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GRUNDFOS
SIMULATION DRIVEN
DEVELOPMENT

Performance-based Tolerance Specification for a

Centrifugal Pump Impeller

Michel Noaparast, Development Engineer
Tobias Randers Olesen, Development Engineer
Dr. Nicholas Pedersen, Senior Manager
GRUNDFOS **PRODUCTS AND OFFERINGS**

be
think
innovate

GRUNDFOS

#1
Pump manufacturer in the world

74
Years old (founded in 1945)

83
Companies across the world

16
Million units produced every year

19
Thousand employees worldwide

3.6
Turnover (billion Euros) 2018

1
Owner

GRUNDFOS PRODUCT RANGE

Contents

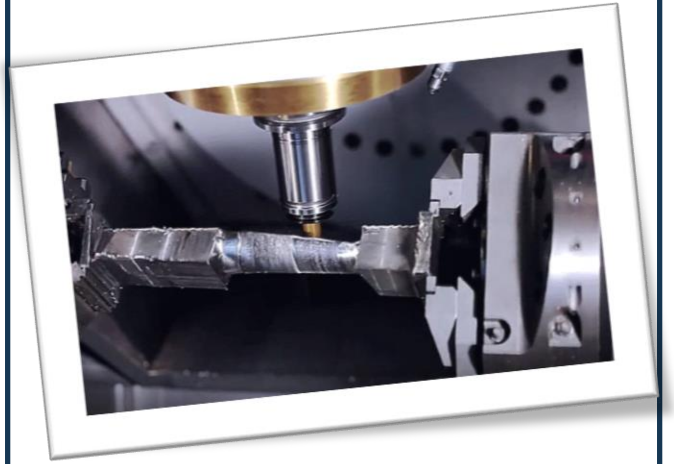
Development process

Hydraulic designer

Tolerance specialist

?

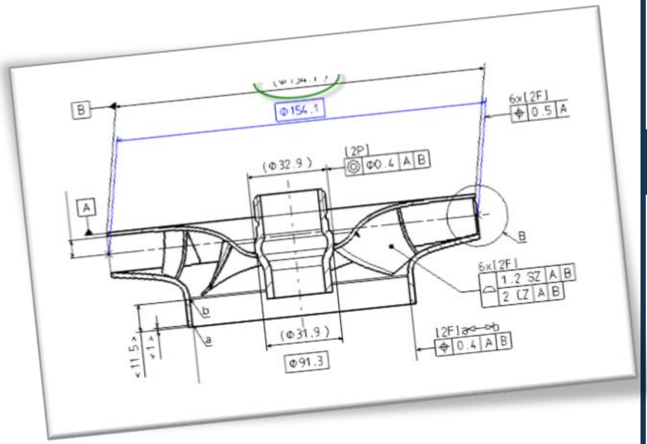
Tooling specialist



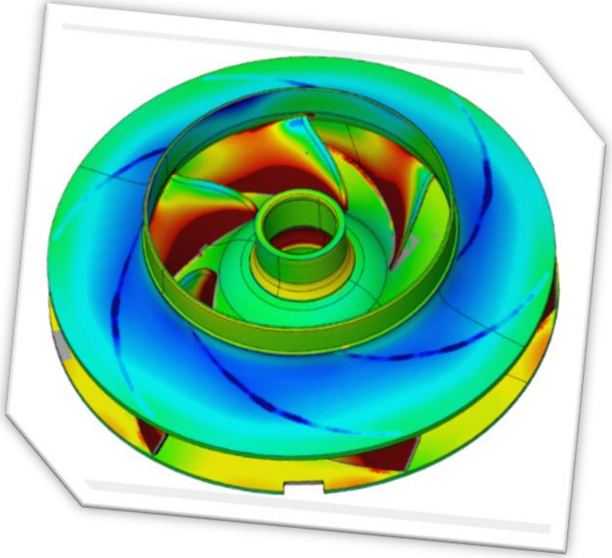
1. Motivation
Development process

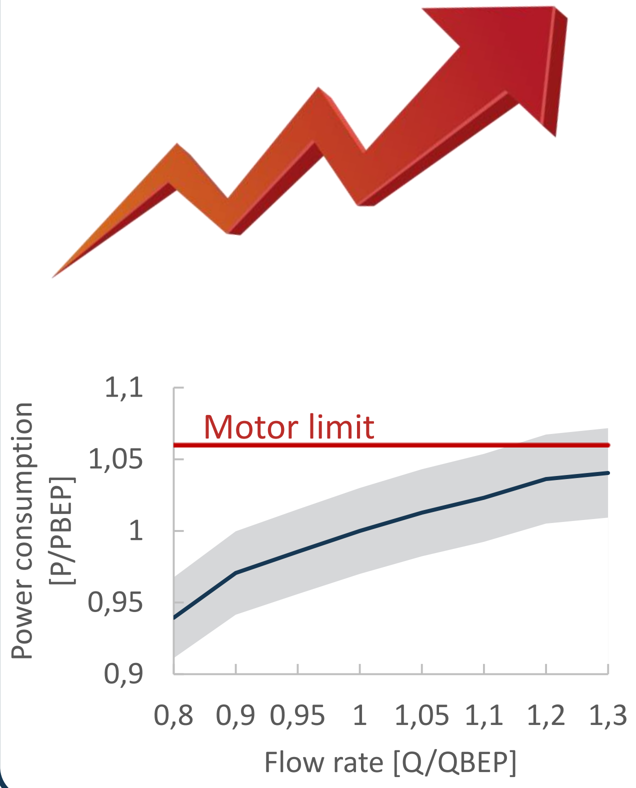
Hydraulic designer

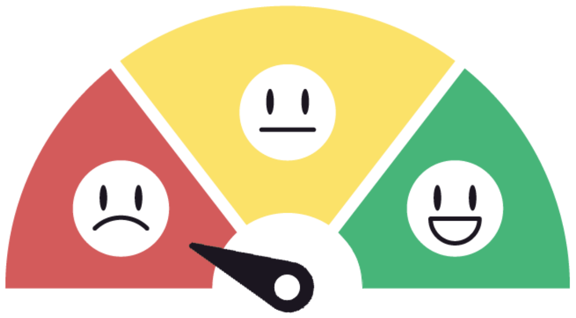
Tolerance specialist



Produced component
with deviations




Motor limit
1,1
1,05
1
0,95
0,9
Power consumption [P/PBEP]
0,8 0,9 0,95 1 1,05 1,1 1,2 1,3
Flow rate [Q/QBEP]



Variations are unavoidable

so how do we control them?

so how do we predict their impact?

so how can we reduce their impact?

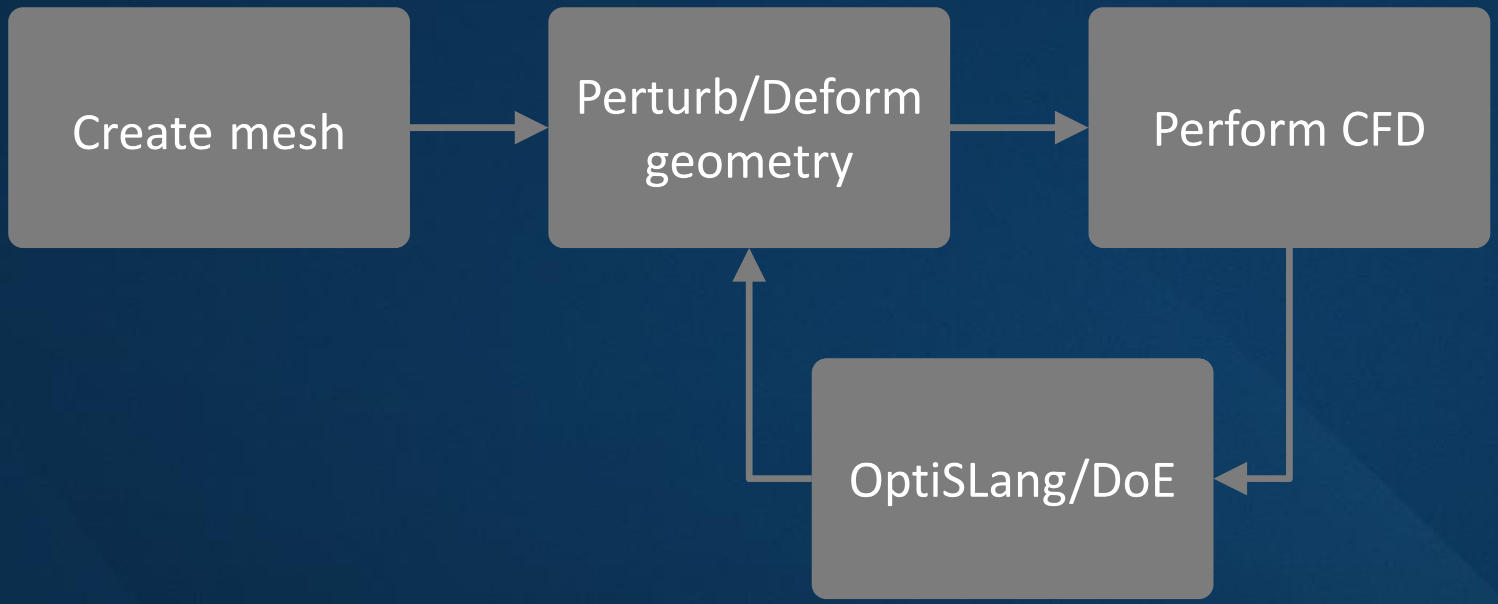
Hypothesis

Can be done by replacing traditional tolerances with tolerance zones based on sensitivity studies.

GRUNDFOS
SIMULATION DRIVEN DEVELOPMENT

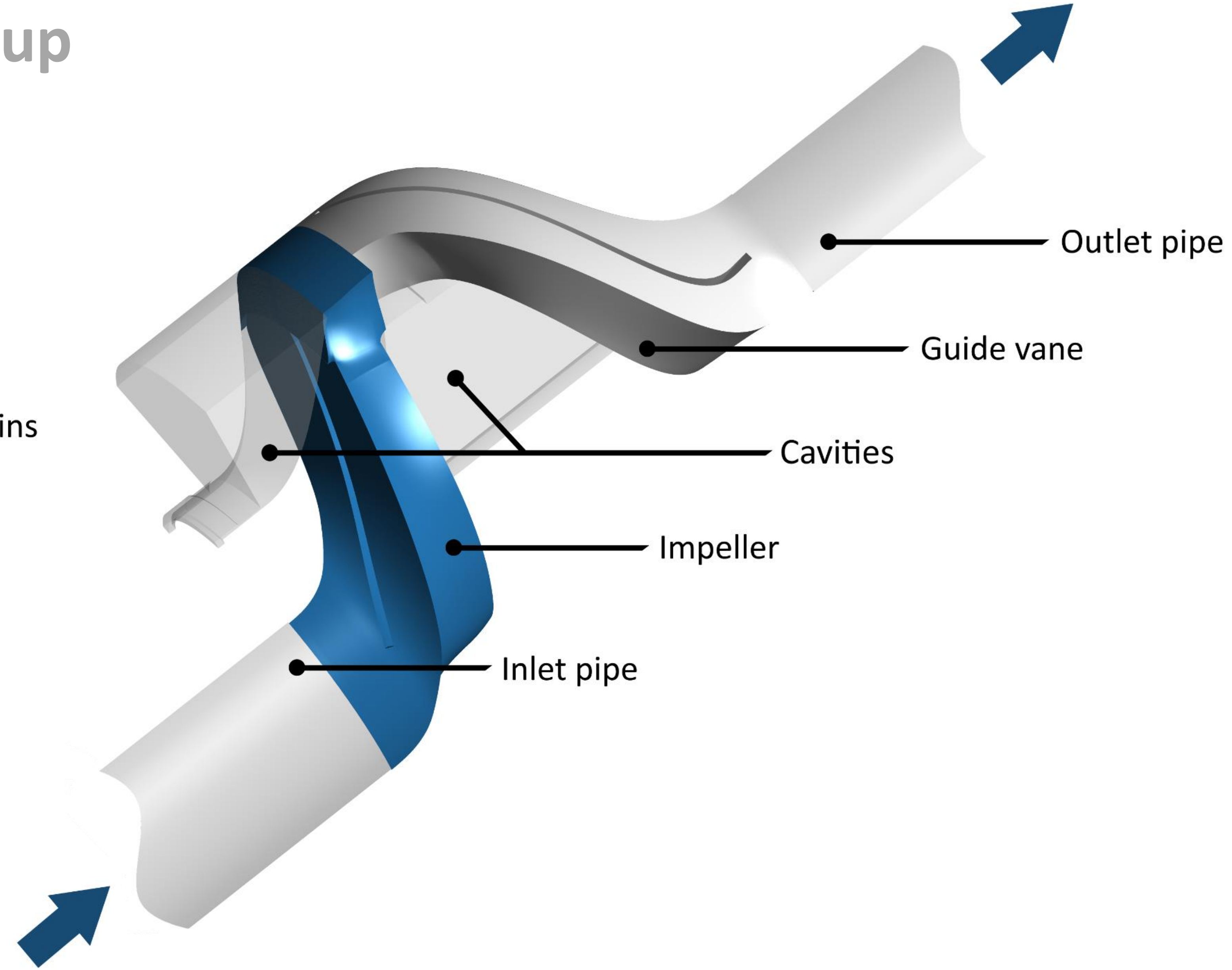
Hypothesis Can be done by replacing traditional tolerances with tolerance zones based on sensitivity studies.

Solution Robustness evaluation



2. Simulation set-up
Fluid domain

- Rotating domain
- Stationary domains
- Cavities

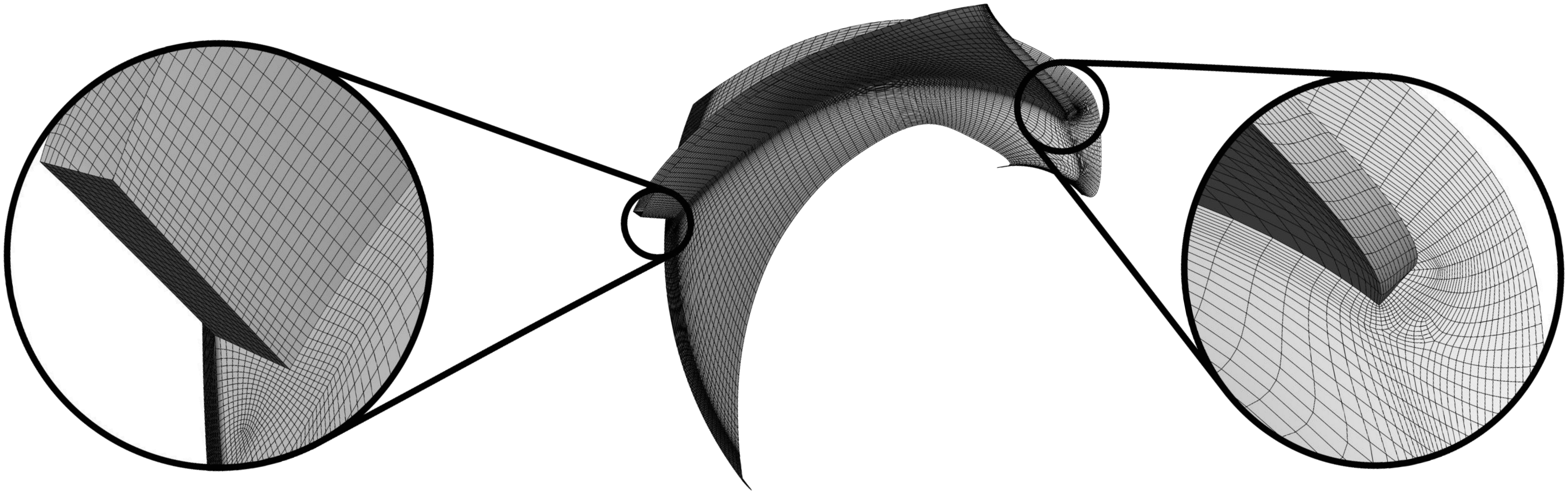


2. Simulation set-up

Mesh properties

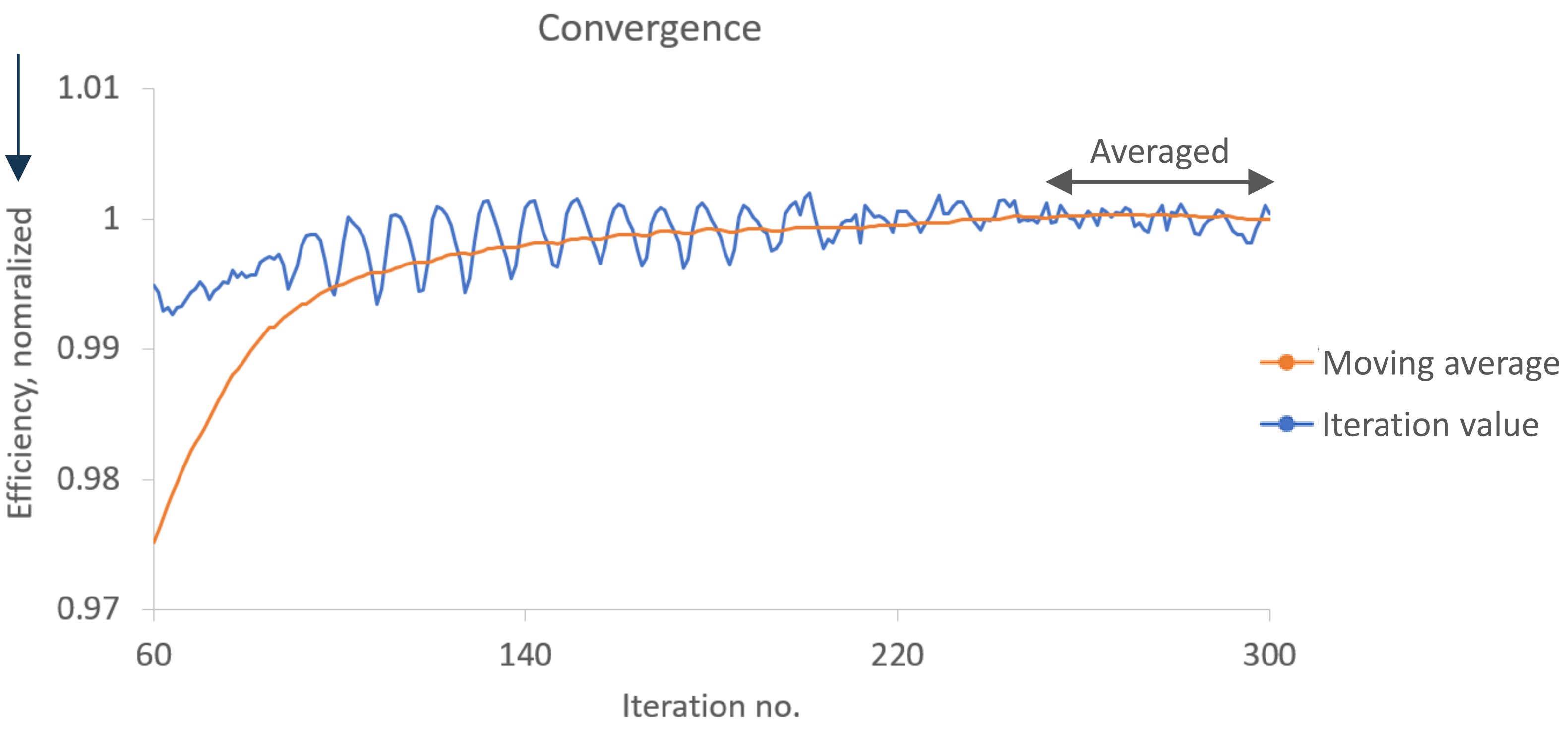
- Structured hexahedral meshes

	Cell count	Min. orthogonal angle
Full domain	585,330	24.7



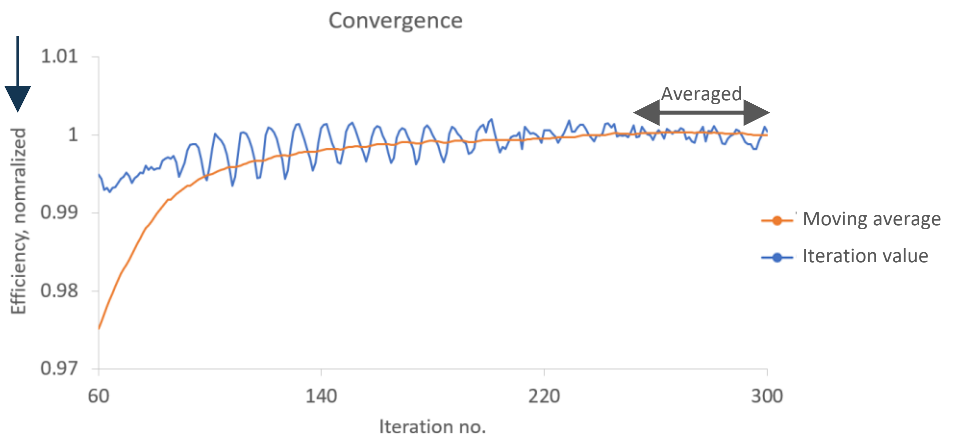
2. Simulation set-up
CFD simulation

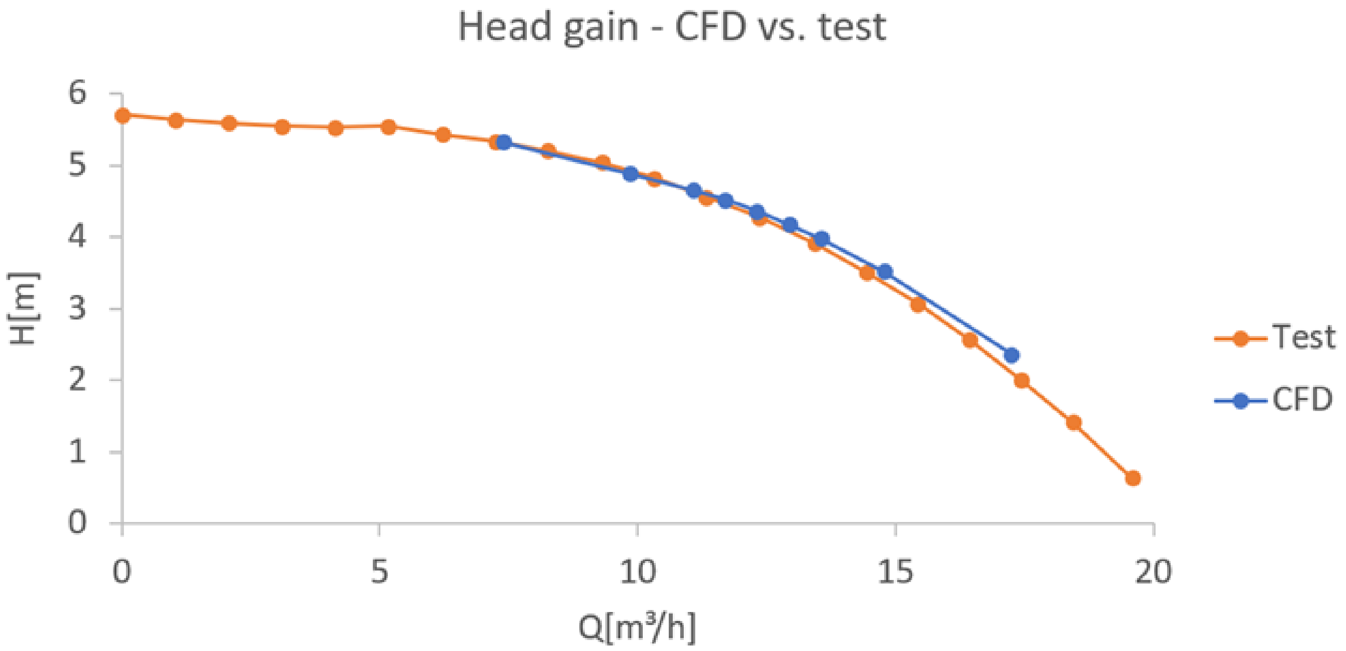
- Convergence good, averaged result



2. Simulation set-up
CFD simulation

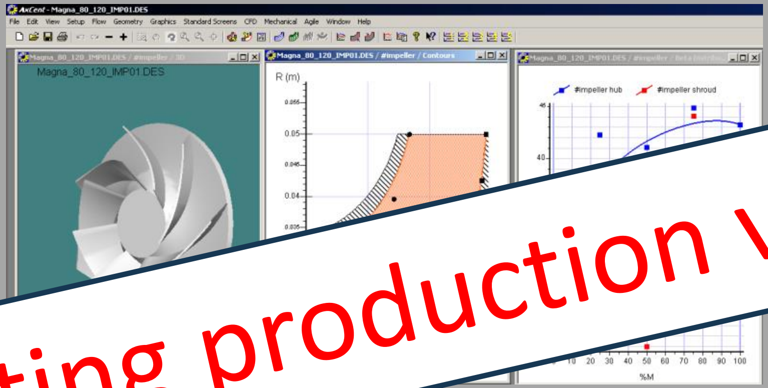
- Convergence good, averaged result
- Good match between CFD and test

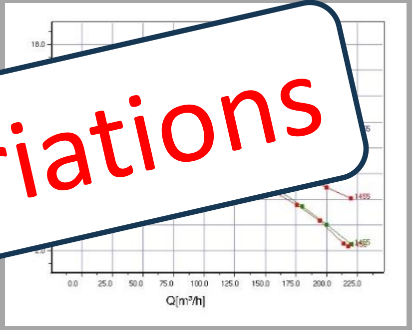




3. Parametrization
Hydraulic design methods

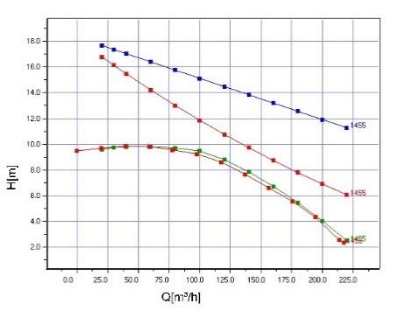
Conventional hydraulic design method
- Direct specification of blade angle distribution
- No direct specification of loading or performance

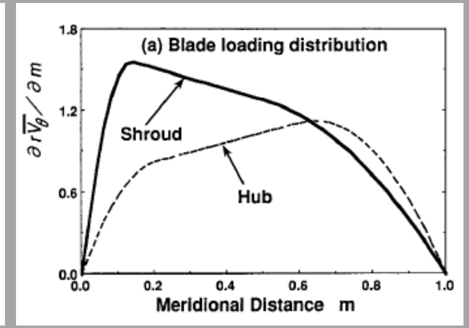


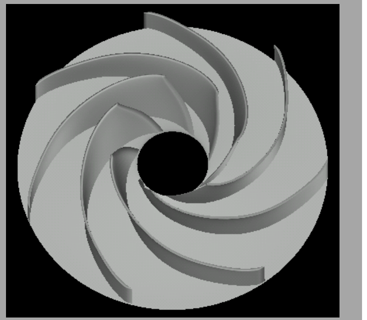


Not suited for imitating production variations

Ir… …od
- … performance and blade loading (pressure difference across blade)
- No direct specification of blade angles







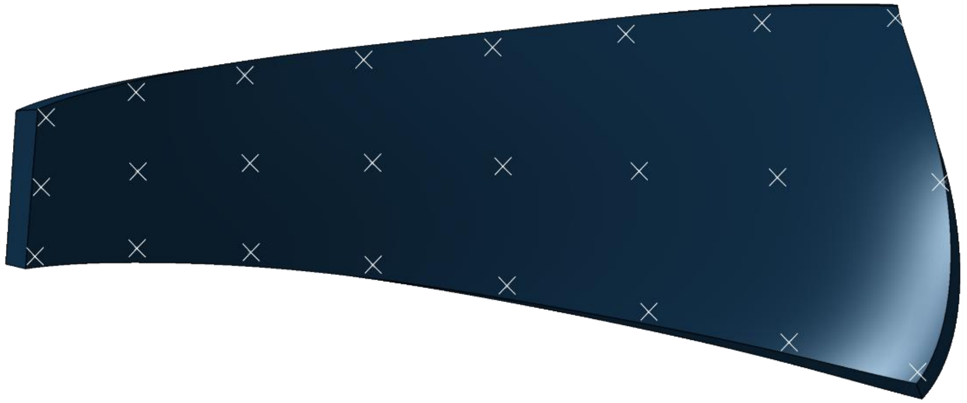
3. Parametrization

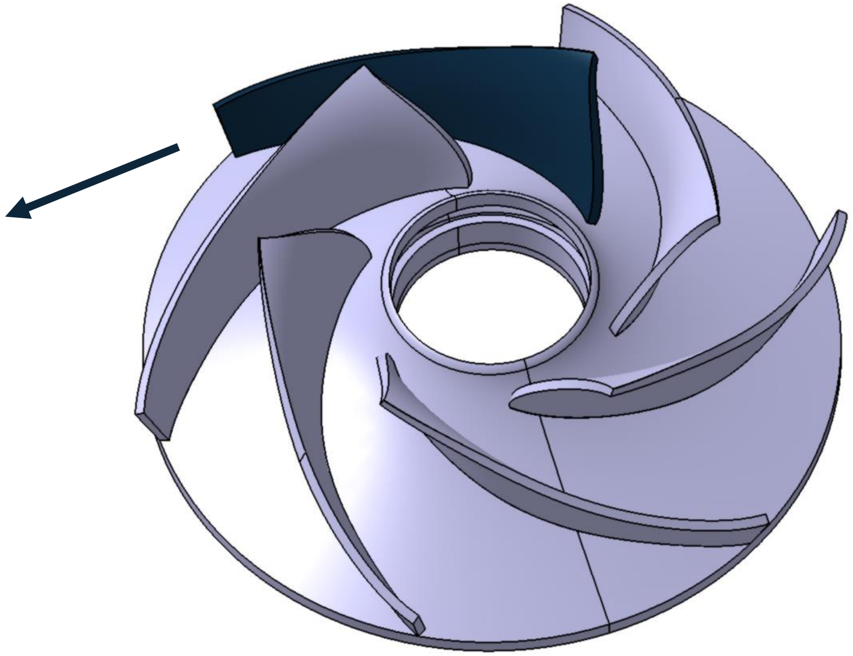
Geometric parametrization

- Metal sheet impeller
- 8x3 control points
- Displacement normal to the surface
- Constant blade thickness

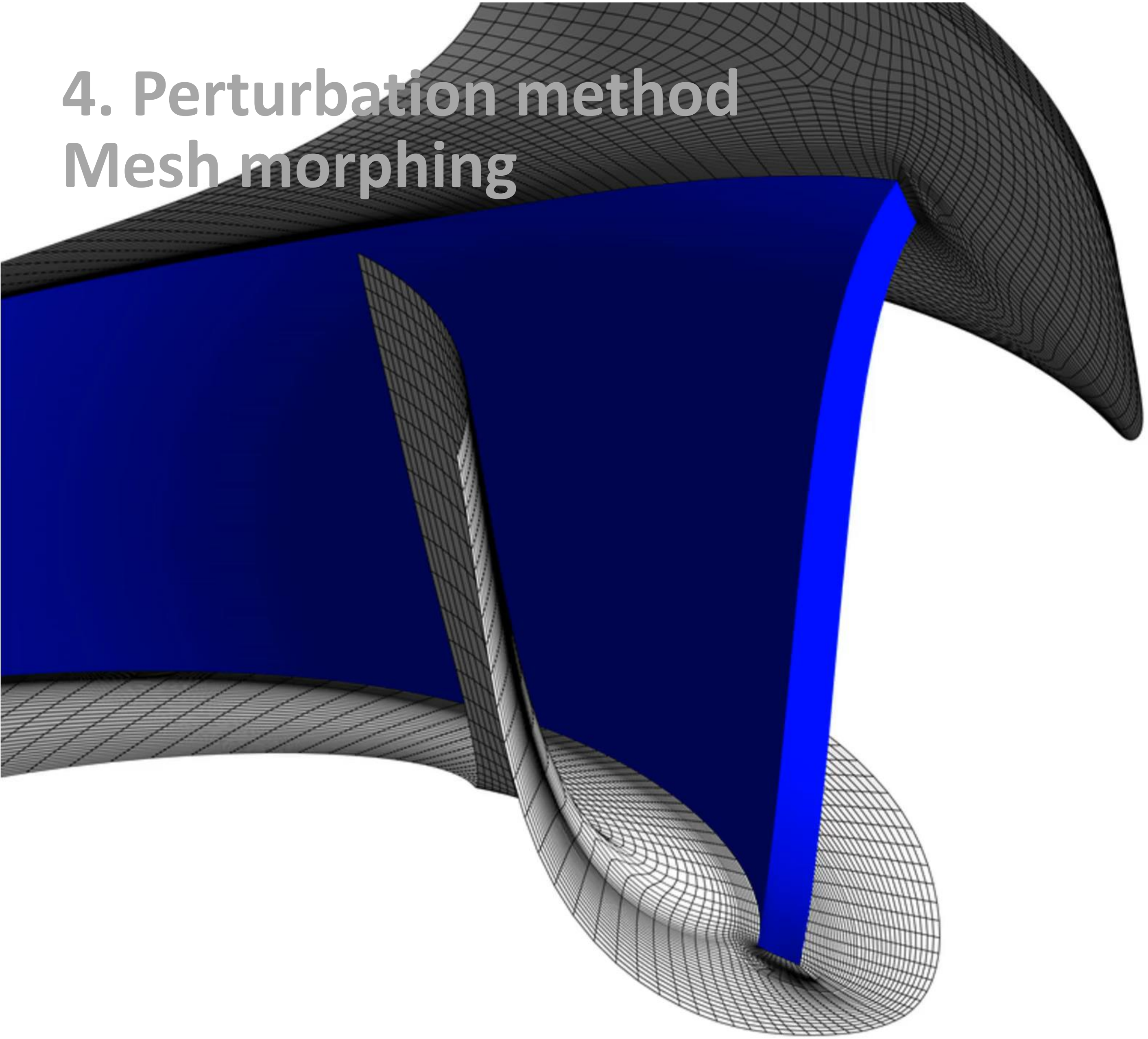
Advantages:

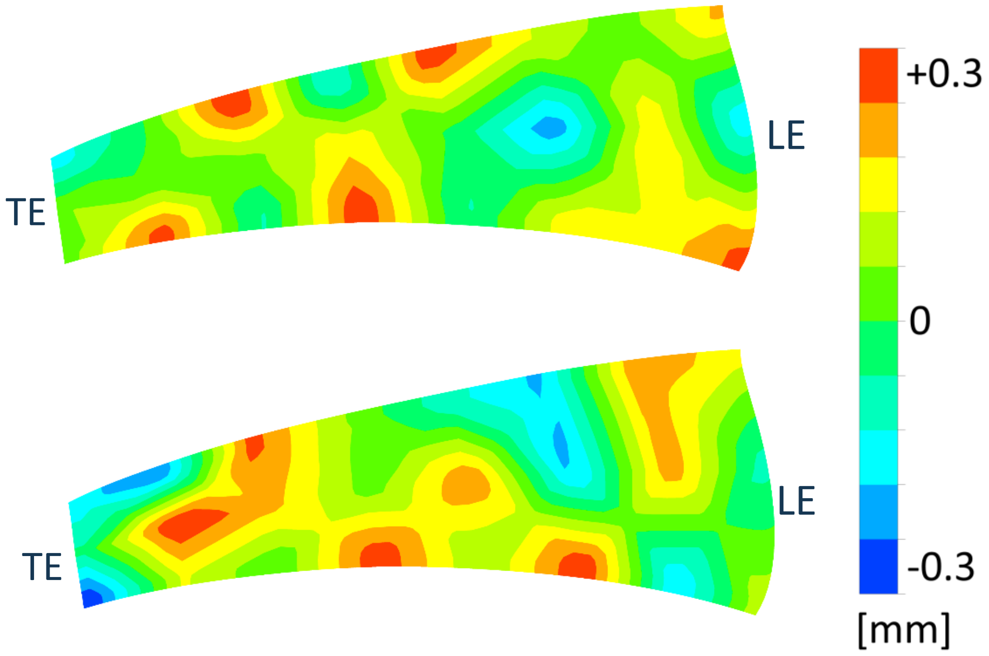
- ✓ Parameters linked to geometry changes
- ✓ Easy to impose tolerances
- ✓ Easy to mimic specific production variations





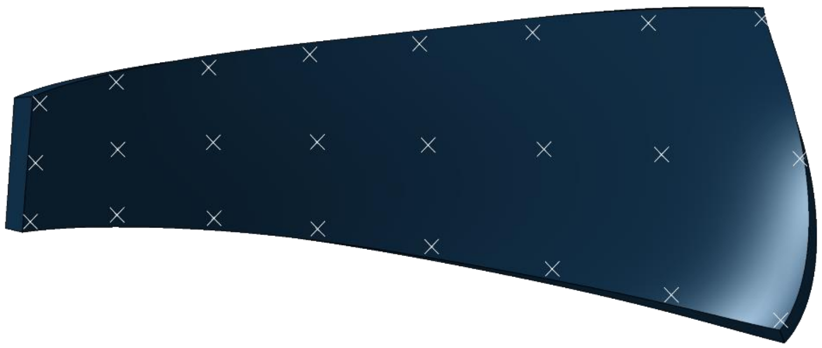
4. Perturbation method
Mesh morphing





5. OptiSLang set-up
Parameters

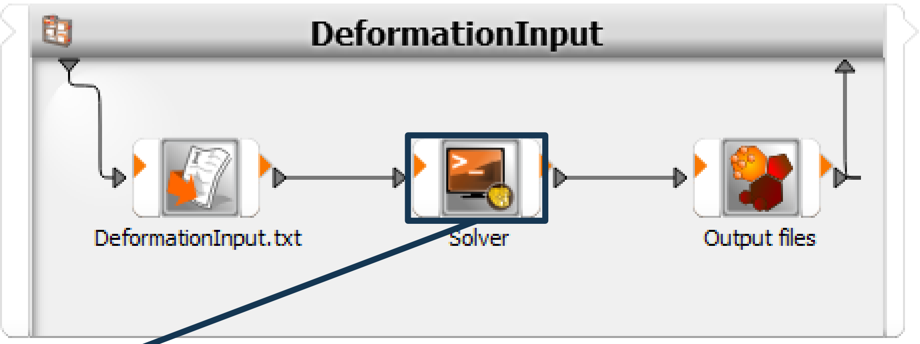
- Robustness evaluation
- Advanced Latin Hypercube Sampling
- 100 samples (>2k)
- Responses
  - Head
  - Power consumption
  - Efficiency
  - Minimum pressure
  - Axial force

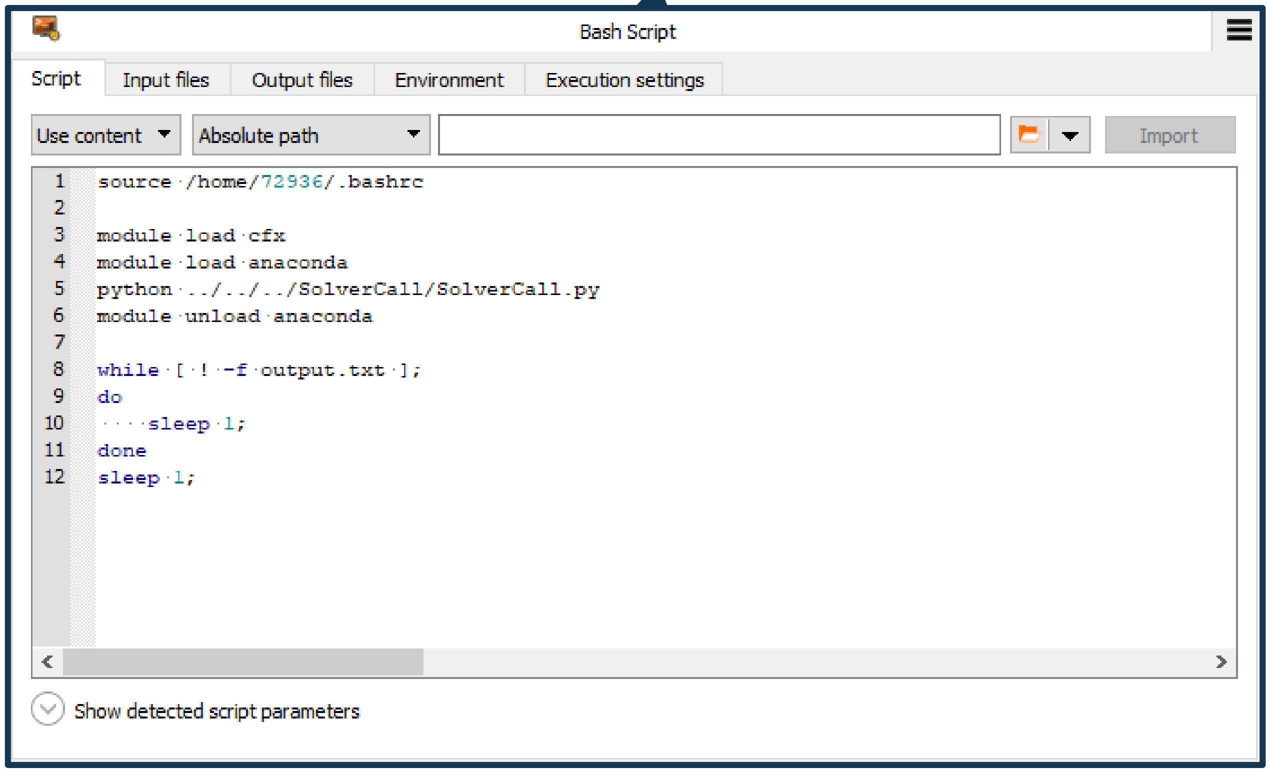


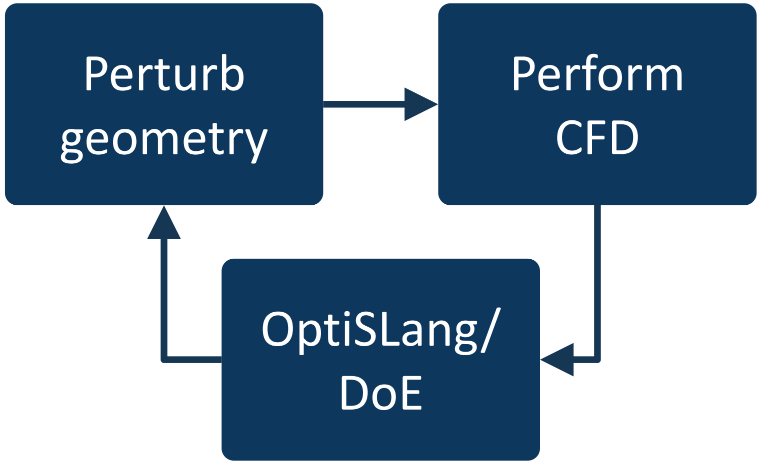
	Name	Parameter type	Reference value	Constant	PDF	Type	Mean	Std. Dev.	CoV	Distribution
1	Parameter_01	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
2	Parameter_02	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
3	Parameter_03	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
4	Parameter_04	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
5	Parameter_05	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
6	Parameter_06	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
7	Paramete			☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
						UNIFORM	0	0.173205	100 %	-0.3; 0.3
	eter_18	Stochastic	0							
19	Parameter_19	Stochastic	0	☐						-0.3; 0.3
20	Parameter_20	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
21	Parameter_21	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
22	Parameter_22	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
23	Parameter_23	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3
24	Parameter_24	Stochastic	0	☐		UNIFORM	0	0.173205	100 %	-0.3; 0.3

5. OptiSLang
Solver call

- Text-based solver (bash)
- Python

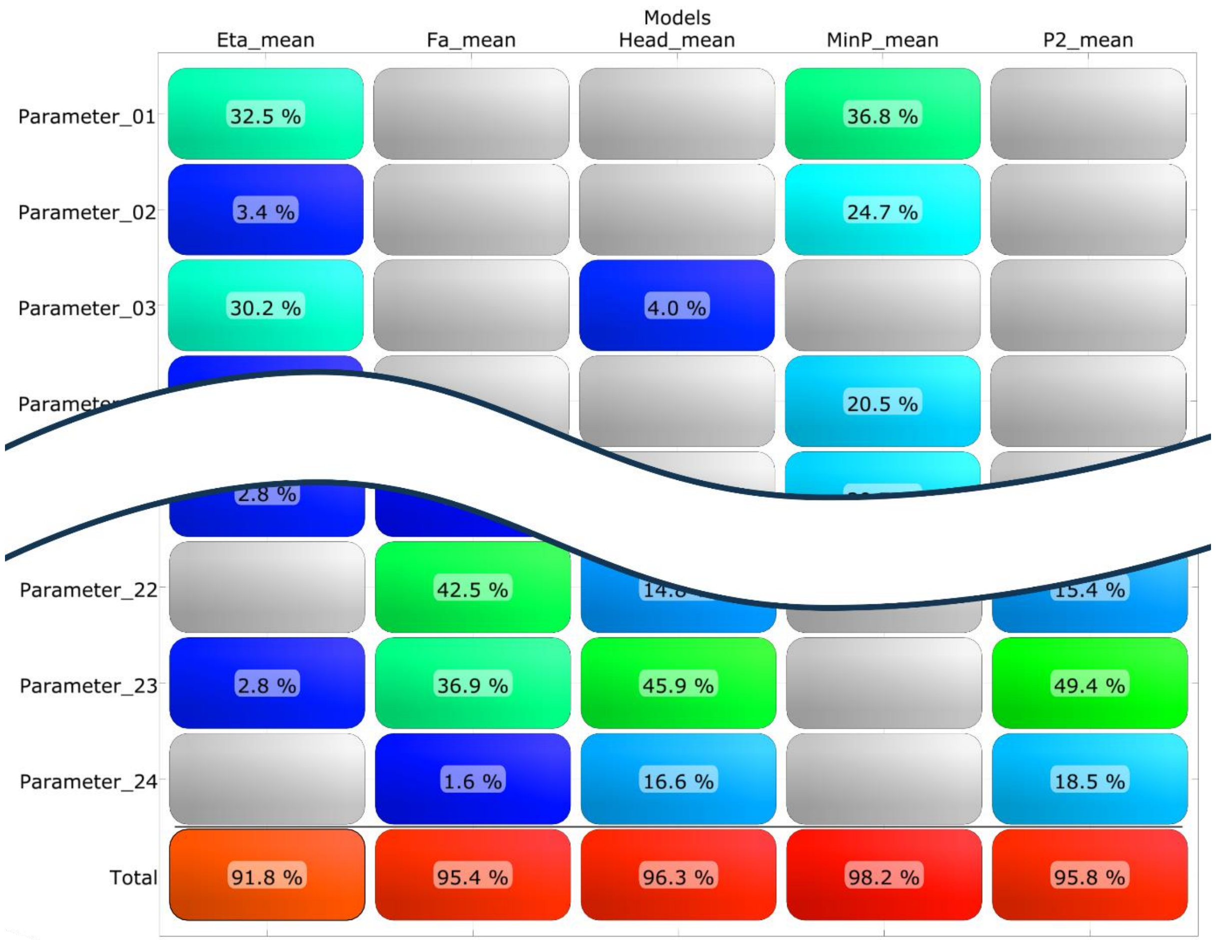


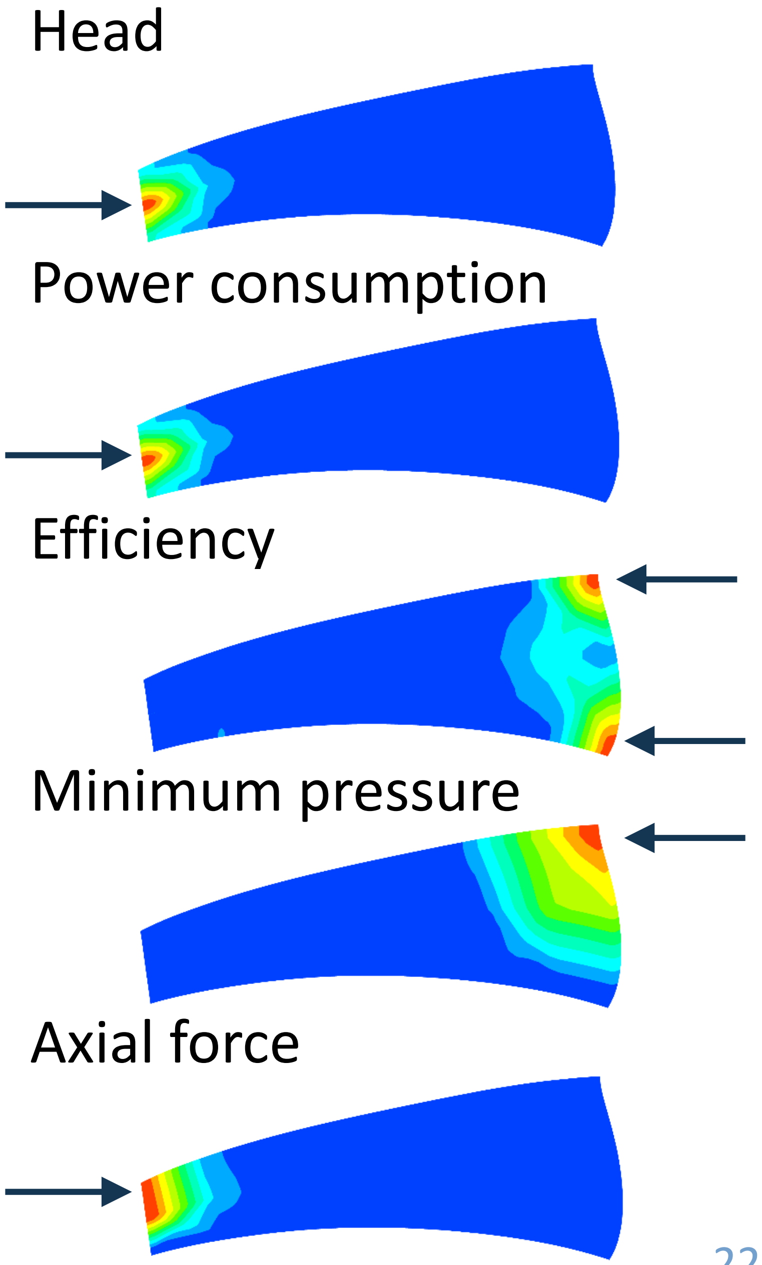




6. Results

Visualization of the sensitivity





6. Results
Visualization of the sensitivity

Head

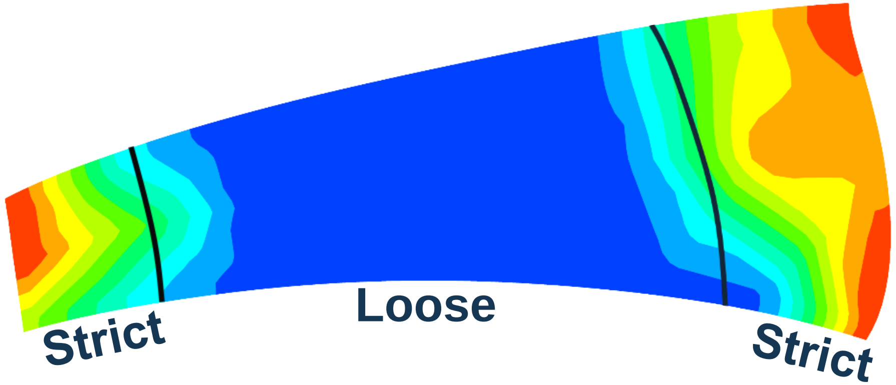
Power consumption

Efficiency

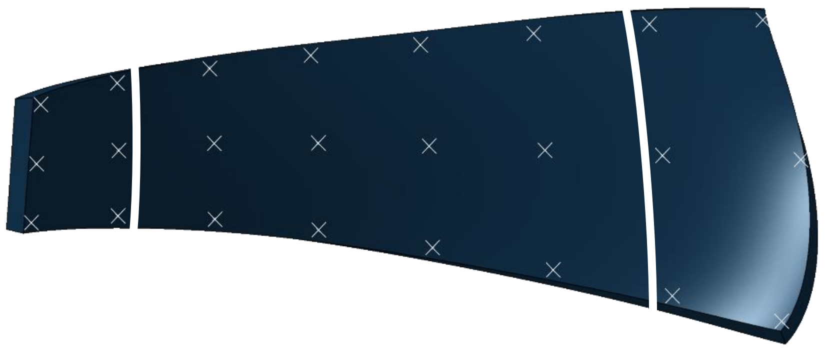
Minimum pressure

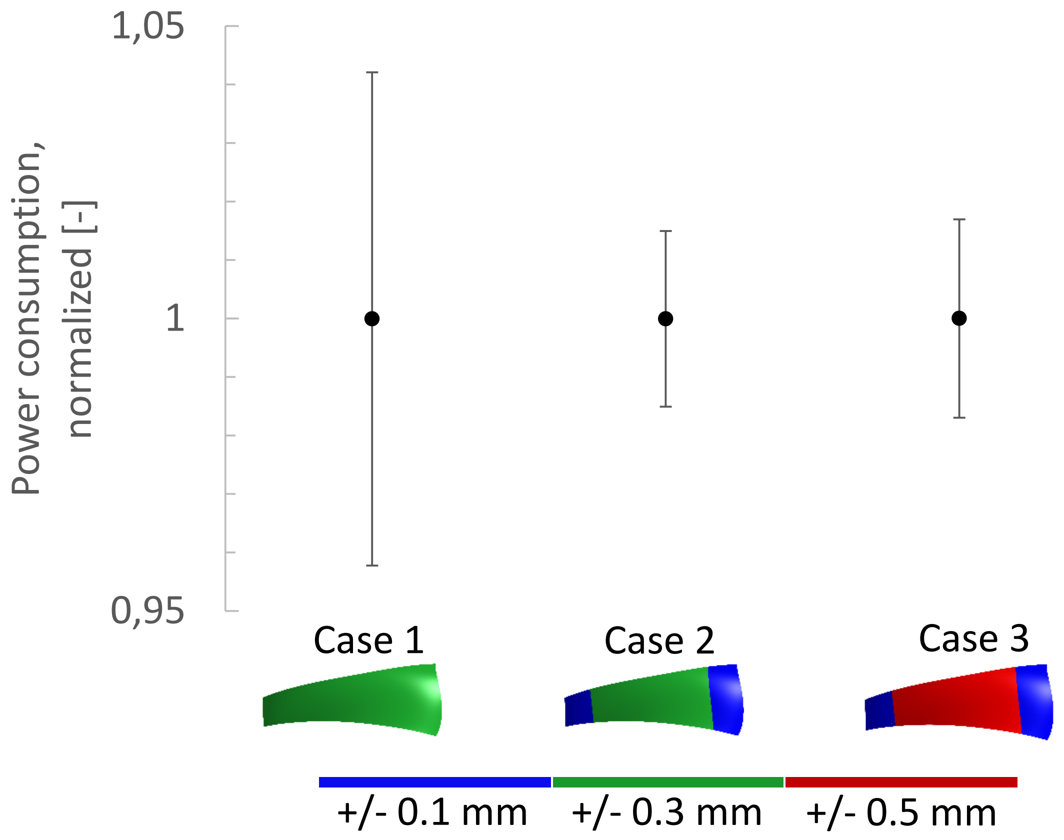
Axial force

Combined sensitivity



6. Results
Adjusted tolerance zones

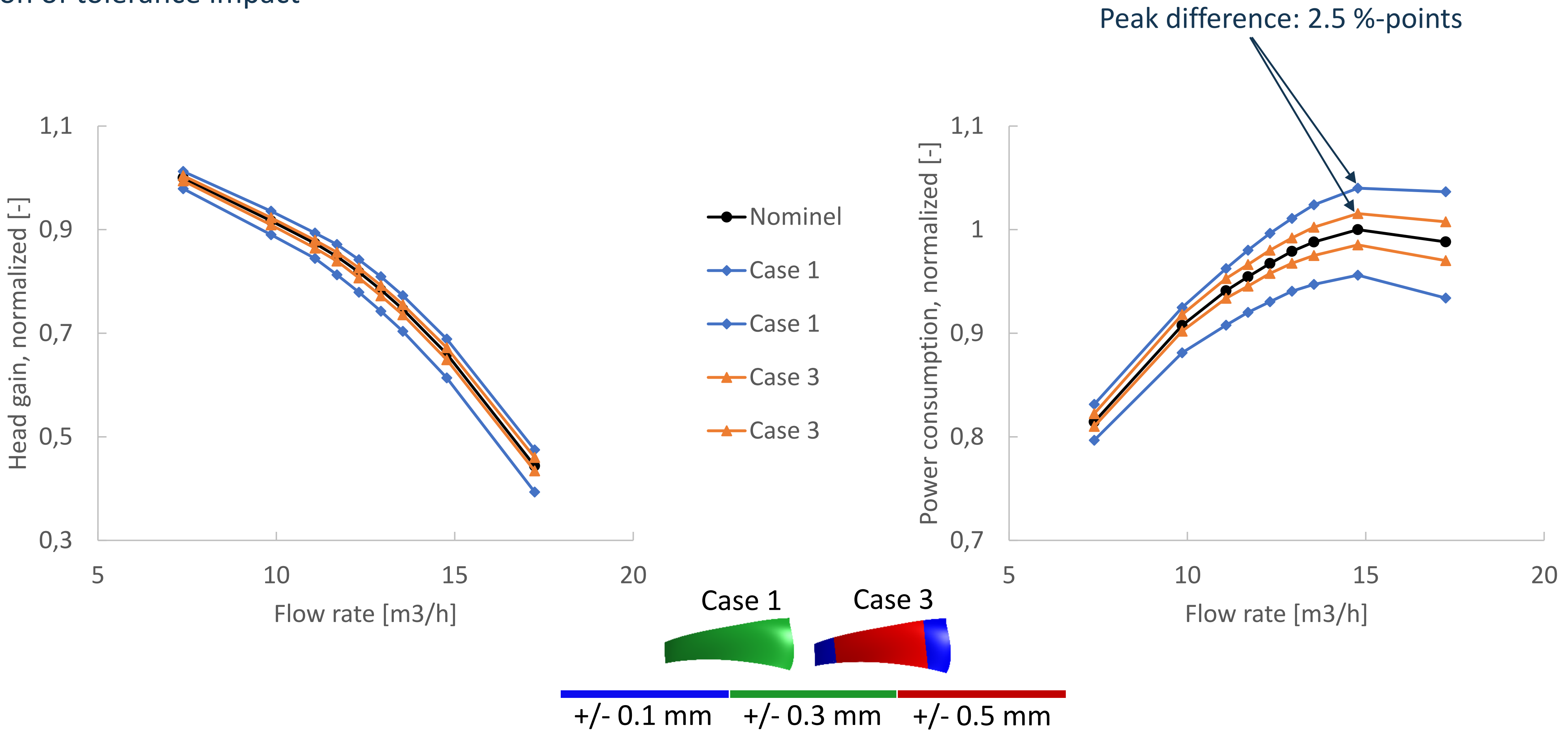




6. Results

Adjusted tolerance zones

- Prediction of tolerance impact



7. Conclusion

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Sensitive regions identified	Tighten tolerances in important regions
	Loosen tolerances in less important regions
	Reduce complexity and/or increase performance
Estimated performance variations	Optimize tolerances and avoid over-engineering
	Estimate required safety margins in design phase
New methodology	Applicable to any geometry
Next steps	Test on more geometries
	Include in design procedures