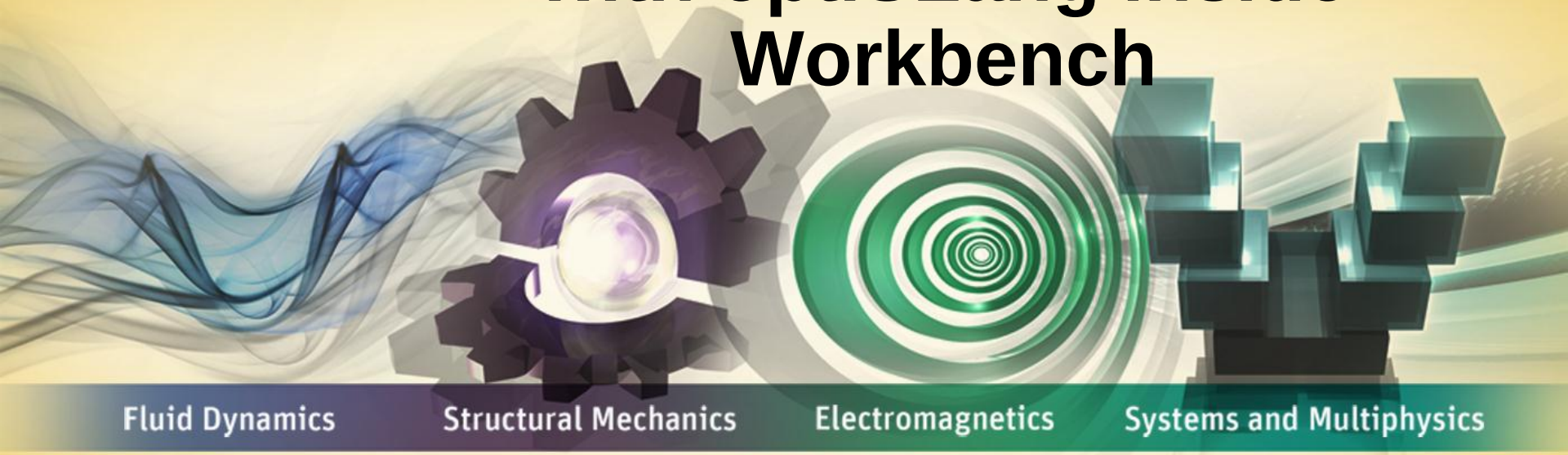
ANSYS

Realize Your Product Promise™

Centrifugal pump design & optimization with optiSLang inside Workbench



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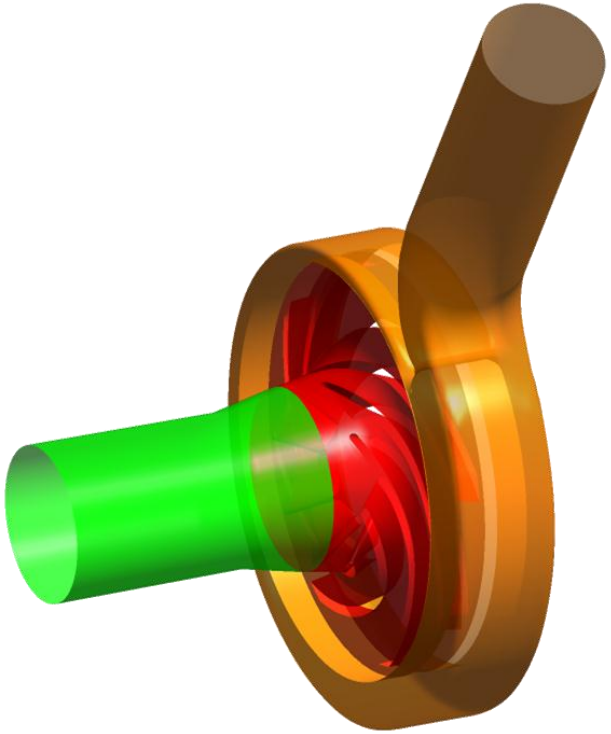
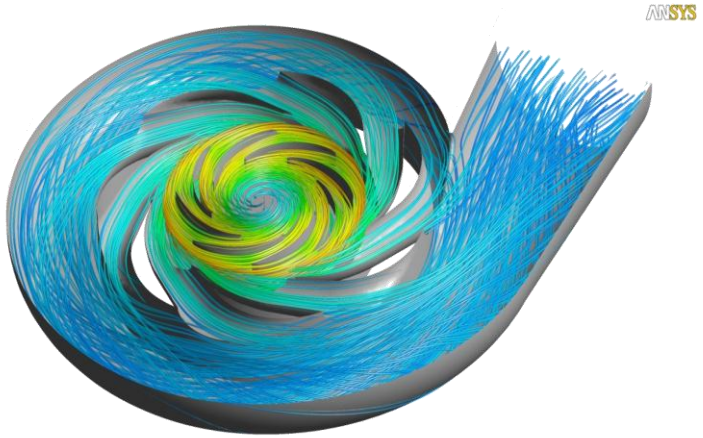
Overview

- Goal and motivation
- Parametric model and setup
- CFD Best Practice Study
- Sensitivity analysis
  - Best Practice for Meta-Model
    - 50, 100, 150 samples
- Optimization
  - Meta-Model Optimization
  - Direct Optimization
- Results
- Summary
- Outlook





Goal and Motivation

- **Since 1st January 2013 EU Directive "Ökodesign-Richtlinie"**
  - **Directive for energy related products**
  - **Pumps has to achieve a certain energy efficiency index**
  - **Progressive efficiency increase until 2020**

- **Goal:**
  - **23 TWh approximated energy saving in the EU in 2020**

  → Equivalent to yearly energy consumption of 14 million EU citizens

2009/125/EG

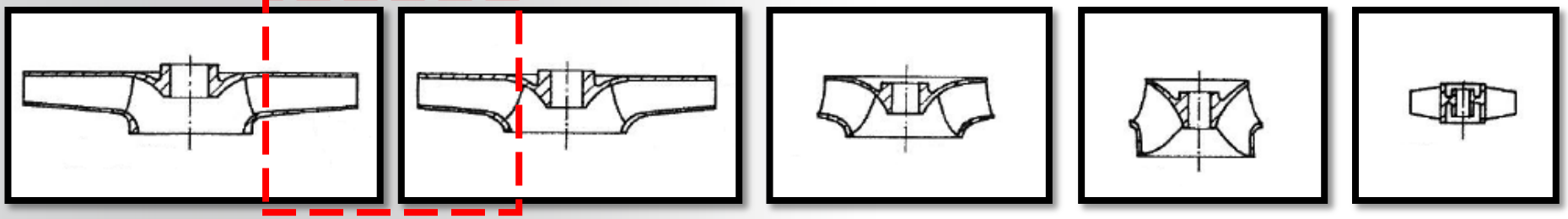
Goal and Motivation

- **Design & optimization platform**
  - ANSYS Workbench
- **Application area**
  - Heating and water supply system
- **Specifications**
  - 70 m head
  - 80 l/s volume flow
- **Dimensions**
  - 300 kg weight with power unit
  - 1 m length
  - 40 cm diameter
  - 60 kW input power

Pre-Design – Specific speed n_q

n_q = 16.8
Radial pump design

$$n_q = n \frac{\sqrt{Q}}{\sqrt[4]{H^3}}$$

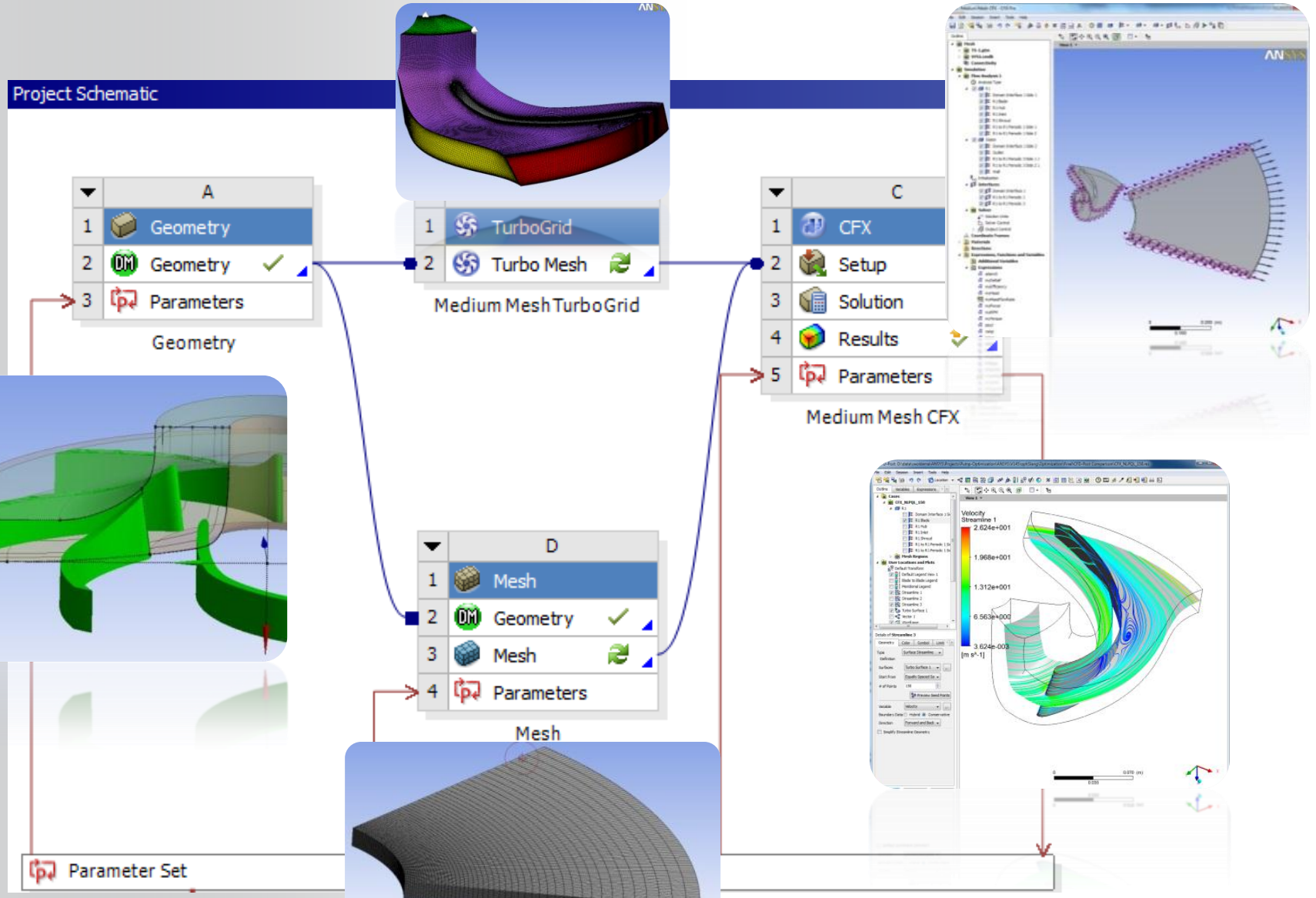


n_q ~ 10 | n_q ~ 25 | n_q ~ 50 | n_q ~ 100 | n_q ~ 200

Volume flow (Q)

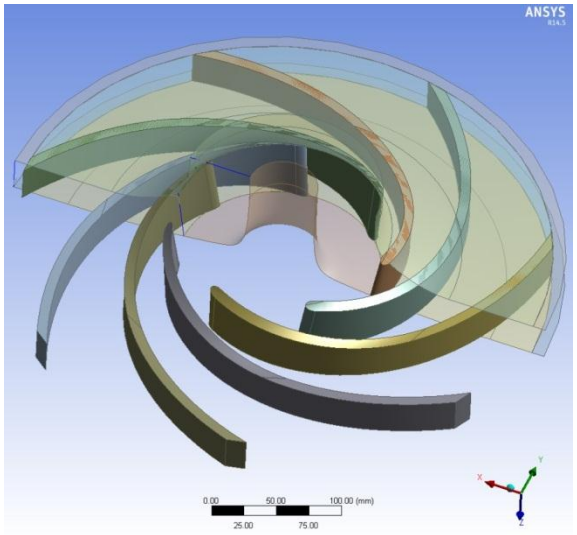
Head (H)

Parametric model and setup – Workbench



Parametric model and setup –BladeEditor

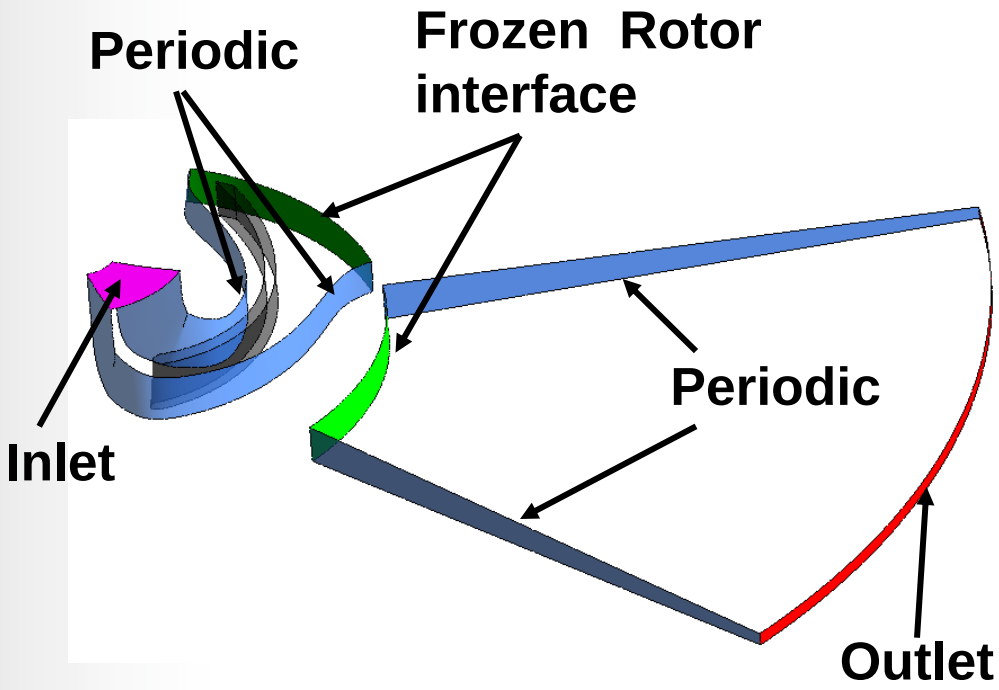
- Create Blades in DesignModeler
  - BladeEditor
- Pre-Design based on nQ
- Blade parameterization
  - Blade angles
  - Blade thickness
  - Number of blades
- Input Parameter
  - 19 geometrical input parameter



	ID	Parameter Name	Value	Unit
1				
2	Input Parameters			
3	Geometry (A1)			
4	P10	BladeAngle1_Hub	15	
5	P22	D1_Angle	8	
6	P9	relPos2	0.7	
7	P13	BladeAngle4_Hub	31	
8	P8	relPos1	0.4	
9	P21	BladeThickn	8	
10	P25	D2_Offset_Outlet	10	
11	P26	R_Outlet	220	
12	P53	RN_Inlet	27	
13	P28	B1_SM	50	
14	P61	Shd_Spline_OffsetRadial1	70	
15	P36	Shd_Spline_OffsetAxial2	20	
16	P35	Shd_Spline_OffsetAxial1	14	
17	P33	Shd_Spline_OffsetRadial2	20	
18	P37	Axial_Height	95	
19	P49	Shd_Spline_OffsetRadial_Corner	12	
20	P50	Shd_Spline_OffsetAxial_Corner	36	
21	P40	Hub_Spline_OffsetAxial1	0.01	
22	P41	Hub_Spline_OffsetAxial2	25	

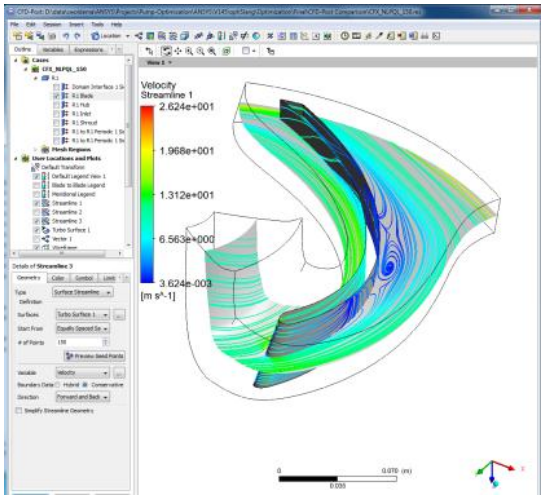
Parametric model and setup – CFX setup

- **Steady State Simulation**
  - **Physical Timescale**
    - 1 [rad] / Ω = 6.63 x 10^{-3} s
- **Frame Change**
  - **Frozen Rotor**
- **SST turbulence model**
- **Advection scheme**
  - **High Resolution**
- **Boundary Conditions**
  - **Inlet:**
    - Mass Flow Rate:
      - Q = 11.4 kg s^{-1}
  - **Outlet:**
    - Average Static Pressure:
      - P_s = 1 bar



Parametric model and setup – CFD-Post

- **Output Parameter**
  - **Convergence**
    - Number of iterations
    - Residuals
    - Max. Grid angle
  - **Geometrical**
    - Key parameter
      - D1, D2, b2, b1
  - **Pump performance**
    - Efficiency
    - Head
    - Min. Pressure



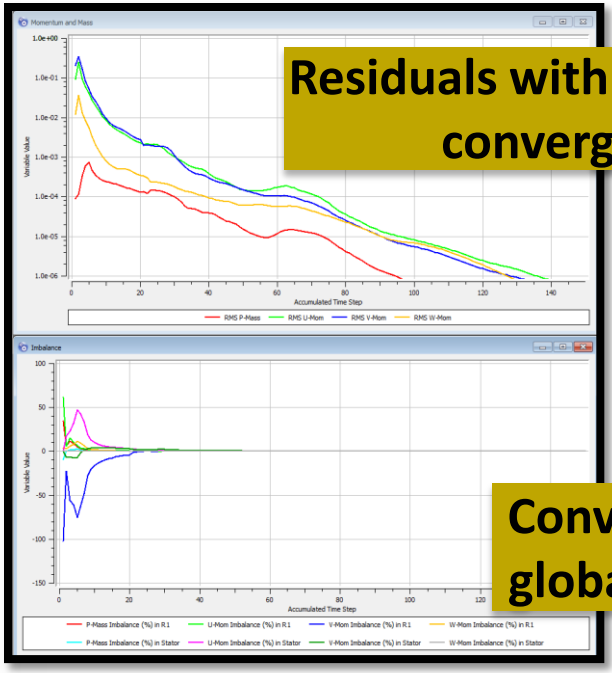
Expressions

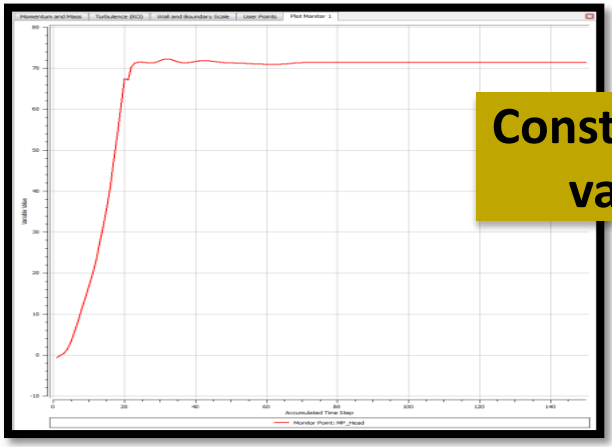
Accumulated Time Step	600
Angular Velocity	myRPM*ramp
Current Time Step	600
D1	2*(sqrt(D1x^2+D1y^2))
D1x	(Point1x +Point2x)/2
D1y	(Point1y +Point2y)/2
D1z	(Point1z +Point2z)/2
D2	2*(sqrt(Point3y^2+Point3x^2))
MaxResidualUVW	max(WRes ,max(URes ,VRes))
MinValAngle	minVal(Orthogonality Angle)@R1
Point1x	probe(x)@Point 1
Point1y	probe(y)@Point 1

CFD Best Practice Study

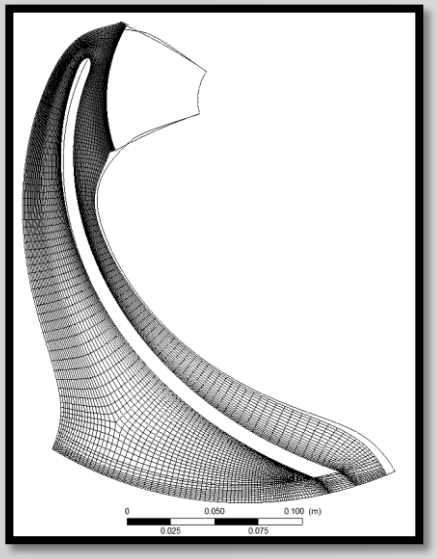
- **Detailed quality assurance**
  - **Comparison of results on different grids**
  - **Select convergence criterion**
    - Monotonic convergence
    - Convergence of global balances

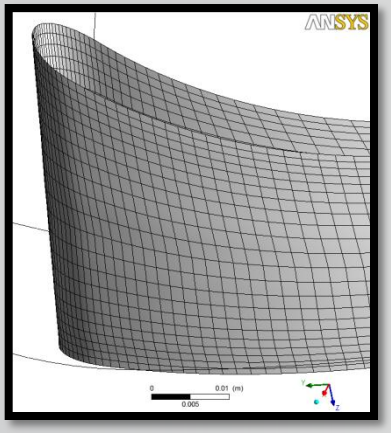
- **Plot target variables as Monitor Points**
  - **Efficiency**
  - **Torque**
  - **Head**



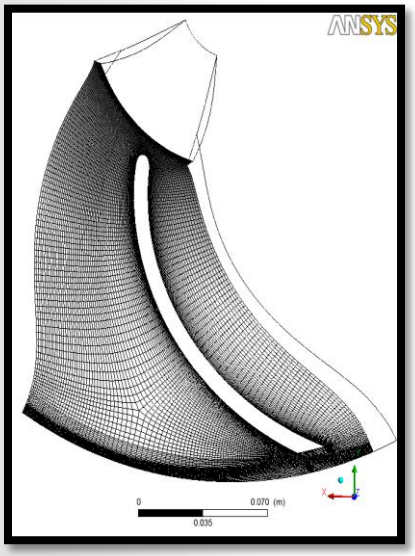


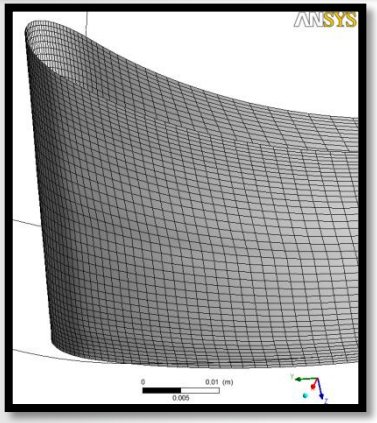
CFD Best Practice Study – Grid



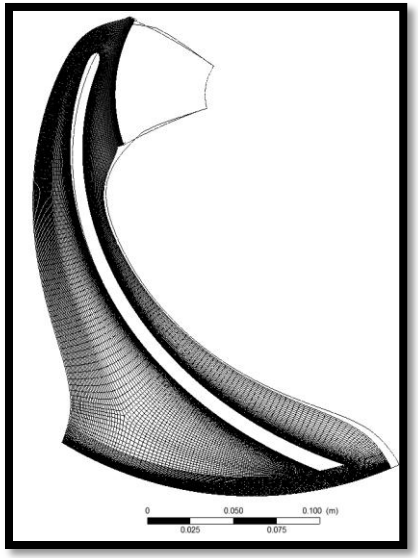


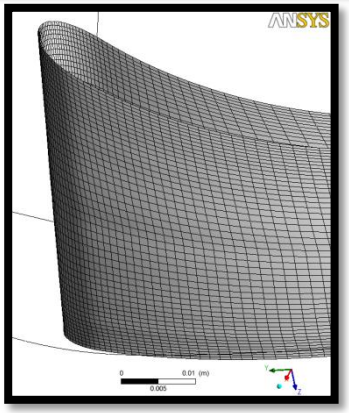
Coarse Mesh





Medium Mesh

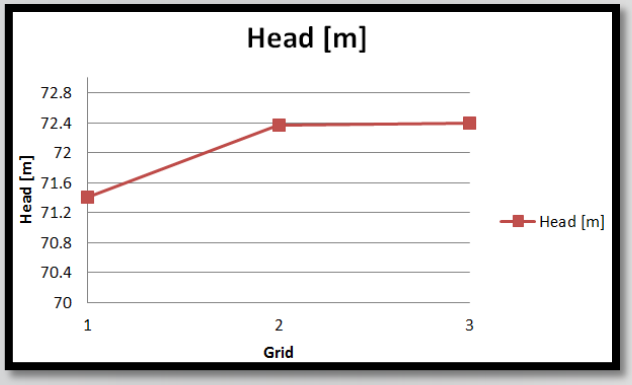


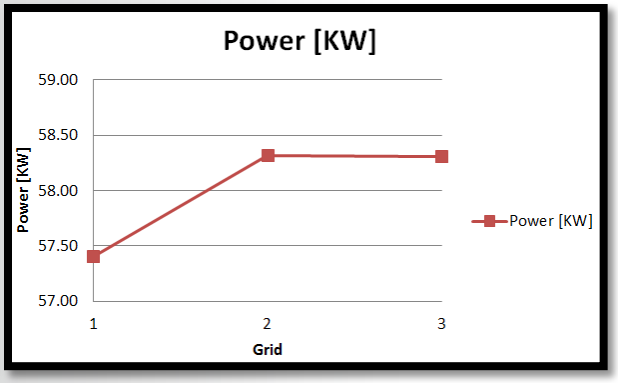


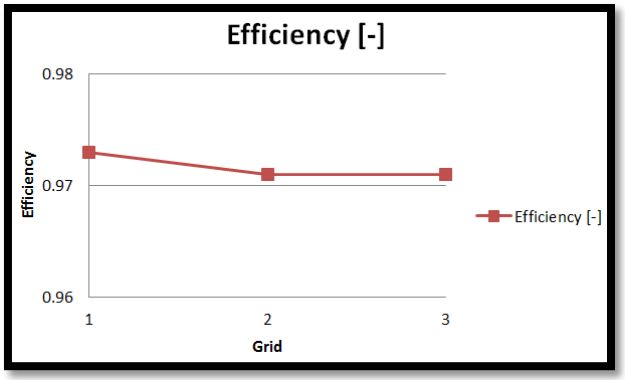
Fine Mesh

CFD Best Practice Study – Target variables

Target variable	Coarse Mesh	Medium Mesh	Fine Mesh
Head, m	71.41	72.37	72.39
Power, kW	57.40	58.31	58.41
Efficiency	0.973	0.971	0.971



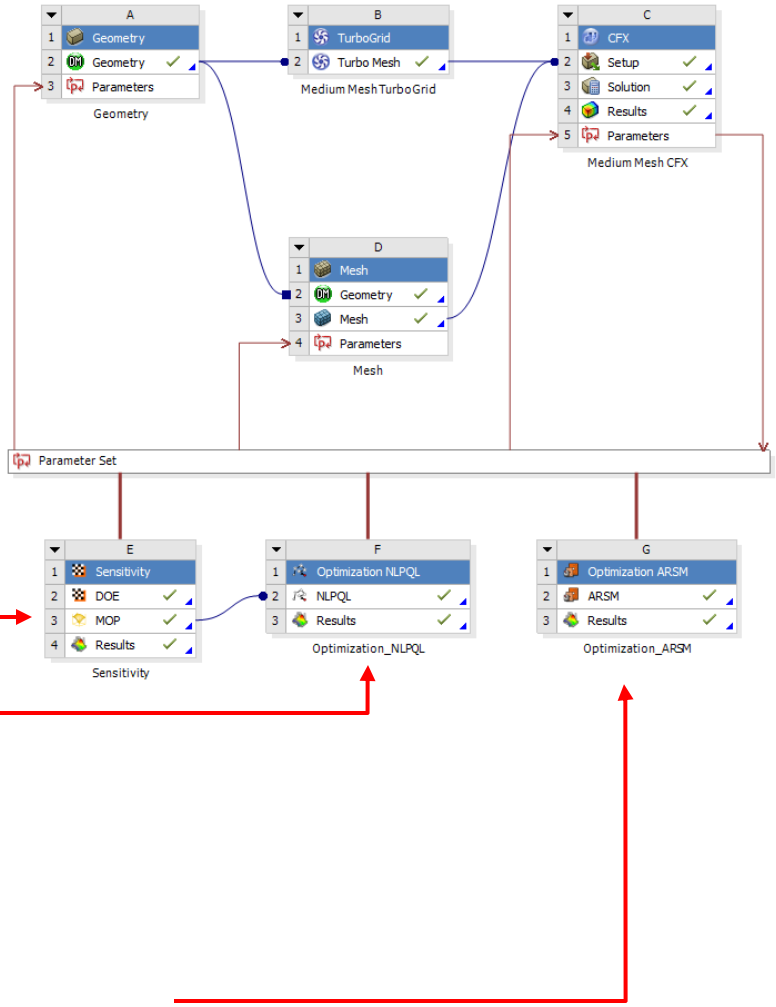




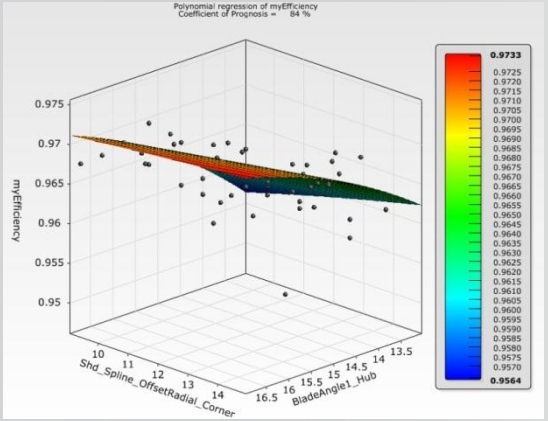
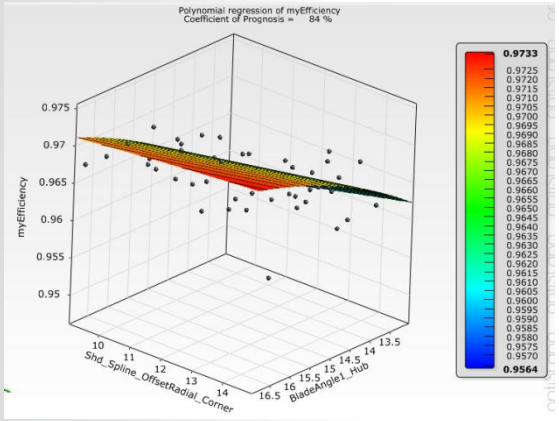
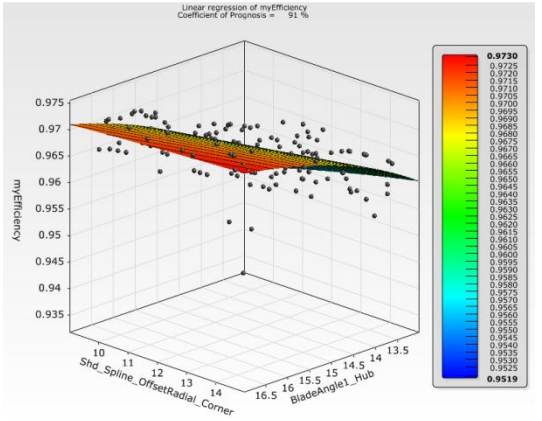
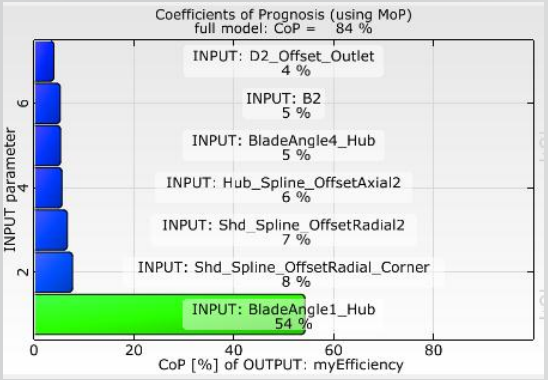
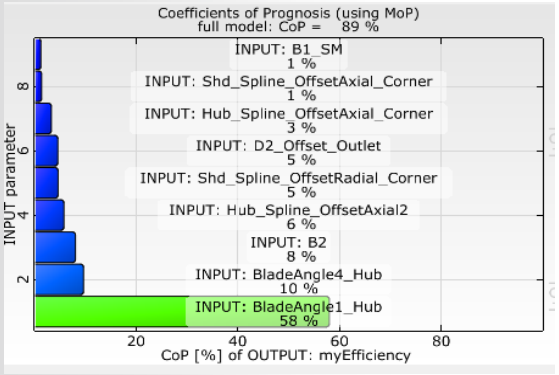
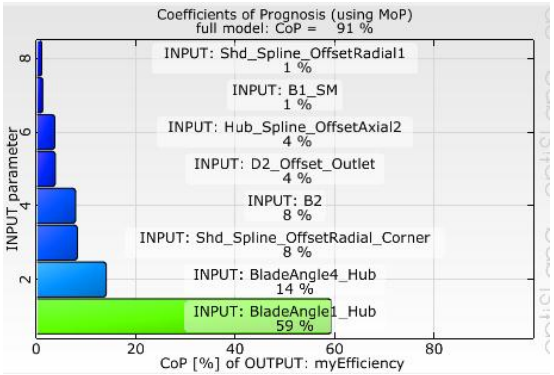
→ **Medium Mesh chosen for further simulations**

Optimization strategy

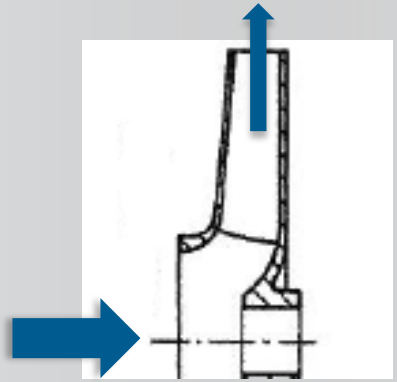
1. **Sensitivity Analysis**
   - Parameter identification
   - Reduce parameter space
   - Best Practice for Meta-Model
     - 50, 100, 150 samples
2. **Optimization on Meta-Modell**
   - Fast optimization on existing database
   - Indicates global optimum
3. **Direct Optimization**
   - Optimize within reduced parameter space



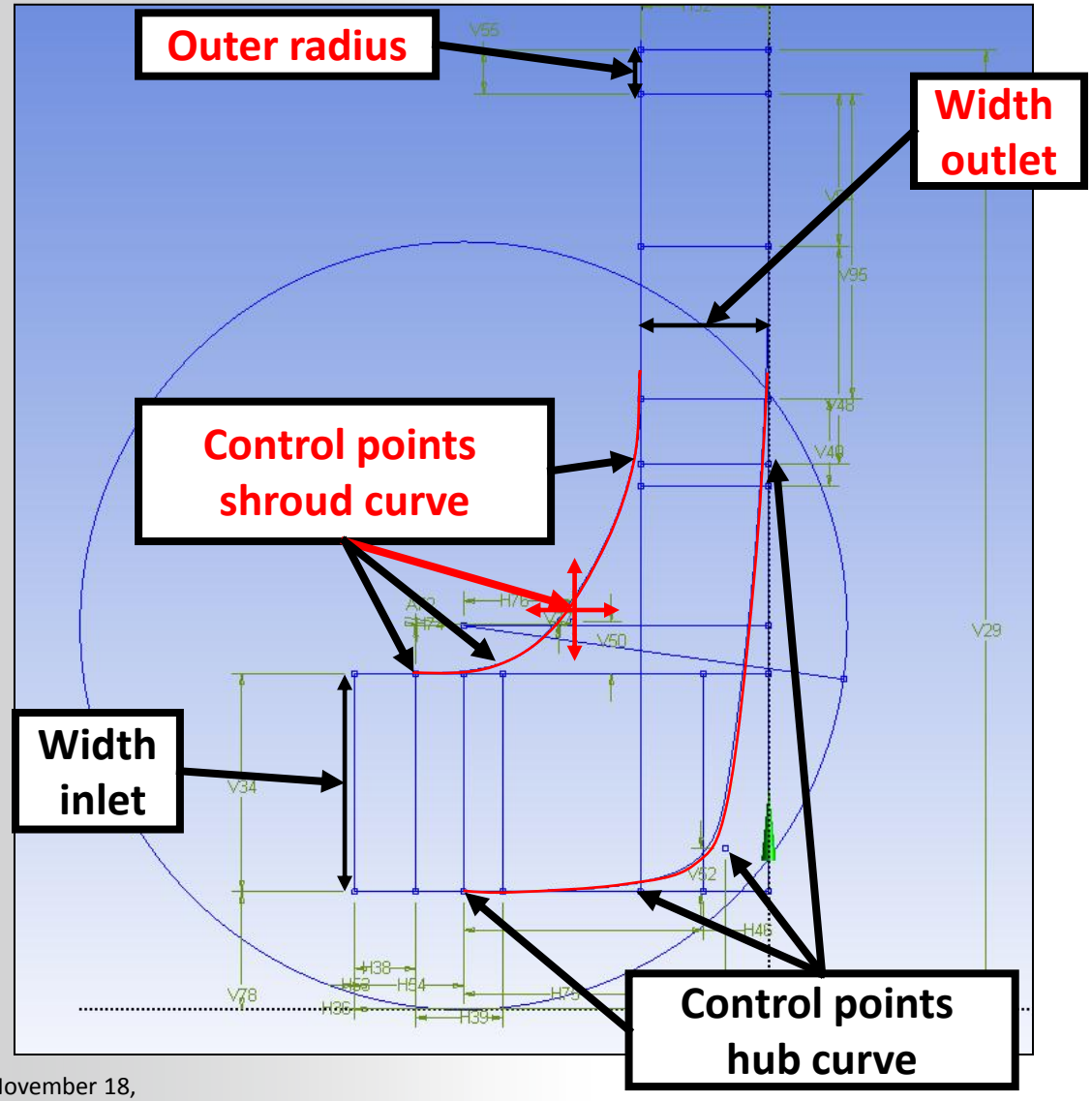
Sensitivity analysis – Efficiency

50 Samples	100 Samples	150 Samples
		
		
COP: 84%	COP: 89%	COP: 91%

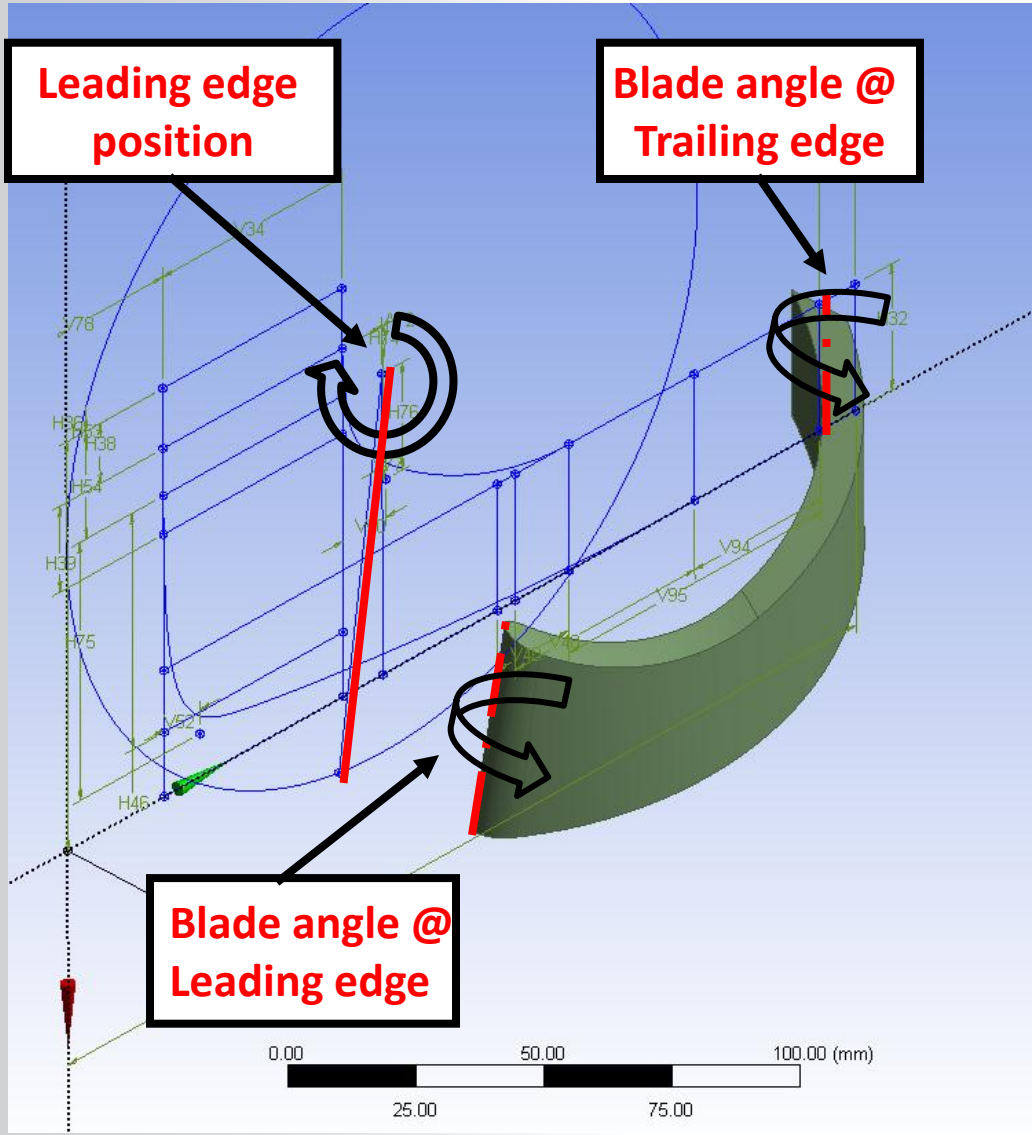
Sensitivity analysis – Parameters

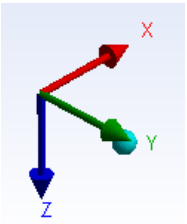


6 important parameters



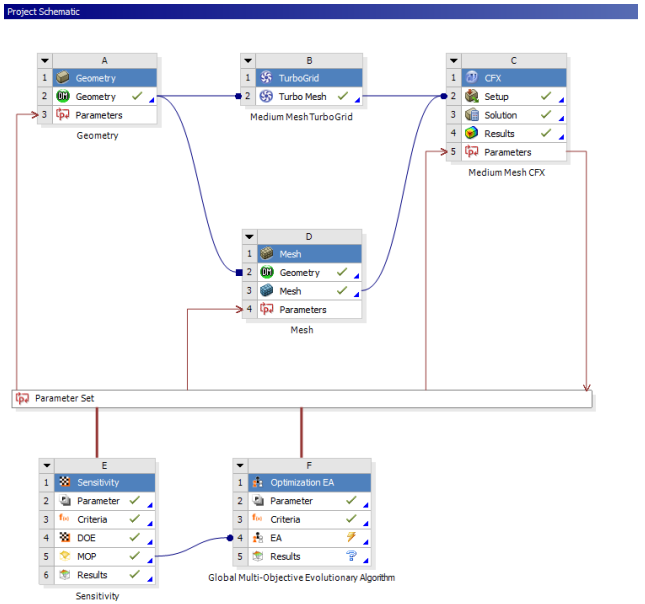
Sensitivity analysis – Parameters

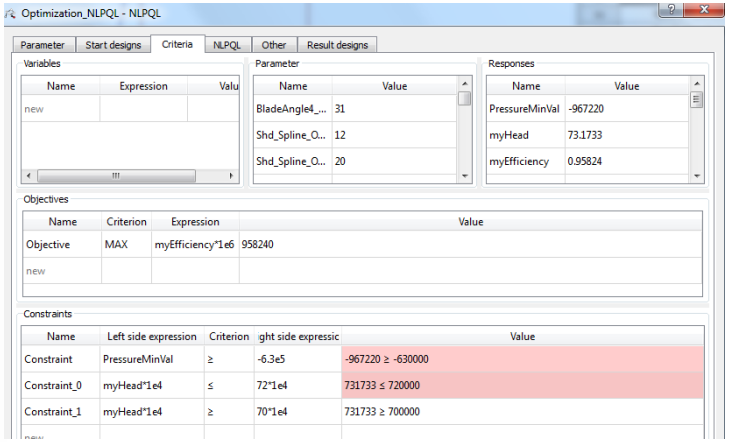




Optimization – Meta-Model Optimization

- Optimize on existing Meta-Model
- Gradient optimization
  - NLPQL algorithm
- Goal
  - Maximize Efficiency <u>for pump best point</u>
- Constraints
  - Head
    - 70 m – 72 m
  - Normalized minimum Pressure
    - ≤ 1



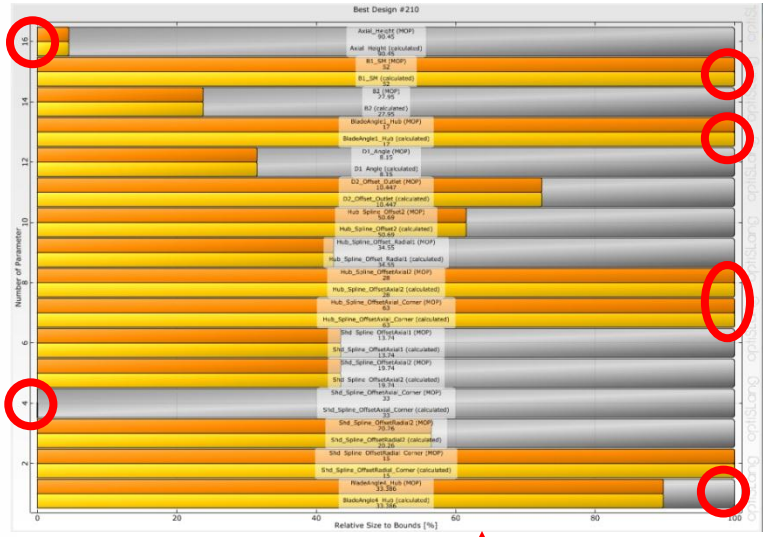


Results – Meta-Model Optimization

	NLPQL 50 DOEs MOP | CFD	NLPQL 100 DOEs MOP | CFD	NLPQL 150 DOEs MOP | CFD
Head, m	71.9 | 71.8 - 0.14 % **COP: 64 %**	71.4 | 70.6 - 1.12 % **COP: 90 %**	72 | 70.7 - 1.8 % **COP: 91 %**
Efficiency	0.974 | 0.974 0 % **COP: 84 %**	0.973 | 0.973 0 % **COP: 89 %**	0.974 | 0.974 0 % **COP: 91 %**
Norm. min. Pressure	0.867 | 0.889 + 2.47 % **COP: 82 %**	0.859 | 0.889 + 3.37 % **COP: 92 %**	0.847 | 0.887 + 4.5 % **COP: 96 %**

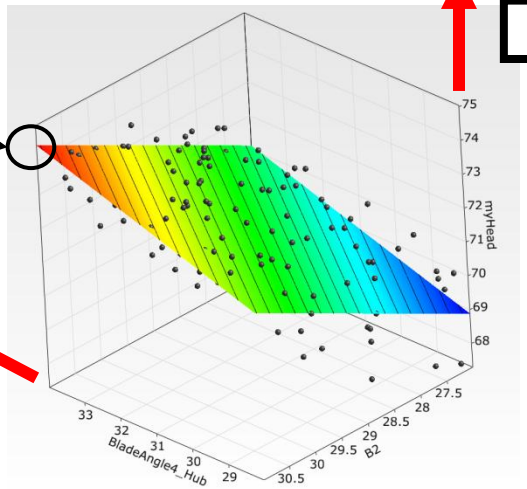
Results – Meta-Model Optimization

- Compare relative size to parameter limits
- Best design at parameter limit
- Parameter range
  - 6 x increase parameter range
  - 2 x decrease parameter range



Head

Best design



Blade angle @ Trailing edge

Outlet width

Results – Meta-Model Optimization

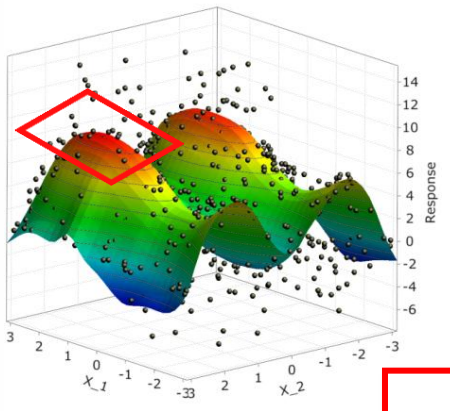
	NLPQL 50 DOEs MOP | CFD	NLPQL 100 DOEs MOP | CFD	NLPQL 150 DOEs MOP | CFD
Head, m	69.99 → 69.31 (- 0.97 %) COP: 64 %	70 → 69.33 (- 0.95 %) COP: 90 %	69.99 → 69.47 (- 0.74 %) COP: 91 %
Efficiency	0.973 → 0.970 (- 0.3 %) COP: 84 %	0.974 → 0.972 (- 0.2 %) COP: 89 %	0.973 → 0.972 (- 0.1 %) COP: 91 %
Norm. min. Pressure	0.868 → 0.856 (- 1.38 %) COP: 82 %	0.860 → 0.871 (+ 1.26 %) COP: 92 %	0.852 → 0.859 (+ 0.81 %) COP: 96 %

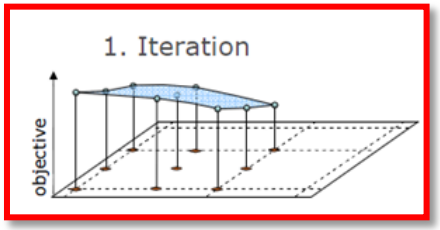
Head: 68-70 m
Best design not @ parameter limit

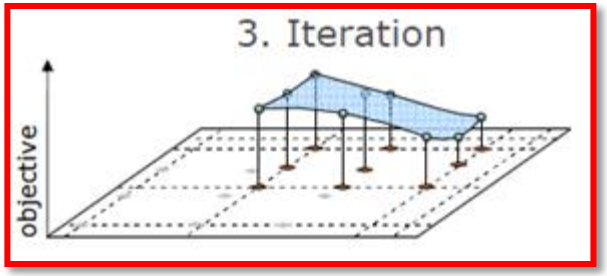
Optimization – Direct Optimization

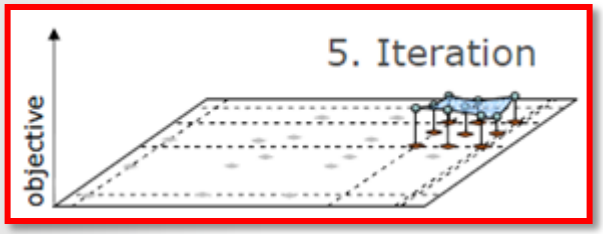
- **Adaptive Response Surface Method (ARSM)**
  - **Improve the approximation quality around the optimum**
  - **Increased parameter range**
    1. Previous best point used as start design
    2. Initial sample new Approximated Response Surface → New best point
    3. New sample with smaller range → New best point
    4. ..

→ Find global optimum









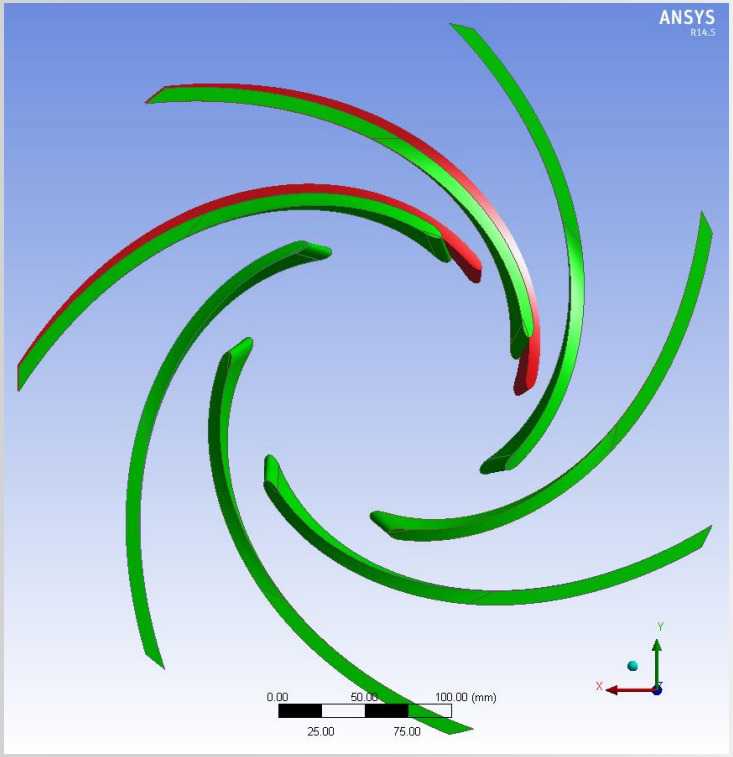
Results – NLPQL vs. ARSM

Increased parameter range

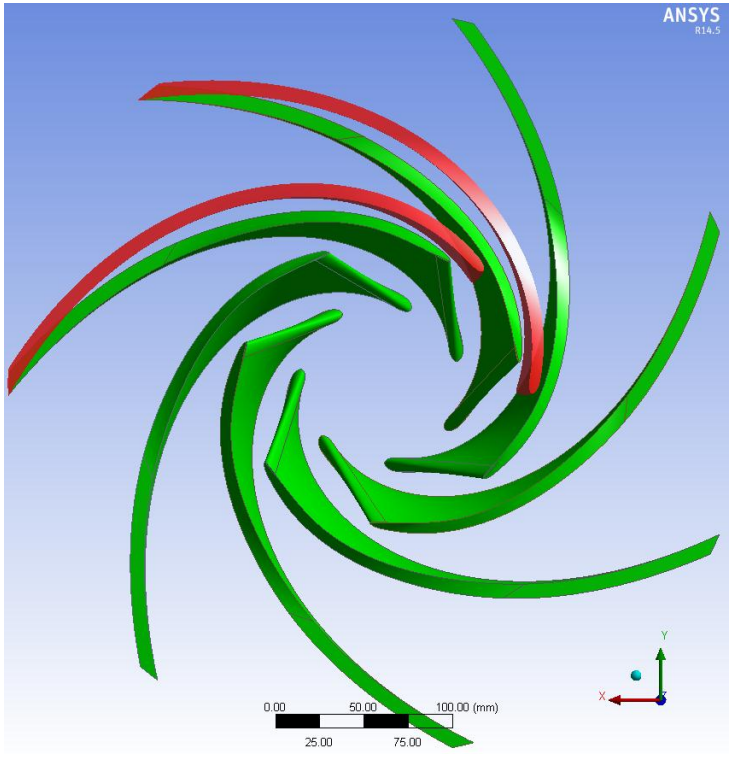
	Start-Design	NLPQL (150 DOEs)	ARSM (80 DPs)
Power, kW	**58.44**	**56.83**	**56.65**
Head, m	**72.3**	**70.7**	**70.9**
Efficiency	**0.967**	**0.974**	**0.98**
Norm. min. Pressure	**1**	**0.887**	**0.856**
Power		- 2.8 %	- 3 %
Efficiency		+ 0.72 %	+ 1.32 %
Norm. min. Pressure		- 11.3 %	- 14.4 %

Results – Blade design

Start-Design vs. NLPQL (150 DOEs)



Start-Design vs. ARSM (80 DPs)



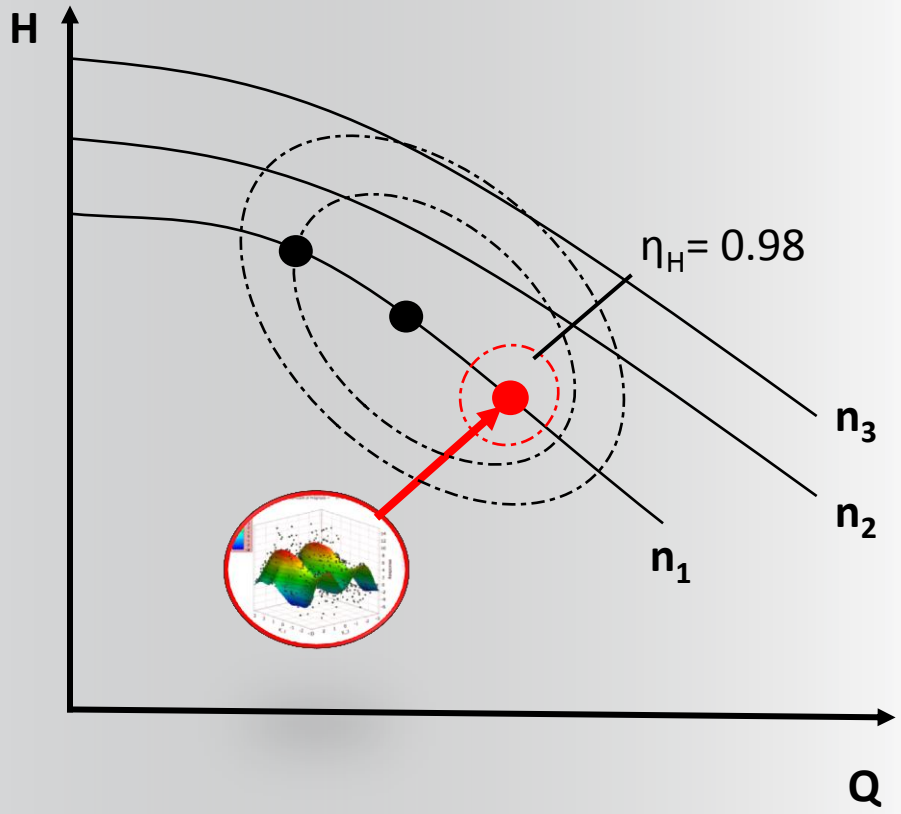
Start-Design: Red
Optimized design: Green

Summary

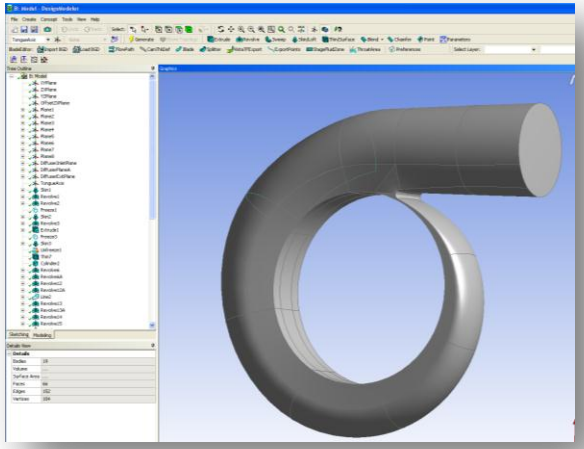
- Parametric pump design
- CFD Best Practice Study
- Sensitivity Analysis
  - Best Practice for Meta-Model with 50, 100, 150 samples
  - COP increases with sample size
  - Important parameter identified with 50 samples
  - More samples necessary for low influence parameters
- Meta-Model Optimization
  - 0.72 % Efficiency improvement
  - 11 % Normalized minimum pressure improvement
- Direct Optimization with increased parameter range
  - 1.32 % Efficiency improvement
  - 14 % Normalized minimum pressure improvement

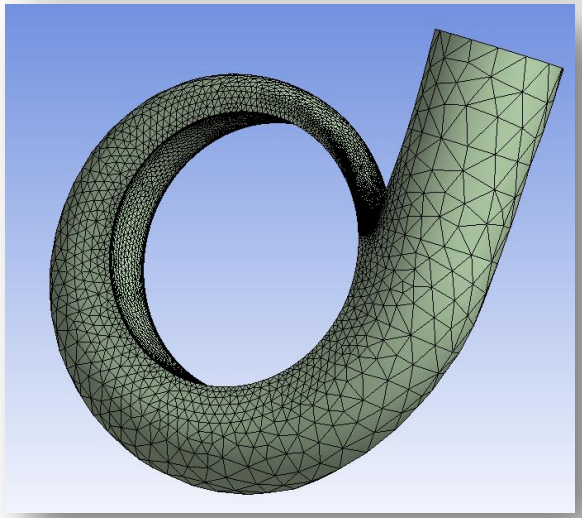
Outlook – Pump characteristic & spiral casing

- **Optimization on pump characteristic**



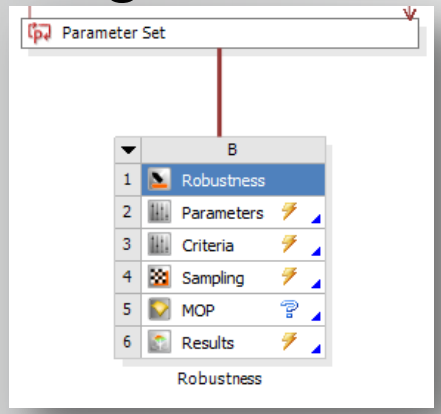
- **Volute**





Outlook – Robust design optimization

- **Investigate the effect by scattering input parameters**



Input parameter

Output parameter