

Design and Optimization of Contra-Rotating Fans

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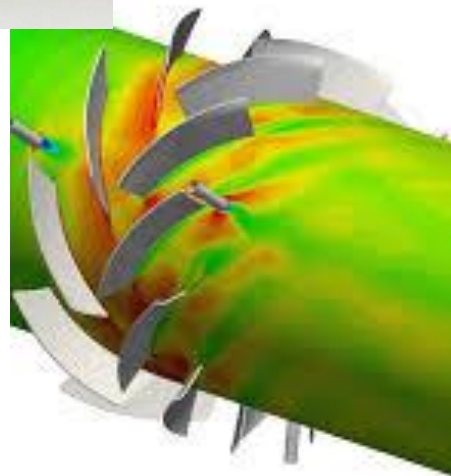
CFturbo GmbH

& ILK Institut für Luft- und Kältetechnik gGmbH

Motivation to use Contra-rotating fans

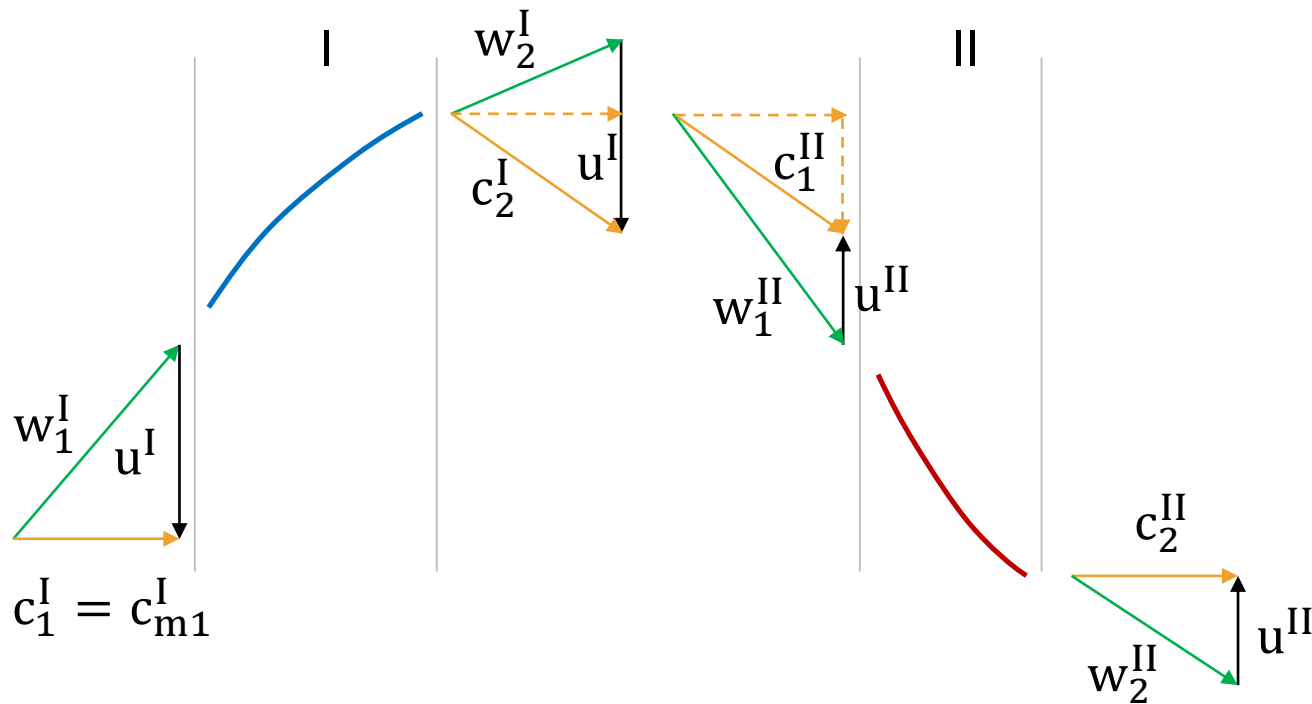


- Very compact compared to a two stage fan with guiding vanes
- Smaller impeller diameter and/or lower speed compared to single stage fans
- Alternative for low pressure radial ventilators
- Potential for better acoustic behavior



Contra-rotating fan principle

First impeller generates a **negative** pre-swirl for the second impeller



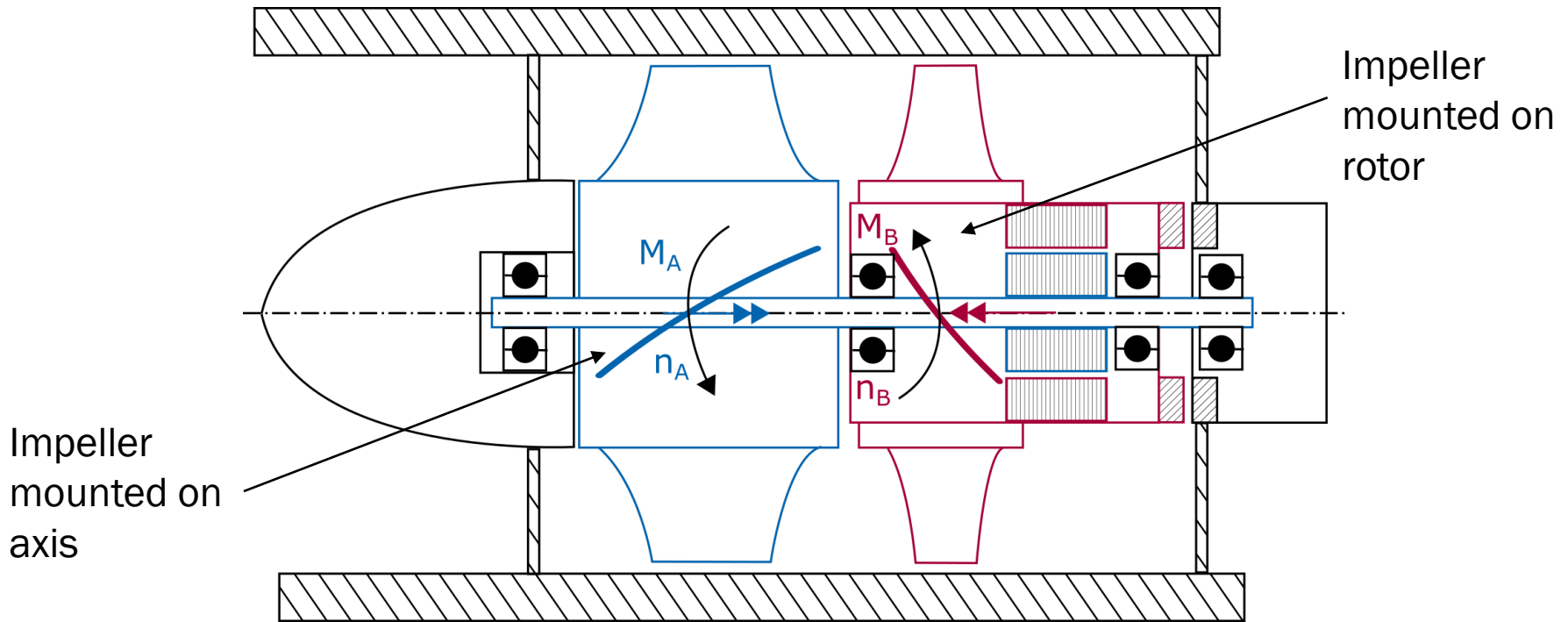
$$Y_{\text{Euler}} = \Delta(c_u \cdot u) \rightarrow Y_I = c_{u2}^I \cdot u^I, \quad Y_{II} = c_{u2}^{II} \cdot u^{II}$$

$$Y_I + Y_{II} = c_{u2}^I \cdot (u^I + u^{II})$$

Gear less single motor driven Contra-rotating fan



Torque/Power distribution imposed by aerodynamic design of impellers



Contra-rotating fan design



Design point: pressure difference Δp_{tot} , flow Q , Fluid properties

Power distribution between 2 impellers defined by either of

- Pressure difference and speed: $\Delta p_{\text{tot,I}}$, n_I und $\Delta p_{\text{tot,II}}$, n_{II}
- Torque and speed: T_I , n_I und T_{II} , n_{II} (with $T \cdot n = \Delta p_{\text{tot}} \cdot Q$)

Example:

	fan	impeller I	impeller II
Q [m ³ /h]	540	540	540
Δp_{tot} [Pa]	1000	690	310
n [rpm]		8000	-5000

Design Point

Initial design

Initial design:

Number of blades [-]	8	6
Profile	NACA 6508	NACA 6508
Stagger angle λ [°]	46.7 .. 36.1	45.0 .. 36.3
Chord length l [mm]	32 .. 24	32 .. 26

Contra-rotating fan design with Cfturbo



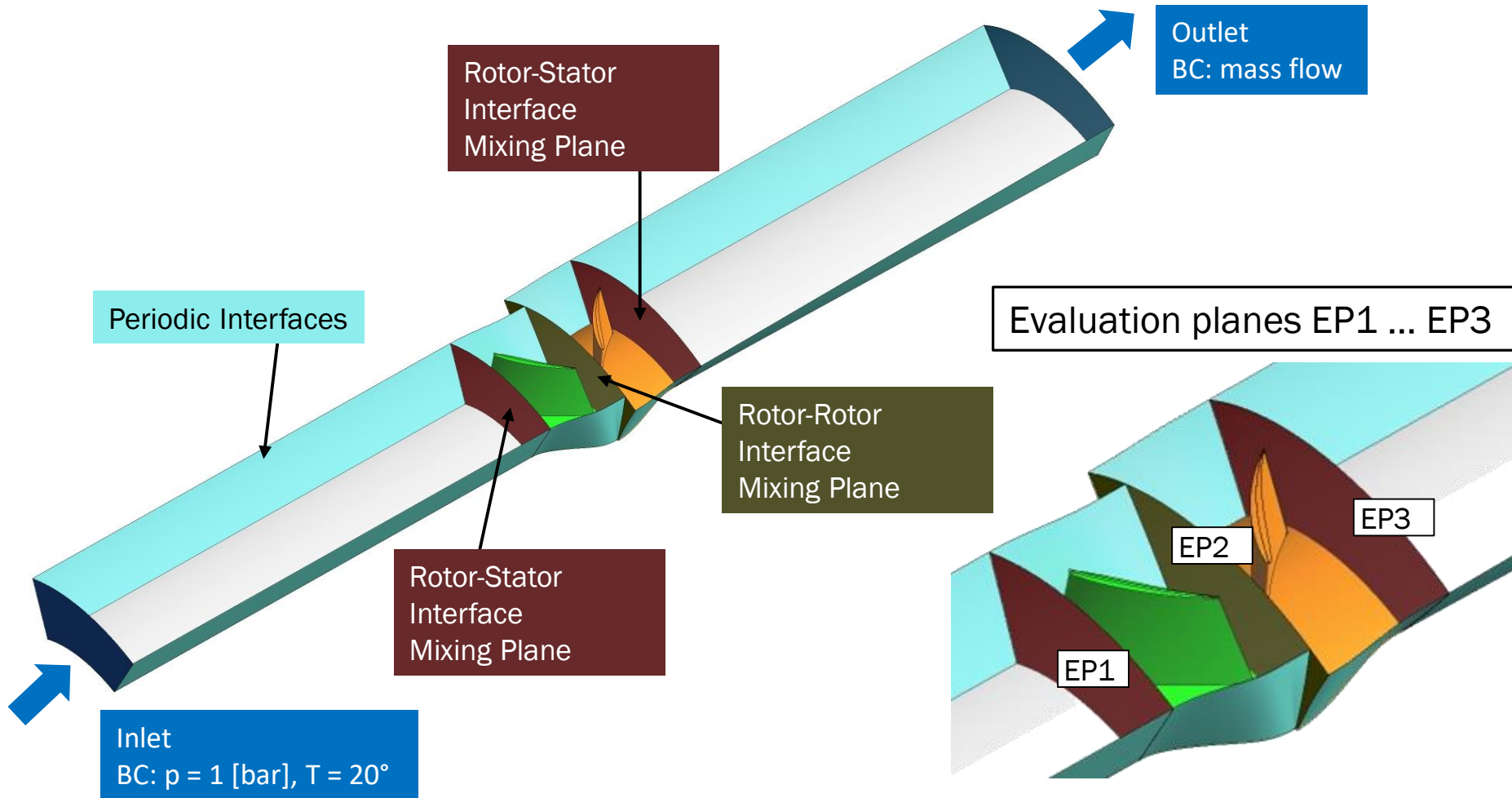
The screenshot displays the Cfturbo software interface for designing a contra-rotating fan. The main window shows a 3D model of the fan with two impellers, one in blue and one in red, rotating in opposite directions. The interface includes a menu bar (Datei, PROJECT, PREFERENCES, HELP), a toolbar with various design tools, and a main workspace with tabs for 'Meridian', '3D Model', and 'Report'.

The 'Main Dimensions' dialog box is open, showing the following settings:

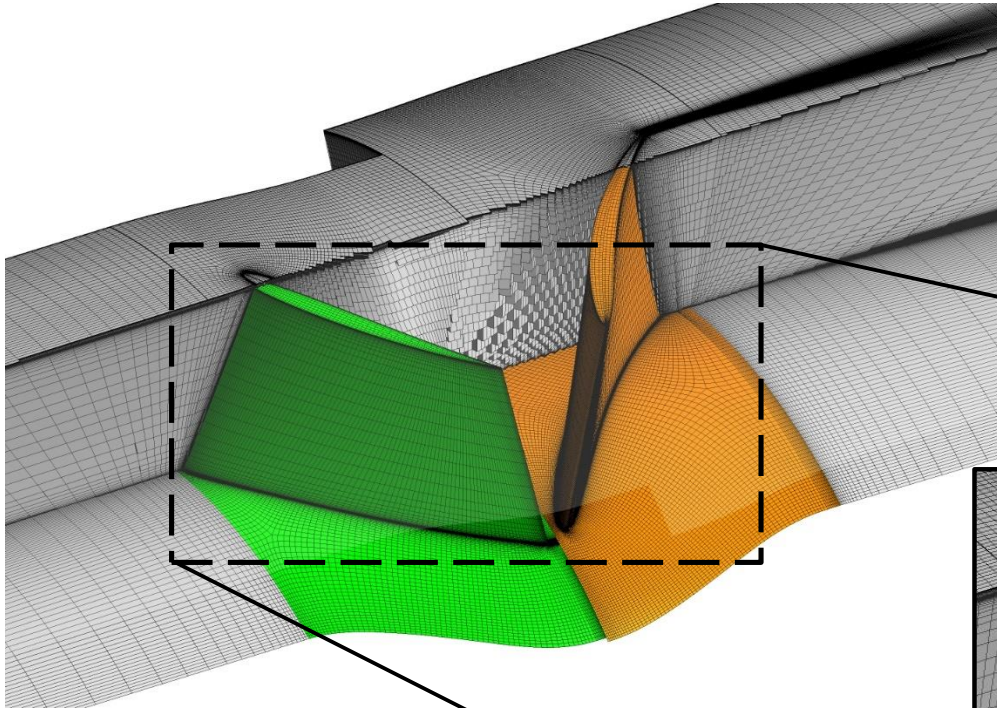
- General:**
 - Manual dimensioning
 - Unshrouded
 - Tip clearance: Inlet 0.12 mm, Outlet 0.12 mm
 - Material density ρ : 7750 kg/m³
 - Impeller type: Standard
- Multi stage options:**
 - Power splitting $\Delta p = 1000$ Pa
 - 0% (slider) to 100%
 - Impeller 1: 67% $\Delta p = 670$ Pa, $nq = 150$
 - Impeller 2: 33% $\Delta p = 330$ Pa, $nq = 159$
 - Contra rotating
 - Alternative speed $n = 5000$ /min
- Blade design mode:**
 - Airfoil (Using pre-defined blade profiles)
 - Mean line (Using Euler equation on mean lines)

The 'Values' tab in the dialog shows a schematic sketch for illustration only, plotting radius r [mm] on the y-axis (ranging from 34 to 66) against axial distance z [mm] on the x-axis (ranging from 25 to 49). The sketch shows the profile of the impeller blades.

Computational model

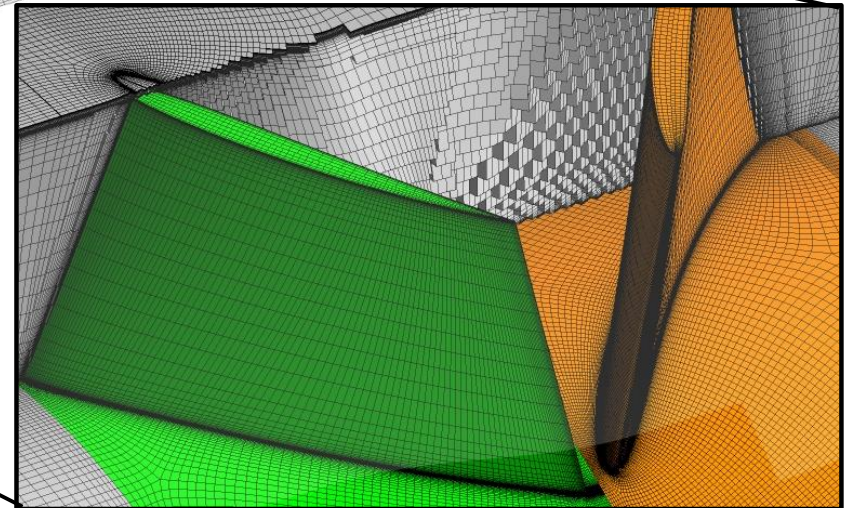


Mesh



Hexahedral Mesh \approx 2 Mio.
elements

ANSYS TurboGrid



- INLET Pressure: 1 [bar]
- OUTLET Volumetric flow: 400 ... 650 [m³/h]

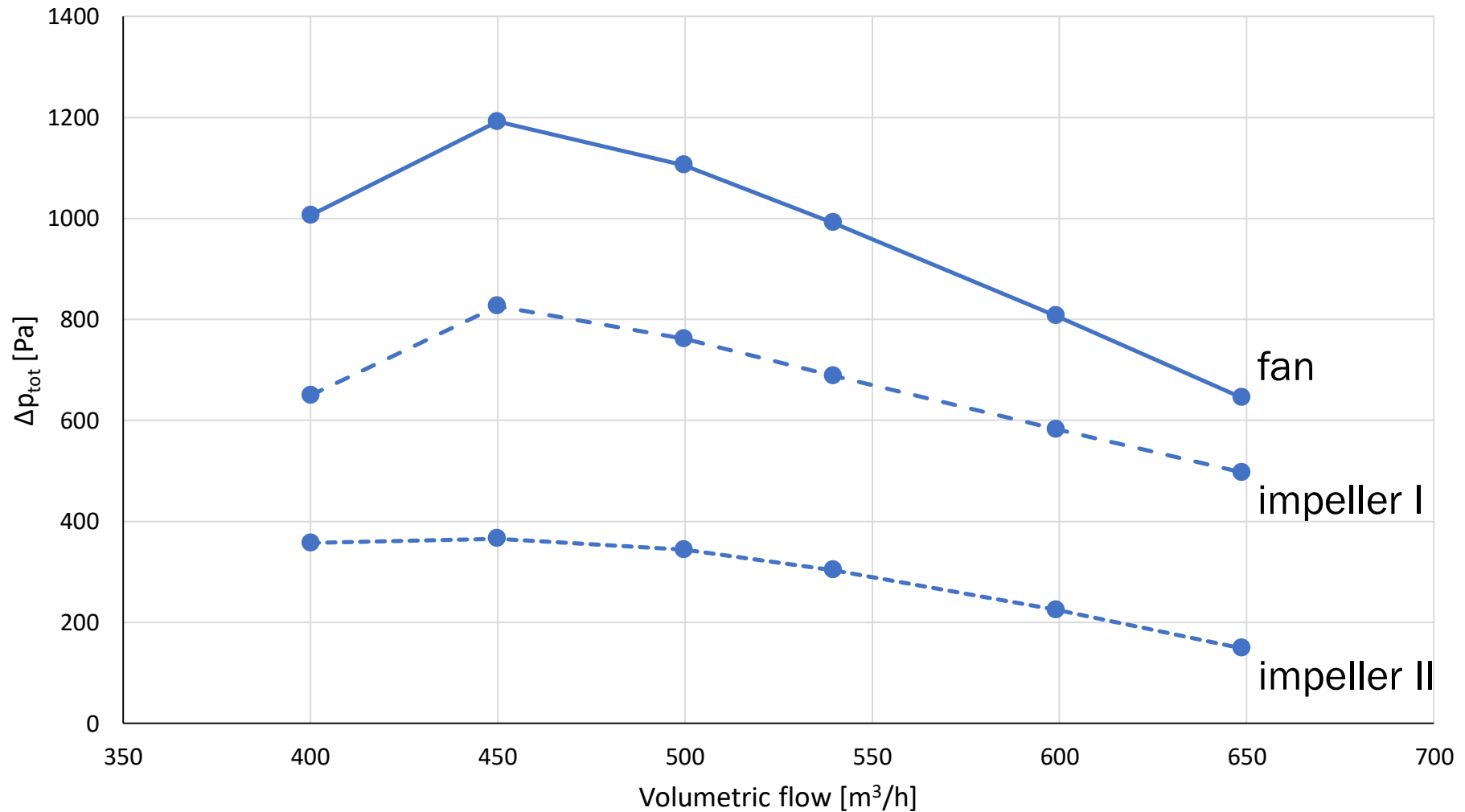
- Rotational speed: 8000 rpm for impeller I
 -5000 rpm for impeller II

- Fluid properties: Air (Perfect Gas)

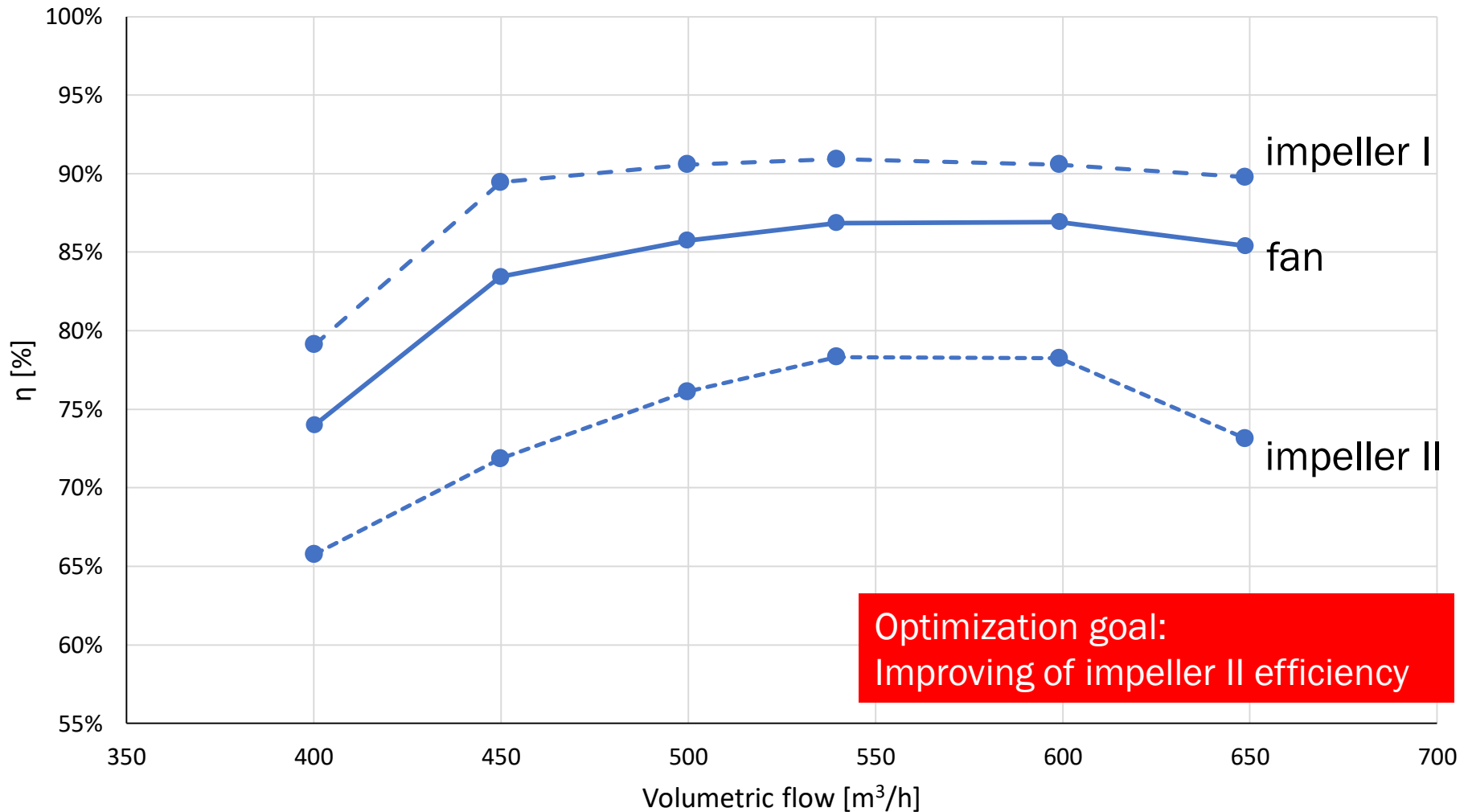
ANSYS-CFX v18.0

- Steady State Simulation
- Heat Transport (Total Energy)
- Mixing-Plane Interface
- SST-Turbulence model
- High Resolution differencing scheme

Simulation of initial design, results



Simulation of initial design, results



Optimization of initial design



Optimization process:

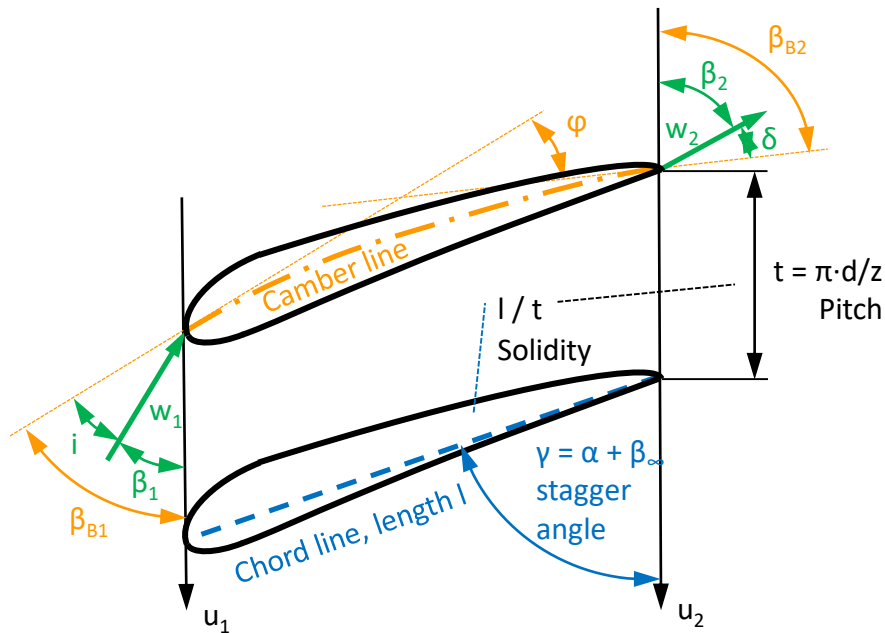


Optimization of initial design

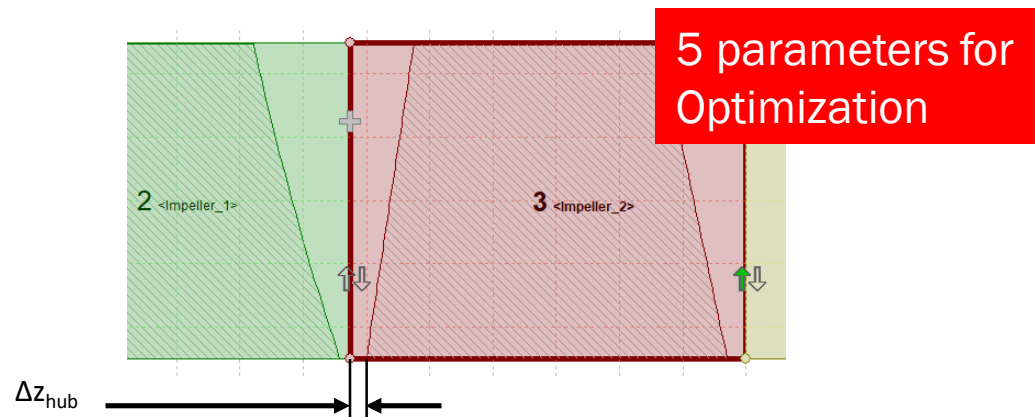
Objective: improve second impeller with respect to efficiency

Restriction: match design point

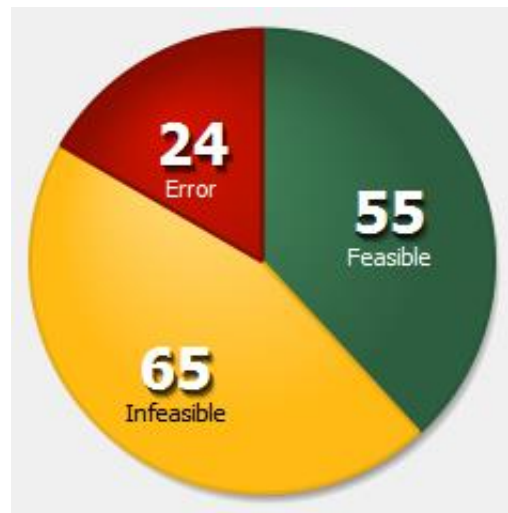
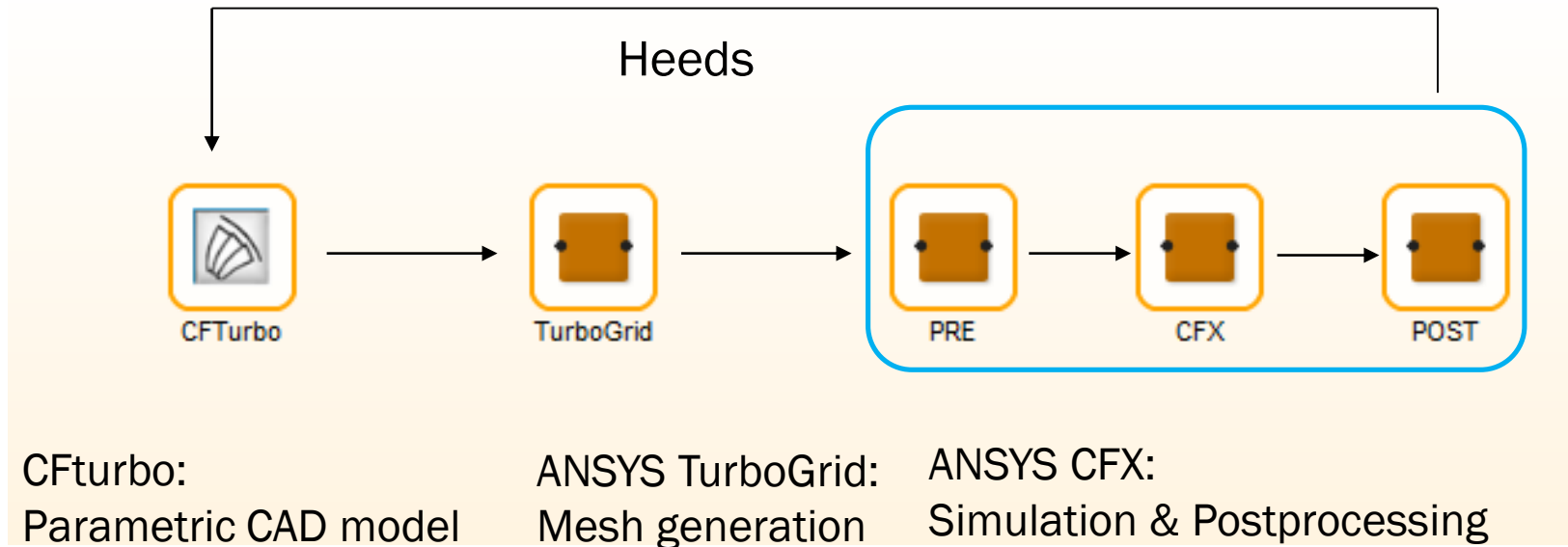
Parameters: only impeller II



Parameters	range
Number of blades z [-]	4 .. 10
Stagger angle λ_{hub} [°]	20 .. 60
Stagger angle λ_{tip} [°]	20 .. 60
Chord length l_{hub} [mm]	32 (const.)
Chord length l_{tip} [mm]	20 .. 32
Leading edge position Δz_{hub} [mm]	1 .. 8



Optimization process



144 Designs
70min/Design / 8 Processors

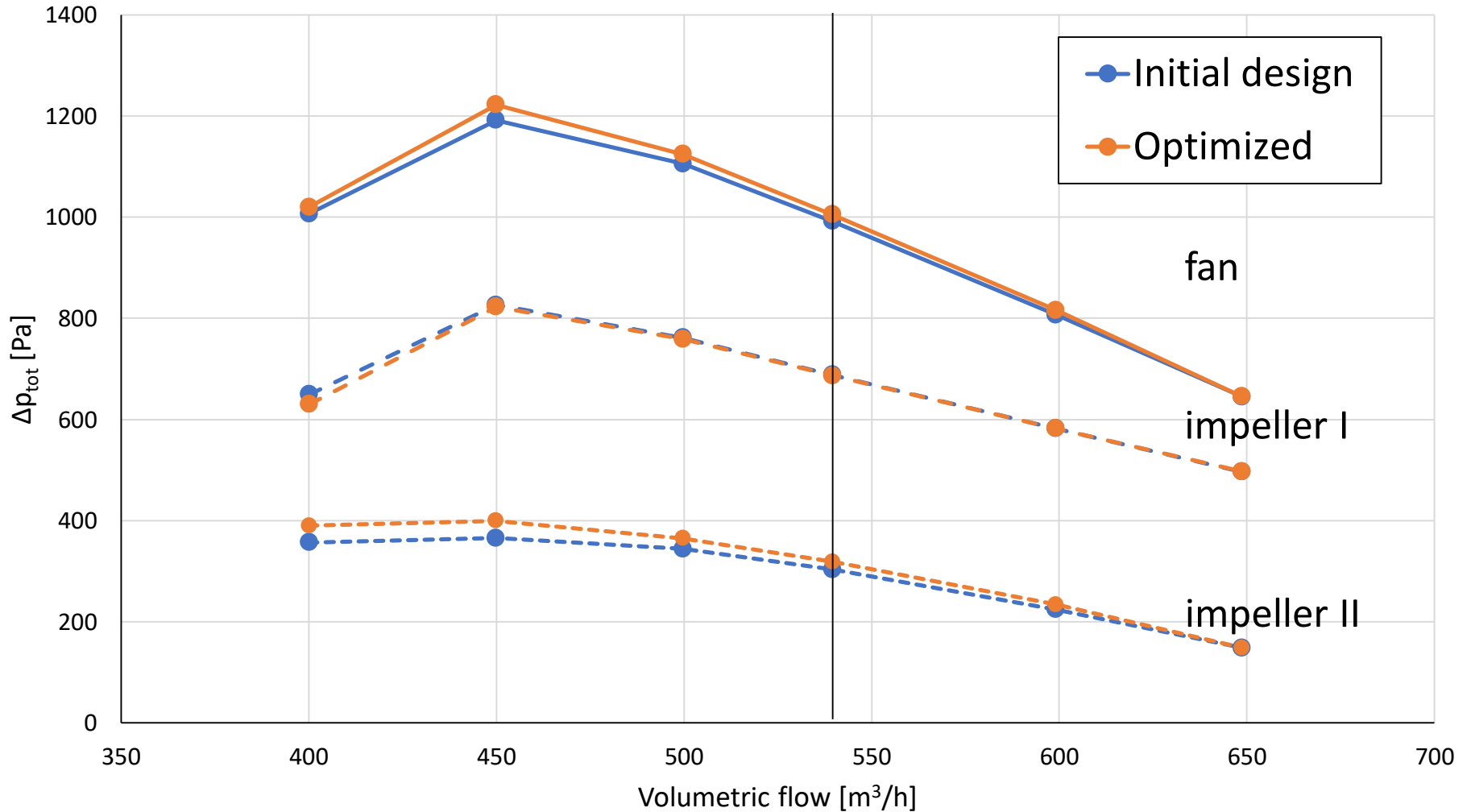
Optimization results impeller II



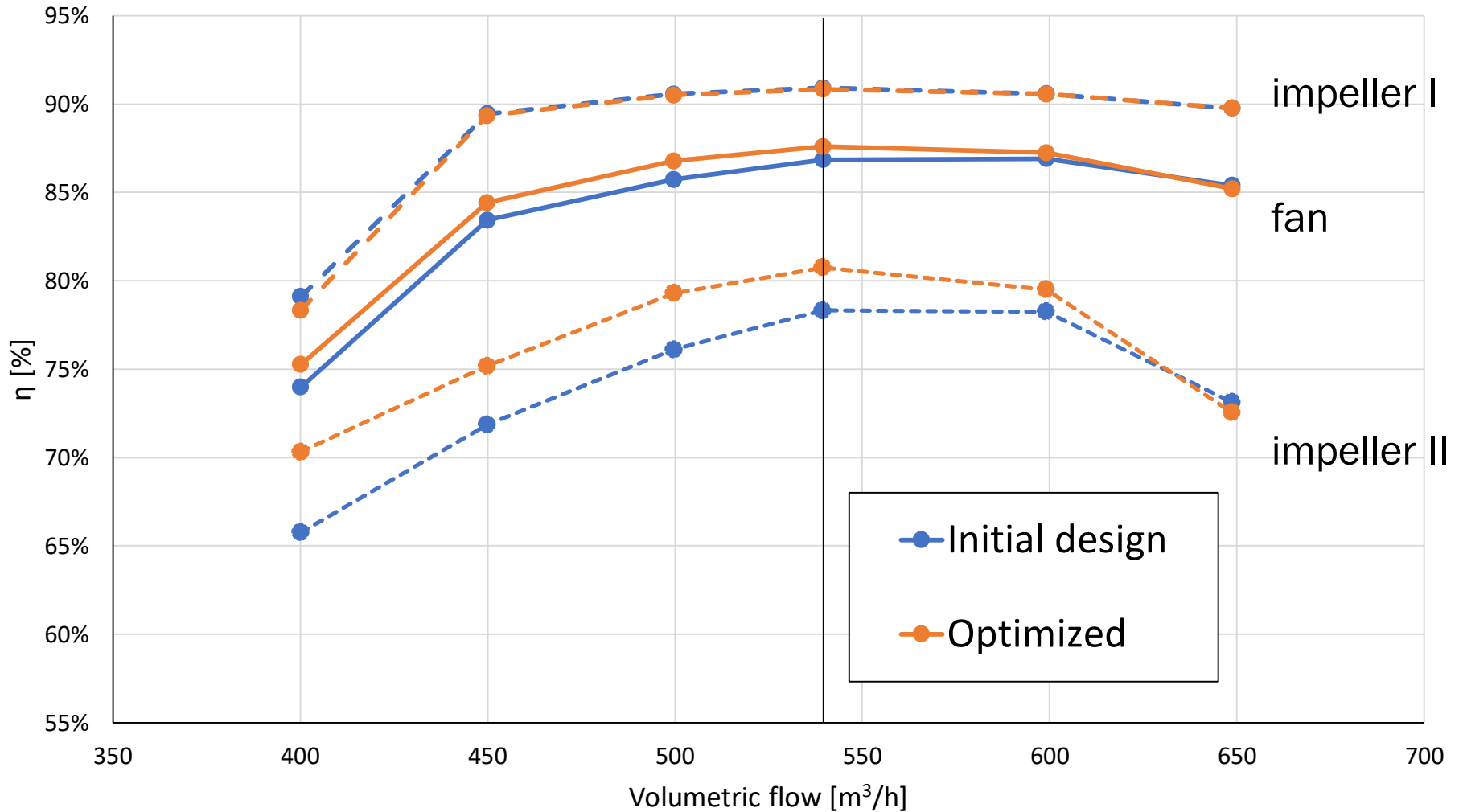
	Initial design impeller II	Optimized design impeller II
Total pressure difference Δp_{tot} [Pa]	303	319
Efficiency η [%]	78	81

	Initial design impeller II	Optimized design impeller II
Number of blades z [-]	6	7
Stagger angle λ_{hub} [°]	45.0	50.0
Stagger angle λ_{tip} [°]	36.1	30.4
Chord length l_{hub} [mm]	32	32
Chord length l_{tip} [mm]	26	26
Leading edge position Δz_{hub} [mm]	1	2.6

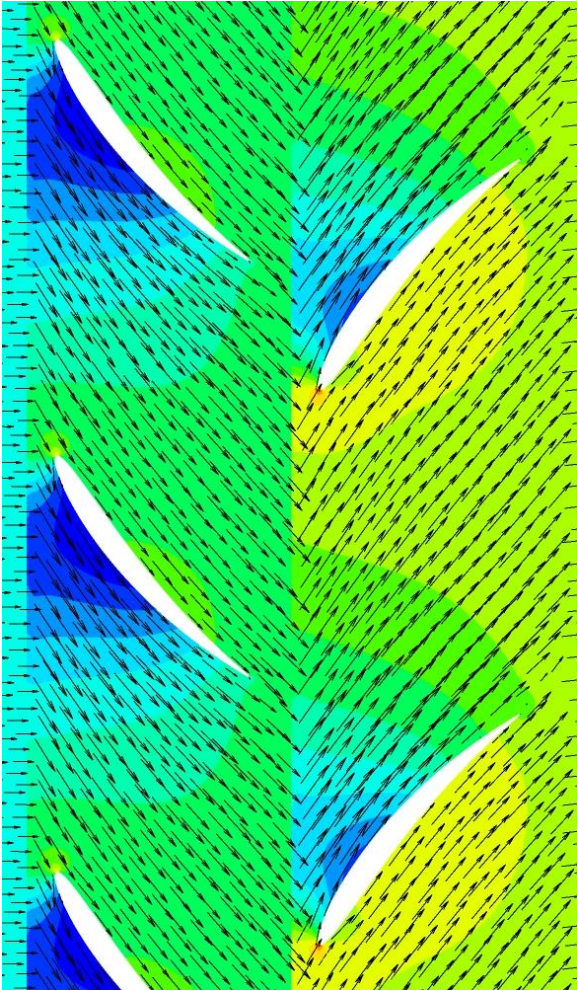
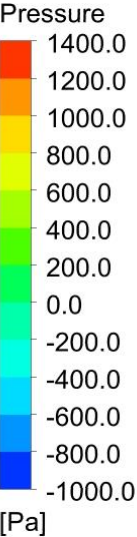
Performance curve



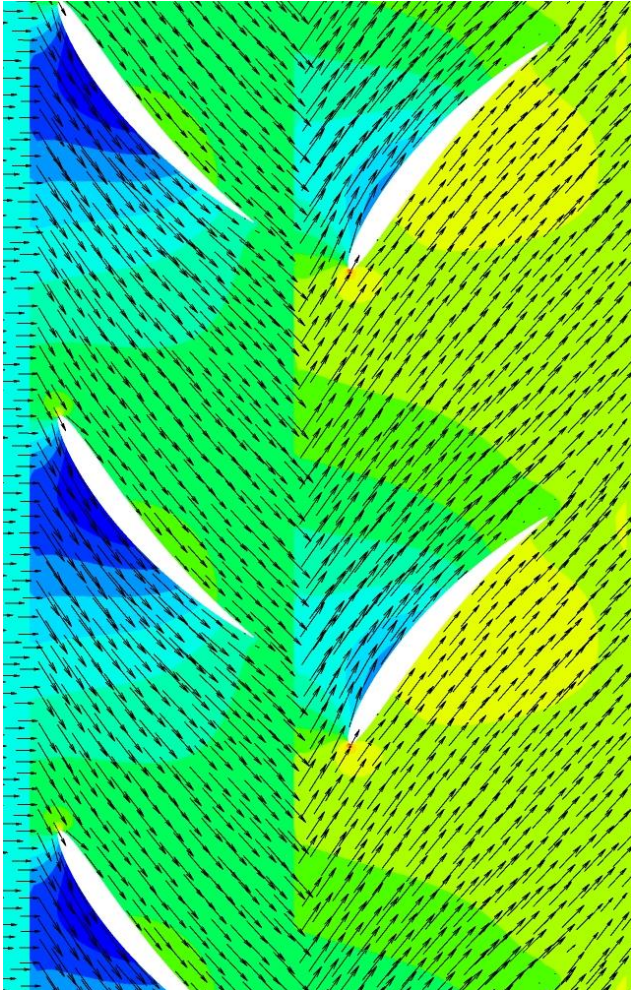
Efficiency



Pressure distribution mid span

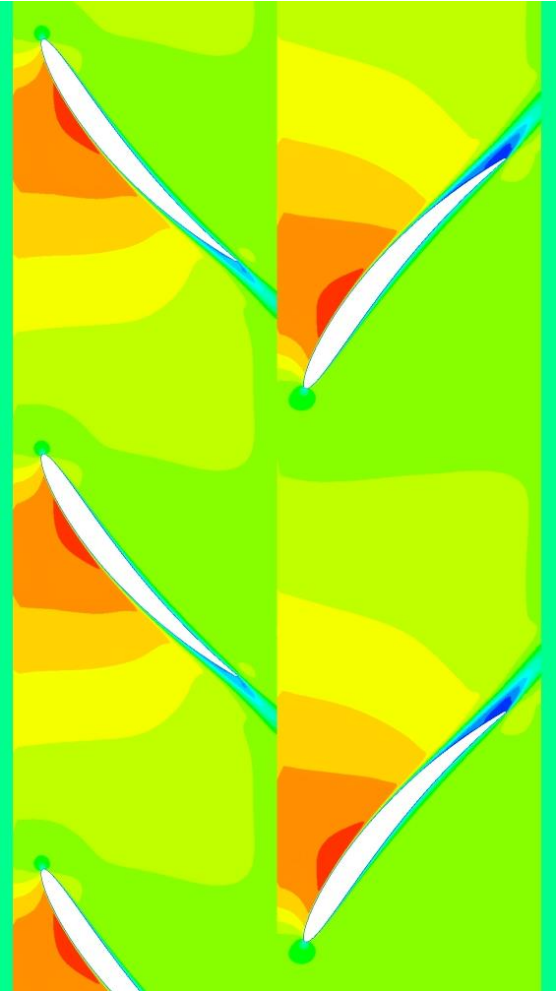
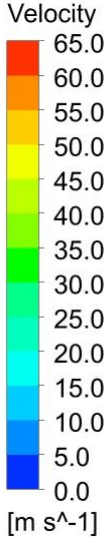


Initial design

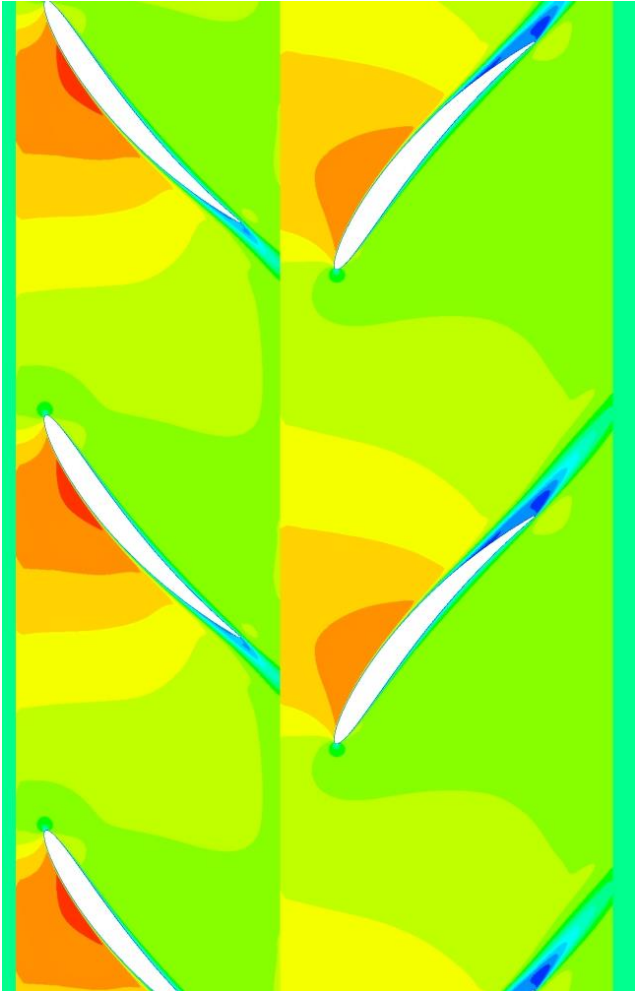


Optimized

Relative velocity distribution mid span



Initial design



Optimized

- Automated process for design and optimization for Contra-rotating fans
- Reasonable initial design for both impellers using CFturbo software
- Optimization of second impeller only
- Simple method: passage only, steady state simulation
- Computational resources
- Validation in progress
 - Transient flow simulations/360°
 - More detailed geometry modeling
 - Experiments
- Acoustic investigations planned

