Designing Better Centrifugal Water Pumps, Faster

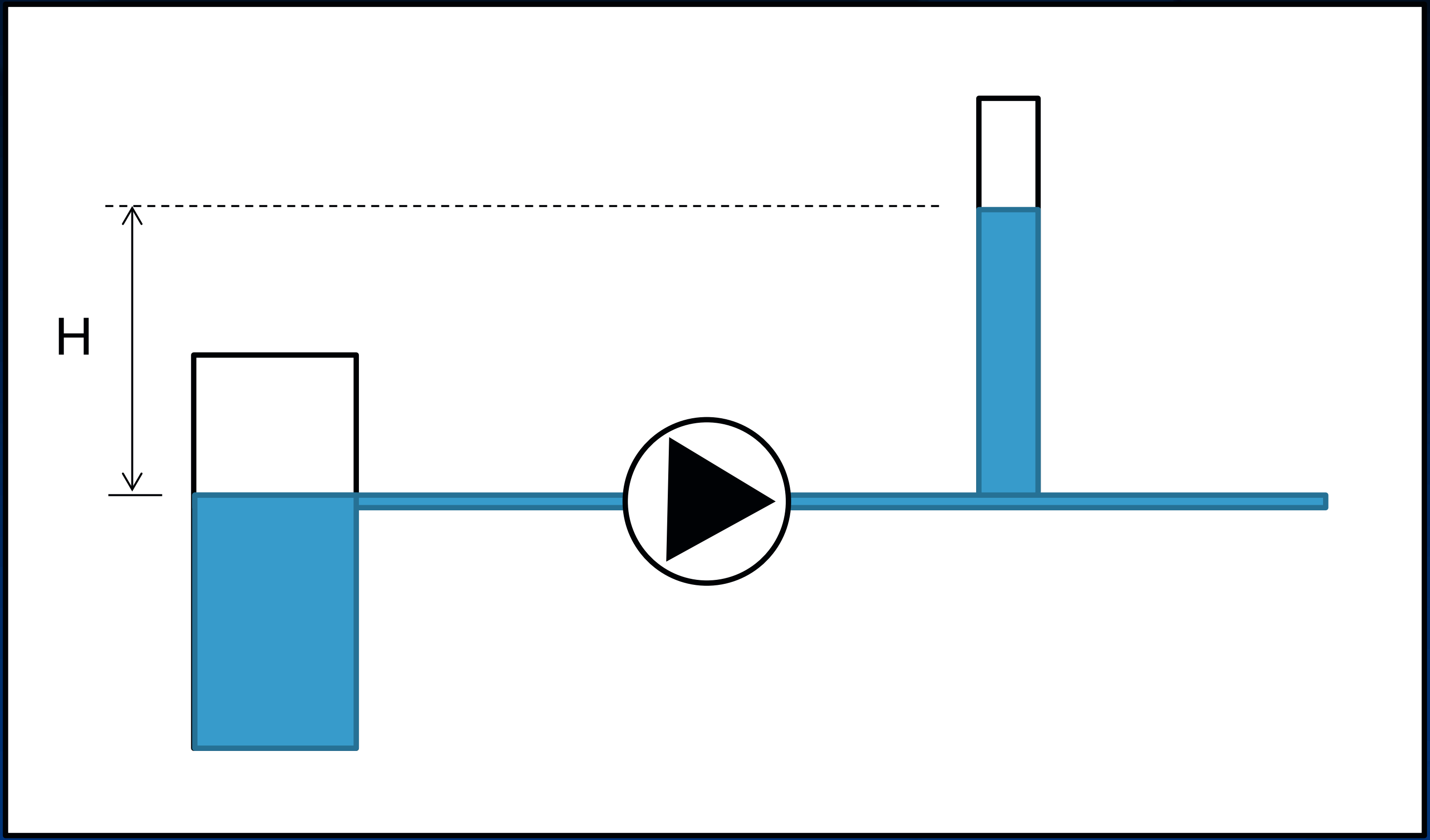
Chad Custer

Outline

- Background
- Optimization objective
- Analysis tools
- Results

Background

- **Pumps are designed to:**
  - Move a certain volume of liquid
  - Produce a certain exit pressure, which is measured in meters of head



Background

- **Reducing the power required to drive the pump:**
  - Allows for a smaller motor
  - Reduces operating cost
- **A small reduction in required power translates to large cost savings**


grundfos.com

Optimization Statement

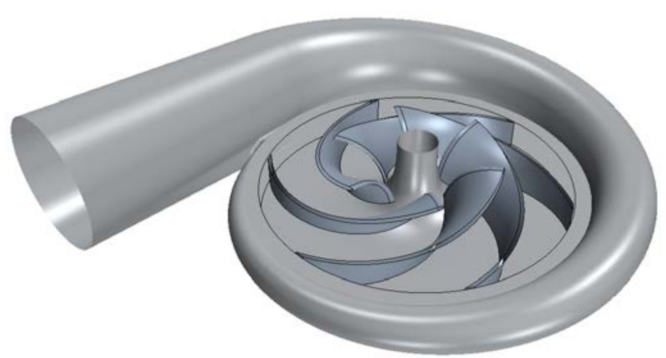
CD-adapco

Objective

1. **Reduce the power required to drive the pump**

Constraints

- **Redesign only the impeller blades (not the casing)**
- **Maintain the specified volumetric flow rate**
- **Maintain the specified outlet pressure**



Existing Design
Flow rate = 400 m^3/h
Pressure head = 30 m
Power required = 38.4 kW

→ ?

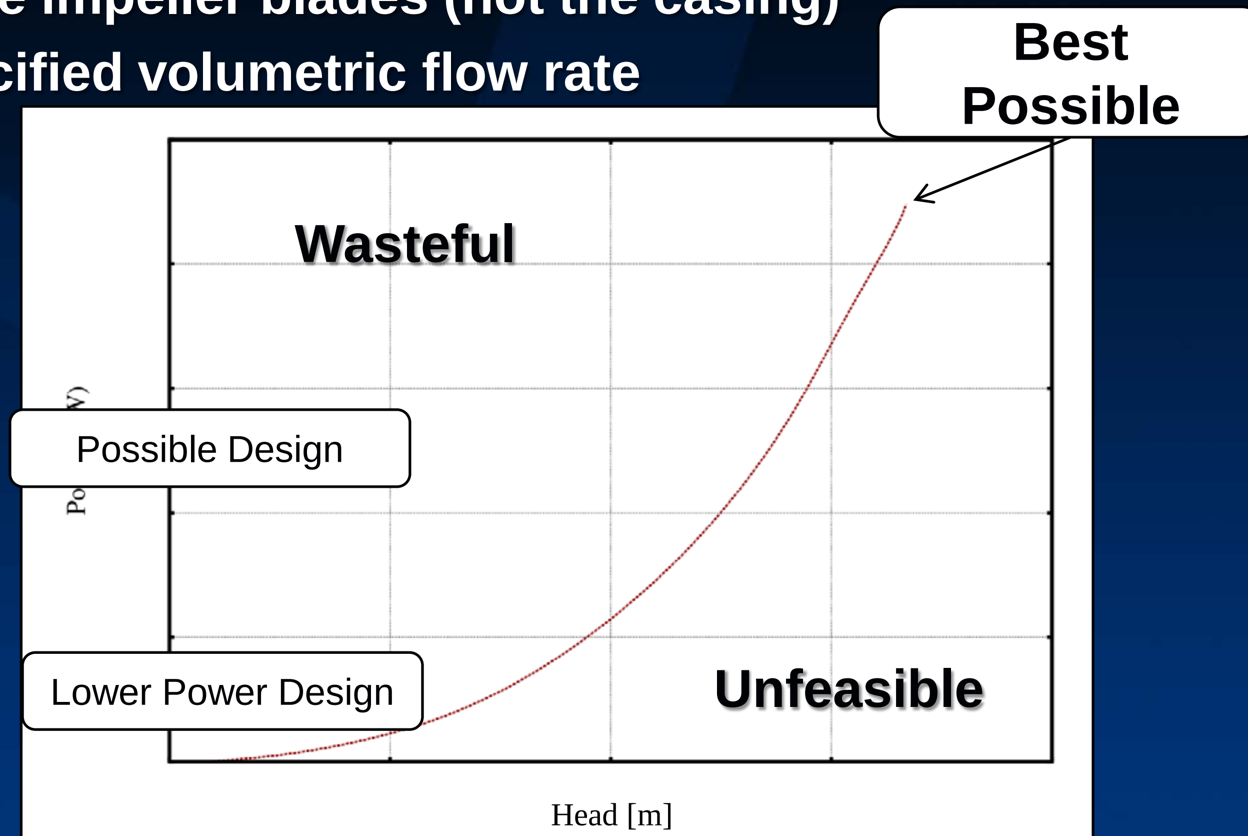
Optimization Statement

Objective

2. Obtain a <u>set</u> of pump designs that require the least power for any given outlet pressure

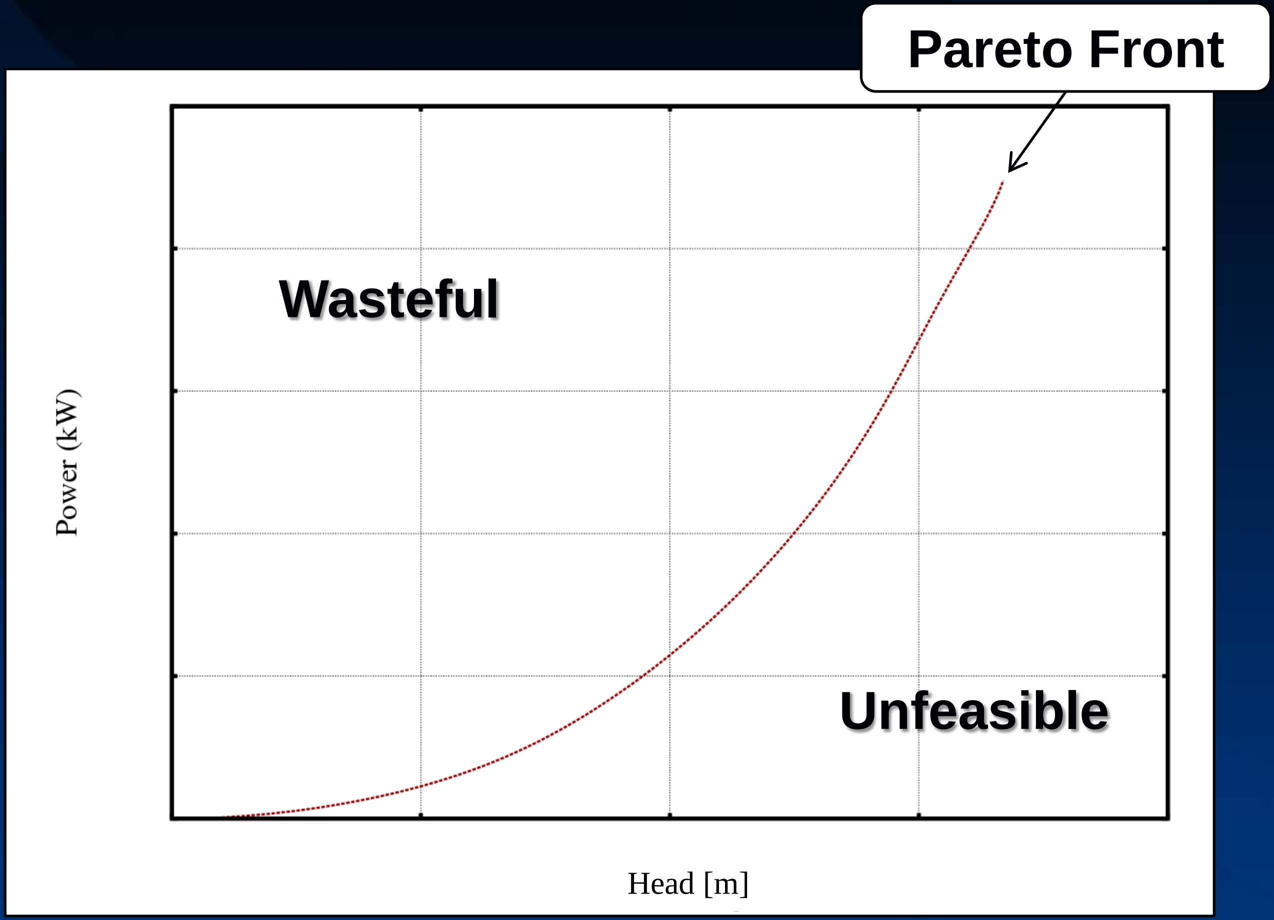
Constraints

- Redesign only the impeller blades (not the casing)
- Maintain the specified volumetric flow rate



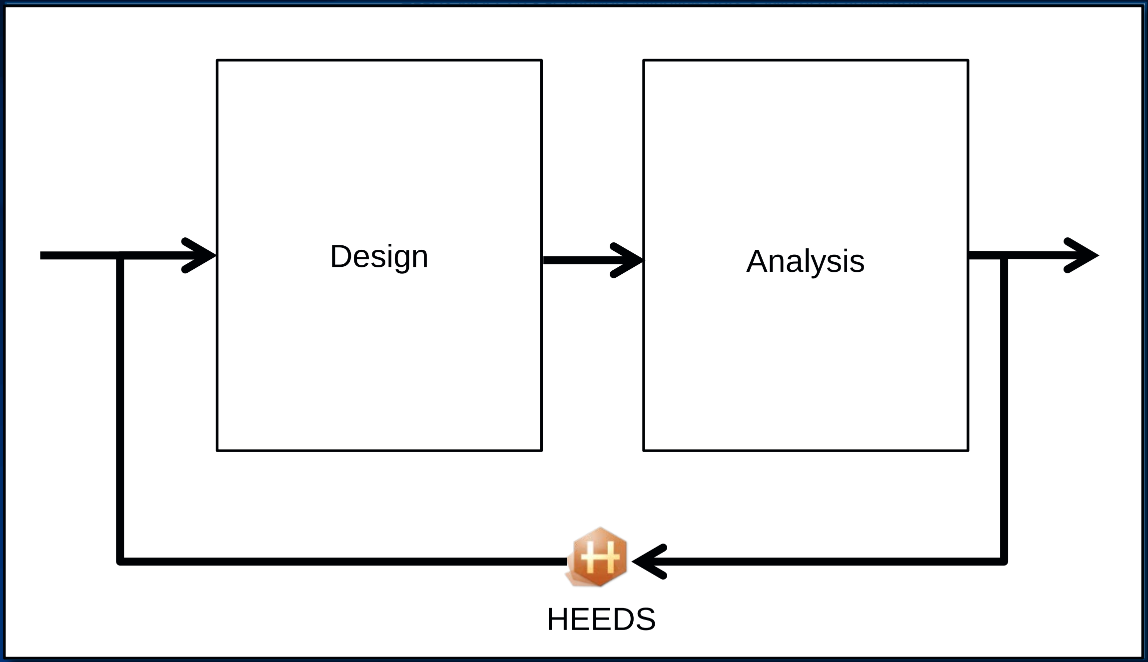
Optimization Algorithm

- The optimization of two competing factors (mass flow and power) is Pareto optimization
- All points on the “Pareto Front” are the best possible designs



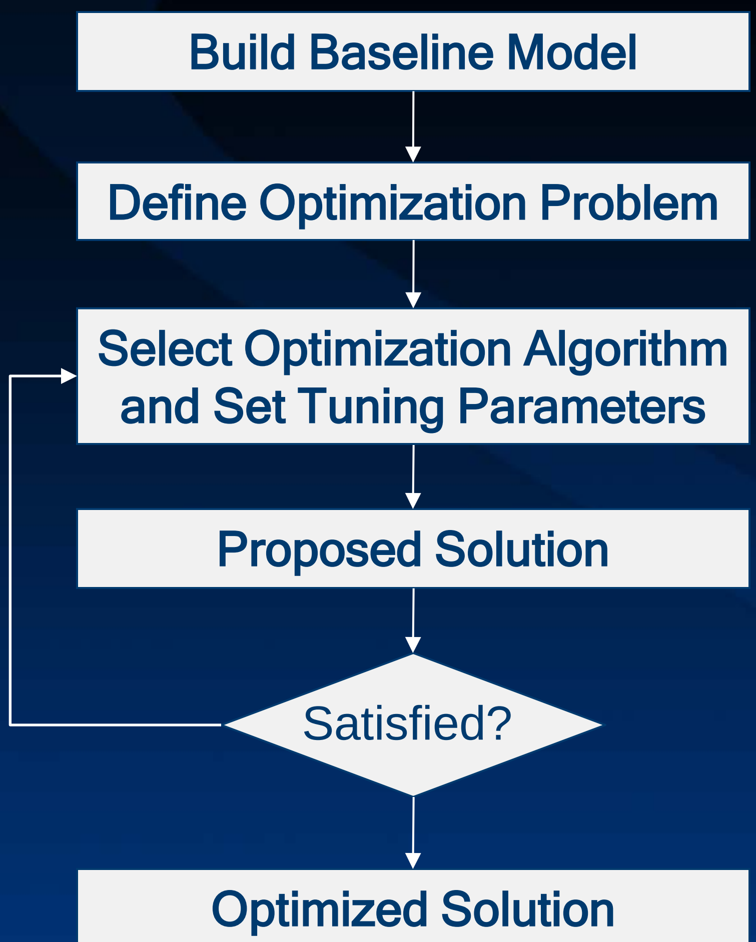
Design and Analysis Tools

- **HEEDS Multidisciplinary Design Optimization (MDO)**
  - Process Automation
    - Automate the Virtual Prototype Build Process
    - Enable Scalable Computation across platforms
  - Design Exploration
    - Efficient Exploration (Optimization, Sweeps, DOE)
    - Sensitivity & Robustness Assessment



Typical Optimization Process

Standard Procedure



Modern Optimization Process

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HEEDS Procedure

Build Baseline Model

↓

Define Optimization Problem

↓

SHERPA

↓

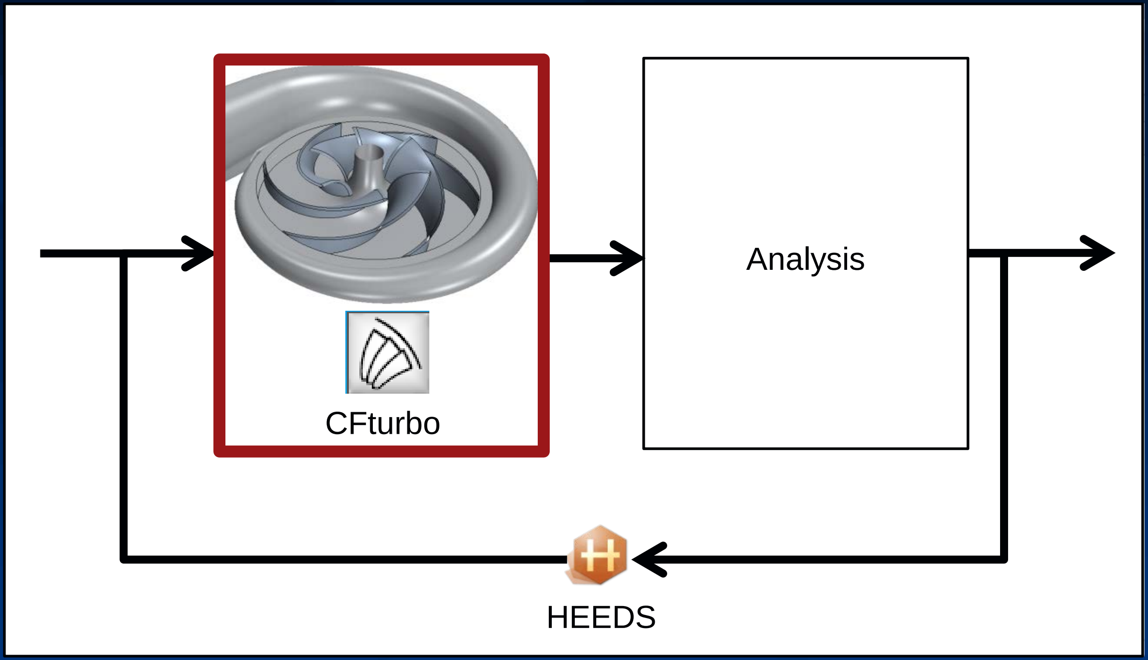
Optimized Solution

- Hybrid
- Adaptive
- No Tuning Parameters
- No Optimization Expertise Required

Design and Analysis Tools

CFturbo Turbomachinery Design

- Interactive design tool
  - Rapid design of high-quality turbomachinery components
  - Integration of established turbomachinery design theory
  - Comfortable, reliable and user friendly
  - Direct interfaces for many CAE-software packages

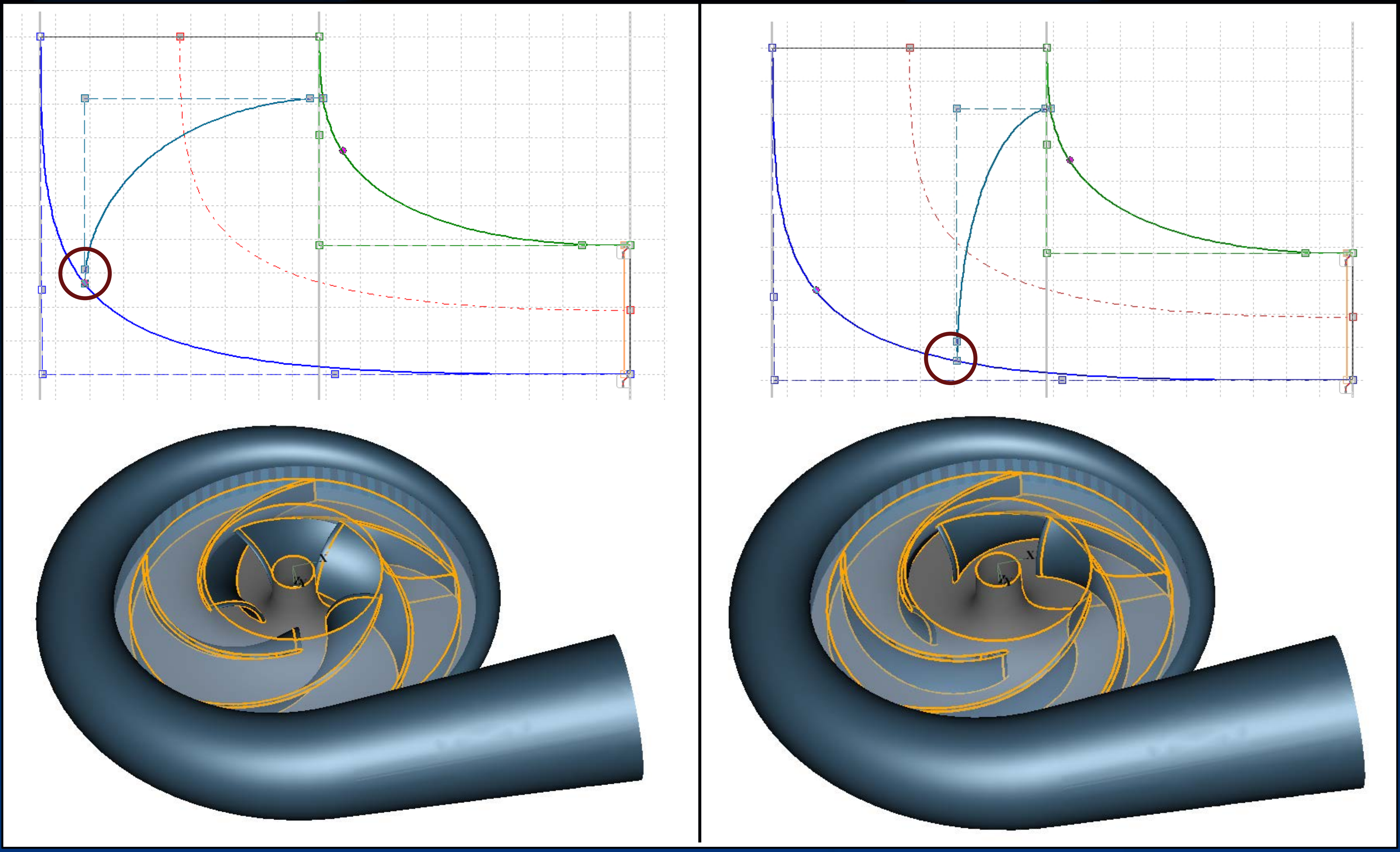


CFturbo Design

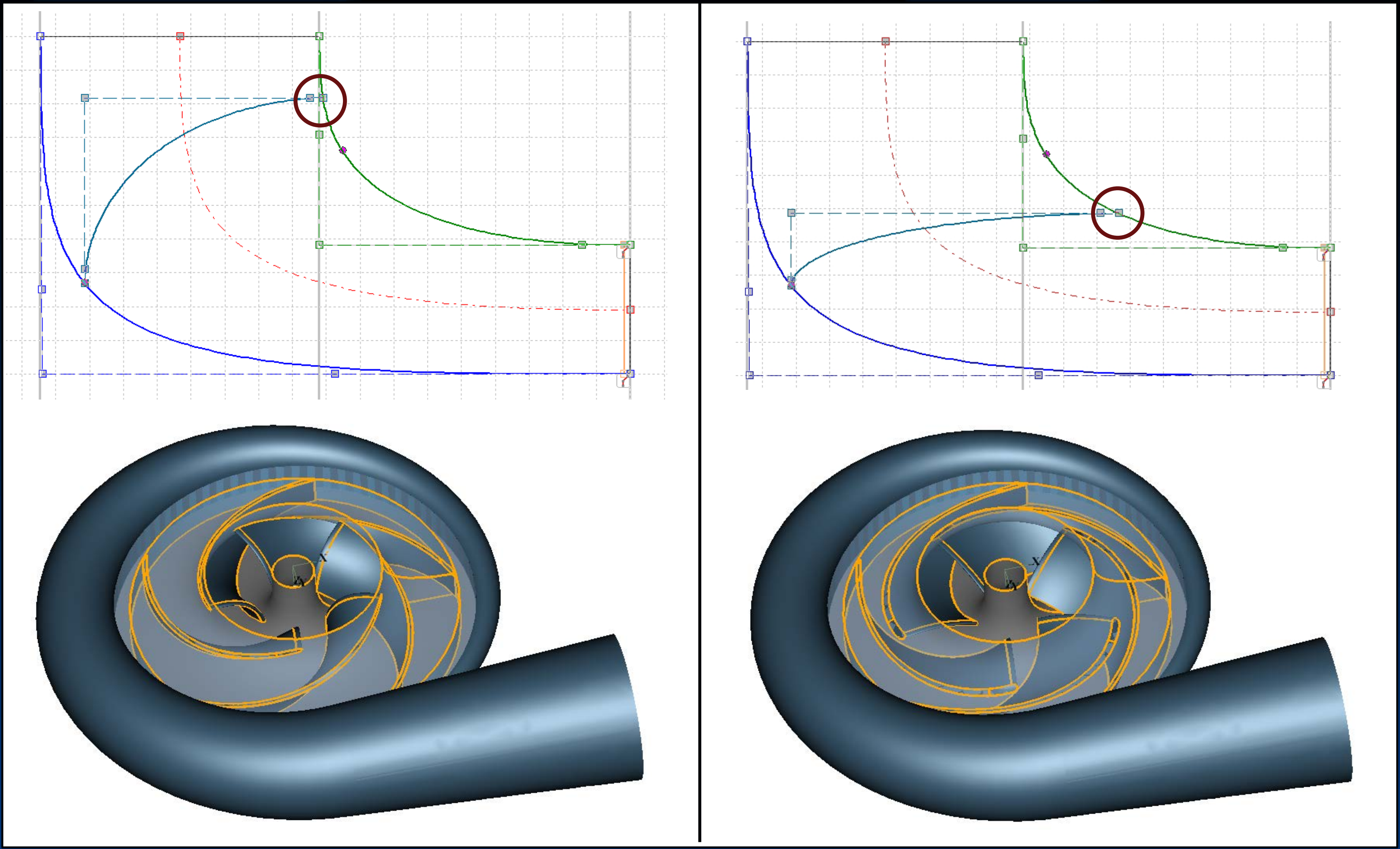
- Turbomachinery design tool that allows for automatic or manual design of machines
- HEEDS will optimize the design based on 16 design parameters

Number of Parameters	Control
1	Number of blades
2	Leading edge position
4	Leading edge shape
3	Leading edge incidence angle
1	Leading edge curvature
1	Trailing edge position
3	Trailing edge incidence angle
1	Trailing edge curvature
16	**Total**

CFturbo Design Parameters: Leading Edge Position



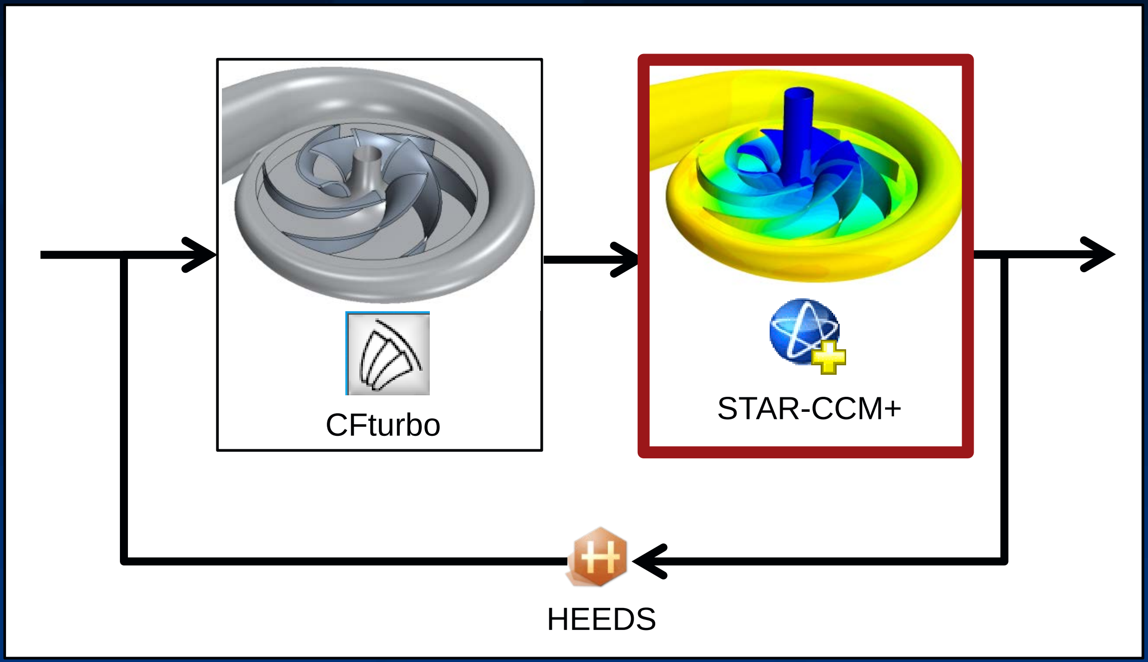
CFturbo Design Parameters: Leading Edge Position



Design and Analysis Tools

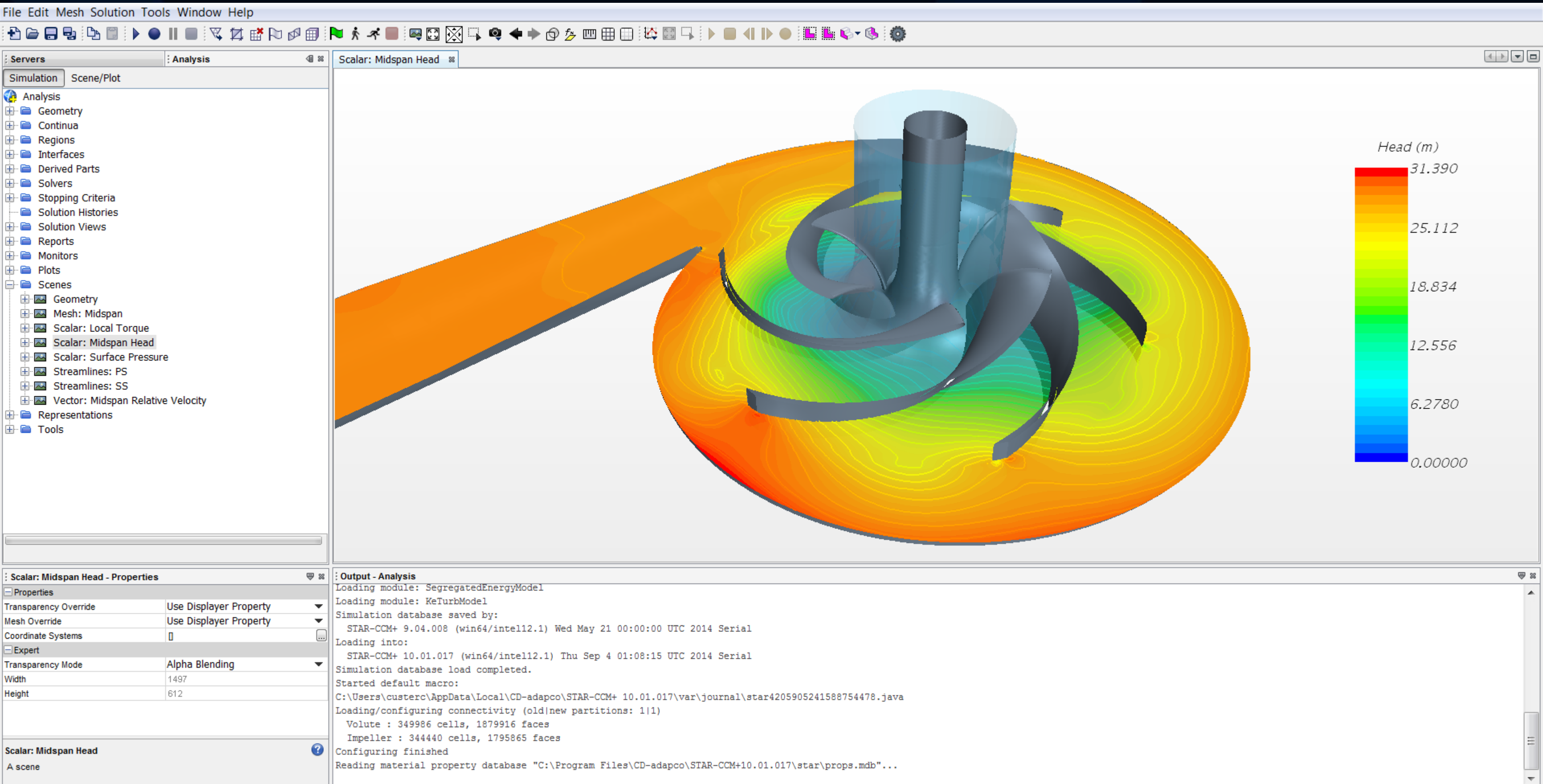
STAR-CCM+ Multi-physics Analysis

- First-principles computational fluid dynamics focused analysis tool
- Integrated environment for:
  - Geometry handling
  - Meshing
  - Solving
  - Post-processing



STAR-CCM+ Simulation

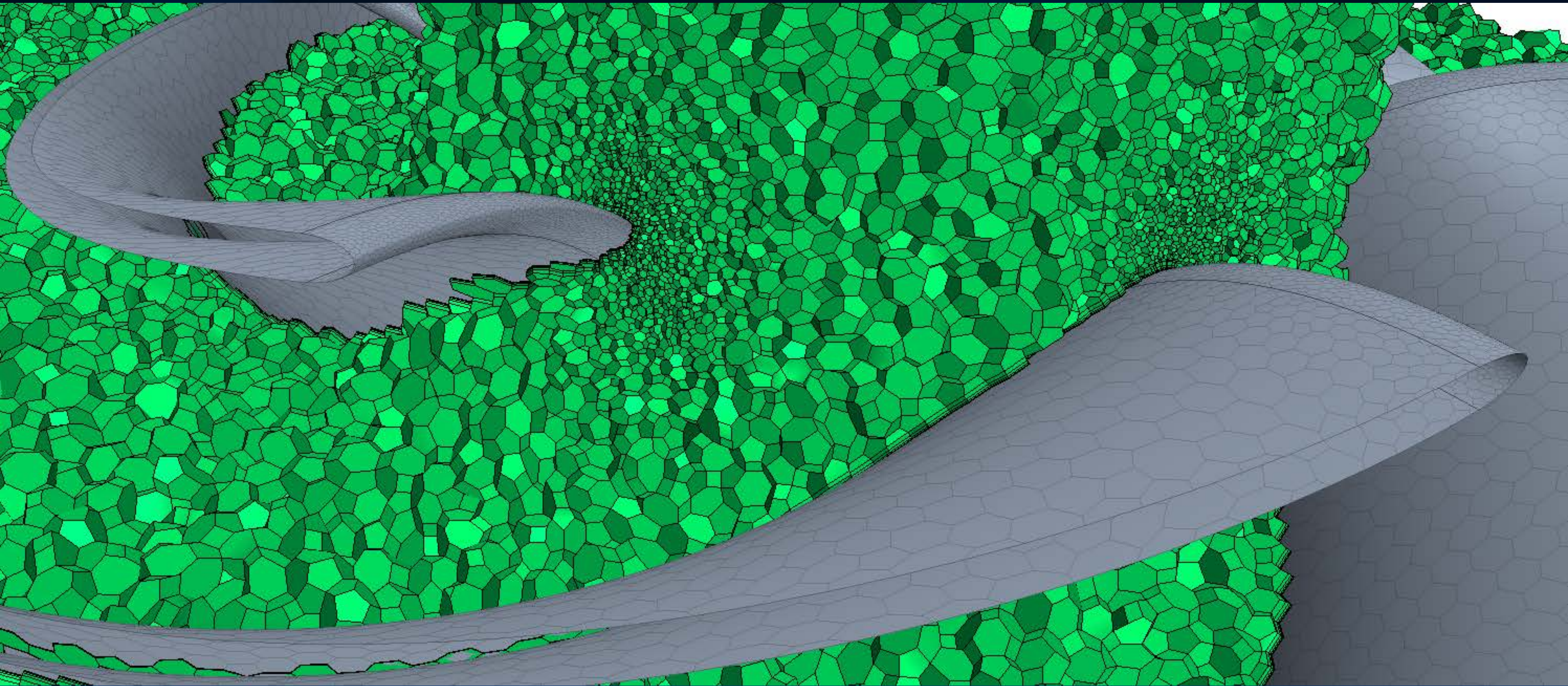
- Integrated environment for pre-processing, meshing, solving and post-processing is ideally suited to optimization analysis



STAR-CCM+ Simulation

Meshing

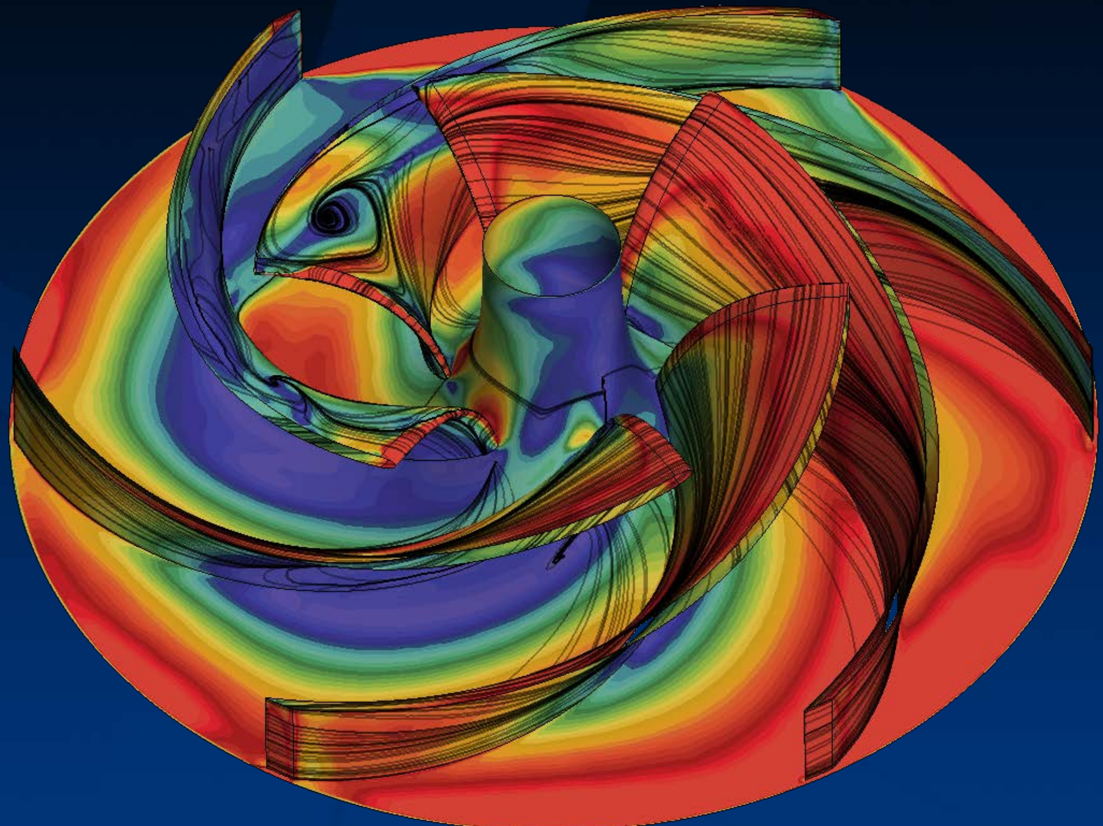
- Approximately 700,000 cells
- Unstructured polyhedral cells
- Body-fitted prism layers for accurate boundary layer prediction



STAR-CCM+ Simulation

Solving

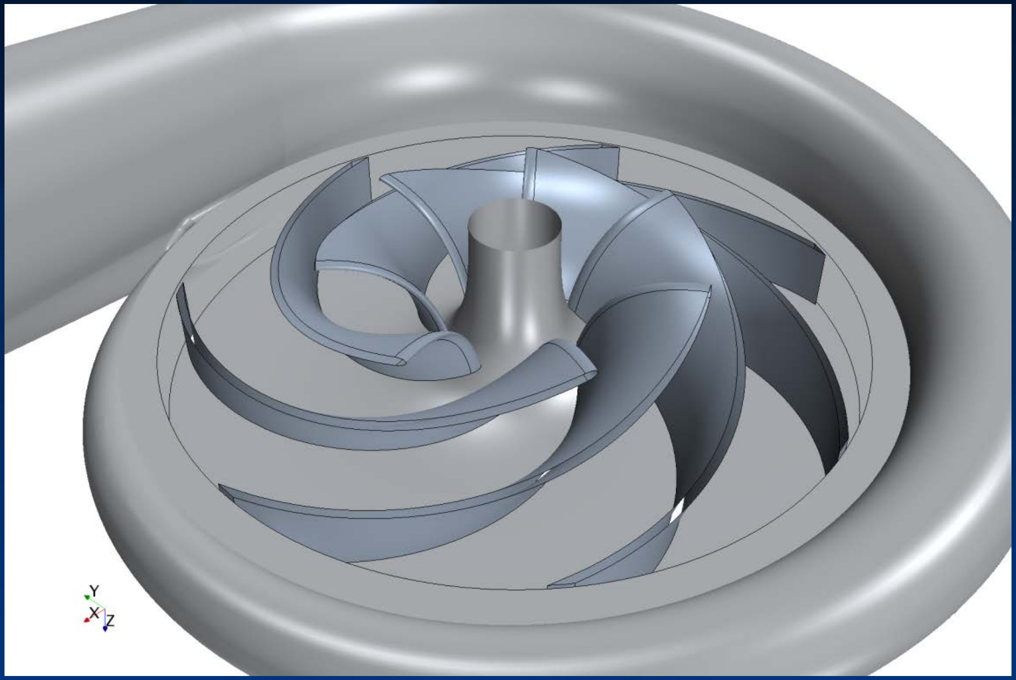
- First-principles Navier-Stokes solution
- Steady, in-place interface
- Segregated solver
- Realizable k-ϵ turbulence model



STAR-CCM+ Simulation

Steps of analysis (which happen automatically)

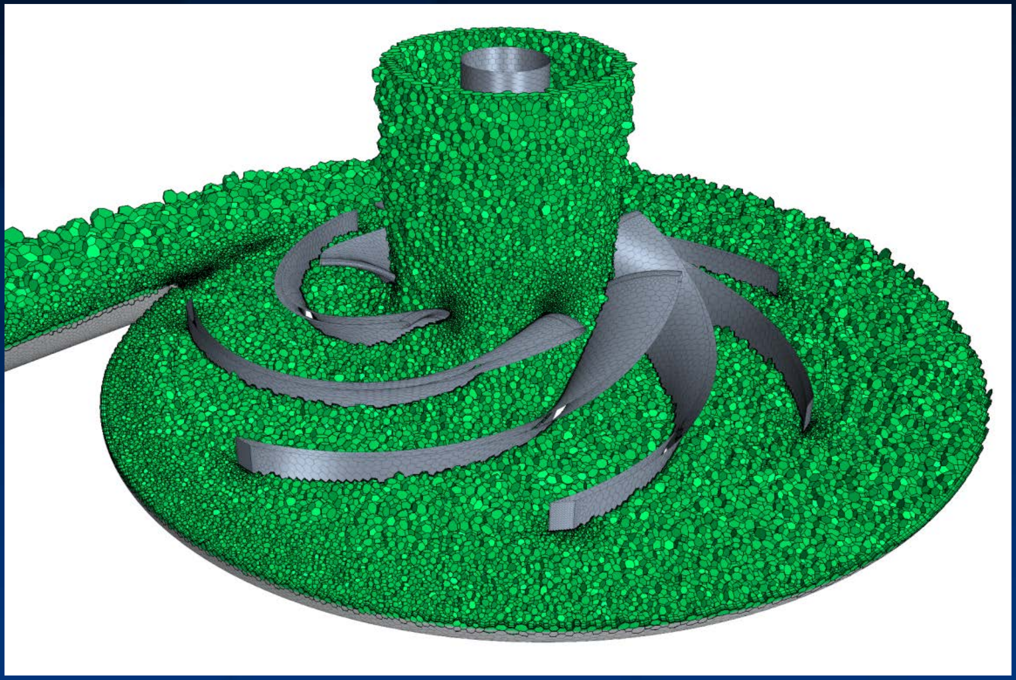
1. Import new CAD geometry



STAR-CCM+ Simulation

Steps of analysis (which happen automatically)

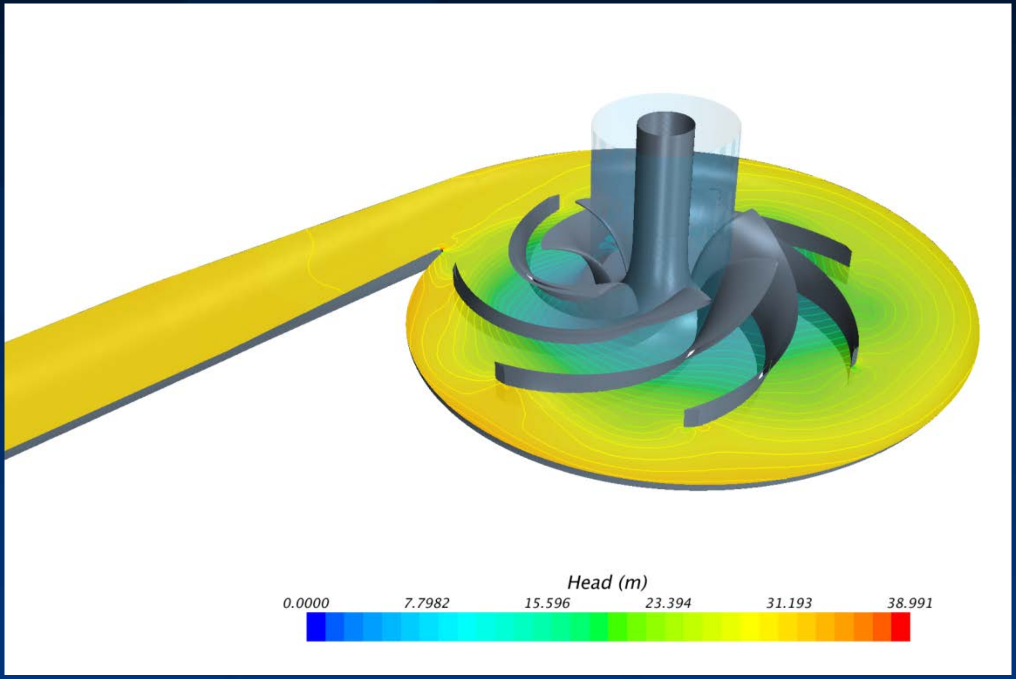
1. **Import new CAD geometry**
2. **Generate mesh**



STAR-CCM+ Simulation

Steps of analysis (which happen automatically)

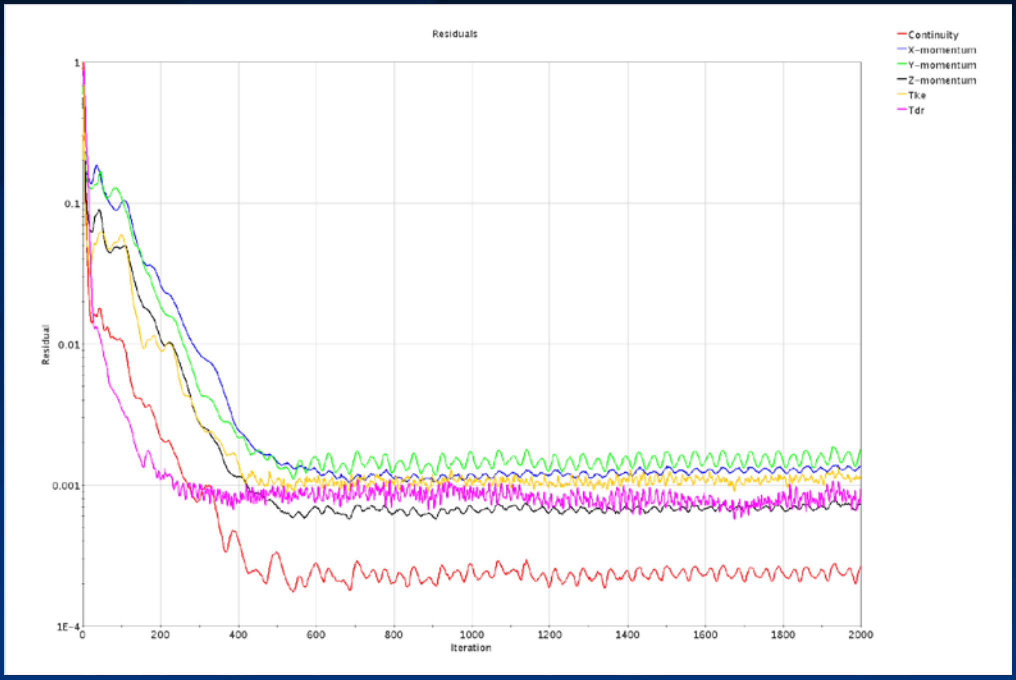
1. Import new CAD geometry
2. Generate mesh
3. Interpolate previous solution onto new mesh



STAR-CCM+ Simulation

Steps of analysis (which happen automatically)

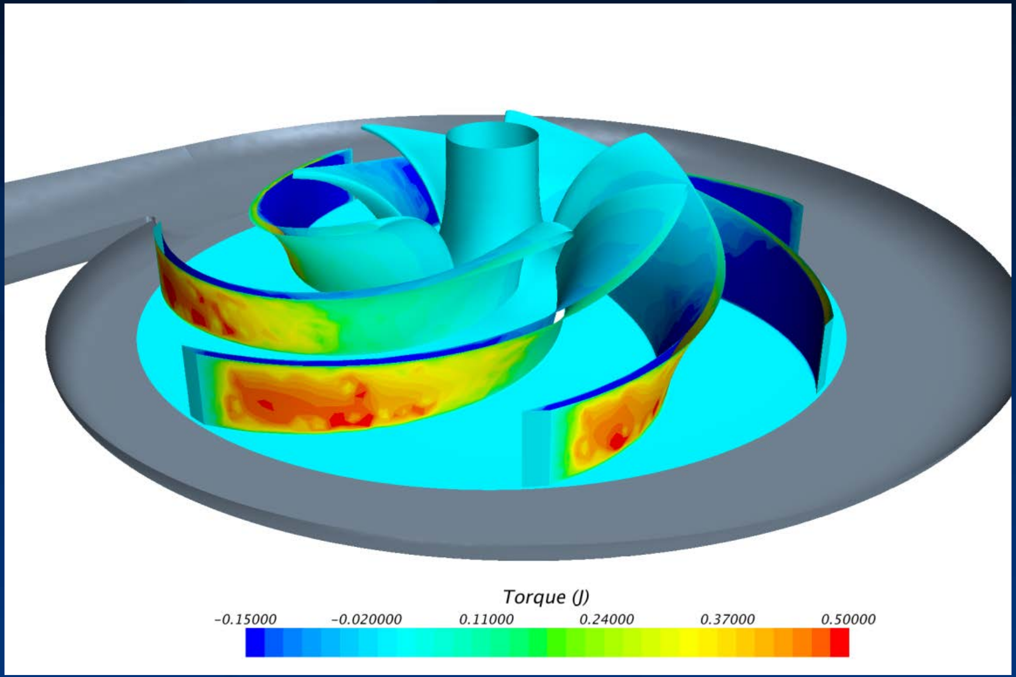
1. Import new CAD geometry
2. Generate mesh
3. Interpolate previous solution onto new mesh
4. Solve



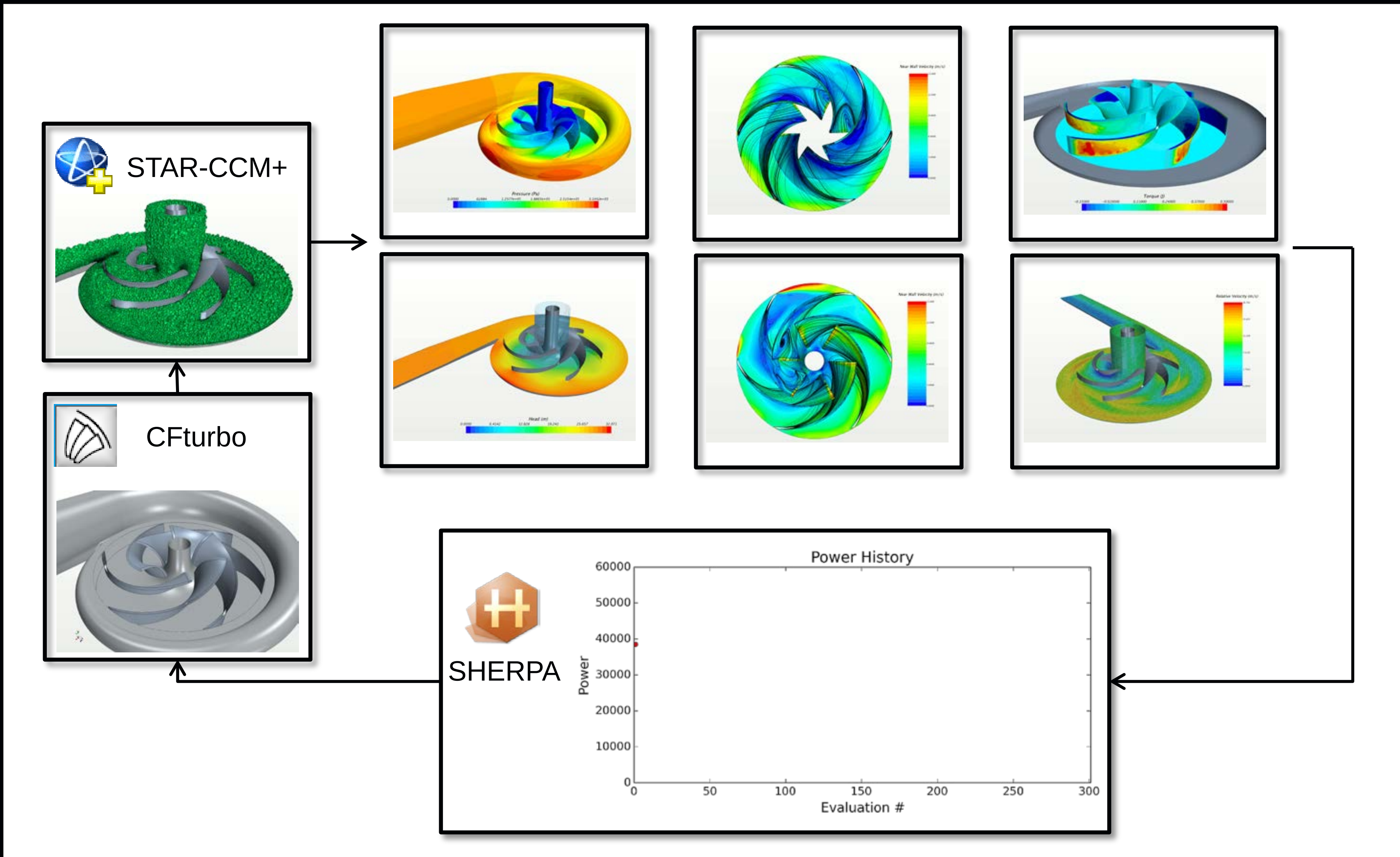
STAR-CCM+ Simulation

Steps of analysis (which happen automatically)

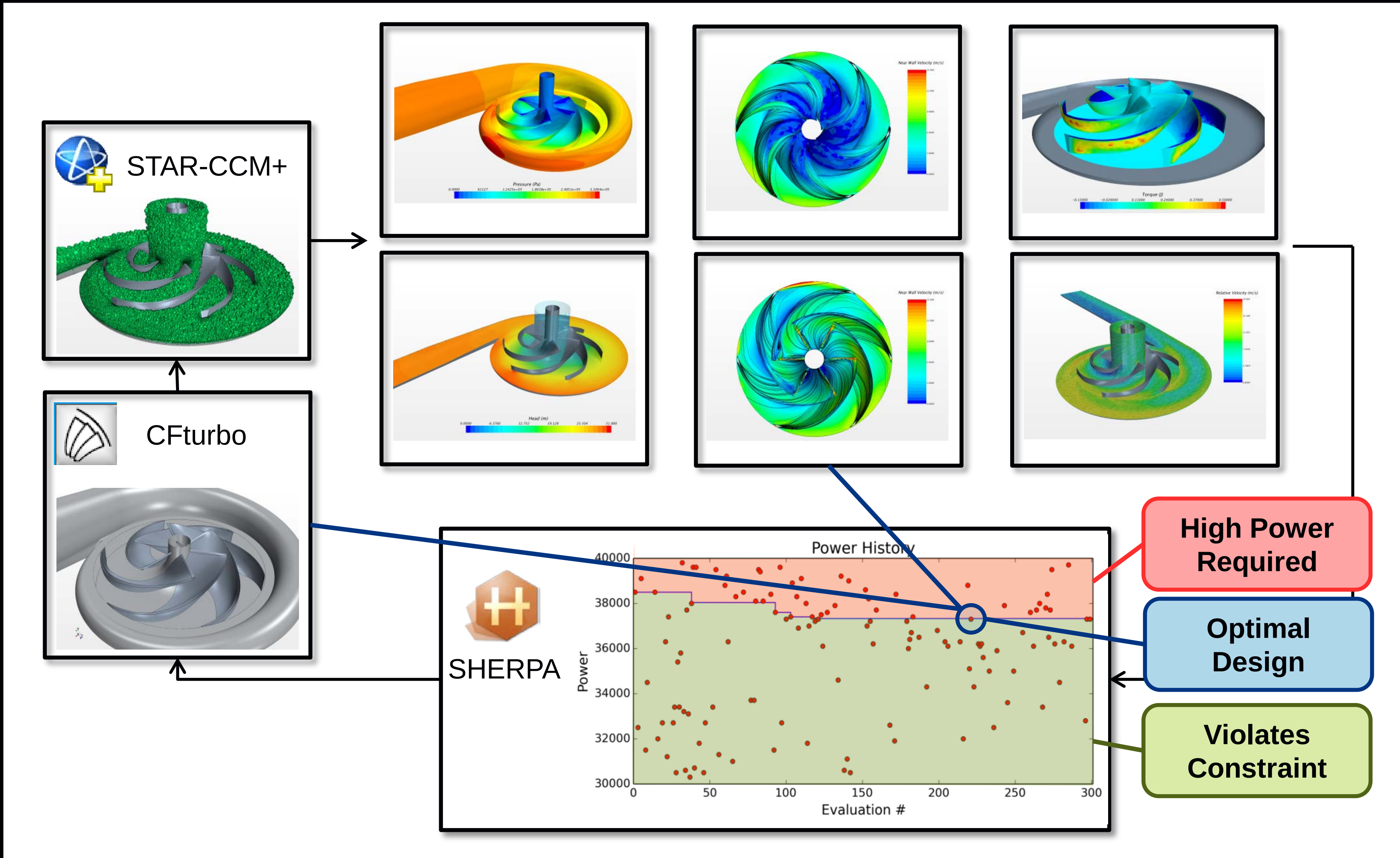
1. Import new CAD geometry
2. Generate mesh
3. Interpolate previous solution onto new mesh
4. Solve
5. Export performance prediction



Optimization Process



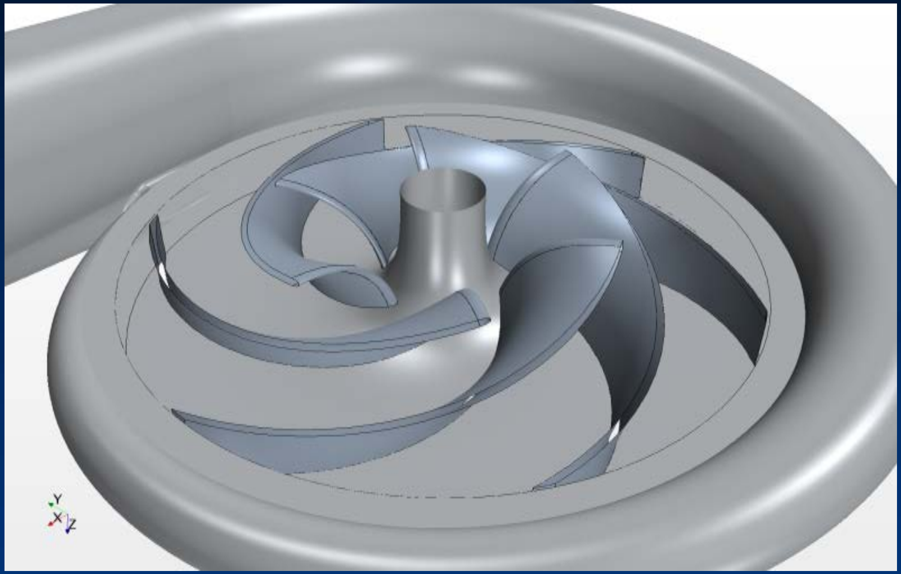
Optimization Process

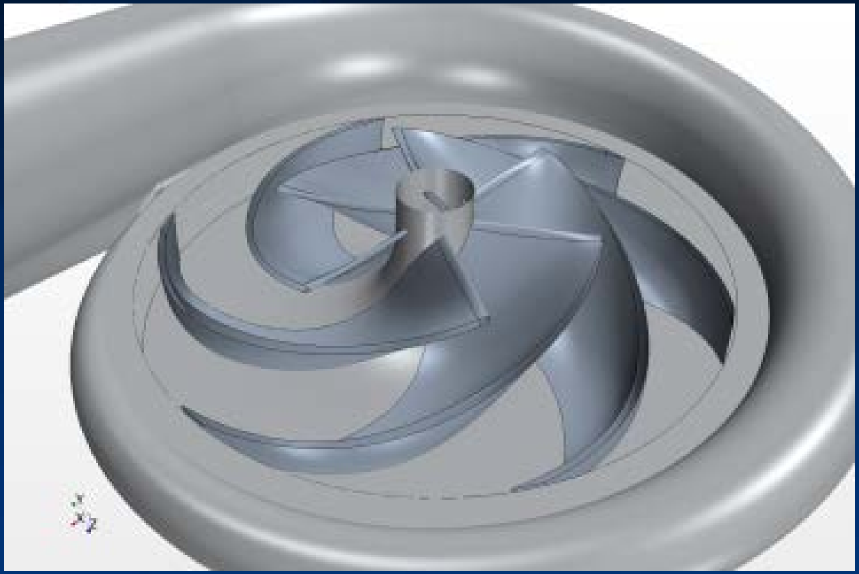


Single Objective Optimization Results

- **Original Design**
  - Flow Rate: 400 m^3/hr
  - Head: 29.2 m
  - Power: 38.4 kW
- **Optimized Design**
  - Flow Rate: 400 m^3/hr
  - Head: 29.5 m
  - Power: 36.0 kW

➢ 6% reduction in power required





Single Objective Optimization Results

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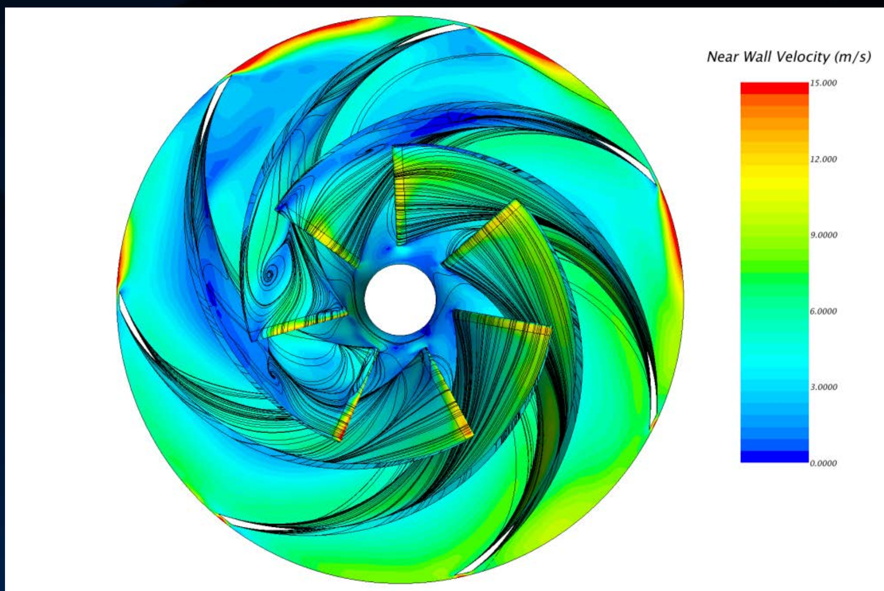
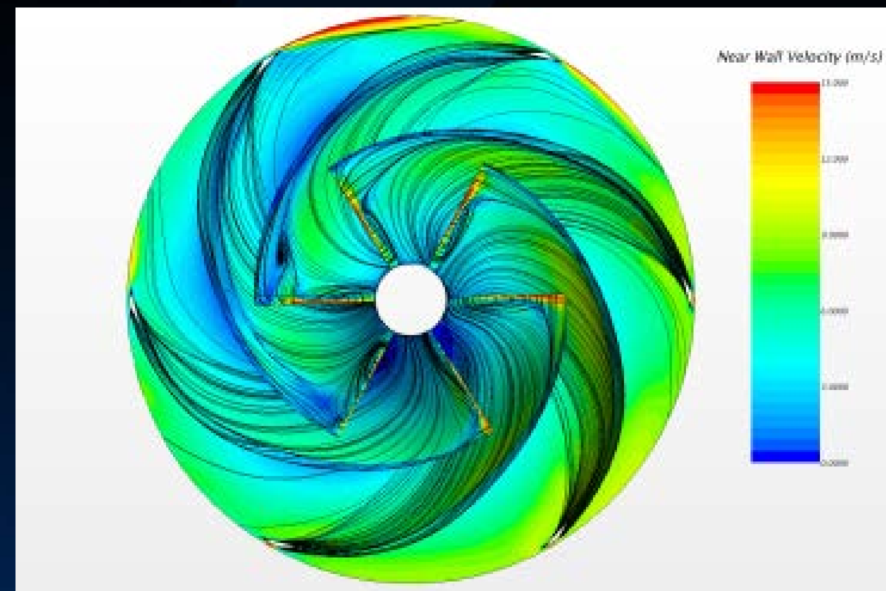
Original Design



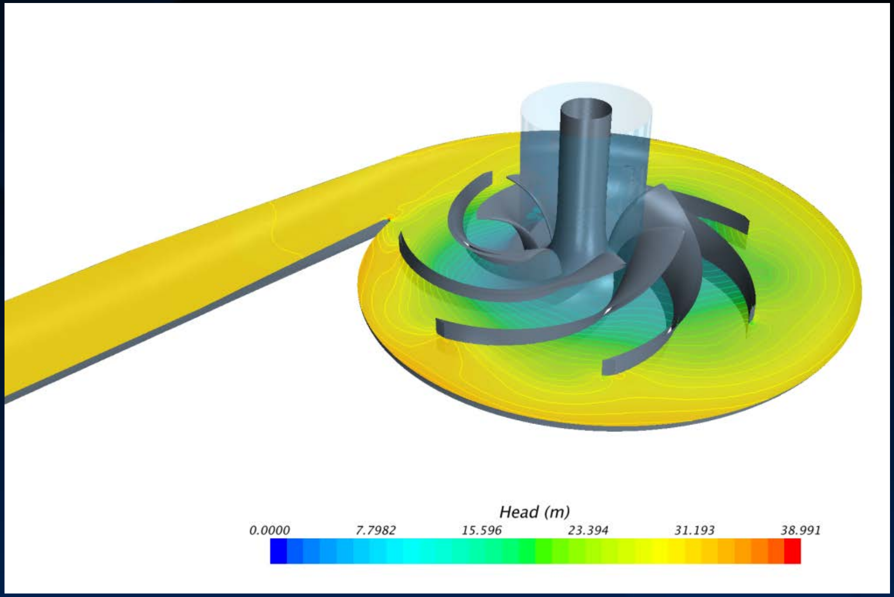
Optimized Design



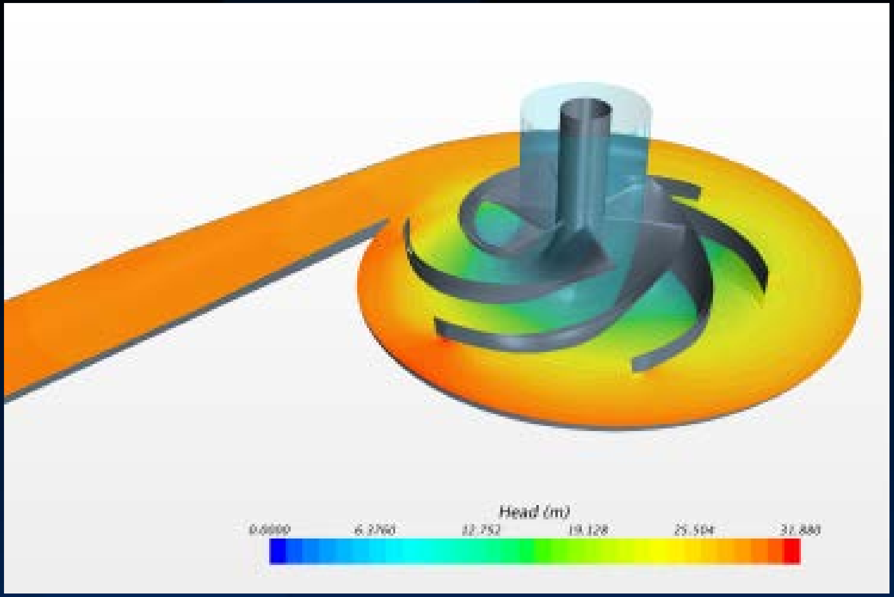
➢Flow remains attached

Single Objective Optimization Results

Original Design



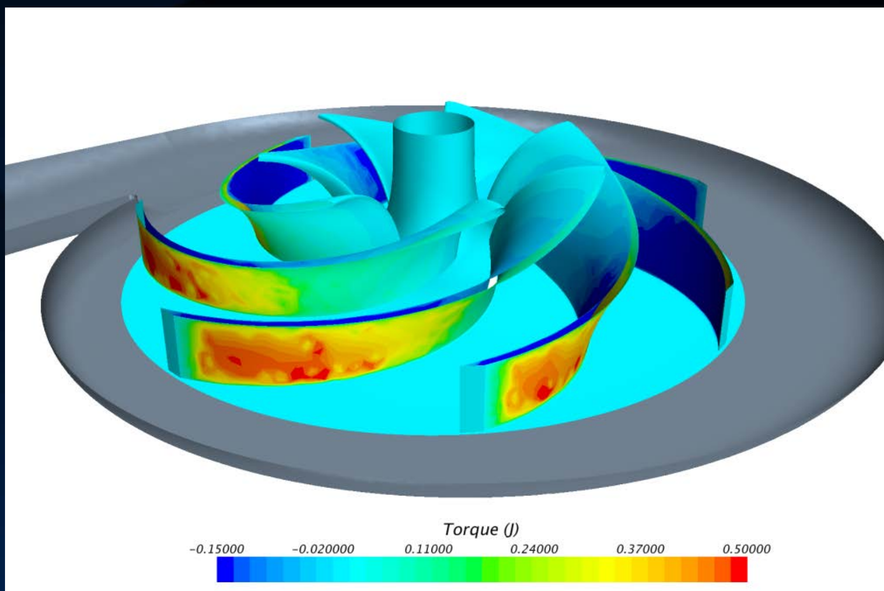
Optimized Design



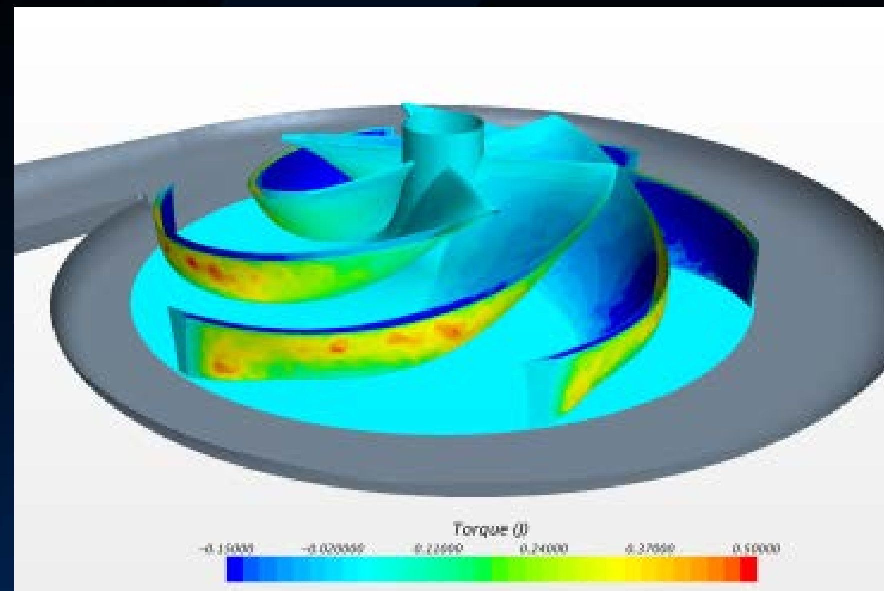
➢Uniform pressure distribution

Single Objective Optimization Results

Original Design



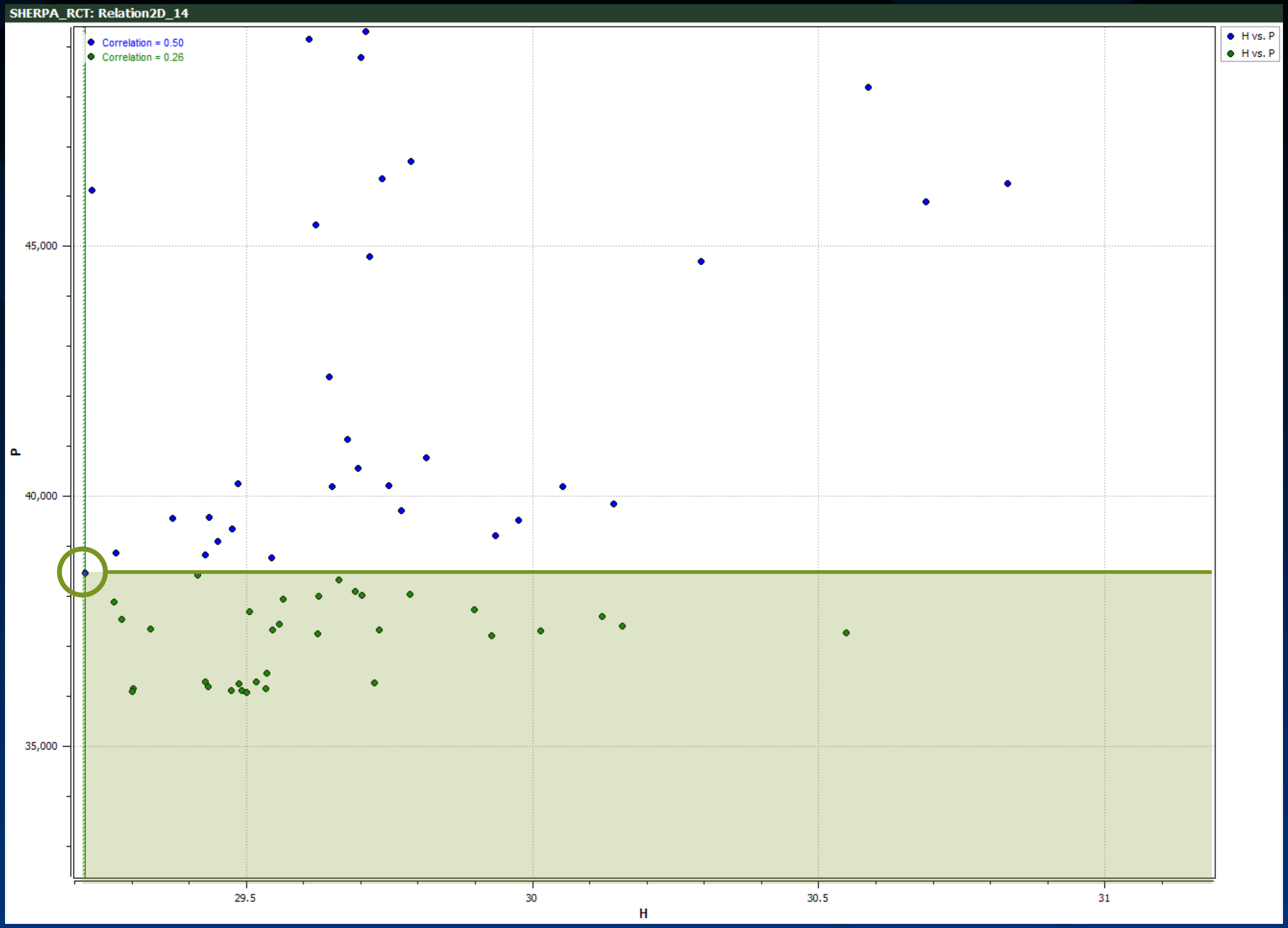
Optimized Design



➢Reduces torque on blades

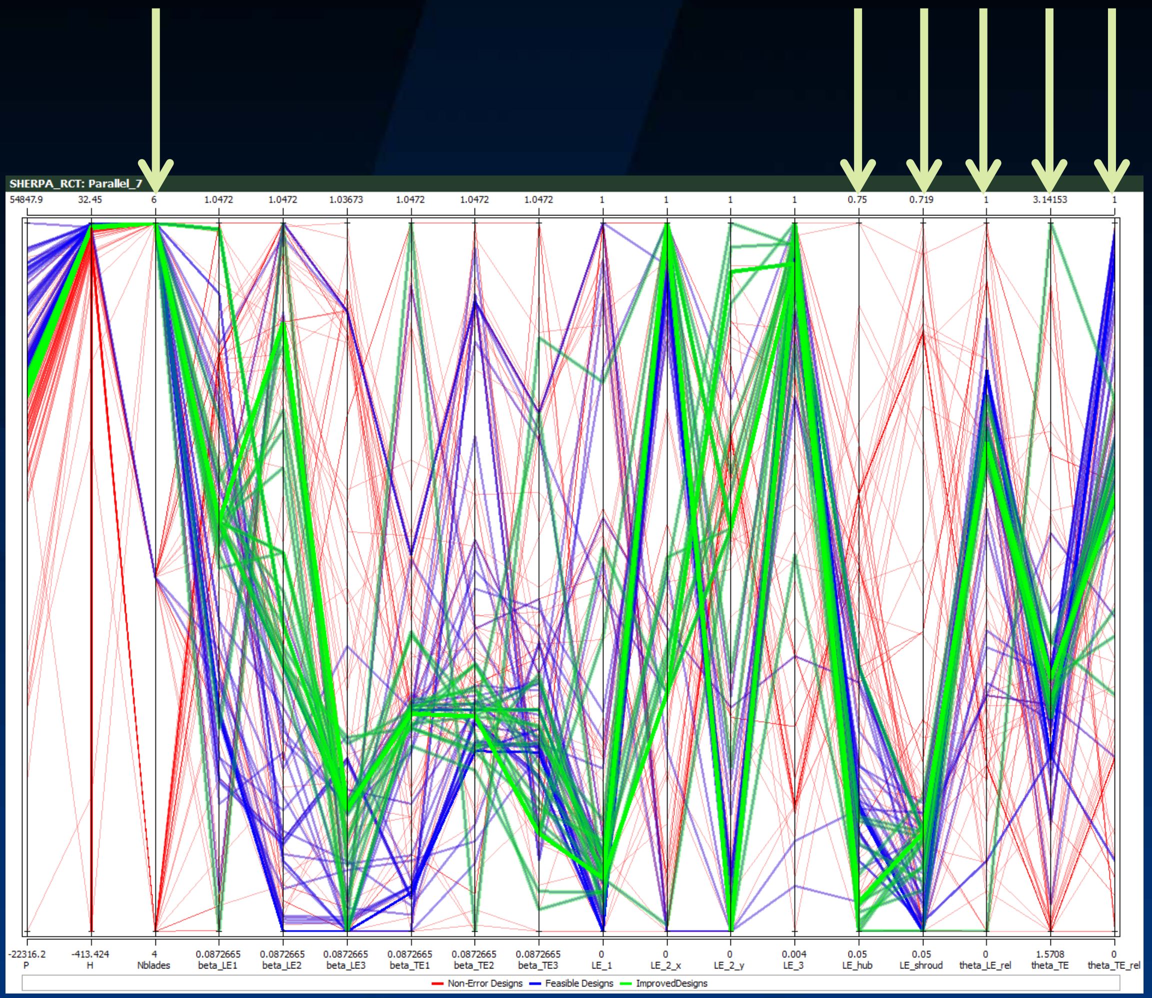
Single Objective Optimization Results

- **33 Designs found with lower power requirement**



Single Objective Optimization Results

- **33 Designs found with lower power requirement**
- **Parallel plot shows that improved designs have similar**
  - Number of blades
  - Leading location
  - Trailing edge location



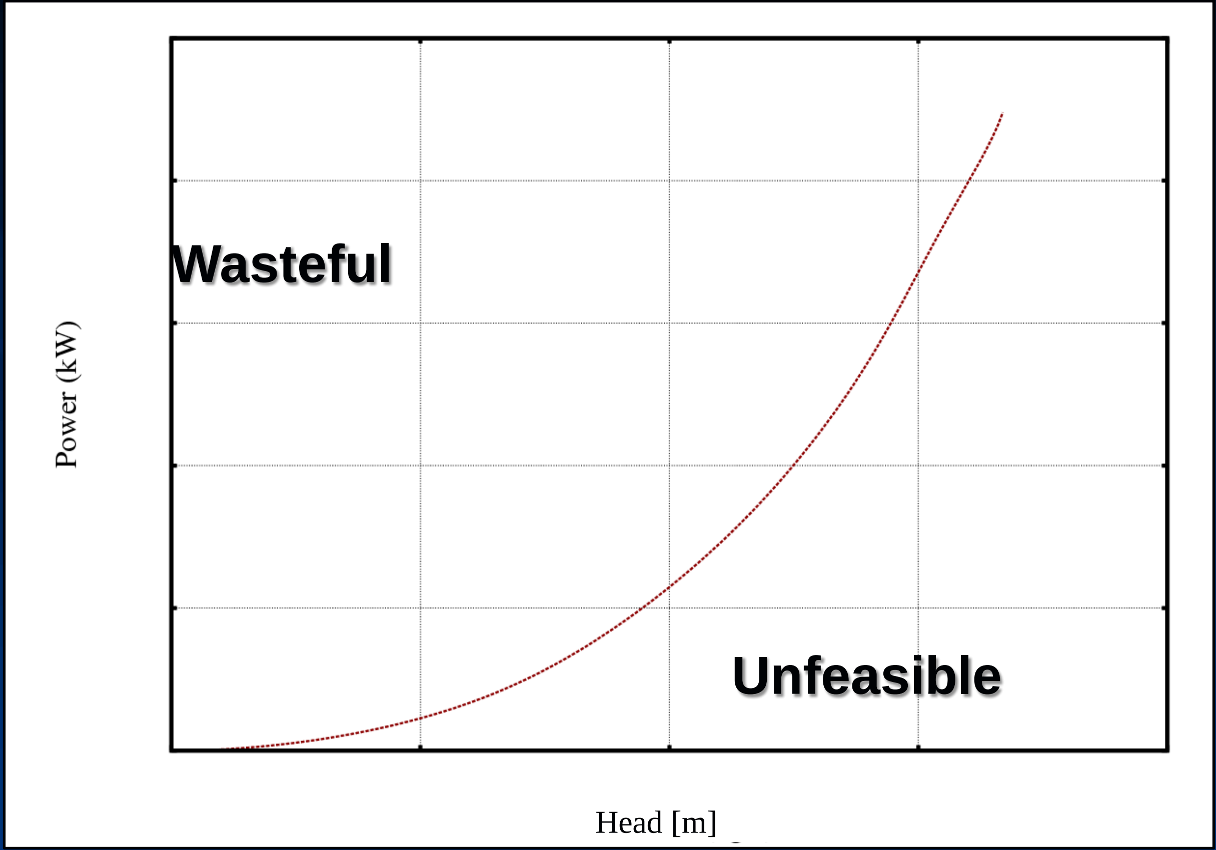
Review of Objective #1

- **Reduced power required 6%**
- **Design parameters and number of runs were the only inputs to the optimization algorithm**
- **Algorithm produced a case that resulted in:**
  - Attached flow
  - Uniform pressure field
  - Low torque
  - ➢ Low power required

Pareto Optimization Results

- Pareto optimization performed to understand trade-off between outlet pressure and power required
- 580 evaluations allowed

Note: It is challenging to increase pressure without changing the diameter of the machine



Pareto Optimization Results

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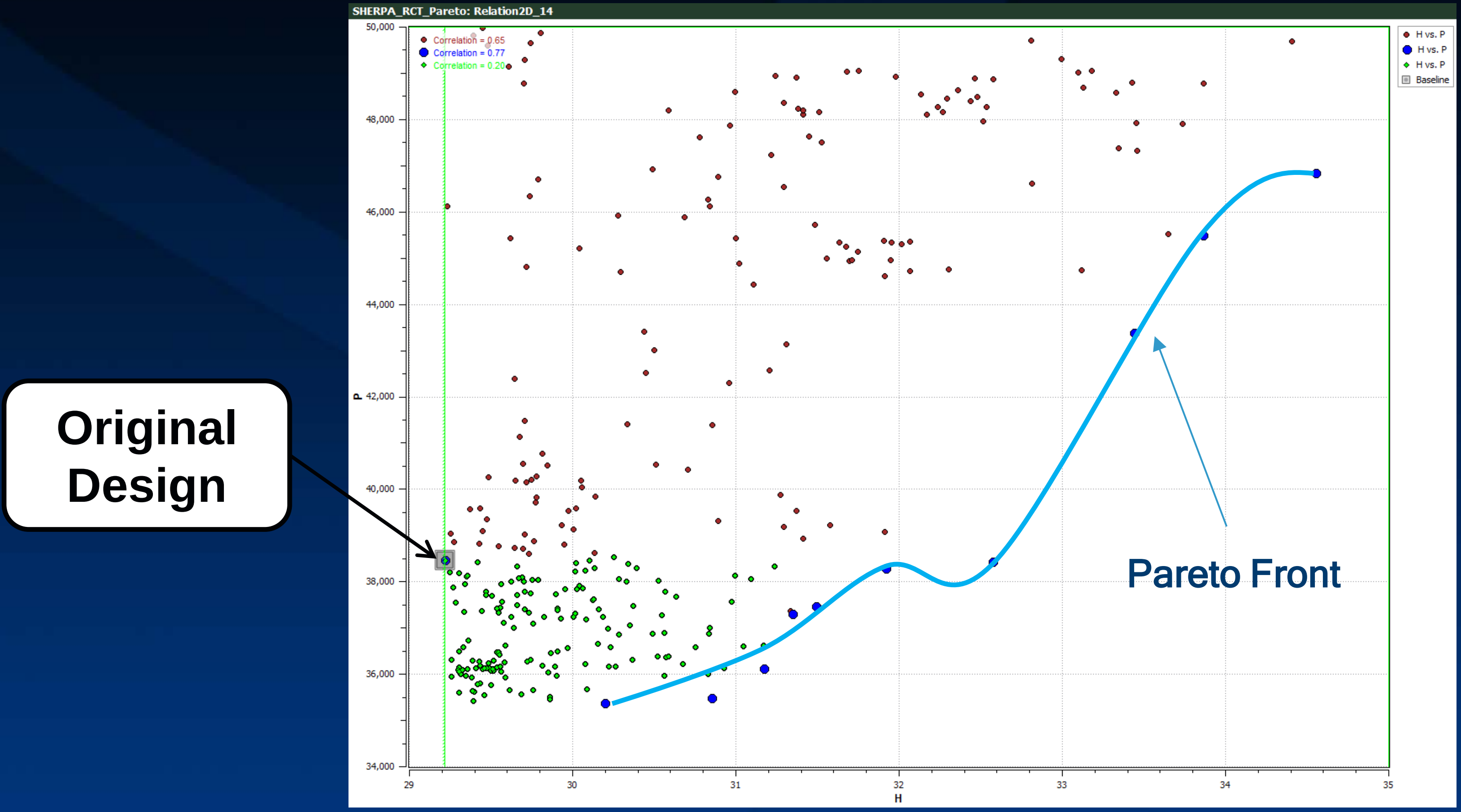
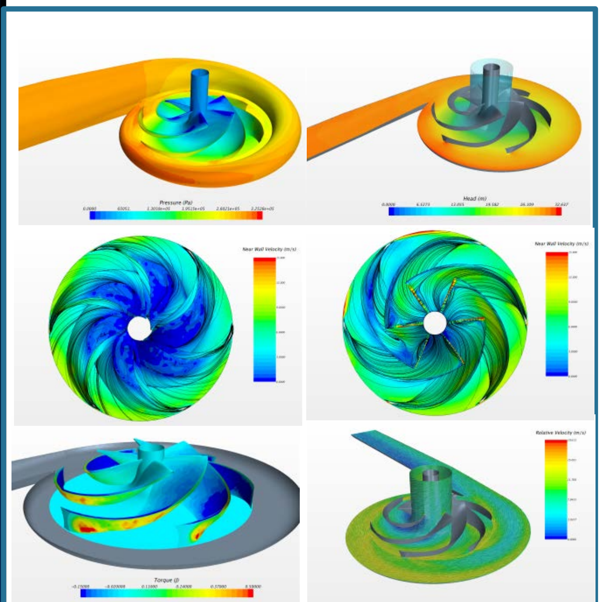
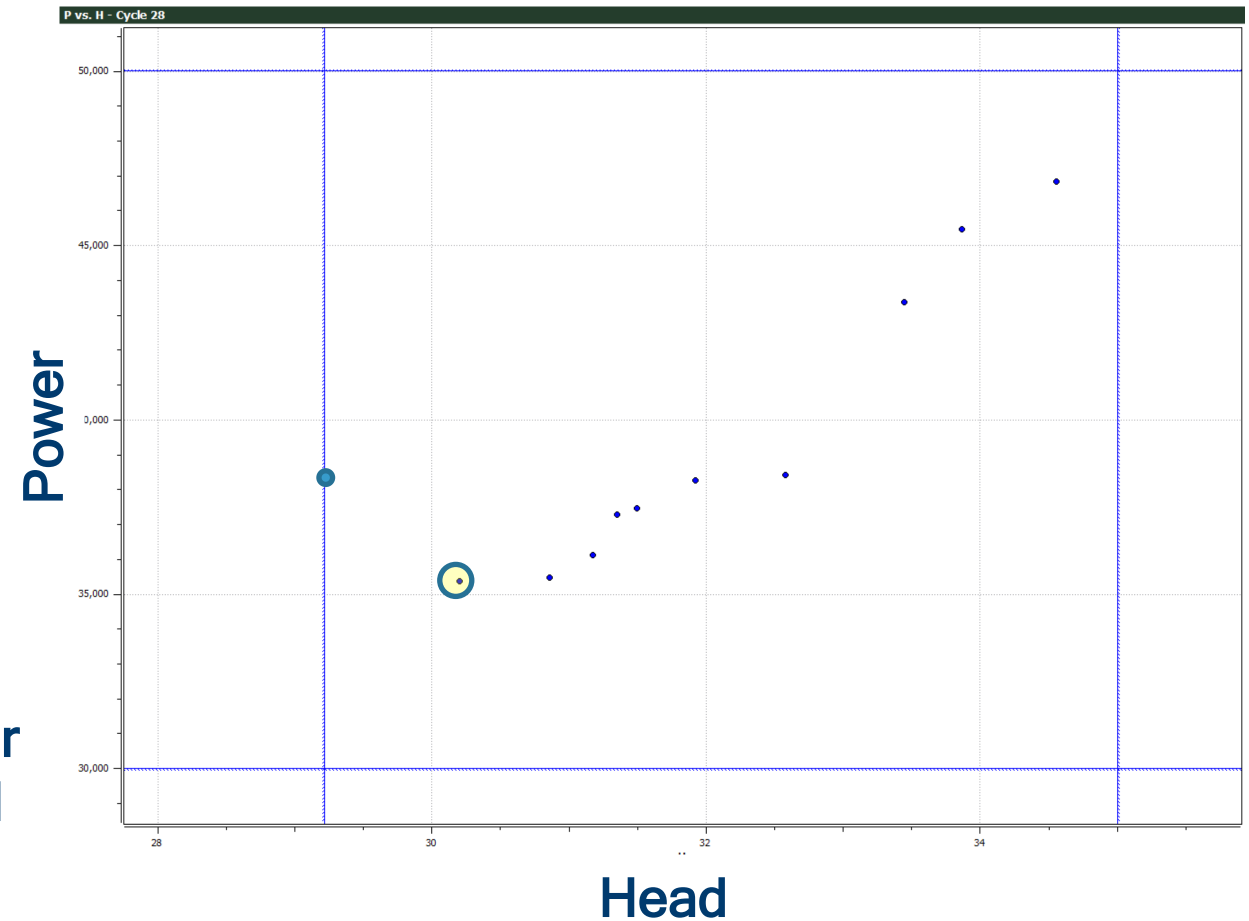


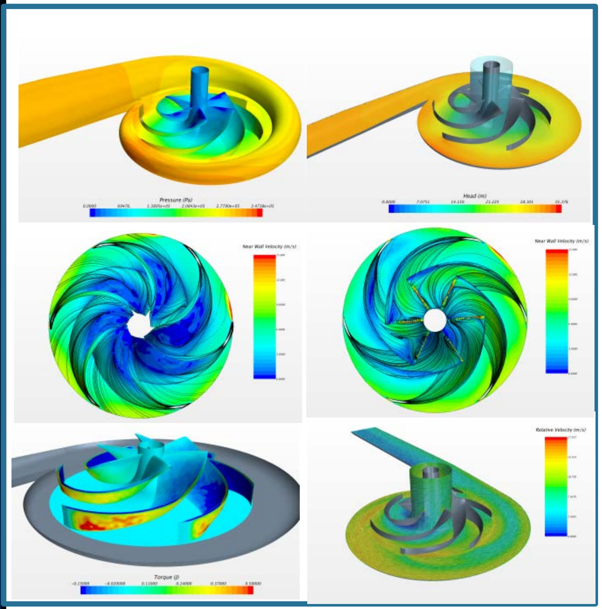
Pareto Optimization Results

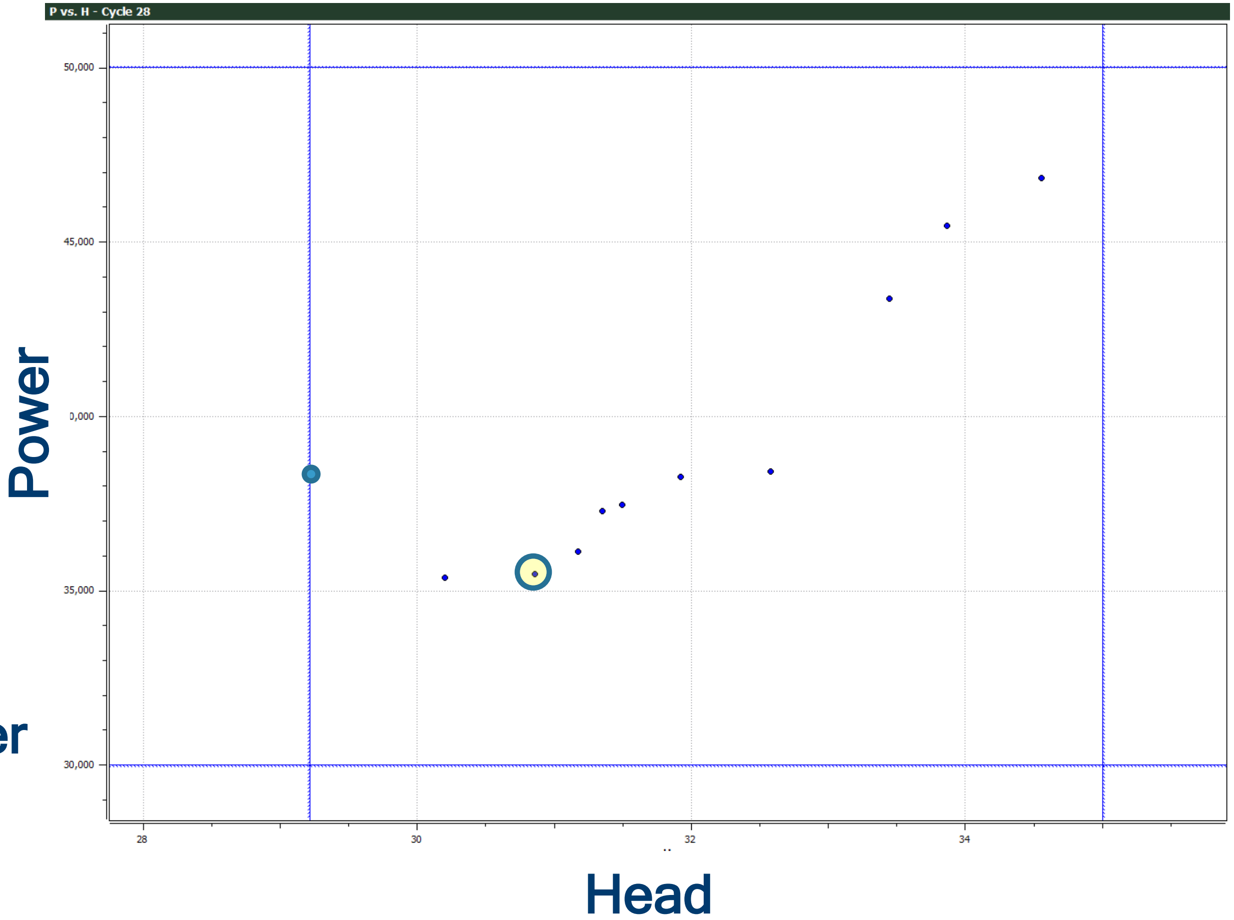




8 % Reduction in Power
3.4 % Increase in Head

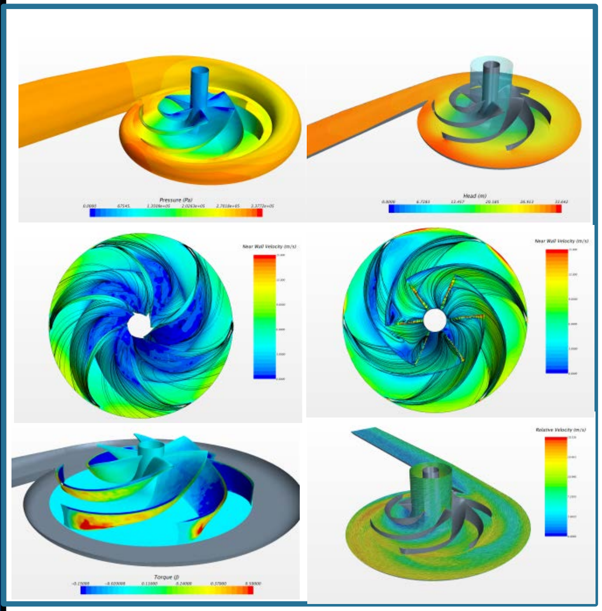
Pareto Optimization Results

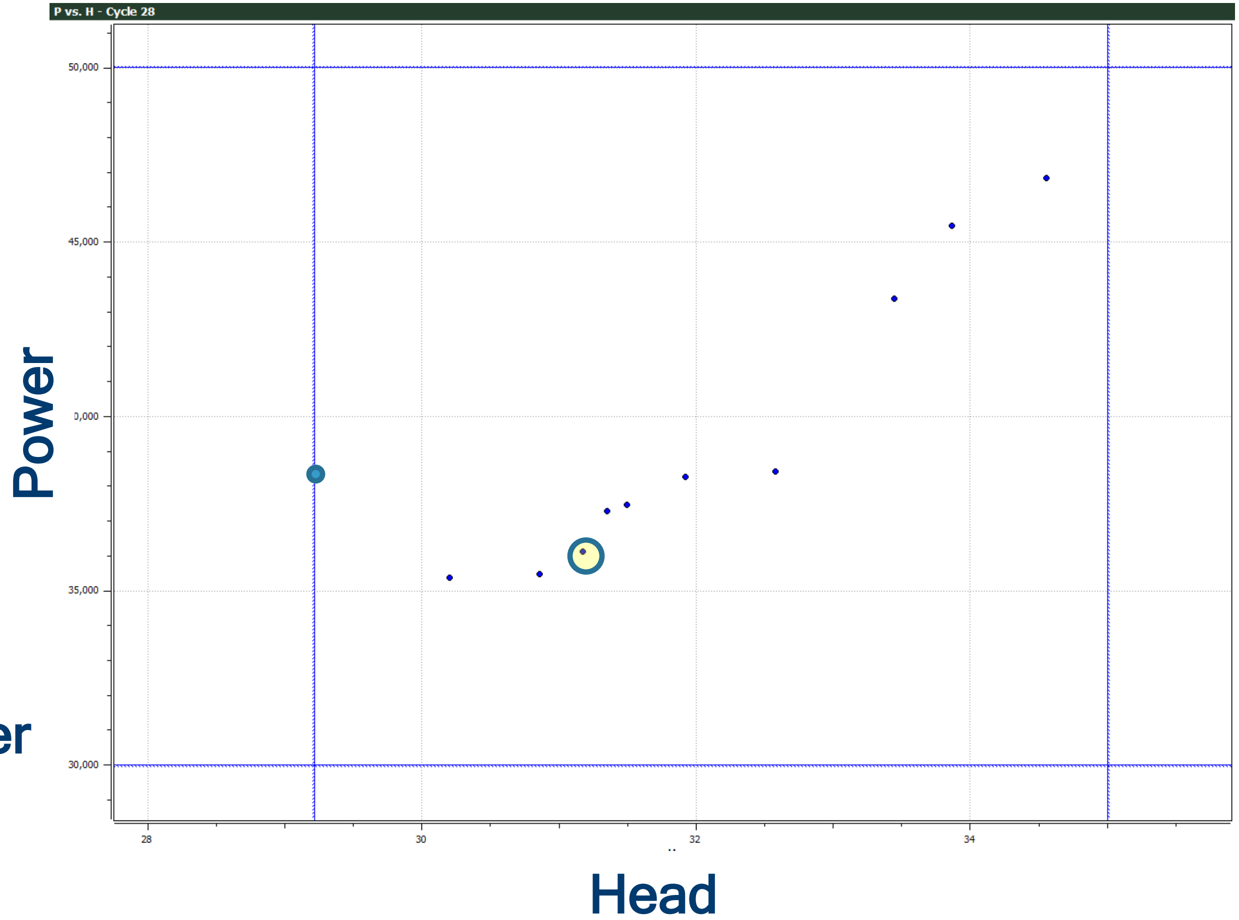




7.8 % Reduction in Power
5.6 % Increase in Head

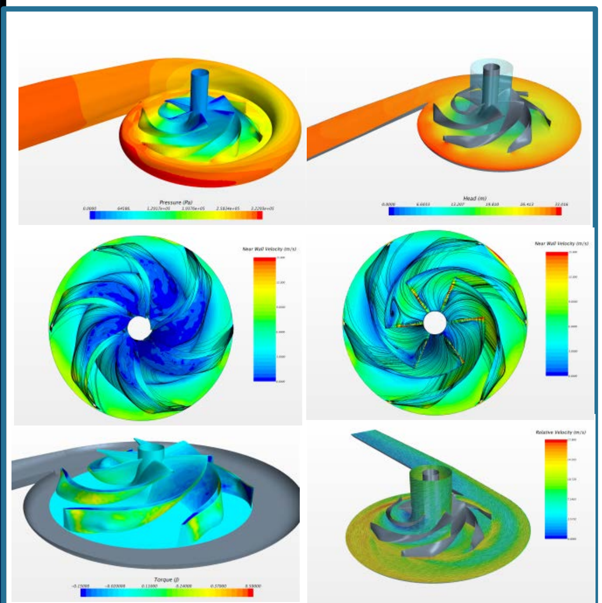
Pareto Optimization Results

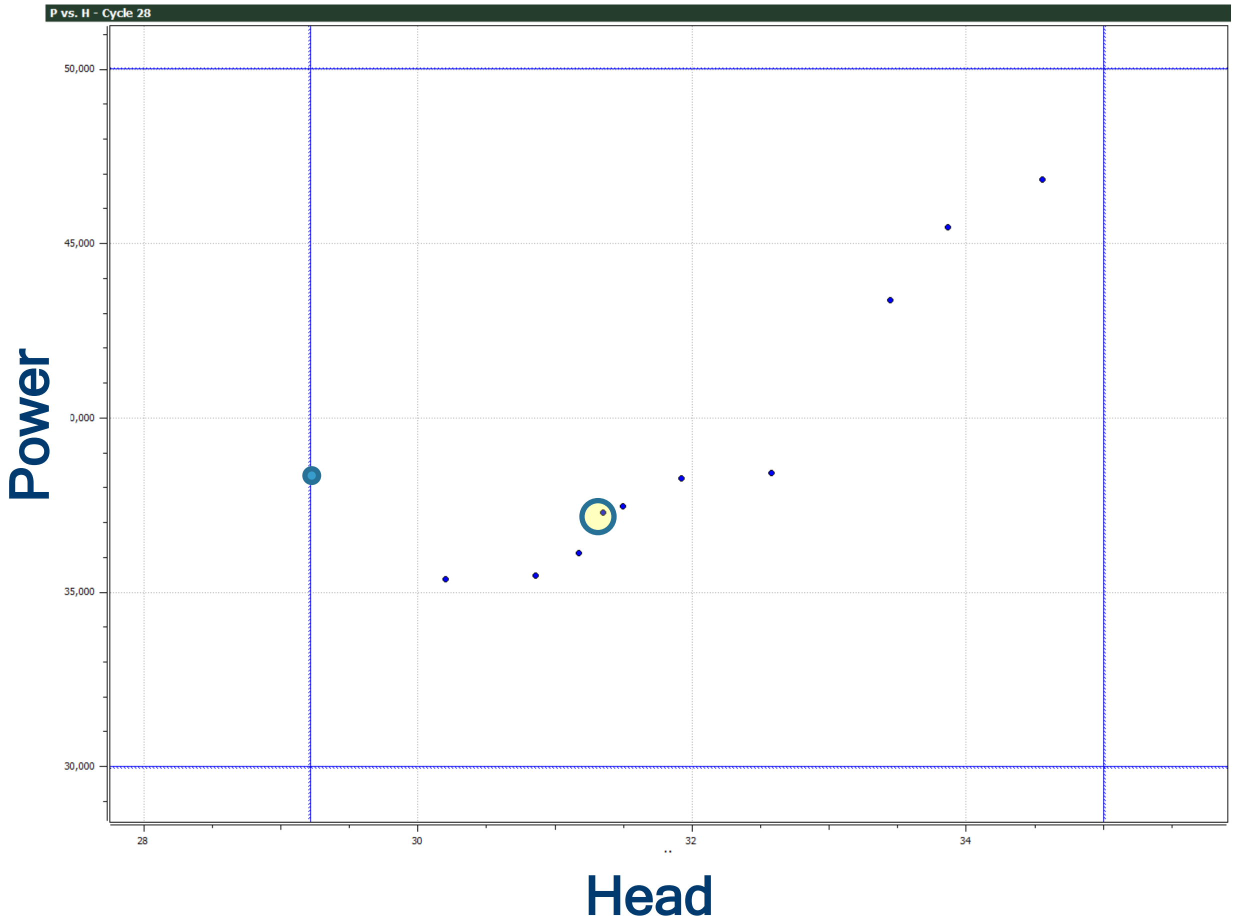




6.1 % Reduction in Power
6.7 % Increase in Head

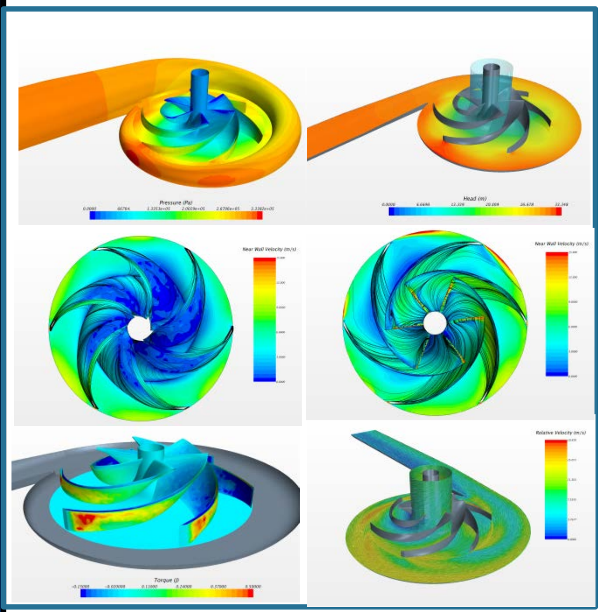
Pareto Optimization Results

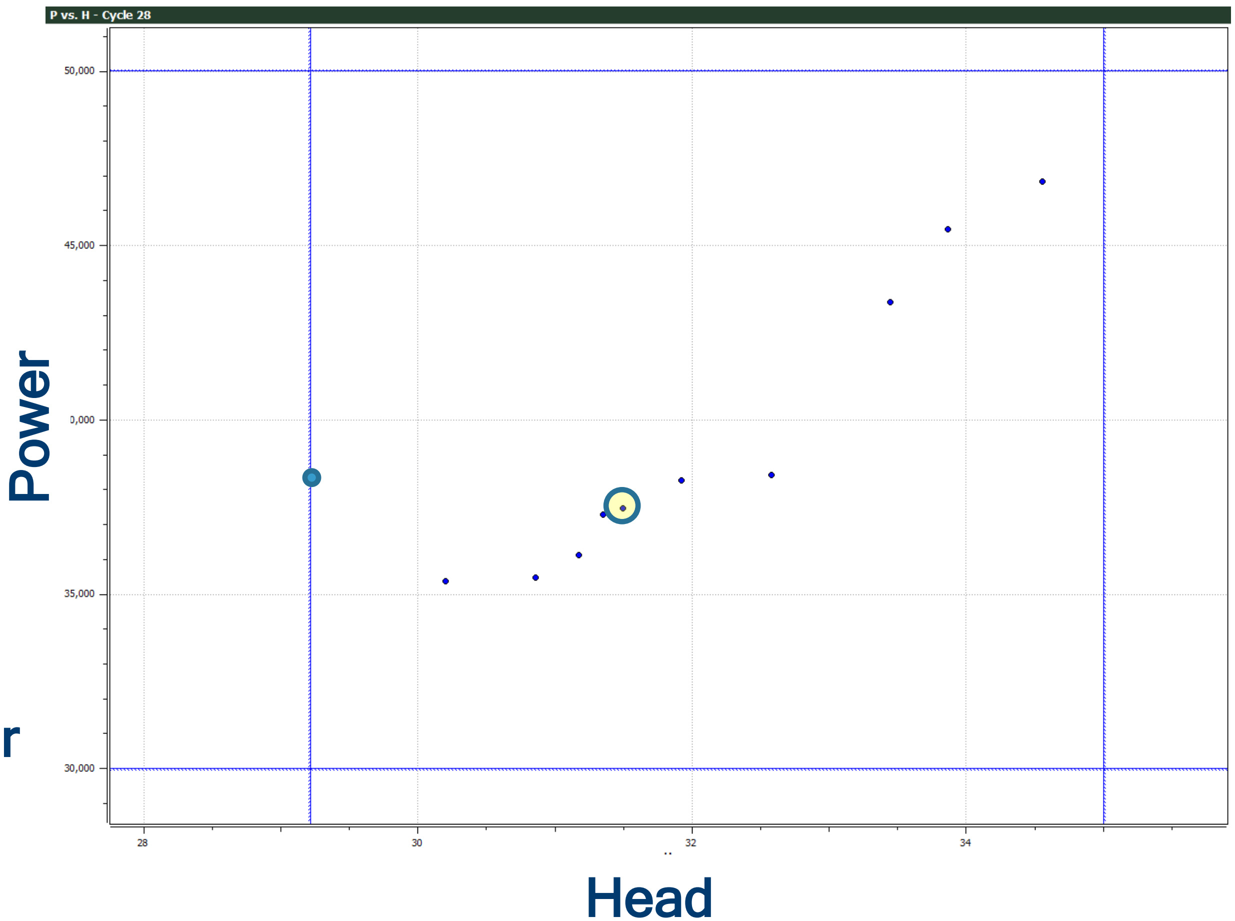




3 % Reduction in Power
7.3 % Increase in Head

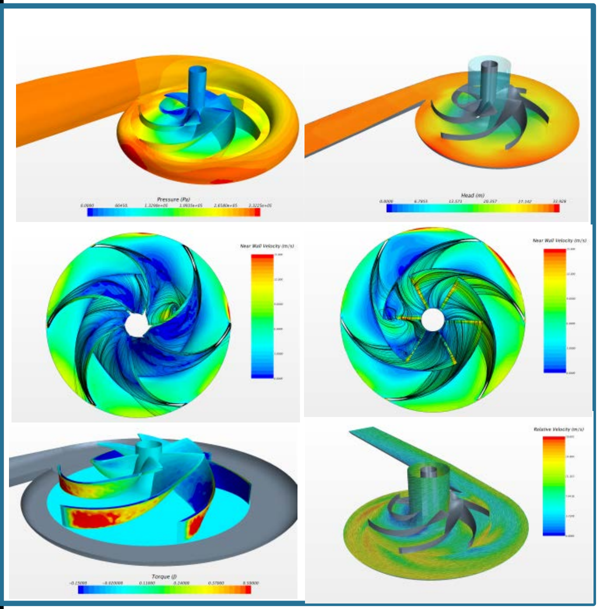
Pareto Optimization Results

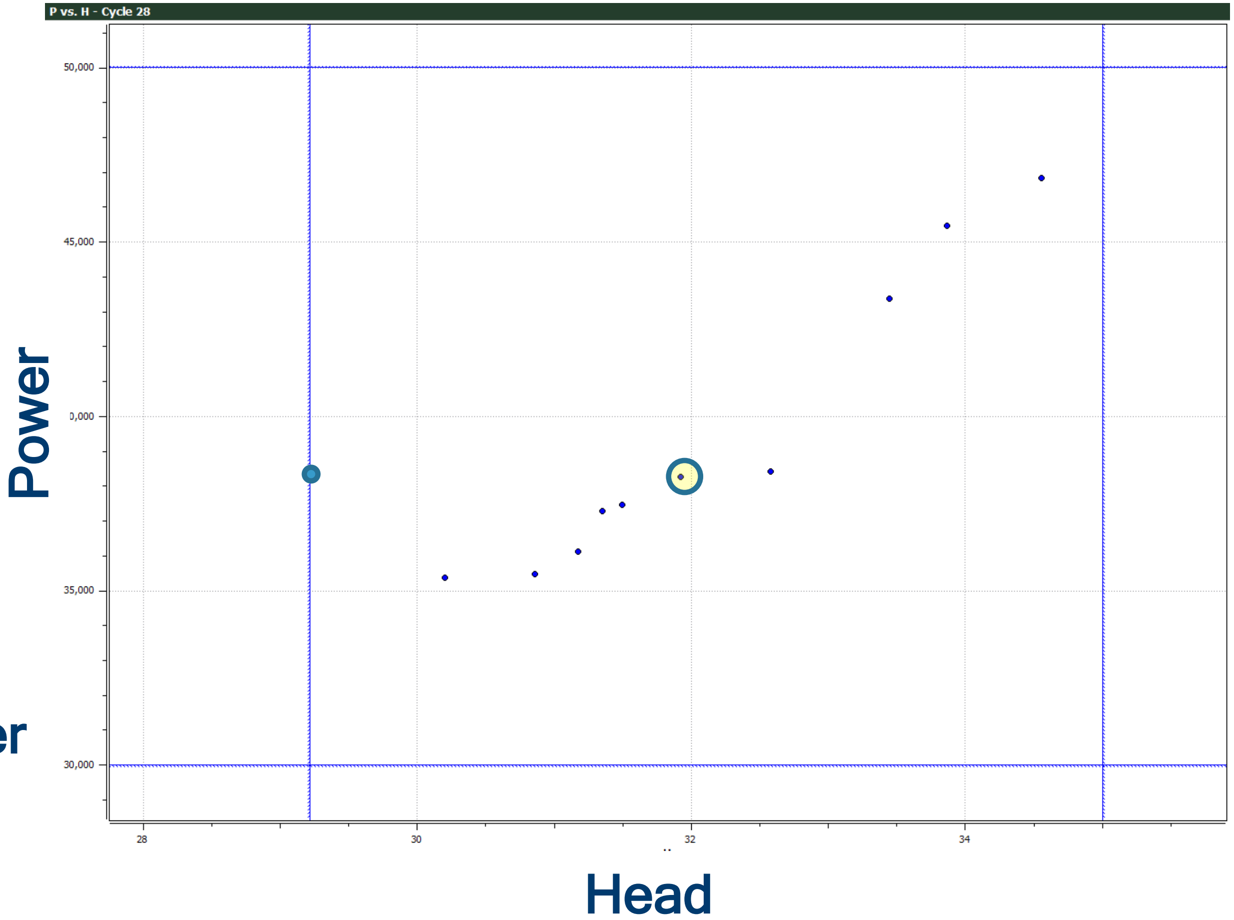




2.6 % Reduction in Power
7.8 % Increase in Head

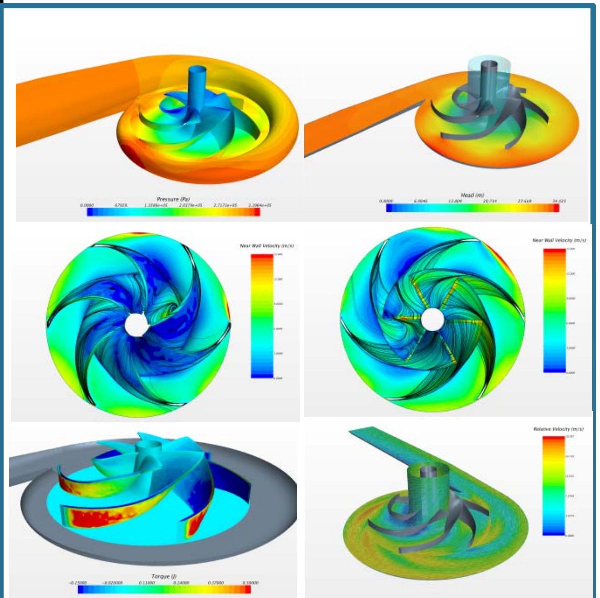
Pareto Optimization Results

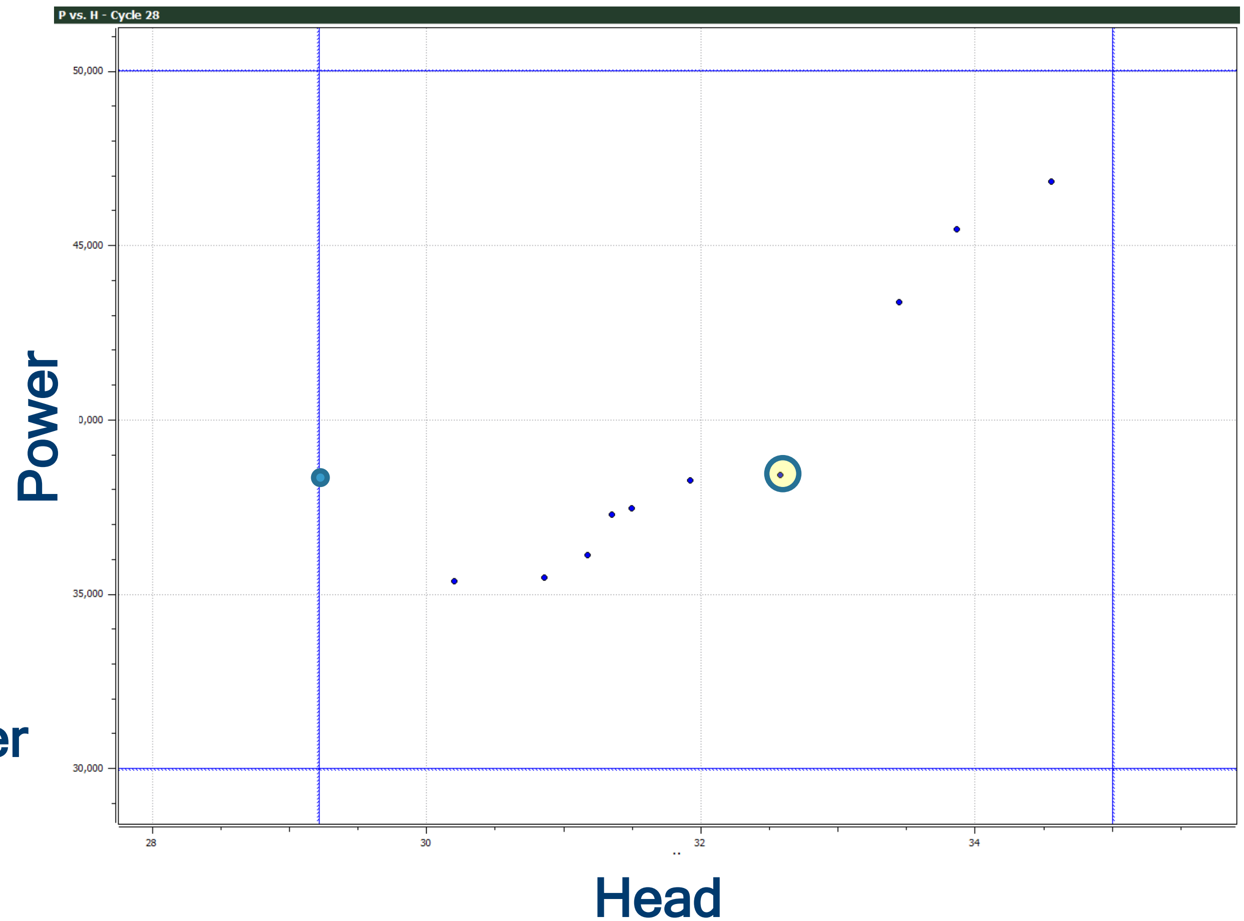




0.5 % Reduction in Power
9.2 % Increase in Head

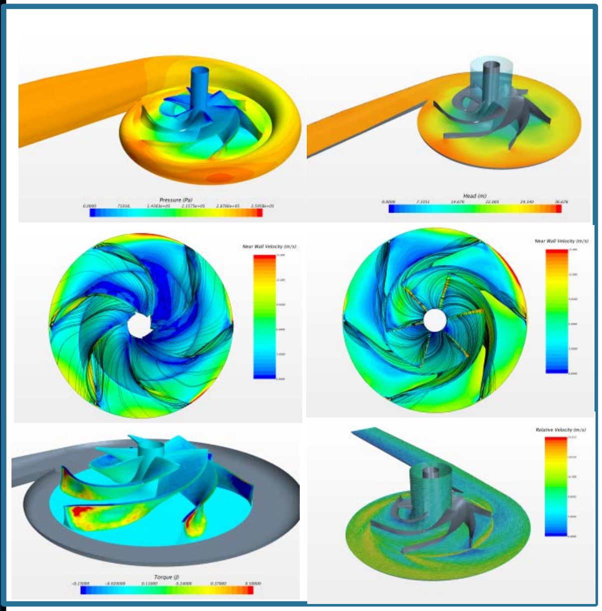
Pareto Optimization Results

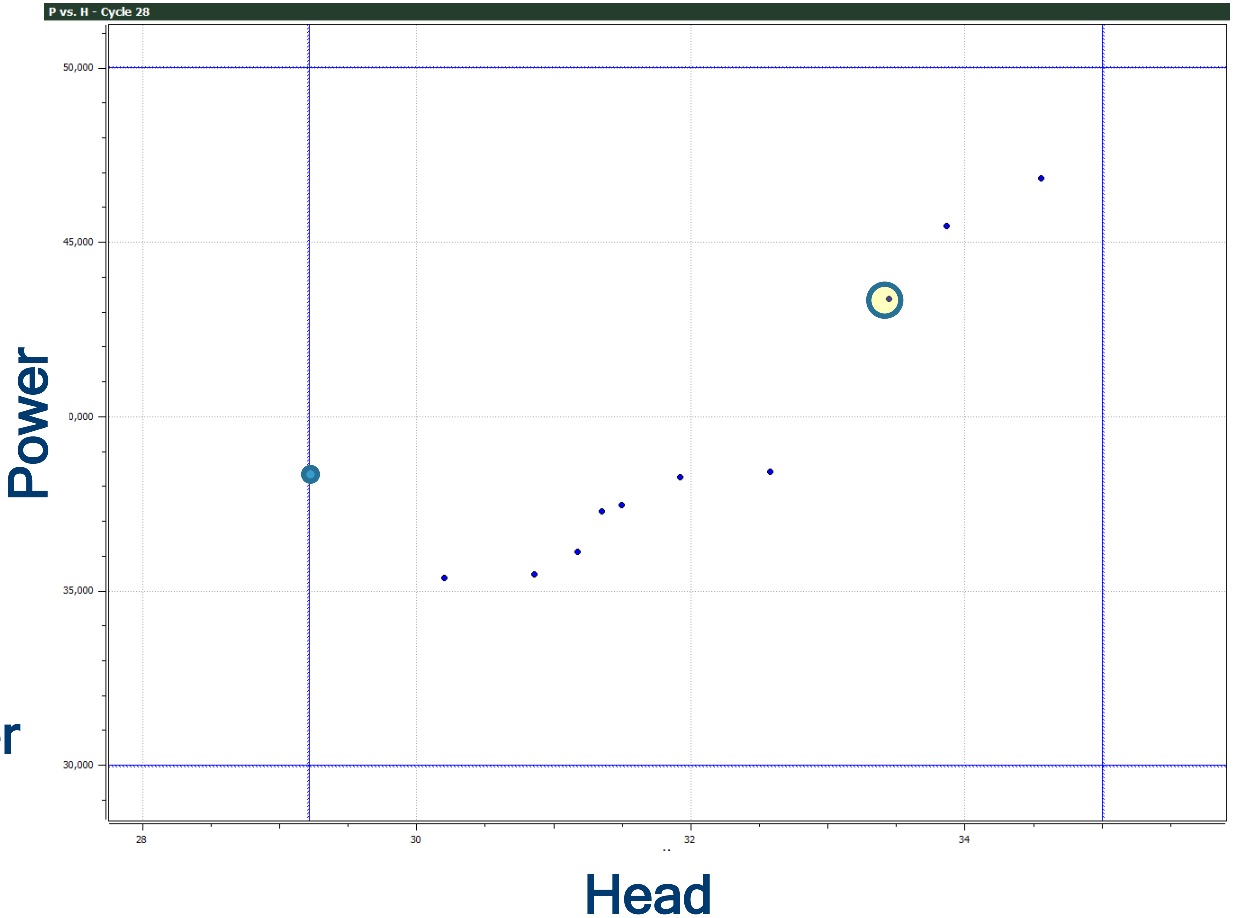




0.1 % Reduction in Power
10.3 % Increase in Head

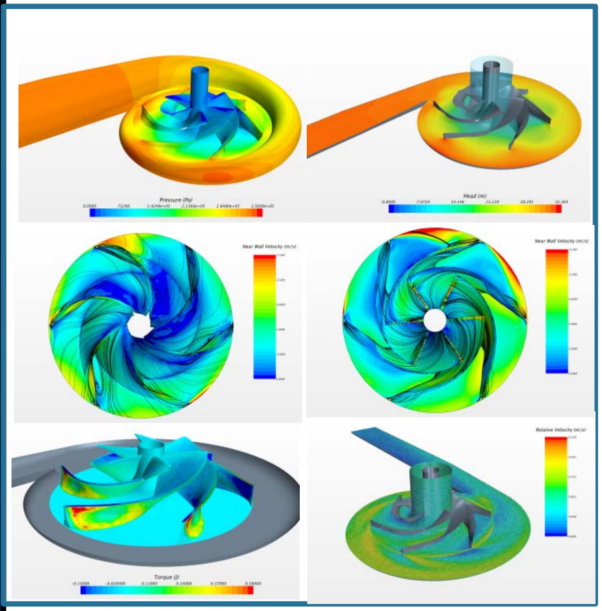
Pareto Optimization Results

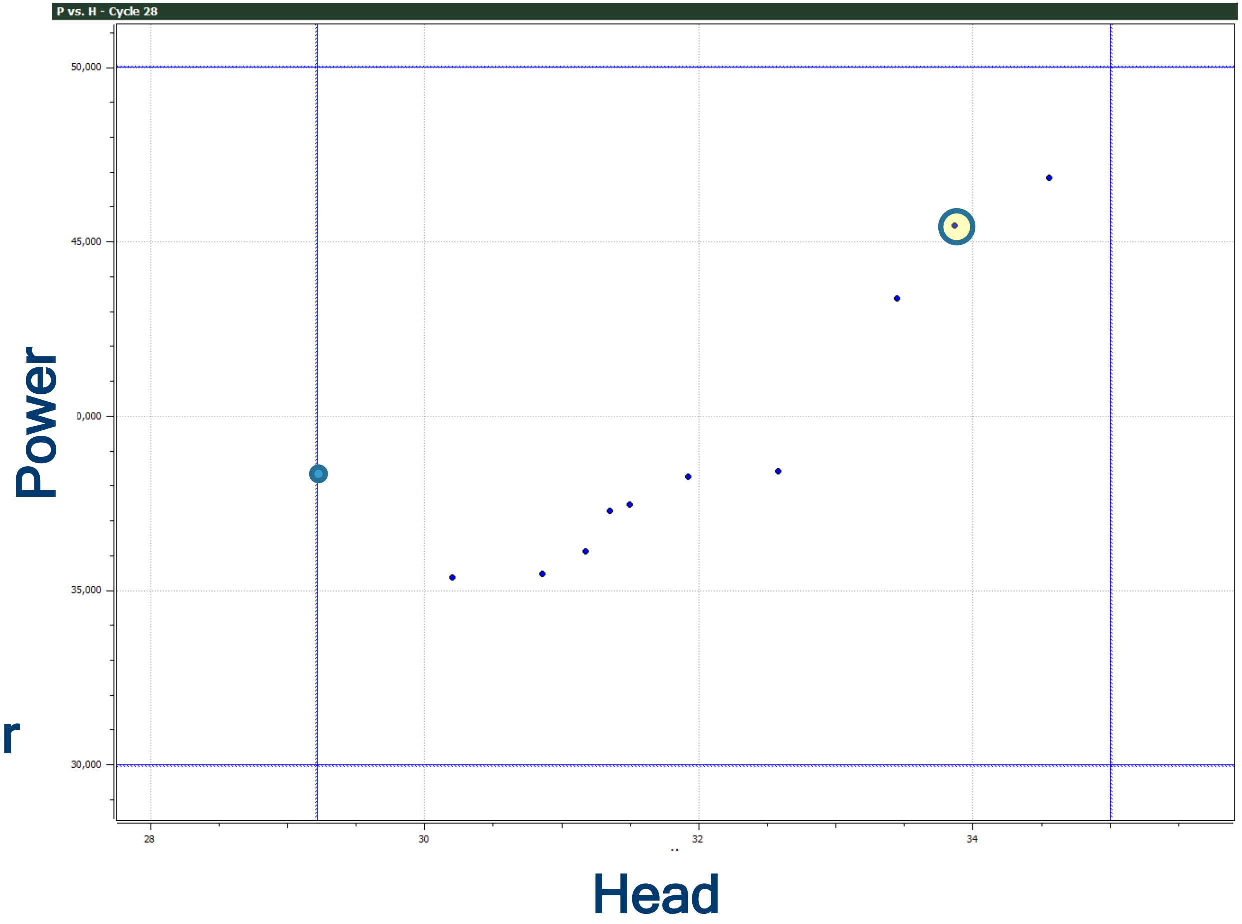




12.8 % Increase in Power
14.5 % Increase in Head

Pareto Optimization Results

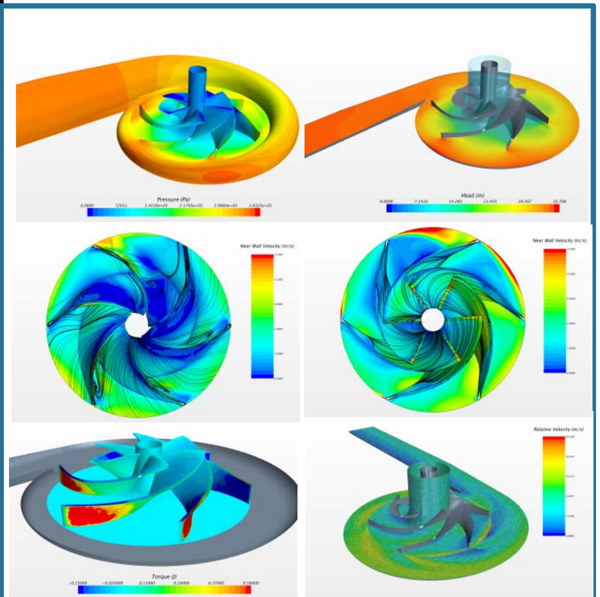


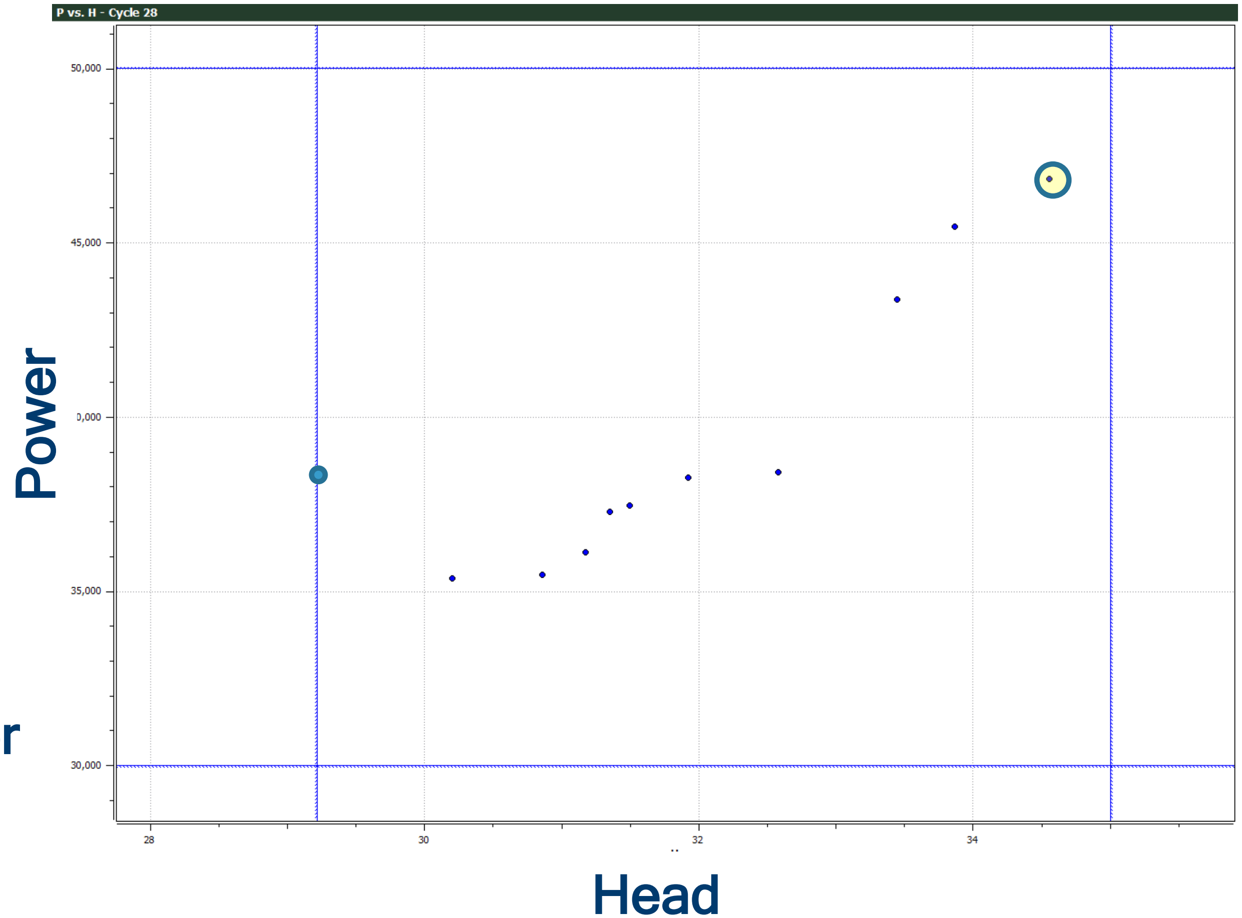


18.2 % Increase in Power

15.9 % Increase in Head

Pareto Optimization Results

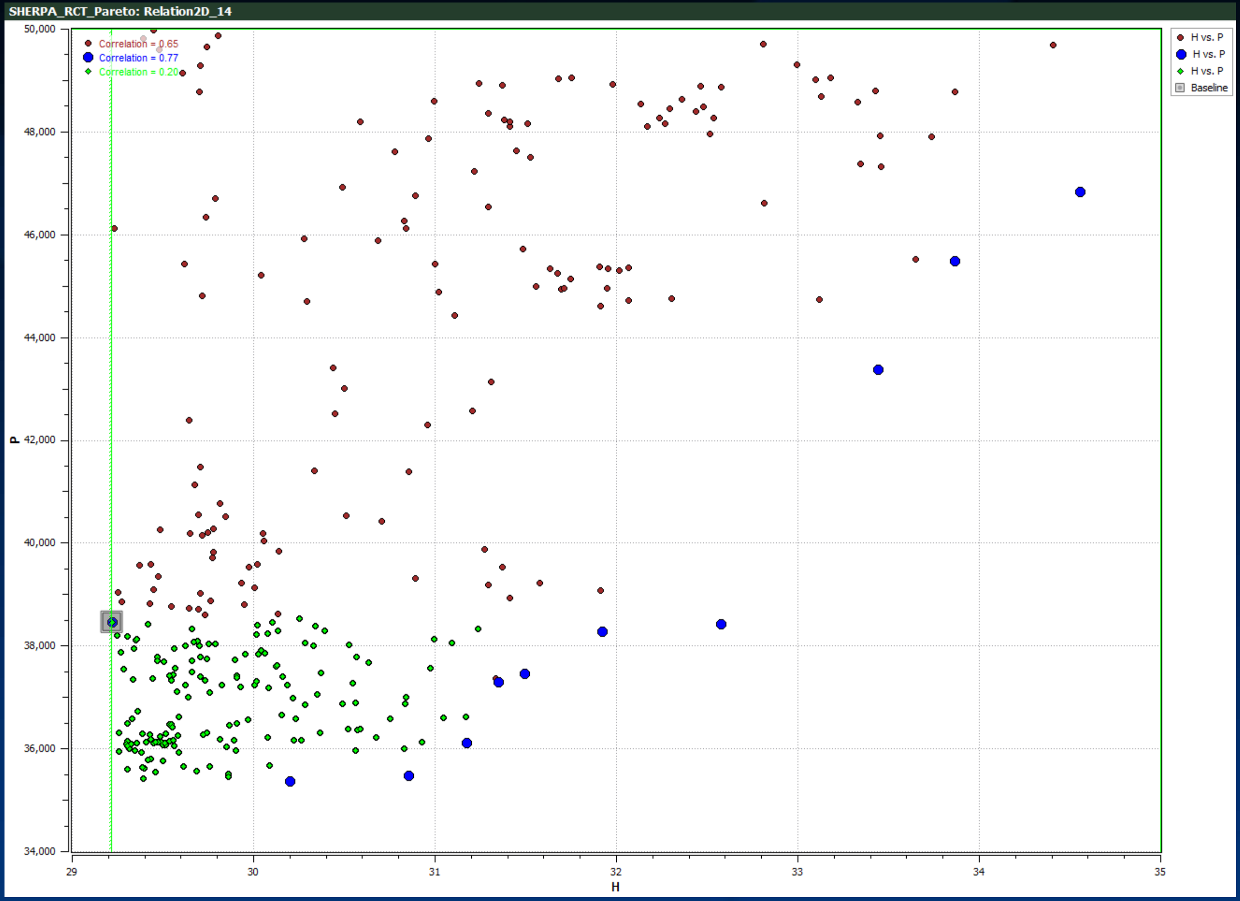




21.8 % Increase in Power
18.3 % Increase in Head

Review of Objective #2

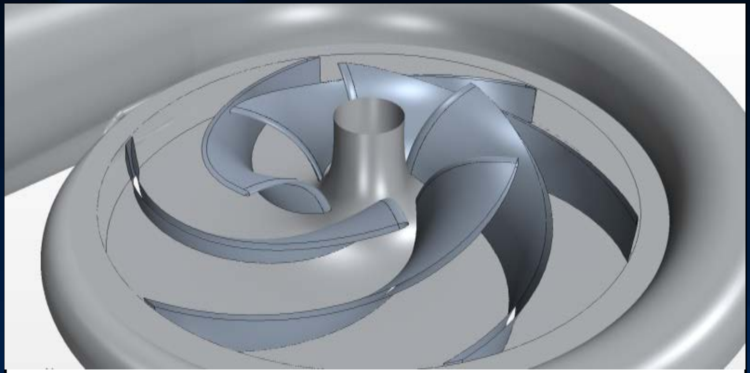
- 10 optimal pump designs produced
- Pressure head up to 34 m



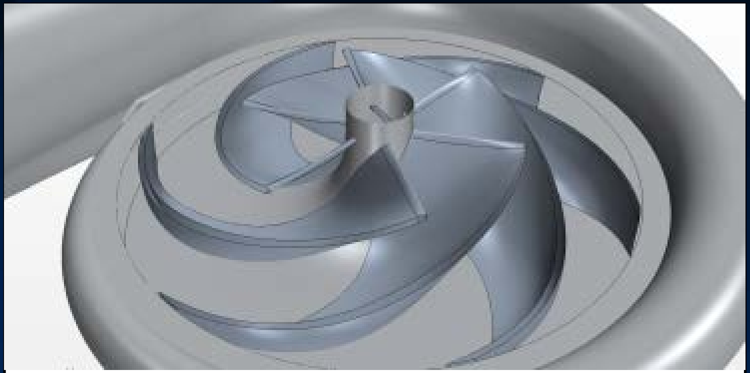
Conclusions

Pump optimization study achieved two objectives:

1. **Improve an existing pump design so that the same flow rate and exit pressure is achieved with lower power**



Existing Design
Flow rate = 400 m^3/h
Pressure head = 30 m
Power required = 38.4 kW

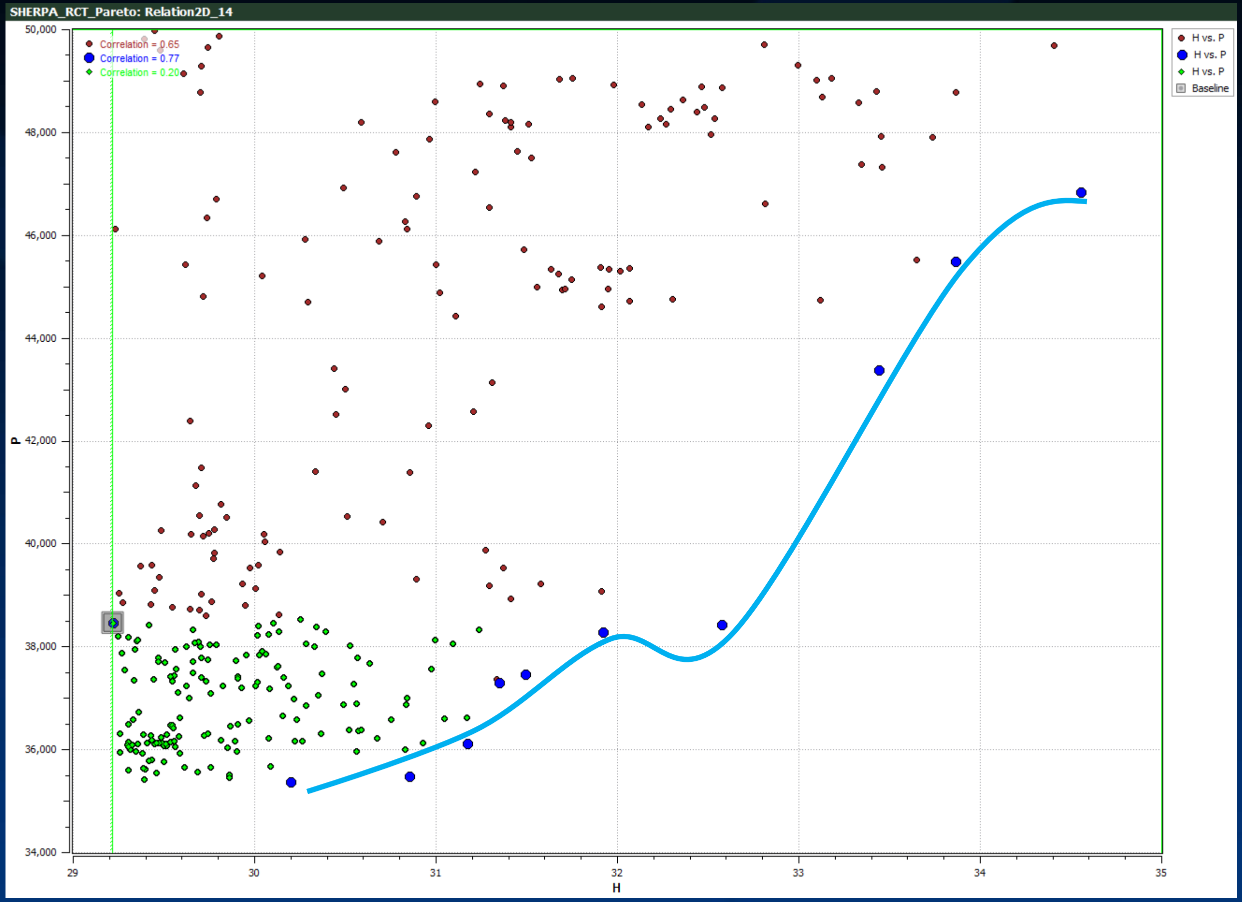


Optimized Design
Flow rate = 400 m^3/h
Pressure head = 30 m
Power required = 36.0 kW

Conclusions

Pump optimization study achieved two objectives:

2. **Found a <u>set</u> of fan designs that require the least power for any given head up to 34m**



Outline

- Background
- Optimization objective
- Analysis tools
- Results