

CFturbo

Hydraulic Design and Optimization
of Multistage Pumps

Authors:

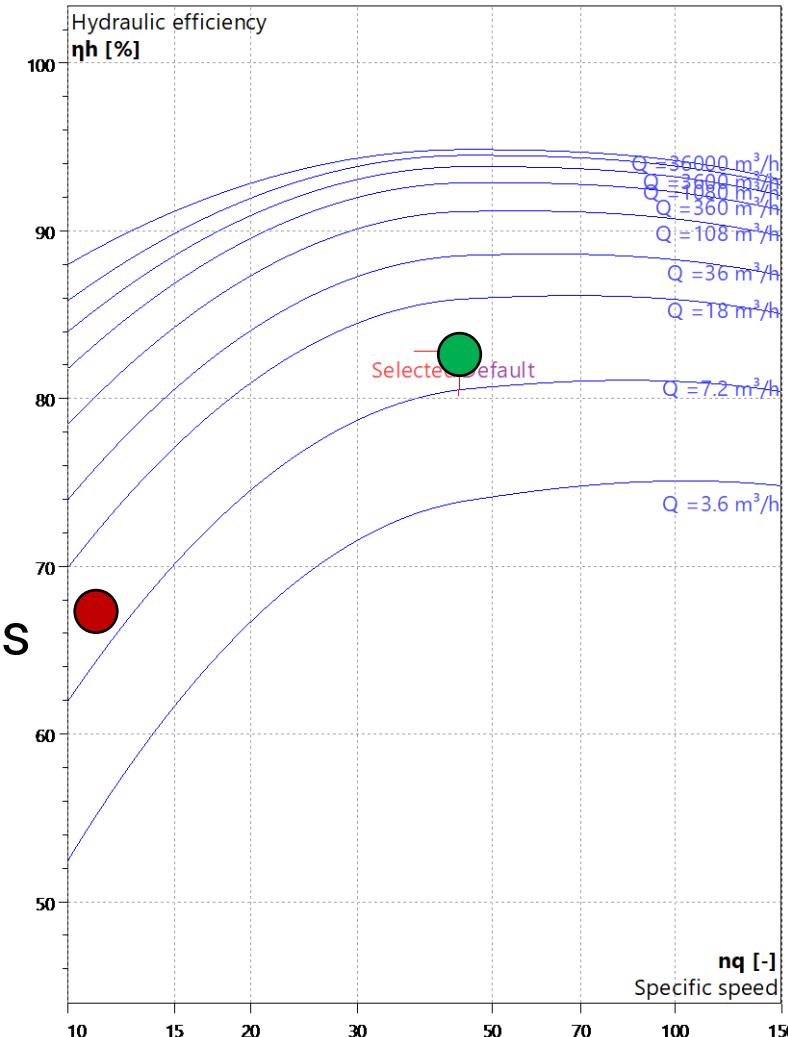
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- Achievable specific work Y for single pump stage is limited
 - Circumferential velocity u (mechanical strength limit)
 - Work coefficient ψ (flow-related limit)
- Multiple stages recommended, if maximum specific work is reached

Benefits of Multistage Pumps:

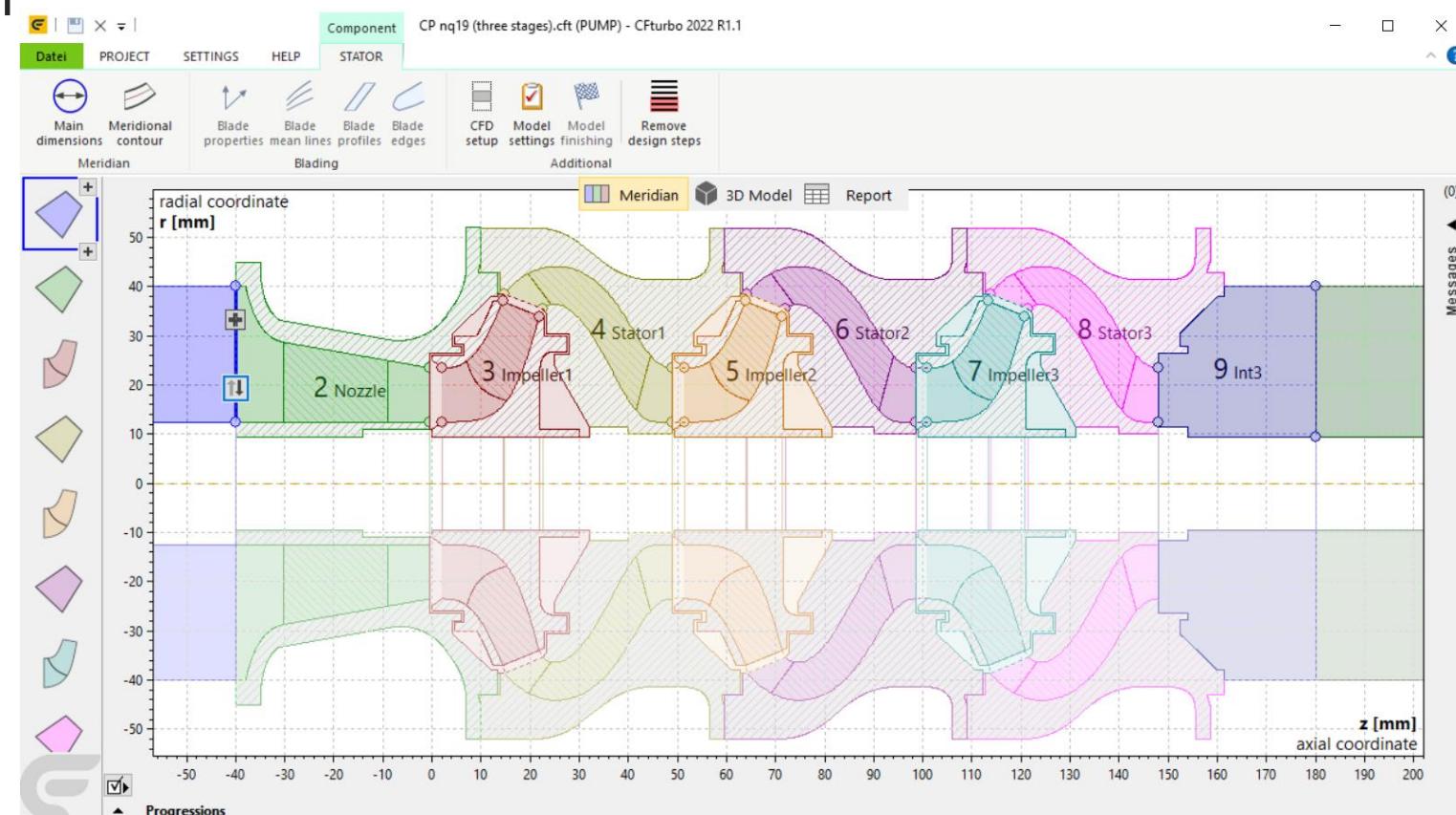
- Increase head and operation range by adding additional stages
- Better packaging (smaller impeller diameter)
- Smaller blade tip clearance achievable
- More efficient impeller designs possible



Conceptual Turbomachinery Design – Duty Point

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- Volume flow rate $Q = 10 \text{ m}^3/\text{h}$ (44 gpm)
- Head $H = 20 \text{ m}$ (65.6 ft)
- Rotational speed $n = 3600 \text{ rpm}$
- Water at 20°C (68°F)

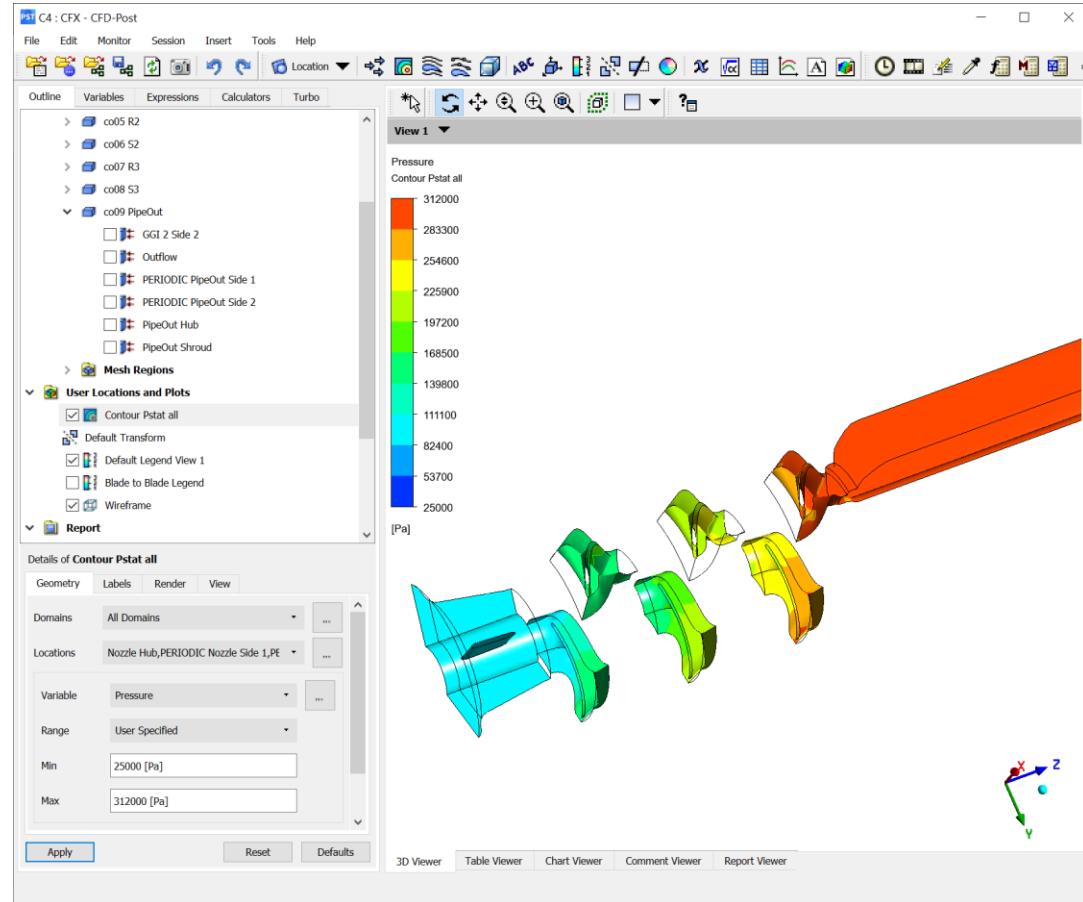


Duty Point Evaluation – Solver Choices

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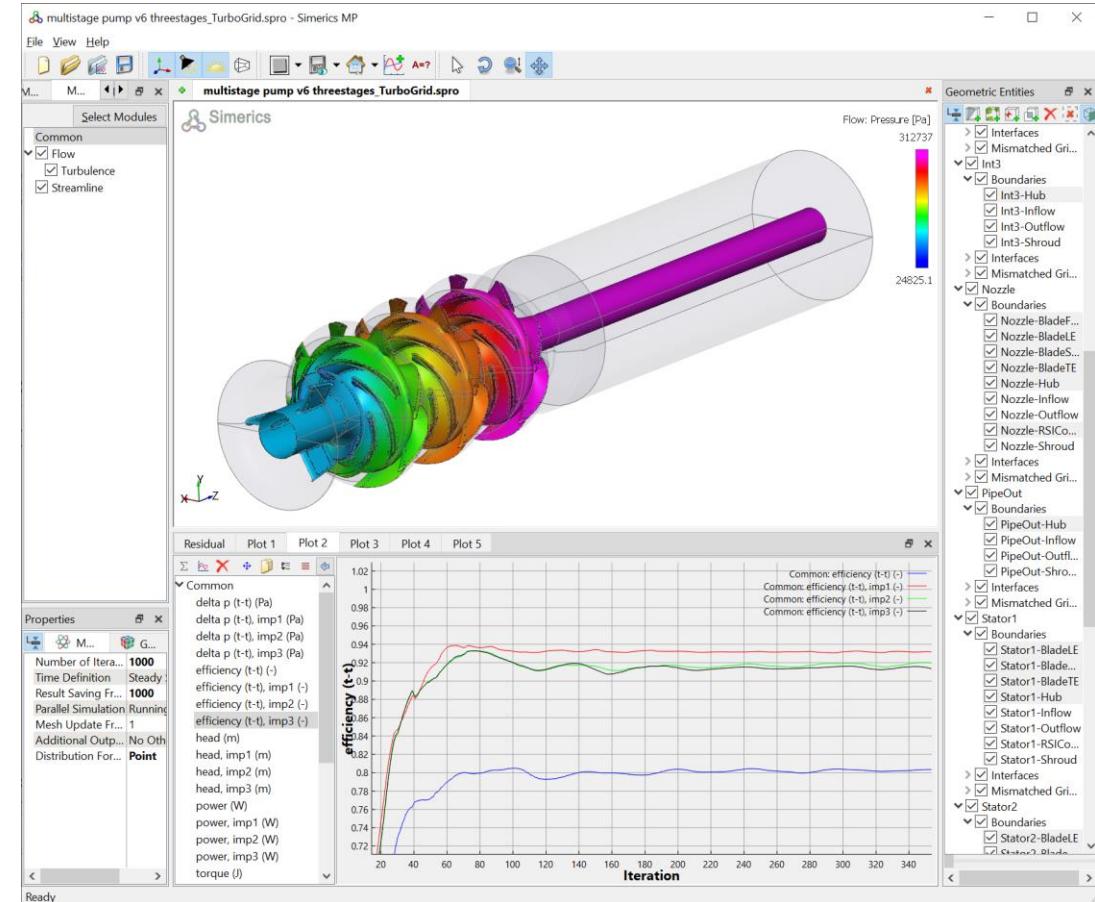
ANSYS CFX

- Segment model
- Steady-state CFD simulations
- 1.3 million nodes



CFturbo SMP (Simerics MP)

- 360° model
- Steady-state and transient CFD simulations
- 4 million nodes



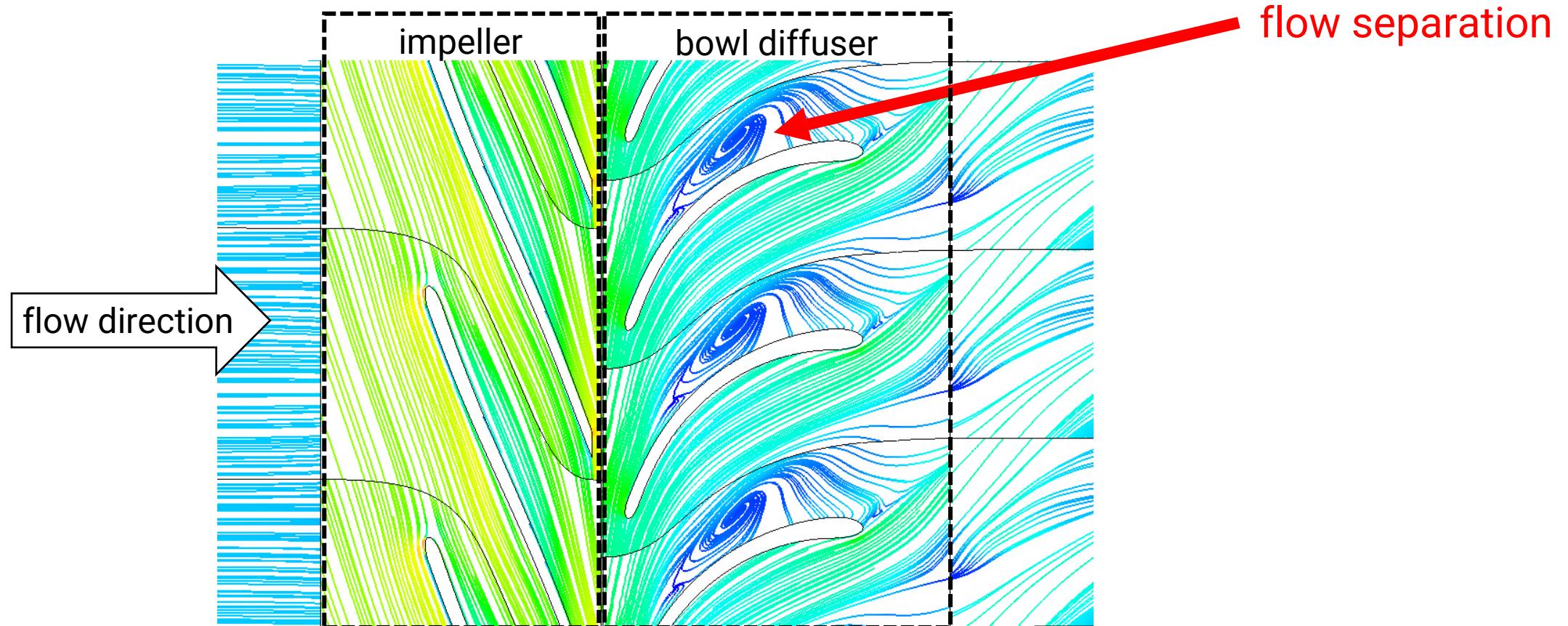
Duty Point Evaluation – Tabular CFD Results

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CFD-solver	H_{total} [m]	H_{Imp1} [m]	H_{Imp2} [m]	H_{Imp3} [m]	$\eta(t-t)$ _{total} [-]	$\eta(t-t)$ _{Imp1} [-]	$\eta(t-t)$ _{Imp2} [-]	$\eta(t-t)$ _{Imp3} [-]
ANSYS CFX (steady-state)	19.46	7.92	7.33	7.36	0.782	0.925	0.913	0.910
CFturbo SMP (steady-state)	20.16	8.10	7.53	7.53	0.802	0.932	0.918	0.915
CFturbo SMP (transient)	19.86	7.80	7.11	7.12	0.828	0.926	0.914	0.913

- Both solver confirm CFturbo's initial design for the duty point, $H = 20\text{m}$
- Simulation results from ANSYS CFX and CFturbo SMP are close together
- Differences between steady state and transient simulations are minor
- Certain drop of head and efficiency comparing 1st stage with 2nd / 3rd
- Impeller efficiency is excellent, diffuser design should be improved

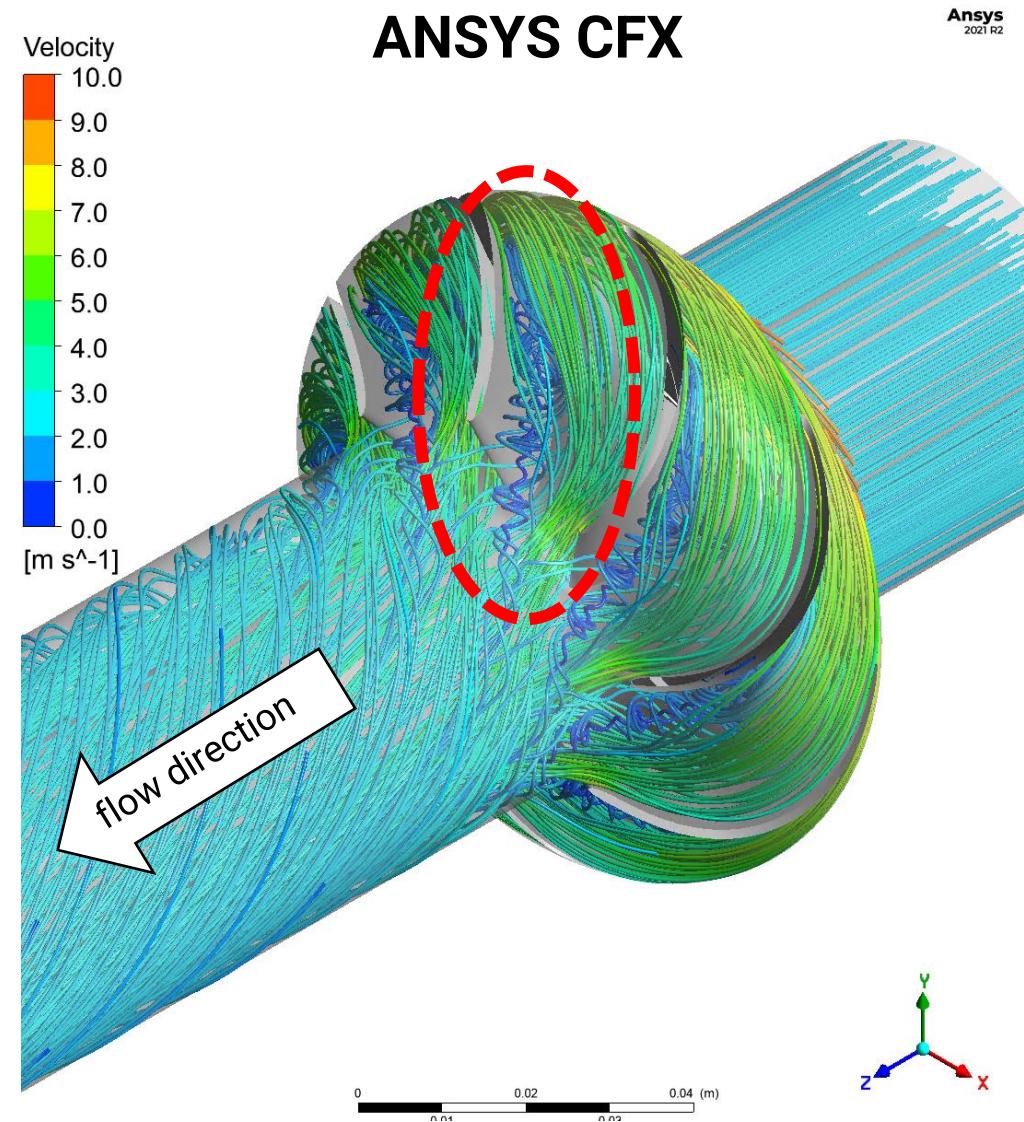
- Streamlines in blade-to-blade view for mid-span
- Baseline design with local flow separation inside the bowl diffuser



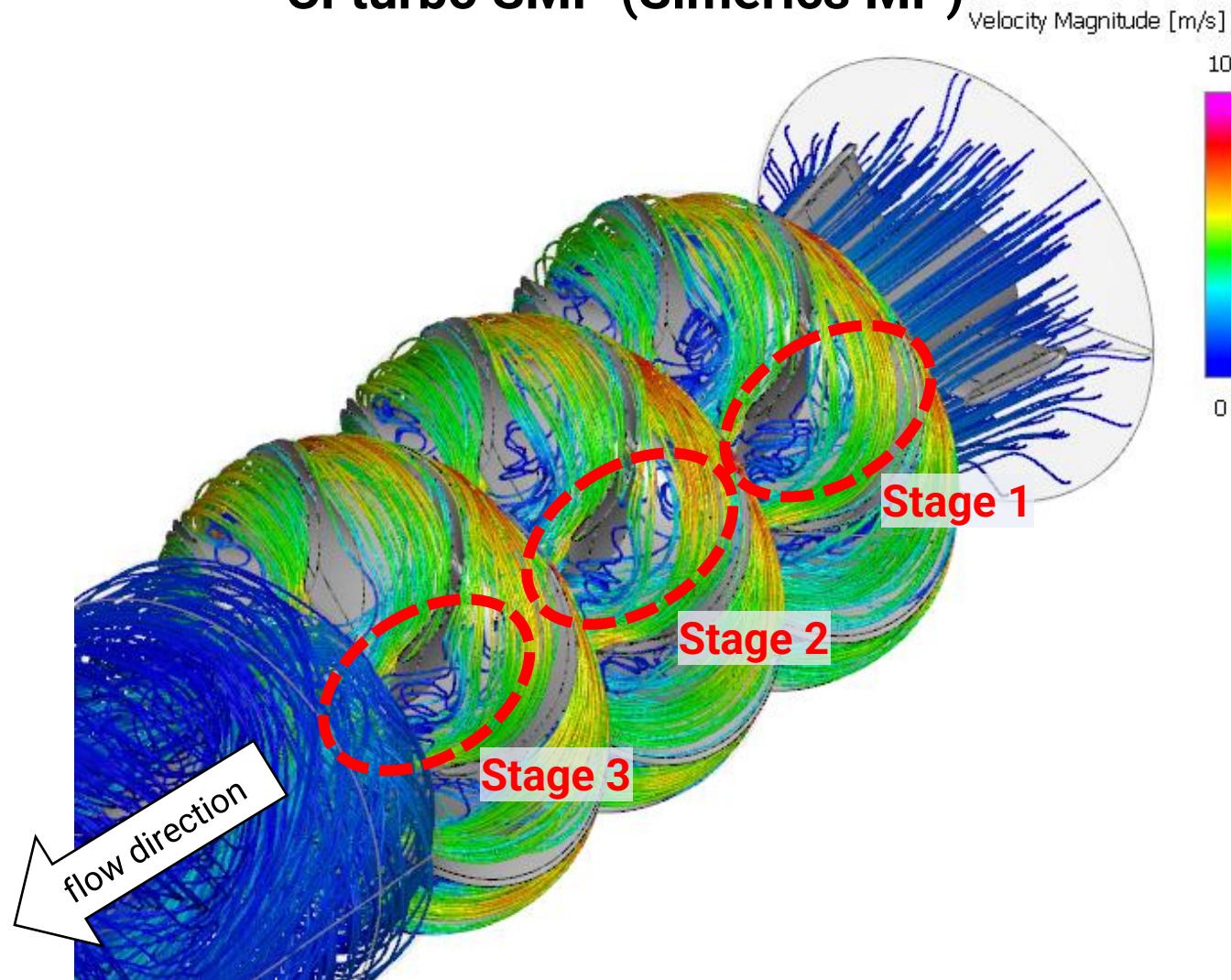
Duty Point Evaluation – CFD Results

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ANSYS CFX



CFturbo SMP (Simerics MP)

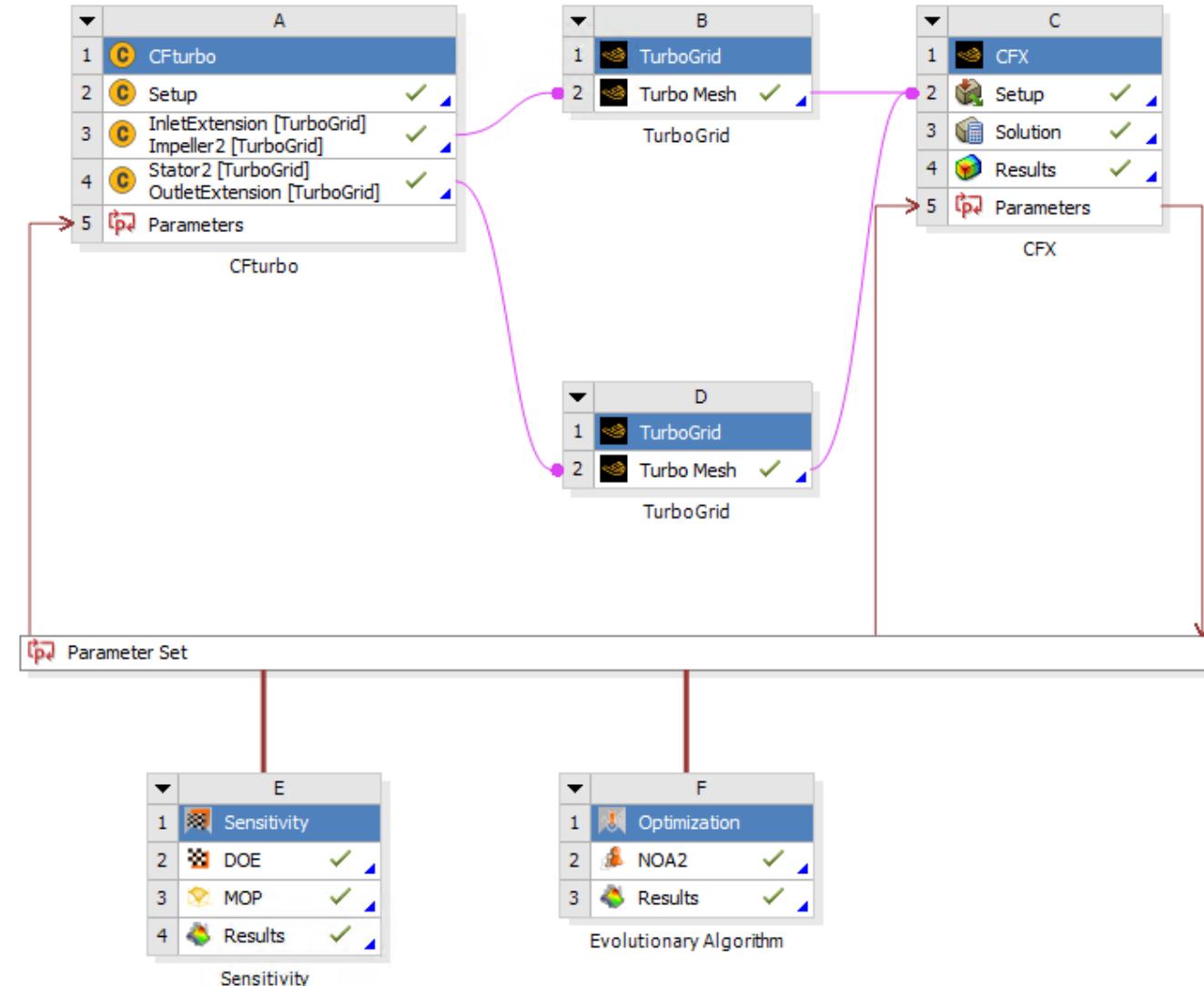
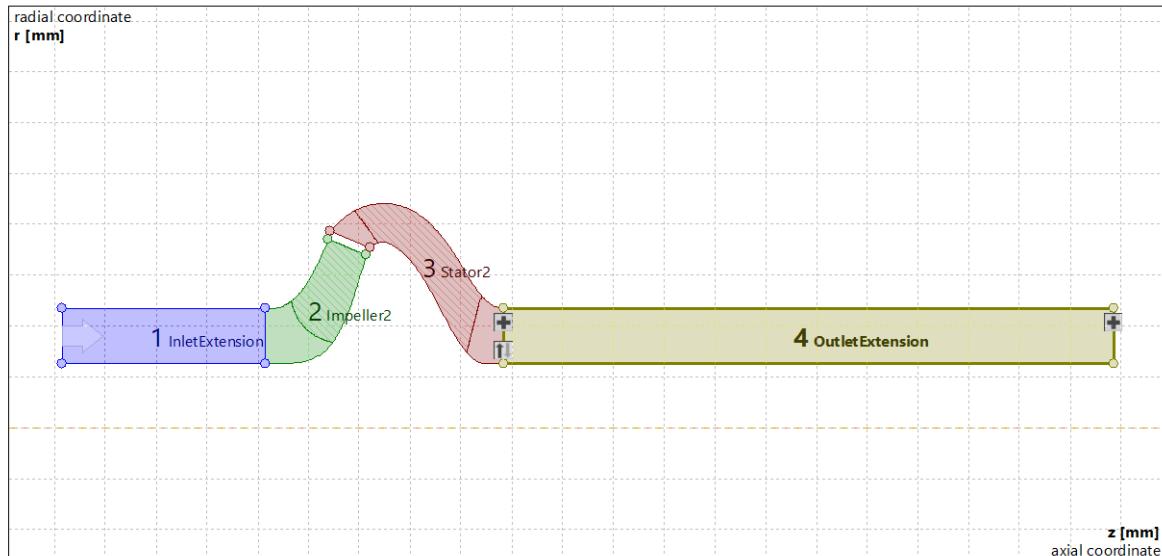


Bowl Diffuser Optimization – Workflow Overview

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- Geometry modeling:
- Meshing:
- CFD solver:
- Sensitivity Analysis:
- Optimization:

CFturbo
TurboGrid
ANSYS CFX
optiSLang
optiSLang

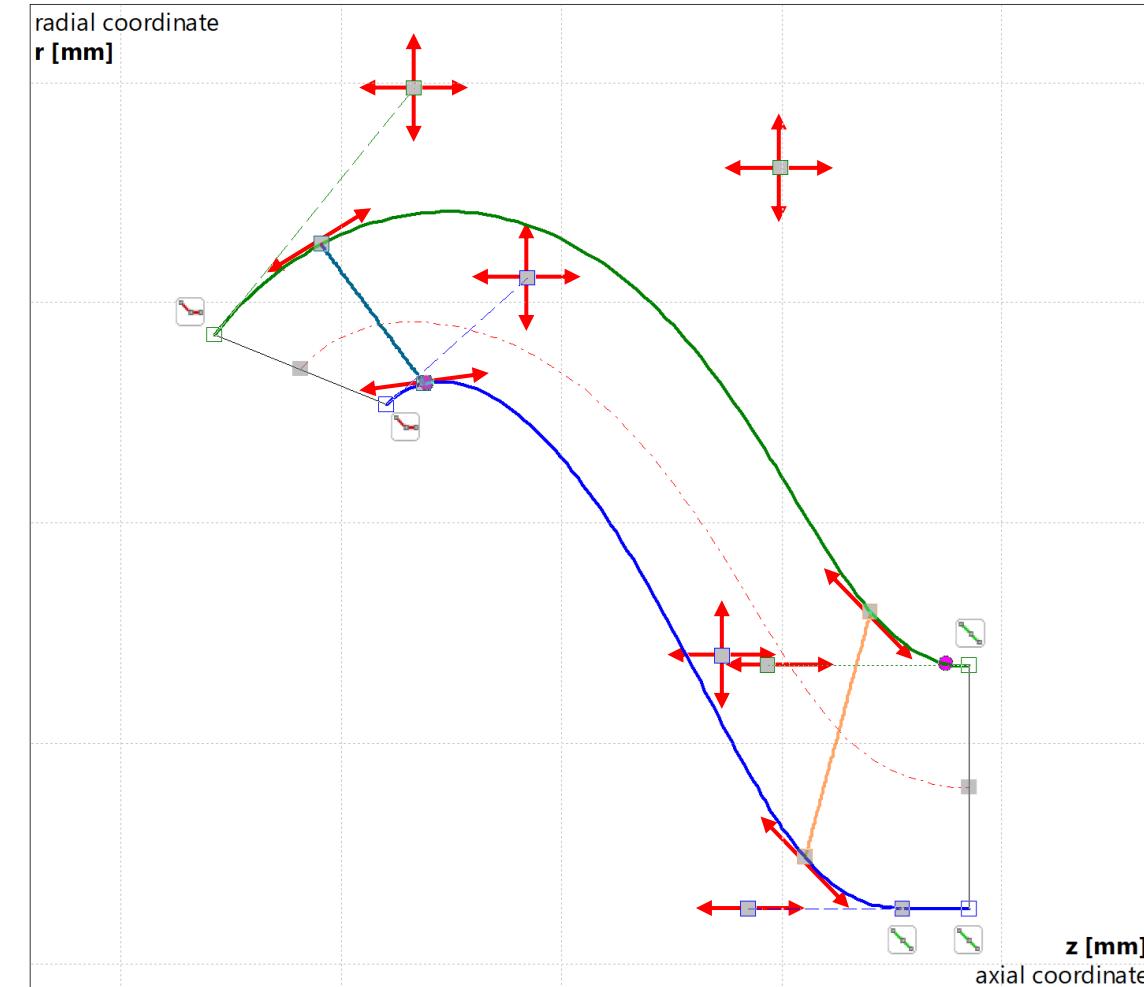


23 geometry parameter for initial DOE

- 14 parameter for meridional design
 - Contour control points; meridional edge position
- 5 parameter for bowl diffuser blade properties
 - Blade angle (LE/TE; hub/shroud); number of blades
- 4 parameter for mean line design
 - Rake angle; wrap angle

7 responses from CFD analysis

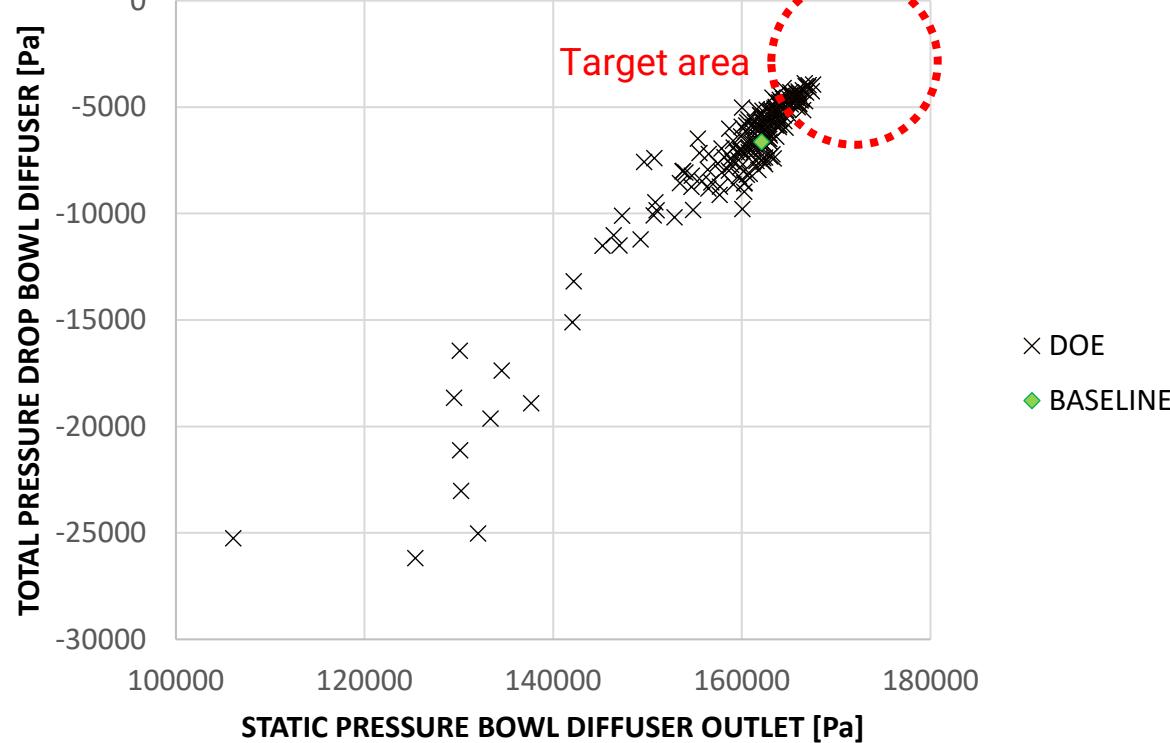
- Efficiencies (impeller; stage)
- Shaft power
- Total pressure/ static pressure bowl diffuser outlet
- Total pressure difference (impeller; bowl diffuser)



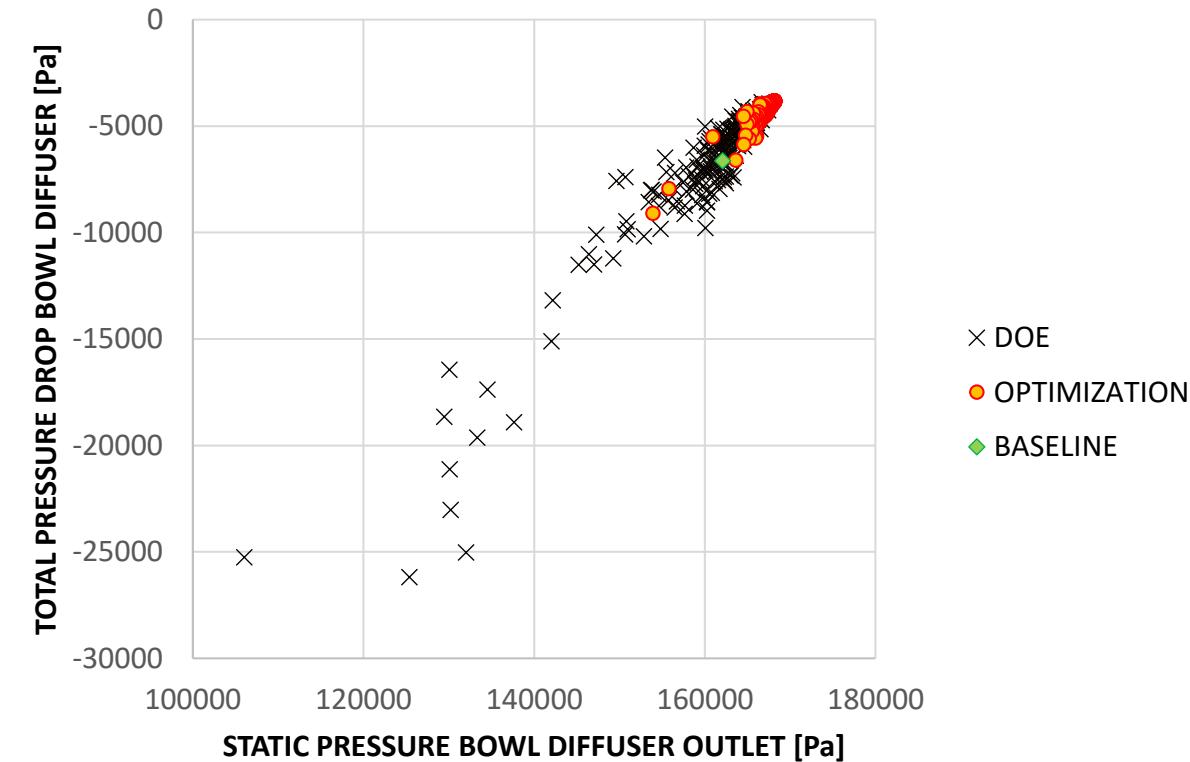
Bowl Diffuser Optimization – Results segment CFD analysis

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Bowl Diffuser DOE (LHS)



Bowl Diffuser Optimization (EA)

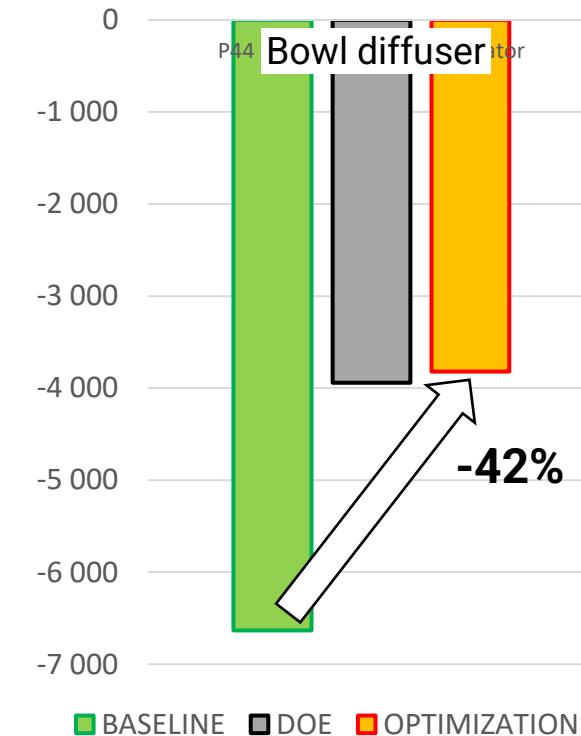


- Optimization objective: maximize static pressure at bowl diffuser outlet
 - Reducing internal pressure losses
 - Reducing swirl component at bowl diffuser outlet

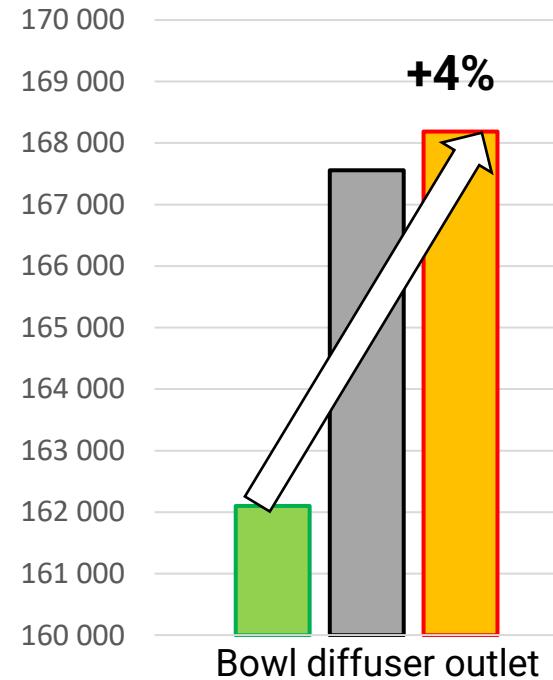
Bowl Diffuser Optimization – Results segment CFD analysis

CFturbo

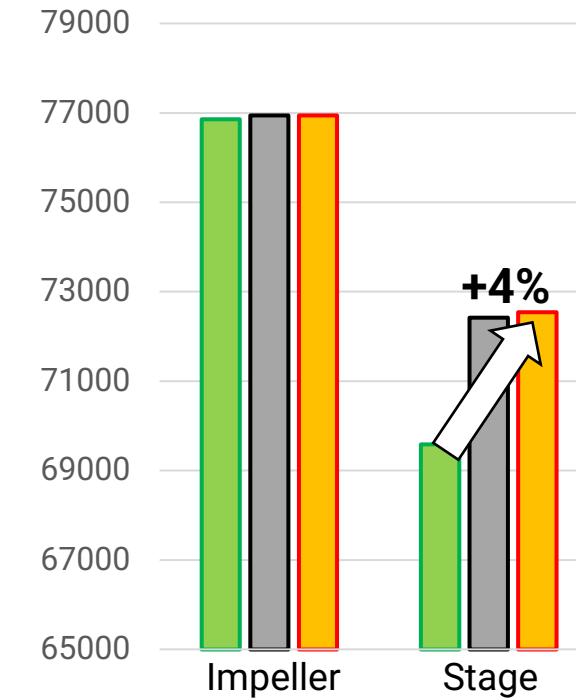
Total pressure drop
bowl diffuser



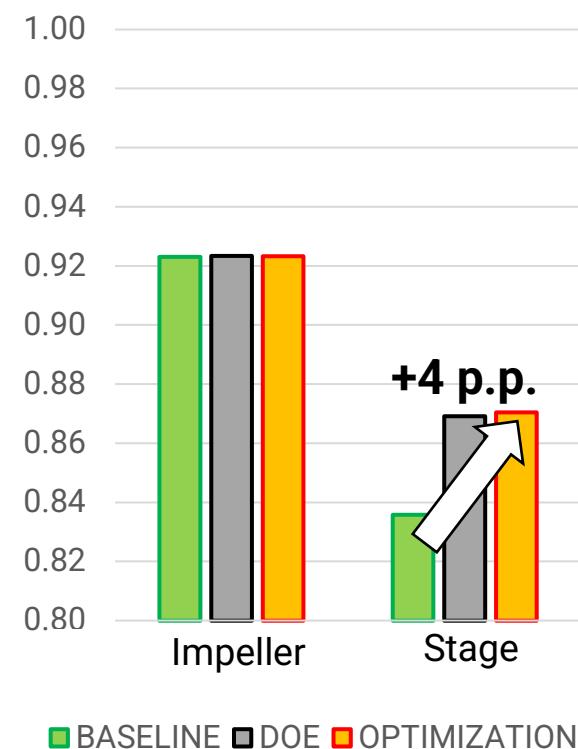
Static pressure
bowl diffuser outlet



Total pressure
difference

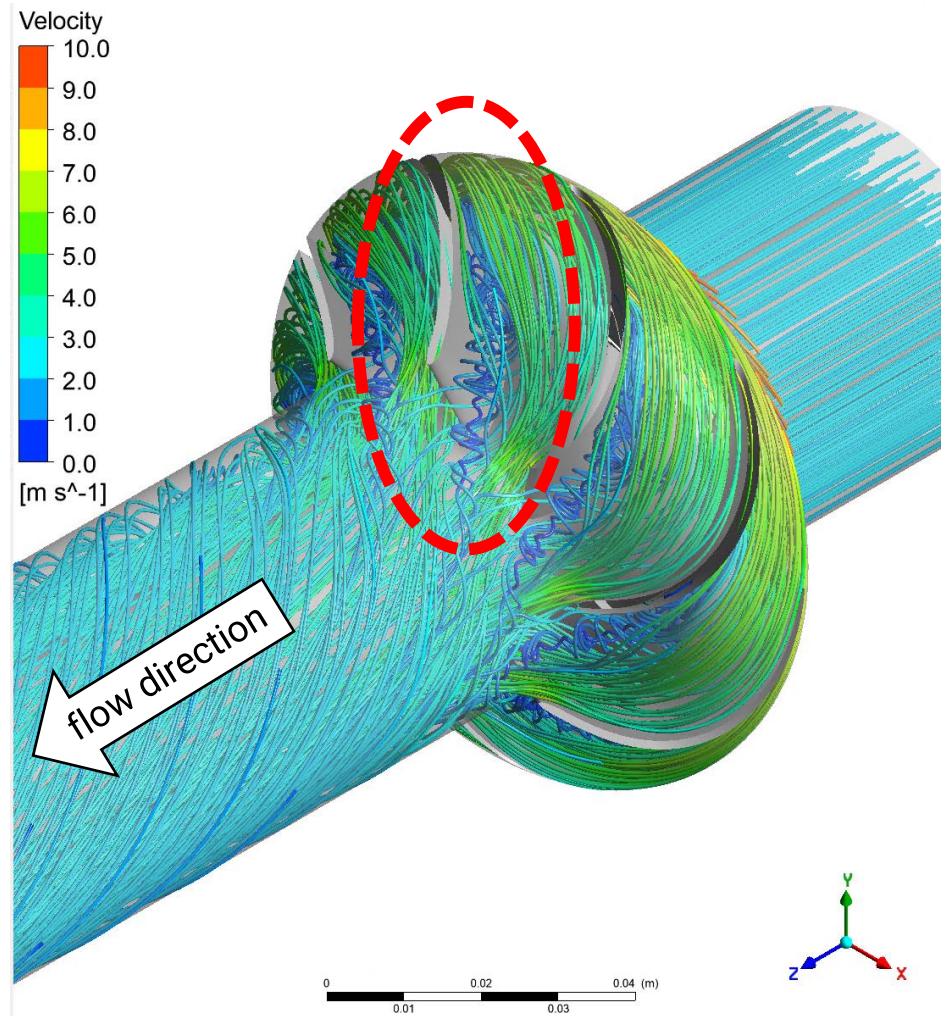


Efficiency

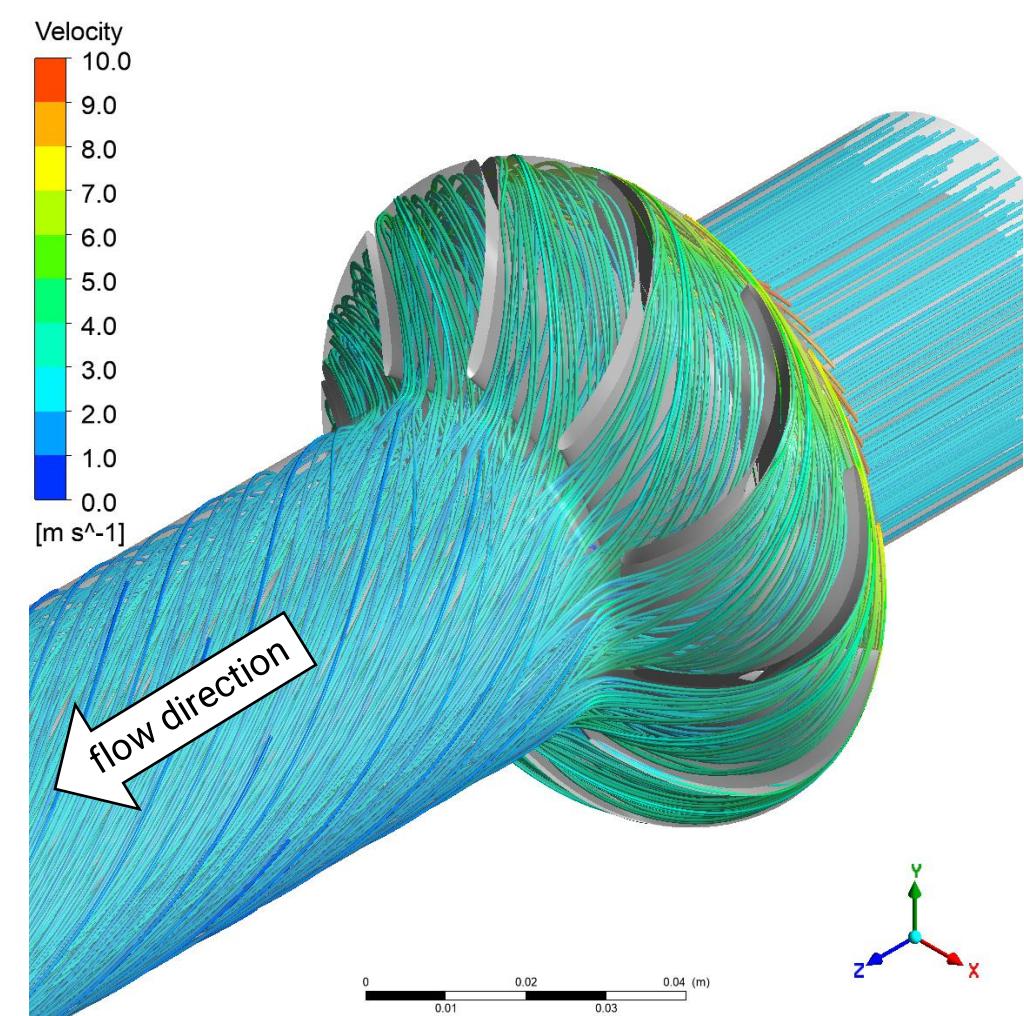


- DOE shows substantial improvements compared to baseline design
- Further optimization increases performance and efficiency only slightly

Baseline Design



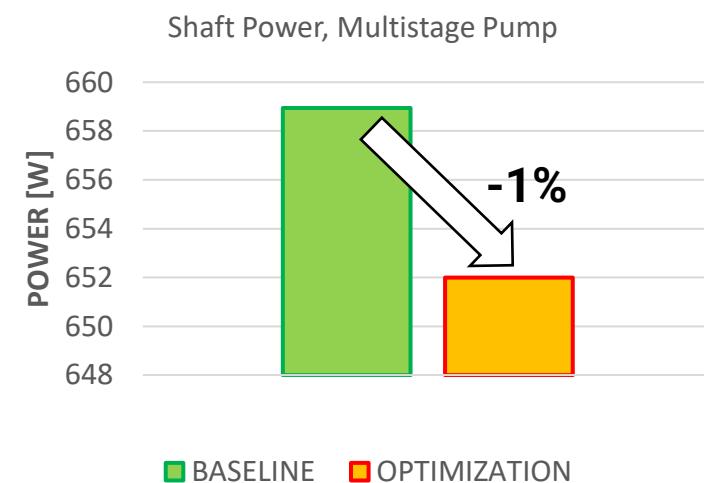
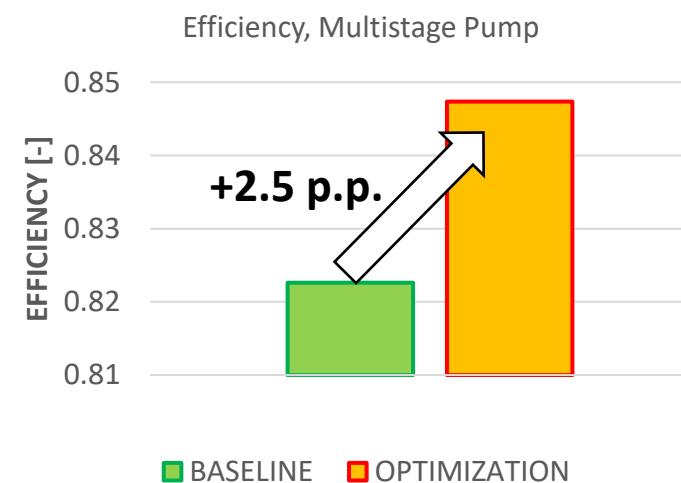
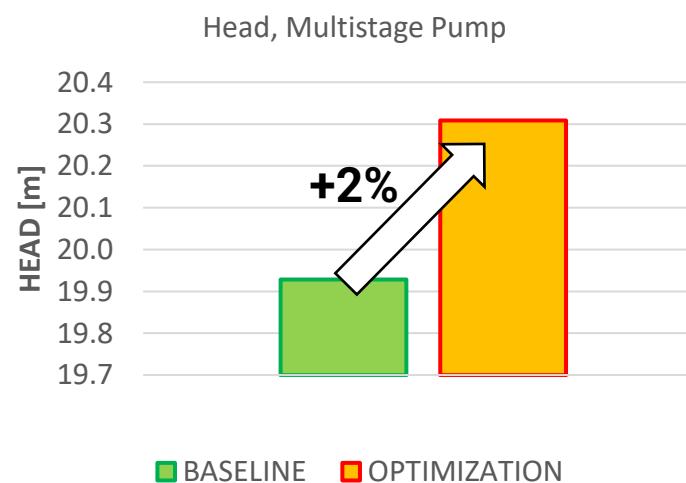
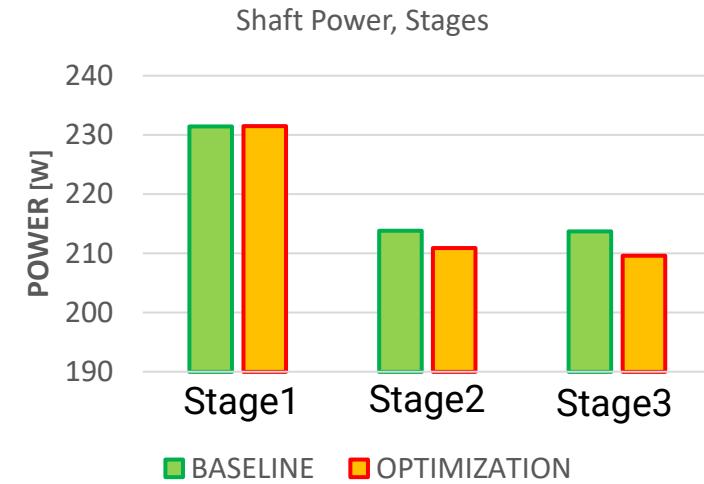
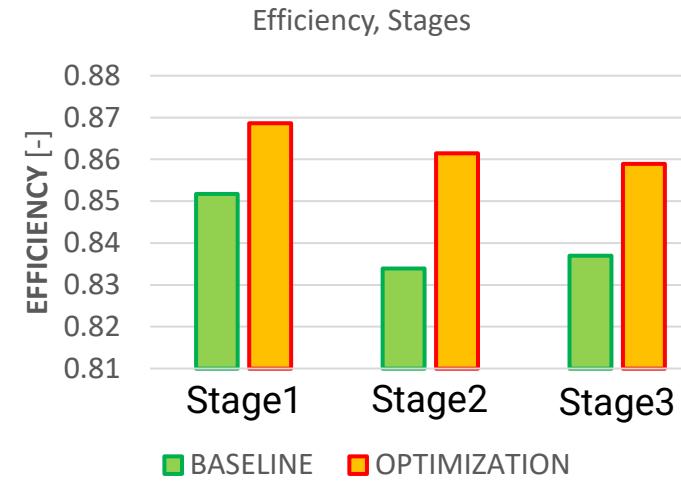
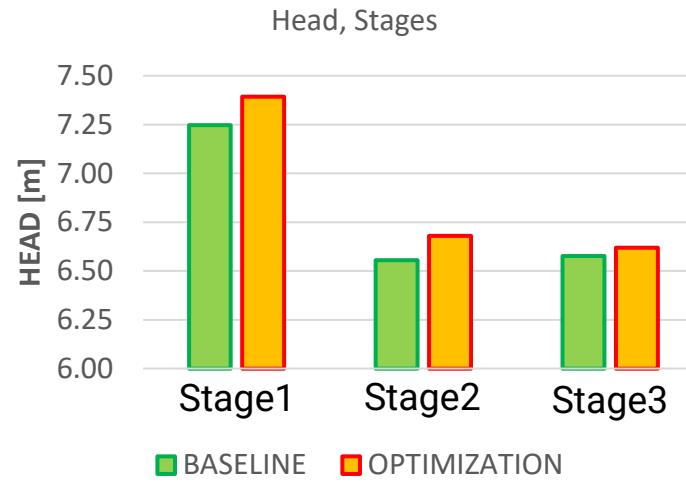
Optimized Design



Bowl Diffuser Optimization – Results transient multistage CFD

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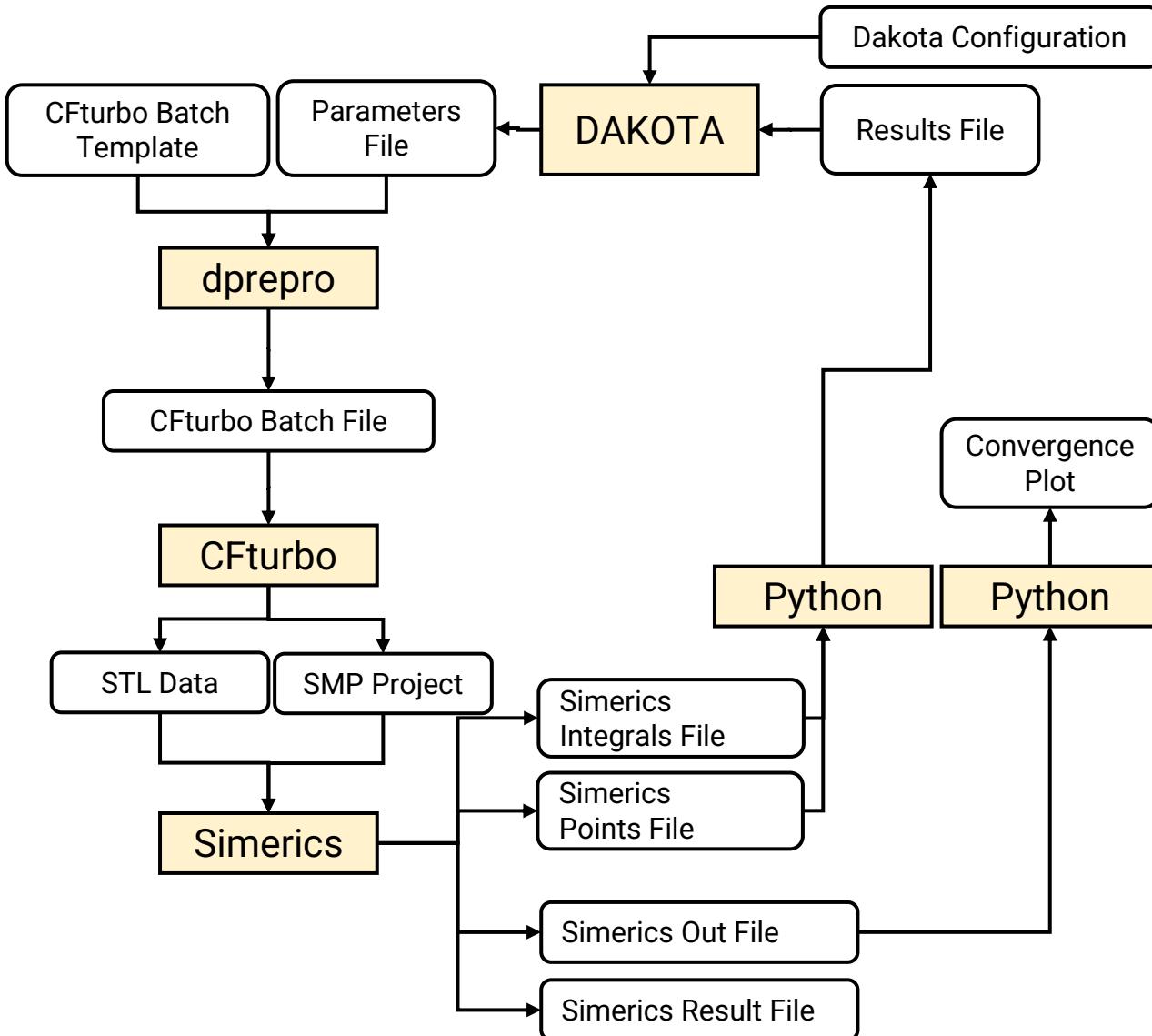
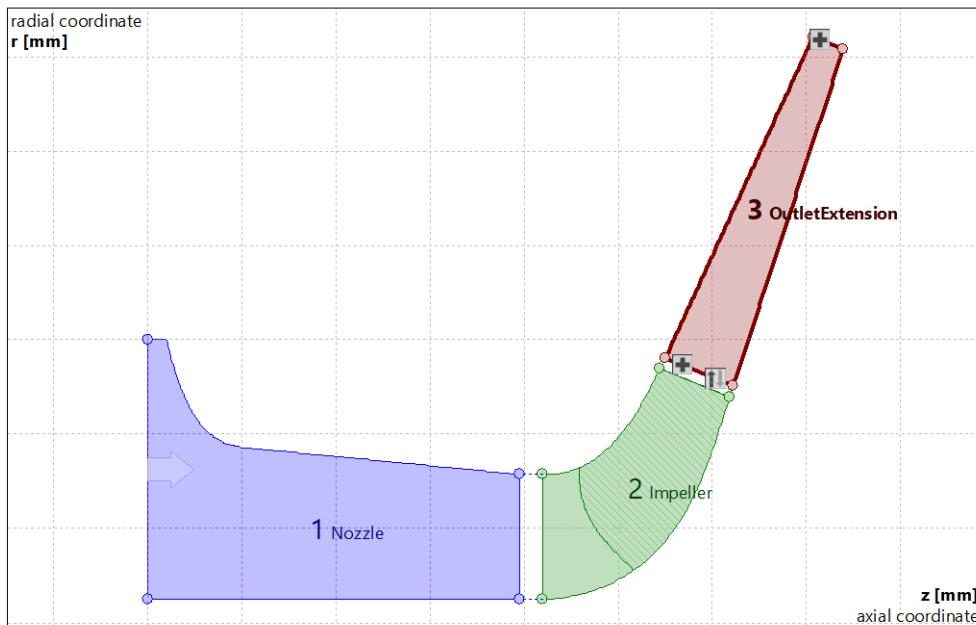
- Transient CFD analysis on the multistage 360° model



Impeller Optimization – Workflow Overview

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- Geometry modeling: CFturbo
- Meshing: CFturbo SMP
- CFD solver: CFturbo SMP
- Sensitivity Analysis: Dakota
- Optimization: Dakota



- For NPSH3 optimization multiple steady-state analyses with cavitation modeling will be needed for each design iteration
- A **reduced model** was used to keep the computational costs low

For each design iteration:

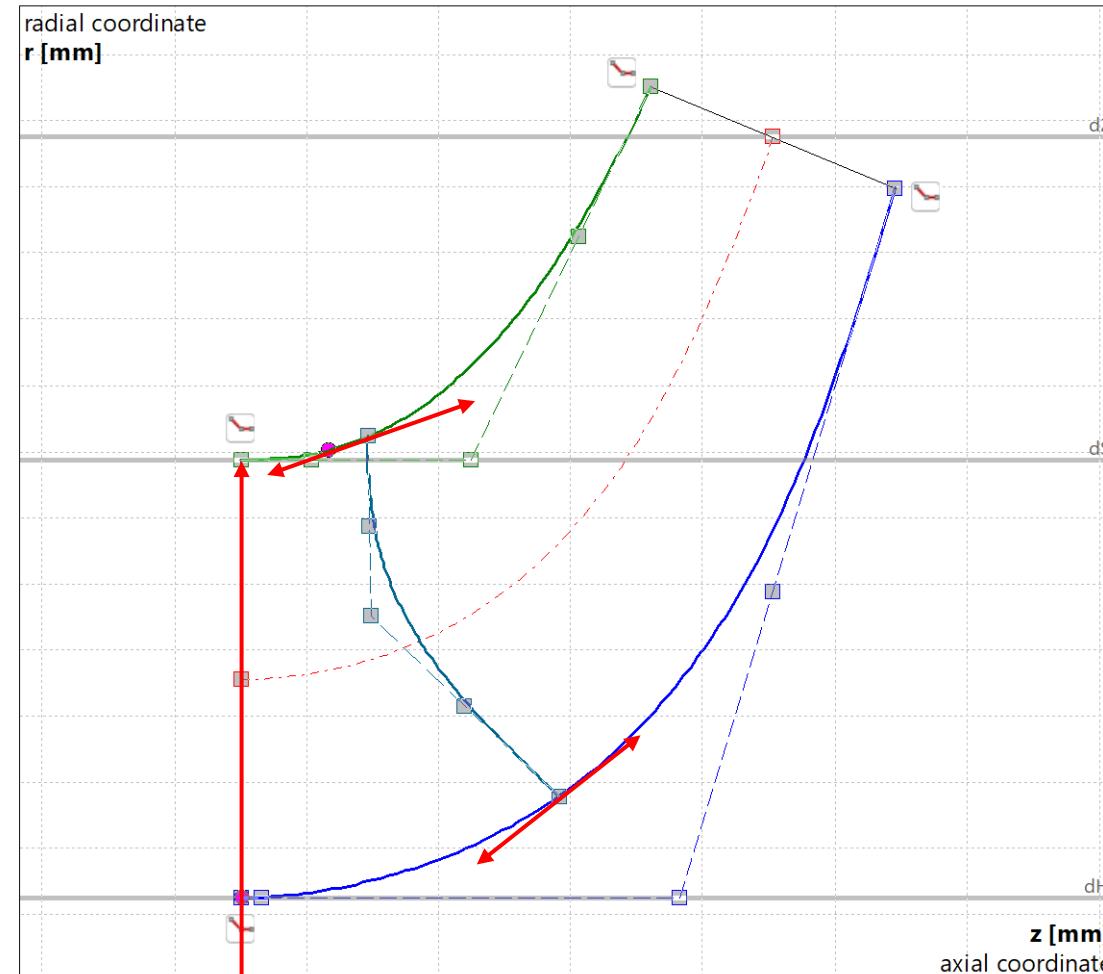
- Steady-state analysis under cavitation-free operating conditions
- Evaluate flow quantities of interest for the cavitation-free operating conditions
- Steady-state analysis under presence of light cavitation due to lowered total pressure at model inlet
- Calculate the relative performance reduction between the CFD analyses due to cavitation effects for each design iteration

6 geometry parameter for initial DOE

- 3 parameter for main dimensions/merid. design
 - Suction diameter
 - Meridional blade position (LE) at hub/shroud
- 3 parameter for impeller blade properties
 - Blade incidence at hub and shroud
 - Blade thickness at leading edge

2 responses from CFD analysis

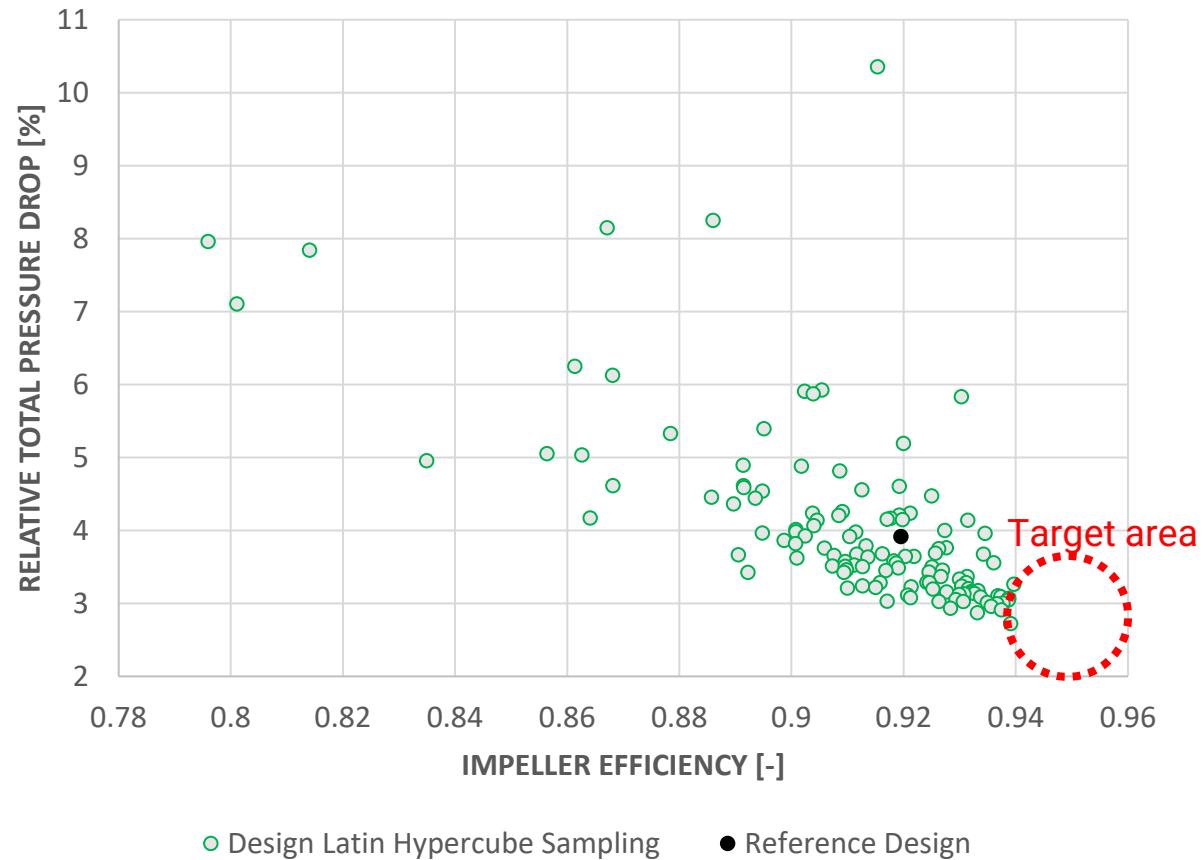
- Efficiency
- Relative total pressure drop (due to cavitation)



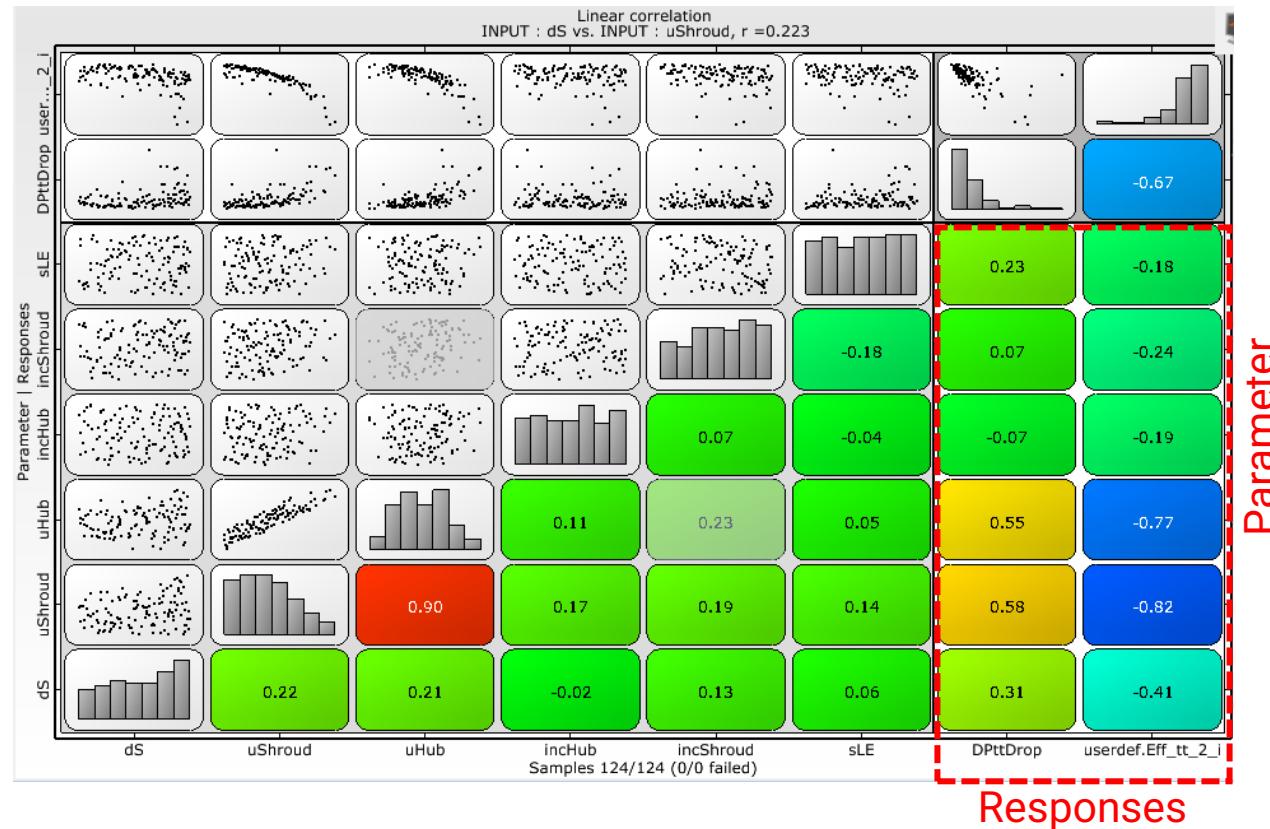
Impeller Optimization – Sampling Results

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Impeller DOE (LHS)



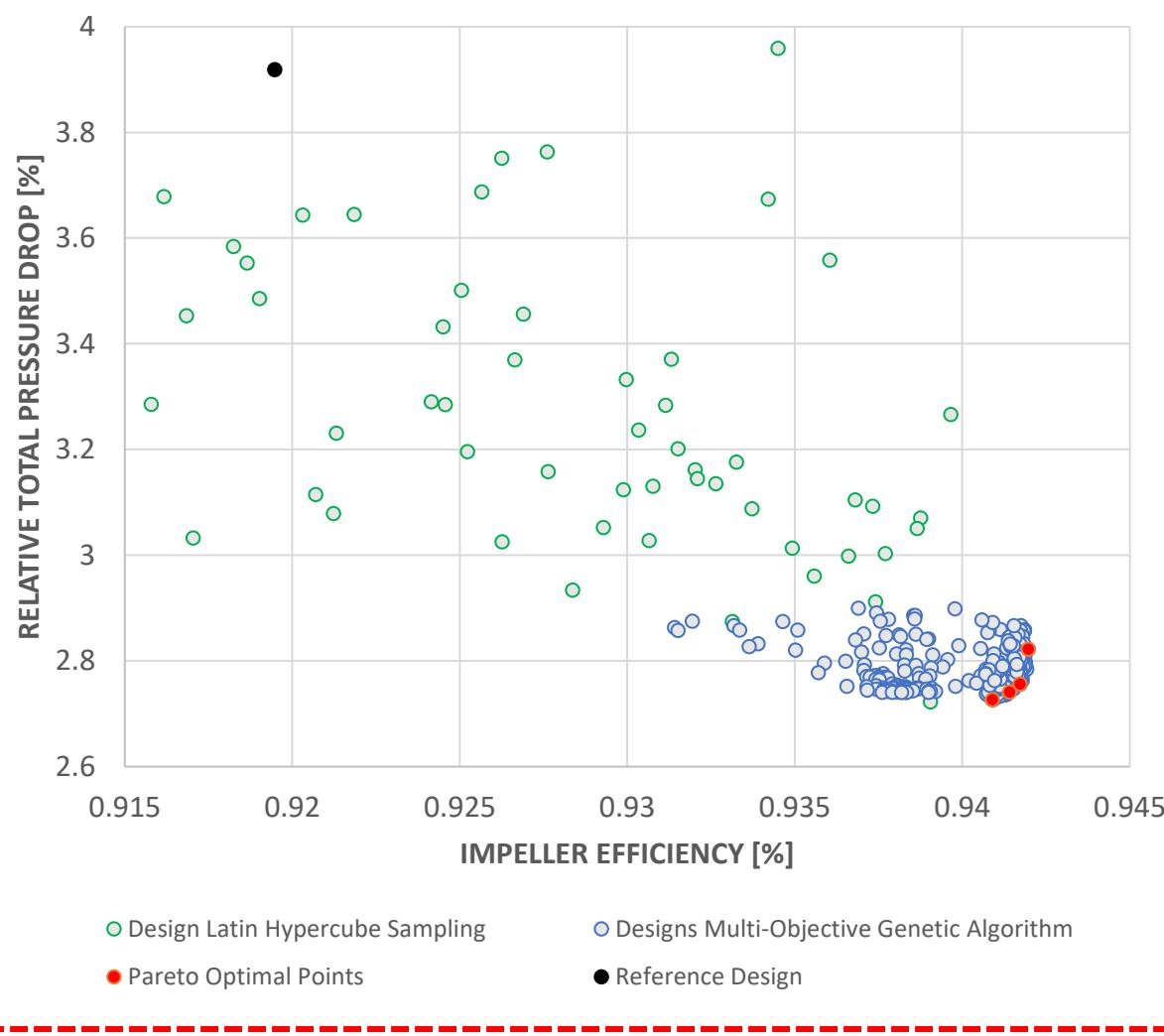
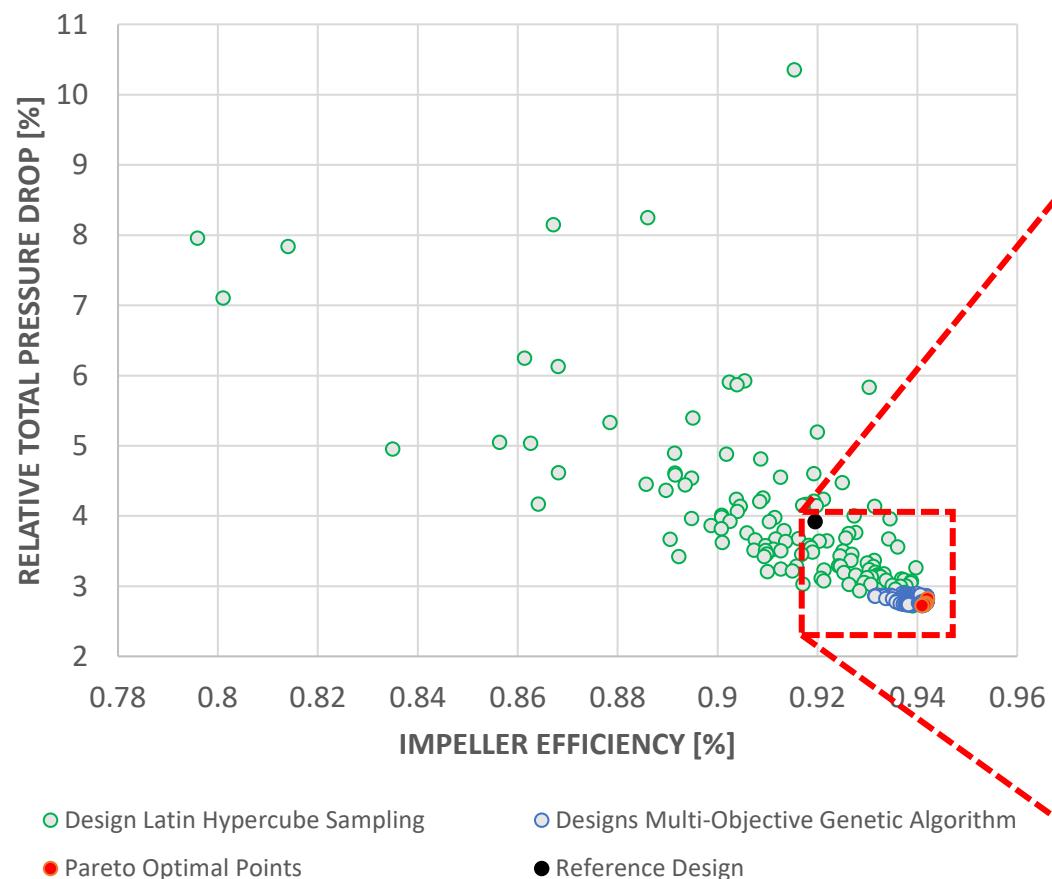
Correlation matrix with ant hill plots



Impeller Optimization – Result classification

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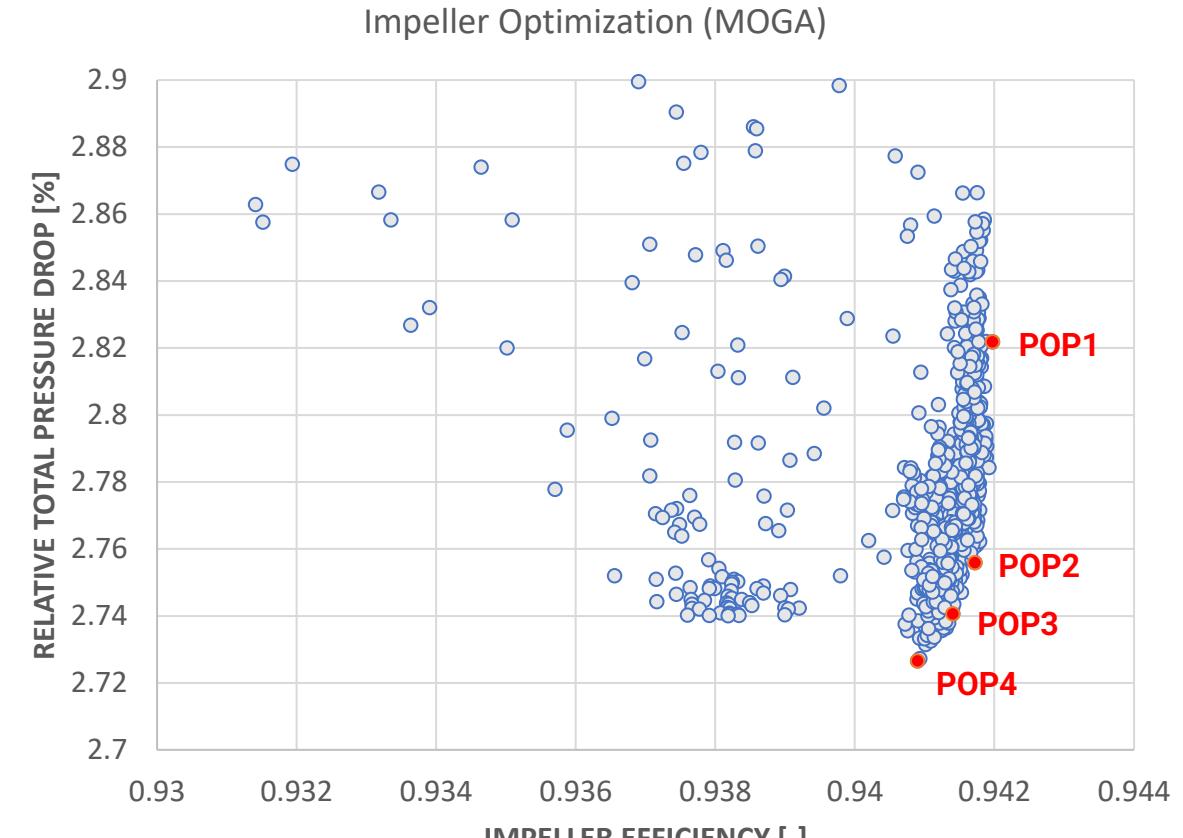
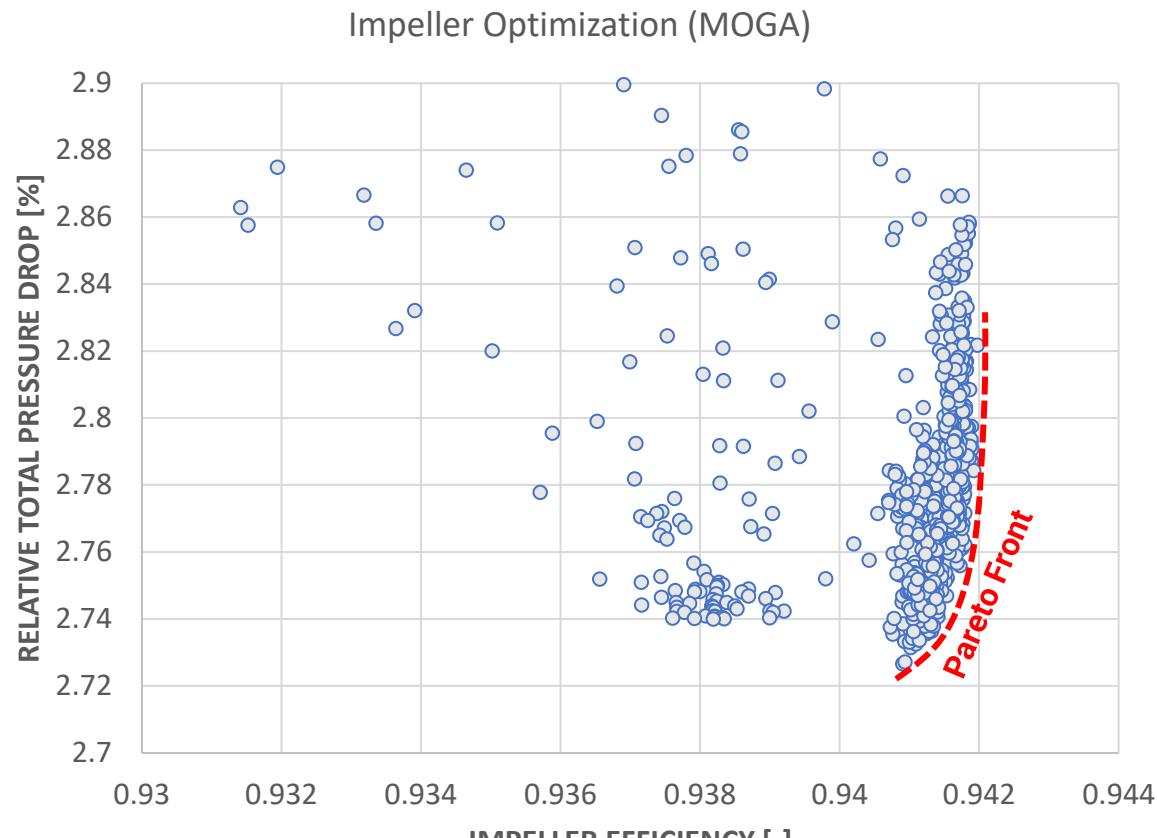
Impeller DOE (LHS) + Optimization (MOGA)



- Impeller efficiency and performance under cavitating conditions was improved

Impeller Optimization – Optimization Results

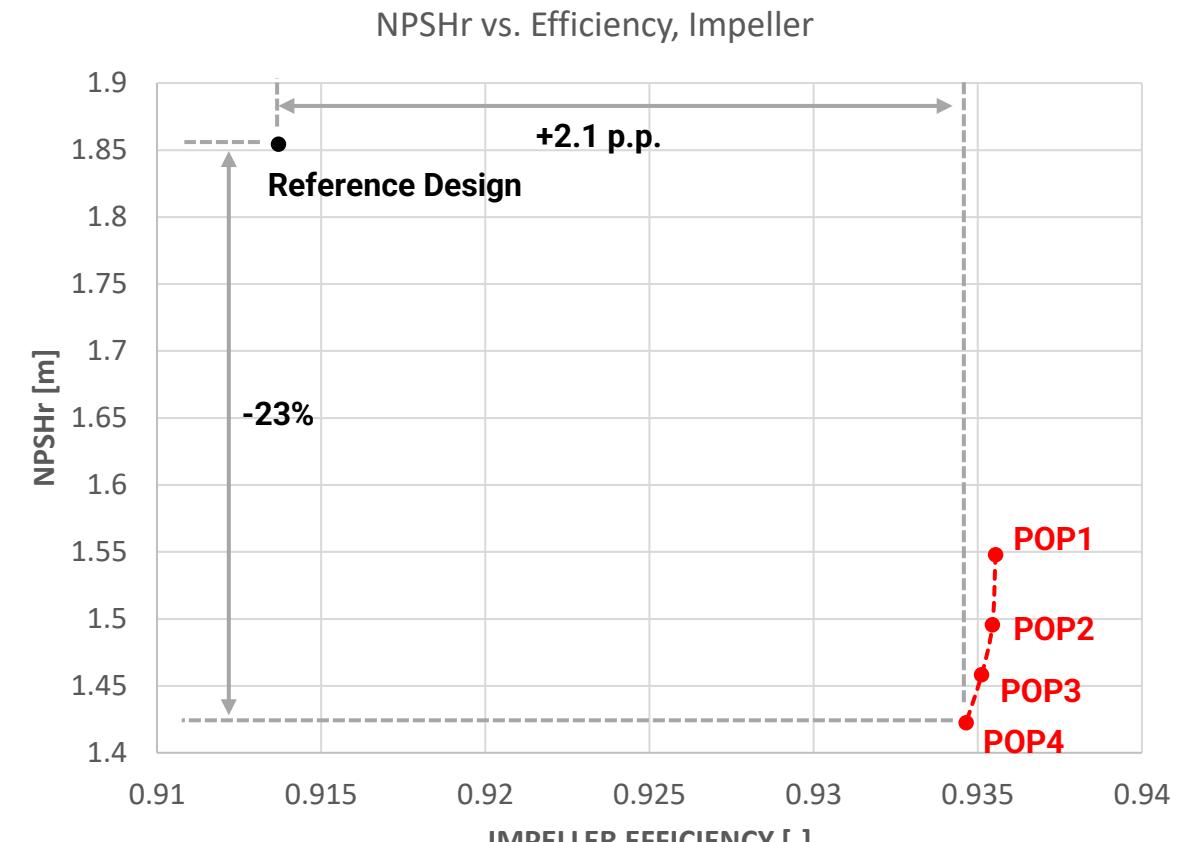
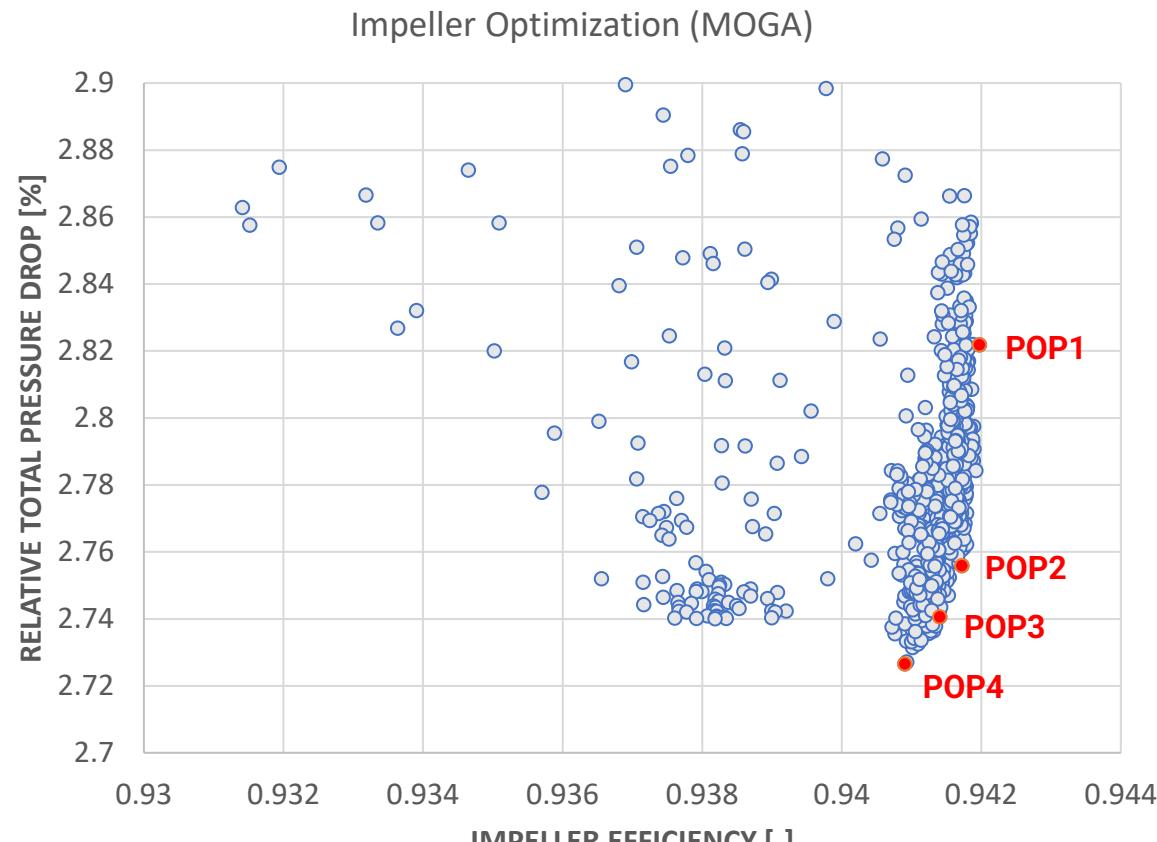
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- Multi-Objective Genetic Algorithm (MOGA) tried to maximize impeller efficiency and minimize the cavitation-induced performance drop

Impeller Optimization – NPSH3 evaluation

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- NPSH_r was evaluated from the **transient** drop curves for Pareto Optimal Point (POP)
- **Steady-state** trends from optimization provide a good estimation for NPSH_r trends

- Results from **automated turbomachinery optimizations** were presented
- Hydraulic design optimization of a bowl diffuser using a parametric conceptual design software fully integrated into industry-leading simulation framework
- A guideline was provided to systematically **improve hydraulic efficiency** and the **required NPSH** value for a multistage pump
- The reliability of the tendencies seen in the steady-state results of the optimization were **verified by fully transient simulations**

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