Multidisciplinary Optimization of Aero Engine Compressor and Turbine Components

Institute of Propulsion Technology, DLR Cologne
Institute of Structures and Design, DLR Stuttgart

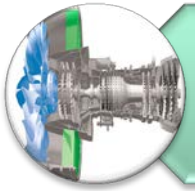
Dr.-Ing. Timea Lengyel-Kampmann,
Dipl.-Ing. Thomas Schmidt

12.-13. April 2018, Stuttgart

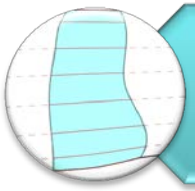
DLR

Multidisciplinary Optimization

Contents



Motivation



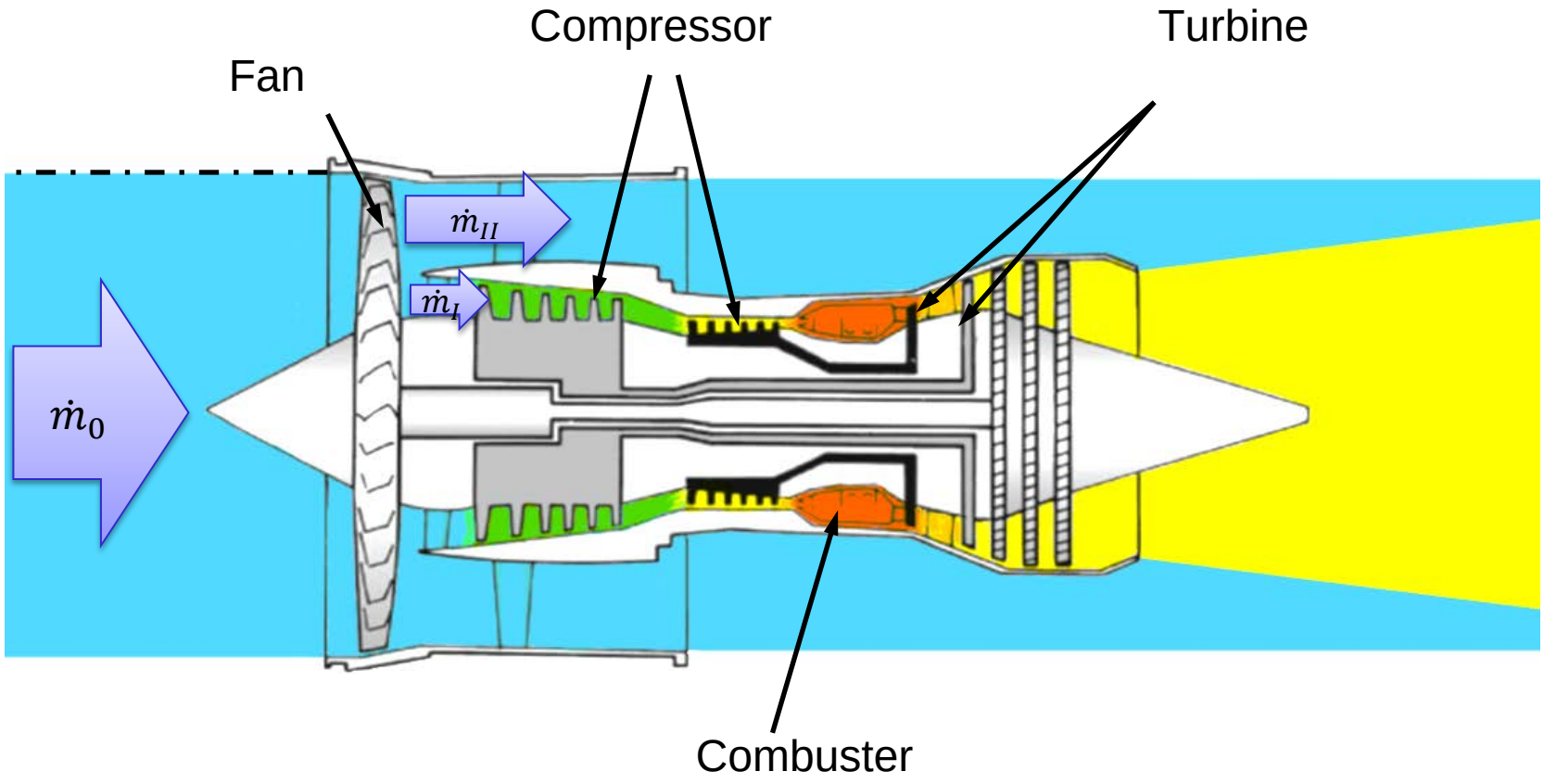
Tools

Examples

Further developments

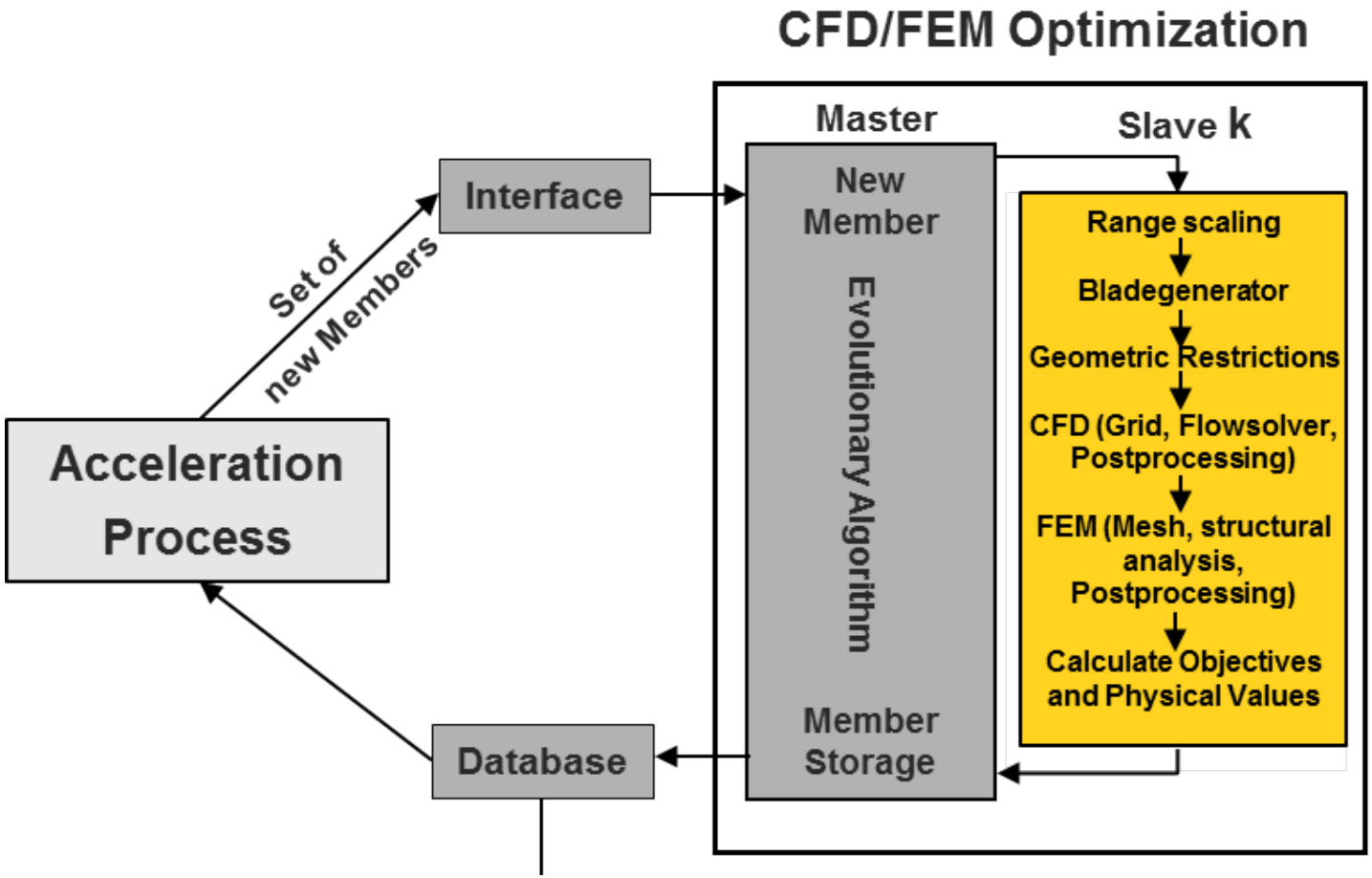
Motivation

Aircraft engine



Tools

Optimiser (AutoOpti)



Tools

Module based optimisation process chain

Root process - AutoOpti

- parametric creation of members
- member validation

Cluster – Slave 1…n

- Blade generator
- Mesh generator for CFD
- CFD calculation (aerodynamic analysis)
- Mesh generator for FEM
- HOT-to-COLD transformation
- Non linear static analysis by PERMAS
- Modal analysis by PERMAS
- Nodal diameter analysis by PERMAS
- Reliability (HYPRA)
- Evaluation of the results

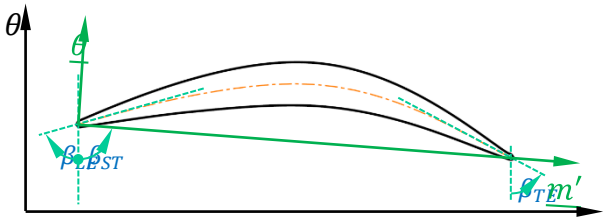
DLR

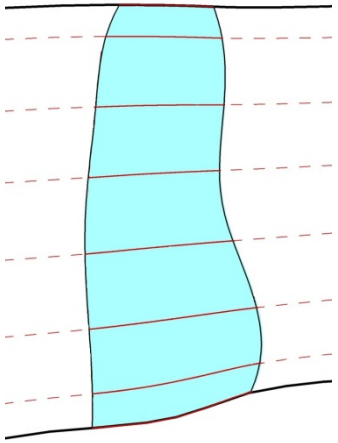
Tools

Preprocessing- Automated blade and mesh generators for the CFD calculation

Blade generator

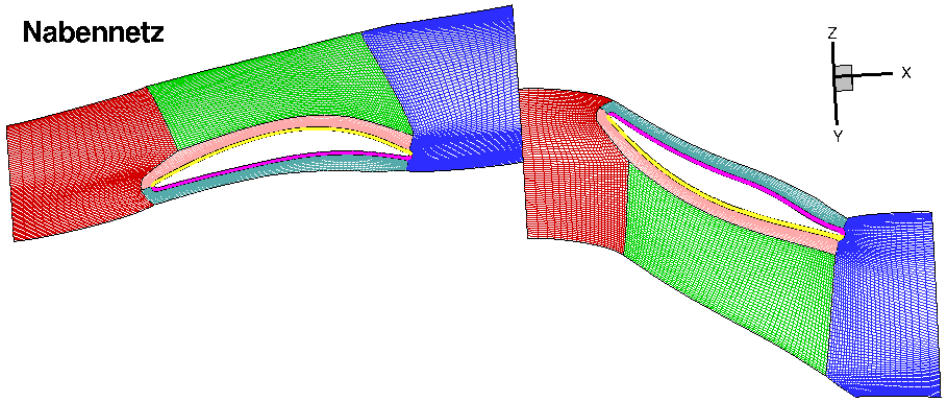
- parametric generation of blade geometries





Mesh generator for CFD

- automated generation of CFD grid, incl. boundary conditions

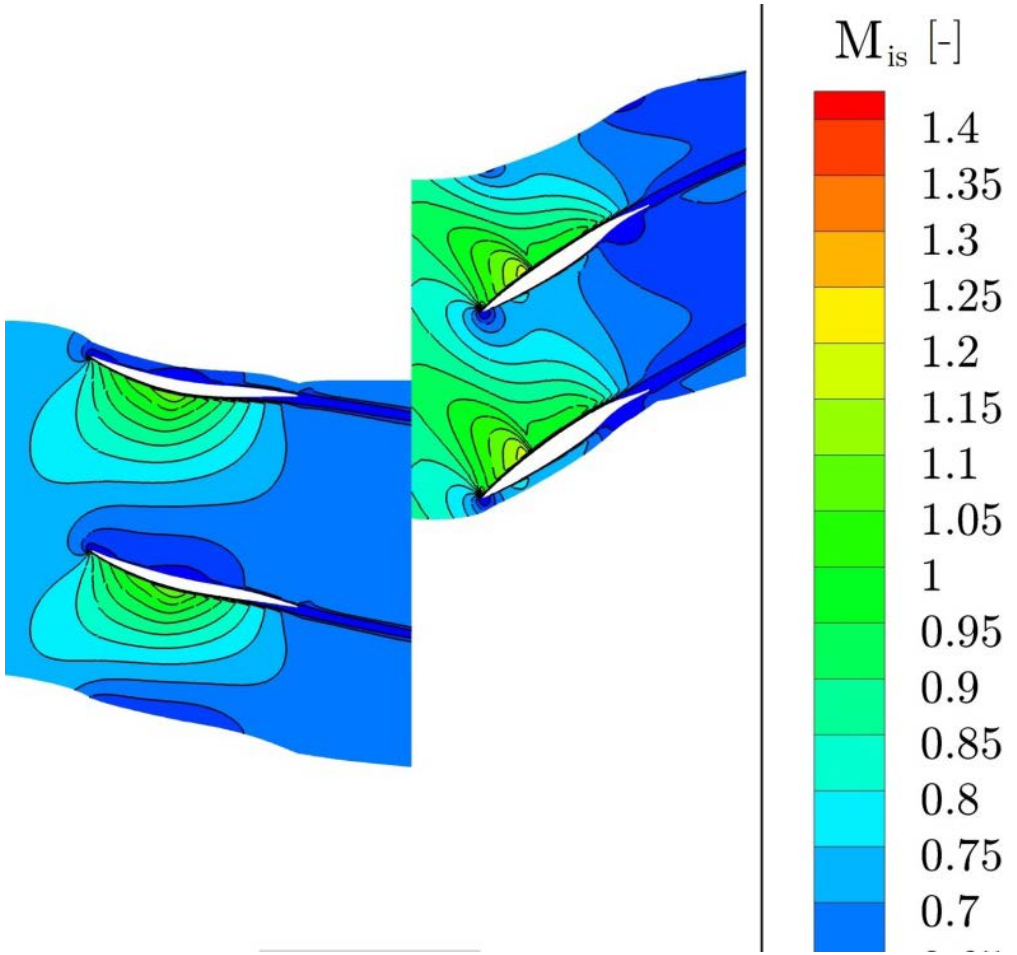


Tools

Solvers – CFD calculation with TRACE

CFD-Solver TRACE

- CFD solver for turbomaschines
- Navier-Stokes equation
- Calculation of aerodynamic properties of the blades



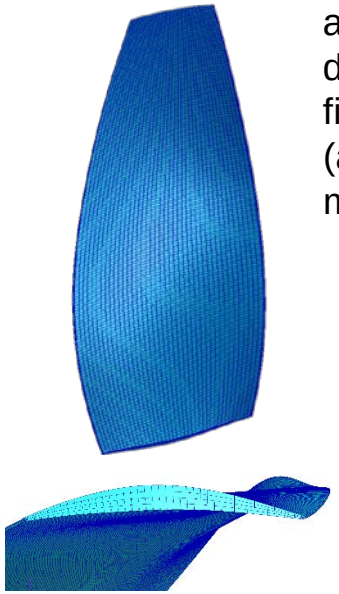
Tools

Preprocessing - Automated mesh generators of the blades for the FEM calculation

FEMBladeNetGen (SHELL, HEX)

- automated generation of complete FE blade model, incl. loads and boundary condtions

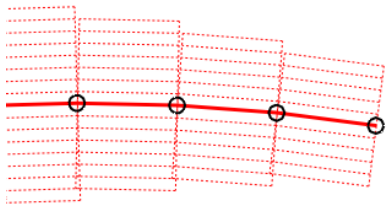
HEX-elements



automatical determination of fiber orientation (anisotopic material)

SHELL-elements

element property - exact layer setup

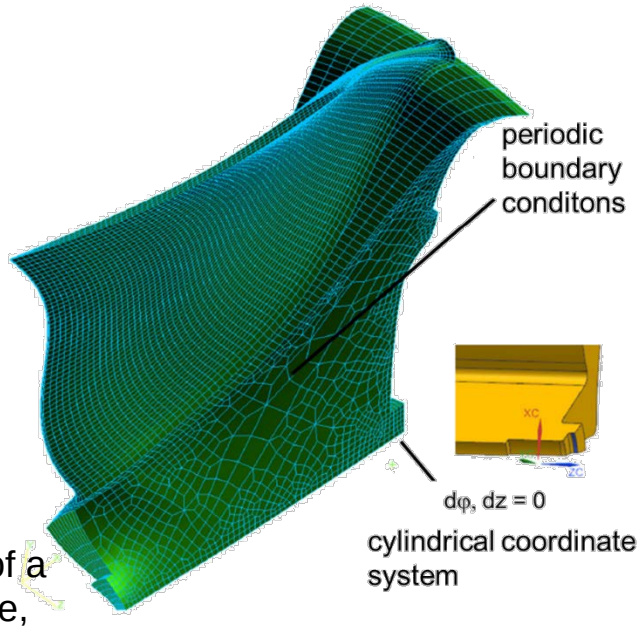


Tools

Preprocessing - Automated mesh generator of the disc for the FEM calculation

FEMDiscNetGen

- parametric generation of arbitary definable disk shape
- automated generation of FE grid of a disc segment, incl. boundary conditions
- merging blade and disc grids to a common model, incl. all loads and boundary conditions



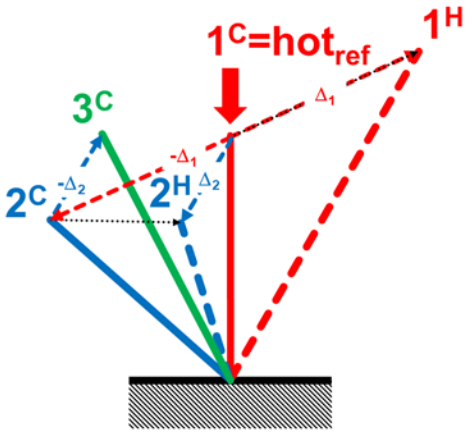
automated generated FE model of a centrifugal compressor, incl. Blade, disc, loads and boundary conditions

Tools

Solver – calculation with PERMAS

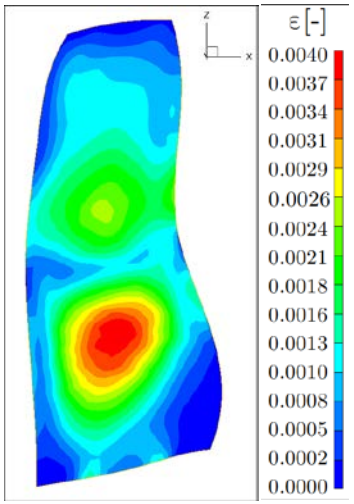
HOT-to-COLD transformation with PERMAS

- determination of corresponding unloaded (cold) geometry
- determination of unloaded tip clearance



FEMAnalysis

- static analysis (stress, displacement, strain, …)
- dynamic analysis (eigenmodes, nodal diameter, frequency margin, …)



DLR

Tools

Postprocessing – automated analysis

HYPRA

- Determination of the failure probability

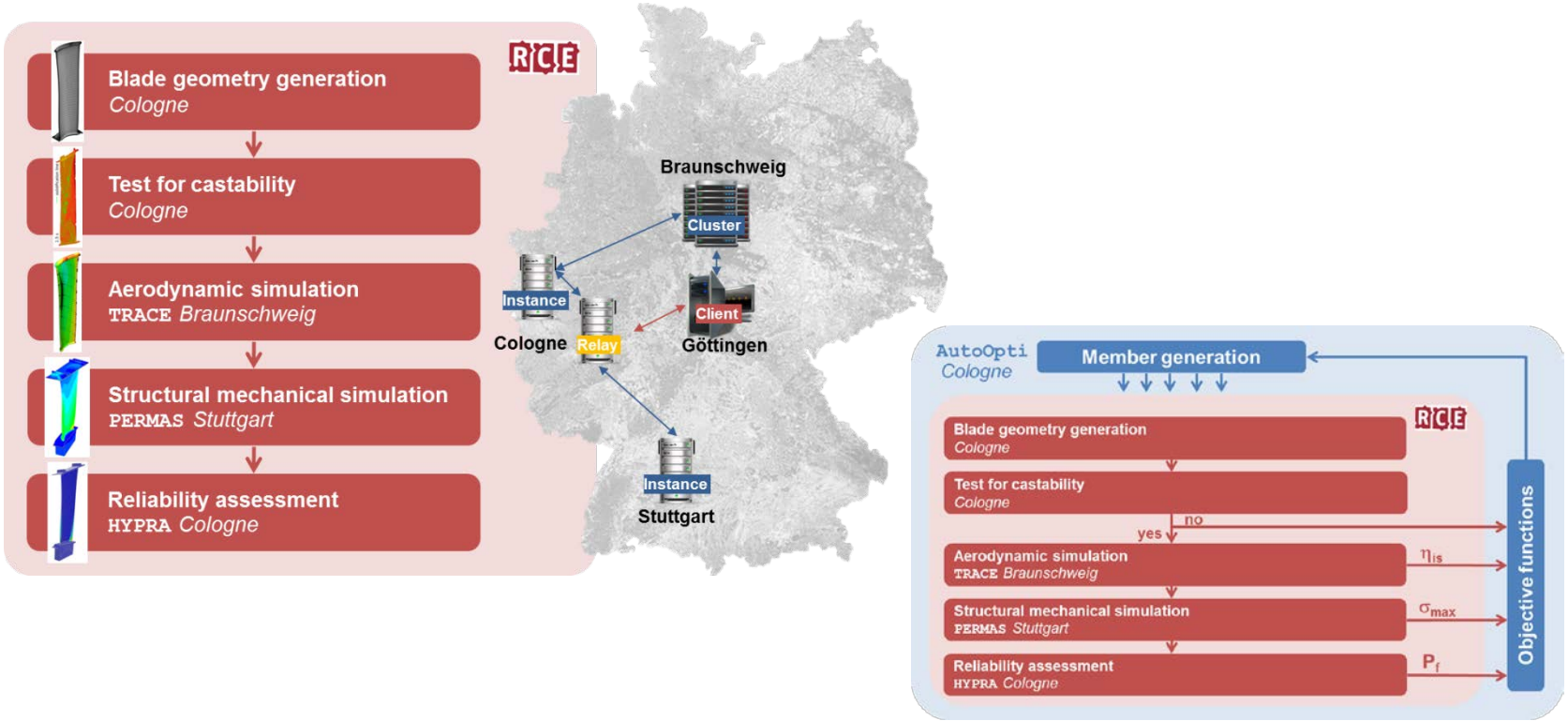
FEMResults

- transfer of the relevant mechanical results to AutoOpti

Examples

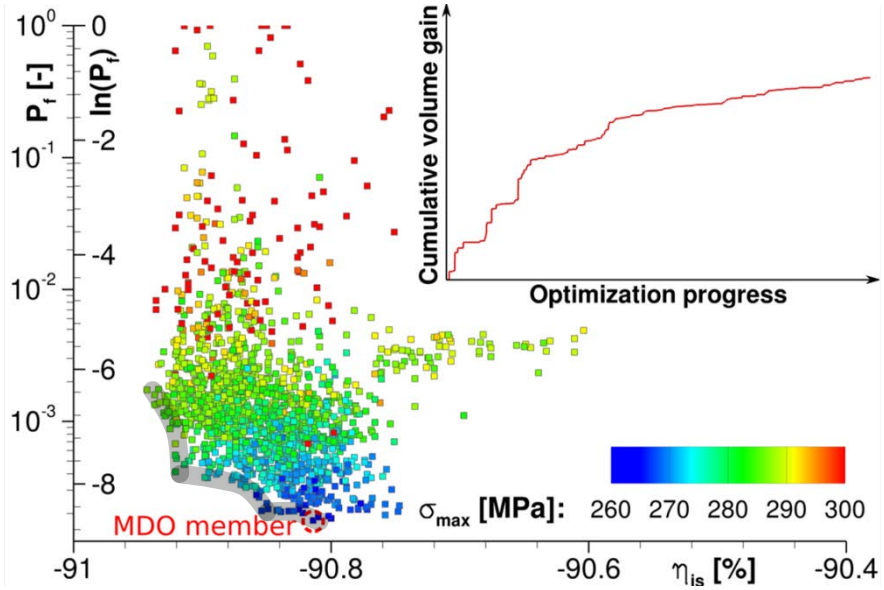
Low pressure turbine

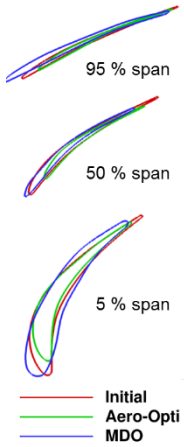
RCE - distributed, workflow-driven integration environment



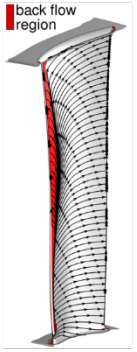
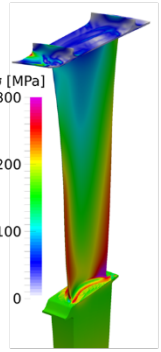
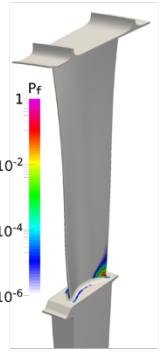
Examples

Low pressure turbine

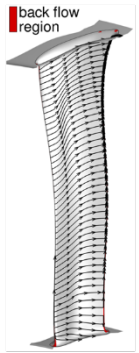
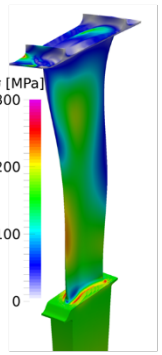
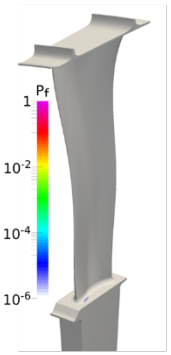
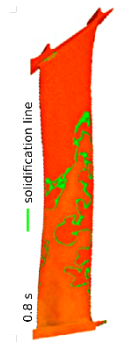




initial member

aerodynamic	structural	reliability	castability
			
η_{is} = 90.2 %	σ_{max} = 473 MPa	P_f = 100 %	low

MDO member

aerodynamic	structural	reliability	castability
			
η_{is} = 90.8 %	σ_{max} = 262 MPa	P_f = 0.018 %	good

DLR

Examples

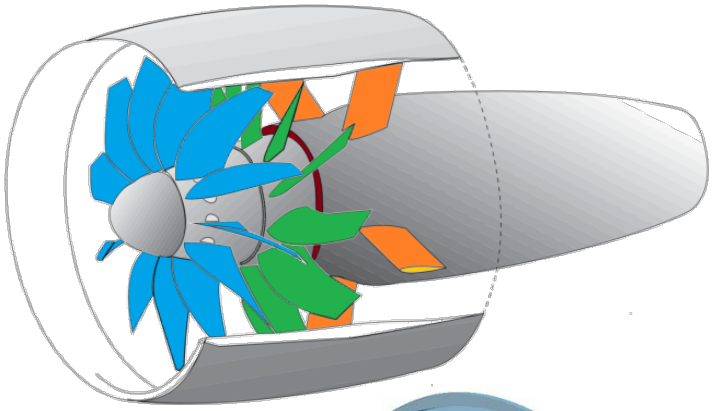
Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

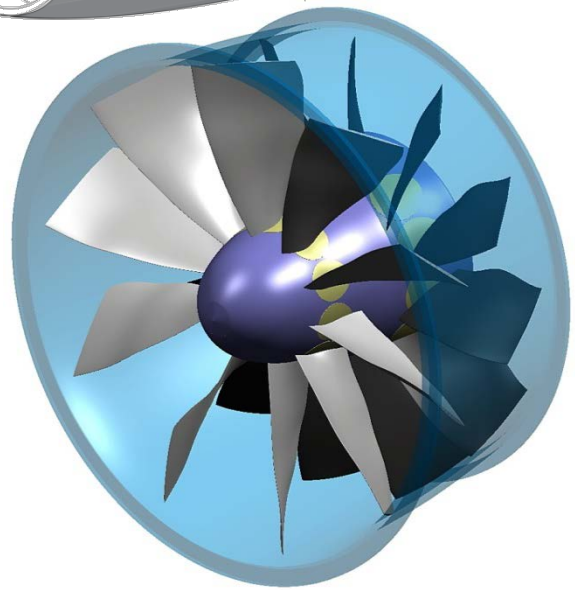
Objectives:

- Improvement of aerodynamic and mechanical characteristics
- Innovative manufacturing techniques (skeleton-plane parallel layer design)

Challenge:

- Integration of anisotropic materials into the design process chain
- Integration of the rotor discs to improve the evaluation of the structural dynamics





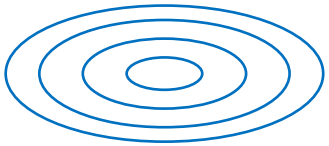
DLR

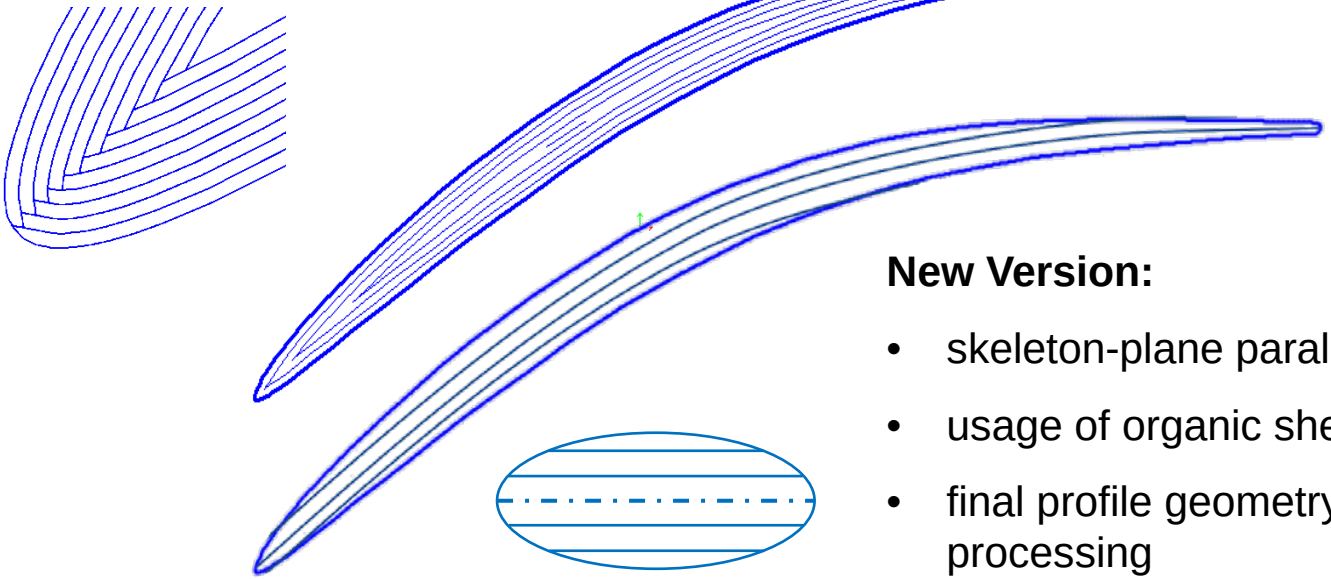
Examples

Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

Conventional Version:

- onion layer design
- layer cuttings have to be fit exactly
- big manufacturing efford





New Version:

- skeleton-plane parallel layer design
- usage of organic sheets
- final profile geometry is made by milling processing

Examples

Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

organo sheet

reshaped organo sheet

milled organo sheet

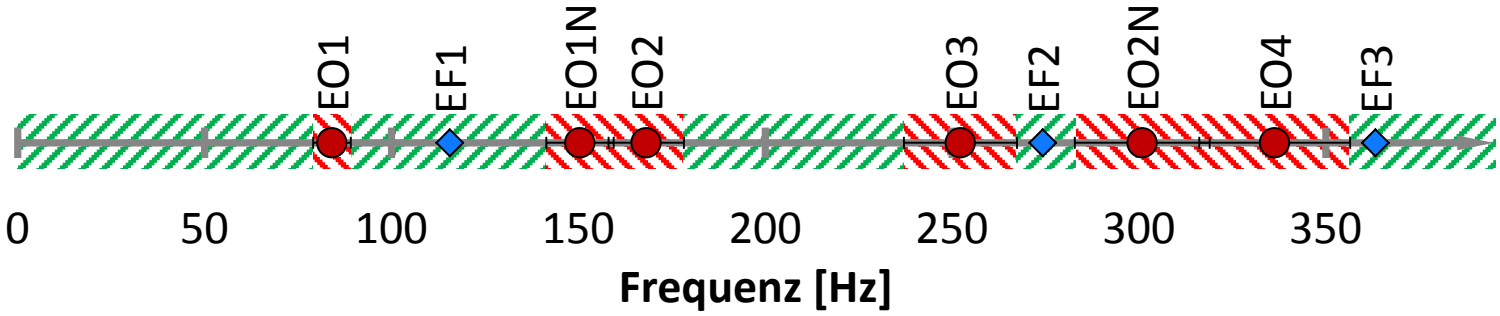
final fan blade

Examples

Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

Target functions

1. function: Aerodynamic efficiency η_{is} → Maximize!
2. function: Maximal displacement u_{max} → Minimize!
3. function: Min. Frequence-distance to allowed range Δf_{zul} → Minimize!



$$max\begin{pmatrix} max(EF - Bo; 0) \\ max(Bu - EF; 0) \end{pmatrix}$$

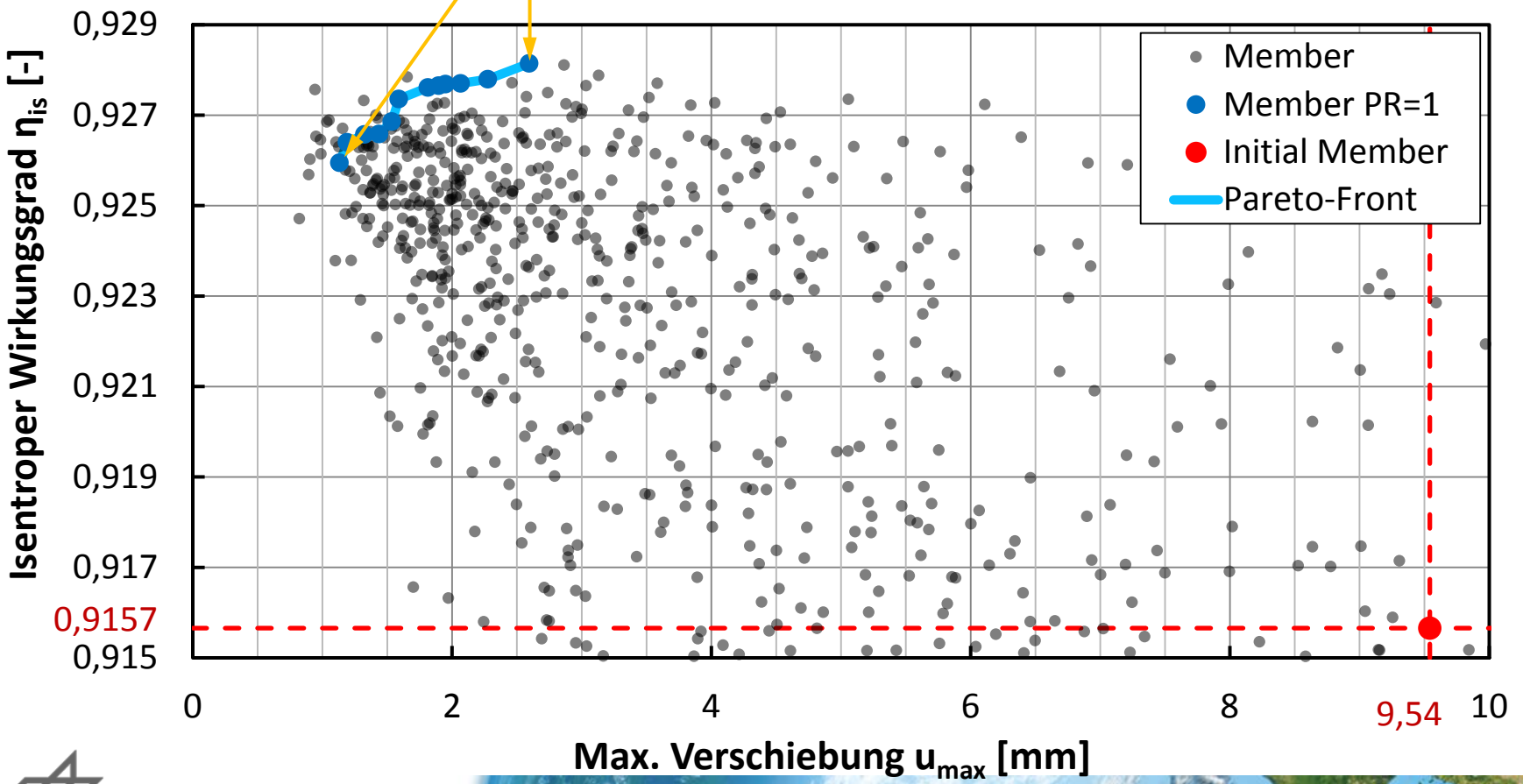
Examples

Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

Pareto-Diagramm

m7070: $\eta_{is} = 0{,}9259;\ u_{max} = 1{,}132\ mm;\ \Delta f_{zul} = 0\ Hz$

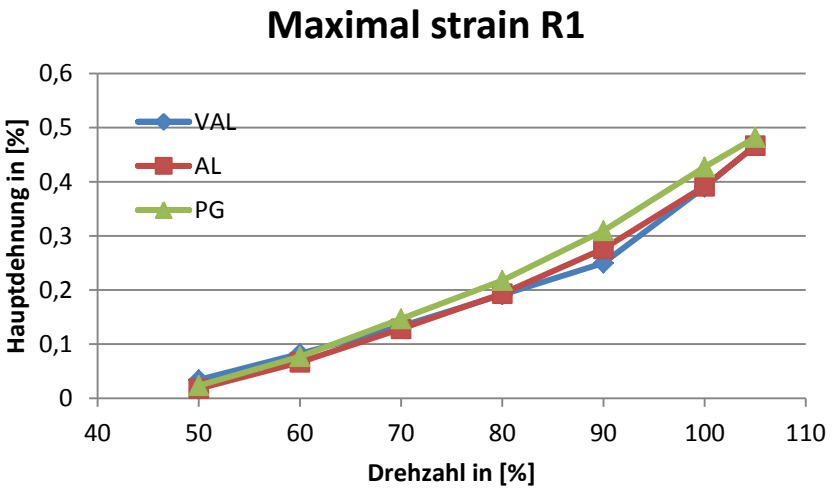
m7307: $\eta_{is} = 0{,}9281;\ u_{max} = 2{,}596\ mm;\ \Delta f_{zul} = 0\ Hz$

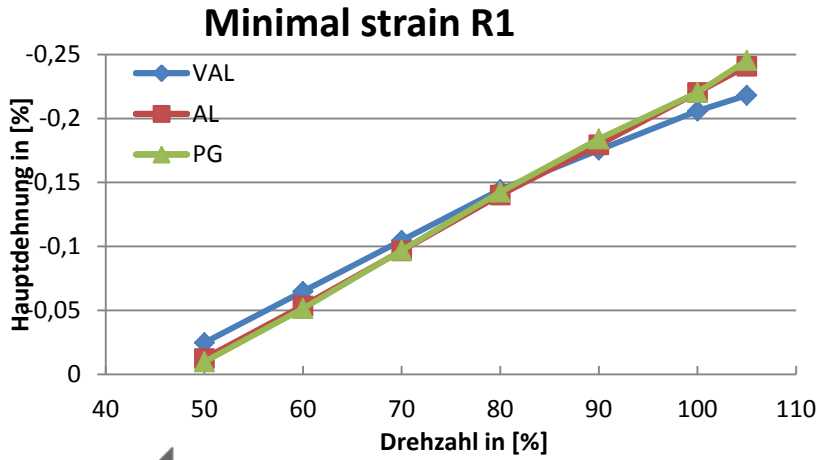


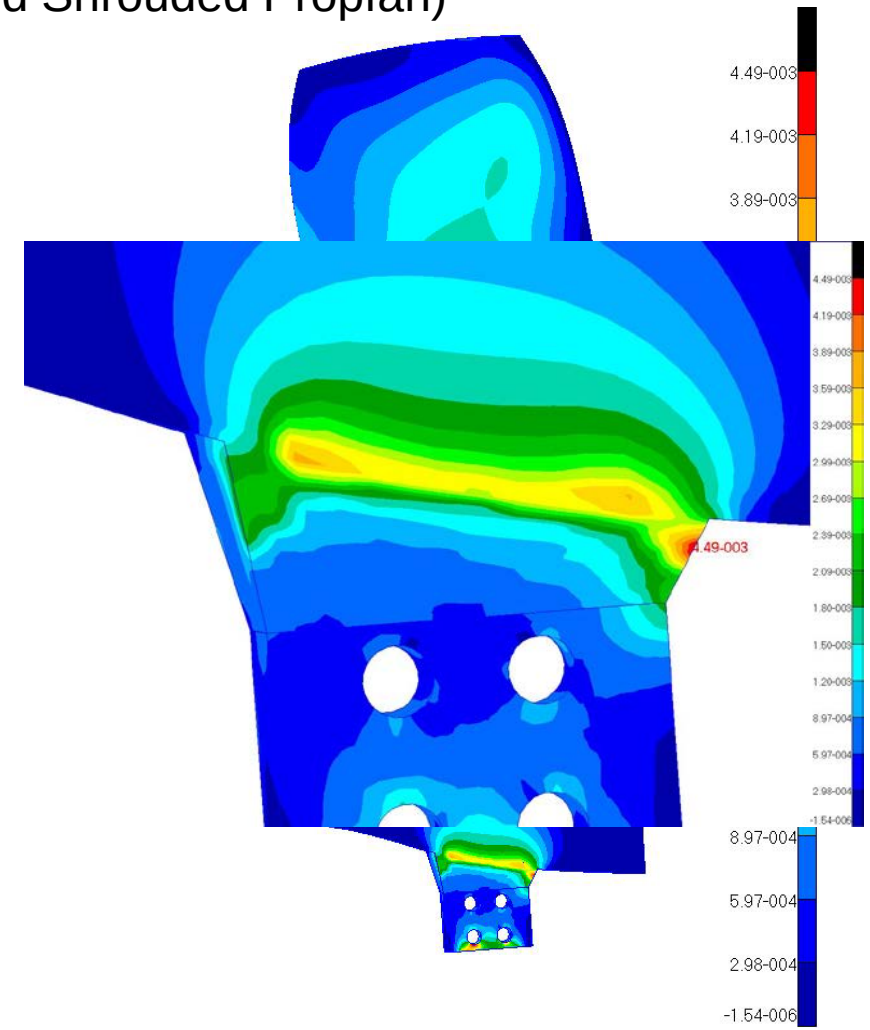
DLR

Examples

Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

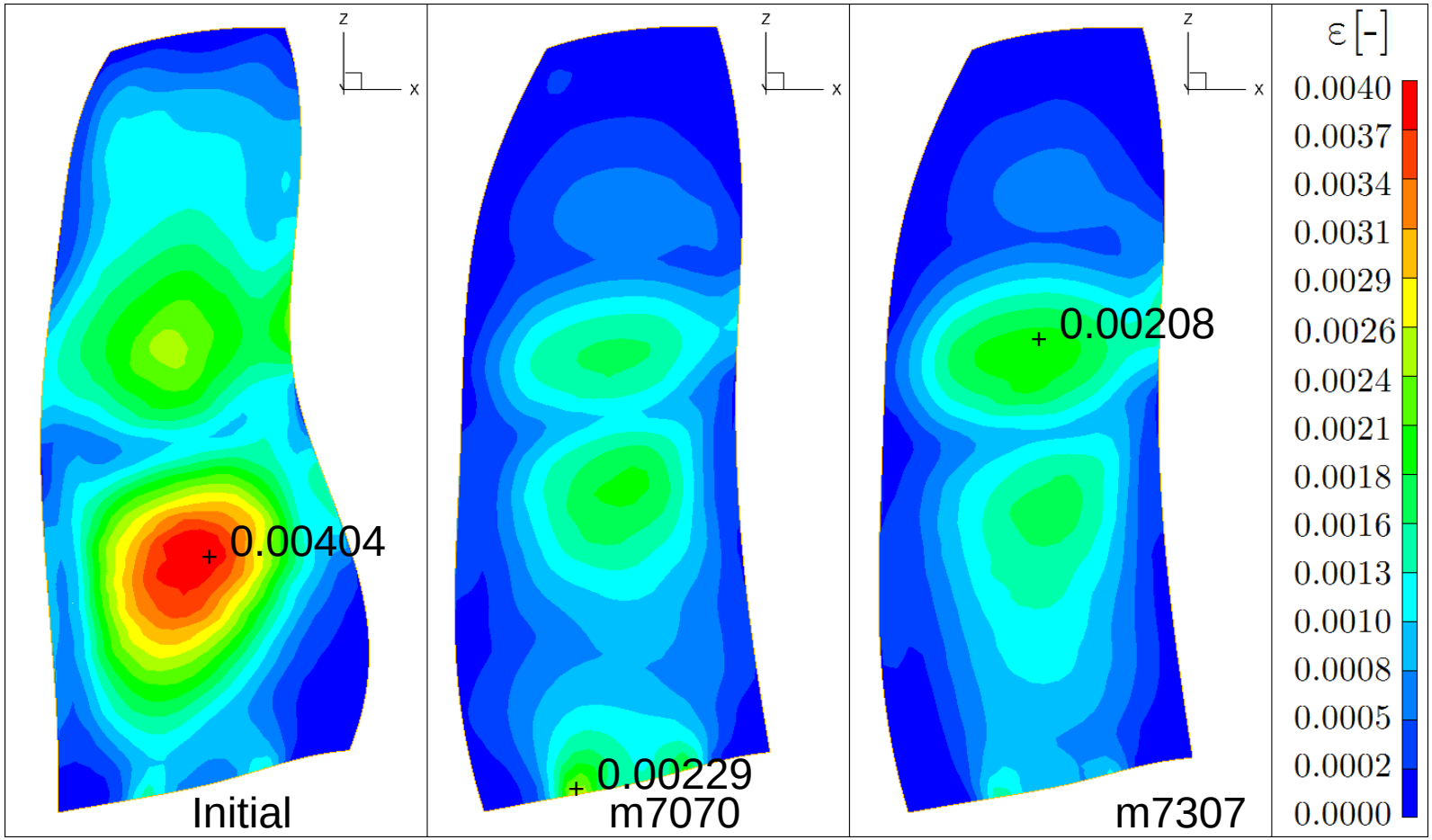






Examples

Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

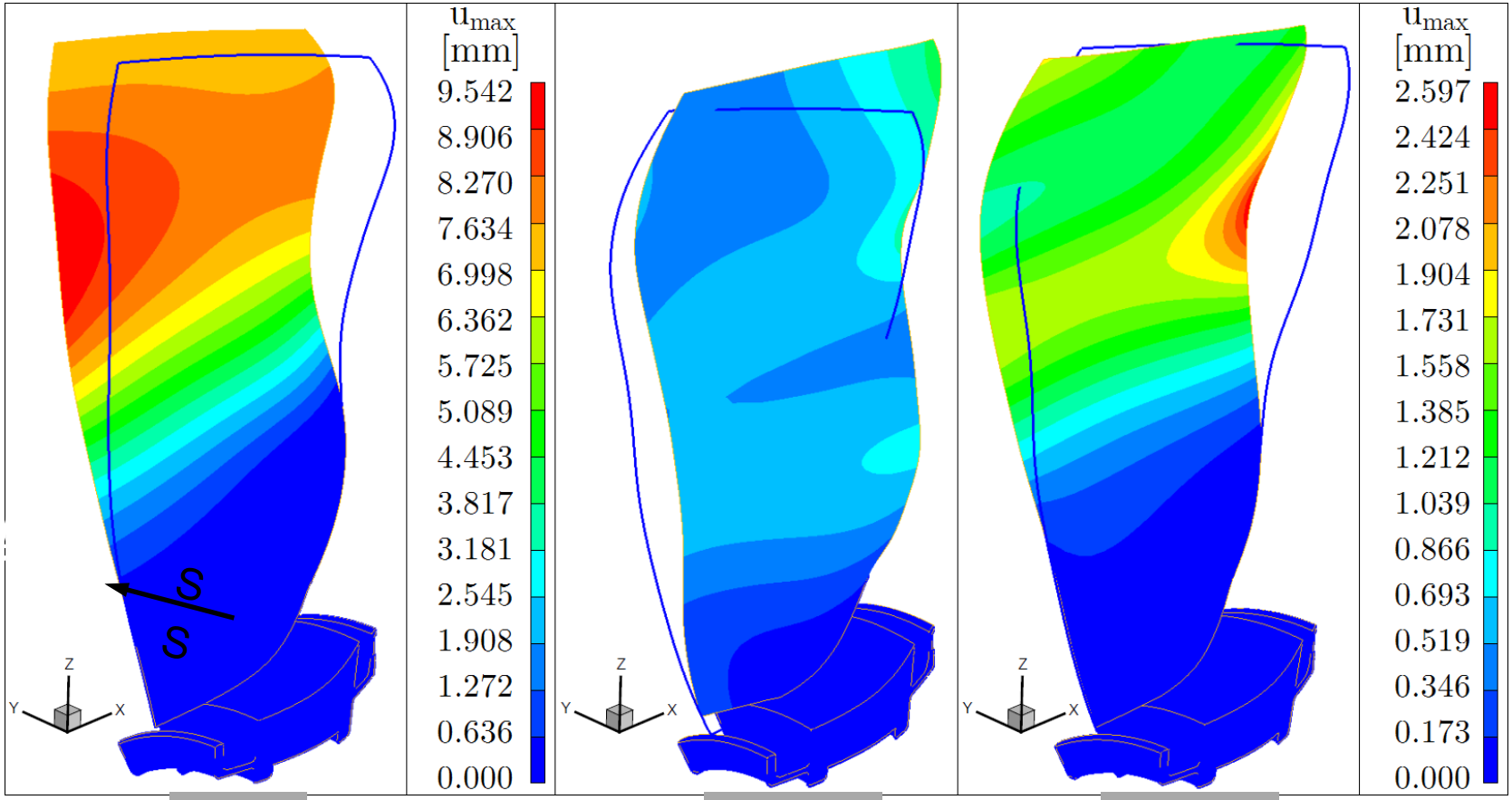


DLR

Examples

Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)

Displacement



Initial

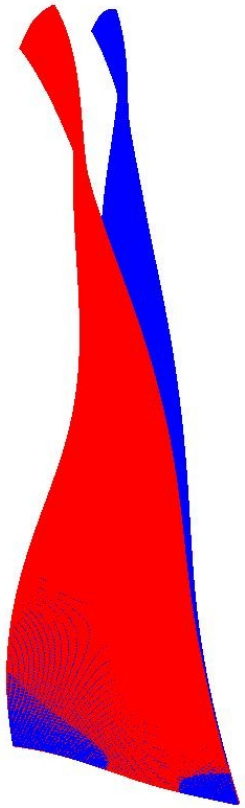
m7070

m7307

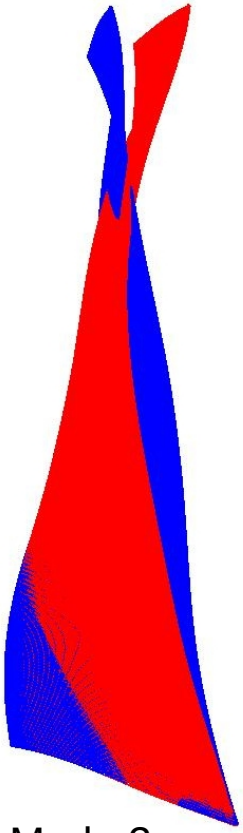
DLR

Examples

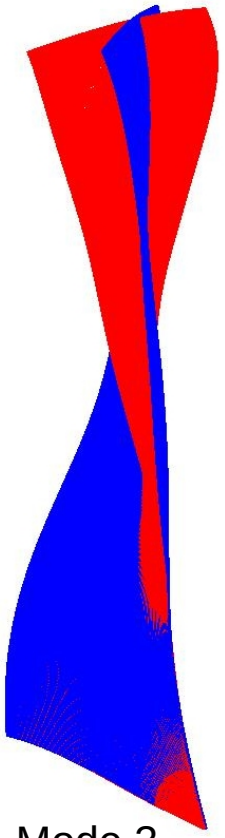
Fan (CRISP - Counter Rotating Integrated Shrouded Propfan)



Mode 1
A_{zul} *[mm]: 4.38*
Axf *[mm/s]*: 0.52



Mode 2
A_{zul} *[mm]: 1.30*
Axf *[mm/s]*: 0.39

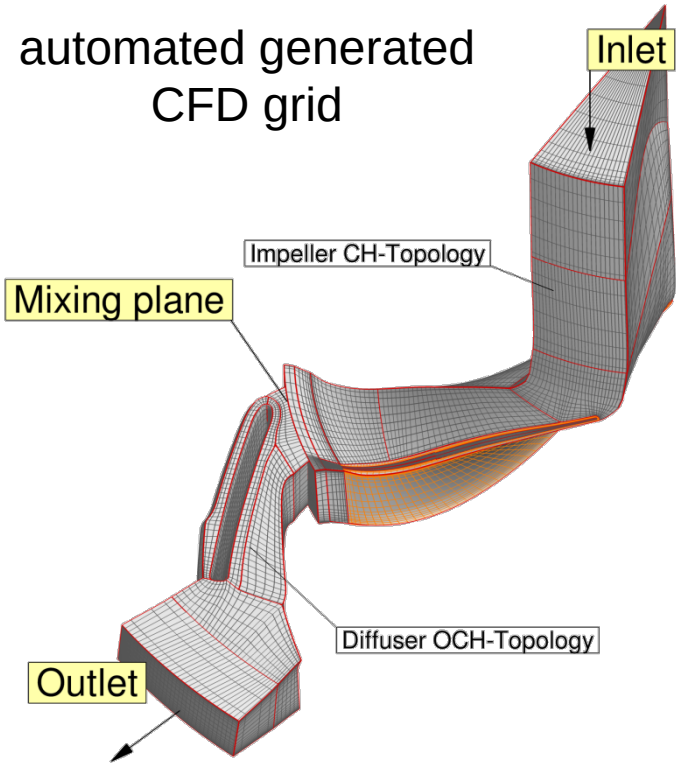


Mode 3
A_{zul} *[mm]: 1.21*
Axf *[mm/s]*: 0.46

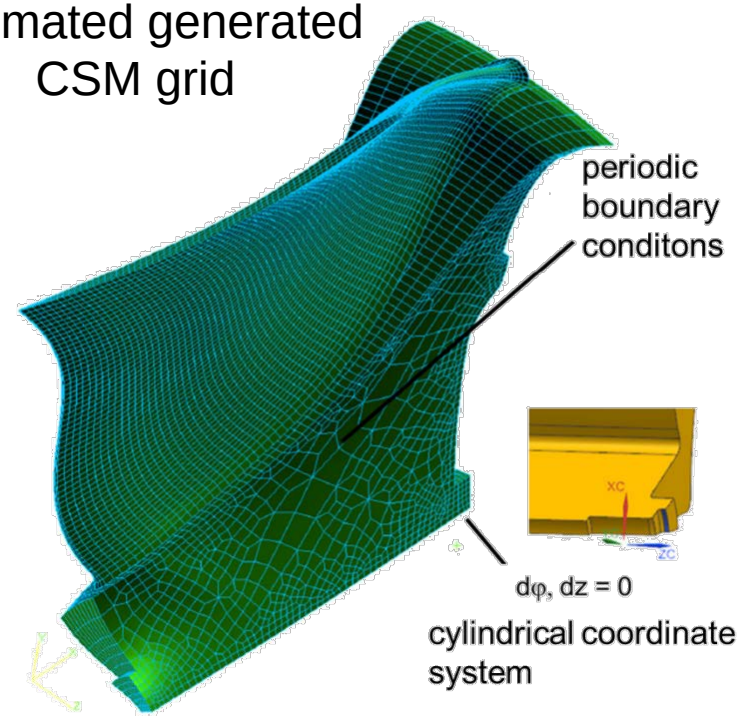
Examples

Centrifugal compressor

automated generated
CFD grid

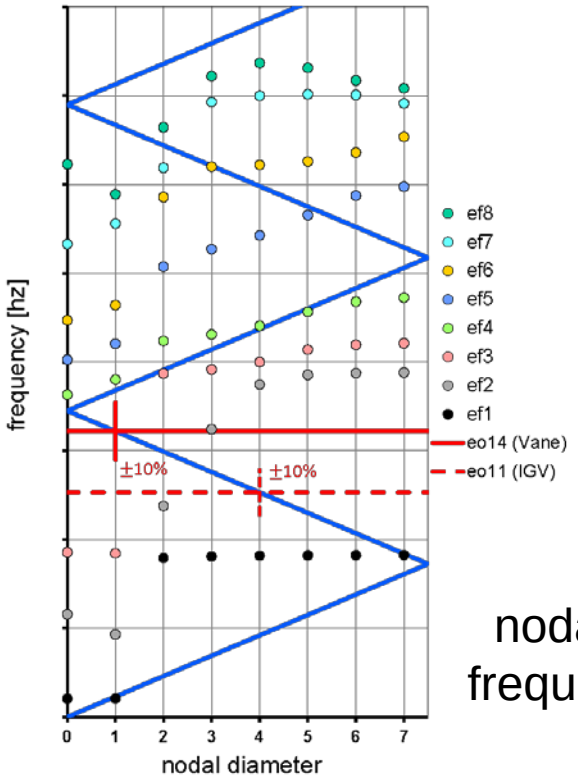


automated generated
CSM grid

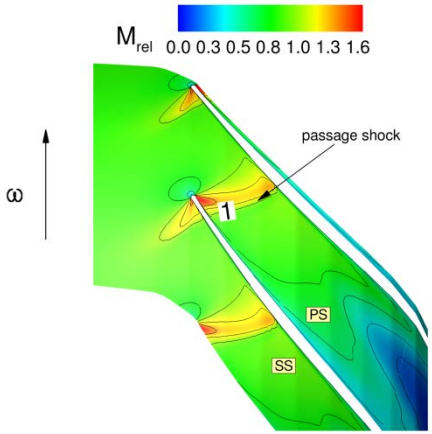


Examples

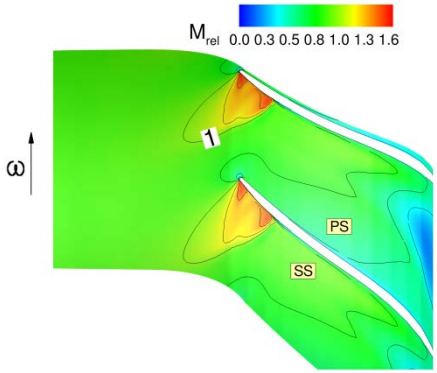
Centrifugal compressor



nodal diameter
frequency margin



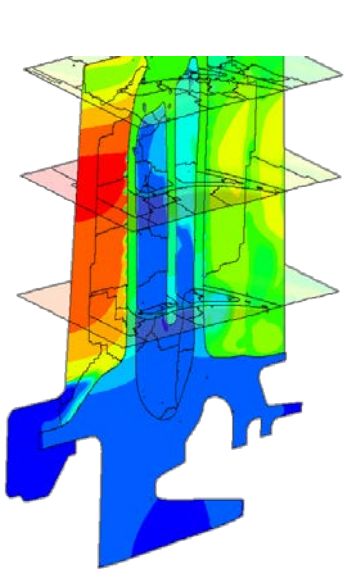
initial
member

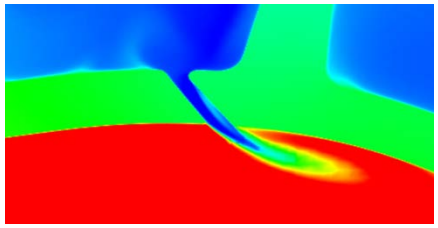


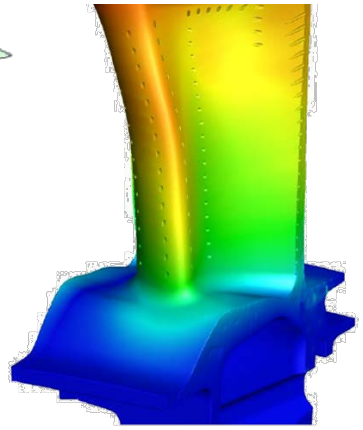
optimised
member

Further development

Revision of FEMBladeNetGen
- integration of truncated trailing edge (centrifugal compressor)
- integration of cooling chanels
- integration of circumferential contouring
- integration of blade roots





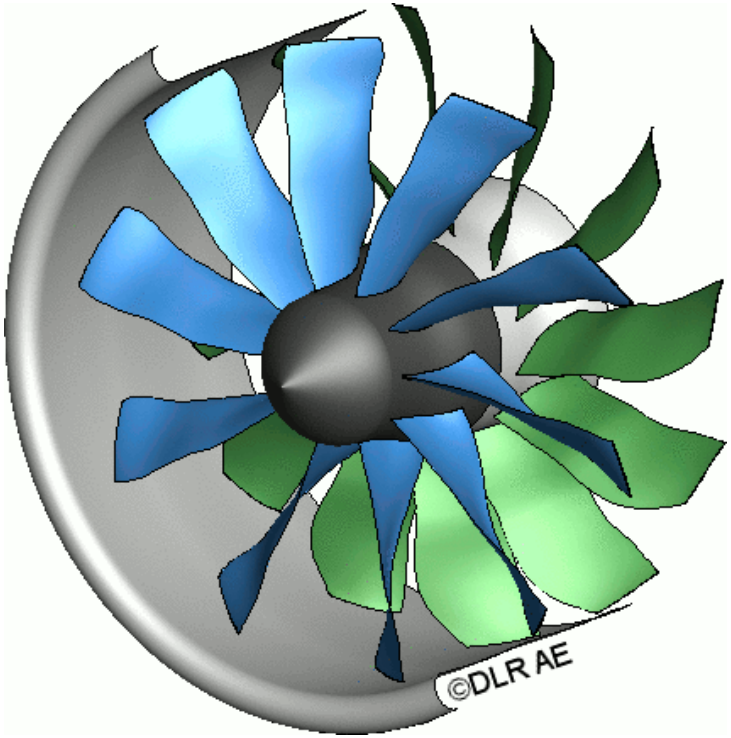


Fluid-structure linking
- calculation of the thermal transfer between inner (cooling) and outer flow

Integration of additional disziplines
- fluid dynamics - flutter analysis
- durability

COLD-to-HOT transfer
- automatic transfer of off design geometries
- compatibility between blade and disc

DLR



Thank you for your attention!

DLR