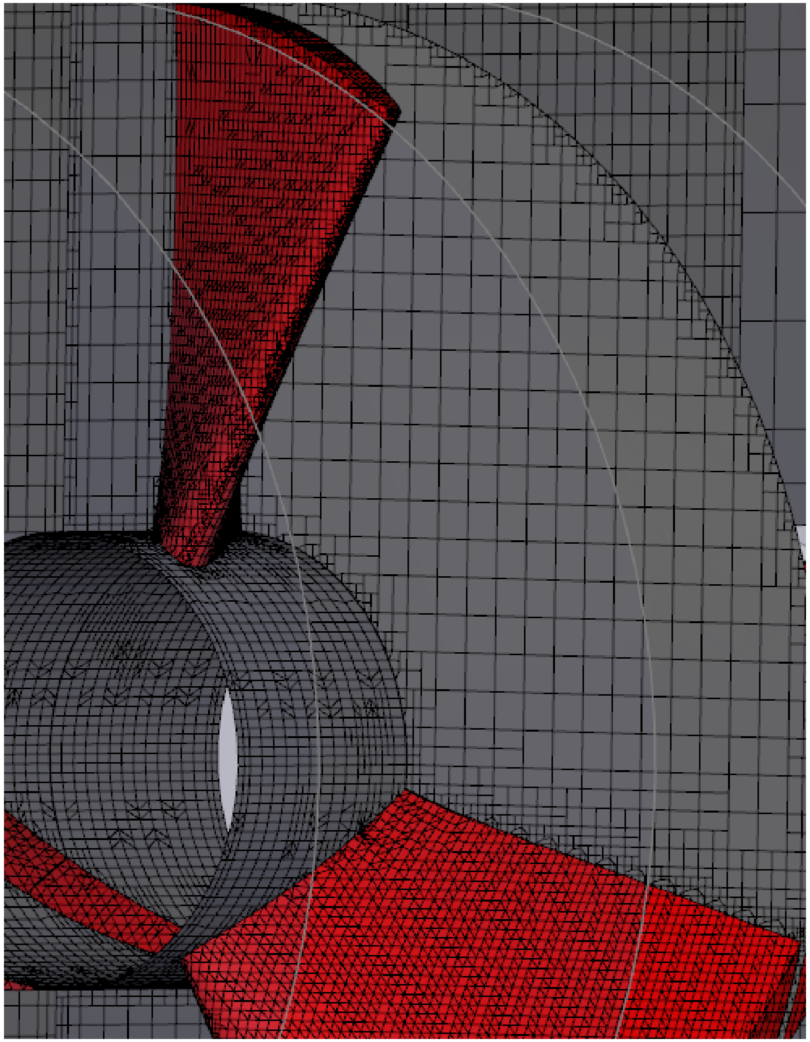
Geometry model with



inflow region impeller outflow region

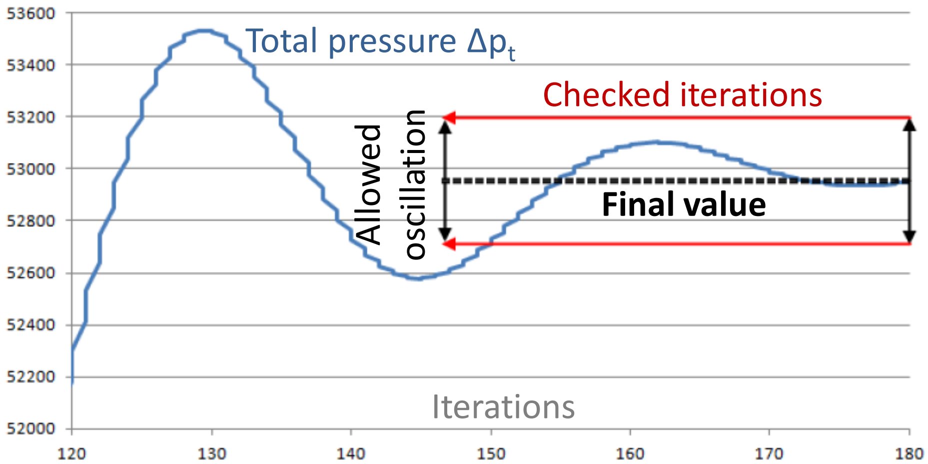
Mesh density after analysis:

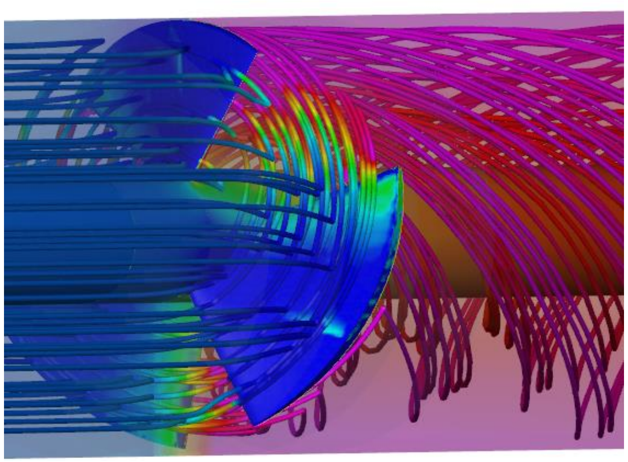
- 292 000 nodes
- 200 000 cells
- Solver speed ⇆ accuracy
- Binary tree mesh



2. Software tools b) PumpLinx

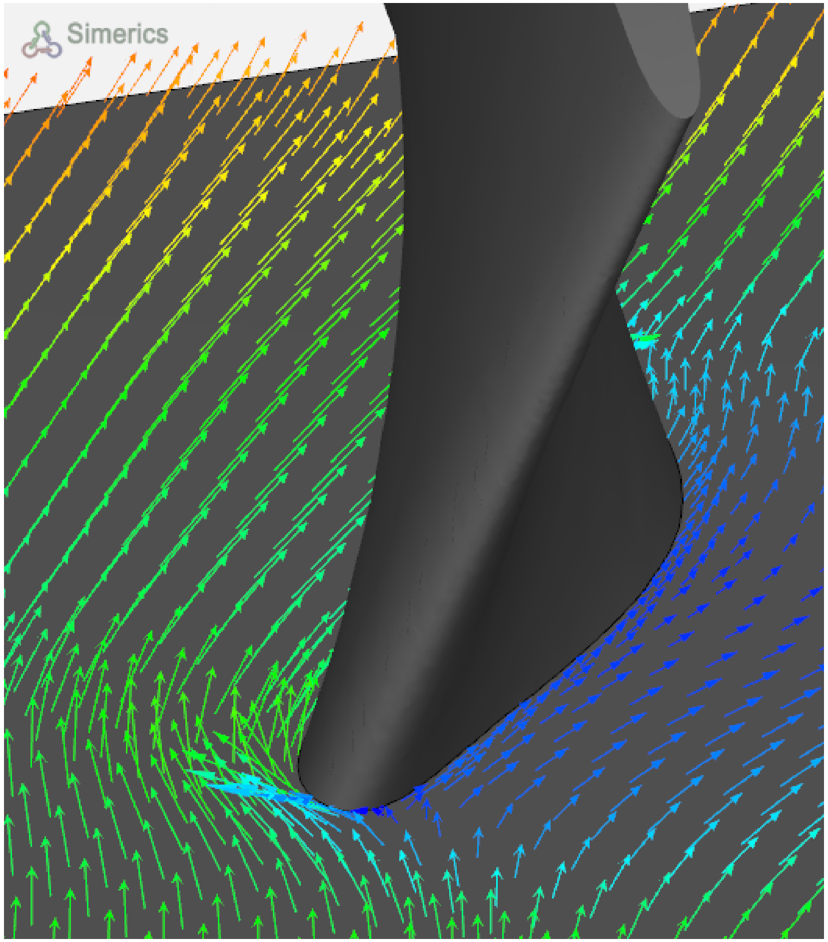
Additional convergence checks





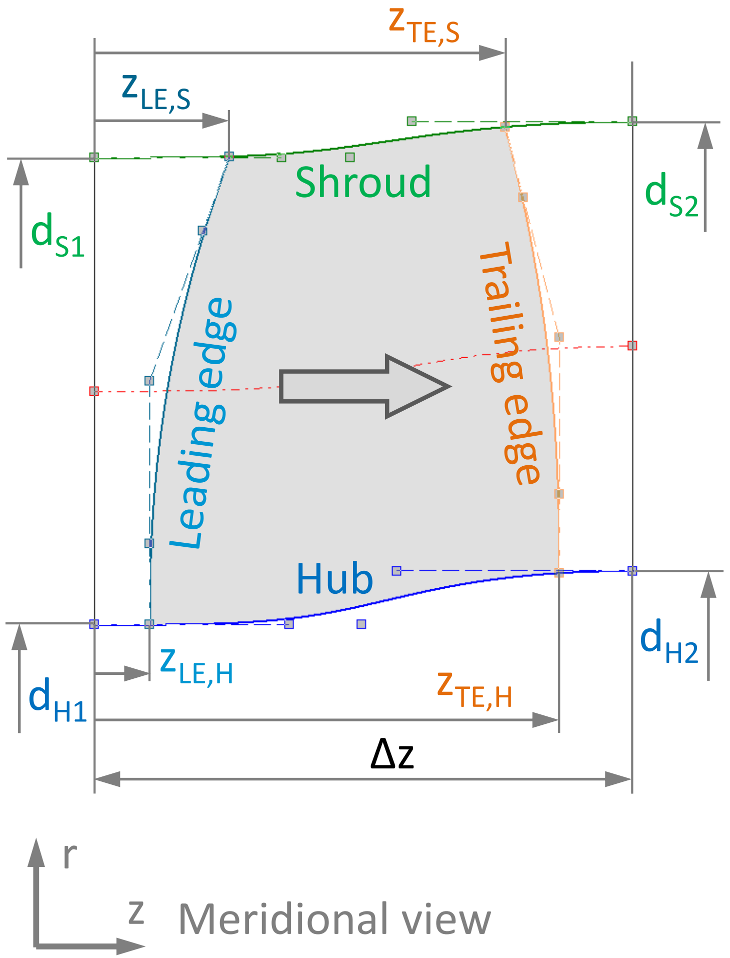
Pressure colored streamlines

Relative velocity vectors



3. Parameters

	#	Parameter	Reference	Minimum	Maximum
Main dimensions	1	$d_{H1} = d_{H2}$	176 mm	140 mm	210 mm
	2	$d_{S1} = d_{S2}$	584 mm	467 mm	700 mm
		$v = d_{H1} / d_{S1}$	0.30	0.20	0.45
Meridional contour	3	Δz	204 mm	160 mm	320 mm
	4	$z_{LE,H}{}^{*}$	0.1	0.2	0.1
	5	$z_{LE,S}{}^{*}$	0.2	0.02	0.4
	6	$z_{TE,H}{}^{*}$	0.9	0.8	0.9
	7	$z_{TE,S}{}^{*}$	0.9	0.6	0.98

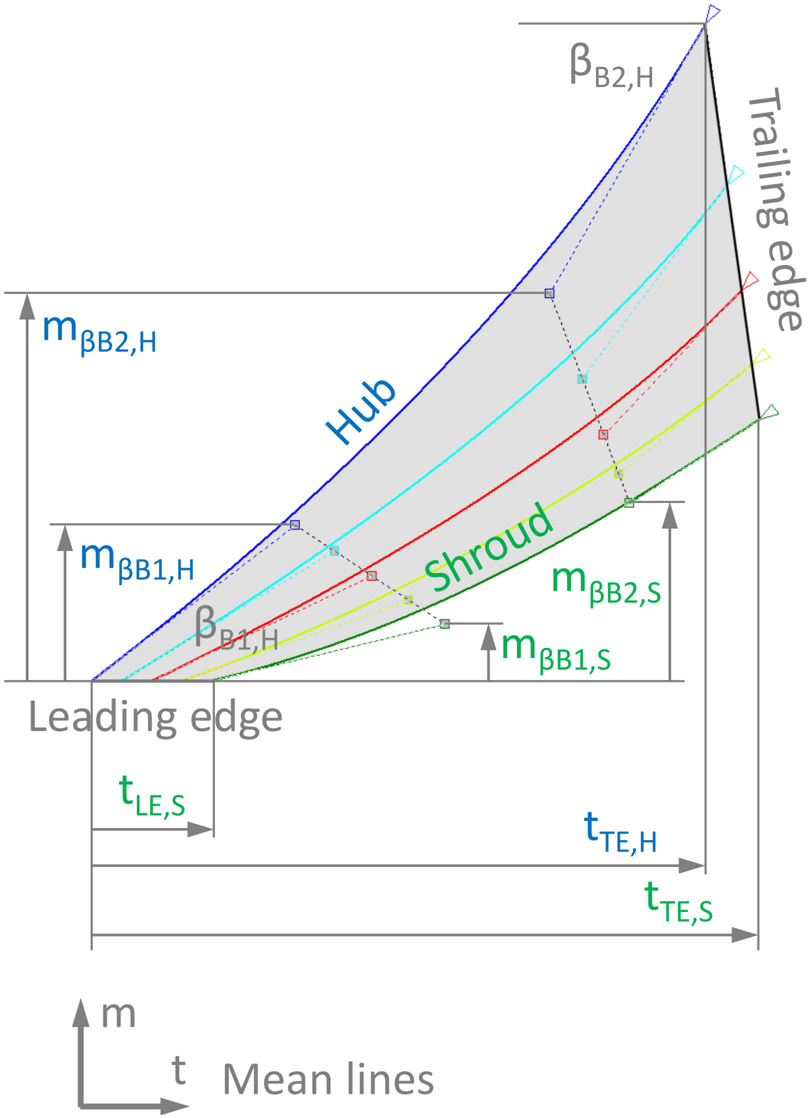


Simplifications:

- Hub and Shroud (Tip) axis-parallel
- Straight meridional leading and trailing edge

3. Parameters

	#	Parameter	Reference	Minimum	Maximum
Blade properties	8	n_{Bl}	3	2	6
Mean lines	9	$t_{LE,S}$	0°	-25°	25°
	10	$t_{TE,S}$	80.3°	64.25°	96.37°
	11	$t_{TE,H}$	80.3°	64.25°	96.37°
	12	$m_{\beta B1,H}$*	0.333	0.1	0.4
	13	$m_{\beta B1,S}$*	0.166	0.1	0.4
	14	$m_{\beta B2,H}$*	0.718	0.6	0.9
	15	$m_{\beta B2,S}$*	0.773	0.6	0.9



Simplifications:

- Free vortex velocity distribution
- Automatic calculation of blade angles β_{B1} (shock-less inflow), β_{B2} (Euler equation)

4. Optimization workflow

Design point

- Flow rate Q = 1.476 m^3/s
- Total pressure difference Δp_t = 0.466 bar (H = 4.755 m)
- Rotational speed = 780 /min
- Water, no pre-swirl

Objective

- Max. hydraulic efficiency η

Constraints

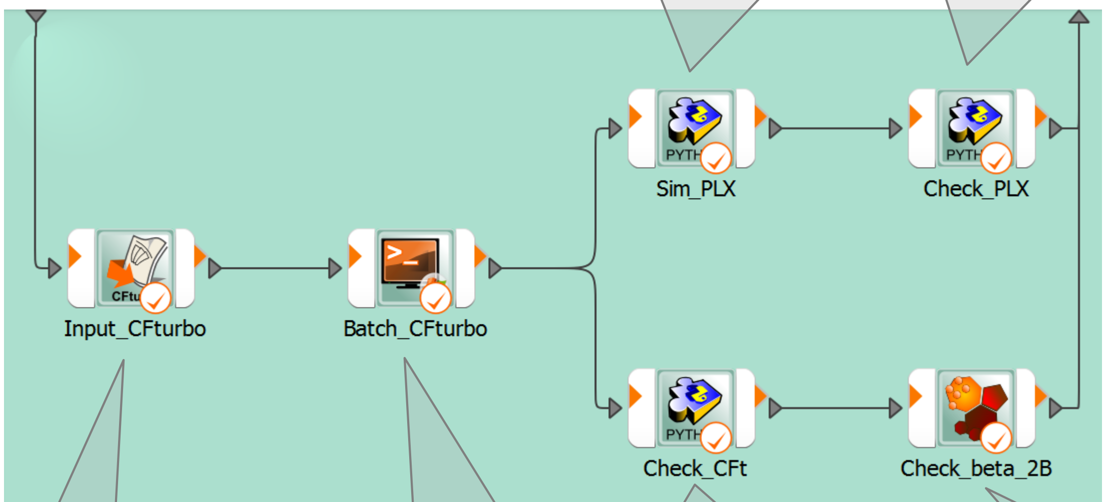
- $\beta_{B2} < 90°$
- Total pressure difference Δp_t ± 10%

4. Optimization workflow

PumpLinx

Meshing, simulation, convergence check, interpretation

Check for meshing and simulations problems



CFturbo

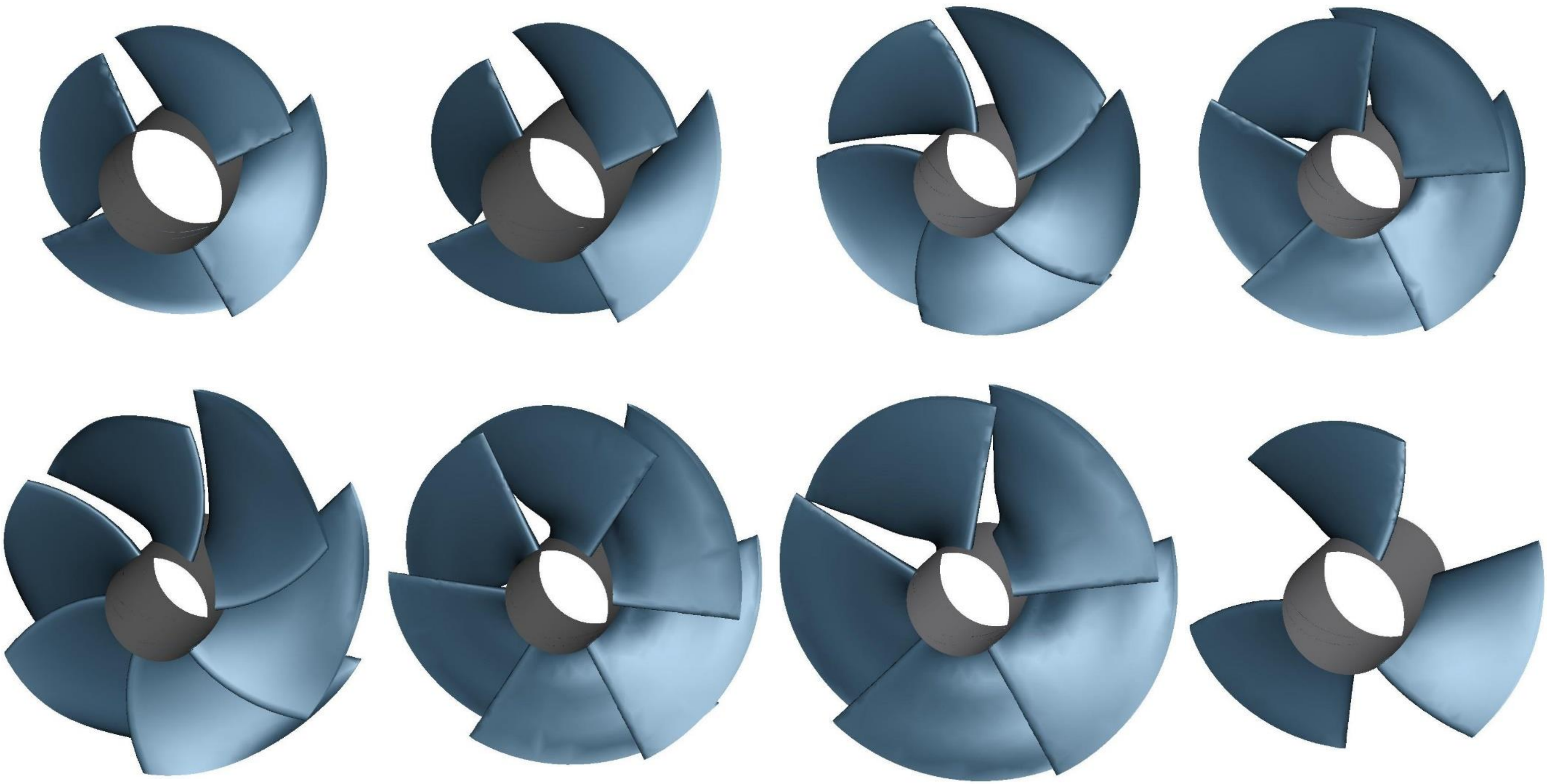
Variation of geometry parameters

Geometry update & export (*.spro, *.stl)

Check log for warnings and errors

$\beta_{B2} < 90°$?

5. Results – Some geometry examples

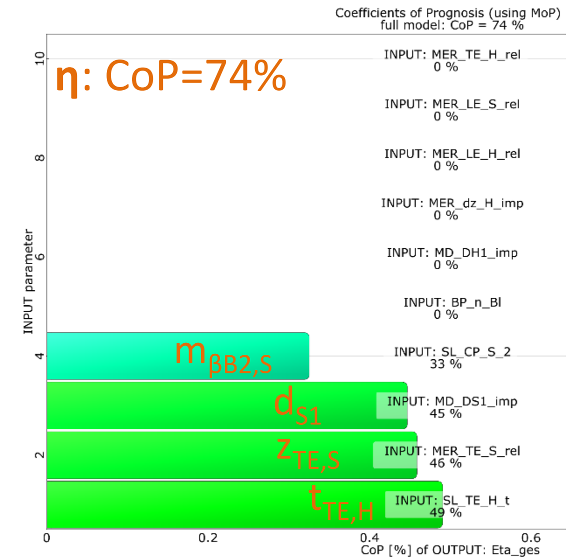


5. Results – Sensitivity analysis/ Number of samples

Advanced Latin Hypercube Sampling

		Samples		
		100	200	300
Failed	CFturbo	15	32	46
	PumpLinx	1	3	9
Valid	samples	84	165	245
Reduced		74	139	233
CoP	Q	83.6 %	86.6 %	89.1%
	Δp_t	85.8 %	90.6 %	88.4 %
	P	91.5 %	92.9 %	94.0 %
	η	57.4 %	66.5 %	73.6 %

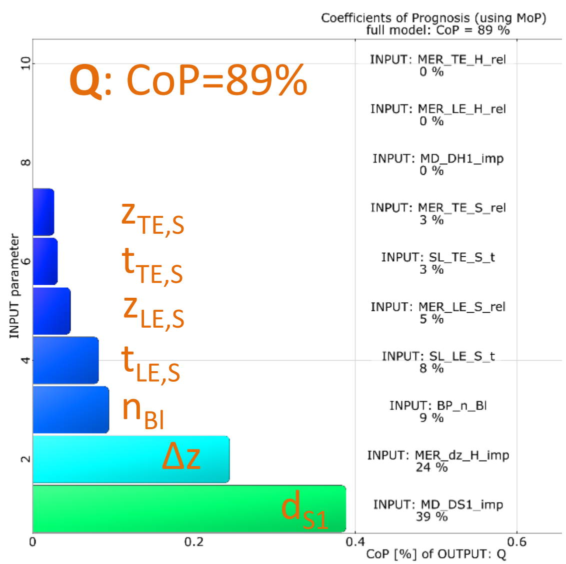
5. Results – Sensitivity analysis/ Coefficient of Prognosis CoP

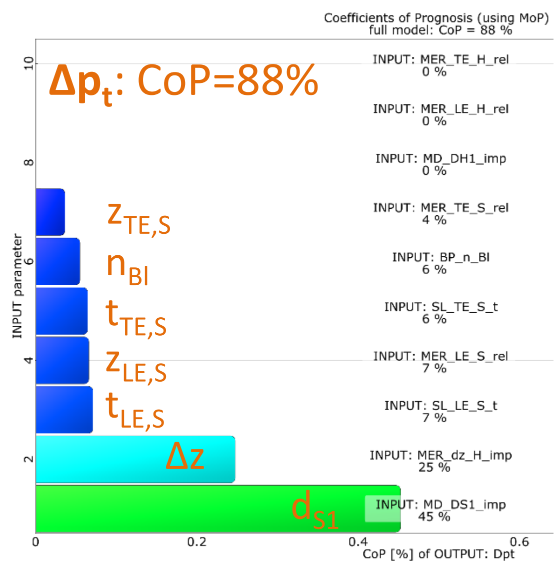


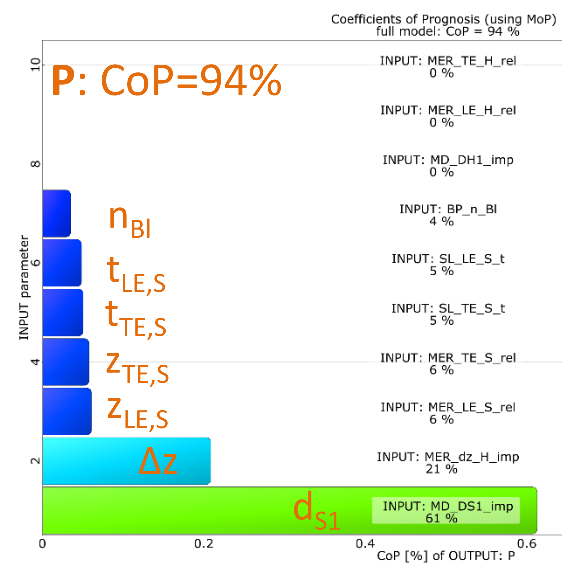
η hydraulic efficiency (objective)

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

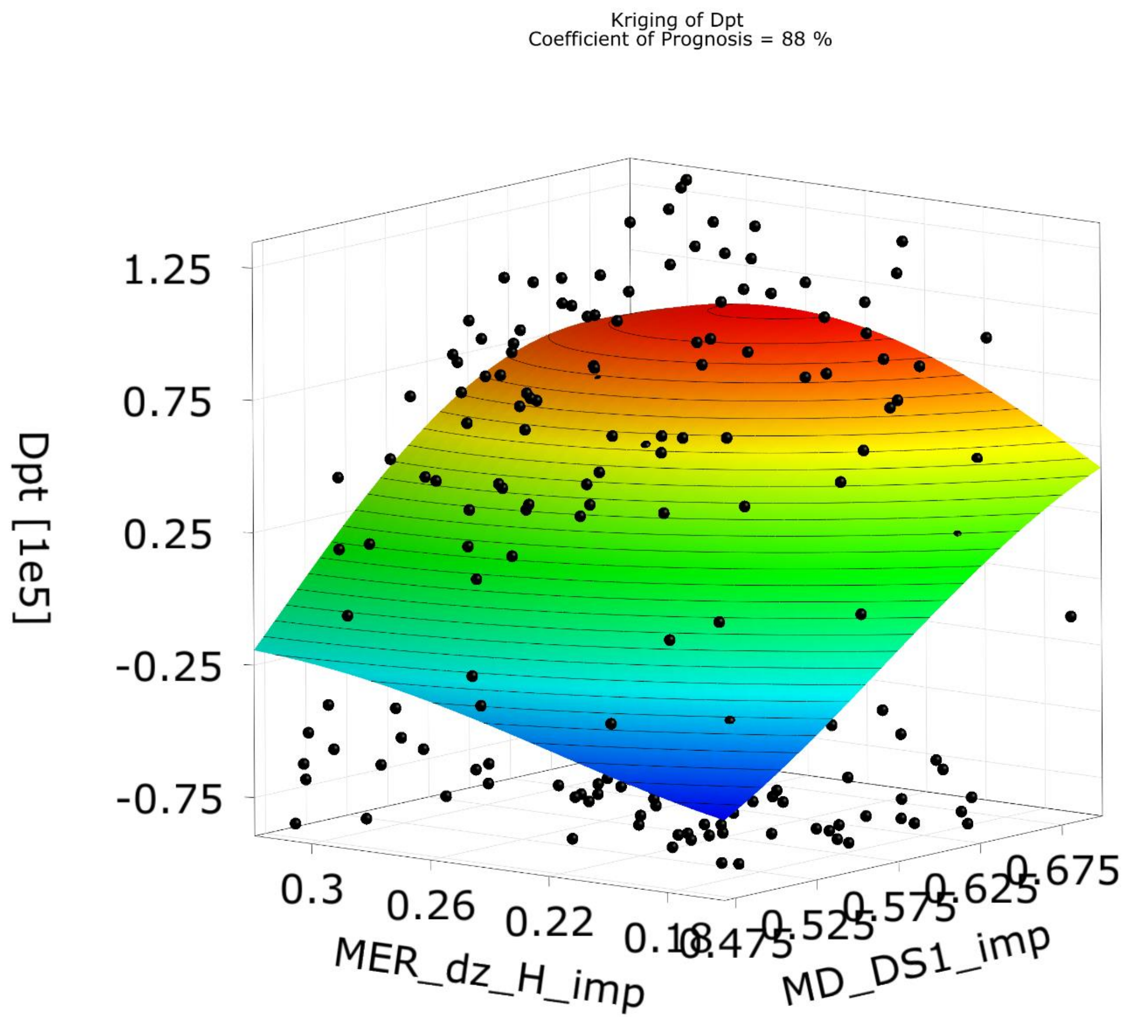
Q	Flow rate
Δp_t	Total pressure difference
P	Power consumption





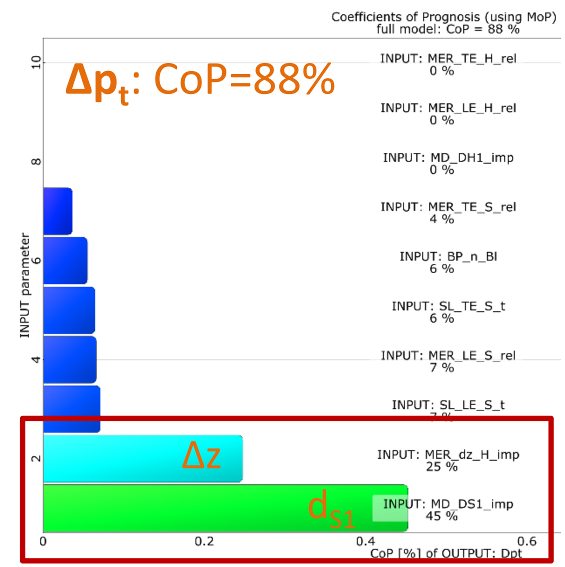


5. Results – Sensitivity analysis/ Metamodel of Optimal Prognosis MOP

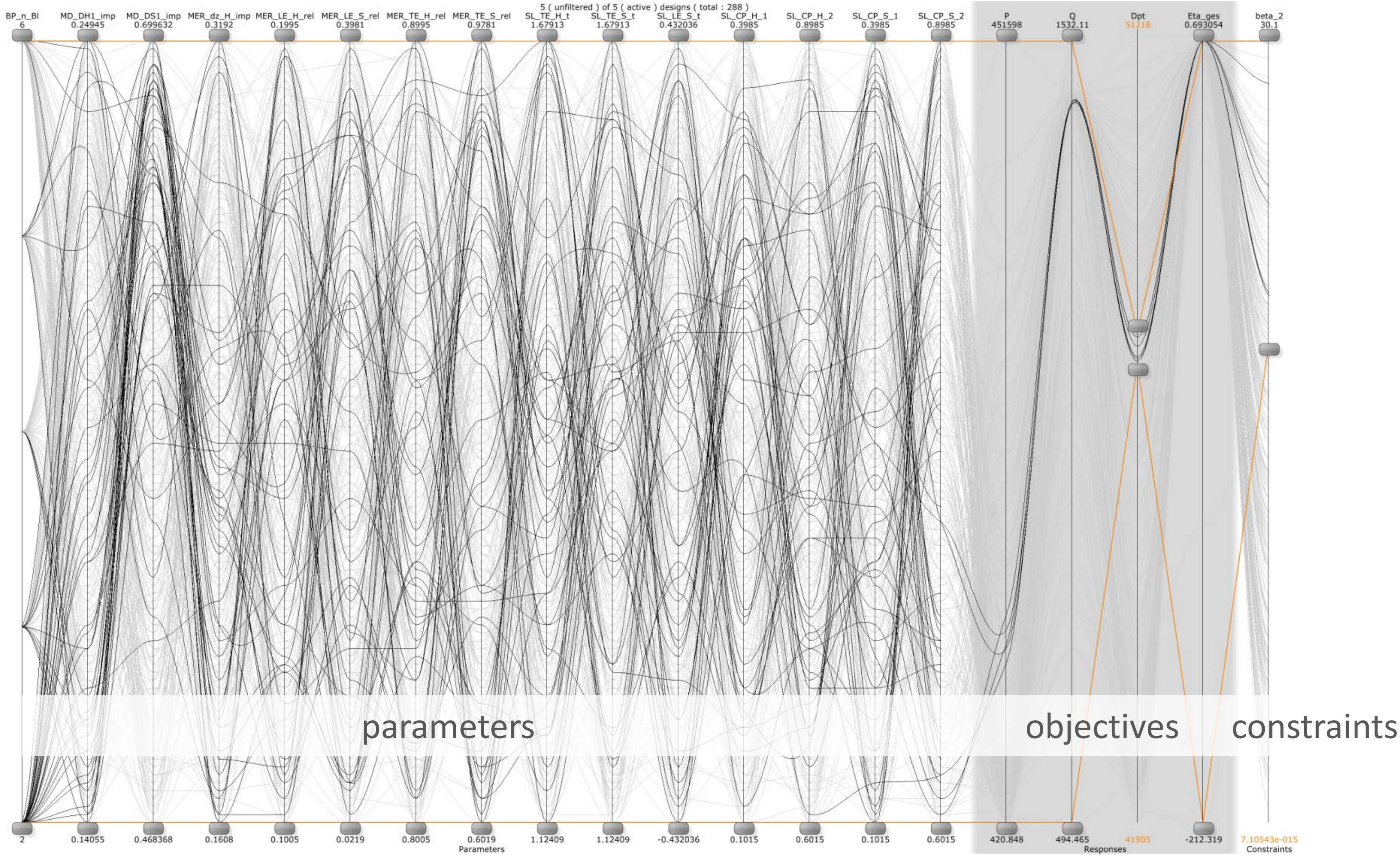


Response surface for

$\Delta p_t = f(d_{S1}, \Delta z)$



5. Results – Sensitivity analysis/ Parallel coordinate plot



5. Results – Optimization

Algorithm	Samples	Simulation time	Simulation time/ sample	η
EA Evolutionary Algorithm	330	72.2 h (3.0 d)	13.1 min	69,9 % + 5.0 %
ARSM Adaptive Response Surface Method	540	126.3 h (5.3 d)	14.0 min	69,3 % + 4.4%

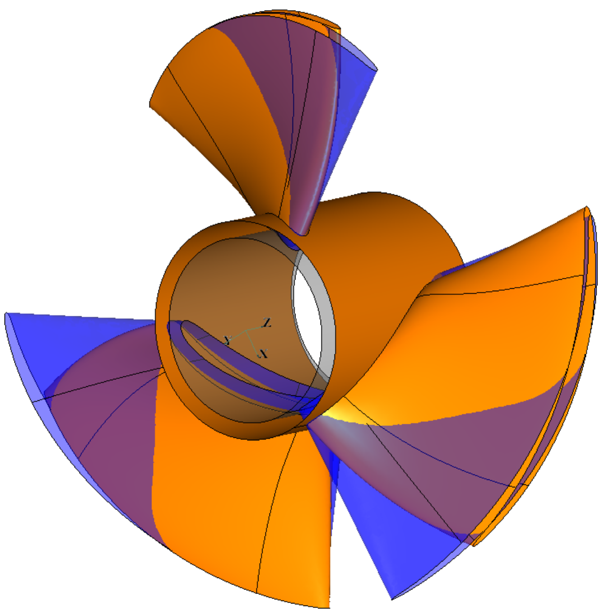
Desktop PC

- 2 x Intel Xeon 3.07 GHz, 6 cores
- 64 GB RAM
- Max. 2 parallel simulation jobs

5. Results – Optimization

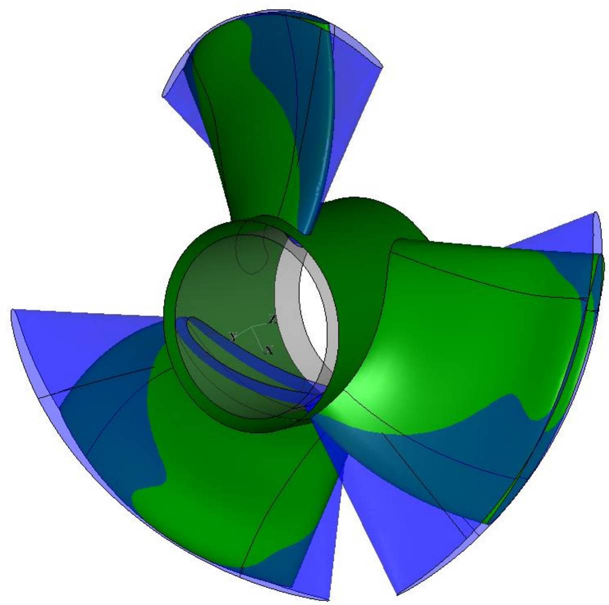
Reference

ARSM



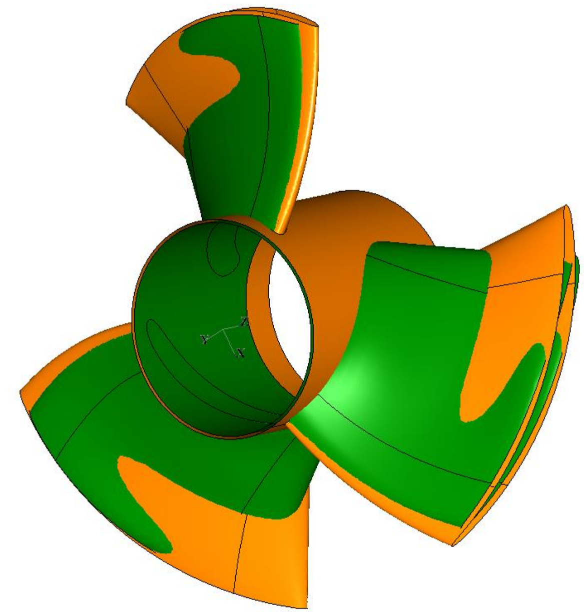
Reference

EA



ARSM

EA



6. Conclusion, prospects

- Optimization process CFturbo + PumpLinx + optiSLang successfully tested
- PumpLinx solver speed is beneficial for optimization and enables optimization on desktop PCs
- CFturbo initial design can be used as very reasonable starting point („pre-optimized“) to save optimization time
- Number of parameters could be reduced to ~ 50% by sensitivity analysis
  → automatic parameter reduction in CFturbo possible in near future
- Metamodel for efficiency seems to be not possible
  → direct optimization with reduced parameter set seems to be the best solution
- Removing geometry simplifications is necessary
- Empirical based performance prediction in CFturbo could be used to further reduce simulation effort → CFturbo "included" metamodel

Thanks to Dynardo (optiSLang) and Simerics (PumpLinx) for licenses and support!

