

Parametric Modeling for Hydraulic Pump Design



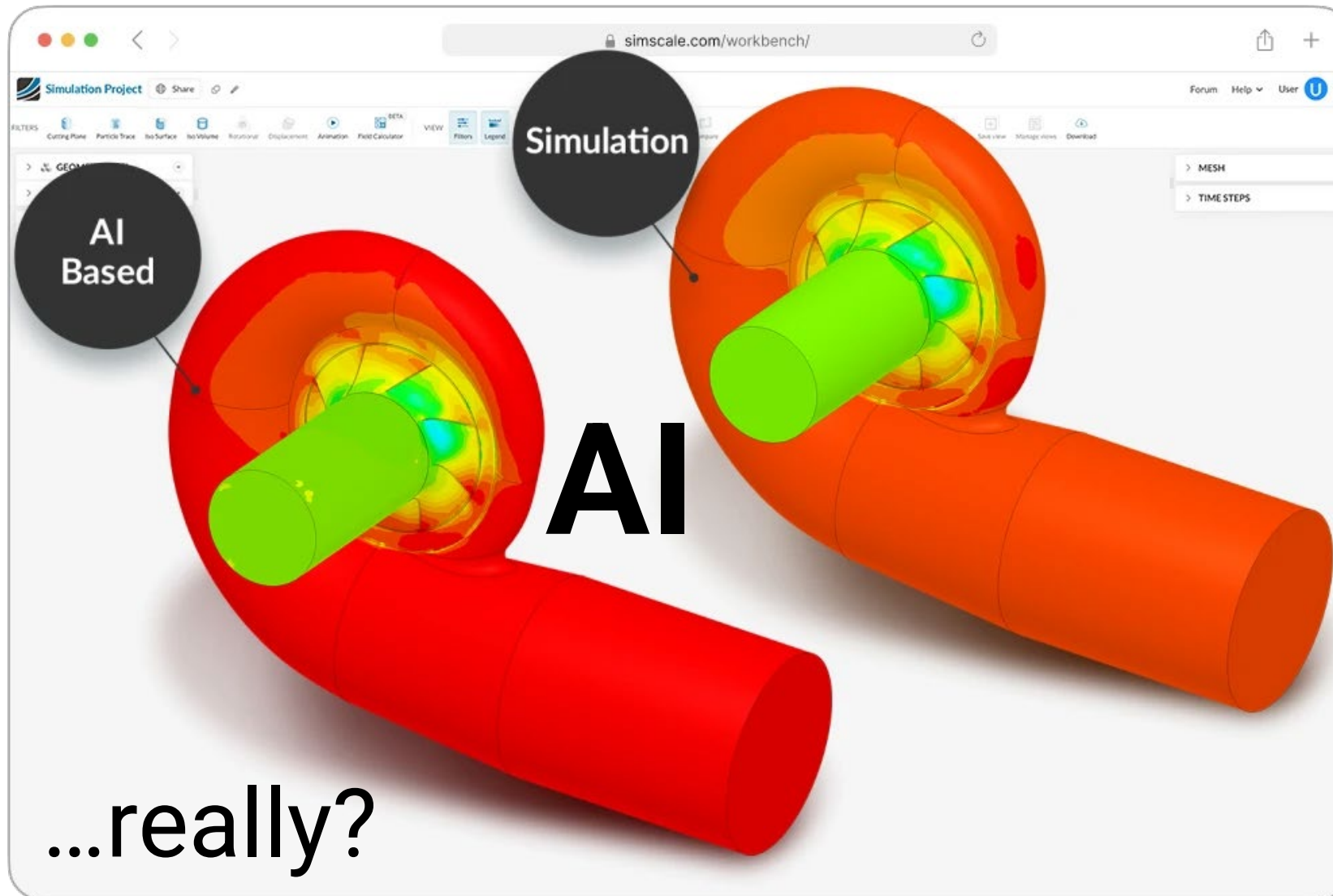
ASME
FEDSM 2026
FLUIDS ENGINEERING DIVISION
SUMMER MEETING

HYATT REGENCY BELLEVUE | BELLEVUE, WA, USA

Ralph Peter Mueller, President CFturbo, Inc. Mount Pleasant, SC United States

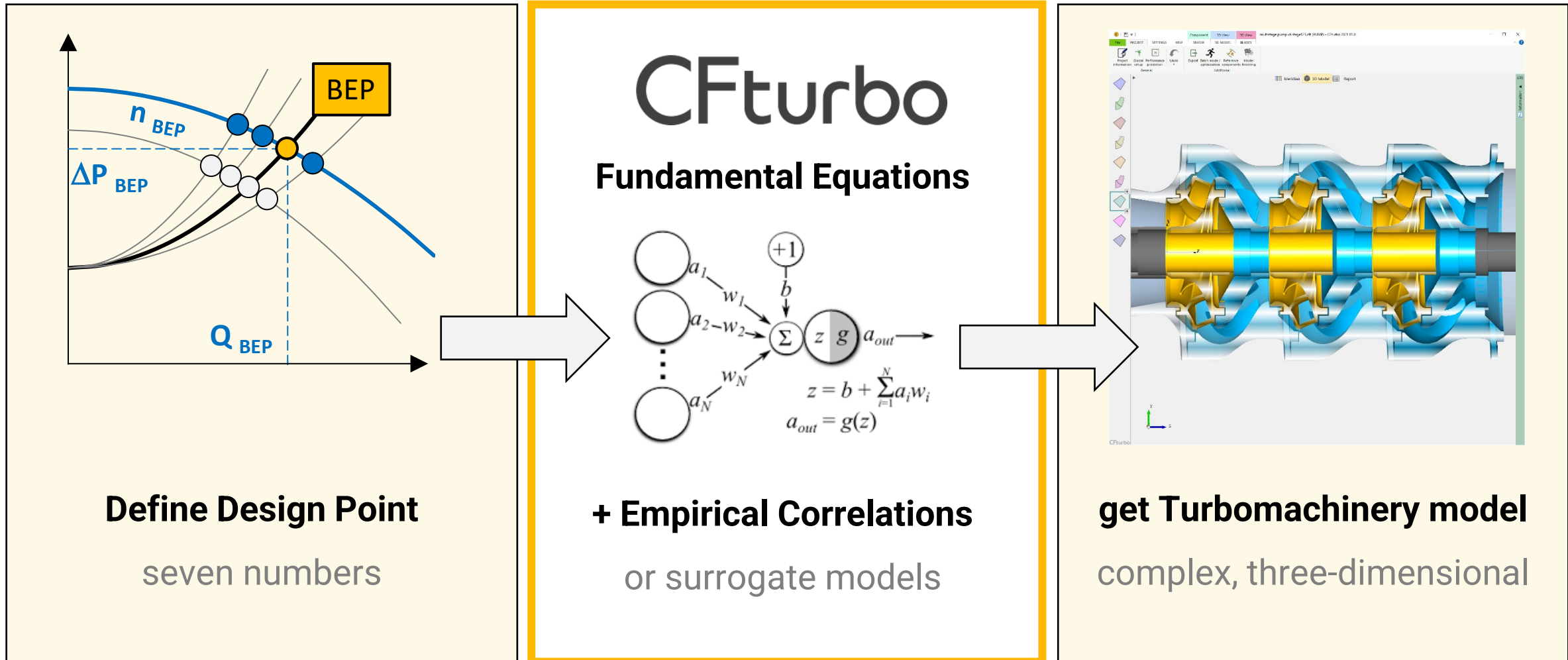
Parametric Modeling for Hydraulic Pump Design

What is needed to design new pumps?



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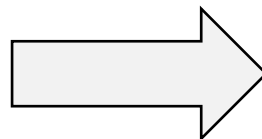
Principal Design Methodology – **All new** conceptual designs



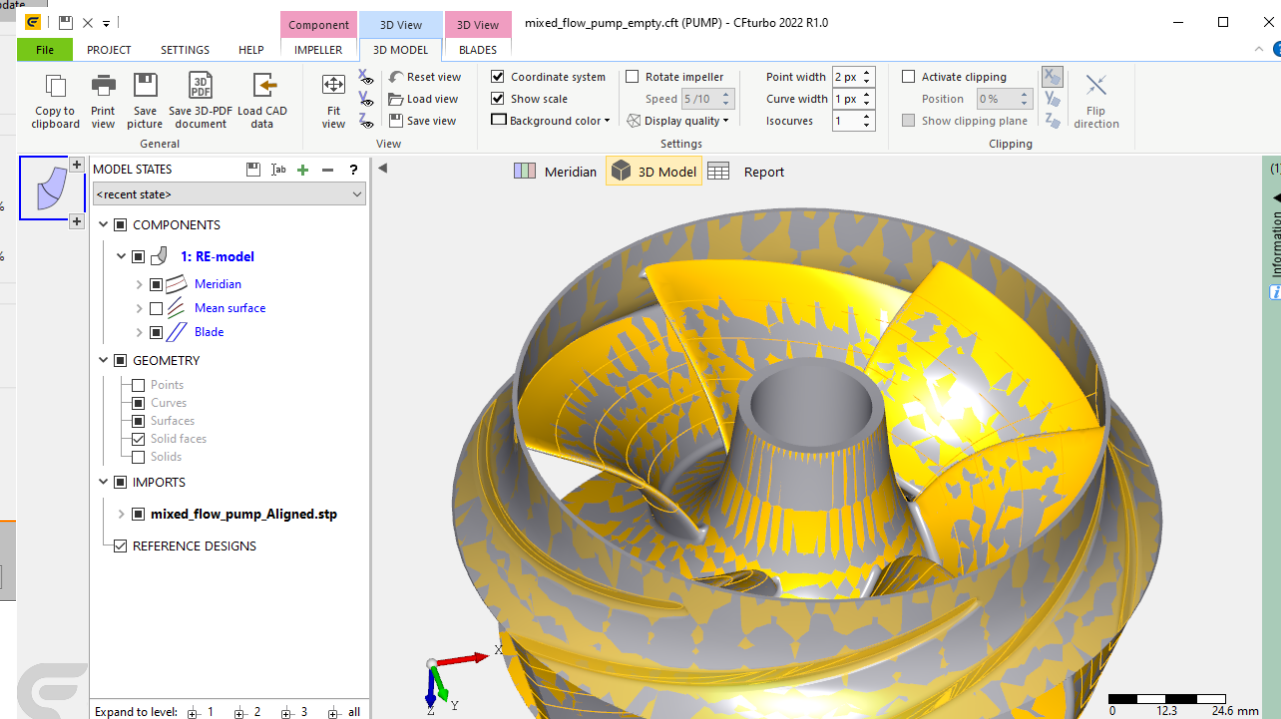
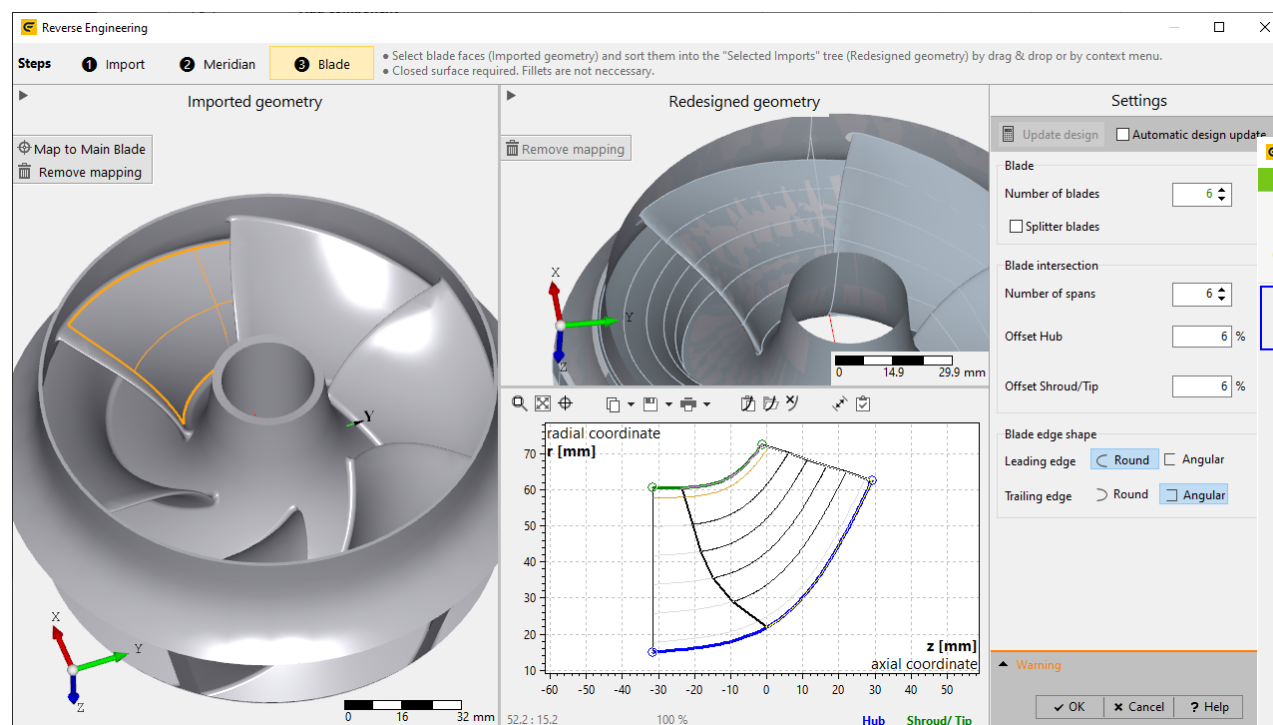
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Principal Design Methodology – **Reverse Engineering** of legacy designs

Import 3D CAD, neutral formats



Create a re-parametrized model

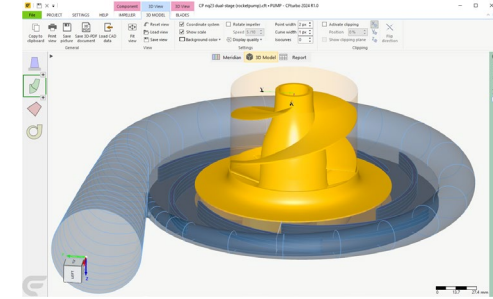


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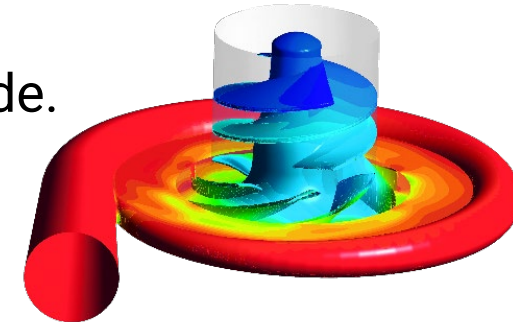


What is needed for fast, reliable, effective pump design (... before doing AI/ML)? - **data!**

1. **Versatile, conceptual Turbomachinery design software** allowing detailed 3D-CAD modeling - leakage flow path, balancing holes, pump out vanes, splitter volute, fillets, radial and meridional trimming ...

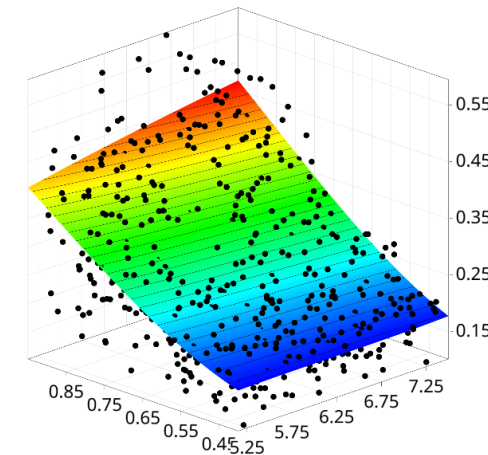


2. **Fully automated grid generation** and high-fidelity CFD simulation code.

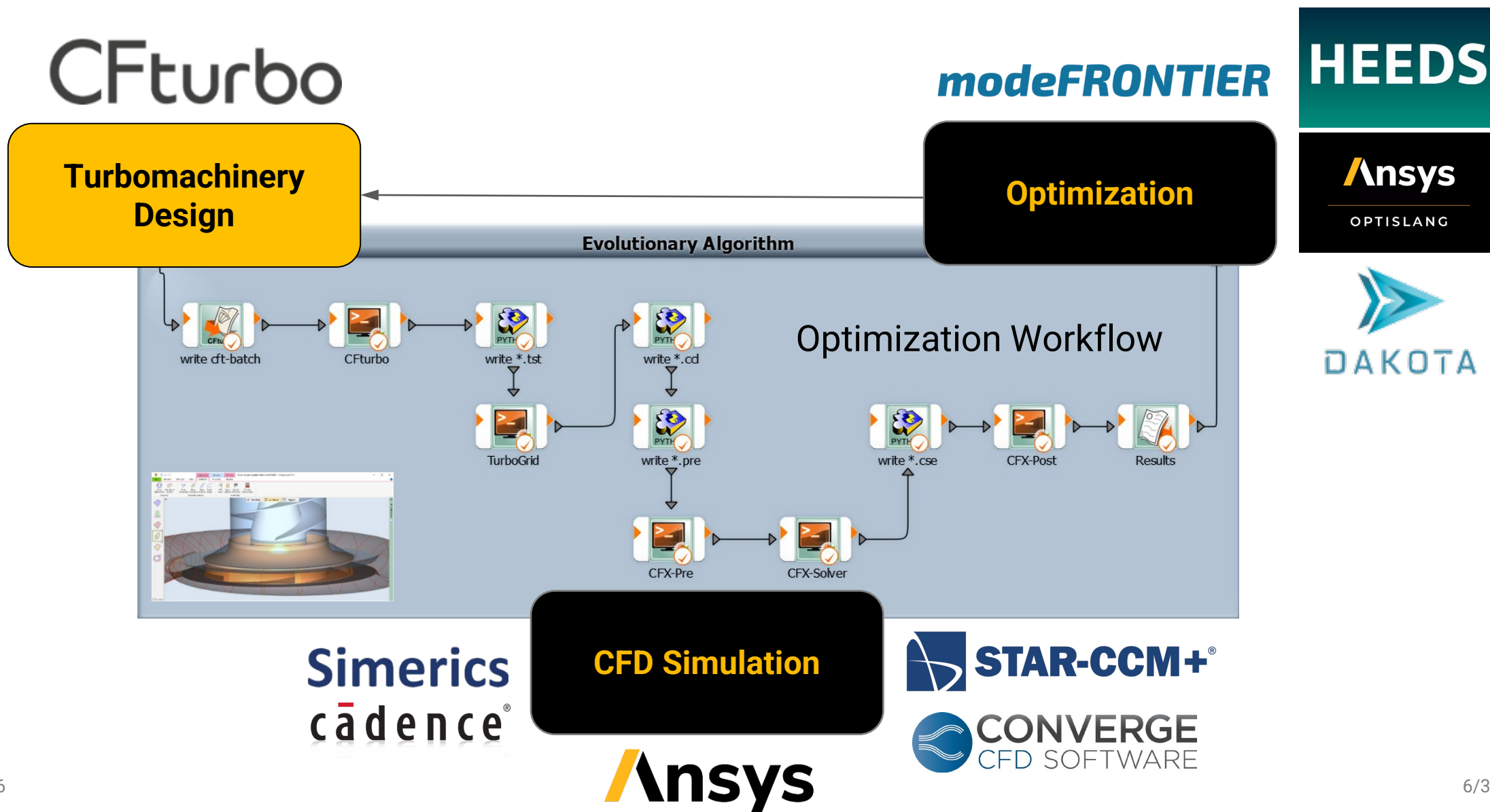


3. User-friendly design exploration (DoE) and optimization workflow.

4. Database to create and utilize robust surrogate models.



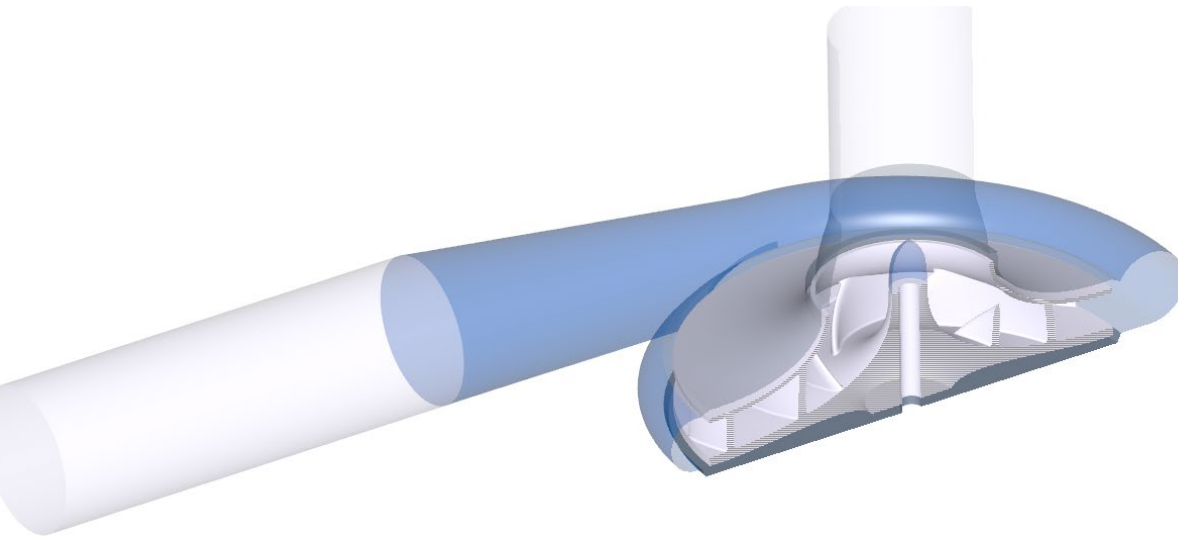
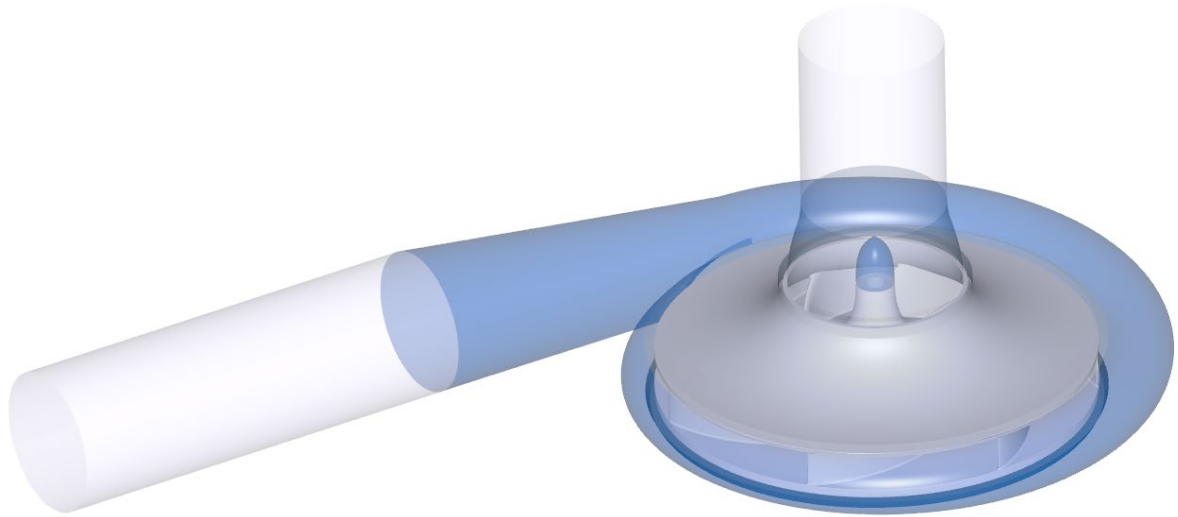
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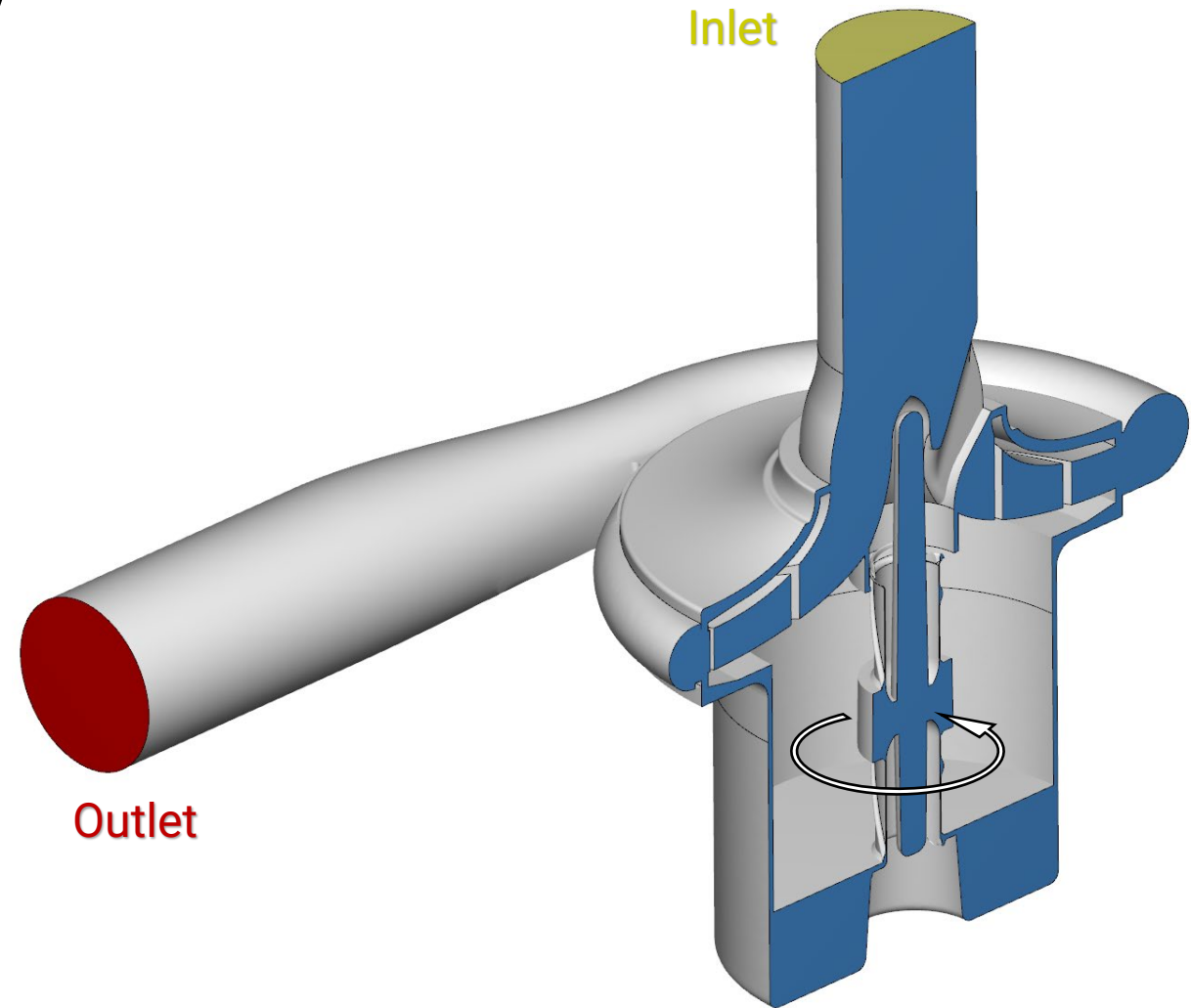


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Example 1 Automotive Coolant Pump – Geometry



Conceptual model



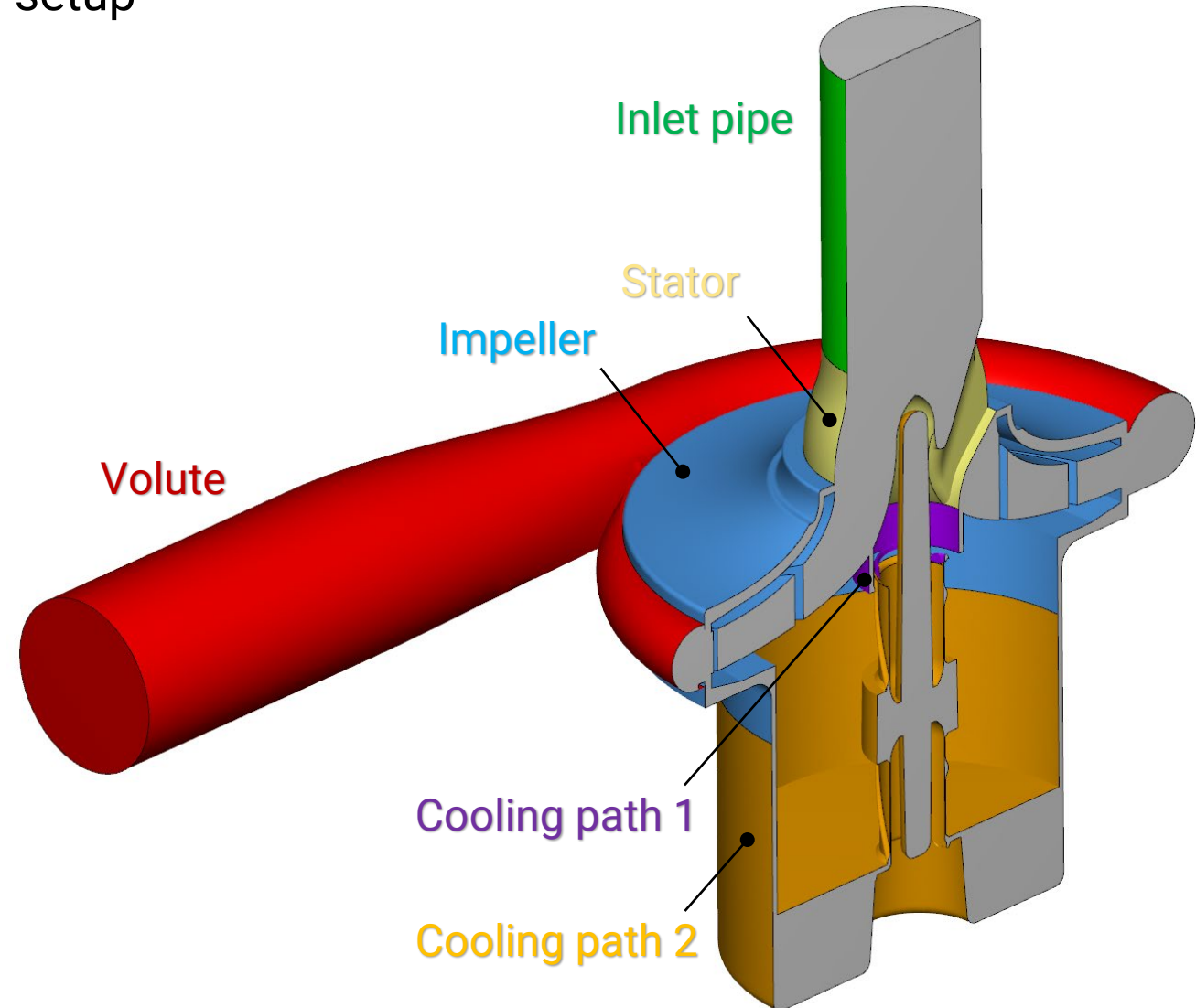
Detailed geometry

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Example 1 Automotive Coolant Pump – Solver setup

Flow domain components

- Inlet pipe
- Stator
- Impeller
- Volute
- Cooling Path 1
- Cooling Path 2

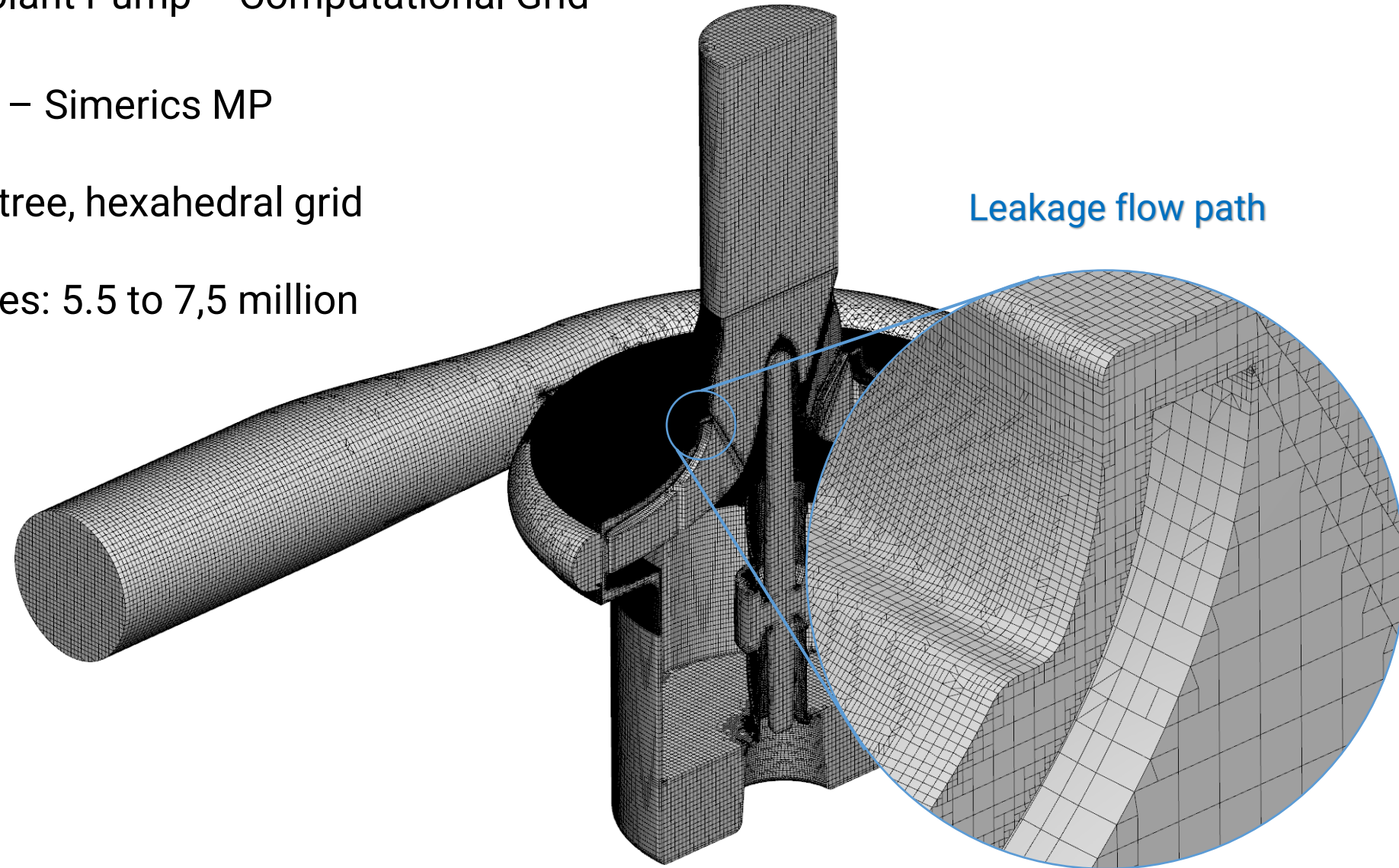




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Example 1 Automotive Coolant Pump – Computational Grid

- Automated Meshing – Simerics MP
- Unstructured binary-tree, hexahedral grid
- Total number of nodes: 5.5 to 7,5 million

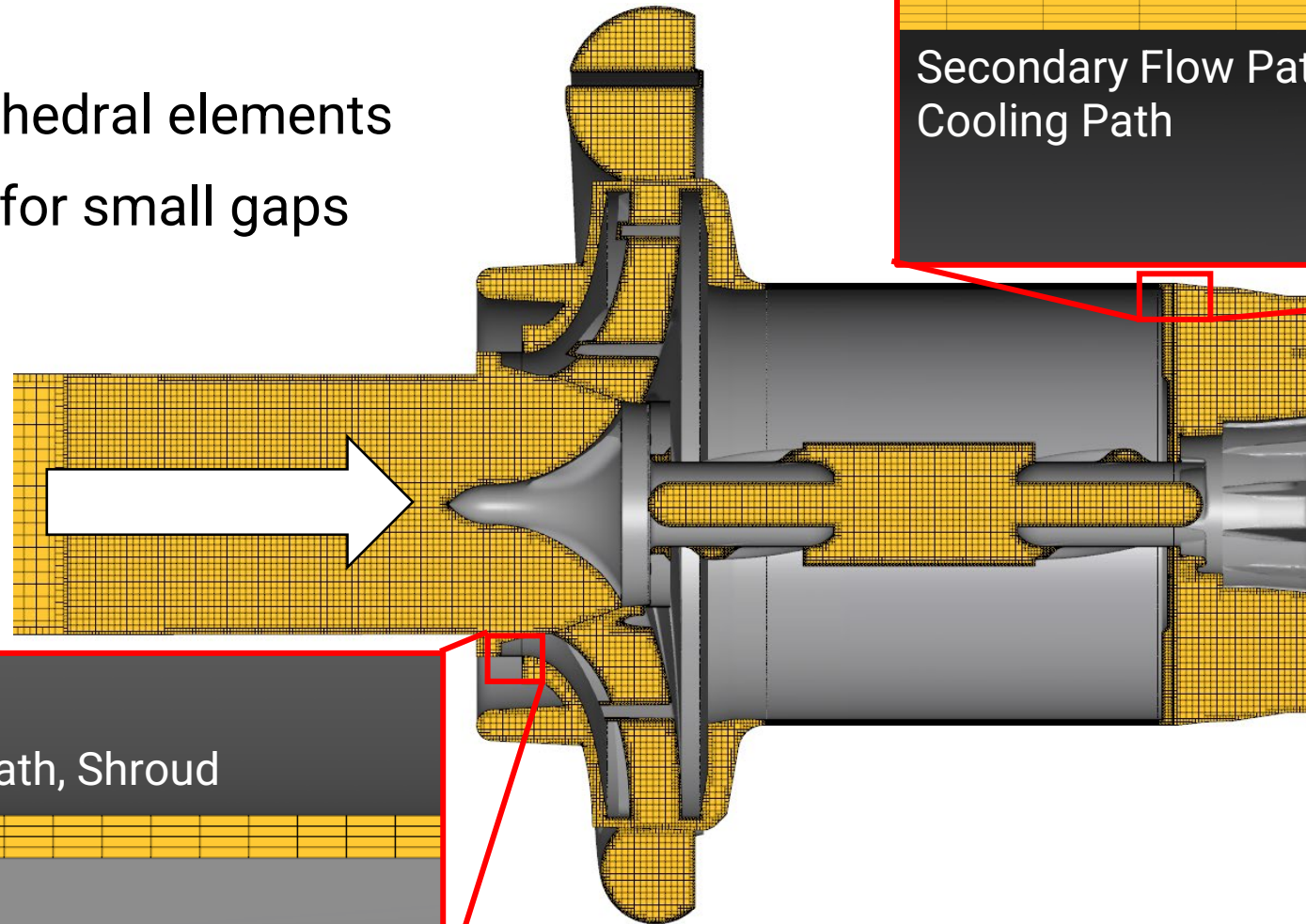




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Example 1 Automotive Coolant Pump

- Dominantly hexahedral elements
- Structured grids for small gaps



Secondary Flow Path,
Cooling Path

Secondary Flow Path, Shroud



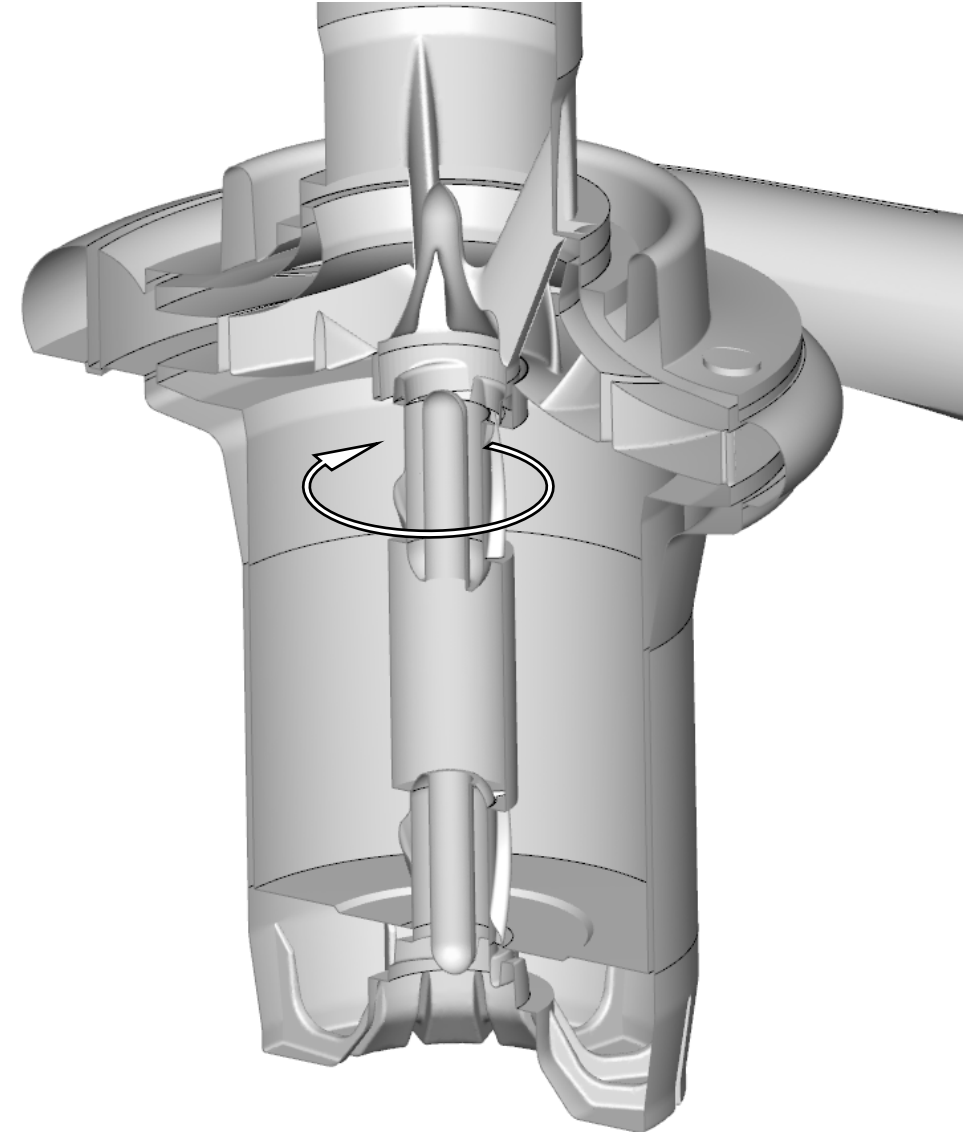
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Example 1 Automotive Coolant Pump – Simulation and Optimization Setup

- Isothermal
- Steady-state (MFR) and transient simulations
- High-order discretization scheme (space, time)
- RNG-based k - ϵ turbulence model
- Unified wall function
- Hydraulic smooth surfaces

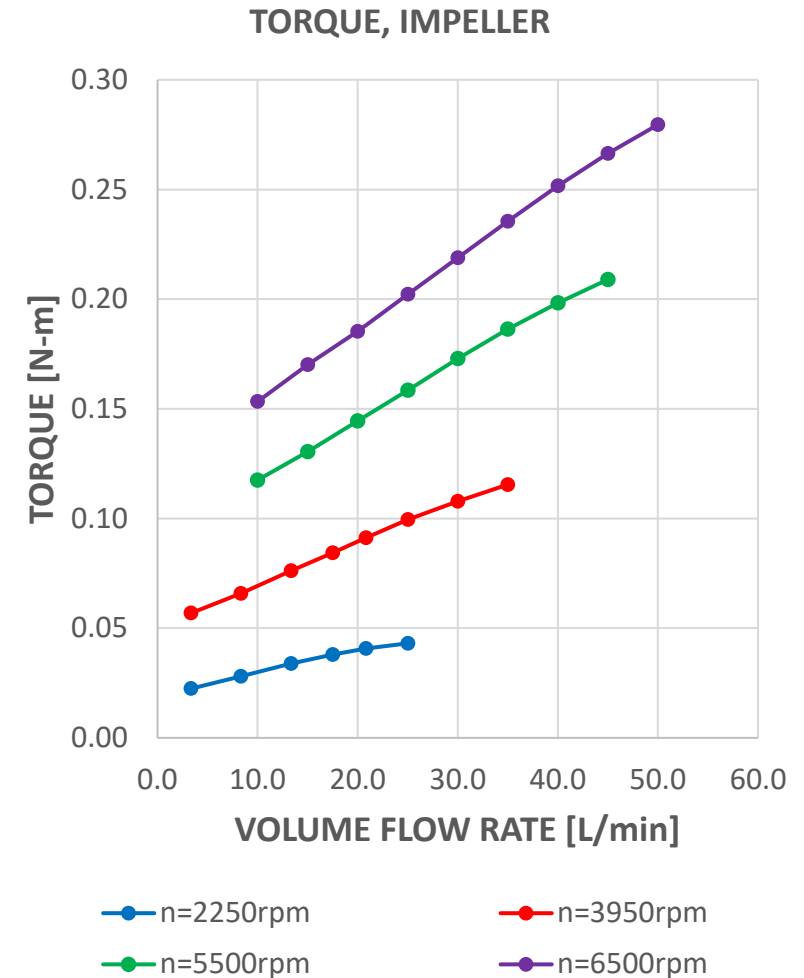
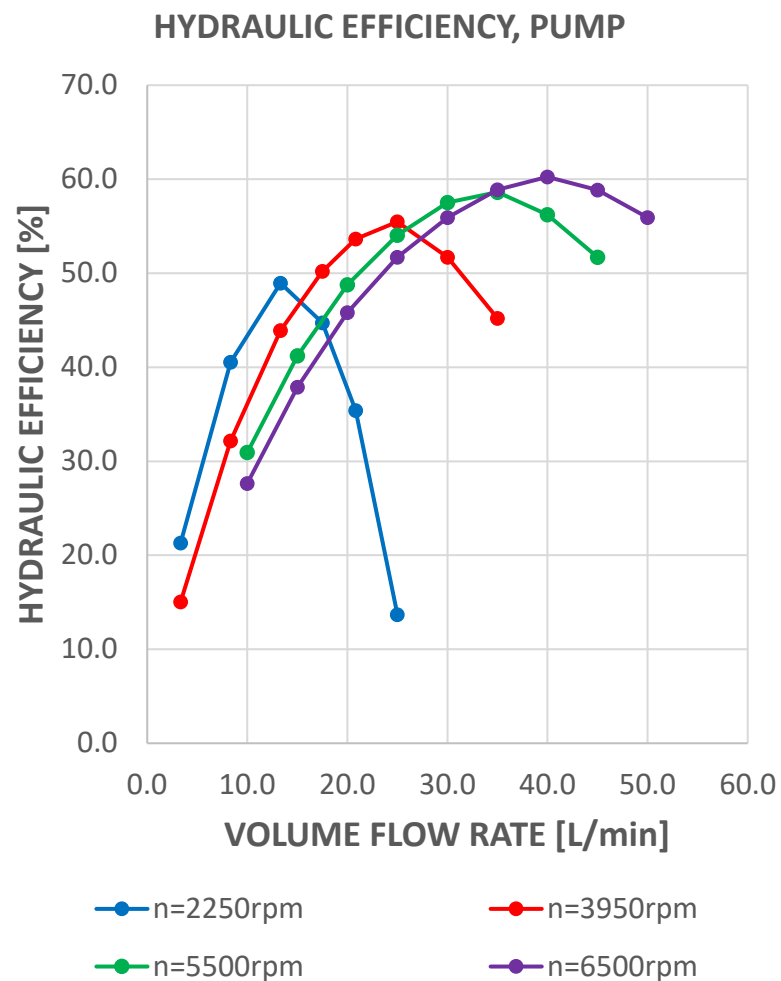
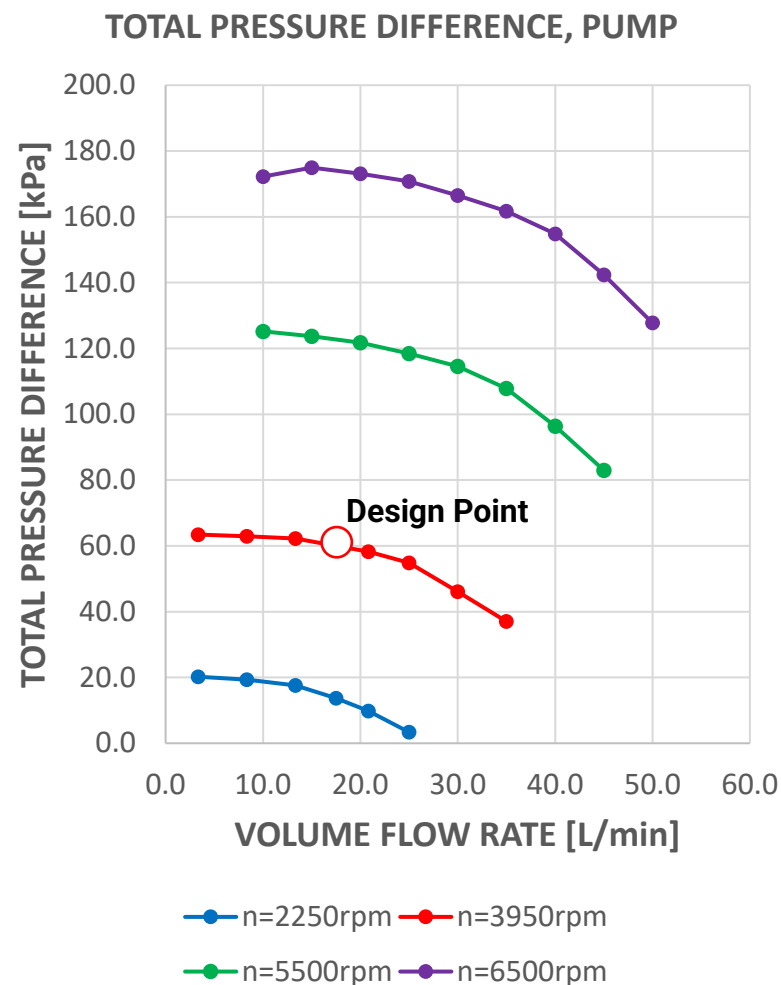
Design optimization:

- CFTurbo + Simerics MP + DAKOTA.
- Statistical methods to identify sensitive parameters.
- Surrogate-assisted optimization.



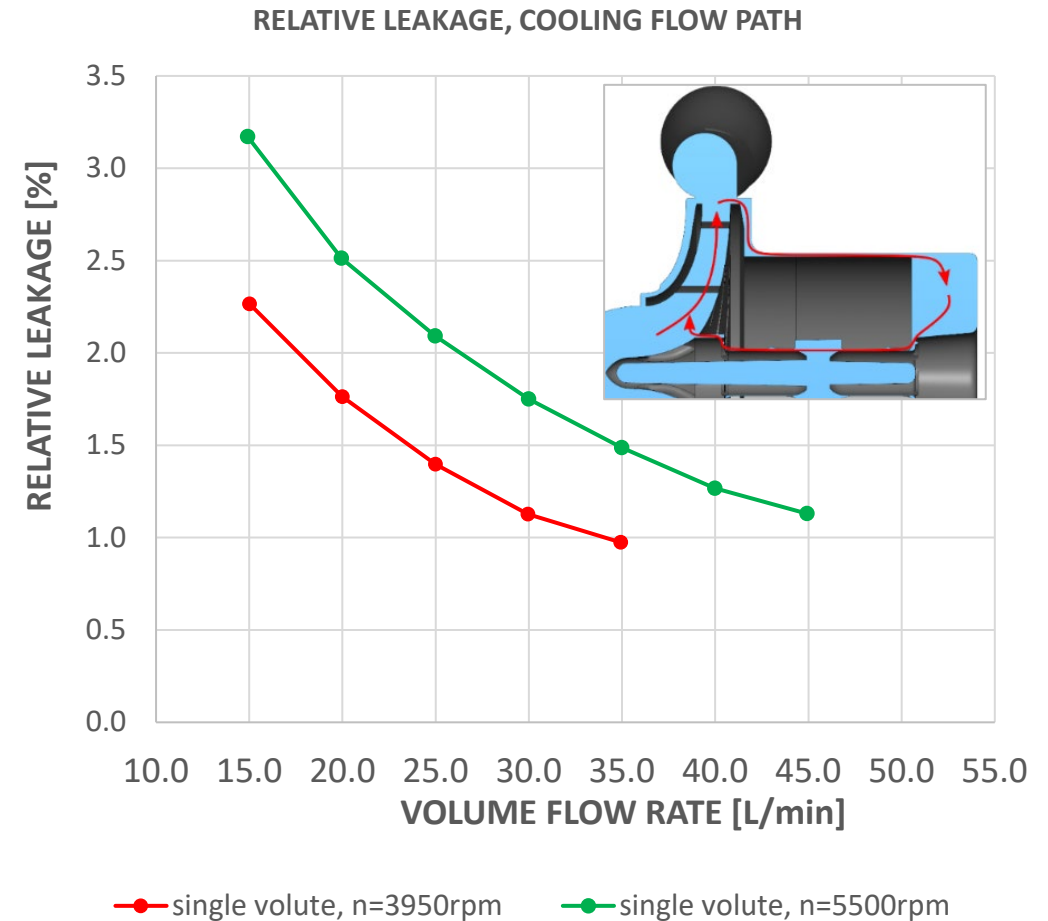
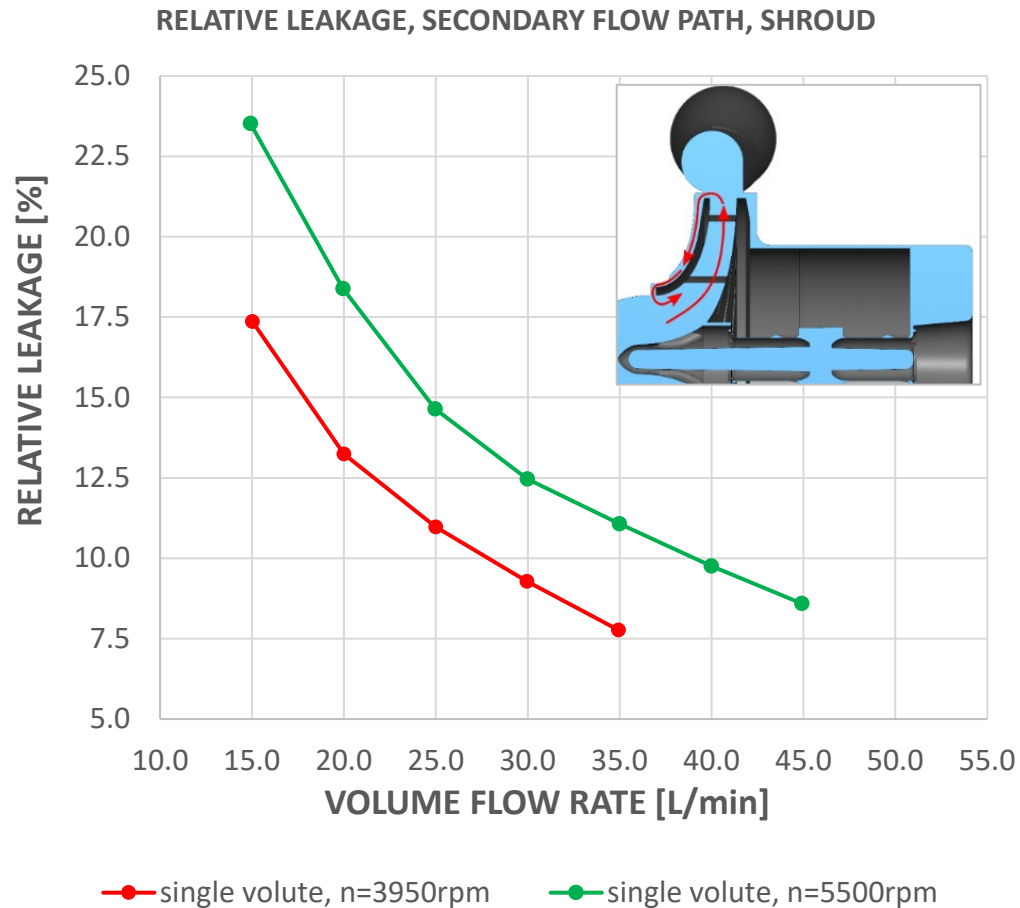
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Example 1 Automotive Coolant Pump – CFD simulations results



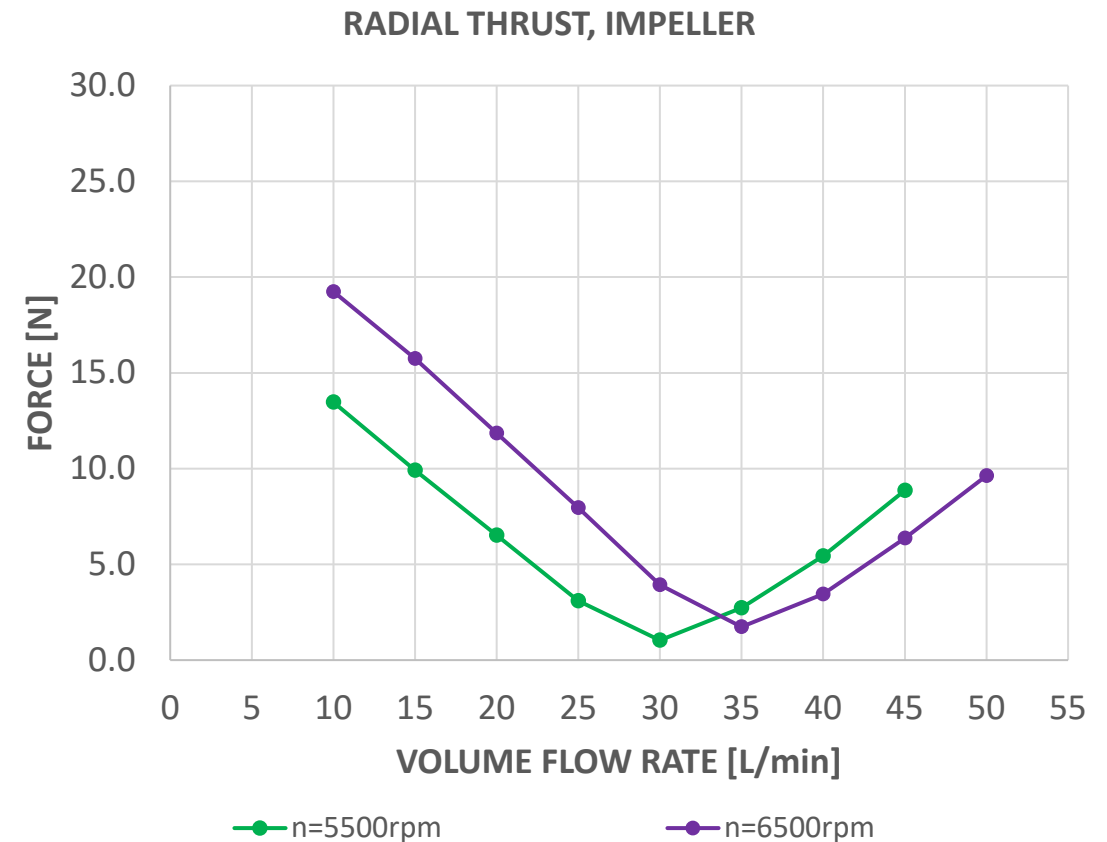
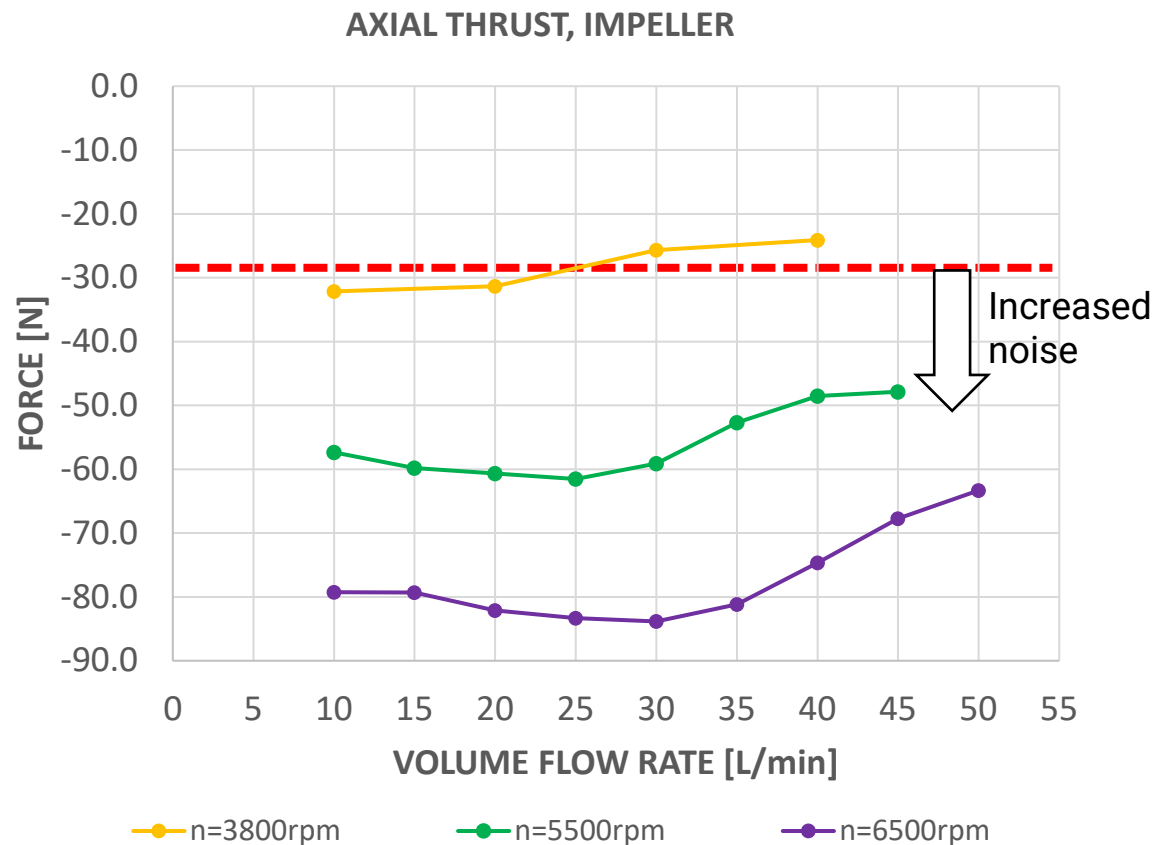
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Example 1 Automotive Coolant Pump – Leakage flow path



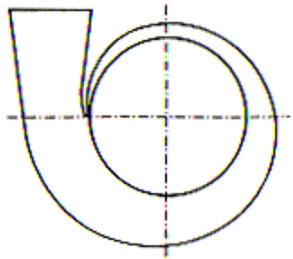
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Example 1 Automotive Coolant Pump – Calculate Axial and Radial Forces



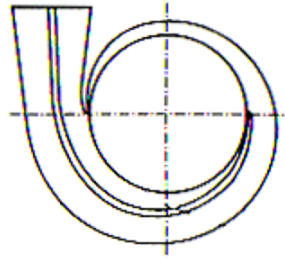
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Example 1 Automotive Coolant Pump – Double (splitter) Volute



Single volute

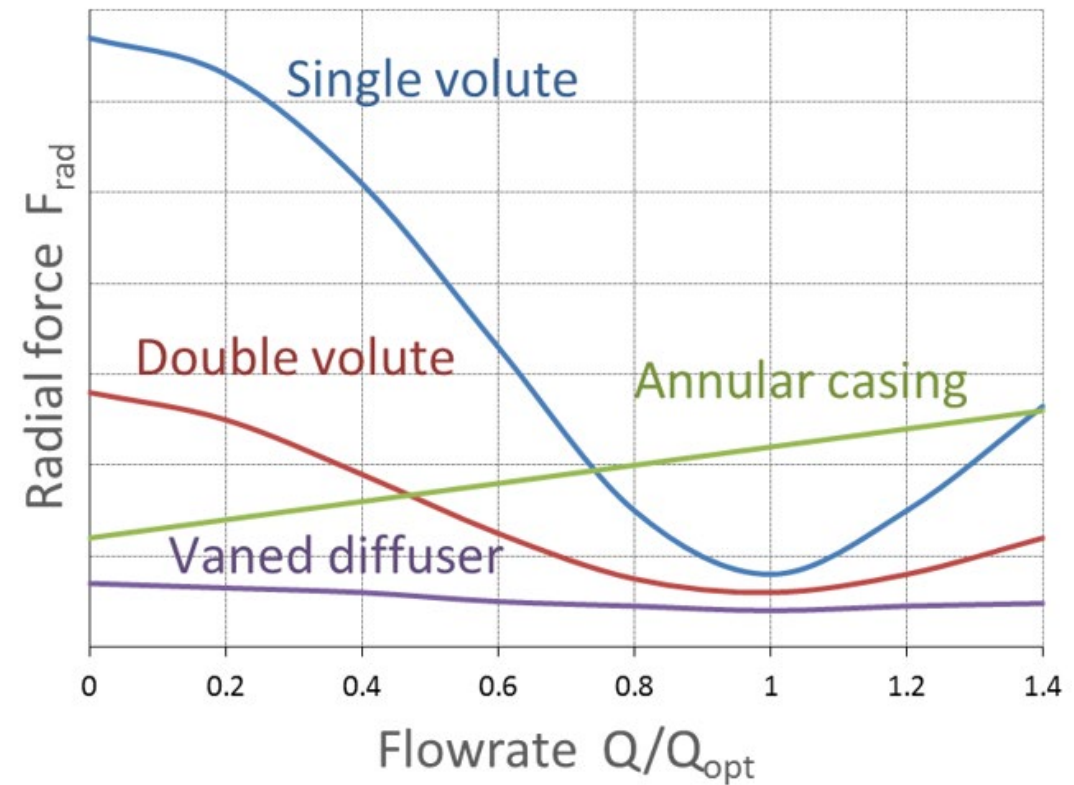
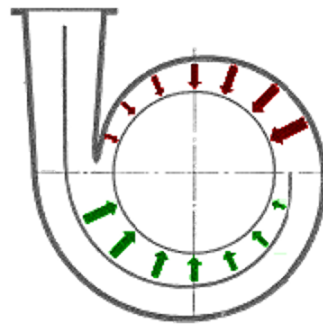
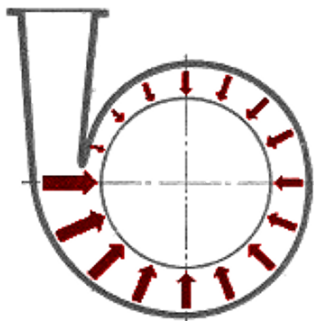
- Lowest production cost
- Preferred for low energy transmission



Double volute

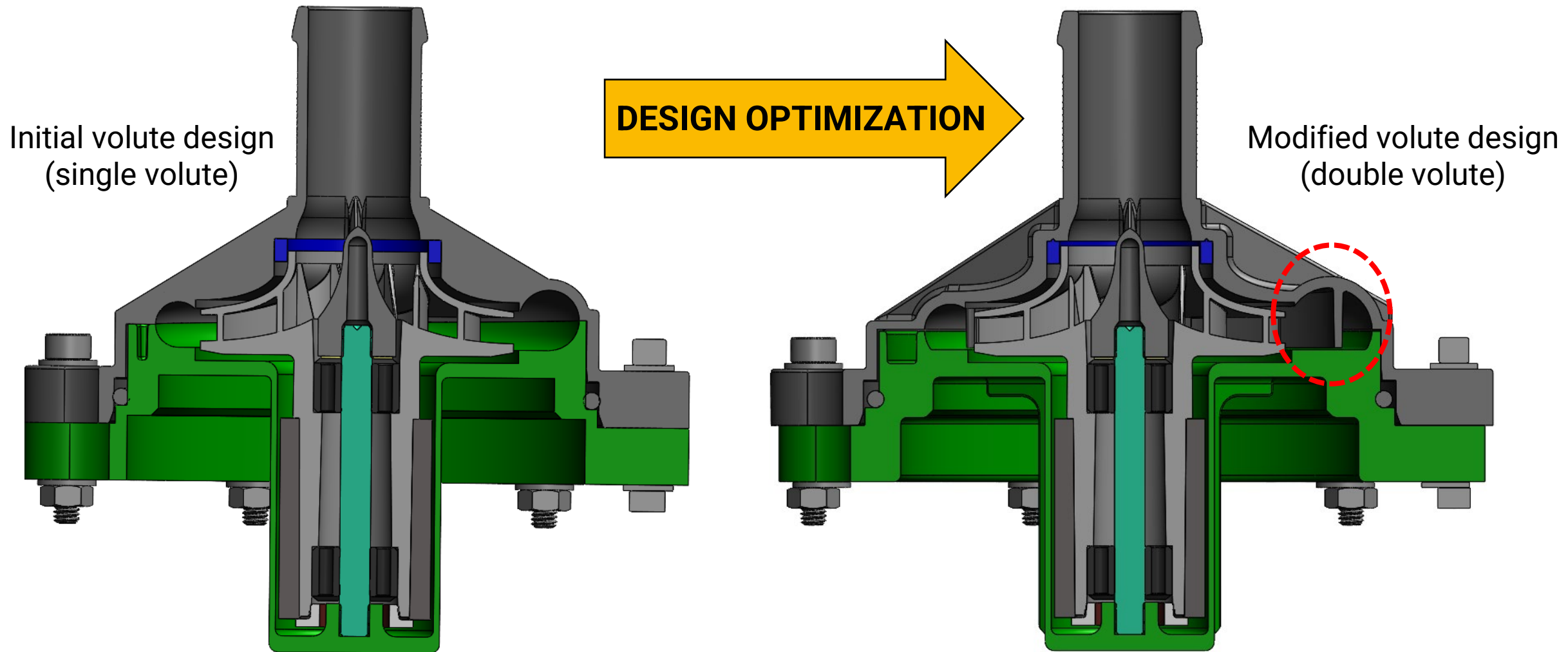
- Reduction of radial forces
- Common pressure joint

Radial force



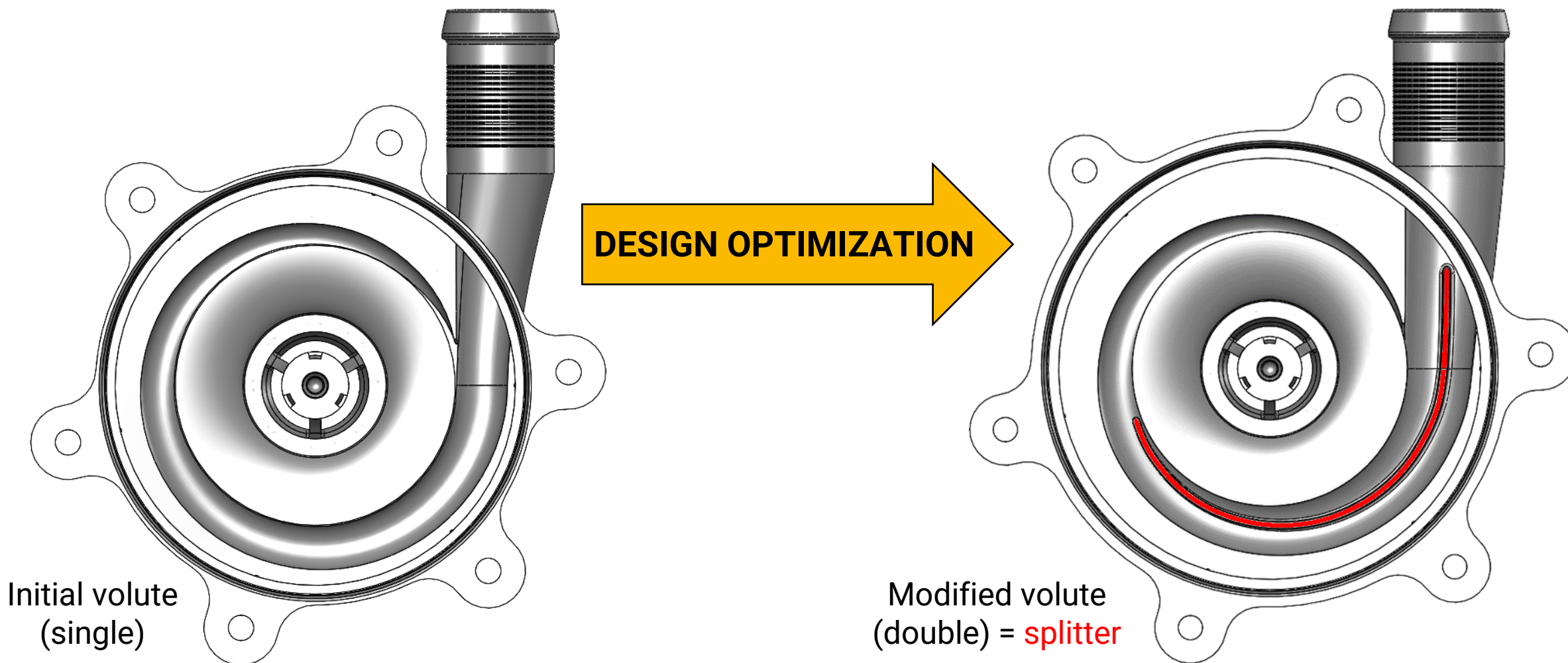
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Example 1 Automotive Coolant Pump



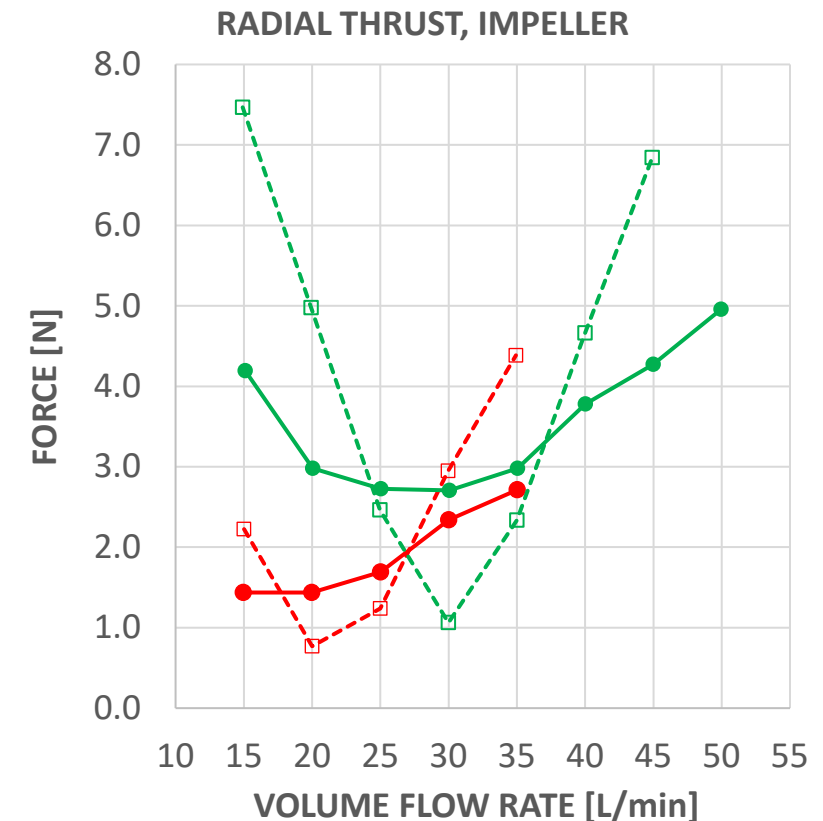
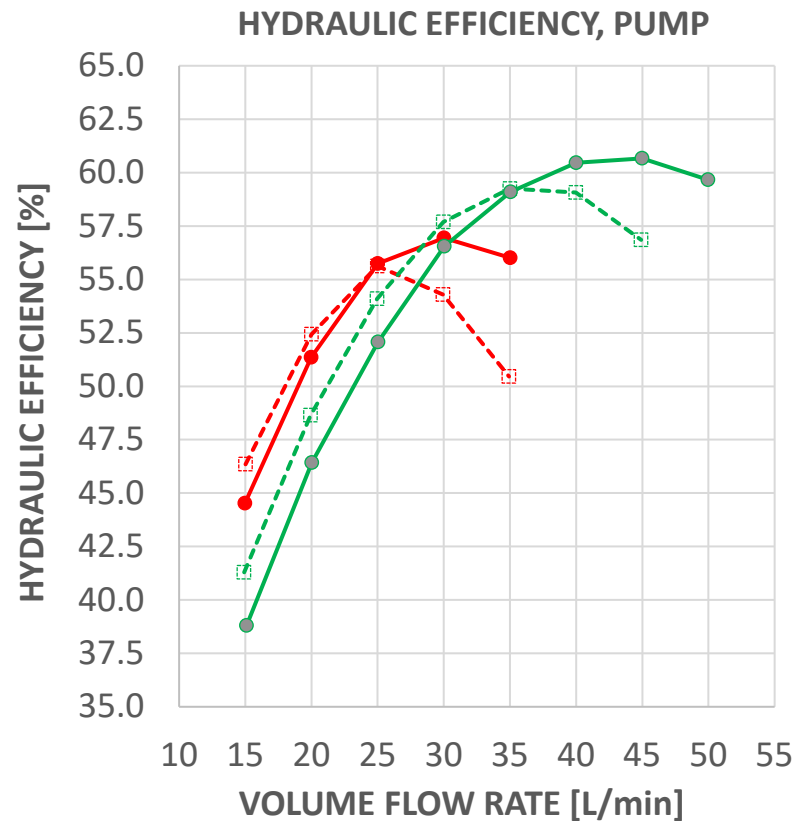
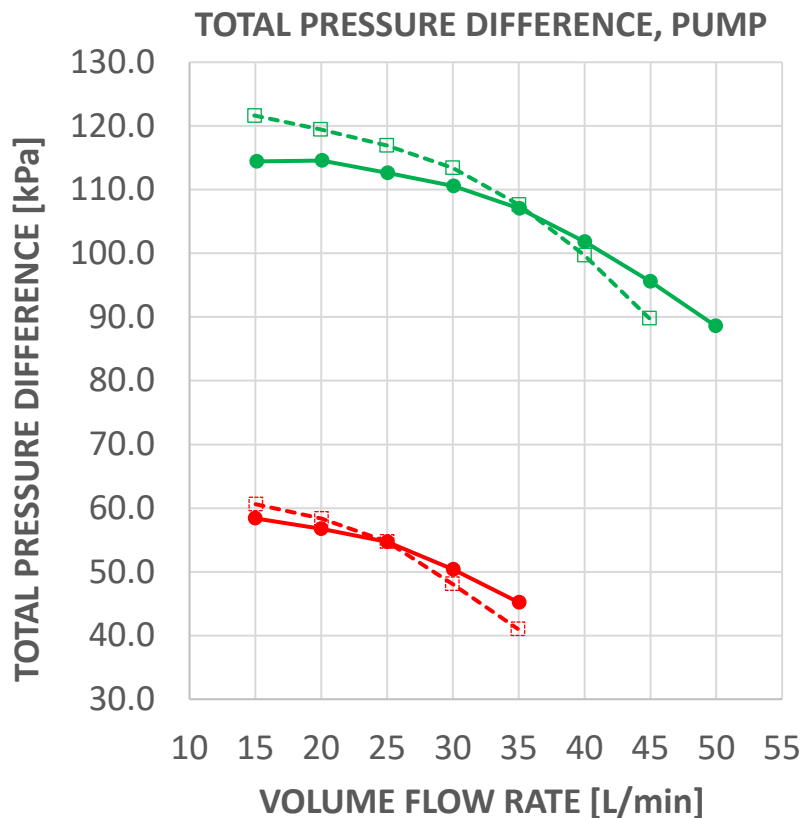
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Example 1 Automotive Coolant Pump



Parametric Modeling for Hydraulic Pump Design

Example 1 Automotive Coolant Pump – Lower thrust while maintaining performance and efficiency



- - □ - - single volute, n=3950rpm - ● - double volute, n=3950rpm
 - - □ - - single volute, n=5500rpm - ● - double volute, n=5500rpm

- - □ - - single volute, n=3950rpm - ● - double volute, n=3950rpm
 - - □ - - single volute, n=5500rpm - ● - double volute, n=5500rpm

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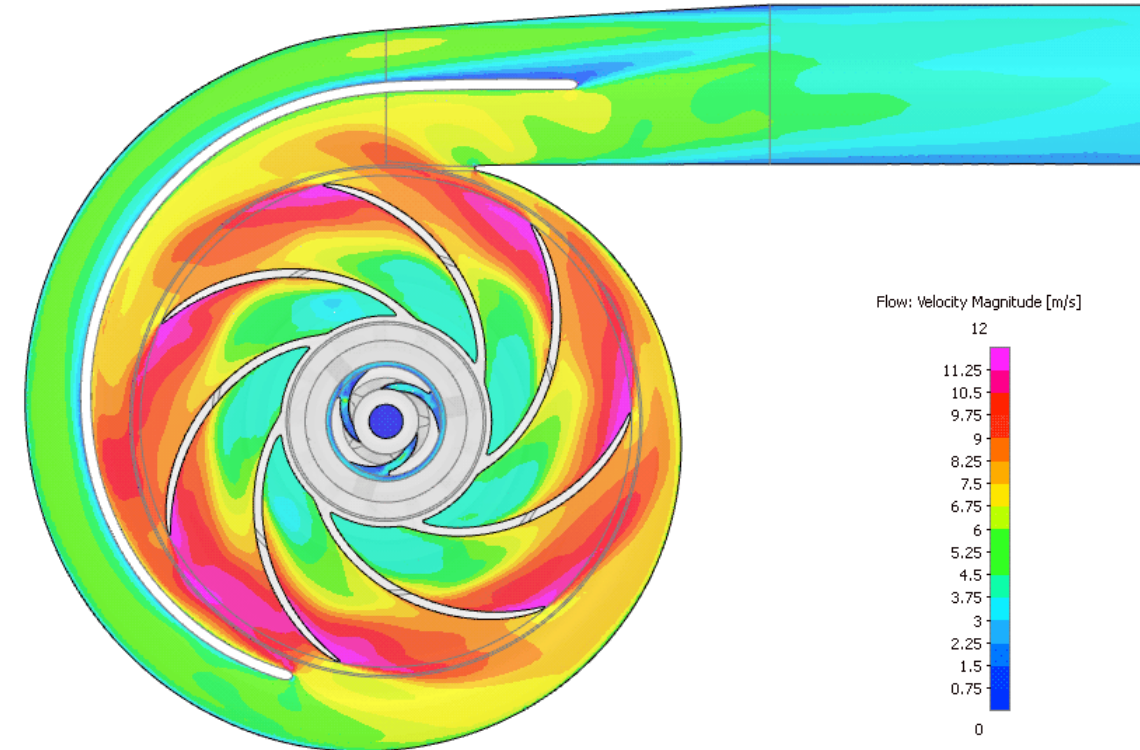
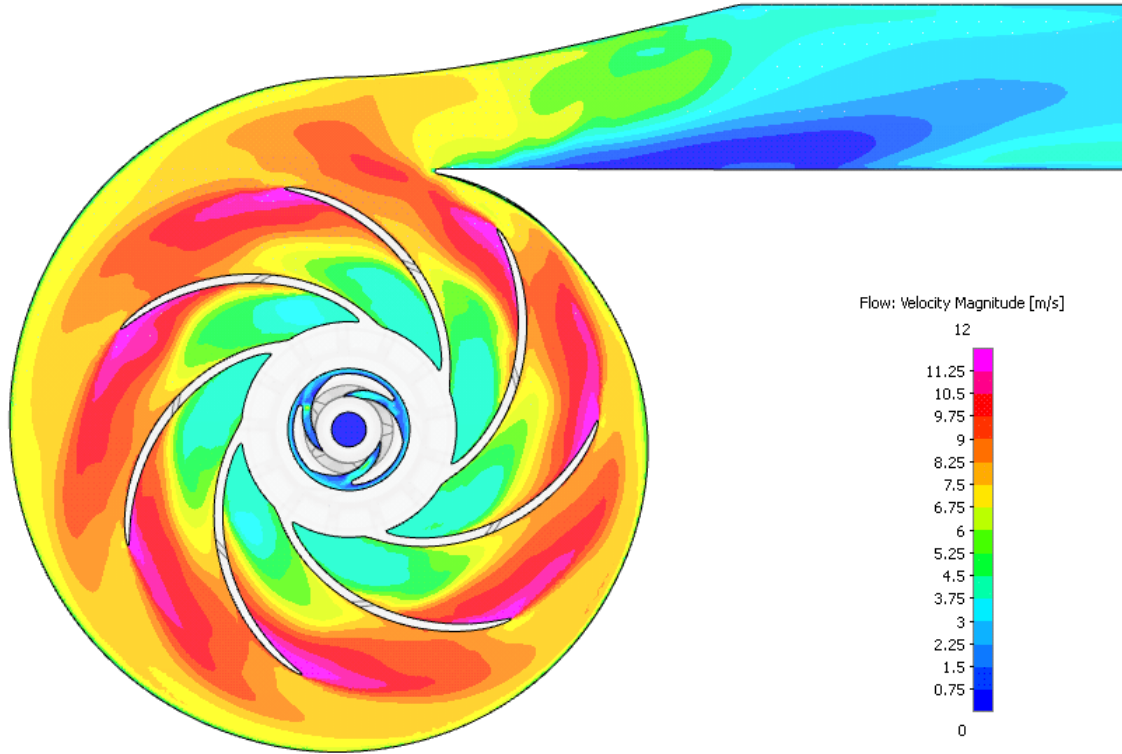
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Example 1 Automotive Coolant Pump

$n=5500$ rpm, $Q=35$ l/min

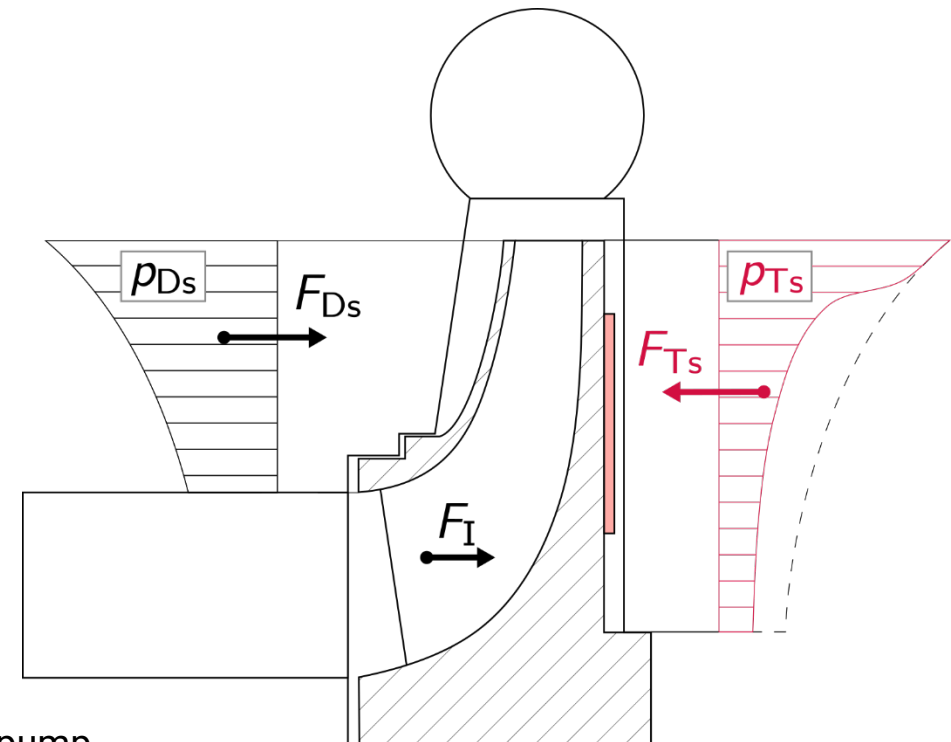
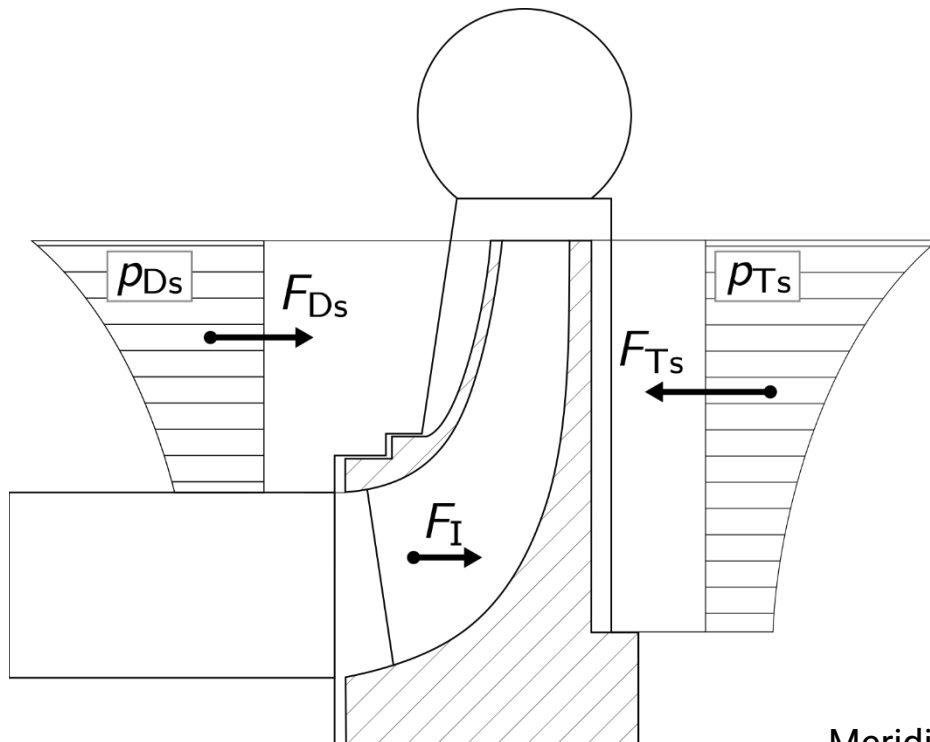
Simetrics



Parametric Modeling for Hydraulic Pump Design

Example 2 Back vanes for centrifugal pump impellers

- Axial force F_{Ax} decisive for the dimensioning of bearings of centrifugal pumps
- Back vanes can reduce F_{Ax}
- **Conflict:** Axial force reduction $\longleftrightarrow$ Efficiency losses



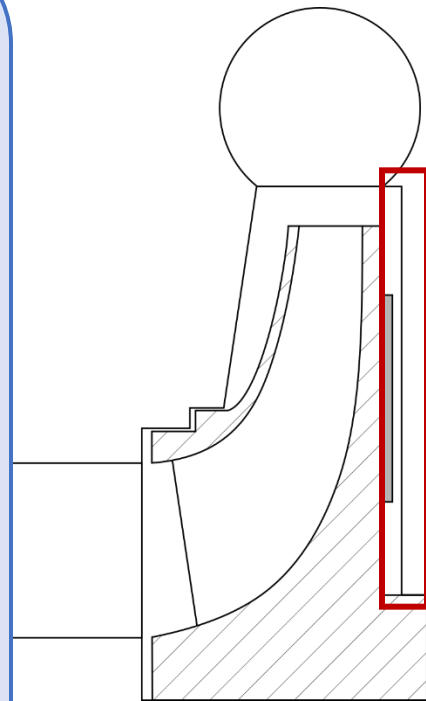
Meridional view of a centrifugal pump
with pressure forces and momentum flux

Parametric Modeling for Hydraulic Pump Design

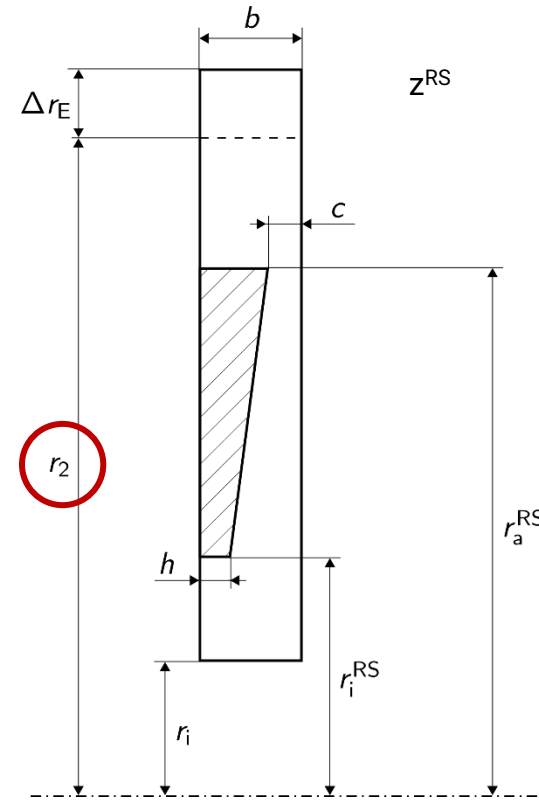
Example 2 Back vanes for centrifugal pump impellers

Parametric:

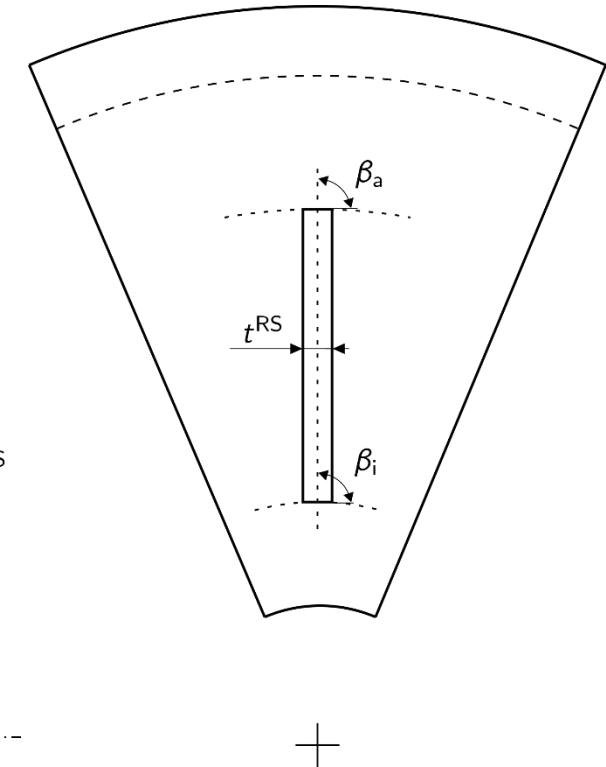
- **Non-dimensional**
 - Avoiding of constraints
 - Scalability
 - Reference impeller radius r_2
- geometrically and numerically **robust**
 - In total **11** geometrical parameters



Meridional view of a centrifugal pump



Parameterization of the secondary flow path region and the back vane



Parametric Modeling for Hydraulic Pump Design

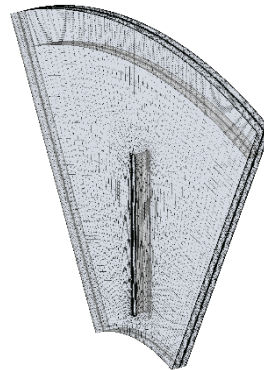
Example 2 Back vanes for centrifugal pump impellers

Problem with full pumps stage



- Results only for one specific pump
→ delivers no general and comprehensive information
- long simulation times

Goal



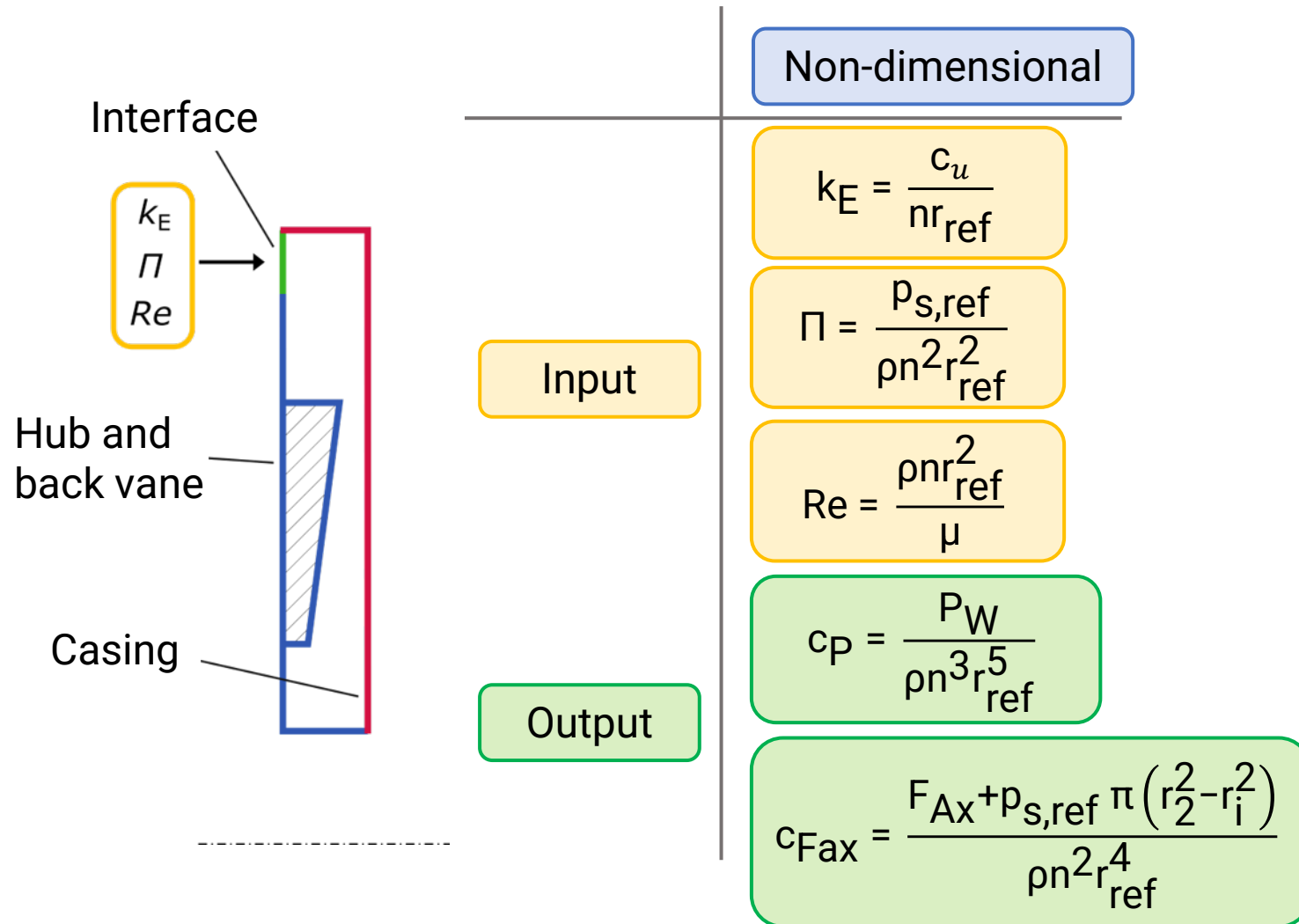
- Model reduction: only secondary flow path behind hub (SFP)
→ **SFP-Model**
- Independent from impeller
- Scalable

Approach

- Considering:
 - Size of pump
 - Operating point
 - Fluid properties
 - State at interface
- **Geometry parameters (11) non-dimensional**
- **Non-Dimensional variables**

Parametric Modeling for Hydraulic Pump Design

Example 2 Back vanes for centrifugal pump impellers



→ With Π -Theorem **fewer input variables**

(3 non-dimensional instead of 6 dimensional (r_{ref} , n , μ , ρ , c_u , $p_{s,ref}$))

→ Non-dimensional numbers allow for **general rules** for different pumps

→ **Total**: 3 key figures + 11 geometric variables

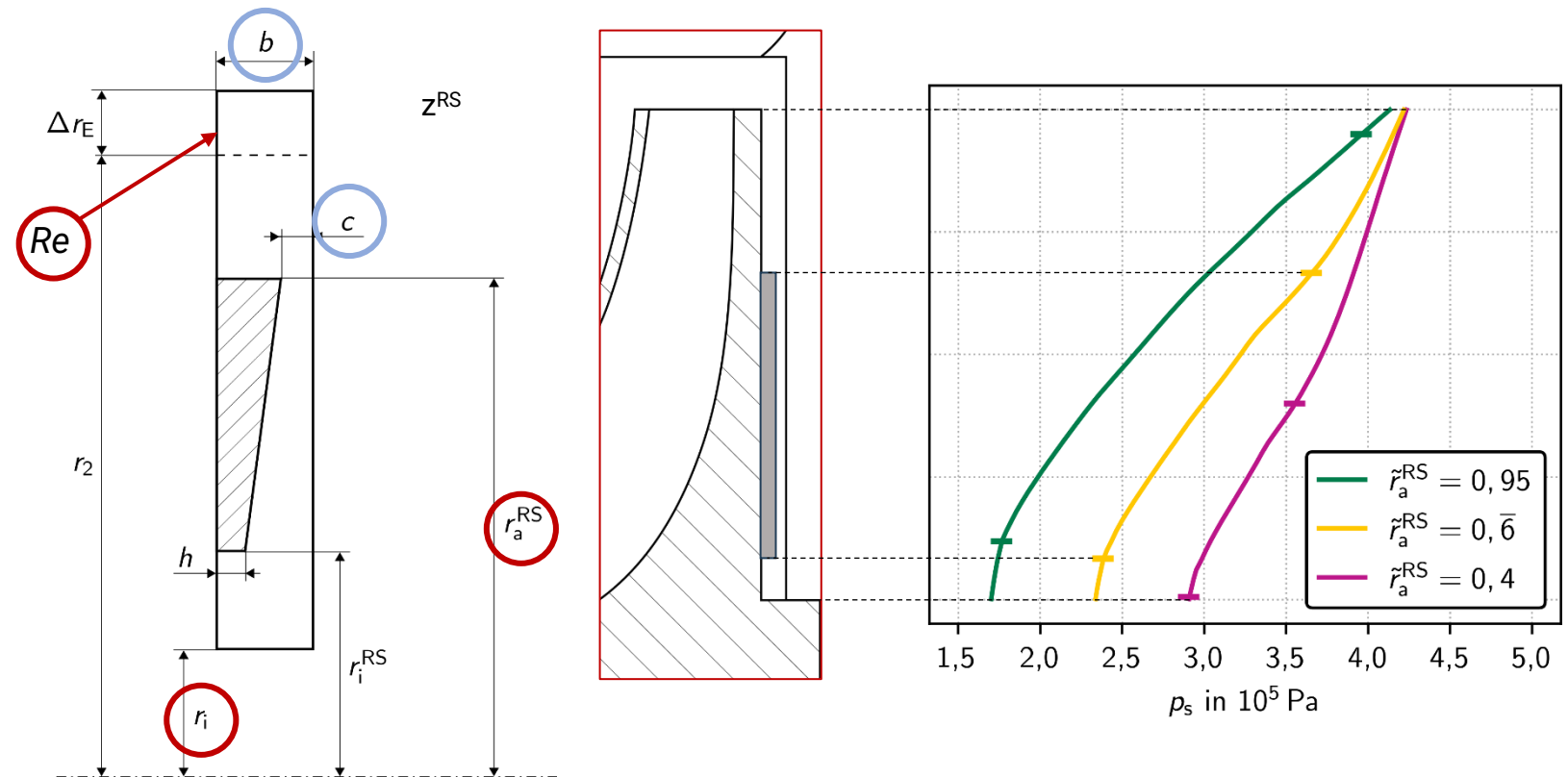
→ **Validation necessary and passed**

Parametric Modeling for Hydraulic Pump Design

Example 2 Back vanes for centrifugal pump impellers

Sensitivity analysis

- **Goal:** Determination of the influence of the input variables on the output
- Wide sampling room to achieve **rules as general as possible**
- 201 Samples
- Most important variables:
 r_a^{RS} , r_i , Re

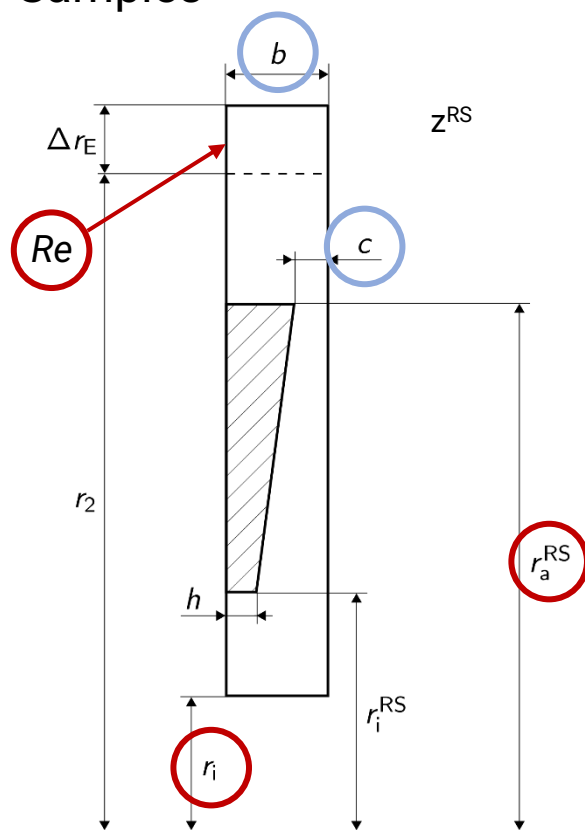


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Example 2 Back vanes for centrifugal pump impellers

Sensitivity analysis

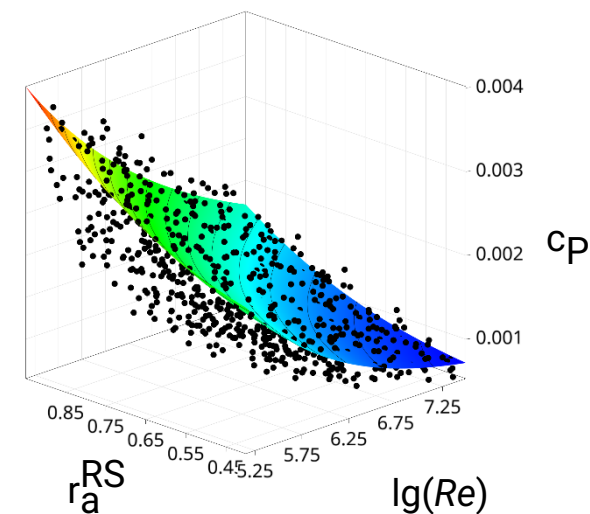
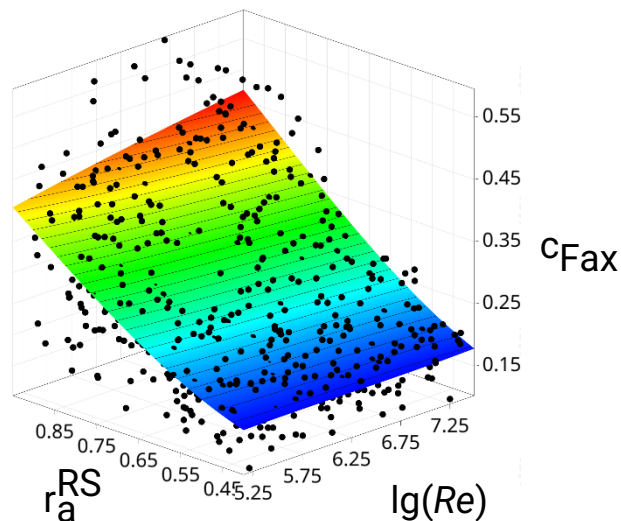
- 201 Samples



Meta model

- New, bigger sampling → 801 Samples
- Based on sensitivity analysis the following variable are ignored: variable gap size, curved vanes, and pressure coefficient → 9 Parameter in meta model

→ CoP (Kriging) for both outputs > 99%

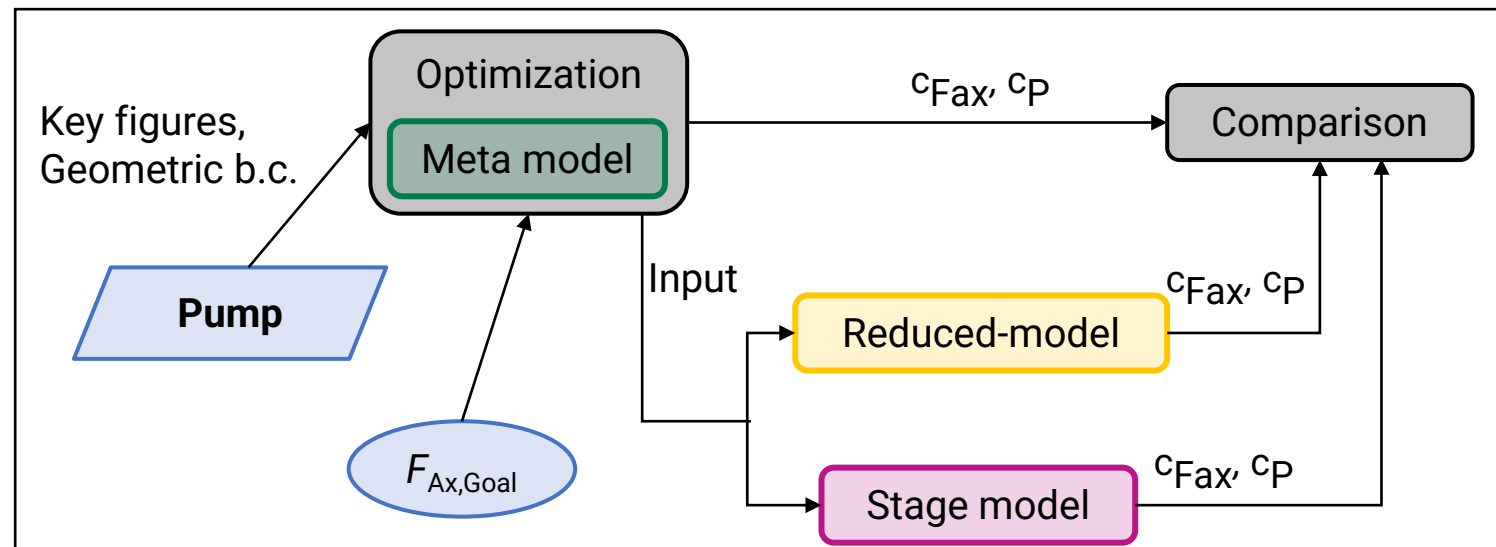
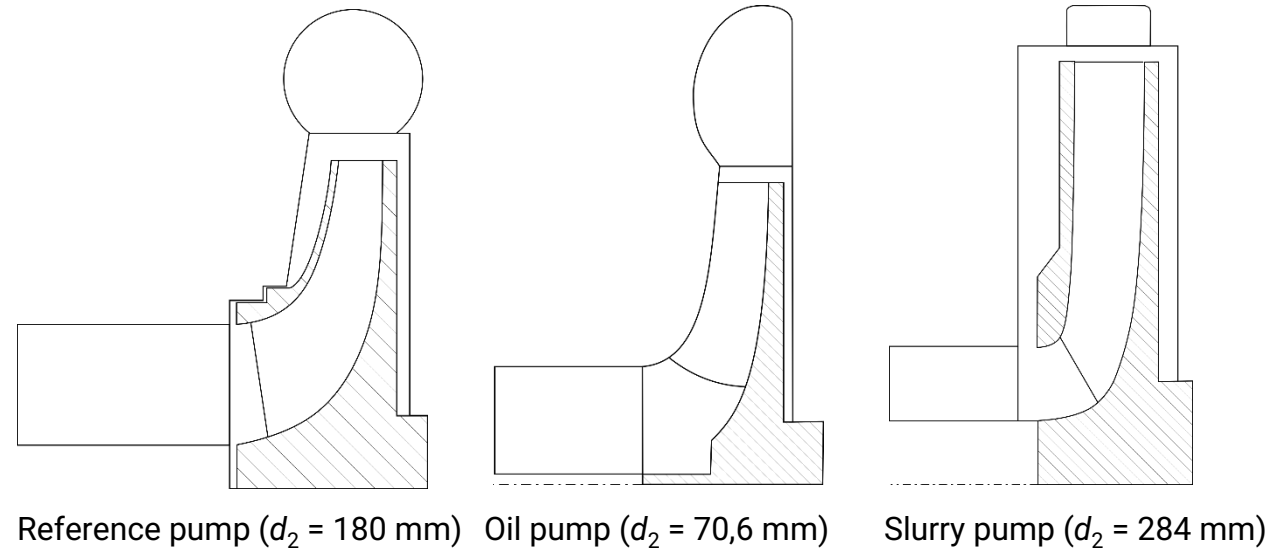


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Example 2 Back vanes for centrifugal pump impellers

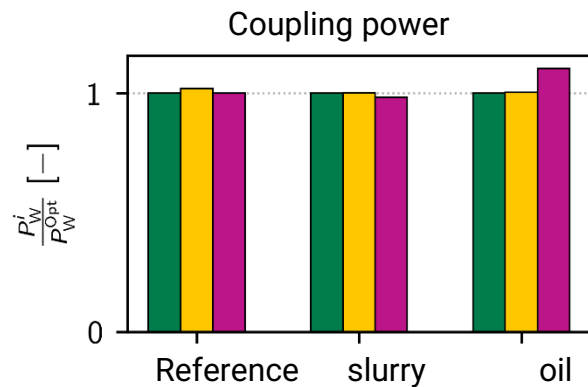
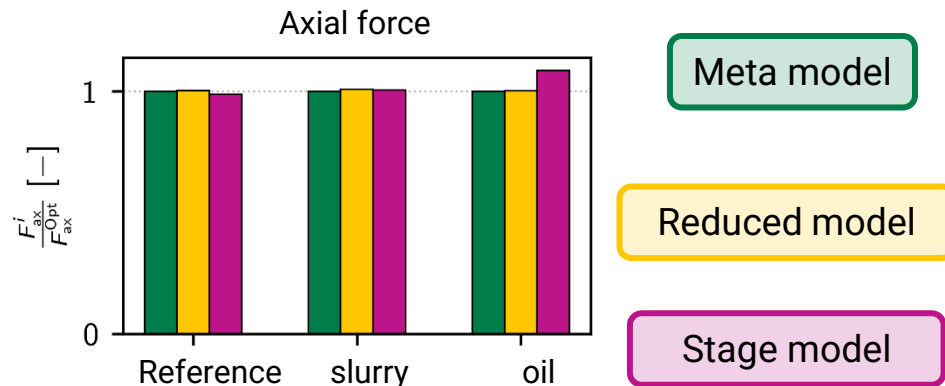
Validation

- **Goal:** Demonstration of quality of meta model model via optimization
- **3 Examples** with constructive differences and different $c_{Fax,Goal}$ and geometric b.c.
→ Key figures are derived from model w/o back vanes and remain constant
- **Optimization:**
Find: $\min(c_P)$
constraint: $c_{Fax} \geq c_{Fax,Goal}$
- **Evolutionary algorithm** (Optimization on meta models very fast)



Parametric Modeling for Hydraulic Pump Design

Example 2 Back vanes for centrifugal pump impellers – validation results



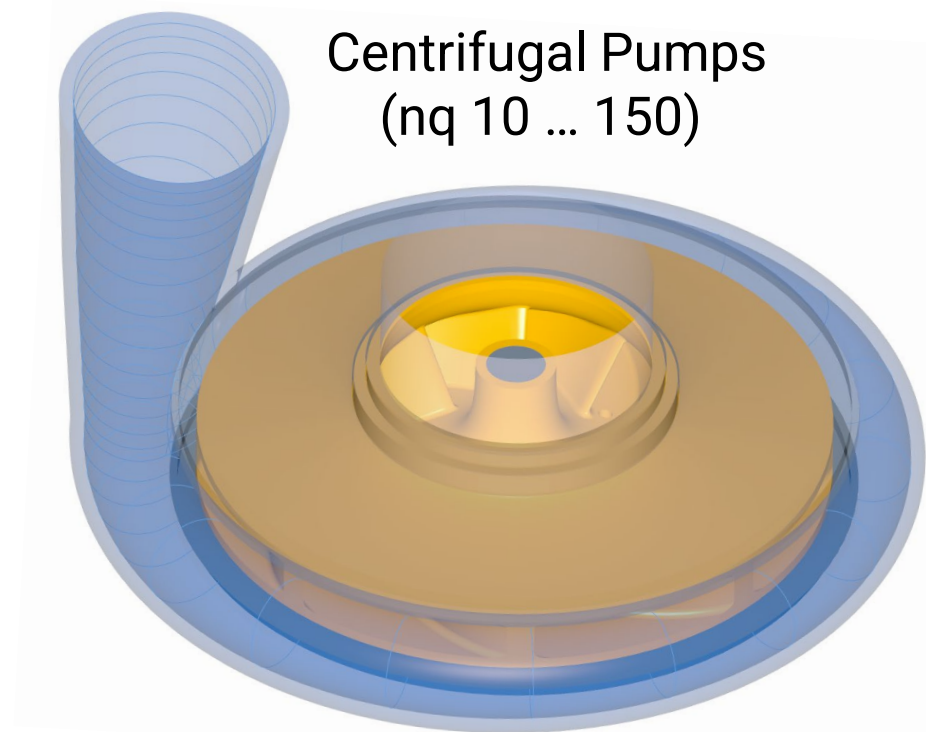
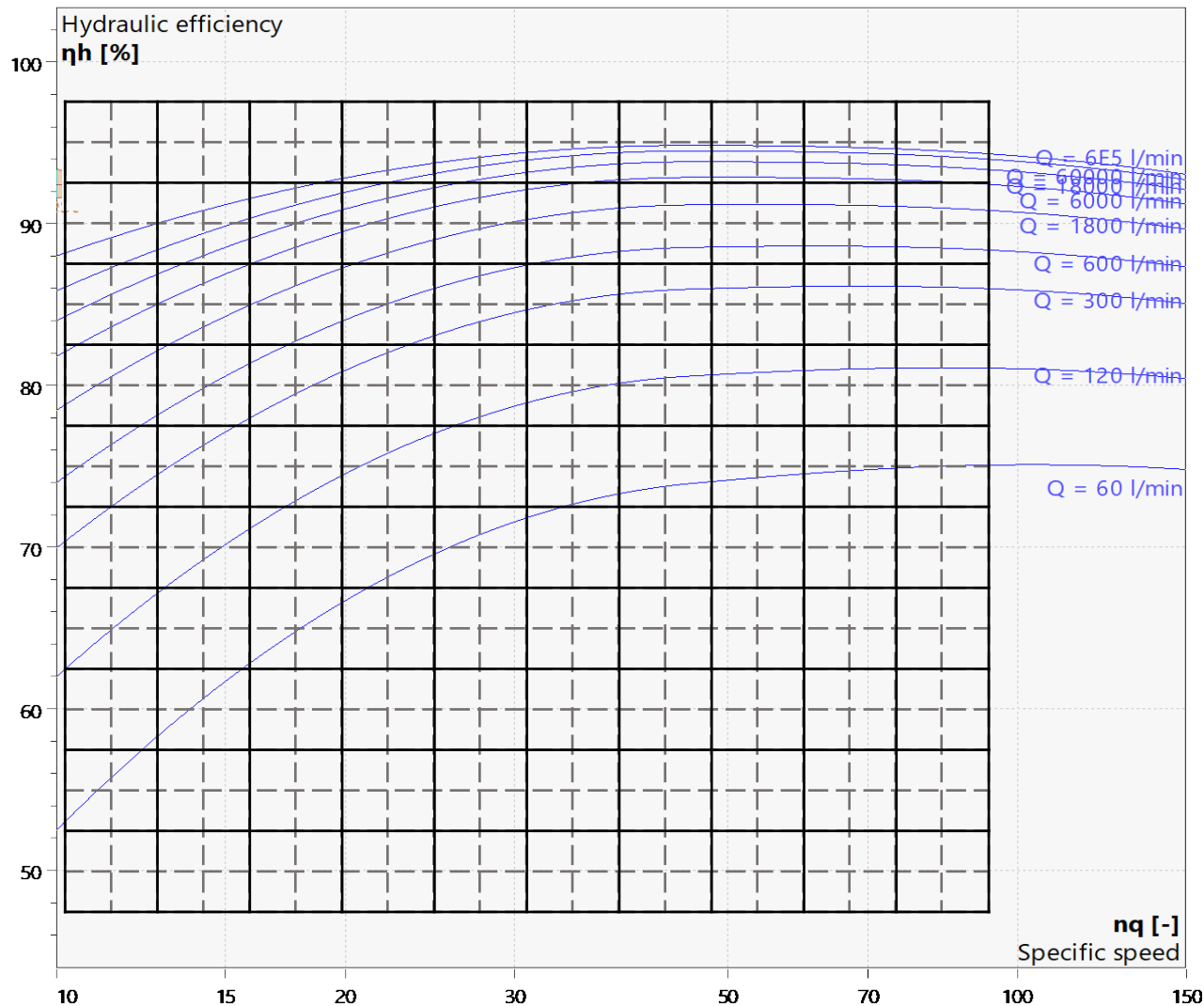
Results

- High quality despite of different dimensions, operating points and fluid properties
- Discernable **Differences at topological changes**, espec. at connection secondary flow path -volute
- Method allows **additional geometric constraints**

Axial force [kN] in secondary flow path			
	Reference	Slurry	Oil
w/o back vanes	-8,67	-32,5	-0,72
Goal	-7,94	-28,5	-0,583
Gain	-7,83	-28,6	-0,632

Parametric Modeling for Hydraulic Pump Design

Summary and Outlook – from empirical correlations to surrogate models

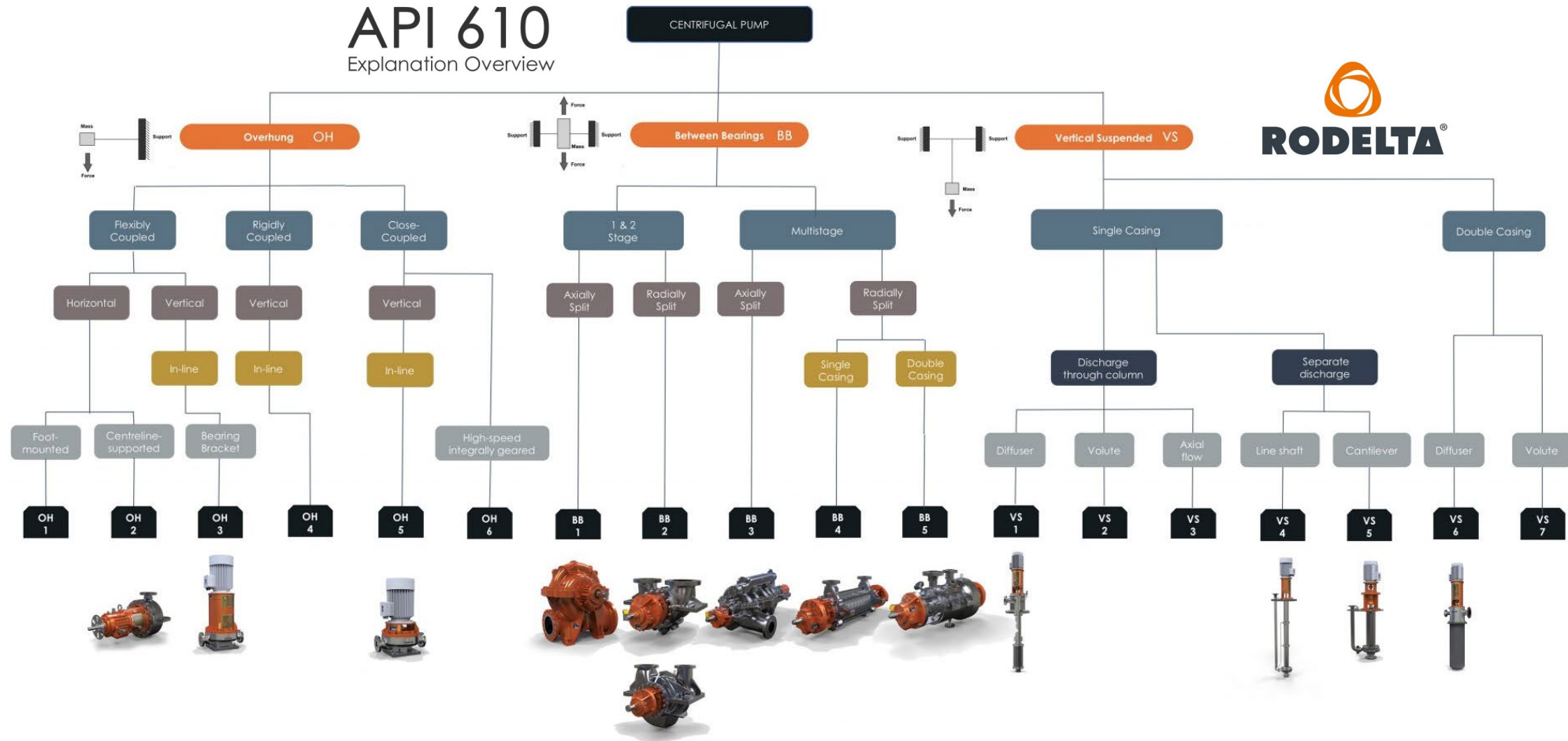


Geometrical details matter ...
how many meta models are needed
to get sufficient, reliable data?



Parametric Modeling for Hydraulic Pump Design

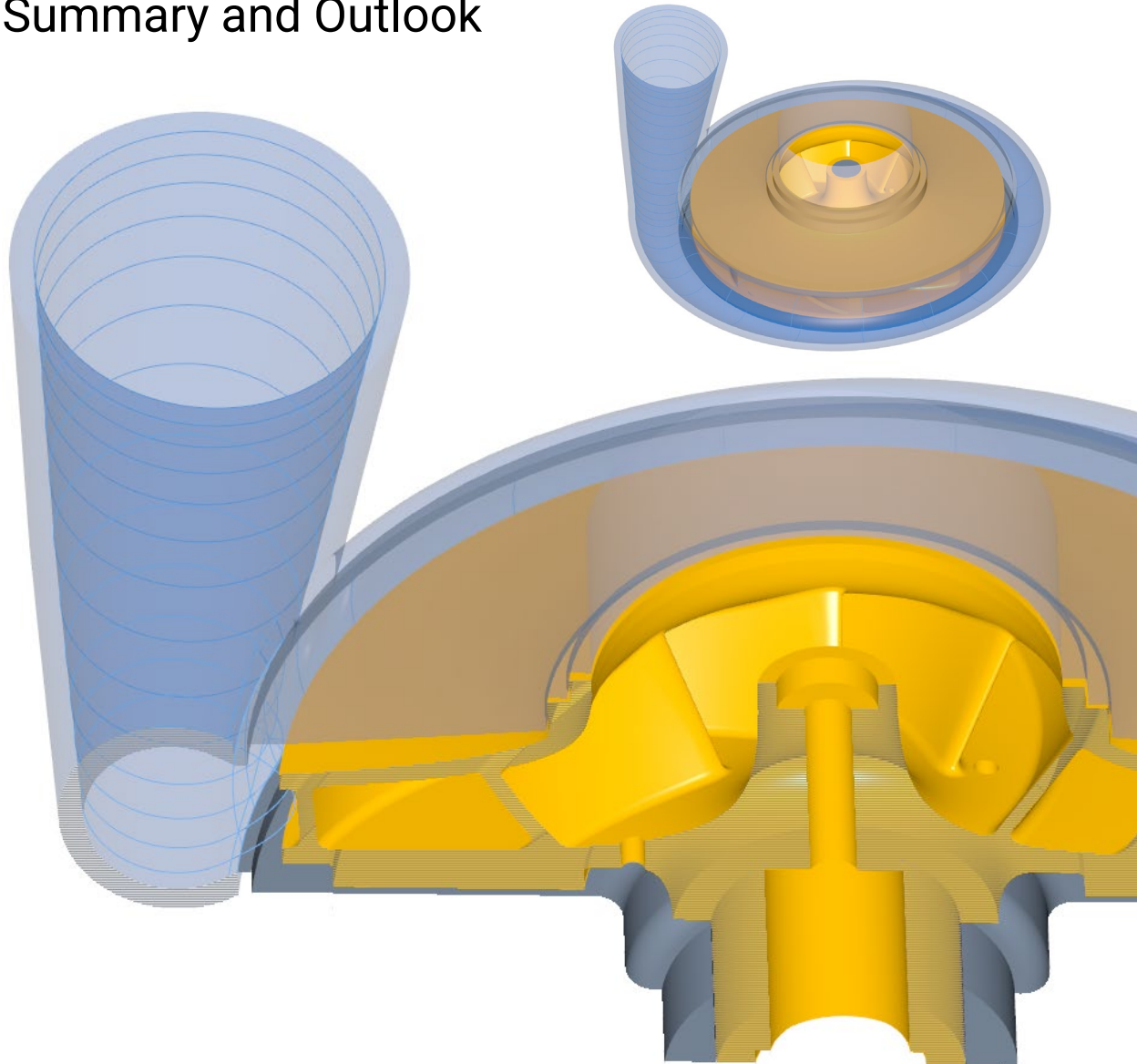
Summary and Outlook – from empirical correlations to surrogate models



Dozens of pump types, hundreds of sizes, thousands of surrogate models, millions of simulations ...

Parametric Modeling for Hydraulic Pump Design

Summary and Outlook



1. **Parametric, versatile design software**
>> leakage balancing holes, pump out vanes, splitter volute, fillets, trimming etc.
2. **Fully automated, fast, accurate, high-fidelity (RANS)/URANS 3D flow simulation**
>> highly-parallel CPU, or GPU-solver
3. **User-friendly design exploration, DoE and optimization** >> made for non-experts
4. **Create and utilize robust surrogate/meta models** >> ML/AI generated database
5. Use data for **new conceptual hydraulic pump designs** and performance prediction