



# Fluid-Mechanical Optimization of a Radial Pump using Xtreme, CFTurbo, TCFD, NetGen & CalculiX

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## Presentation Content

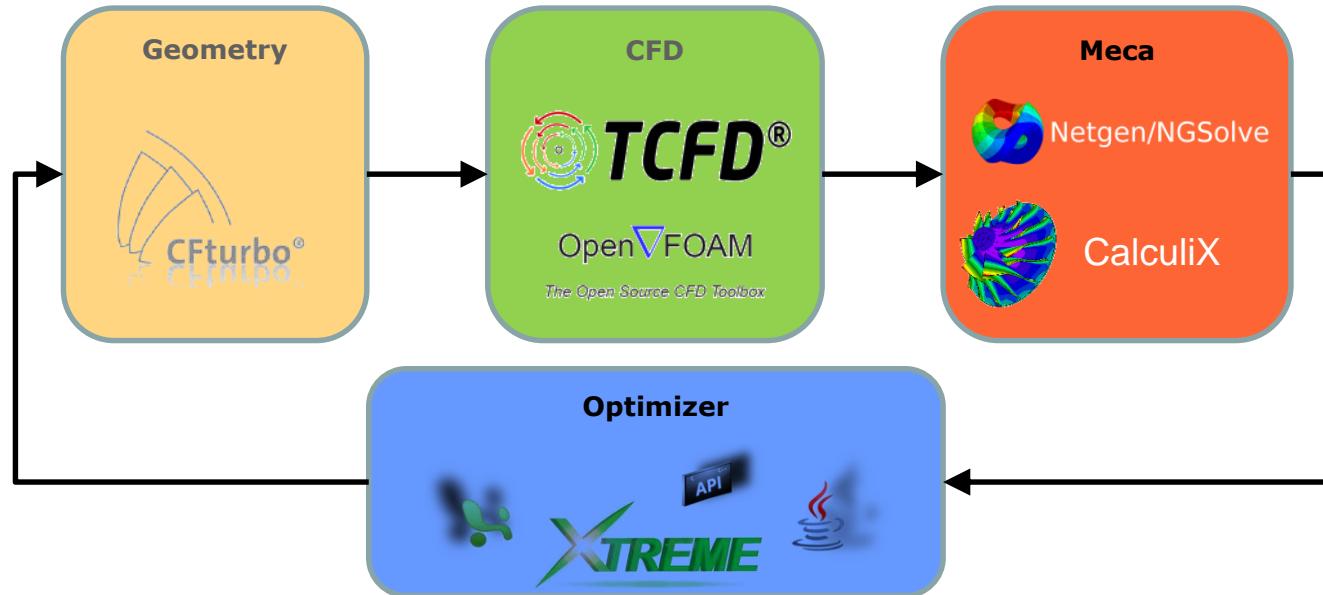
- Motivations
- Software presentation
  - Xtreme
  - CFTurbo
  - TCFD
  - NetGen
  - CalculiX
- Geometrical Parameters
- Optimization Workflow, objectives and constraints
- Optimization results
- Conclusions

## Motivations

- Demonstrate How Radial Pump and Turbomachines in general can be highly improved during the design phase
- How?
  - Using Integrated Multi-Disciplinary Simulations
  - Using Highly Efficient Optimizer
  - Using Fluid (CFD) and Mechanical (stress – vibration) Goals

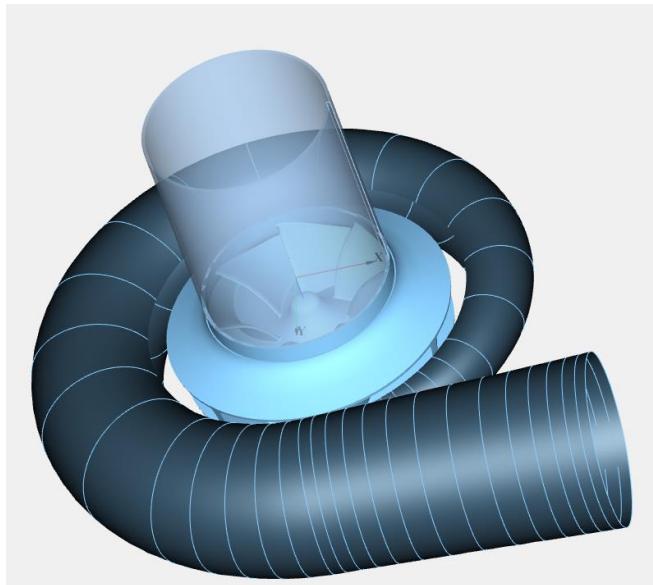
- Optimization workflow

- **CFTurbo** for the geometry
- **TCFD** for the CFD simulation
- **NetGen** for the mechanical mesh
- **CalculiX** for the mechanical static and dynamic calculation
- **Xtreme** for the optimization
- **Python** for the coupling between all these software



## Geometrical parameters

- CFTurbo GmbH
- 13 parameters

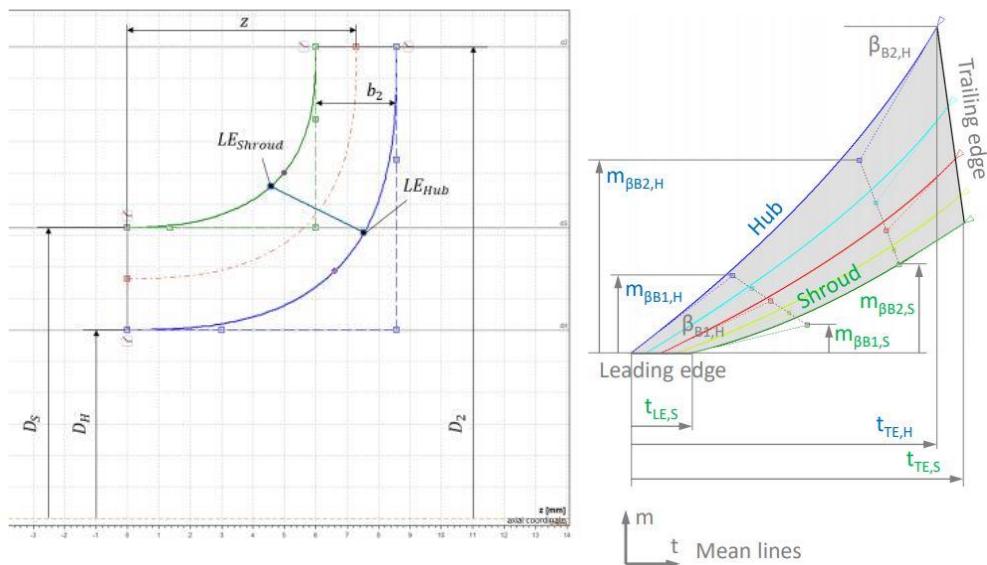


Impeller main diameter : 286 mm

Number of blades : 7

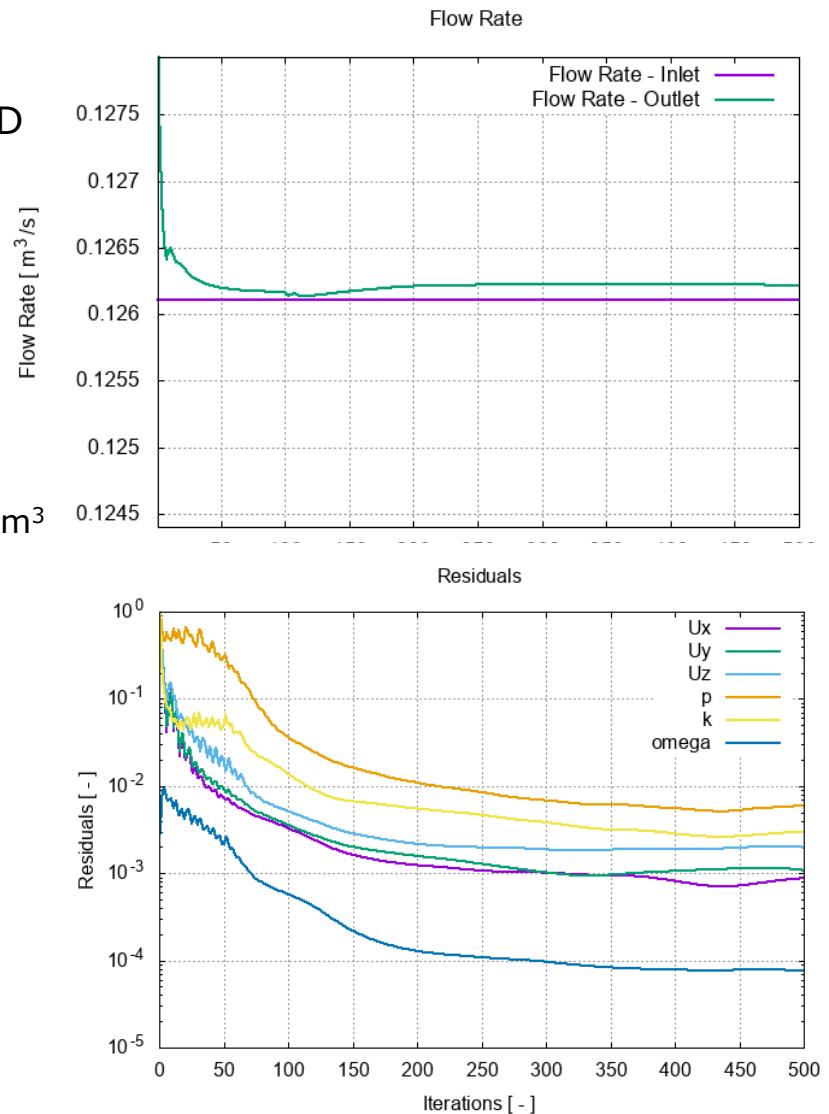
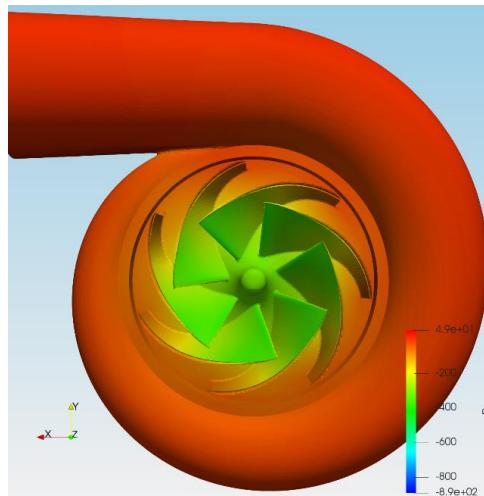
- The main dimensions are kept constant in this study to focus on the Fluid and vibration mode optimization but could be included without any problem in a future run
- No constraint or control of the pump head is applied in this test case

	#	Parameter	Reference	Minimum	Maximum
Meridional Countours	1	LE Hub [%]	0,43	0,4	0,5
	2	LE Shroud [%]	0,15	0,1	0,2
Blade Properties	3	LE Hub Thickness [mm]	0,0043	0,003	0,007
	4	TE Hub Thickness [mm]	0,0043	0,003	0,007
	5	LE Shroud Thickness [mm]	0,0038	0,0015	0,006
	6	TE Shroud Thickness [mm]	0,0038	0,0015	0,006
	7	TE Circumferential Angle at Hub [°]	81	75	85
	8	LE Circumferential Angle at Shroud [°]	0	-5	5
	9	TE Circumferential Angle at Shroud [°]	81	75	85
	10	Blade Angle LE Hub [°]	37	30	40
	11	Blade Angle LE Shroud [°]	15	12	20
	12	Blade Angle TE Hub [°]	26	20	30
	13	Blade Angle LT Shroud [°]	20	15	25



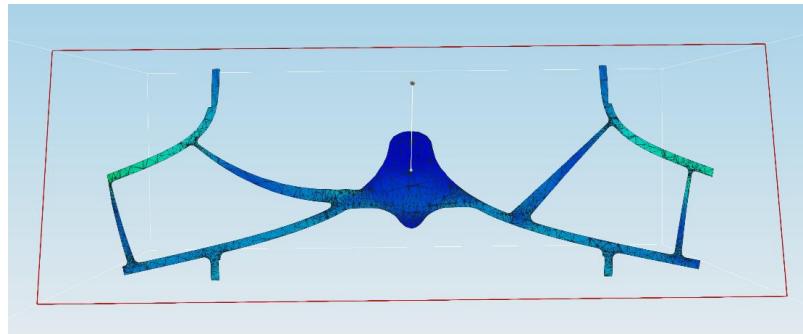
## • Fluid Simulation

- TCFD (Turbomachinery CFD) from CFD Support (Based on OpenFoam)
- Steady Simulation
- 1.200.000 mesh cells
- CPU time 21 minutes on 6 cores
- **Operating Conditions**
  - Incompressible Fluid : water
  - Rotational speed : 1770 rpm
  - Flow rate  $Q = 0,12611 \text{ m}^3 / \text{sec.}$  ( $454 \text{ m}^3 / \text{h}$ )
  - Head : 33m



## • Mechanical Simulation

- 2 Open Source Software: NetGen and CalculiX
- NetGen was recompiled to run in batch mode with full access to the mesh settings and the use of advanced mesh settings
- Pump material : PVC (density= 1400 kg/m<sup>3</sup>, Young Modulus=3500 Mpa, Elastic limit=35 Mpa)
- 143740 nodes, 470071 elements, 1<sup>st</sup> order and fixed nodes wheel hub

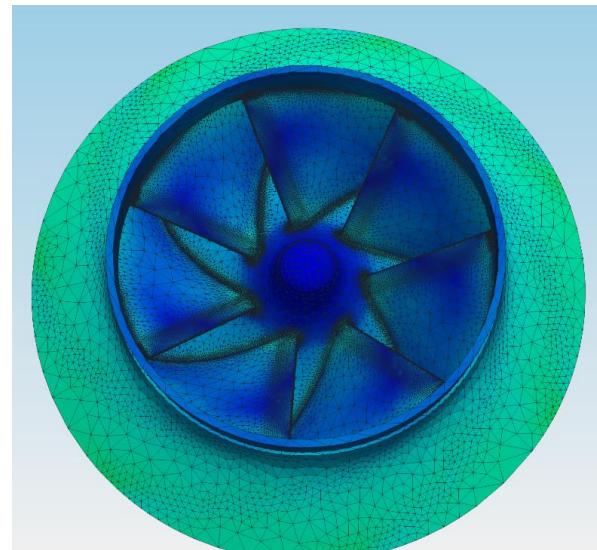
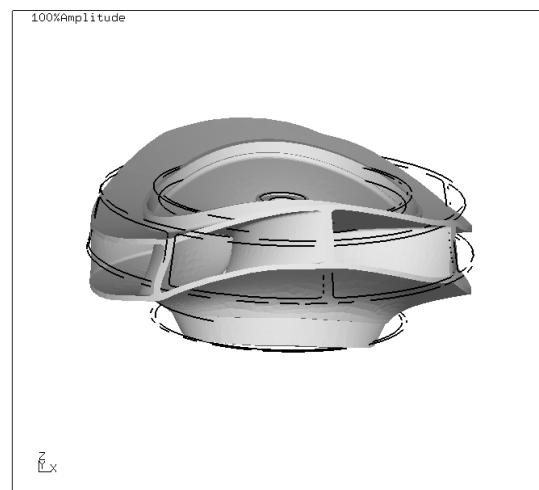


Von Misses Stresses

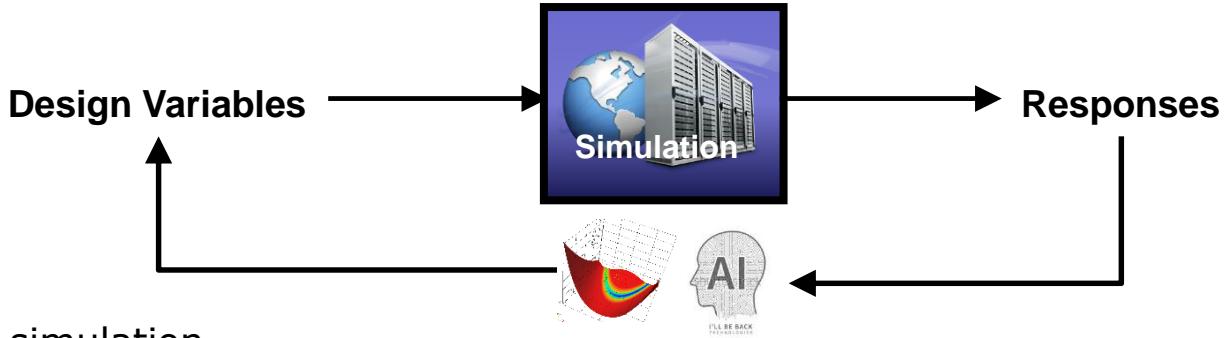
Second vibration mode



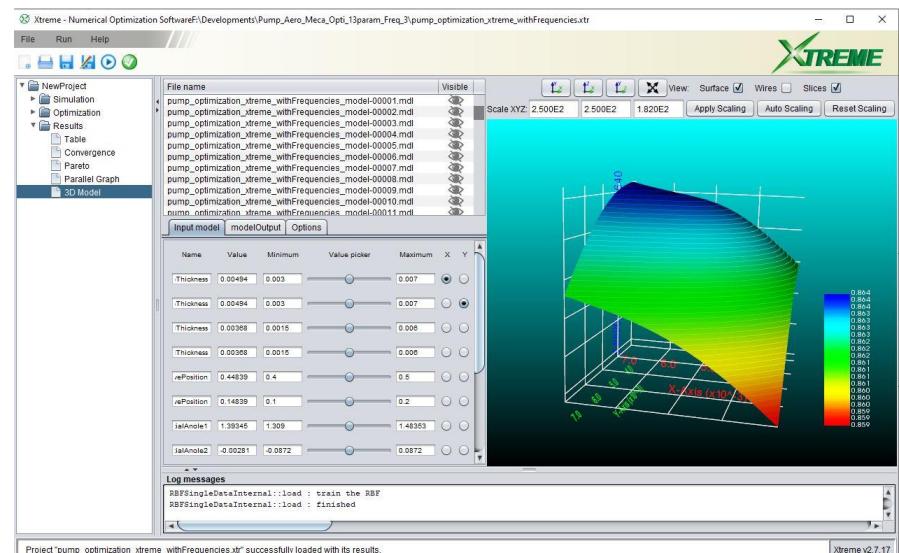
Fifth vibration mode



## • Xtreme Optimizer



- Black box method => any simulation
- Global optimization
- Multiple objectives
- Is capable to deal with uncomputable simulations
- Learning
- Very fast convergence
- Graphical user interface and meta model 3D representation
- Continuous / Integer / Discrete design variables
- Continuous variable optimization and sequence optimization



## • Optimization conditions, objectives and constraints

### - Operating Conditions

- Incompressible Fluid : water
- Rotational speed : 1770 rpm
- Flow rate  $Q = 0,12611 \text{ m}^3 / \text{sec.}$  ( $454 \text{ m}^3 / \text{h}$ )
- Head : 33m
- Pump material : PVC (density= 1400 kg/m<sup>3</sup>, Young Modulus=3500 Mpa, Elastic limit=35 Mpa)

### - Design / Optimization Objective

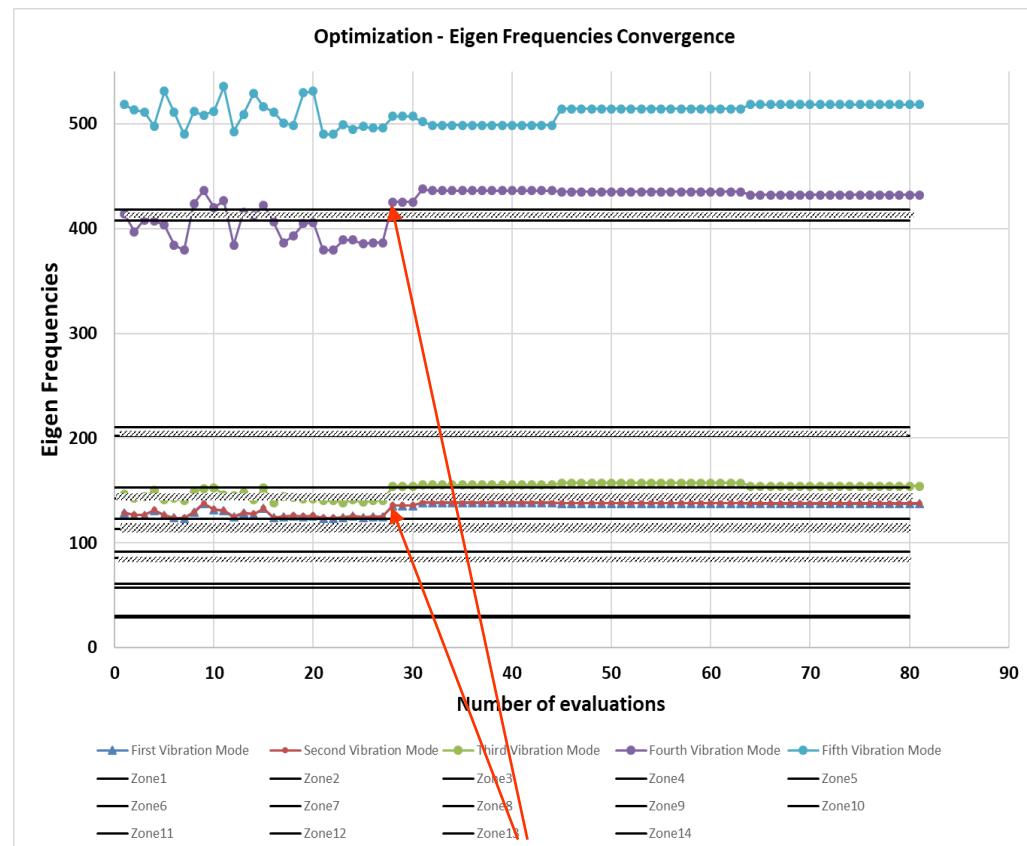
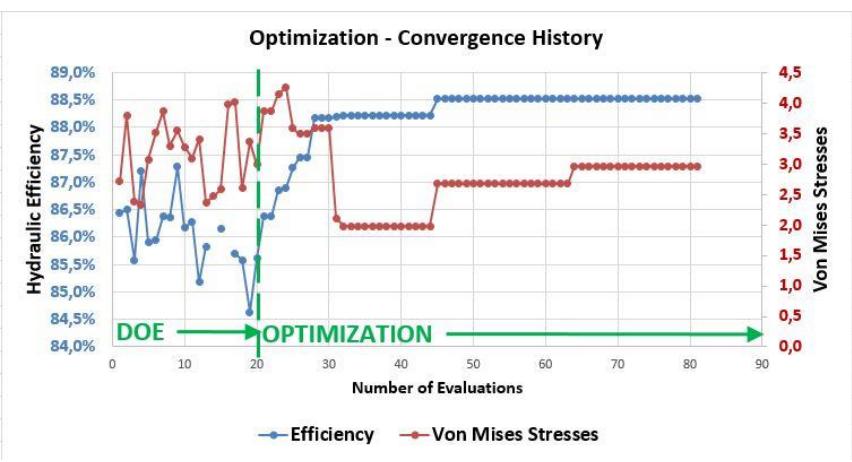
- Maximize Hydraulic Efficiency

### - Design / Optimization constraints

- Limit Mechanical Constraints (Von mises) < 10 MPa
- Constraints on the First 5 Vibration Eigen Frequencies
  - Forbidden frequencies and imposed forbidden ranges:
    - » Rotational frequencies = 29,5 Hz; [28,5, 30,5] Hz
    - » 2 \* Rotational frequencies = 59 Hz; [57, 61] Hz
    - » 3 \* Rotational frequencies = 88,5; [85,5, 91,5] Hz
    - » 4 \* Rotational frequencies = 118; [113, 123] Hz
    - » 5 \* Rotational frequencies = 147,5; [142,5, 152,5] Hz
    - » 7 \* Rotational frequencies = 206,5; [202,5, 210,5] Hz (7 is the number of blades)
    - » 14 \* Rotational frequencies = 413; [408, 418] Hz (14 is twice the number of blades)

## • Optimization convergence

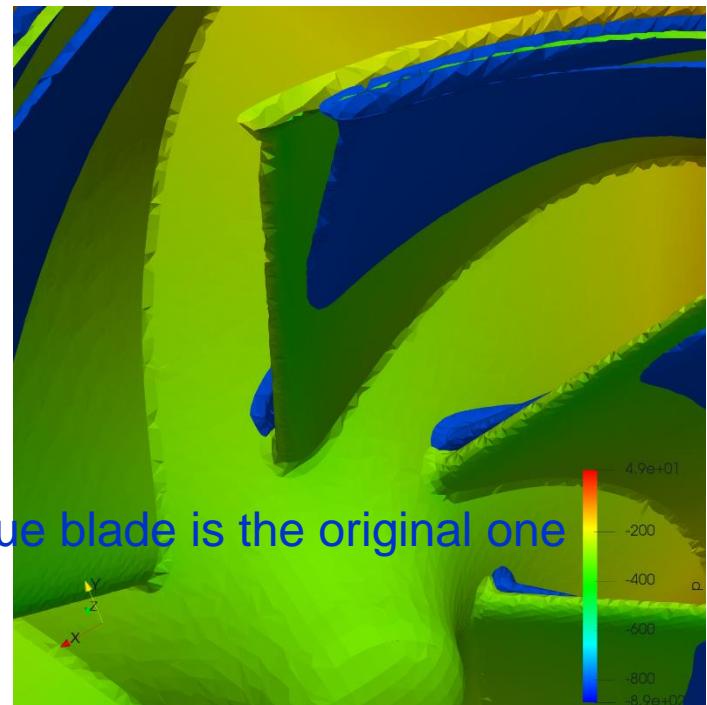
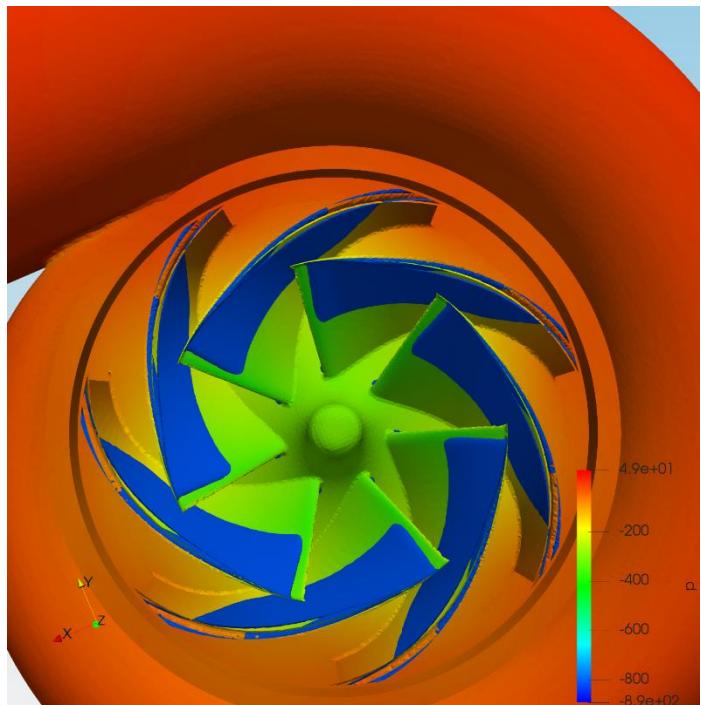
- 20 initial samples
- 60 optimization iterations
- Convergence almost reached after 40 simulation (20 + 20)
- 1 full simulation takes 1 hour
- Full convergence in 2 days on a simple desktop



Jump thanks to the genetic algorithm

## • Optimization results

- Hydraulic efficiency from 86,4 % to 88,5 %
- Von mises stress from 2,71 Mpa to 2,97 Mpa < 10 Mpa
- Eigen frequencies (First 5 modes)
  - From: 128.5; 128.8; 146.4; 413.8; 518.4 Hz
  - To : 137.5; 137.8; 154.2; 432.0; 518.6 Hz



## • Optimization Results

	LE Hub Thickness [mm]	TE Hub Thickness [mm]	LE Shroud Thickness [mm]	TE Shroud Thickness [mm]	Hub Relative Position [%]	Shroud Relative Position [%]	TE Circumferential Angle Hub [°]	LE Circumferential Angle Shroud [°]	TE Circumferential Angle Shroud [°]	Blade Angle LE Hub [°]	Blade Angle LE Shroud [°]	Blade Angle TE Hub [°]	Blade Angle TE Shroud [°]	Efficiency [%]	Max Von Mises Stresses [Mpa]
Min	3	3	1,5	1,5	40	10	75	-5	75	30	12	20	15		
Max	7	7	6	6	50	20	85	5	85	40	20	30	25		
Initial	4,30	4,30	3,80	3,80	43,00	15,00	81,00	0,00	81,00	37,00	15,00	26,00	20,00	86,44	2,71
Best	6,27	3,00	1,50	1,50	40,00	20,00	85,00	-5,00	85,00	30,00	12,00	20,00	15,00	88,52	2,97

Efficiency +2,1 %

## • Optimization Time

	Samples Initial DOE	Simulation Time	Simulation Time / sample	Samples at Final Optimization	Optimization Time
Min	20	20h	60 min	63	63 h

Desktop PC

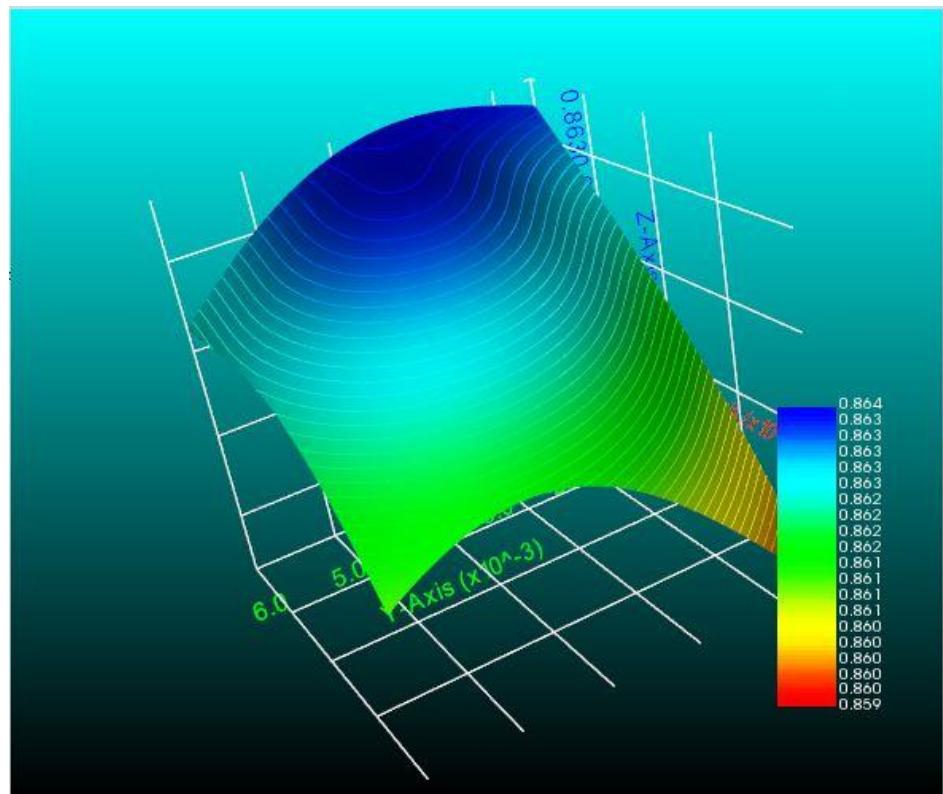
Intel Core i7-3930K @ 3.20GHz, 6 cores  
32 GB RAM

## • Uncomputable simulations

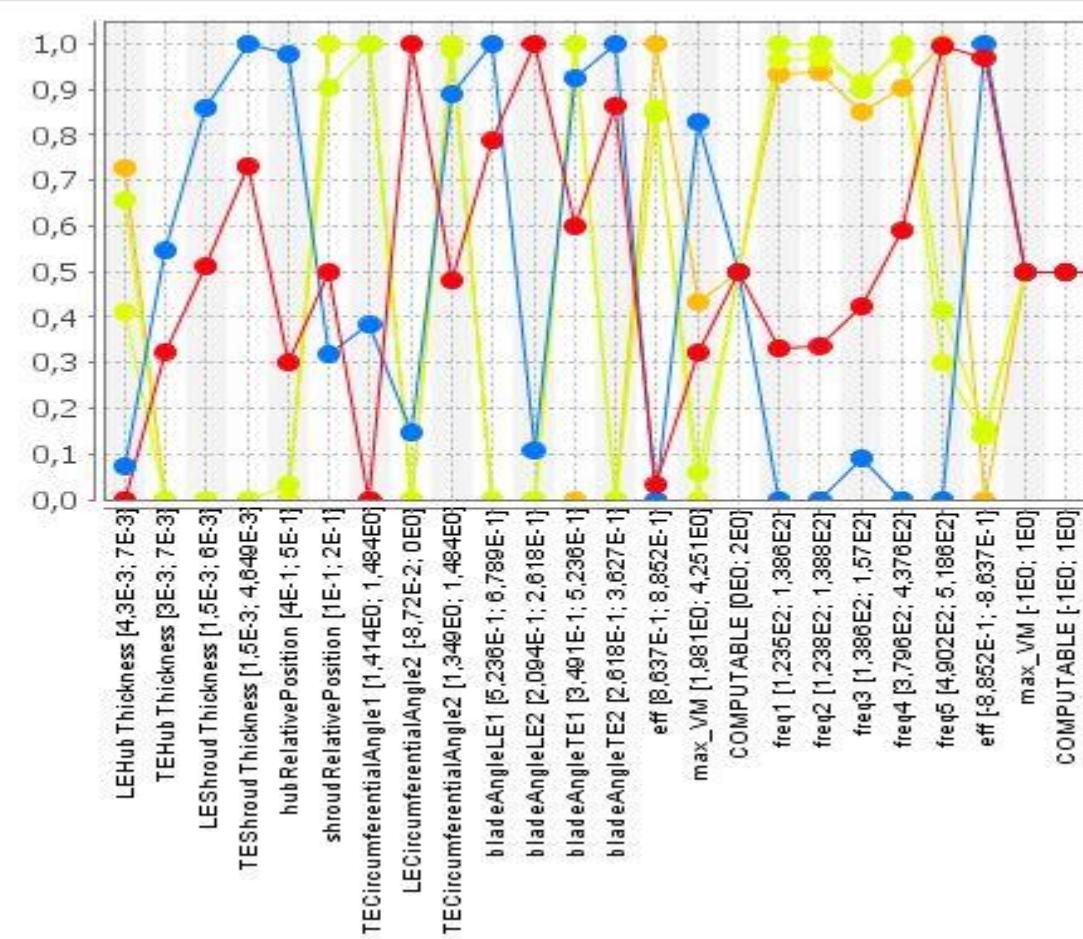
- 80 simulations performed
- All Geometry successful
- 6 CFD calculations not converged
- All mechanical meshes successful
- All mechanical simulations OK

- Response Surface / Sensitivity Analyses

- Thanks to the neural network approximate model of Xtreme, the response surfaces are available in any variables
- This example shows:
- Efficiency =  
 $fct(LEHubThick, LESHroudThick)$



- Response Surface / Parallel coordinates plot



## • Conclusions

- Full Fluid-Mechanical Optimization Demonstrated
  - 13 parameters in less than 60 simulation runs
  - Wall clock time less than 60 hours on a normal single processor desktop
  - Vibration frequencies taken into account
  - Robust simulation and optimization procedure
- Possible Next Steps
  - More and/or Different Design Variables : number of blades, hub/shroud contours, volute, etc.
  - Unsteady Simulation
  - Static Interaction between Fluid and Mechanic
    - Ready at Optimal computing but not demonstrated inside an optimization case
    - Apply Fluid Pressure on Mechanical Computation
    - Apply Mechanical Deformation on Fluid Simulation

Thanks to CFTurbo GmbH and CFD Support s.r.o. (TCFD) for licenses and support