Multi-objective optimization of a centrifugal compressor for turbocharging

TECHNISCHE UNIVERSITÄT DARMSTADT

Johannes Ratz
Gas Turbines and Aerospace Propulsion
TU Darmstadt

Source:
MTU Friedrichshafen GmbH

MASCHINENBAU
We engineer future

GLR

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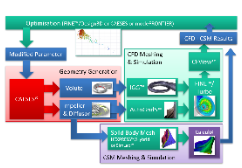
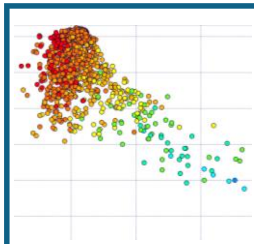


Optimization-Workflow



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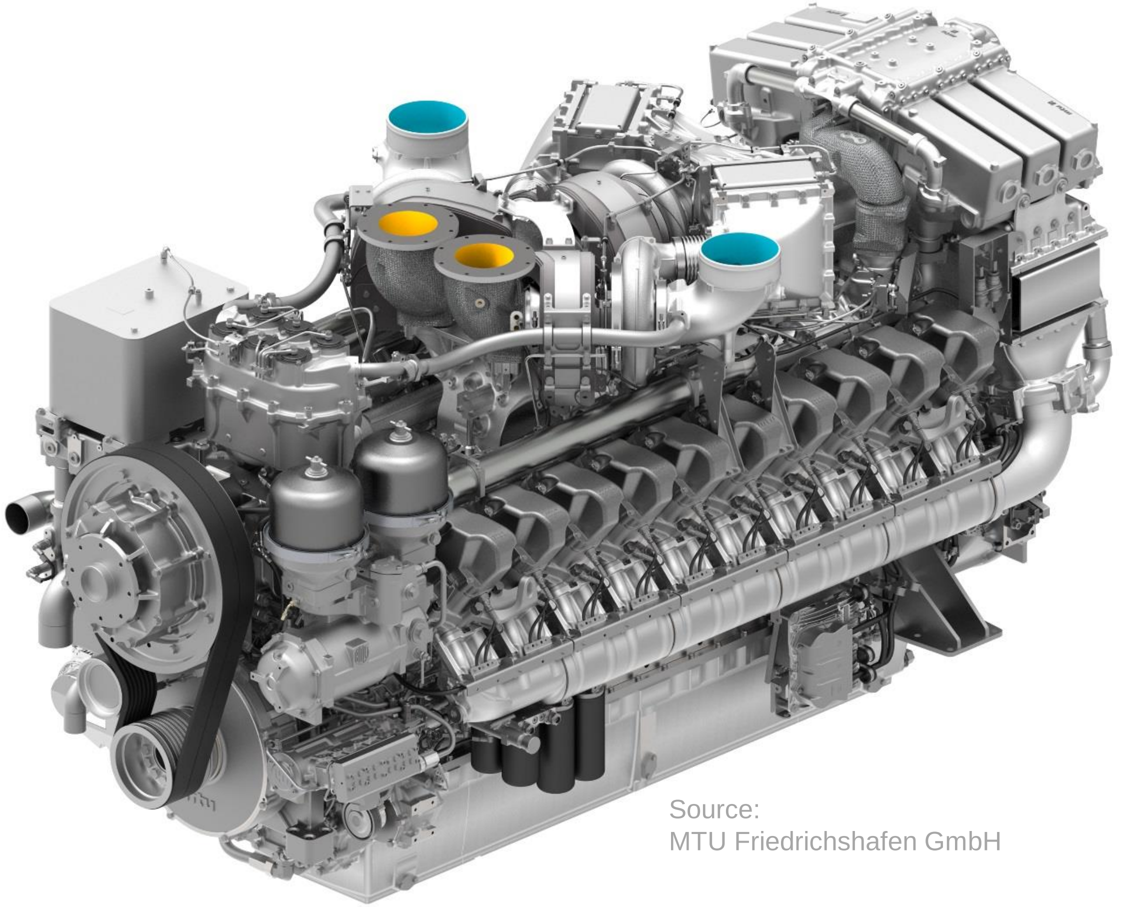

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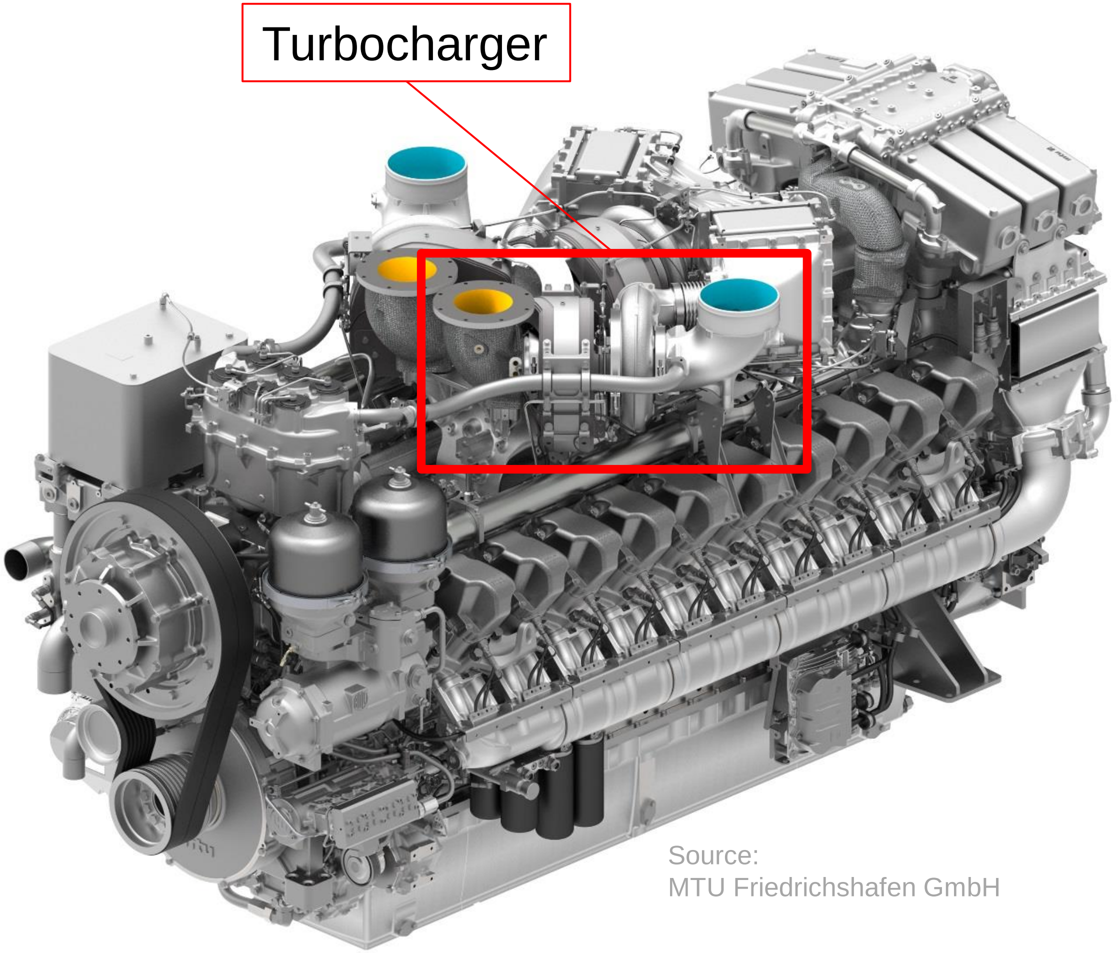

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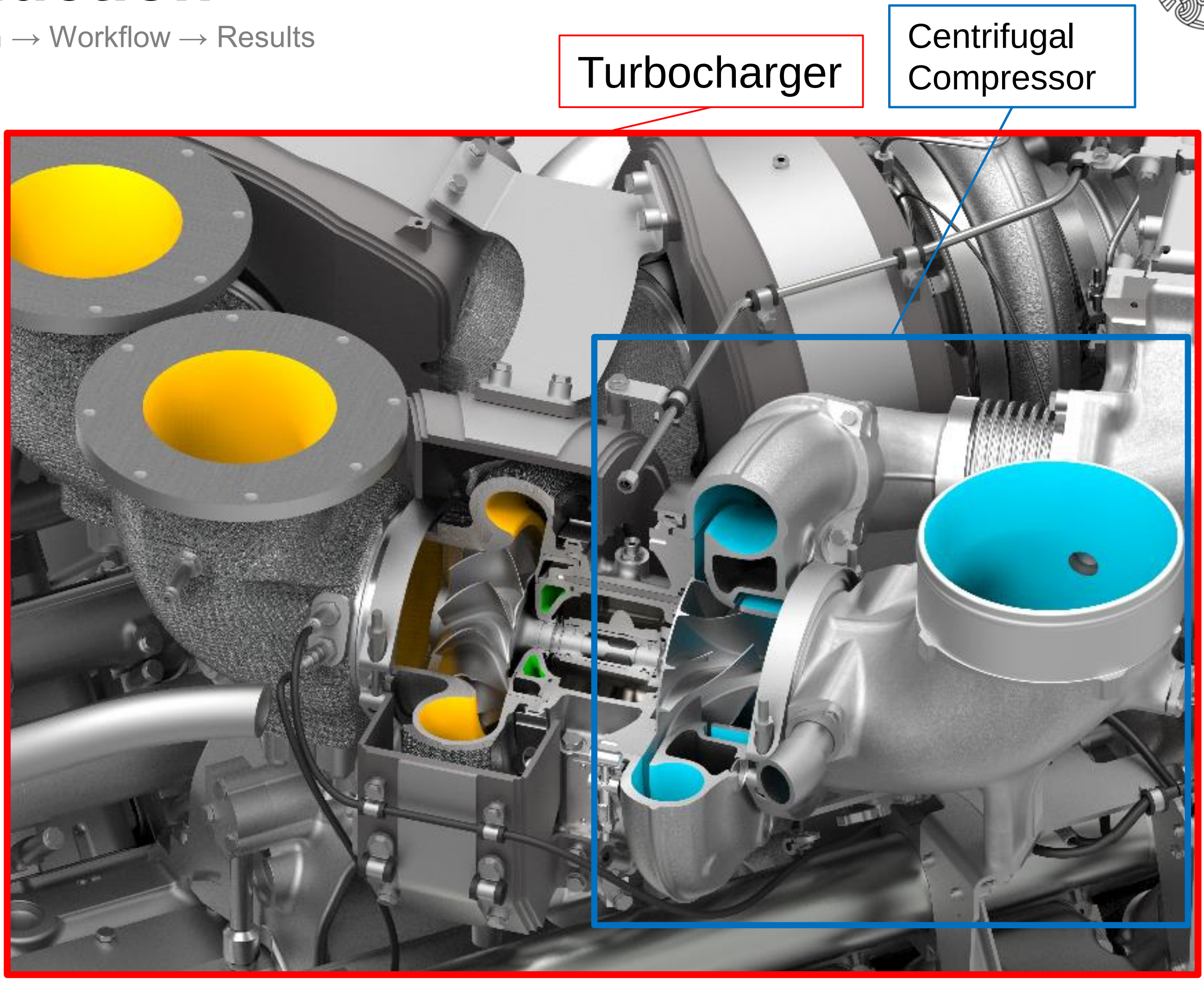

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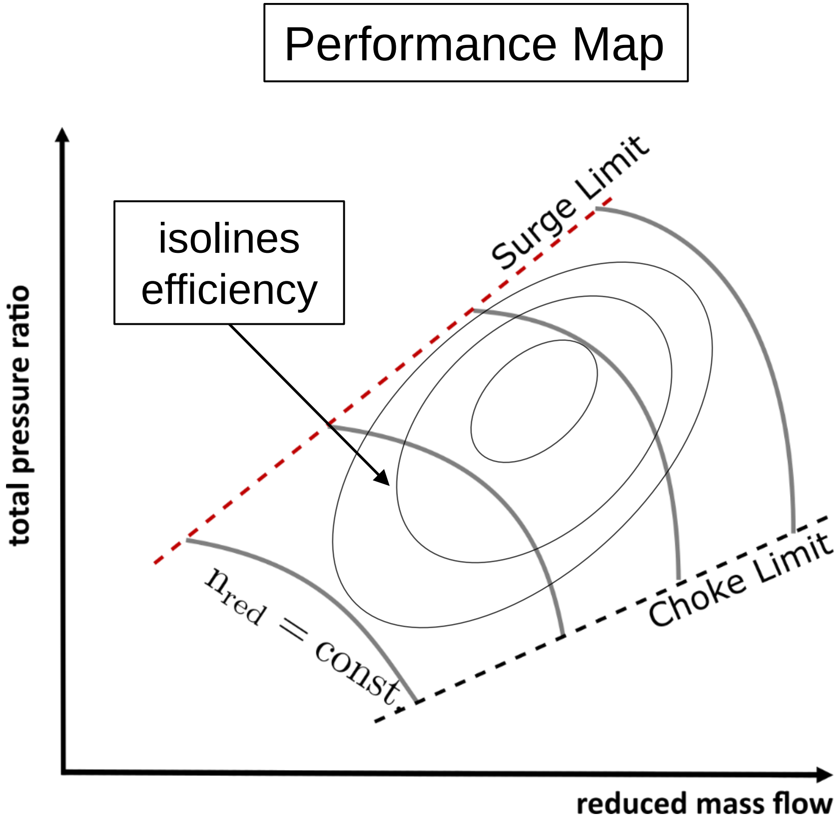

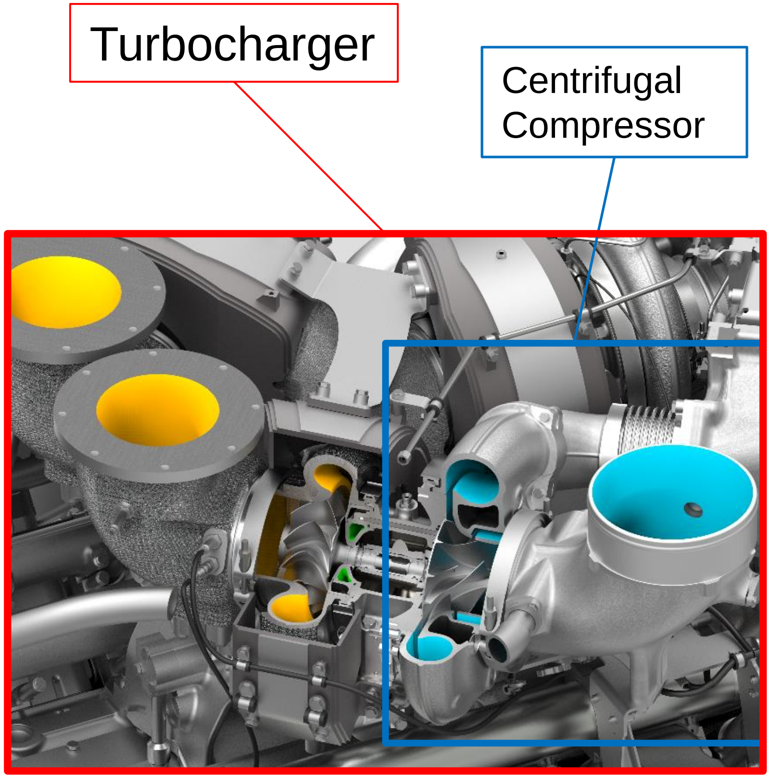

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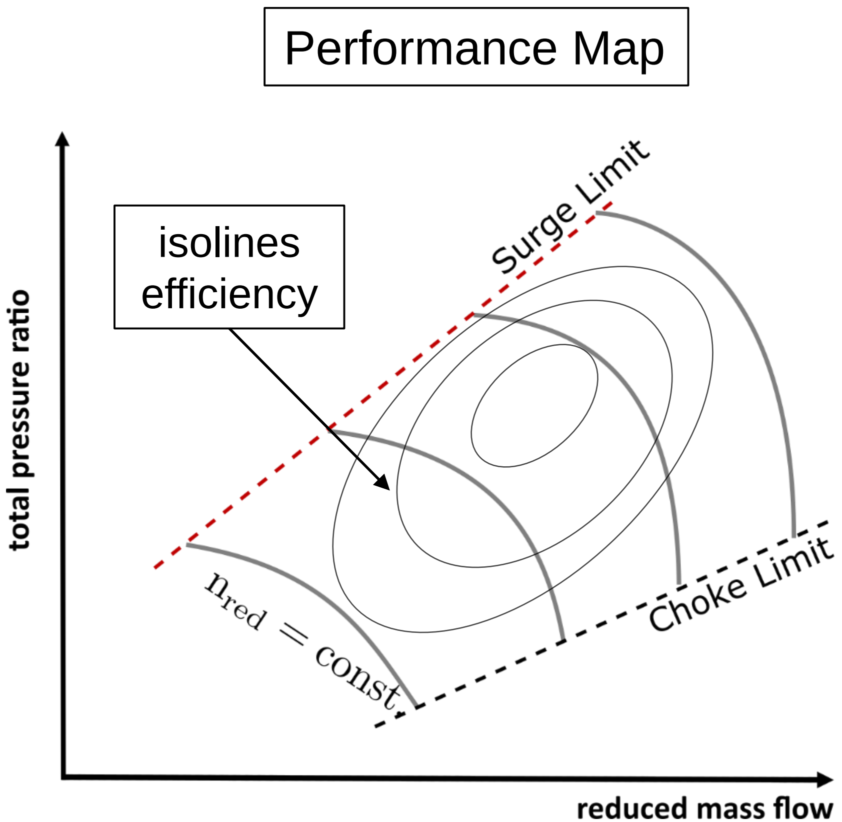

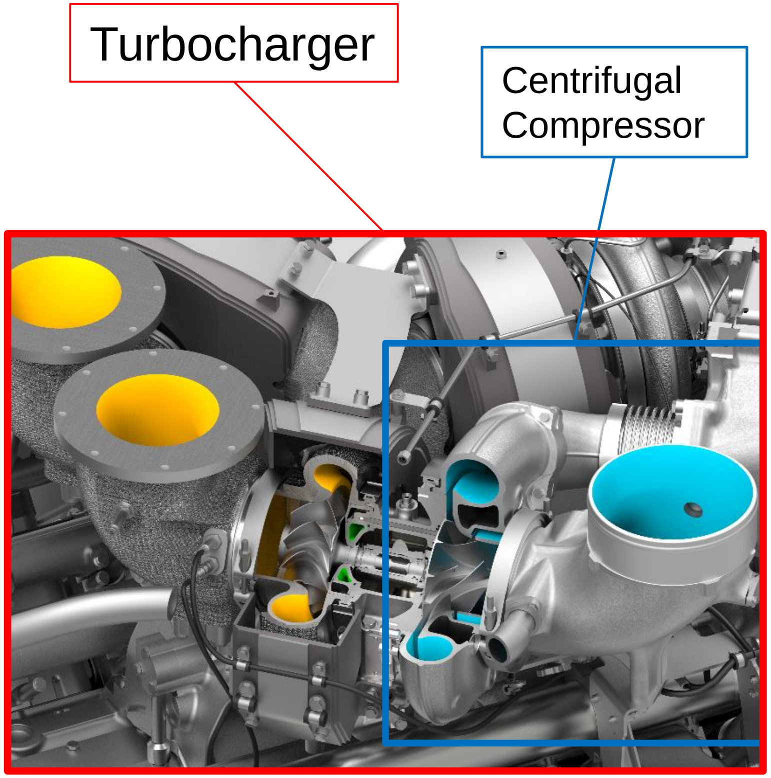

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➡ 1. Objective: Increase Efficiency

Introduction

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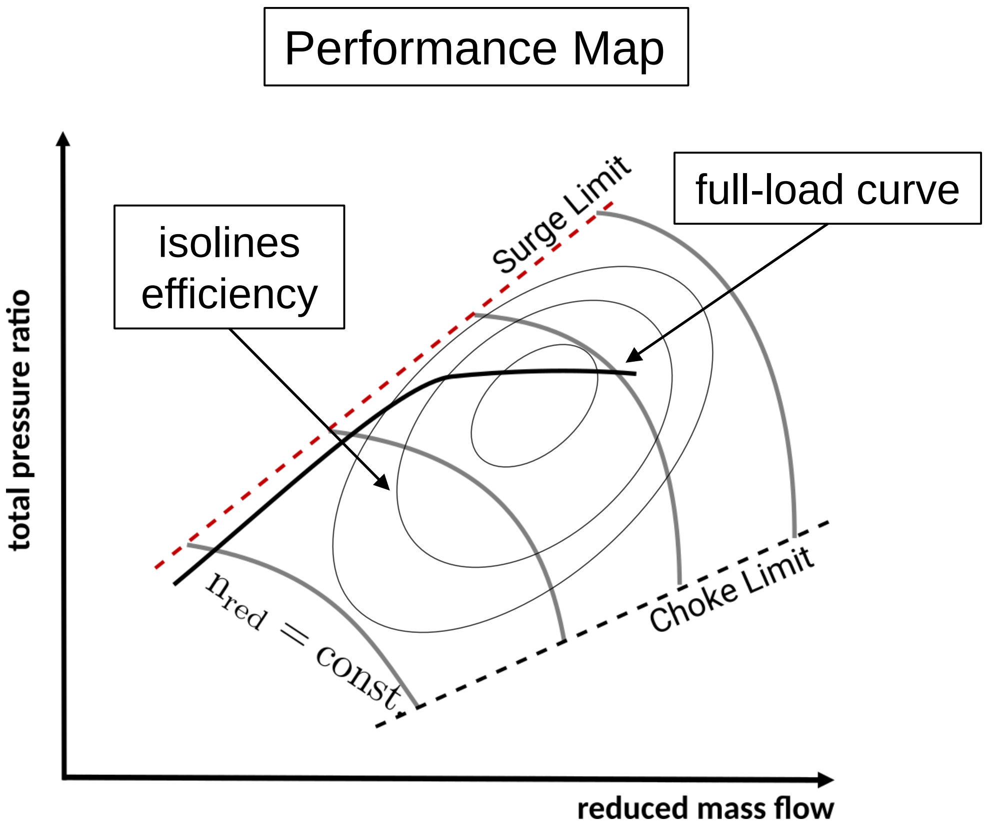

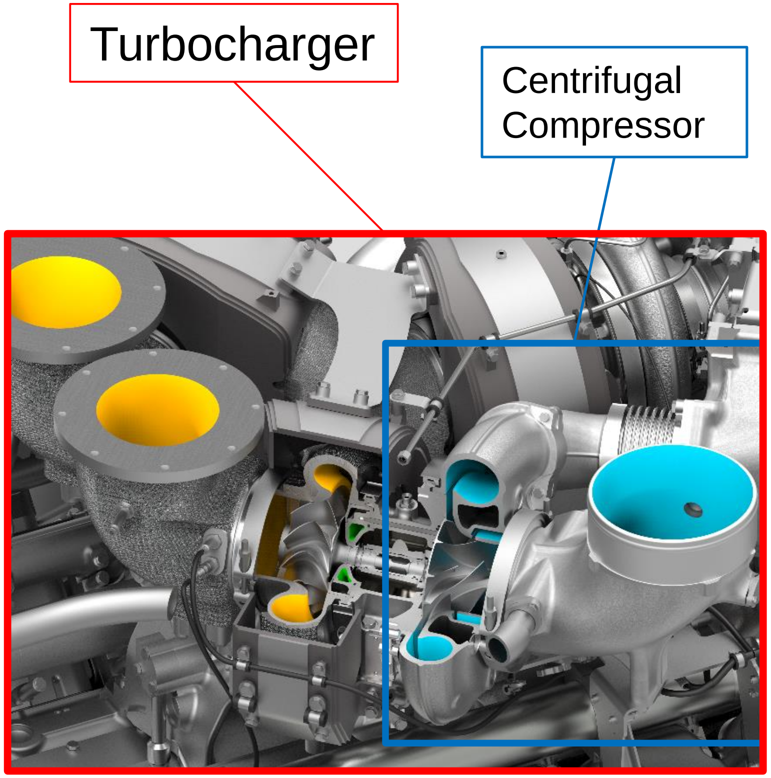

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➡ 1. Objective: Increase Efficiency

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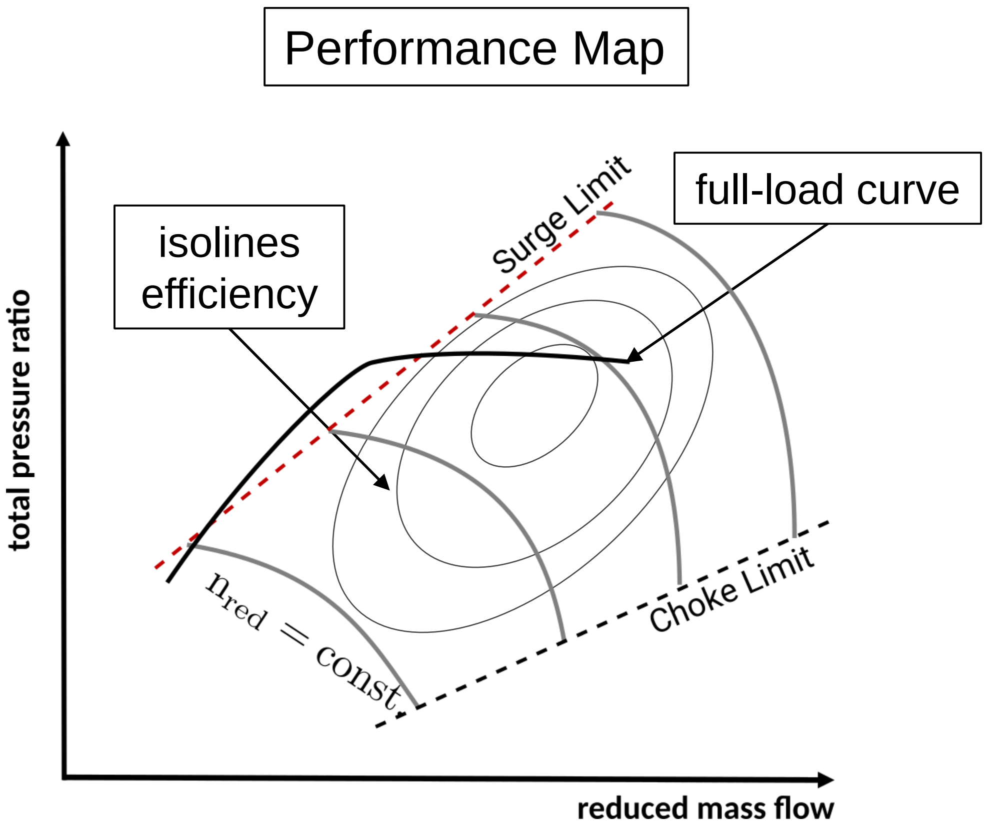

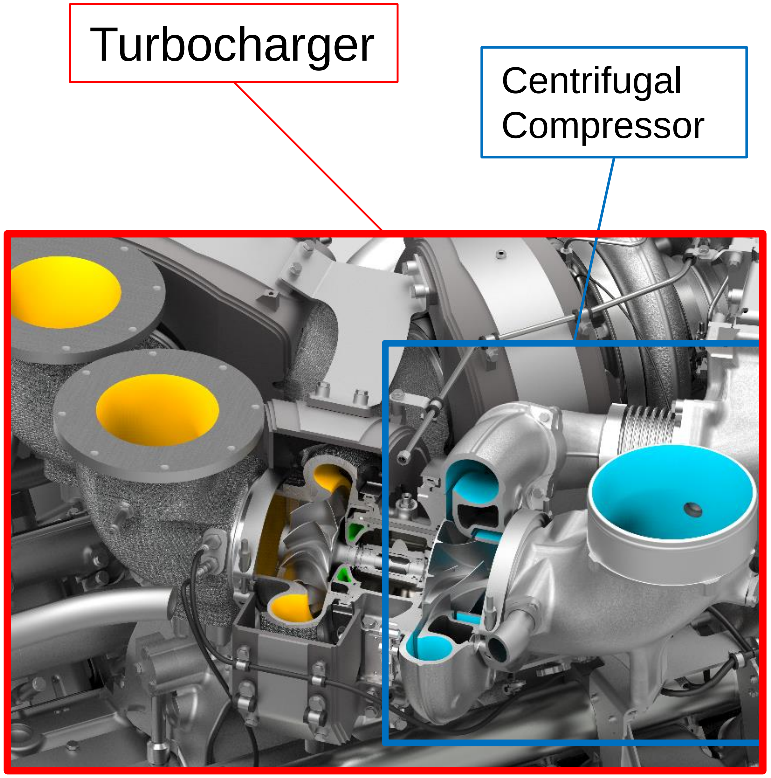

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➡ 1. Objective: Increase Efficiency

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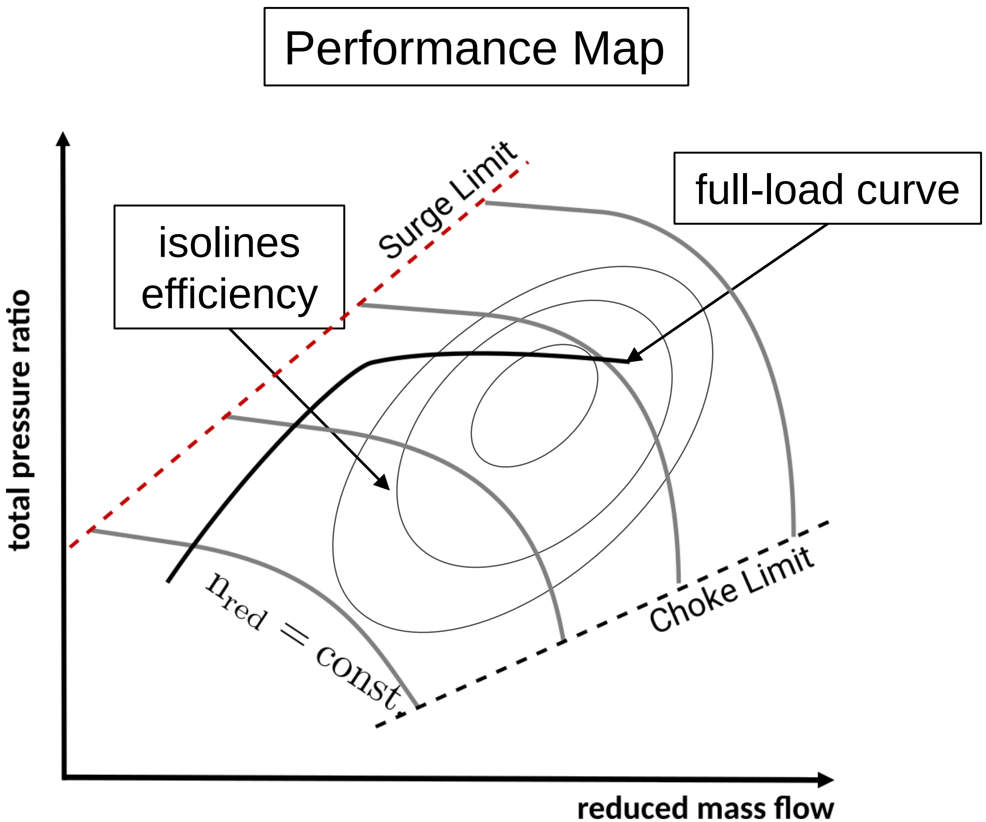

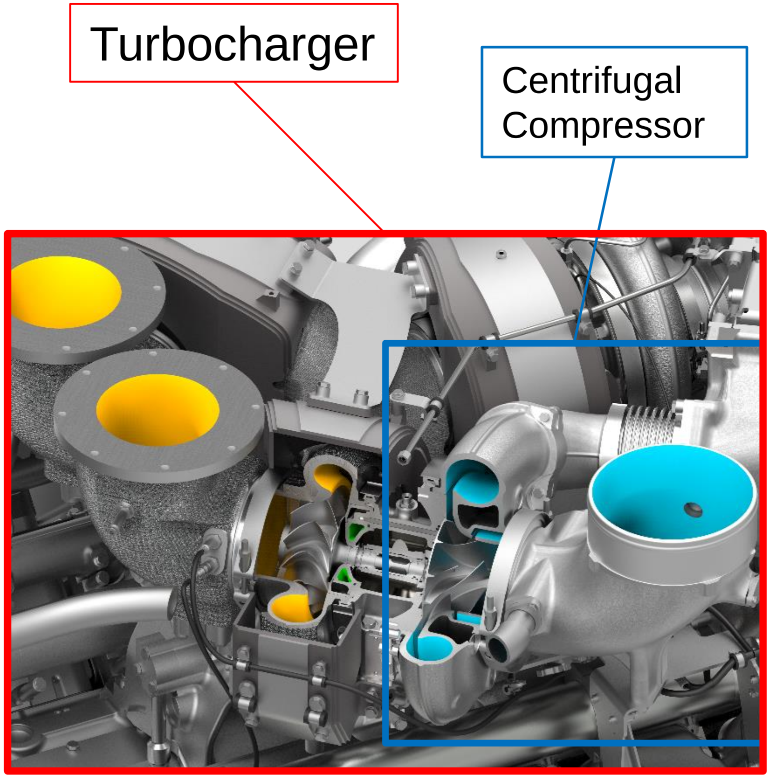

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➡ 1. Objective: Increase Efficiency

➡ 2. Objective: Increase Performance Map Width

Introduction

- ➡ 1. Objective: Increase Efficiency
- ➡ 2. Objective: Increase Performance Map Width

⟹ CFD

Problem: A pure aerodynamic optimization often leads to a poor structural integrity.

- ➡ 1. Constraint: Von Mises Stresses
- ➡ 2. Constraint: Eigenfrequency

⟹ CSM

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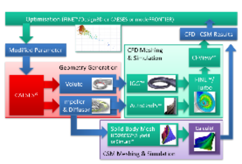

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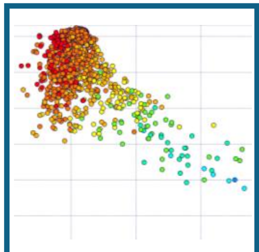

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Workflow

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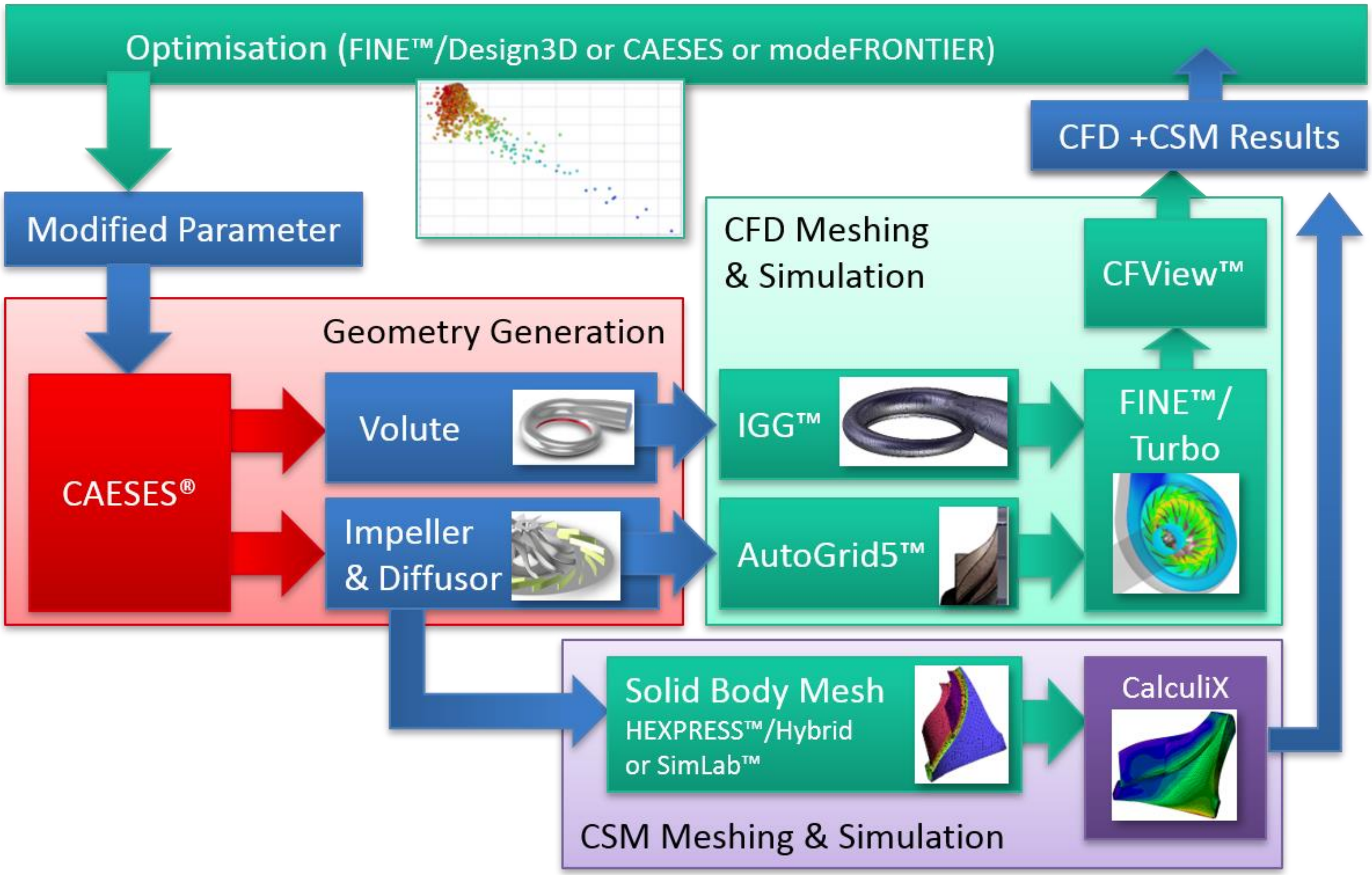
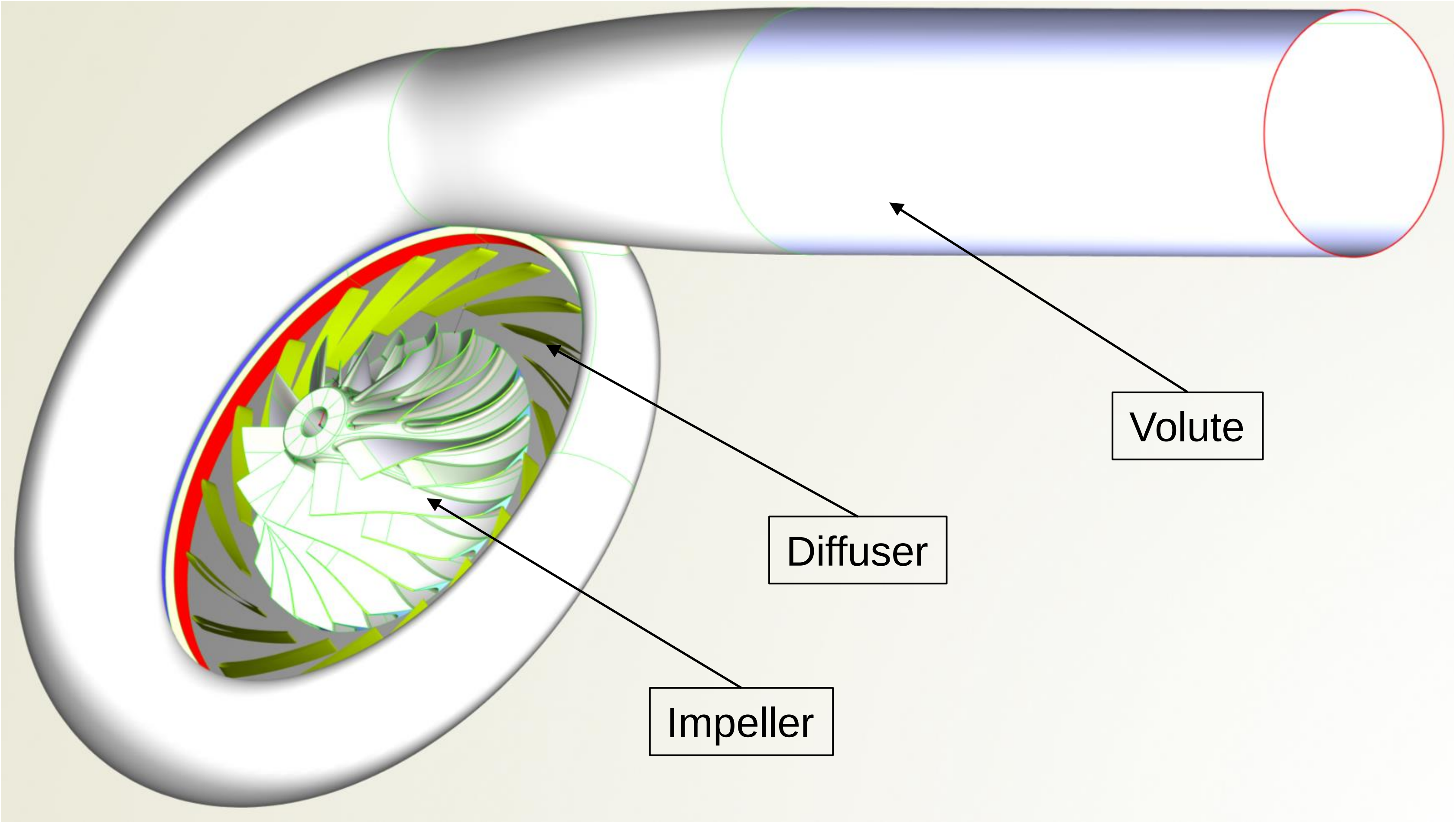
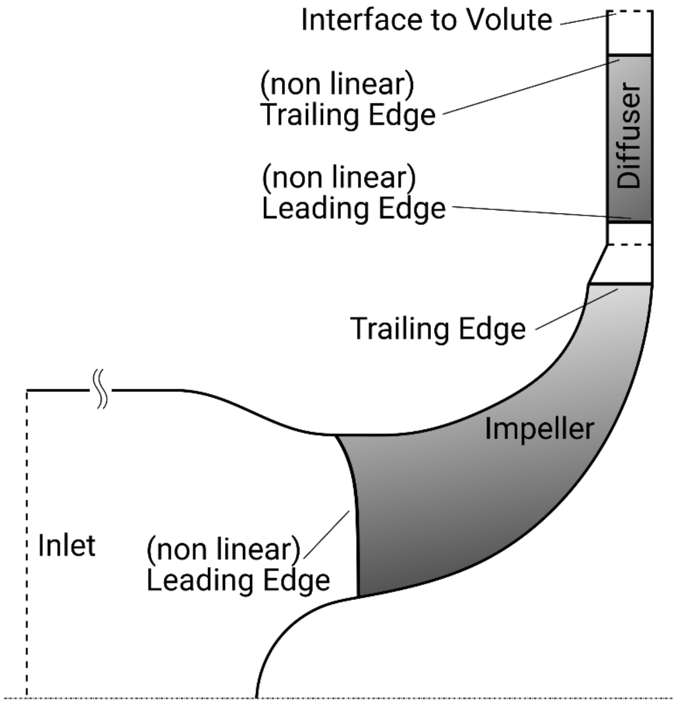


Workflow - Parametrization

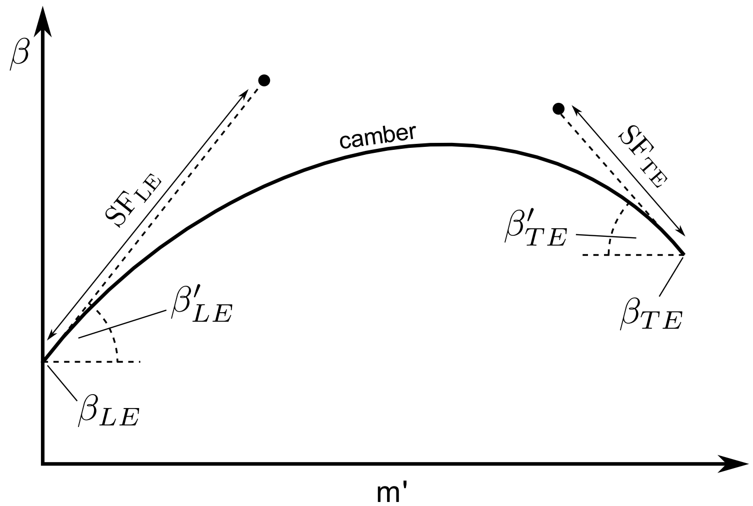


Workflow - Parametrization

Meridional



Betaangle - Distribution



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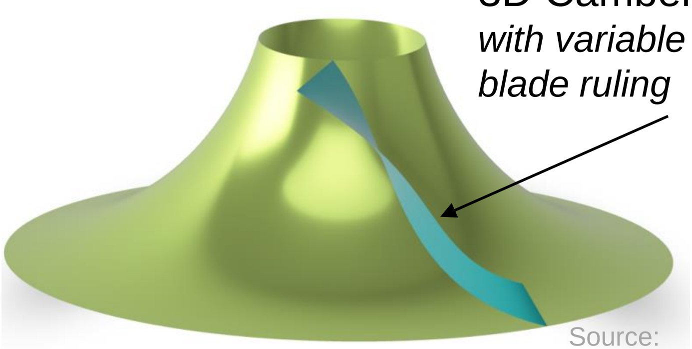

3D Camber Surface
with variable blade ruling

Source:
Friendship Systems

Workflow - Parametrization

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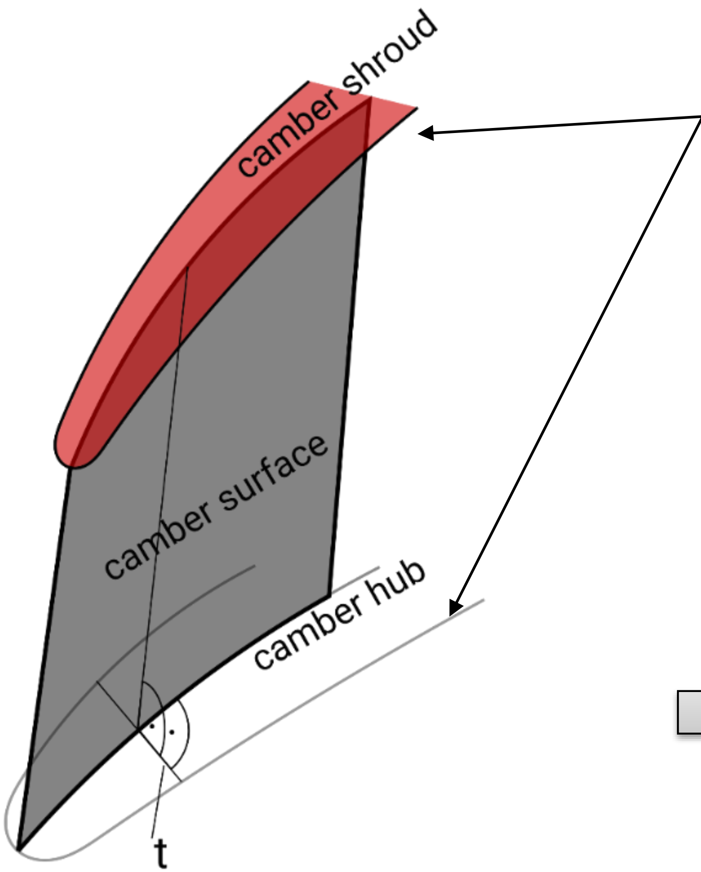
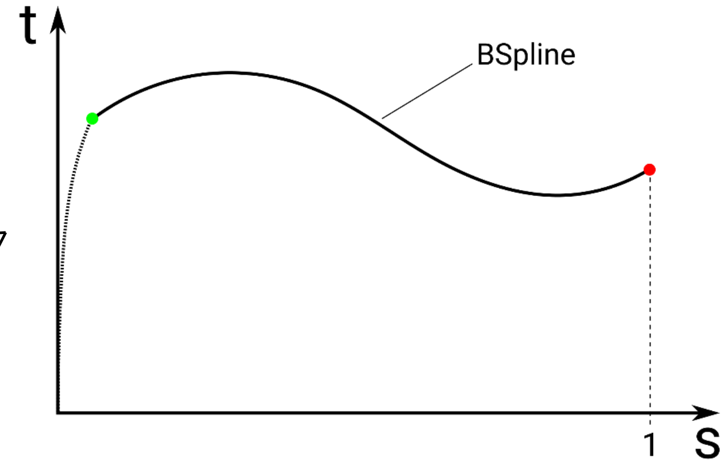
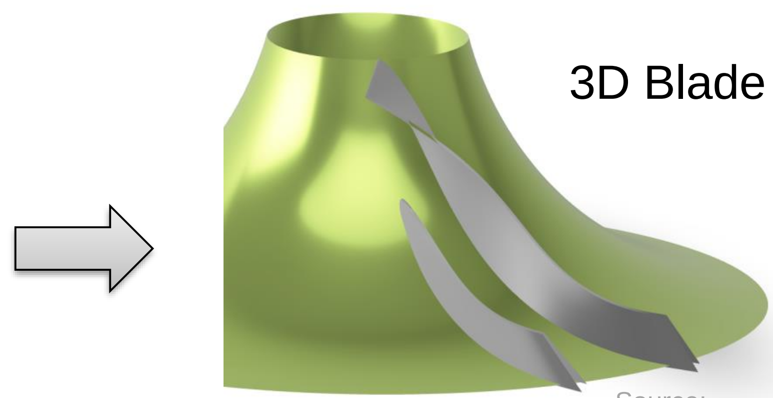
Thicknessdistribution





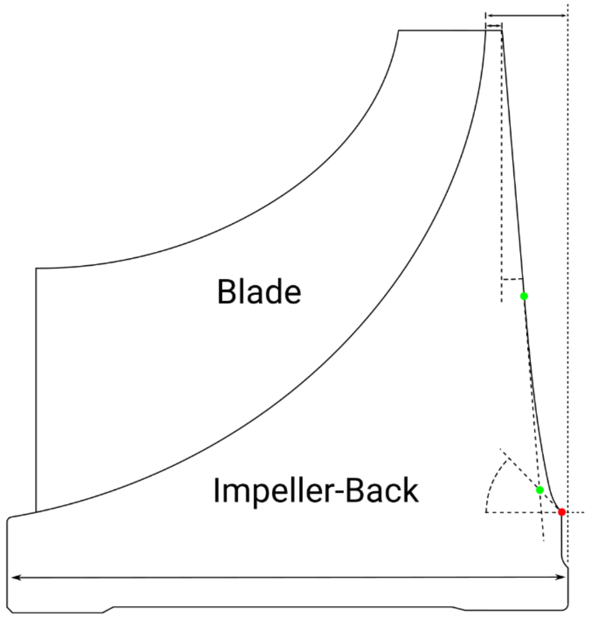


3D Blade

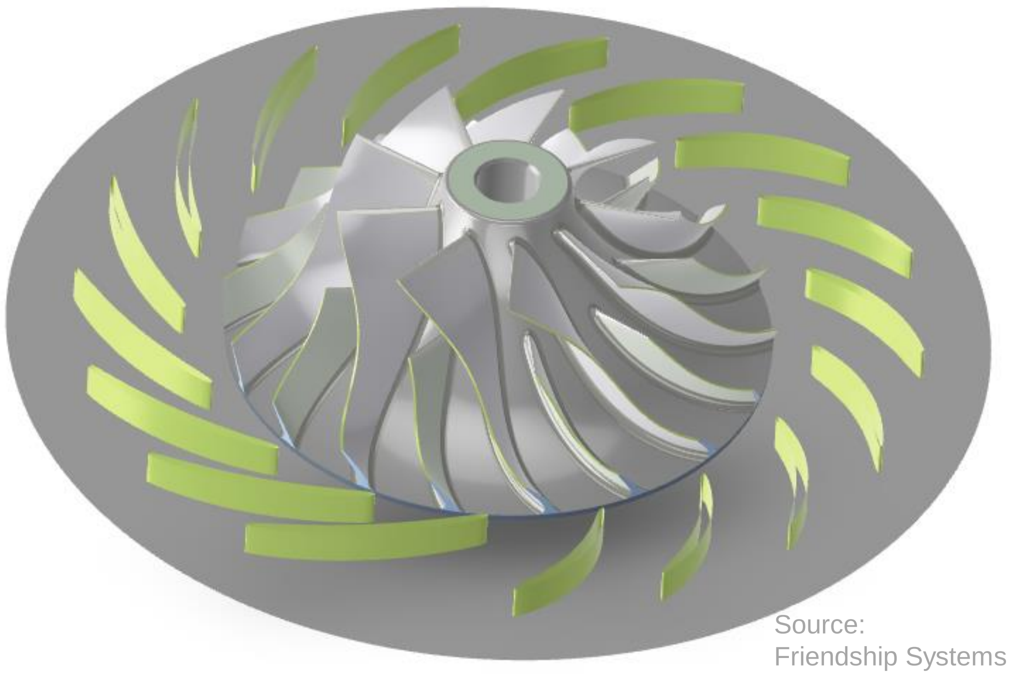
Source:
Friendship Systems

Workflow - Parametrization

Solid



Final 3D Impeller and Diffuser



Source:
Friendship Systems

Geometry Export:

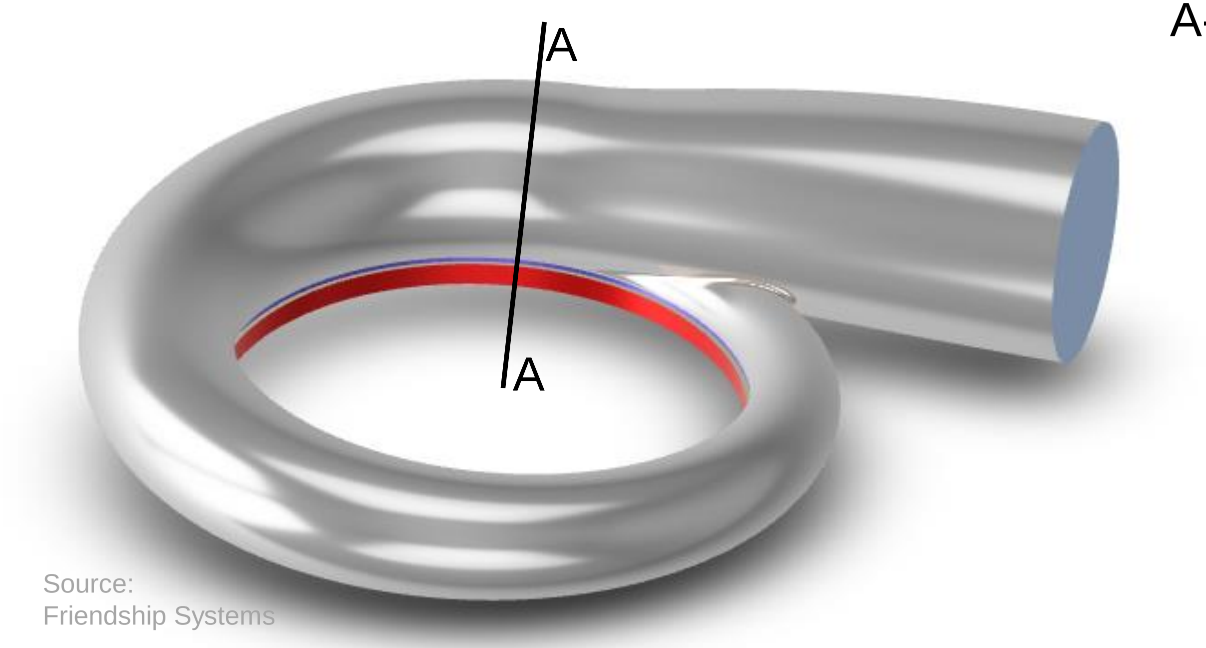
CFD (Meridional Contour, Blades) → geomTurbo (Numeca)

CSM (Impeller Solid) → Parasolid

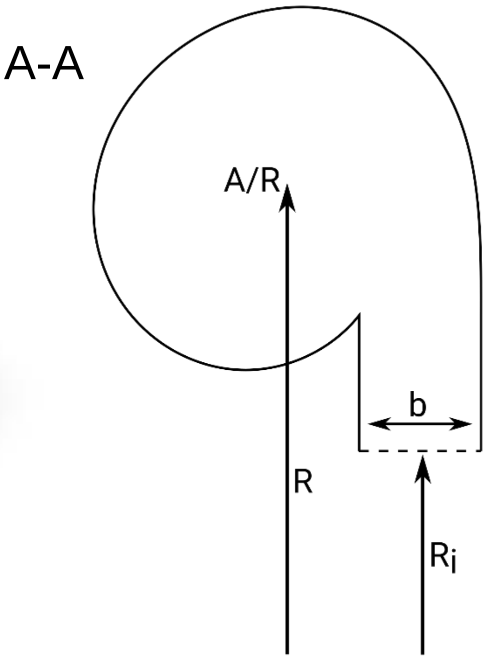
Workflow - Parametrization

Introduction → **Workflow** → Results

Volute

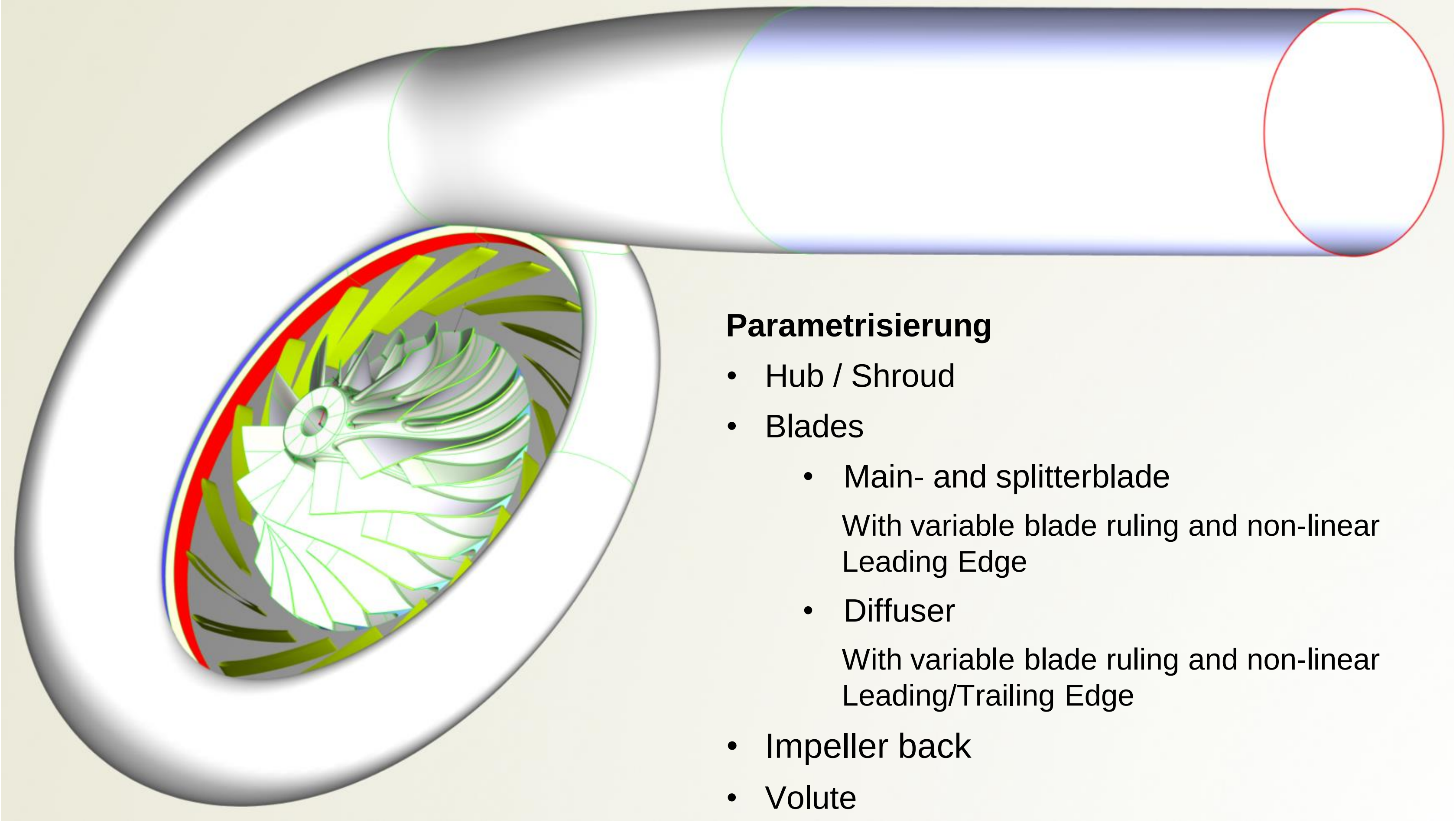


Source:
Friendship Systems



Geometry Export:
CFD → Parasolid

Workflow - Parametrization



Parametrisierung

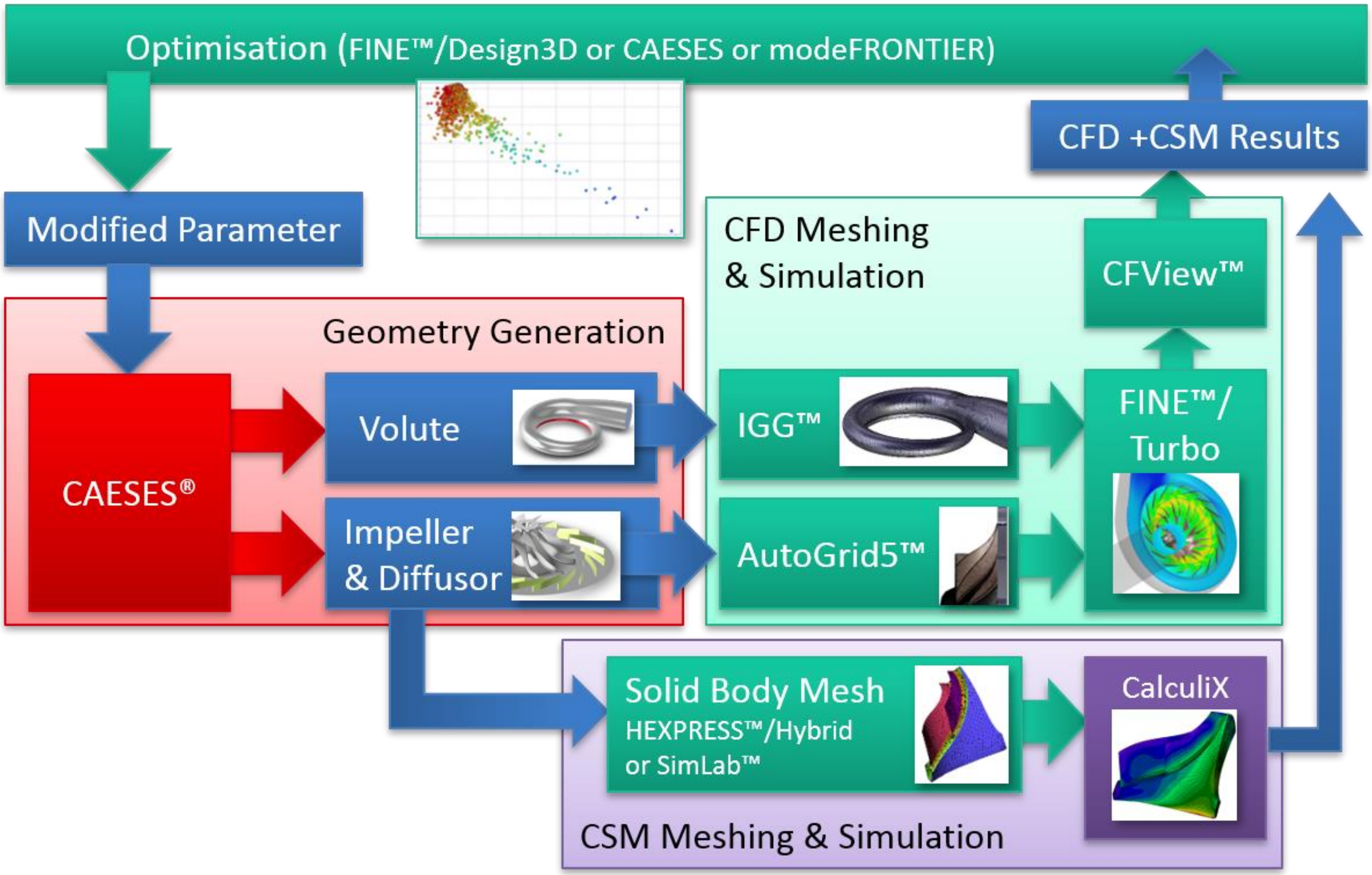
- Hub / Shroud
- Blades
  - Main- and splitterblade

    With variable blade ruling and non-linear Leading Edge
  - Diffuser

    With variable blade ruling and non-linear Leading/Trailing Edge
- Impeller back
- Volute

Workflow

Introduction → **Workflow** → Results



Workflow - CFD

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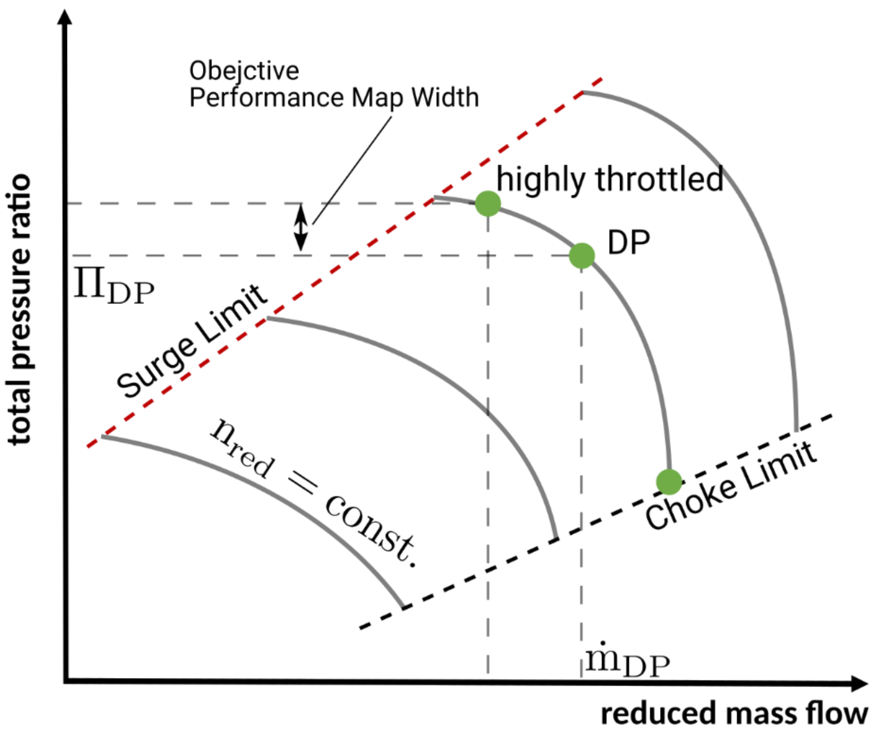
Solver *Numeca FINE/Turbo*



Objectives:

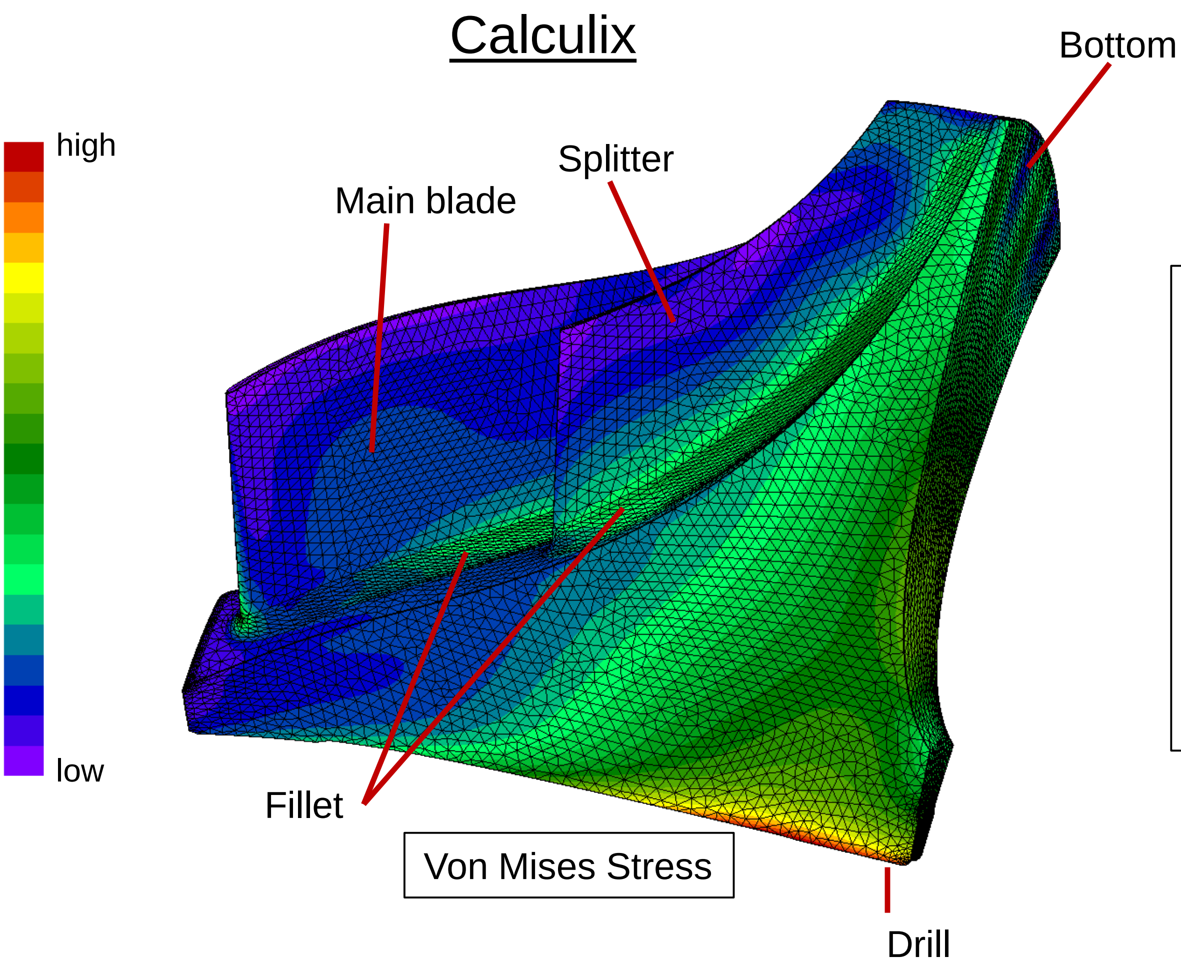
- Isentropic Efficiency η_{DP}
- Performance Map Width $\frac{\pi_{highly\ throttled}}{\pi_{DP}}$

Constraints:

- Total Pressure Ratio π_{DP}
- Choke Mass Flow

Workflow - CSM

Introduction → **Workflow** → Results

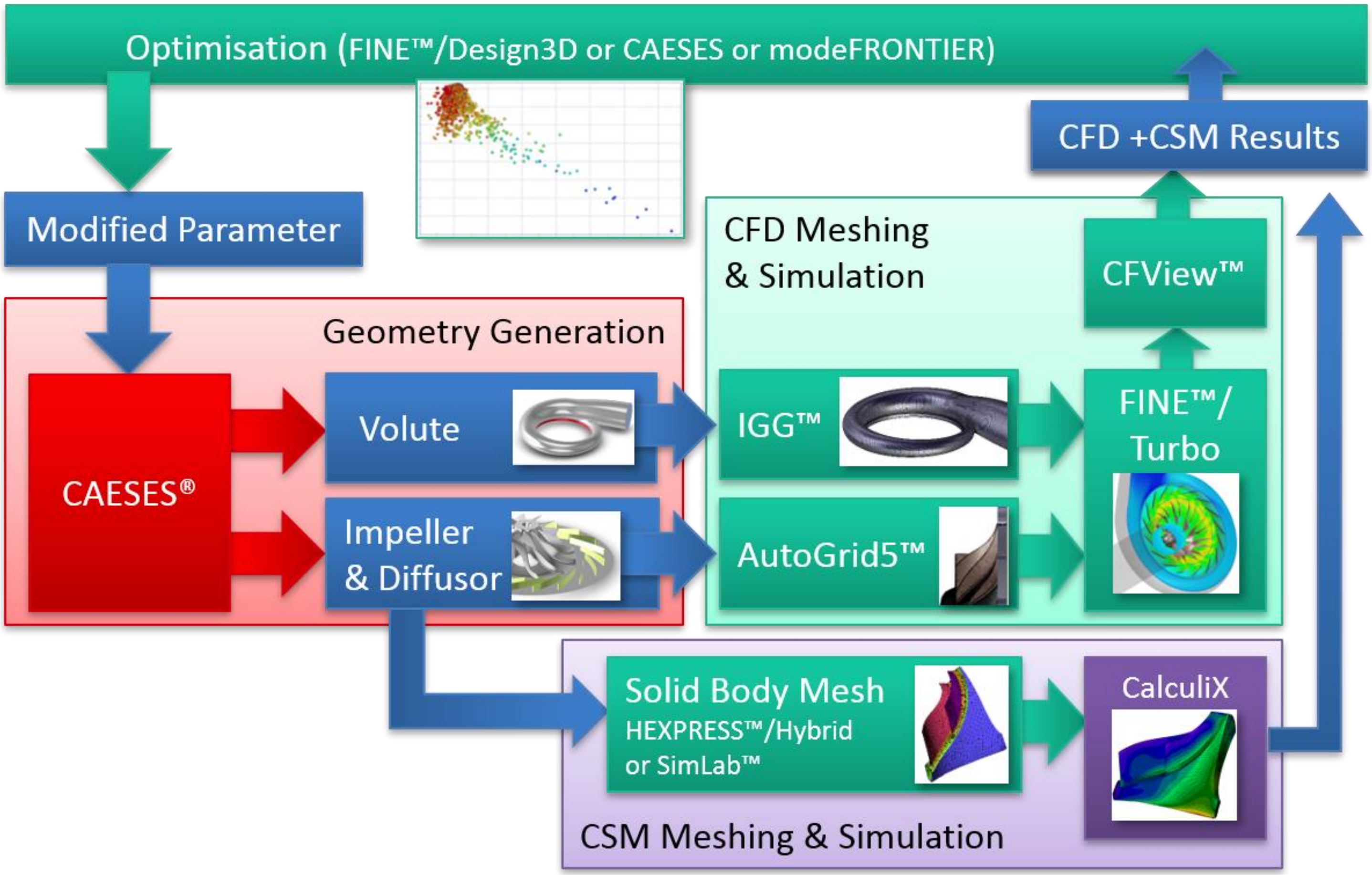


Constraints:

- 1. blade eigenfrequency
- Max. von Mises stress:
  - Main blade
  - Splitter blade
  - Fillet
  - Bottom
  - Drill

Workflow

Introduction → **Workflow** → Results



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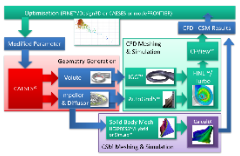
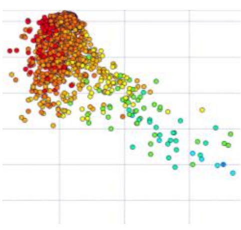


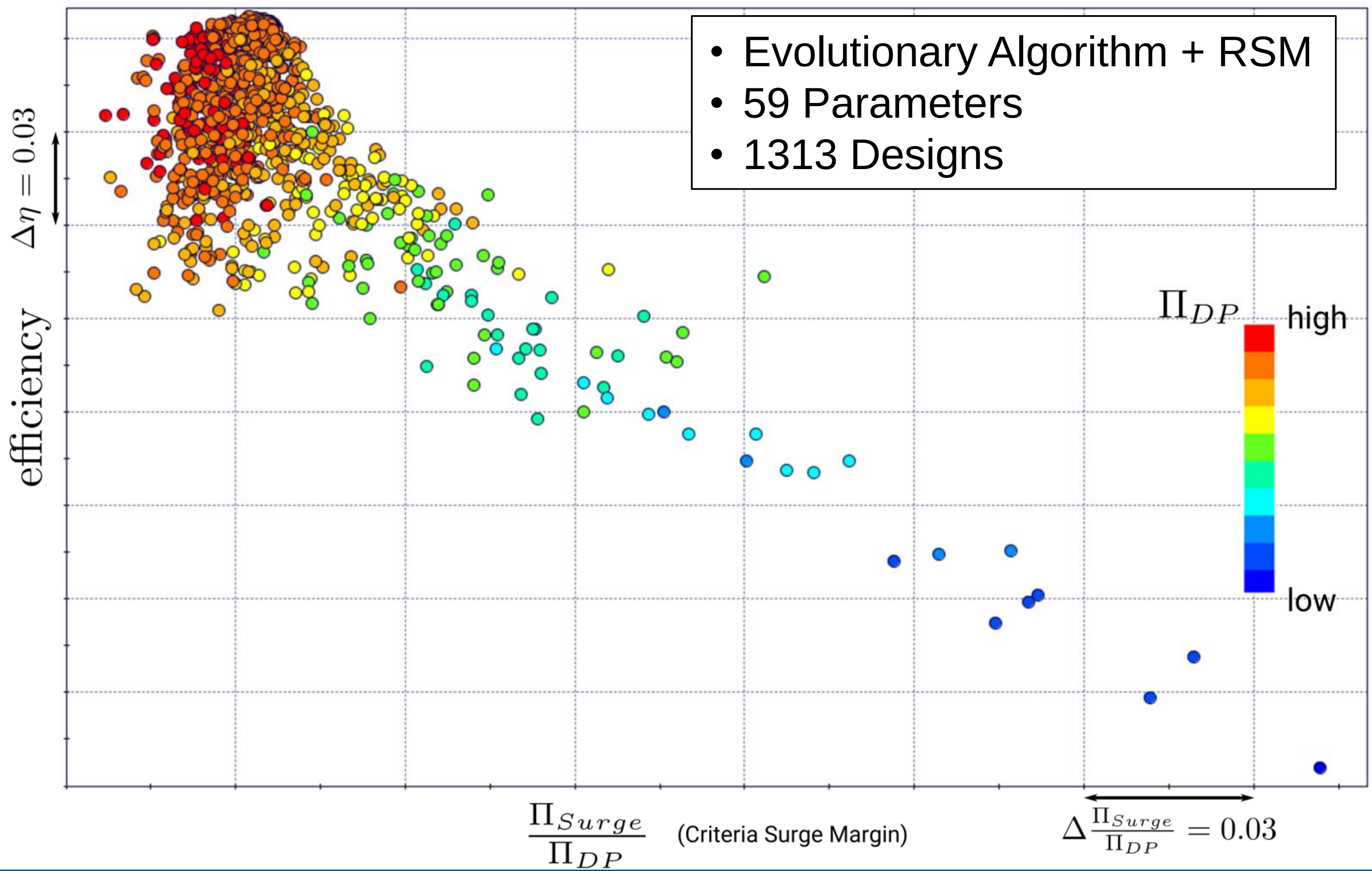
Optimization-Workflow



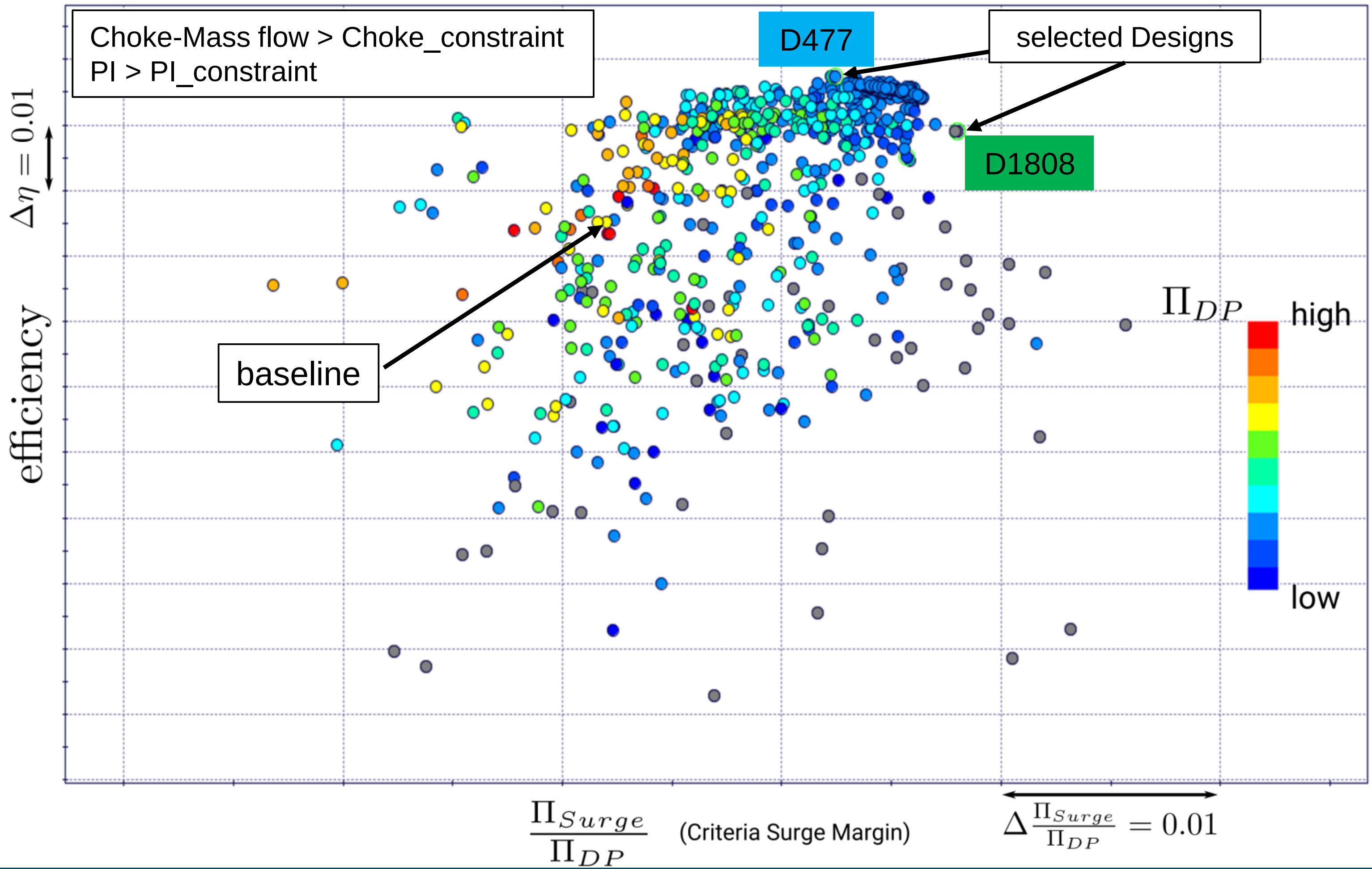
Results

Results

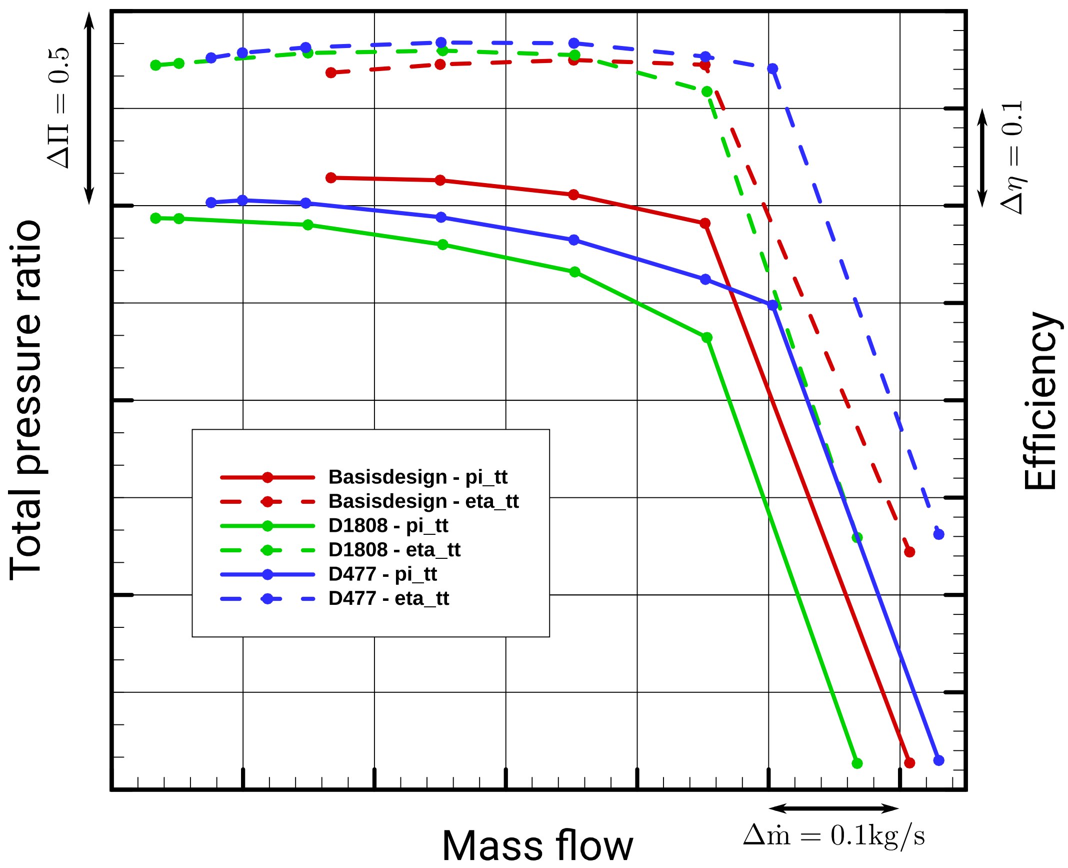
Introduction → Workflow → **Results**



Results


Choke-Mass flow > Choke_constraint
PI > PI_constraint
D477
selected Designs
D1808
baseline
$\Delta\eta = 0.01$
efficiency
Π_{DP}
high
low
$\frac{\Pi_{Surge}}{\Pi_{DP}}$
(Criteria Surge Margin)
$\Delta\frac{\Pi_{Surge}}{\Pi_{DP}} = 0.01$

Results



D477

η_{DP} → + 2.2 percentage points
π_{DP} → - 0.1 (3.25%)

Map width $\left(\frac{\dot{m}_{Choke}-\dot{m}_{Stall}}{\dot{m}_{Choke}}\right)$
→ + 5.3 percentage points

D1808

η_{DP} → + 1.4 percentage points
π_{DP} → - 0.17 (5.5%)

Map width $\left(\frac{\dot{m}_{Choke}-\dot{m}_{Stall}}{\dot{m}_{Choke}}\right)$
→ + 5 percentage points

Compliance of structural constraints

Thank You for Your Attention!

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