Silesian University of Technology

Institute of Power Engineering and Turbomachinery

Research on Flow Phenomena in Turbomachinery
IPET

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ERCOFTAC Spring Festival 2011, Gdansk

Overview

- information about the Institute
- two-phase flows
- aerodynamic noise calculations
- optimisation problems
  - seal with honeycomb land at turbine blade tip
  - convective blade cooling with CHT
- experimental work
  - comprehensive investigations of the unsteady flows
  - wet steam test rig

Information about the Institute

Director: Prof. Marek PRONOBIS

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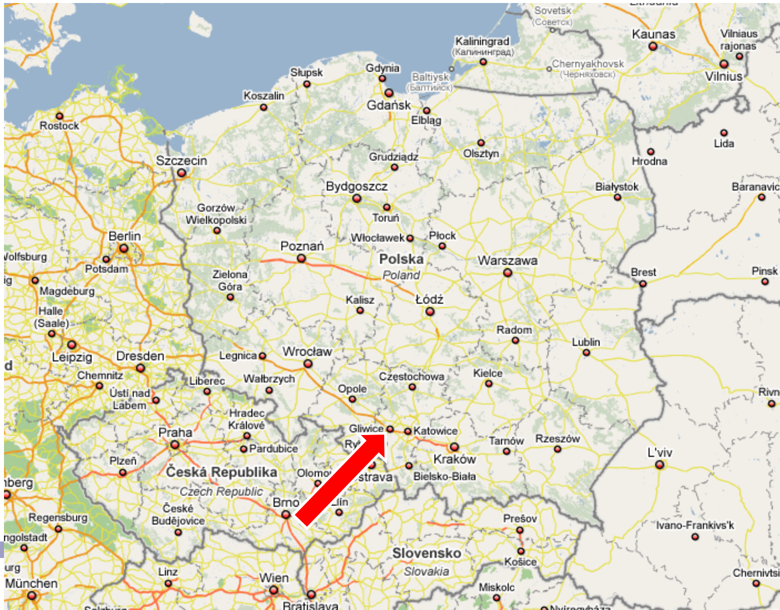
Structure:

- **Division of Flow Machines and Power Systems**
  HEAD: Prof. Henryk ŁUKOWICZ
- **Division of Boilers and Steam Generators**
  HEAD: Prof. Marek PRONOBIS
- **Division of Metrology and Power Processes Automation**
  HEAD: Prof. Janusz KOTOWICZ
- **Division of Power Machinery Design and Operation**
  HEAD: Prof. Andrzej RUSIN



Information about the Institute

Research and academic staff

- 4 full professors
- 5 assoc. professors
- 26 assistant professors
- 2 docents
- 3 lecturers
- 16 PhD students
- 8 engineering and technical staff members
- 5 administrative staff members

Information about the Institute

Main research activities

- Development of calculation and measuring techniques for analysis of physical phenomena in steam and gas turbines, compressors, pumps, steam boilers and heat exchangers
- Modernisation of power plant systems and thermal cycles
- Life-time and risk assessment of power plant components
- Operational control of machines
- New technologies in power and heat generation
- Post-combustion carbon capture (amines)

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Two-phase flows

Main research topics:

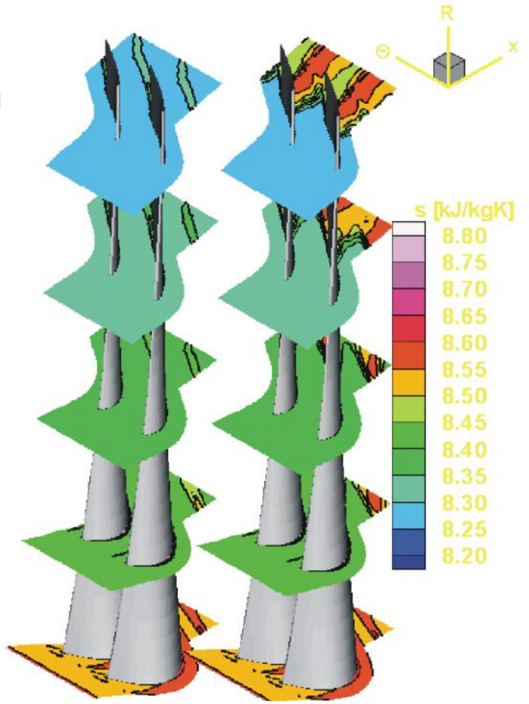
- steam turbine - wet steam flows with condensation
- wing - flows of moist air

Numerical tools:

- ANSYS CFX
- In-house code TraCoFlow

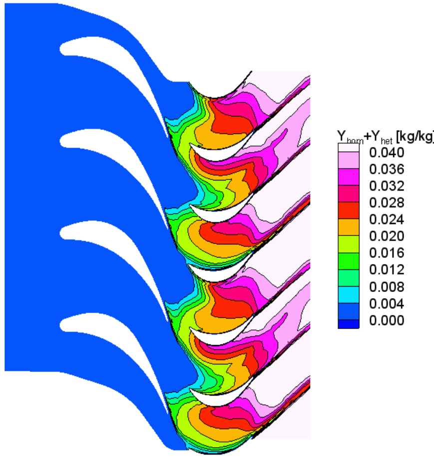
TraCoFlow - Physical Model

- 3-D flow, turbulent, high-speed, two-phase
- real gas model for steam
- Single-Fluid Model
- no interaction between droplets
- homogeneous condensation
- heterogeneous condensation on insoluble and soluble particles
- flow through blade passages in the multistage turbine
- flow is steady-state – averaging procedure between blade rows



Adiabatic *Diabatic*

Entropy



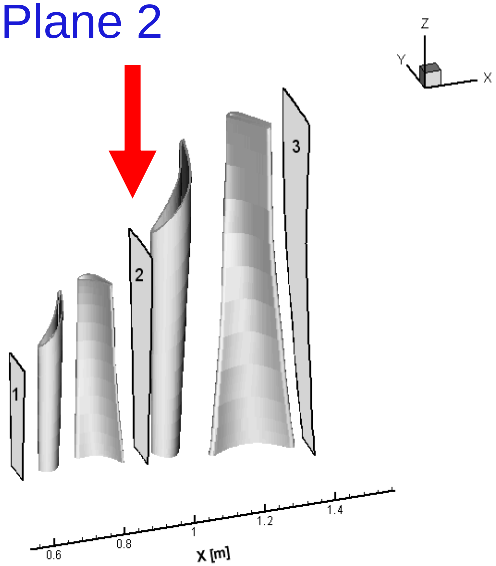
Wetness

Two-phase flows

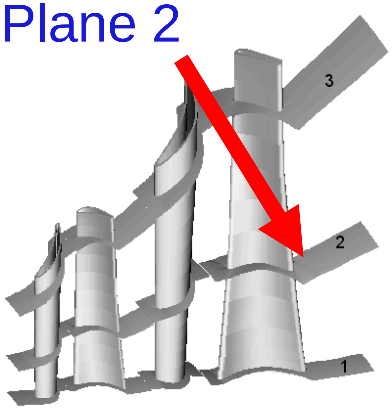
Homo/Heterogeneous condensation on soluble impurities

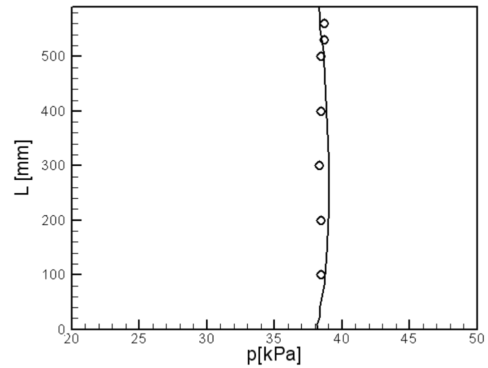
Calculation results

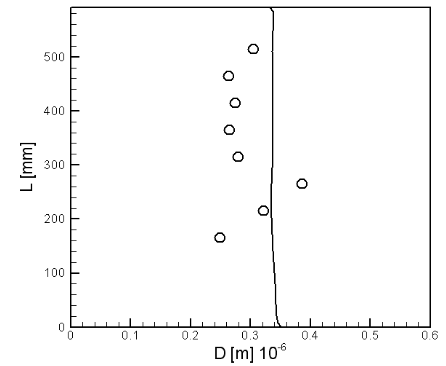
Plane 2

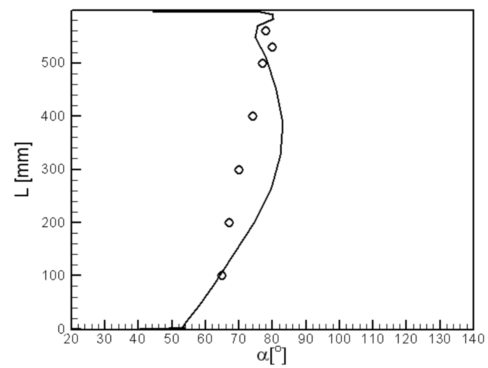


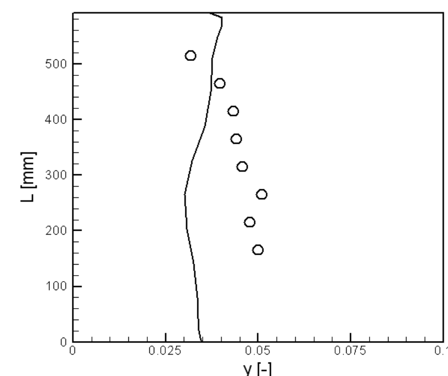
Plane 2



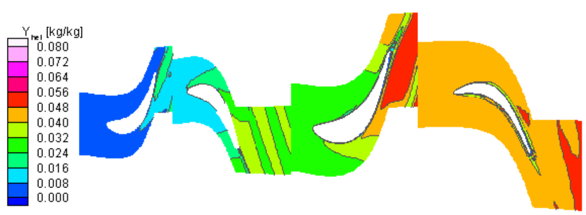




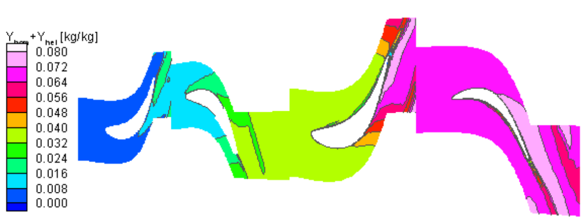




Heterogeneous wetness fraction



Global wetness fraction



Two-phase flows

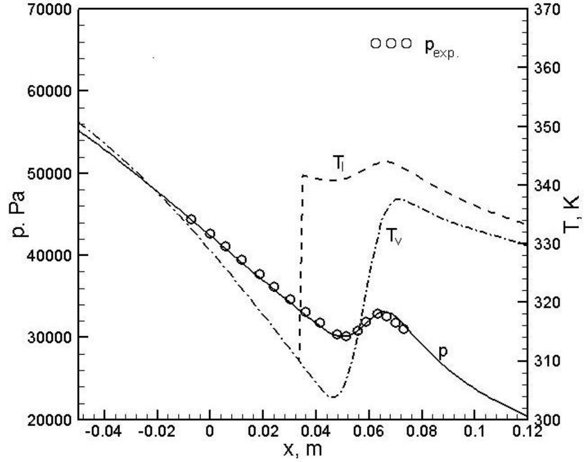
Ongoing project:

Extension of the TraCoFlow to the Two-Fluid Model

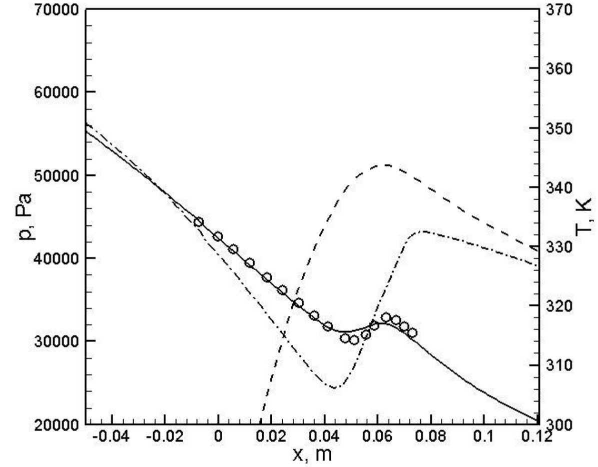
- velocity slip between phases
- separate sets of governing equations for water and vapour
- implementation of droplet size distribution

Barschdorff nozzle

p_0 = 78 390 Pa, T_0 = 380.55 K



Single-Fluid Model



Two-Fluid Model

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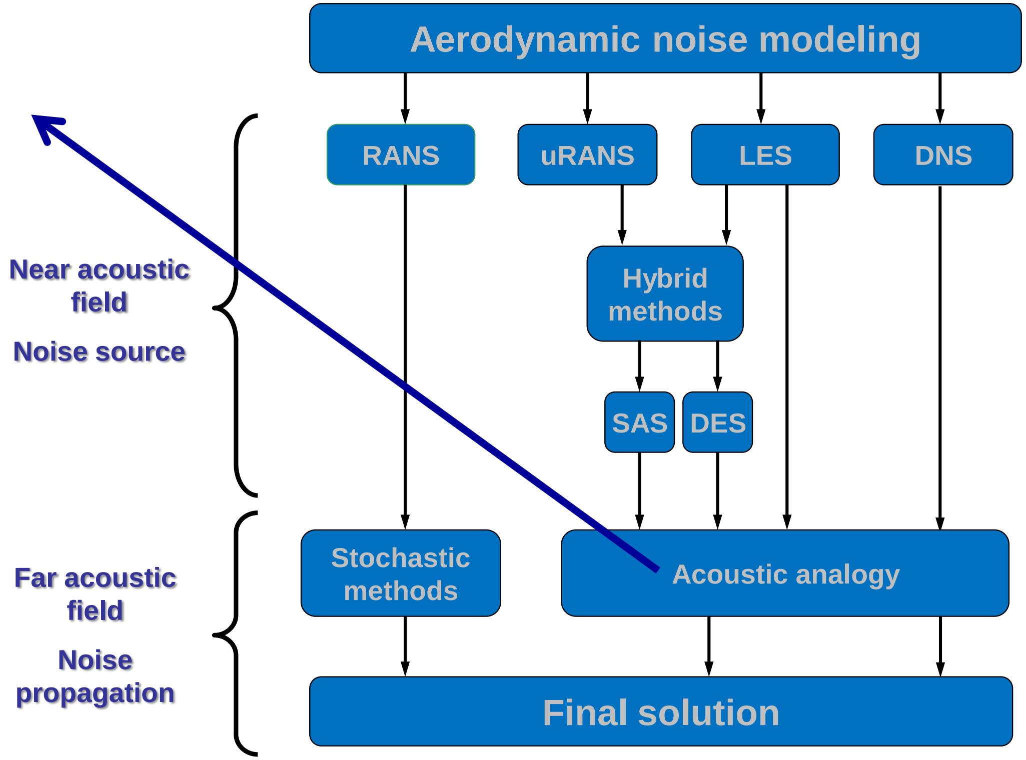
Acoustic analogy

(Euler acoustic postprocessor - EAP)

- The Euler equations are formulated using decomposition of the actual variables into the mean flow part and fluctuating part
- The Euler equations for fluctuating variables are solved



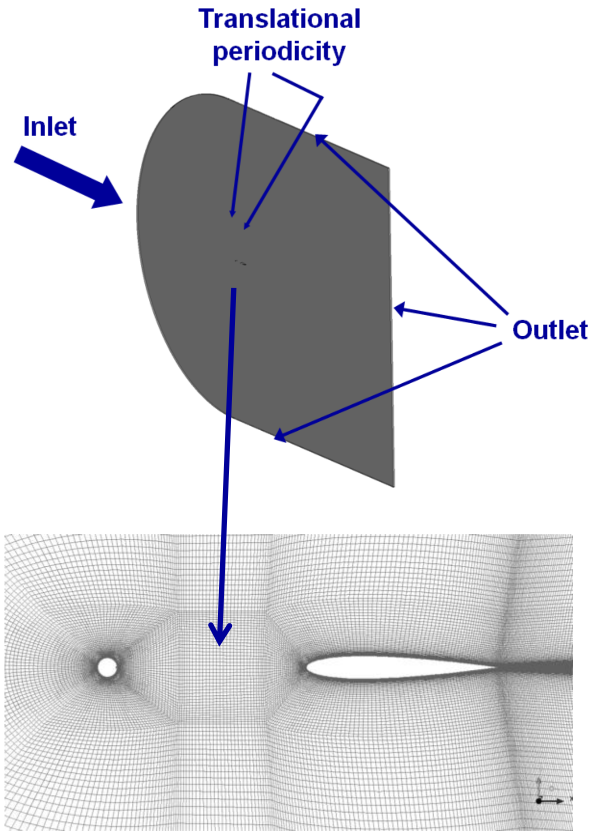
The solver uses:

- Finite volume method
- 3rd Order spatial discretisation
- 3rd Order time integration (explicit Runge-Kutta method)

Flow around cylinder and airfoil

Case data:

Inlet velocity: - 70 m/s
Averaged static pressure - 1 bar
Time step size: - Δt=1e-5 or 5e-6 (LES)
Total time step number: - 4000
FFT analysis: - last 2048 time steps
Calculation time: - 10-20 days
(7x2CPU IntelXeon 2.6GHz)



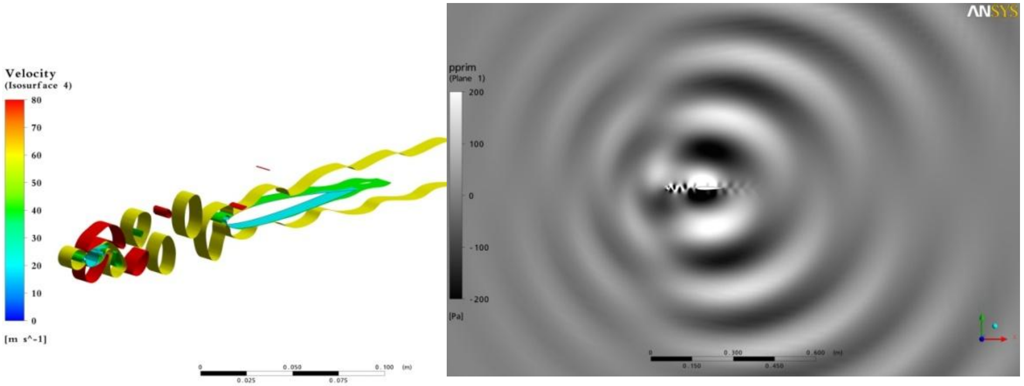
The calculations were performed with different tubulence models:

- **uRANS – SST (2D)**
- **SAS – Scale Adaptive Simulation**
- **DES – Detached Eddy Simulation**
- **LES – Large Eddy Simulation**

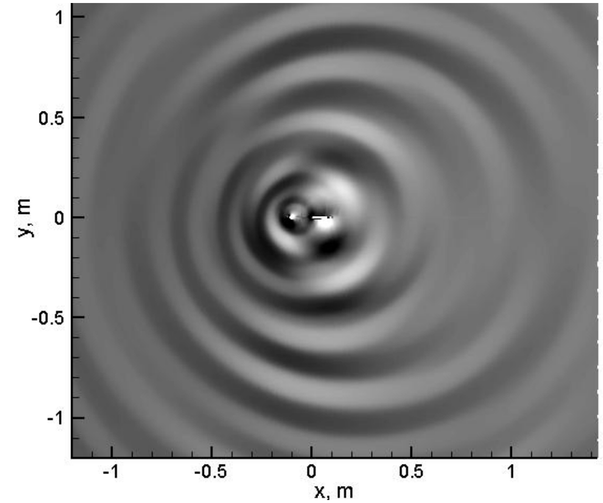
	uRANS	SAS, DES	SAS, DES	LES
Number of nodes in spanwise direction	5	25	40	40
Spanwise distance	2mm	20mm	20mm	20mm
Spanwise grid resolution	0.4mm	0.8mm	0.5mm	0.5mm
Domain size	0.413 M	2 M	3.4 M	3.4 M

CFD results – uRANS SST, SAS, EAP

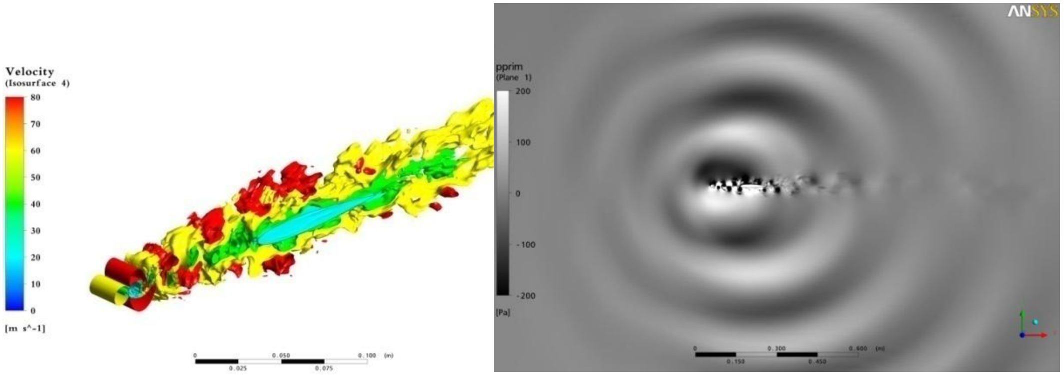
$p' = p_{instantaneous} - p_{mean}$



Velocity and acoustic pressure distribution - uRANS SST 5 layers



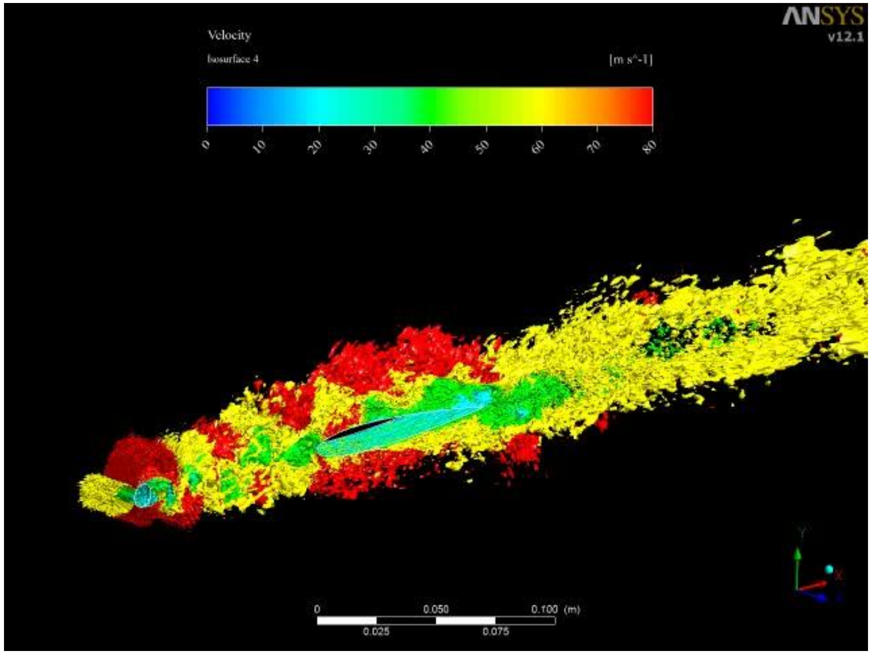
Euler Acoustic Postprocessor results

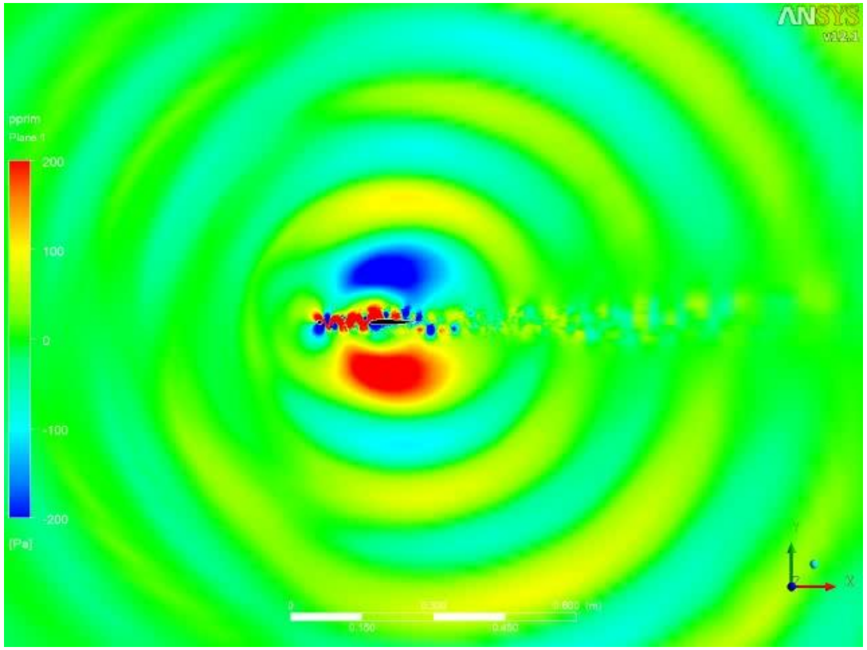


Velocity and acoustic pressure distribution - SAS 40 layers

CFD results – LES

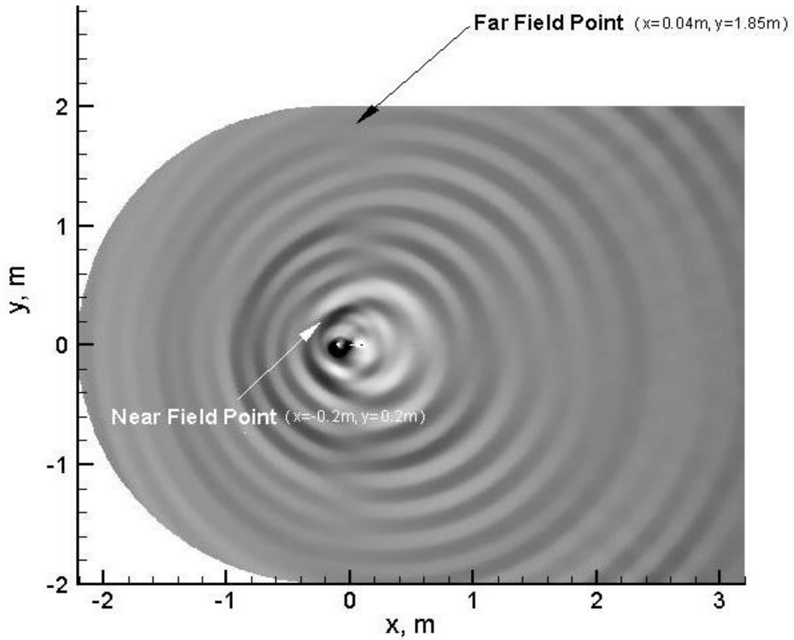
$p' = p_{instantaneous} - p_{mean}$



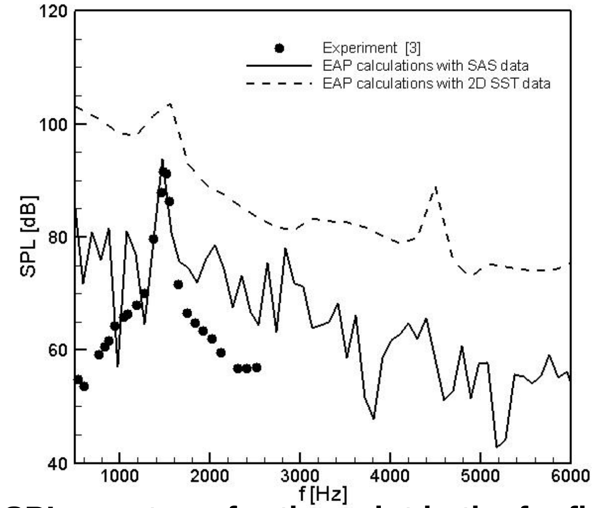


Velocity distribution and acoustic pressure distribution – LES model

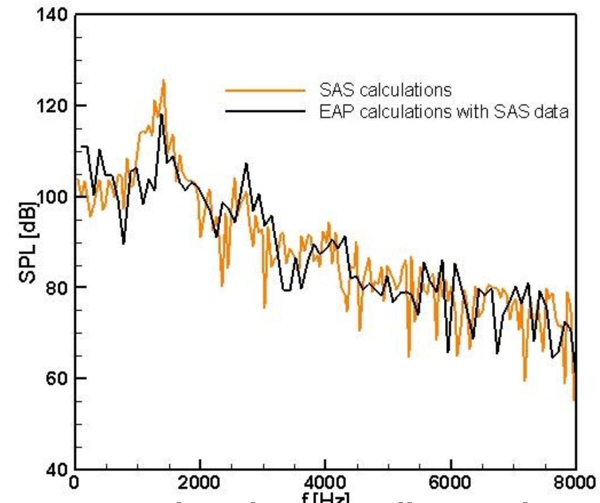
Far field noise propagation - Euler acoustic postprocessor results



The size of the used uniform numerical mesh is about 100k nodes. At least 10 points per wave length were used.



SPL spectrum for the point in the far field



Comparison between direct noise calculations and acoustic analogy for the point in the near field

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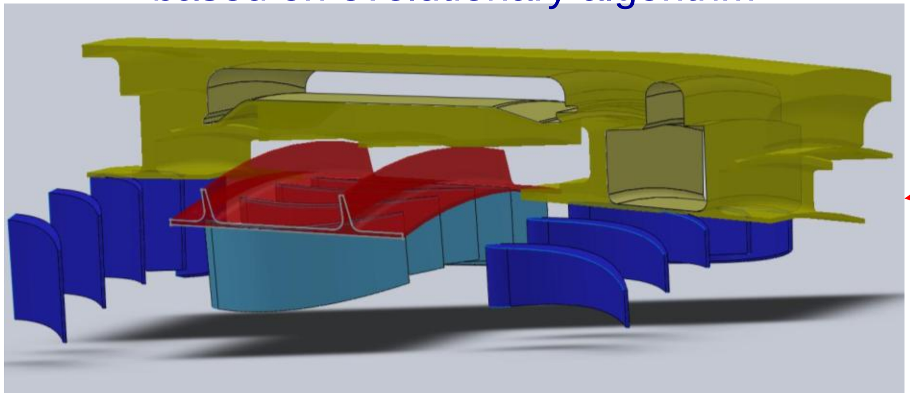
Optimization problems
seal with honeycomb land at turbine blade tip

Aim

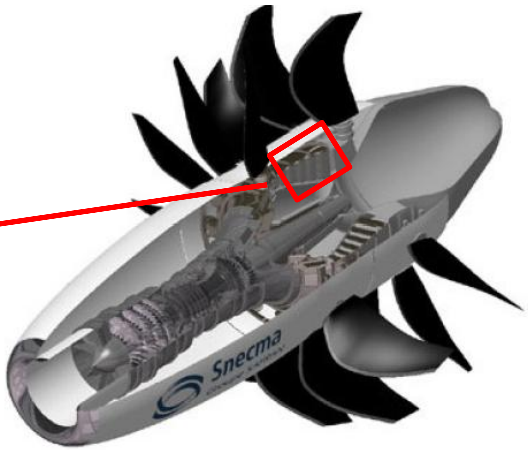
- optimal geometry configuration of the blade tip seal with honeycomb land to reduce the leakage flow
- assessment of thermal conditions in the cavity and in the seal region

Tools

- Goal Driven Optimization implemented in ANSYS Workbench
- In-house optimization code based on evolutionary algorithm



Tip region of the blade - LP turbine



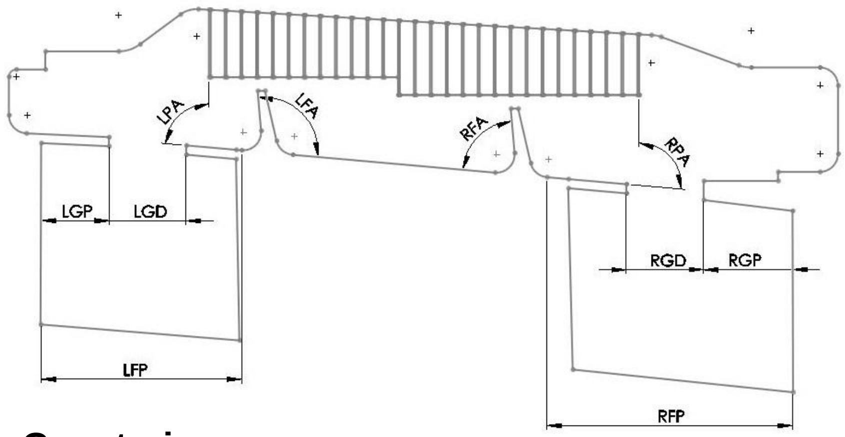
Engine with contra-rotating open rotor

Optimization problems

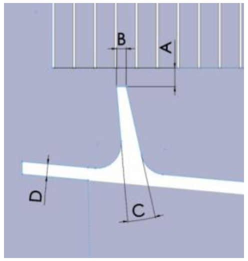
seal with honeycomb land at turbine blade tip

Parameters description

The goal is to minimize the mass flow rate through the tip seal.



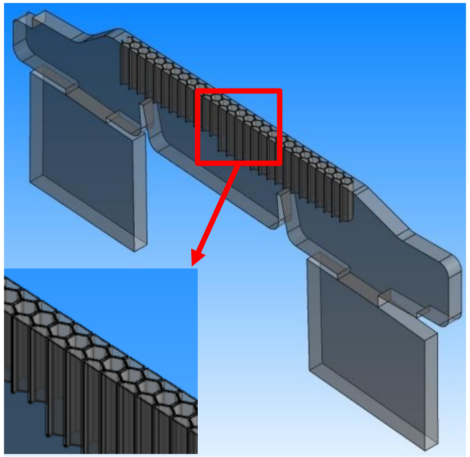
Constants



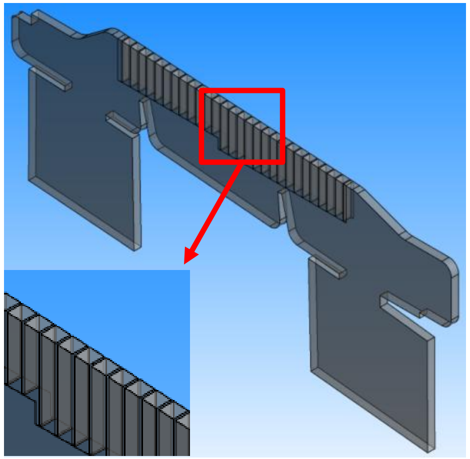
Constrains

No	Parameter	Shortcut	Limits of changes, %	
1	Left fin angle	LFA	-5.0	25.0
2	Right fin angle	RFA	-31.3	6.3
3	Left fin position	LFP	0.0	22.5
4	Right fin position	RFP	0.0	11.0
5	Left platform angle	LPA	-17.6	0.0
6	Right platform angle	RPA	-10.6	0.0
7	Left gap dimension	LGD	-17.6	17.6
8	Right gap dimension	RGD	-17.6	17.6
9	Left gap position	LGP	-12.8	3.4
10	Right gap position	RGP	-8.7	8.7

Geometry simplification



3D unstructured mesh



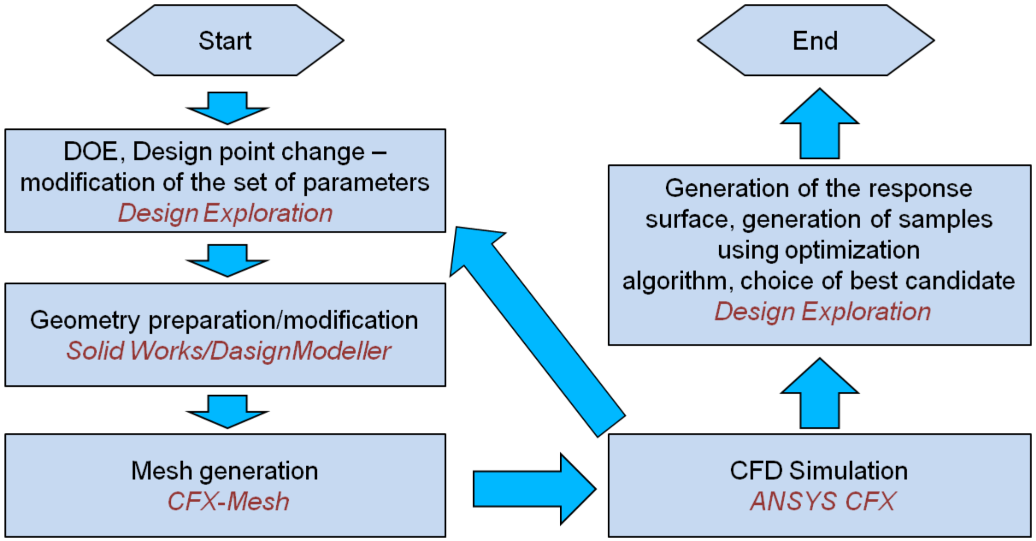
Extruded 2D unstructured mesh

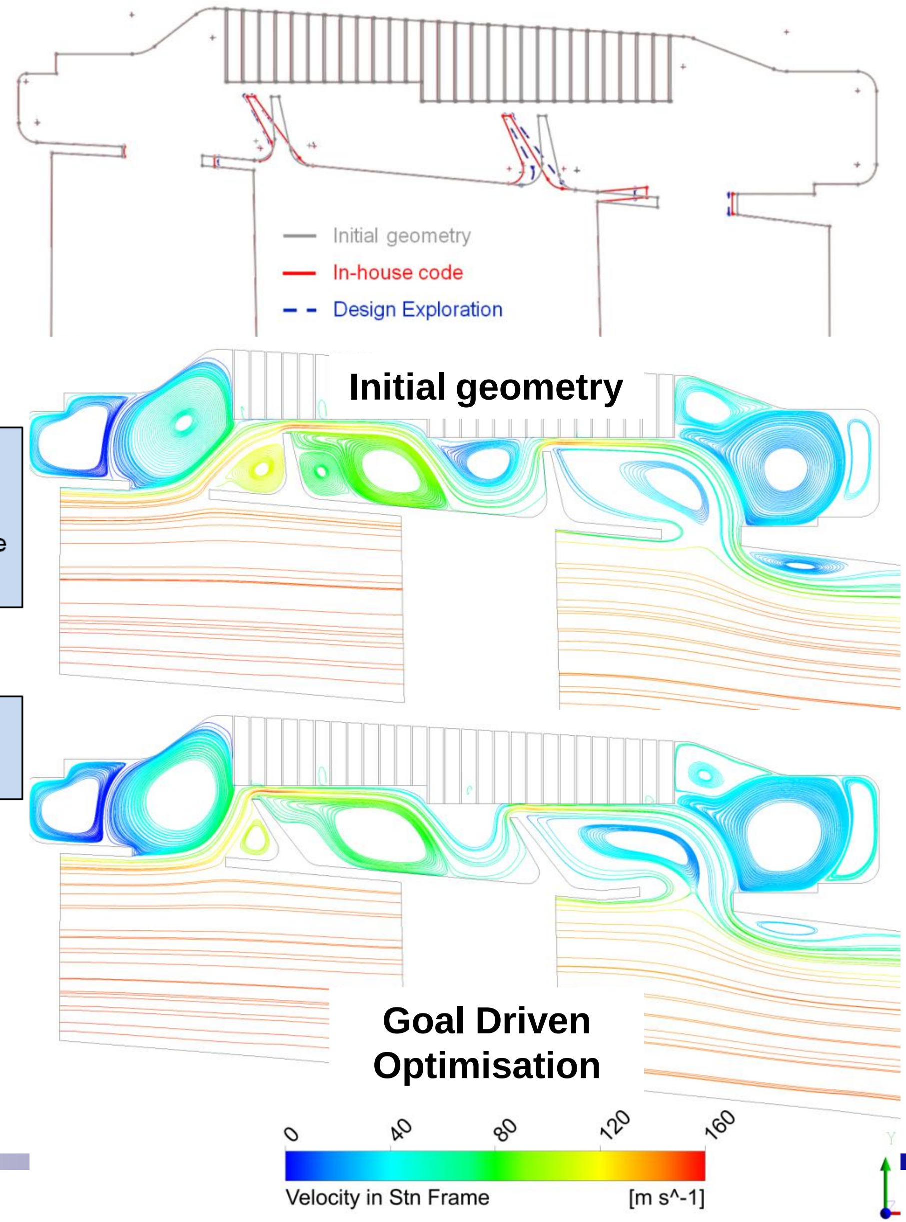
Optimization problems

seal with honeycomb land at turbine blade tip

Optimization procedure

Goal Driven Optimization





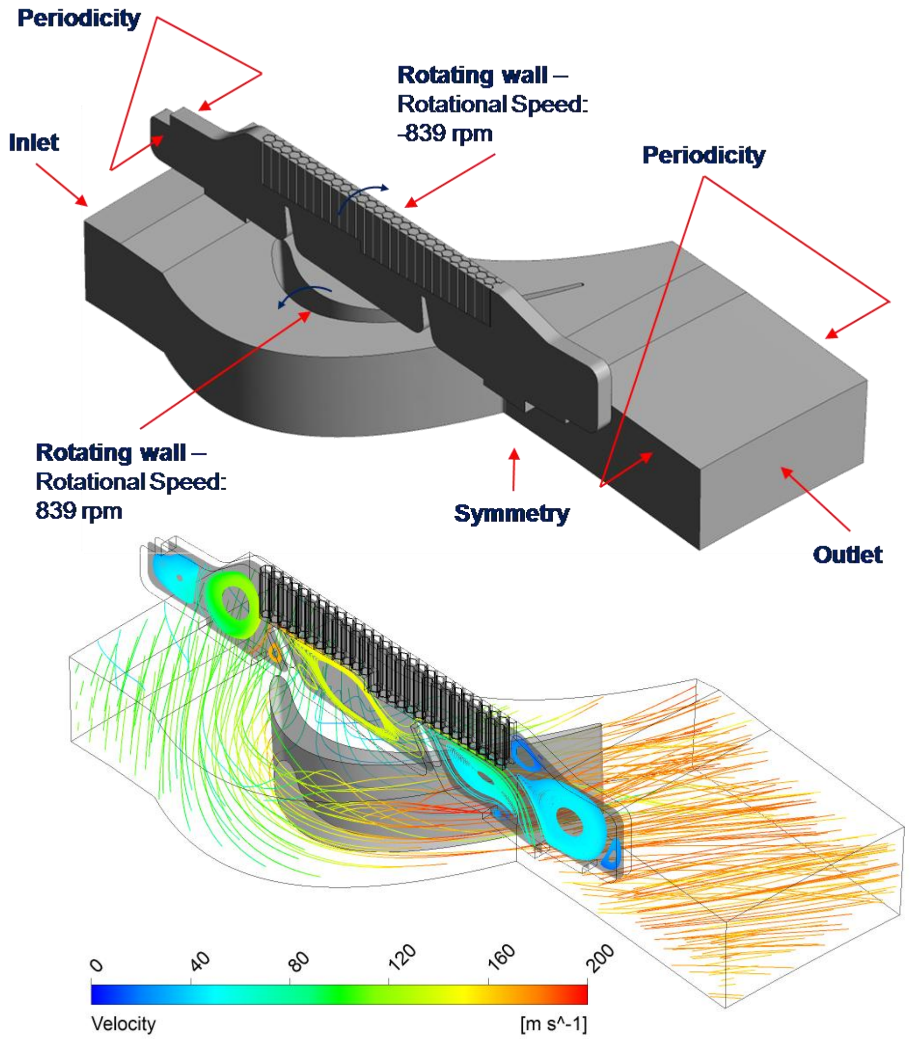
mass flow rate reduction 16% for GDO

Optimization problems
seal with honeycomb land at turbine blade tip

Verification

- Full structure of the honeycomb land
- 3D blade-to-blade channel
- 3.4M nodes hexa dominant mesh in the seal area
- 1.8M nodes hexa mesh in the blade-to-blade domain

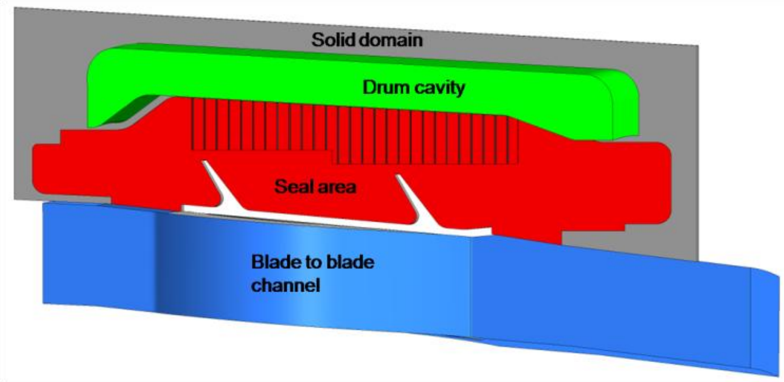
mass flow rate reduction 14.3%

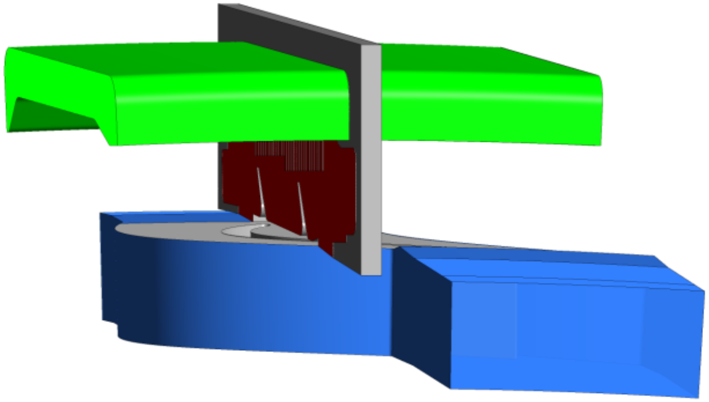


Optimization problems

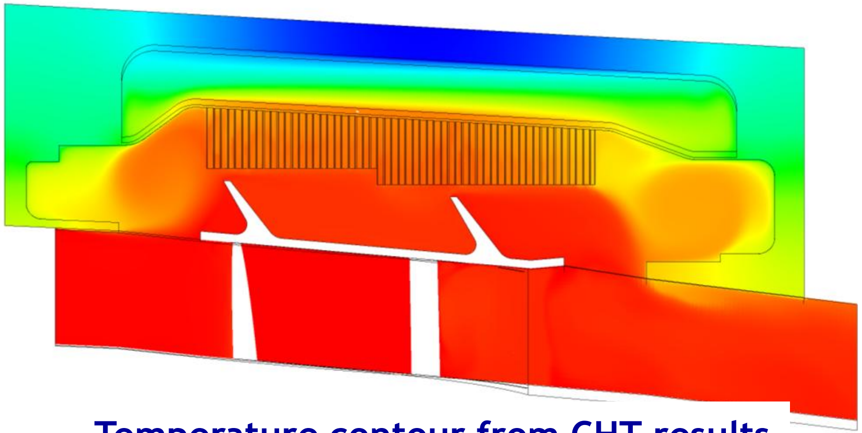
seal with honeycomb land at turbine blade tip

CHT analysis





Geometrical model for CHT analysis



Temperature contour from CHT results

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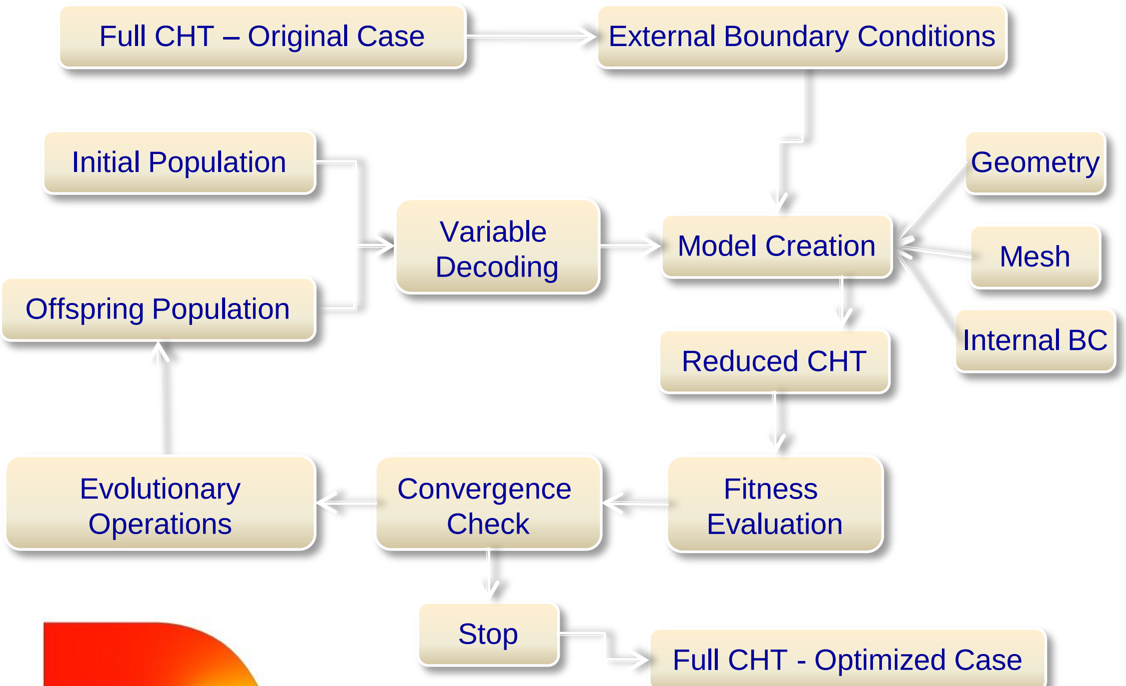
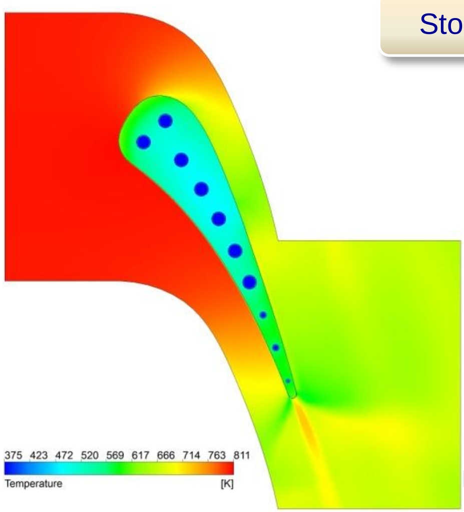
Cooling system optimization of turbine blades

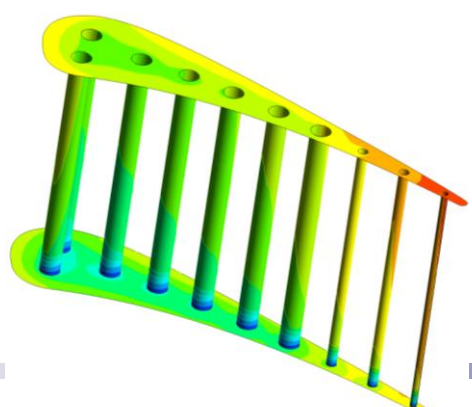
- Optimization of location and size of circular cooling passages within a turbine blade
- Shape optimization of non-circular cooling passages
- The task solved with an in-house optimization software based on the evolutionary algorithm. The software cooperates with commercial FEA/CFD systems
- Multi-objective and multidisciplinary optimization problem solved with both a weighted single-objective function and the Pareto approach
- A novel methodology based on CHT computations involved in the optimization

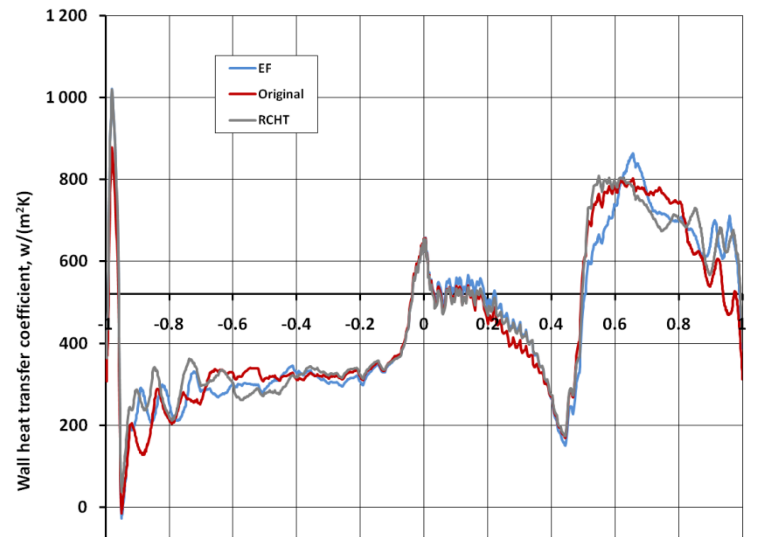
Cooling system optimization of turbine blades

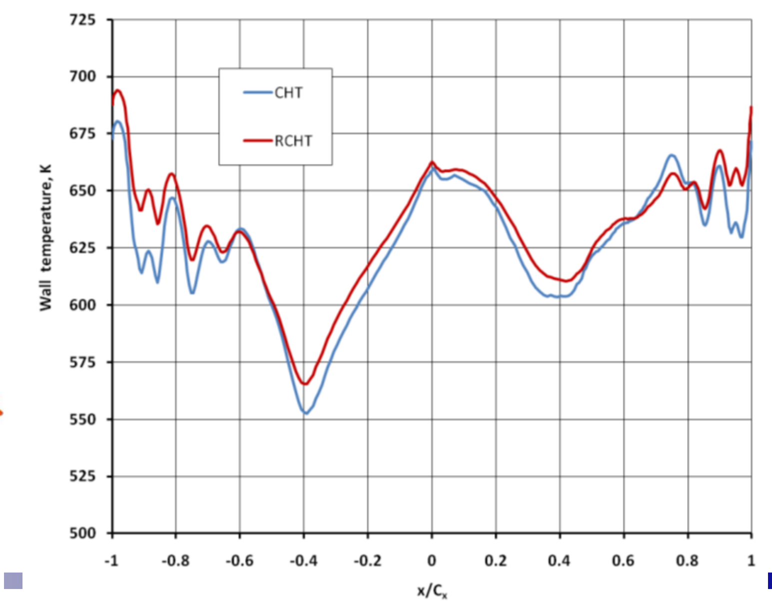
Computational Process





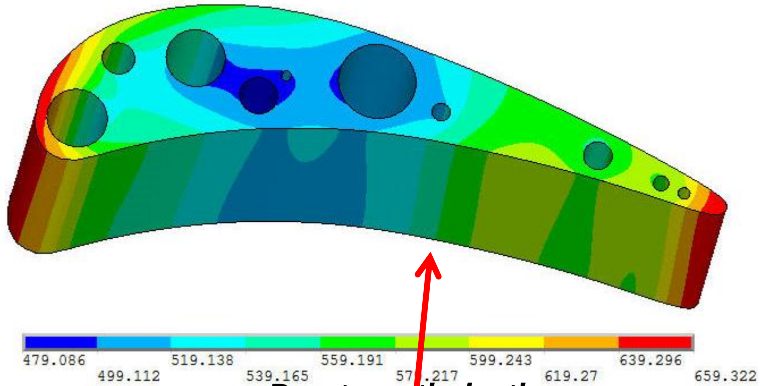




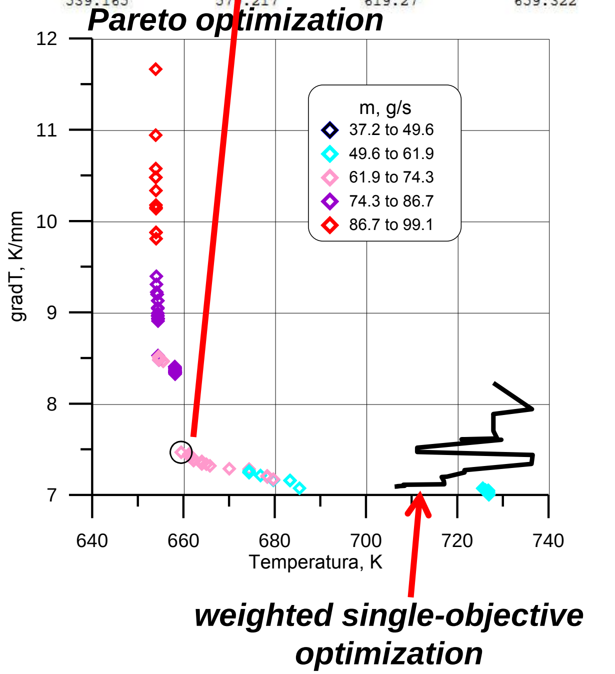


Cooling system optimization of turbine blades

Cooling structure and shape optimization



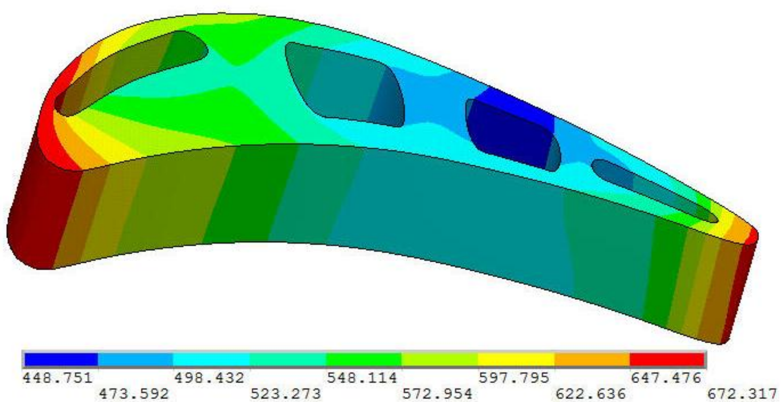
Pareto and weighted single-objective optimization of a blade cooled with circular and complex passages



Due to optimization the number, size and location or shape of passages change

The optimization allows operational improvement by reduction in:

- solid temperature
- thermal load
- coolant mass flow



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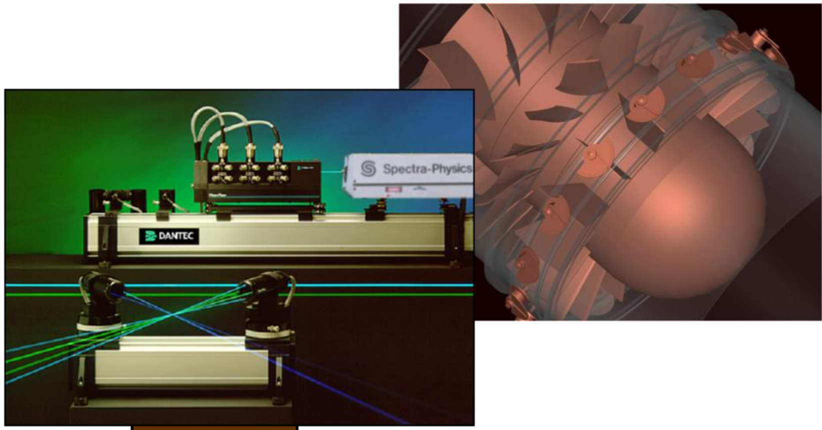
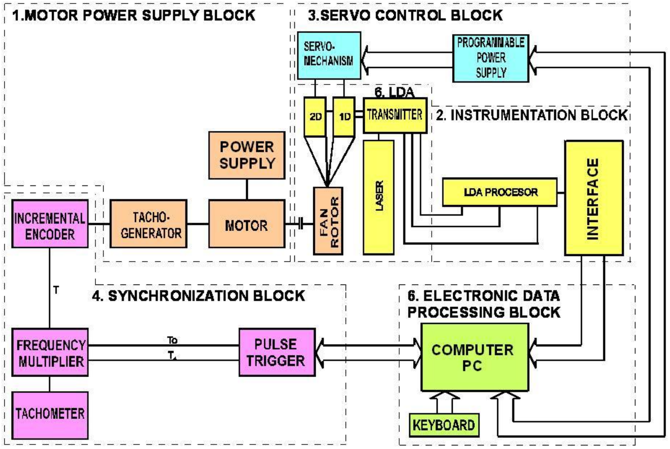
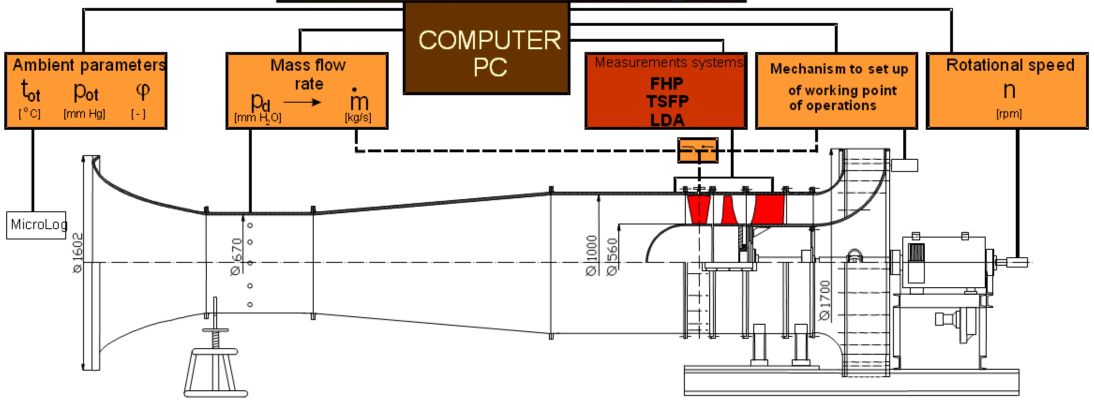
Comprehensive investigations of the unsteady flow



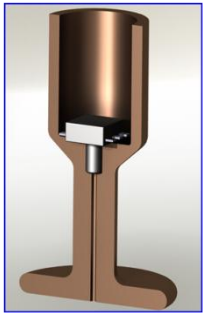
The objectives of the study are experimental and computational investigations of the unsteady flow in the axial low speed compressor stage





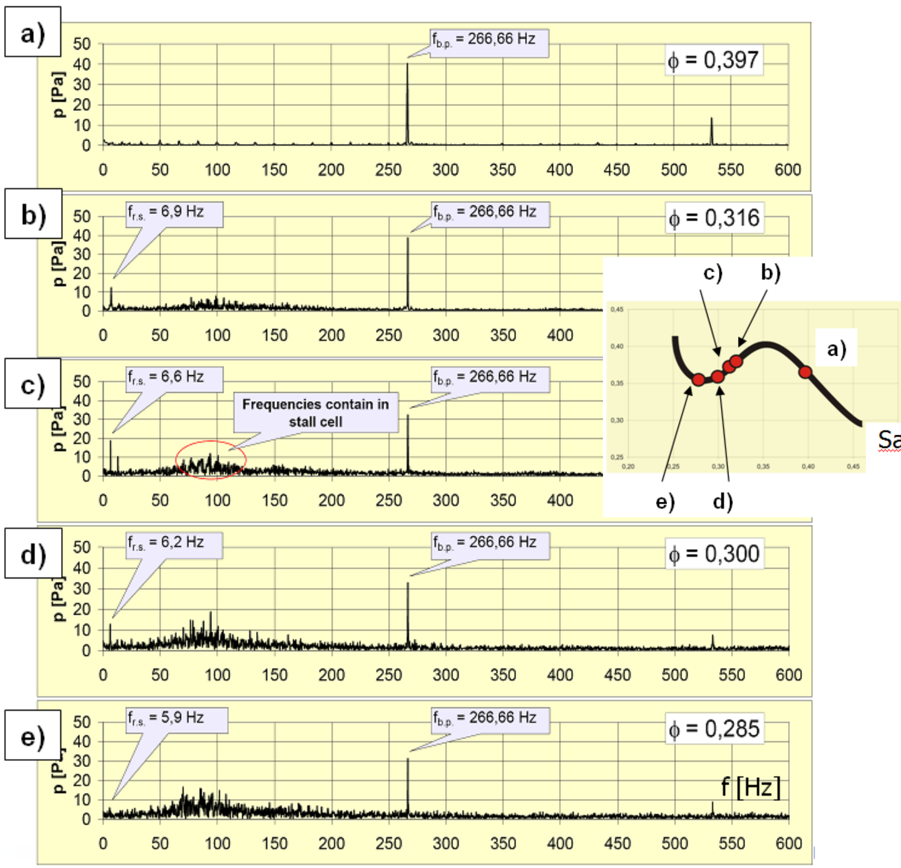
Three measuring systems based on the different principles are used:

- **TSFP** - 2-sensors fast response straight and 90 degree triple split fiber probes
- **3D-LDA** - Three-dimensional Laser Doppler Anemometer system.
- **HFPT** - High frequency pressure transducers to measure unsteady pressure field on rotor casing (in-house)



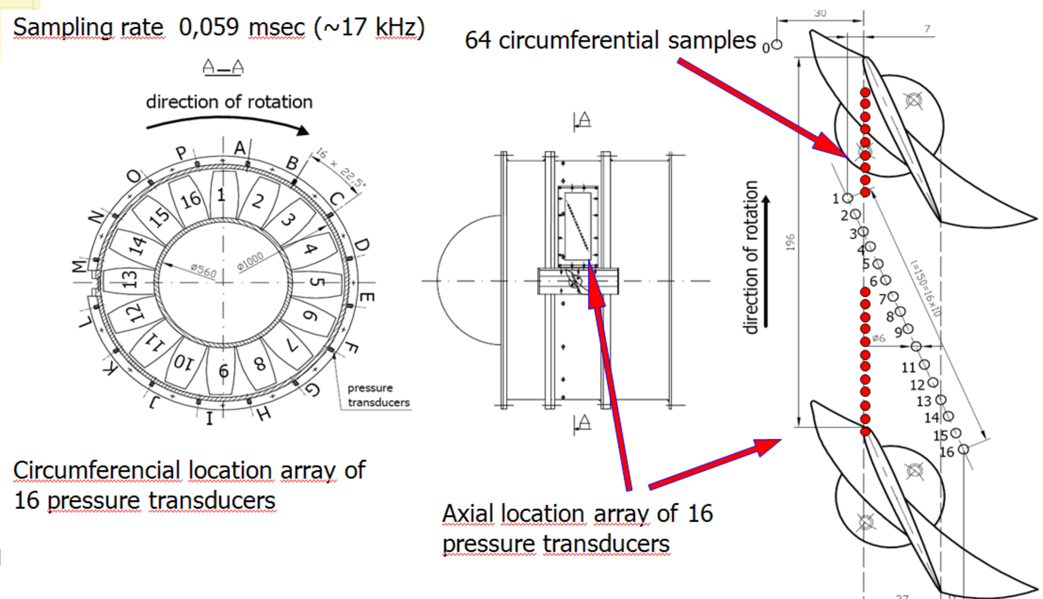
Comprehensive investigations of the unsteady flow

Detecting and analyzing rotating stall inception



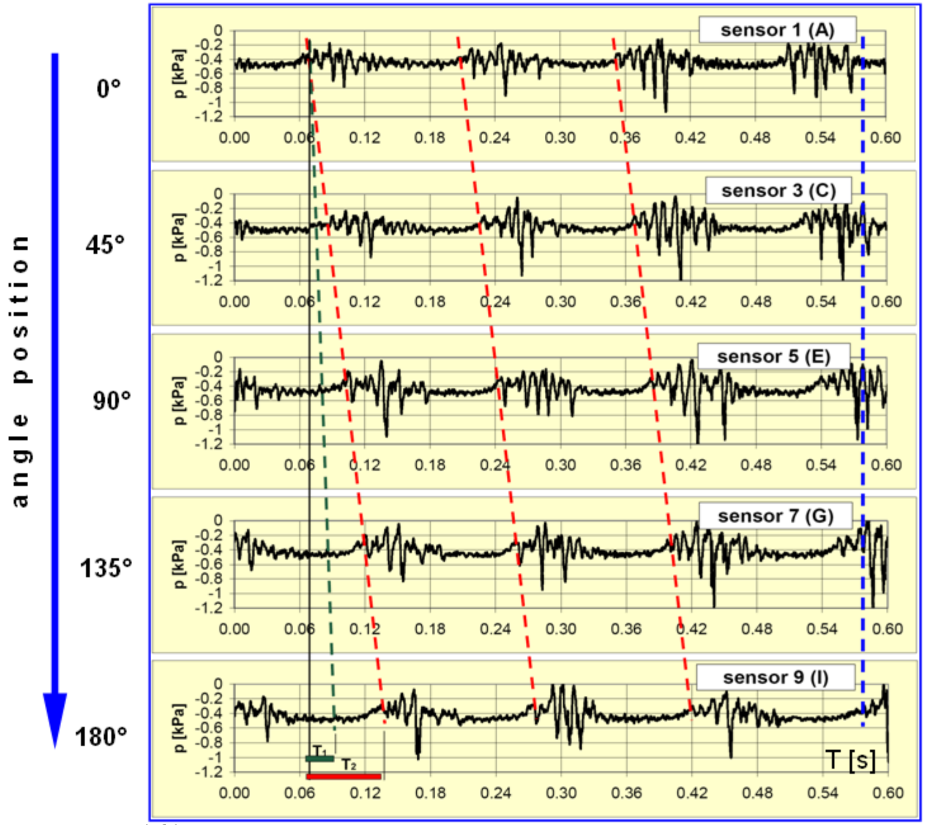
Periodic multisampling and averaging technique was applied with a high response pressure sensor to obtain phase locked pressure distribution and its fluctuation on the casing wall in the axial, radial and circumferential directions.

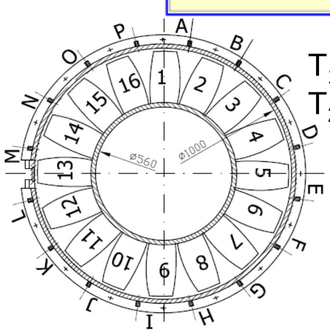
Motivation for the research was to compare the results from the three applied analysis technique to better understand the physical mechanisms which lead to rotating stall: visual inspection of the traces, spatial Fourier decomposition and wavelet filtering



Comprehensive investigations of the unsteady flow

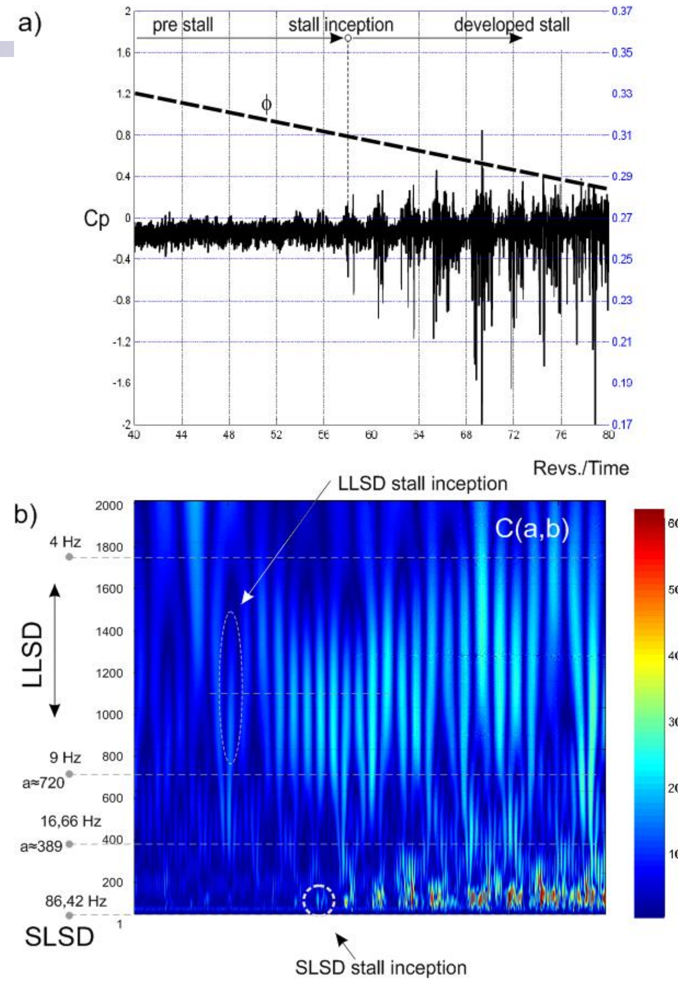
Propagation of rotating stall in circumferential direction





T_1 – a half revolution time, of **the impeller**

T_2 – a half revolution time, of **the stall cell**



Variation of the wavelet transforms of the casing rotor static pressure signals, near the rotor leading edge, in the transient stalling process:

(a) time behavior of the pressure signals visual inception

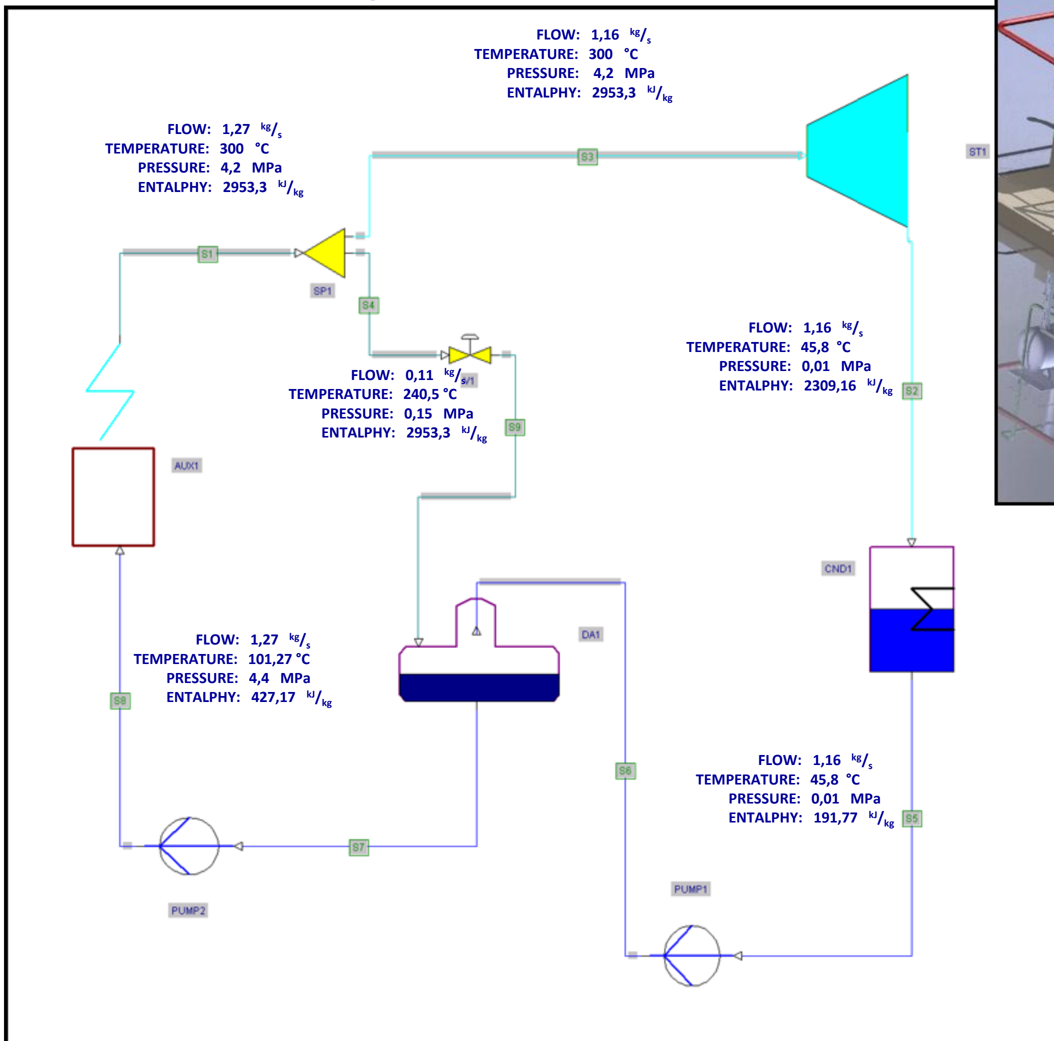
(b) Morlet wavelet spectrogram

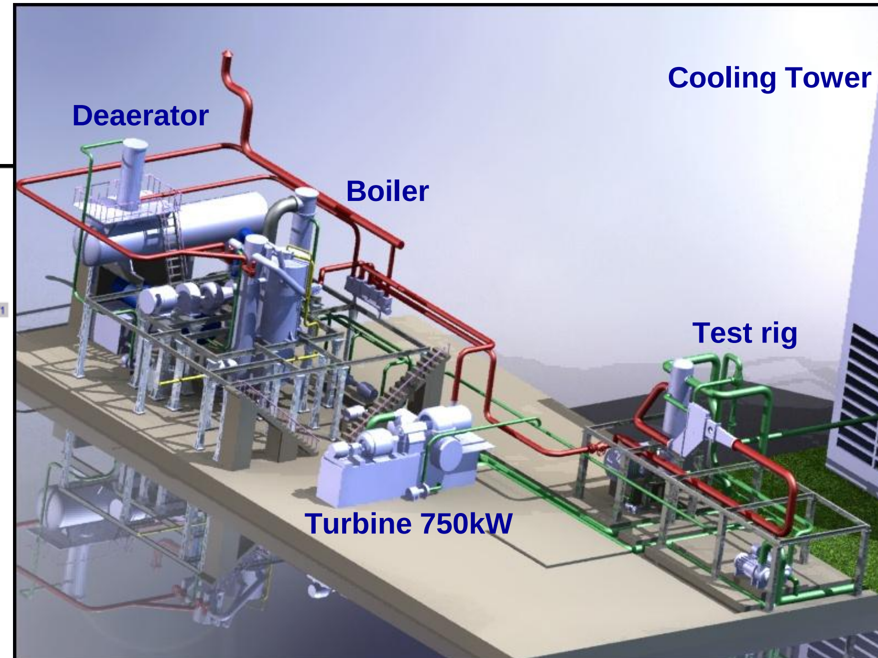
Overview

- information about the Institute
- two-phase flows
- aerodynamic noise calculations
- optimisation problems
  - seal with honeycomb land at turbine blade tip
  - convective blade cooling with CHT
- **experimental work**
  - comprehensive investigations of the unsteady flows
  - **wet steam test rig**

Wet steam test rig

Small Rankine cycle and wet steam test rig





LIVE STEAM PARAMETERS

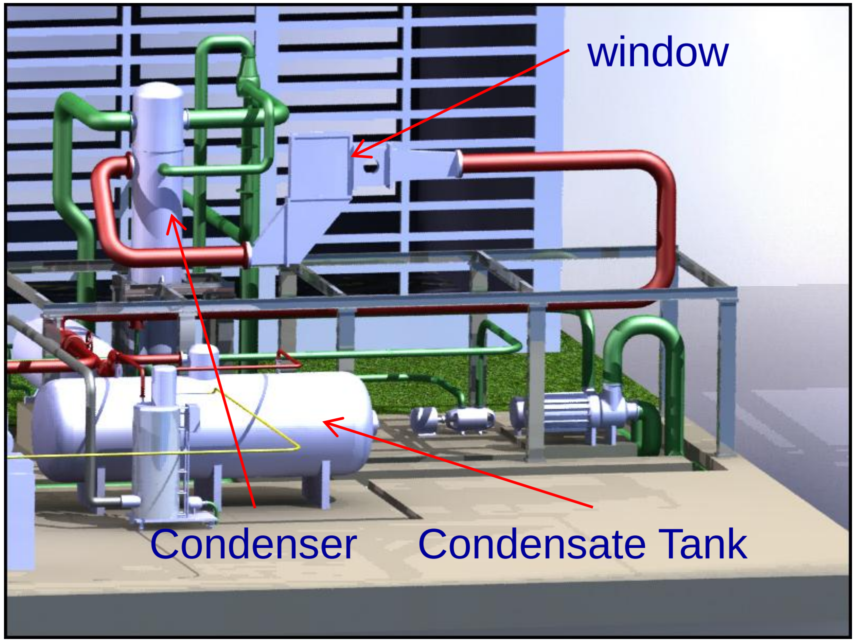
TEMPERATURE:	300 (290)	ºC
PRESSURE:	4,2 (1,6)	MPa
EFFICIENCY:	92	%

Wet steam test rig

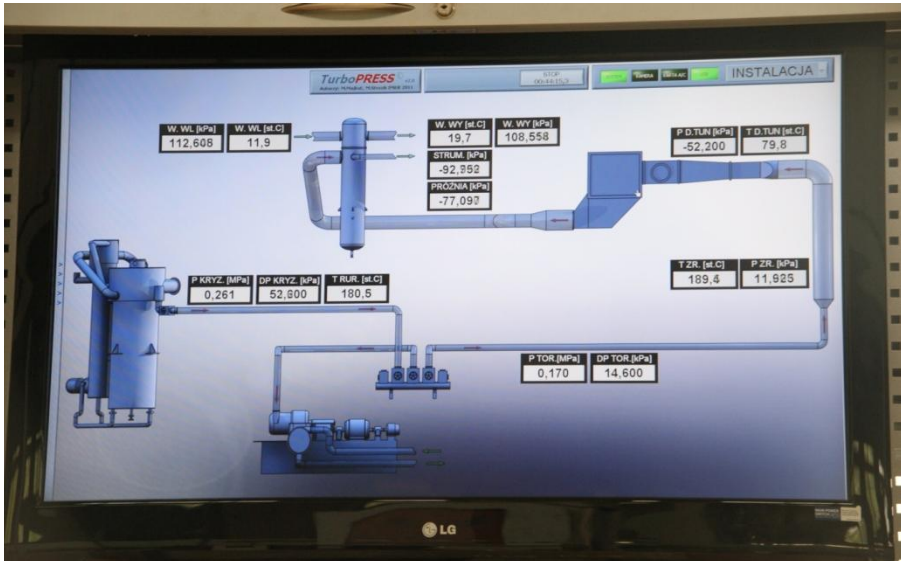
Wet steam flow measurements in:

- nozzle
- linear blade cascade

TEST RIG STEAM PARAMETERS		
FLOW:	3 ± 1	$^{kg}/_{s}$
PRESSURE:	0,11 (0,05)	MPa



Operation control panel (LabView)



Thank you !