TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Mechanical Engineering · Institute for Fluid Mechanics · Professorship for Turbomachinery and Jet Propulsion

Probabilistic CFD Analysis of High Pressure Turbine Blades considering real geometric Effects and non-axisymmetric assembling

Jens Scharfenstein, Kay Heinze, Matthias Voigt, Konrad Vogeler

(Technische Universität Dresden)

Marcus Meyer

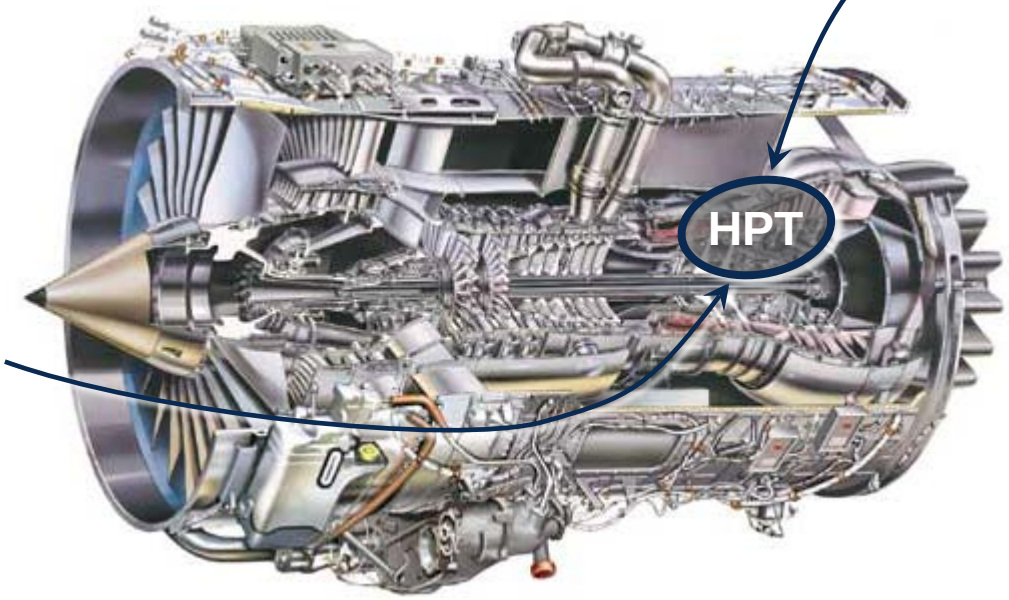
(Rolls-Royce Deutschland GmbH & Co KG)

Probabilistic Workshop, October 10th & 11th, Dresden

Geometric scatter driven by:

manufacturing

- o abrasion of milling tools
- o quality standard
- o tooling tolerances
- o …



airline 1
airline 2
…

- o location
- o cycles
- o services
- o …

Rolls-Royce

BR715 Engine

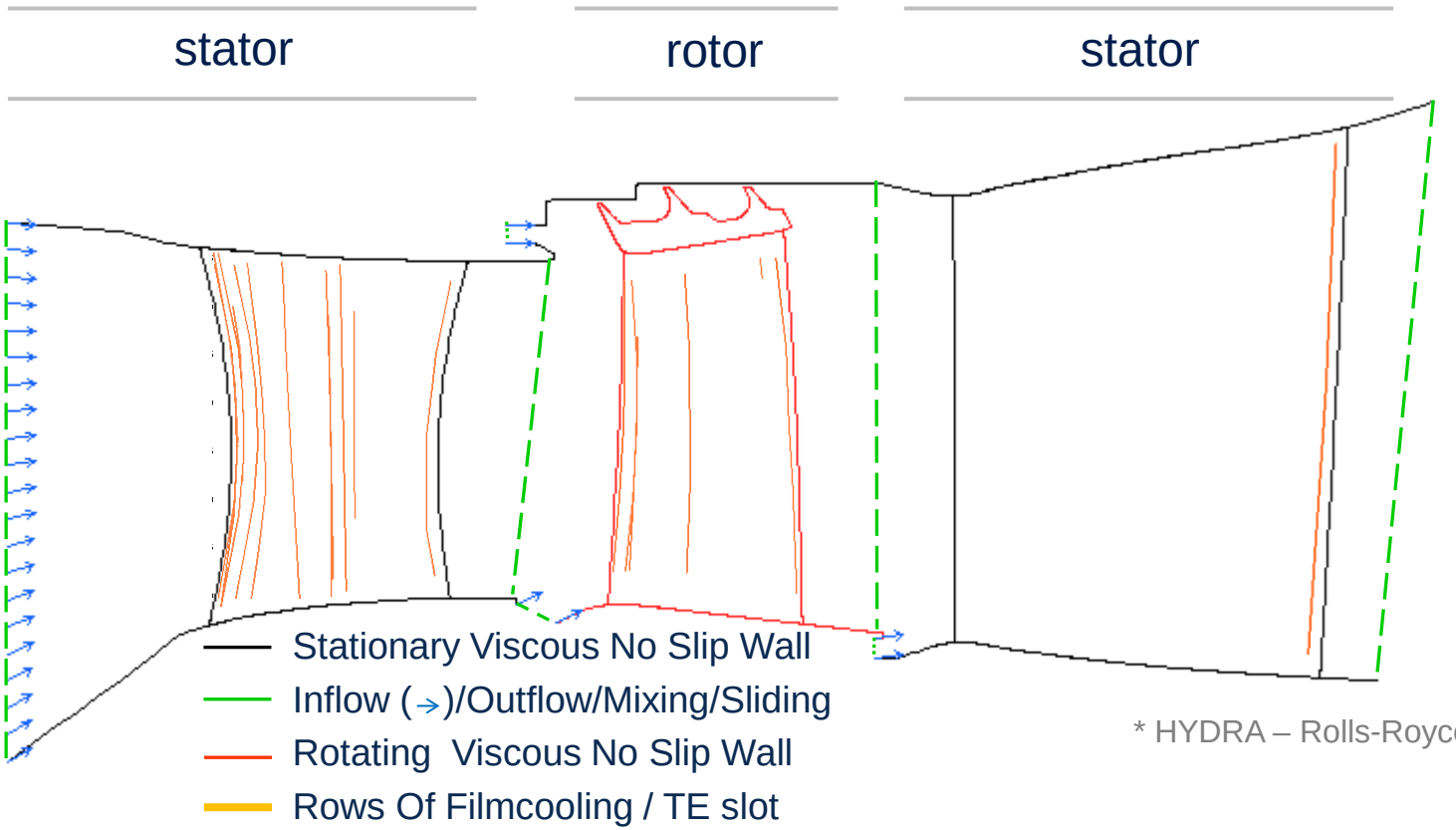
Effects due to geometric scatter?

Probabilistic Simulation considering real geometric effects

Deterministic Model

- a validated model to simulate the process

BR715 high pressure turbine - 1.5 stage



* HYDRA – Rolls-Royce CFD-code

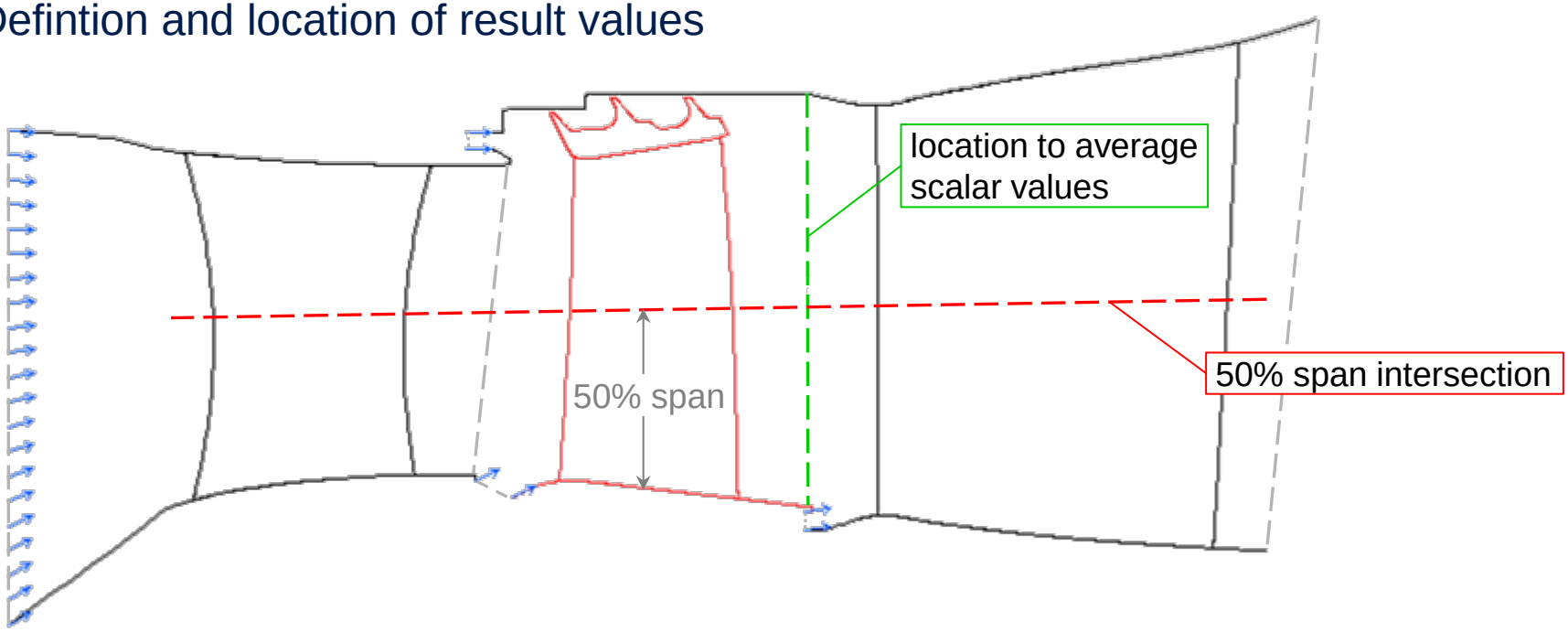
→ validated CFD-mesh already provided by Rolls-Royce

BR715 high pressure turbine - 1.5 stage

	stator	rotor	stator	
node quantity	1 021 840	2 482 900	1 315 266	/ 4 820 006
coolant	yes	yes - flexible	yes	

model	steady-state RANS, Spalart-Allmaras, real gas

Defintion and location of result values

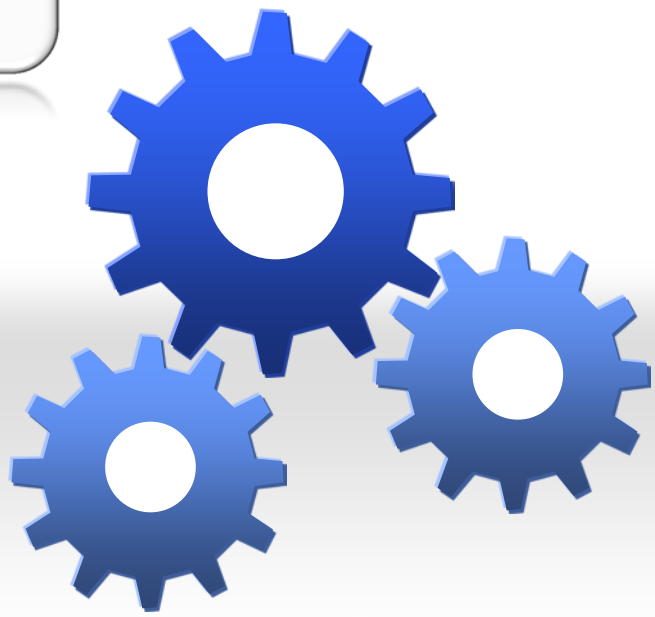


Rotor reaction: $$\rho = \frac{h_{rotor,in} - h_{rotor,ex}}{H_{0,vane,in} - H_{0,rotor,ex}}$$

Turbine inlet capacity: $$\dot{m}_{red} = \frac{\dot{m}_{in}\sqrt{T_{0,in}}}{P_{0,in}}$$

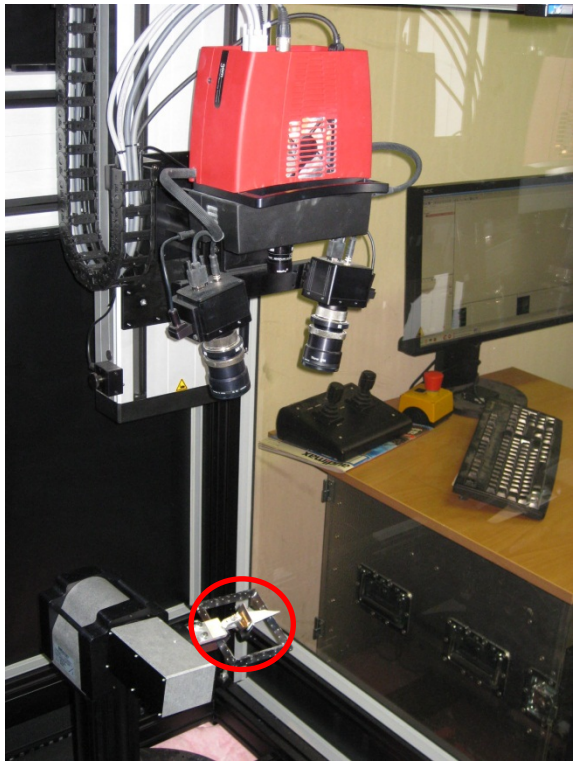
Stage efficiency: $$\eta = \frac{\sum_{i=inlets}(\dot{m}H_0)_i - \sum_{i=exits}(\dot{m}H_0)_i}{\sum_{i=inlets}(\dot{m}H_0)_i - \sum_{i=sec_{exits}}(\dot{m}H_0)_i - \left(\dot{m}H_{0\_ideal}\right)_{main\_exit}}$$

Probabilistic Simulation considering real geometric effects



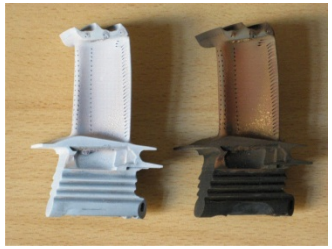
Deterministic Model
- a validated model to simulate the process

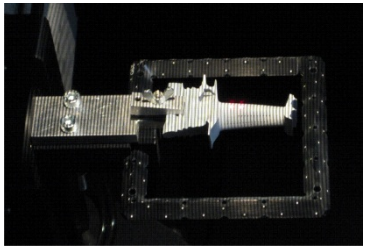
Input Parameter
- distribution function and corresponding parameters of real geometric parameters
- correlations between the real input parameters

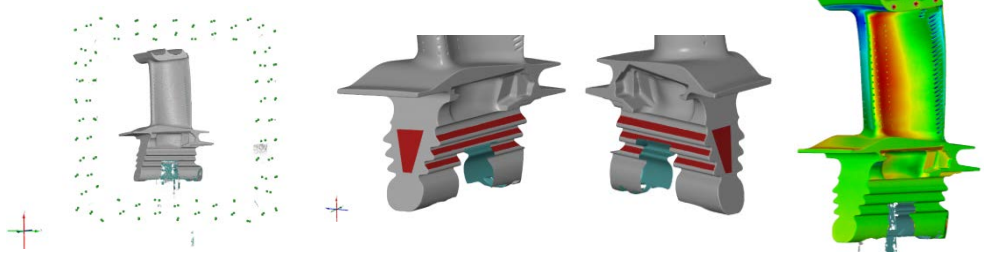


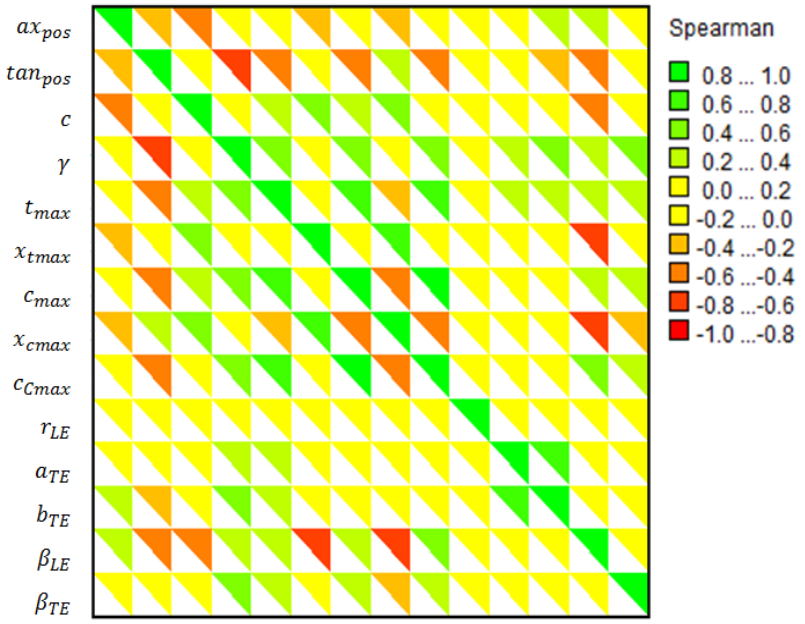
GOM ATOS SO 4M

- Blade specific measurement accuracy of 0.008 mm at planar faces and 0.027 mm at areas with high curvature (e.g. trailing edge)
- Measurement area up to 300 mm x 300 mm
- automation unit with 6 degrees of freedom
- application of reference frame to combine the scanned views
- additional quality control algorithms integrated

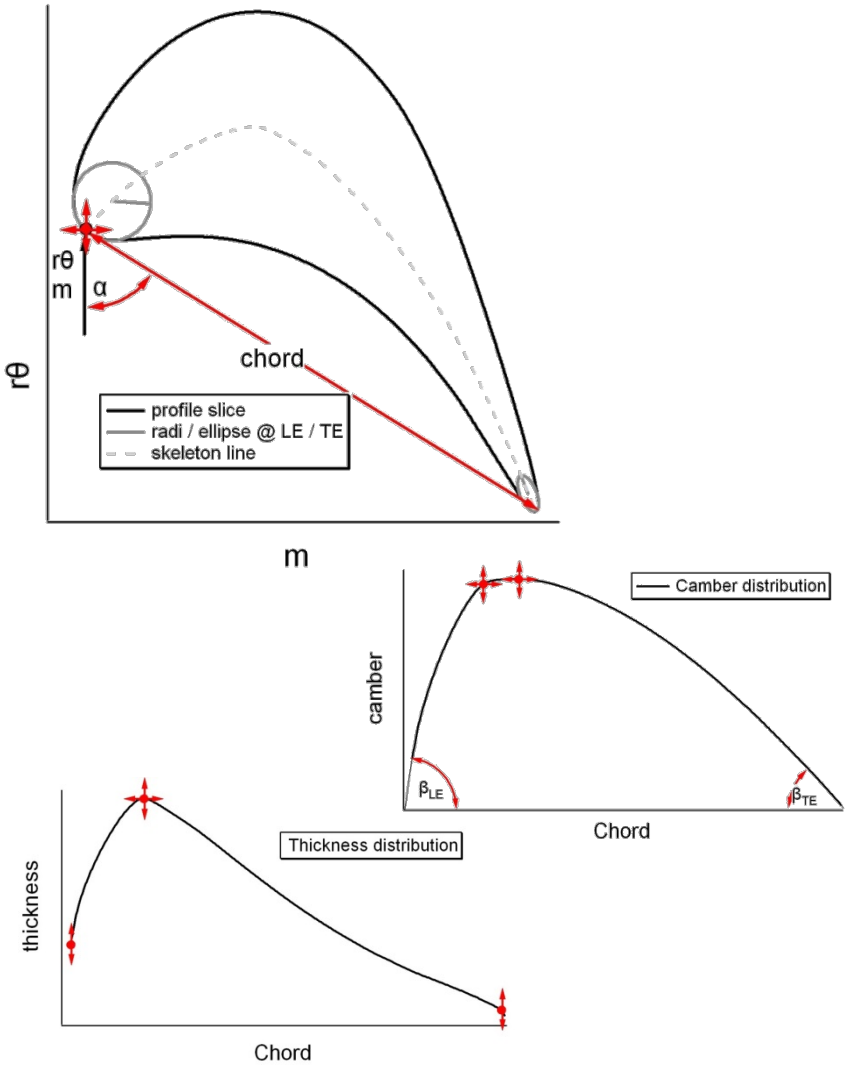


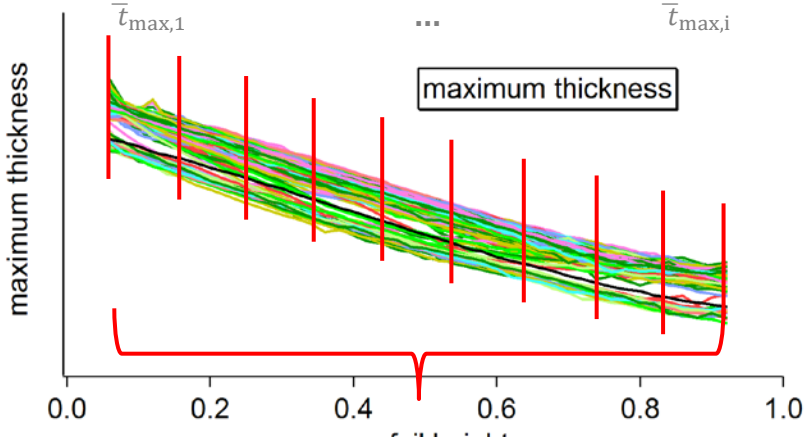


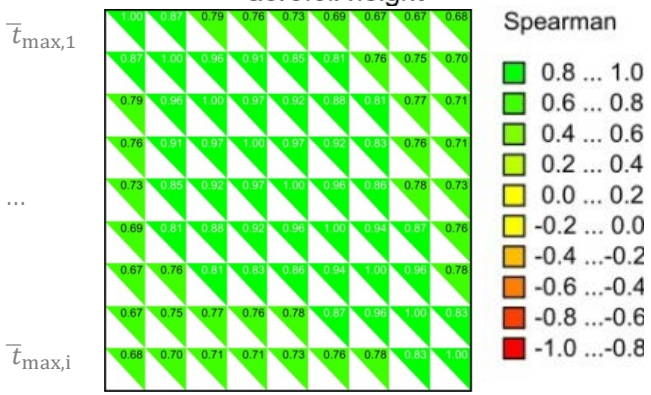


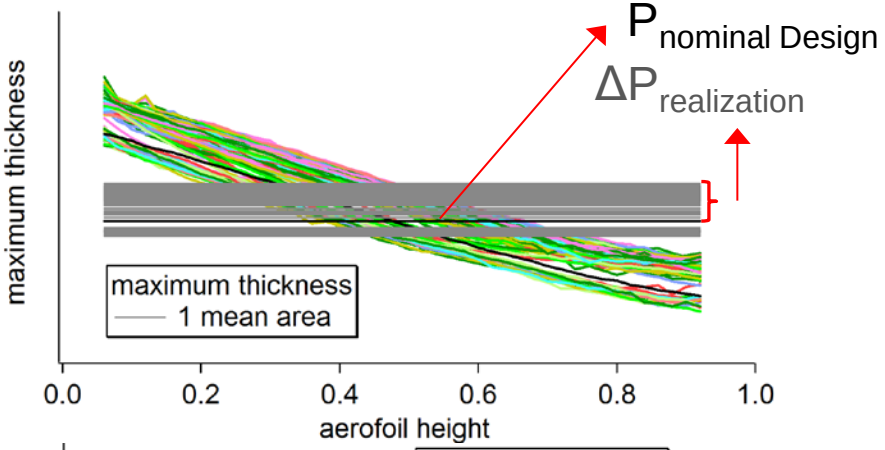


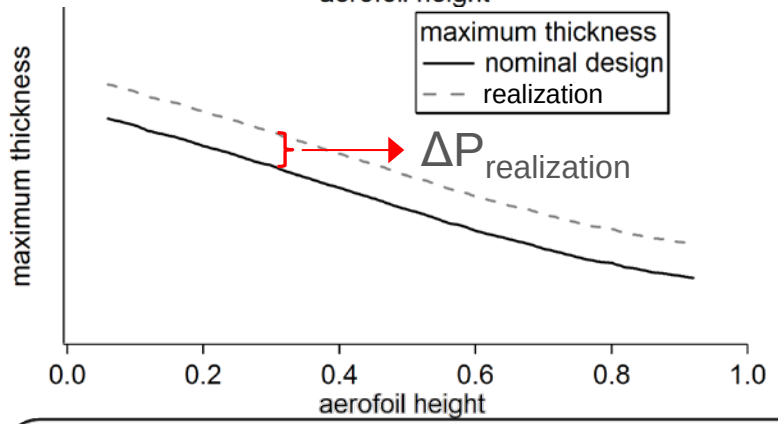
- about 500 scanned HPT-blades
- 61 profile slice extraction according to the streamlines
- 14 parameters to describe the profile slice geometry







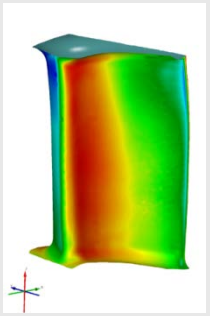
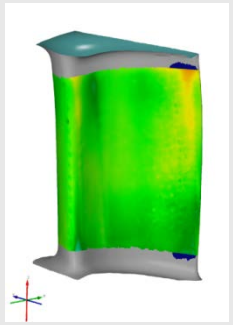
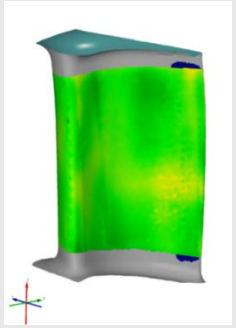
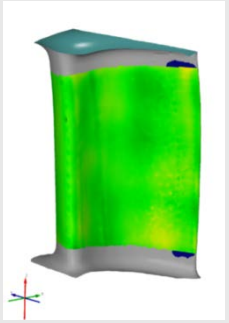




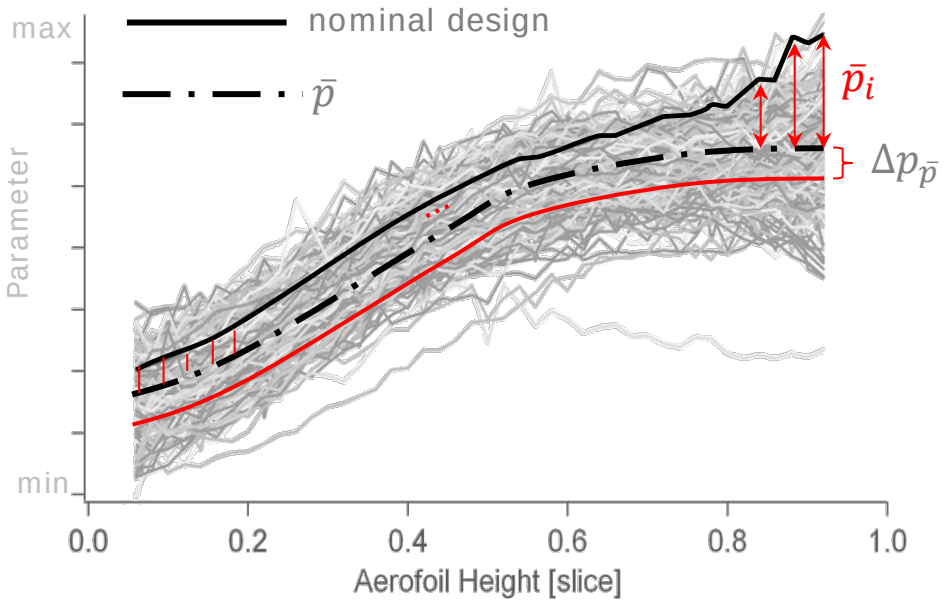
- high correlations between different areas of parameter maximum thickness

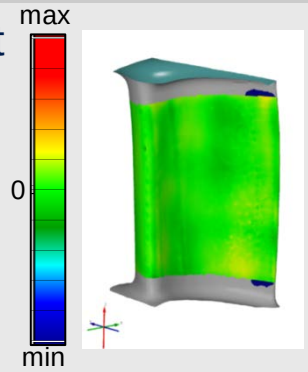
- applied delta model (1 mean area)
- $P_{nominal\ Design} + \Delta P_{realization} = P_{realization}$
- Ref.: Heinze et. al, 2013, *CEAS Aeronautical Journal*

basic delta model

method	original	1 mean area setup	2 mean area setup	4 mean area setup
parameters	-	14	28	56
deviation plot profile setup vs. digitised aerofoil	max 0 min 			

- method to rebuild profile shows small deviations to the digitised aerofoil compared to the digitised aerofoil vs. nominal design
- more geometric effects can be considered with an increased number of parameters / mean ares



method	4 mean area basic setup	1 mean area improved setup
parameters	56	14
deviation plot profile setup vs. digitised aerofoil		

- use mean value of measurement as reference instead of nominal design
- more realistic description of real geometric behaviour with less parameters compared to basic setup

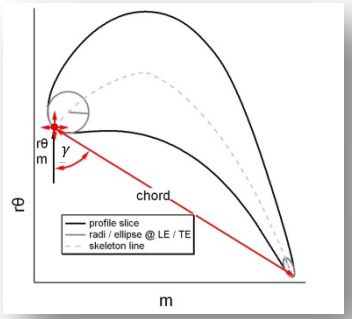
BR715 high pressure turbine - 1.5 stage

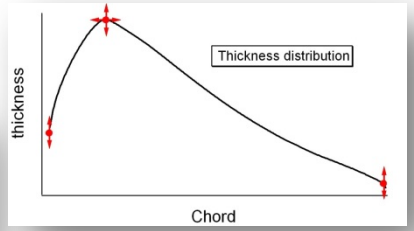
	stator	rotor	stator	
node quantity	1 021 840	2 482 900	1 315 266	/ 4 820 006
coolant	yes	yes - flexible	yes	
model	steady-state RANS, Spalart-Allmaras, real gas			
input	nominal design	nominal design & scatter of used delta parameters	nominal design	
action		rebuilt aerofoil & shroud		

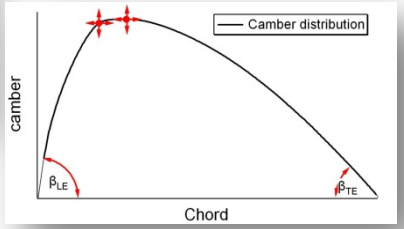
Introduction of geometric variability to CFD-model

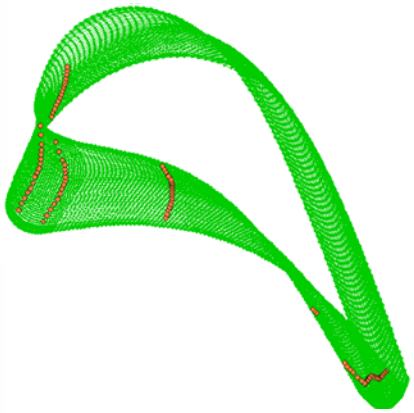
measurement vs. nominal design delivers delta parameters

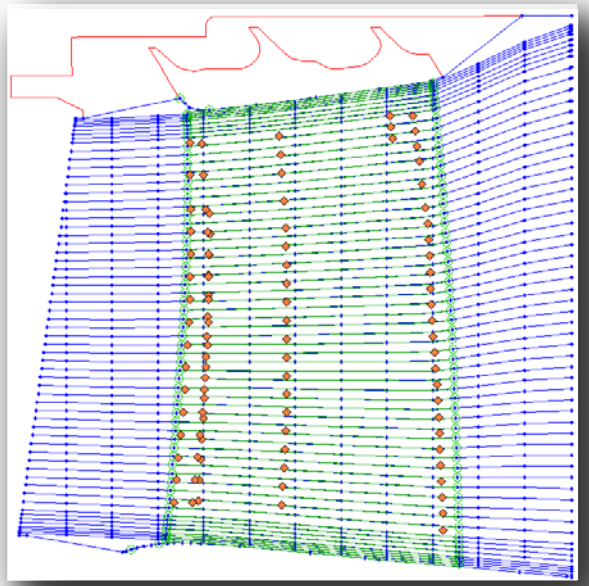
- 61 slices
- 61 flexible profiles
- shroud adapt to aerofoil
- coolant follows aerofoil











Probabilistic Simulation considering real geometric effects

Probabilistic Method

- depends on the investigations e.g. Monte-Carlo-Simulation (MCS) with optimized Latin Hypercube Sampling (LHS)

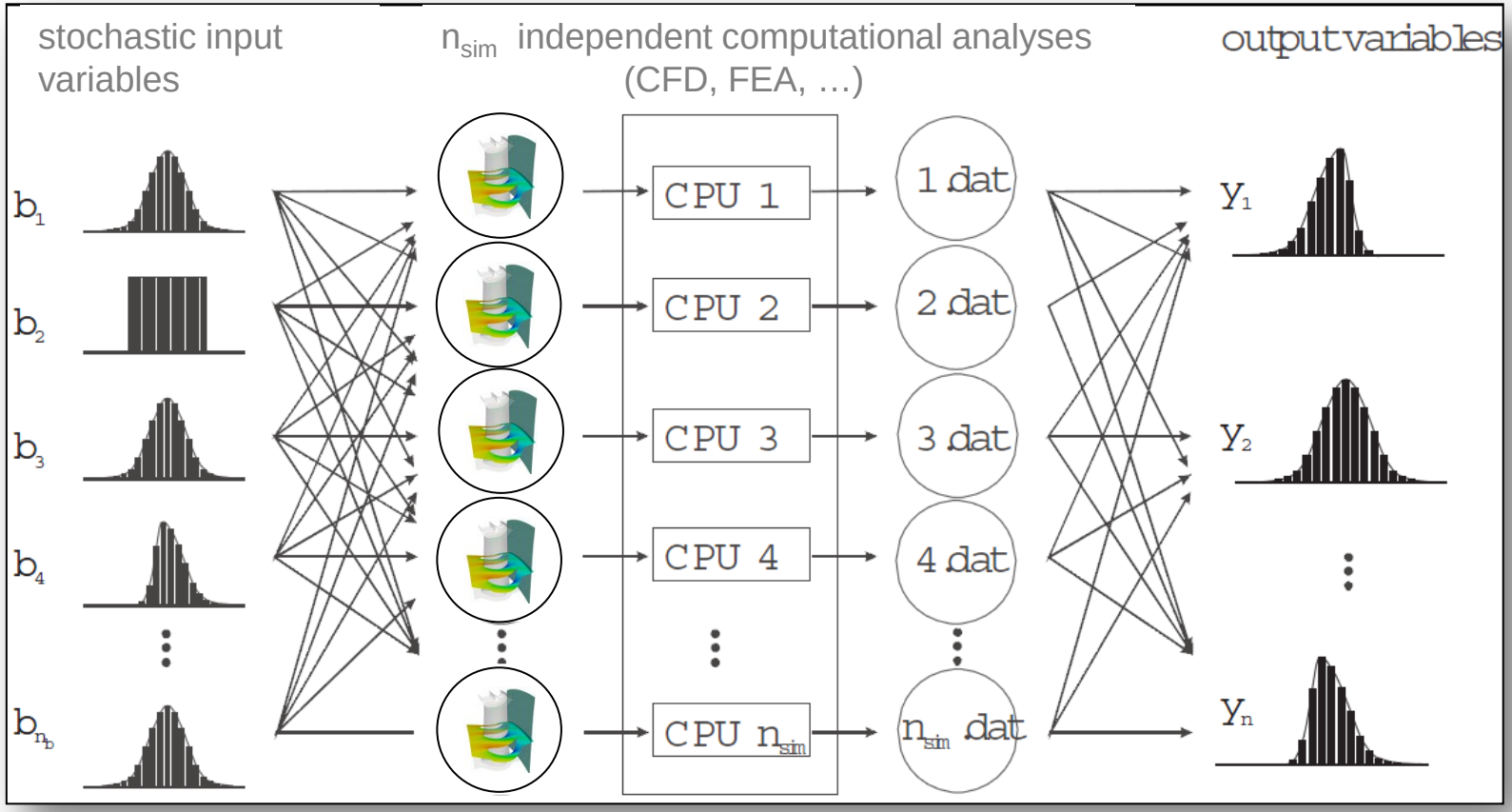
Deterministic Model

- a validated model to simulate the process

Input Parameter

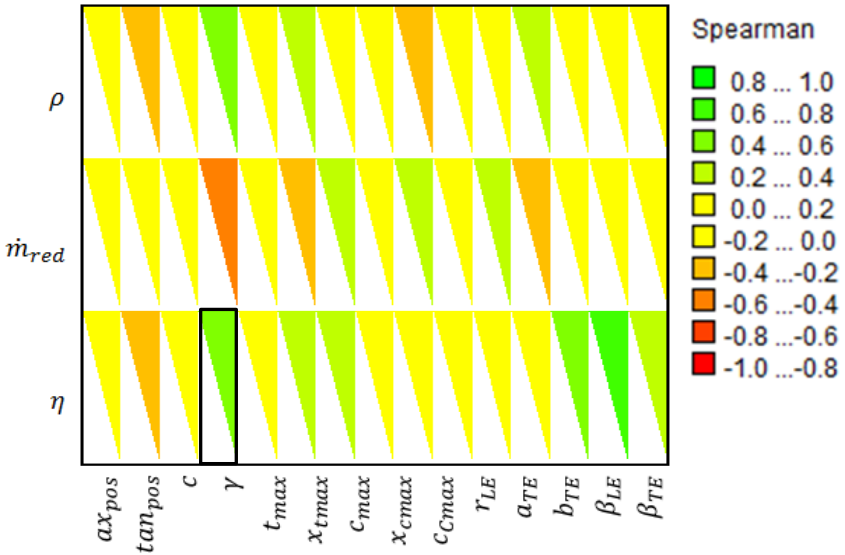
- distribution function and corresponding parameters of real geometric parameters
- correlations between the real input parameters

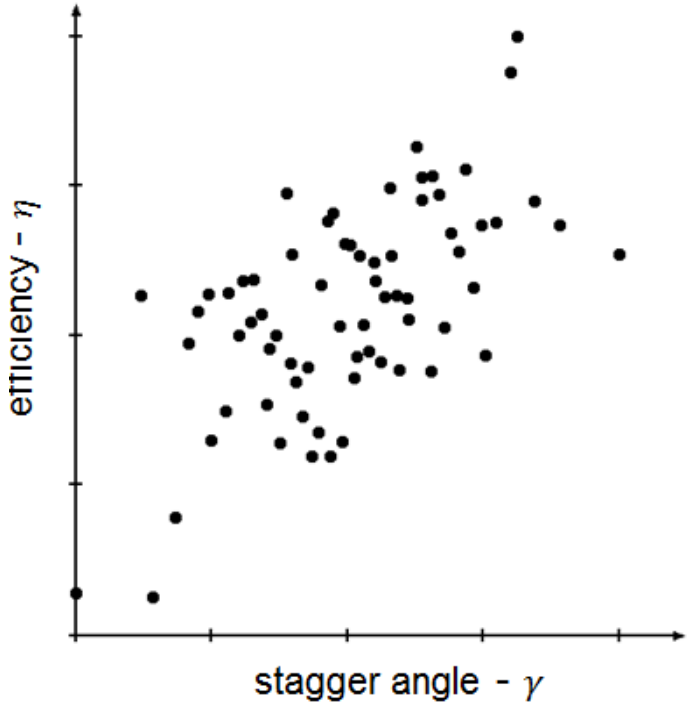
Monte-Carlo-Simulation using ProSi*



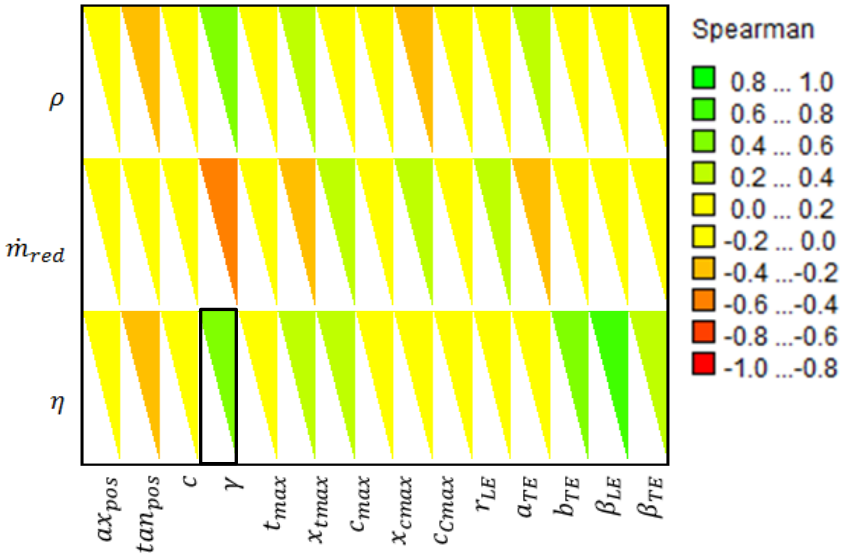
* ProSi – probabilistic tool designed by TU Dresden

Look for correlations (n_{sim}=70):

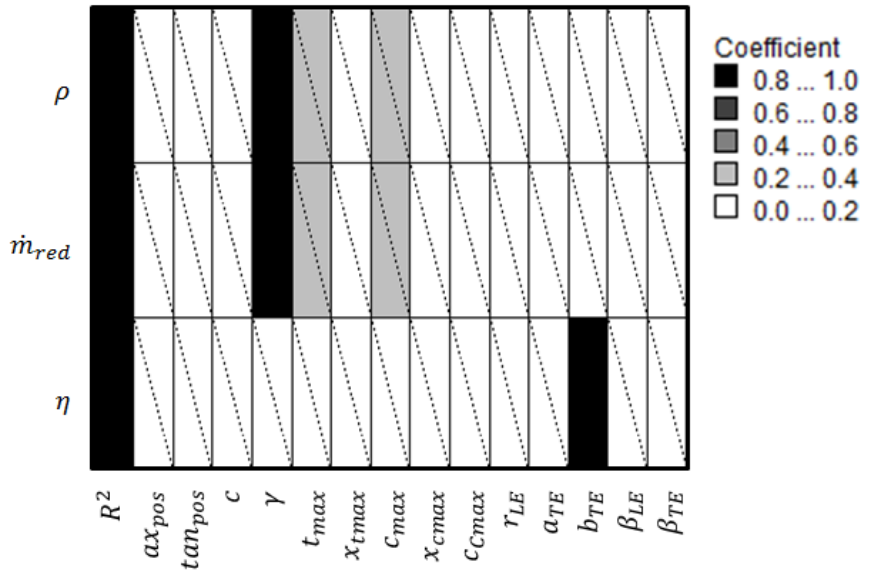




Look for correlations (n_{sim}=70):



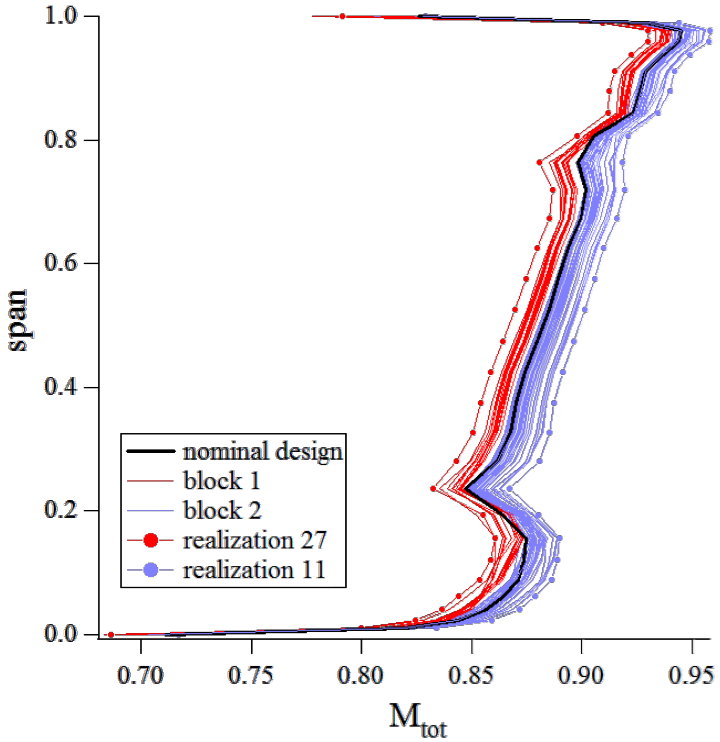
Coefficient of Importance (COI):



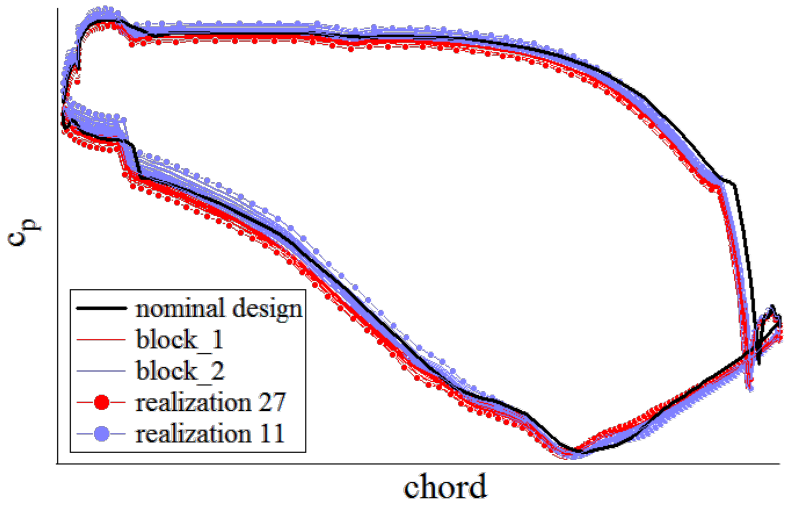
metamodel → 2nd order

1D:

M_{tot} at rotor exit

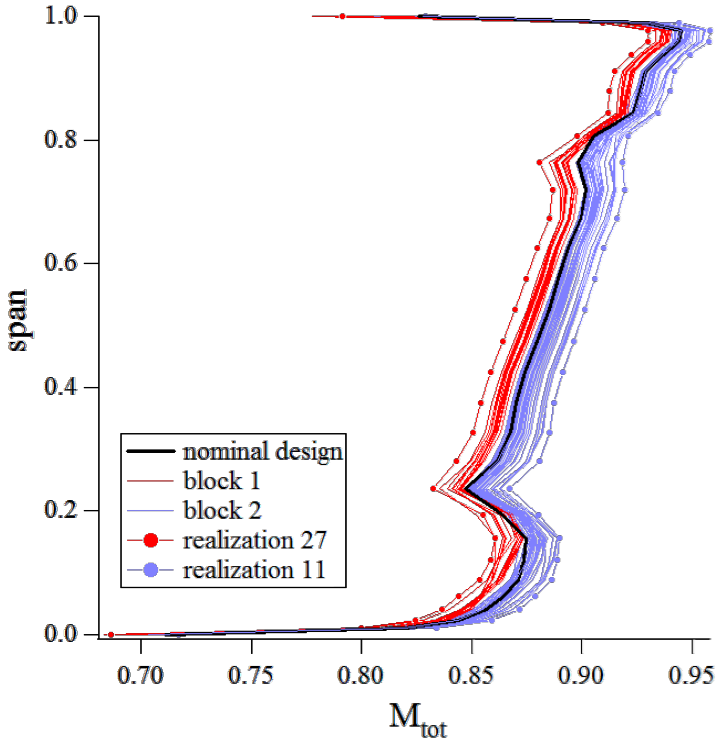


c_p at 50% span



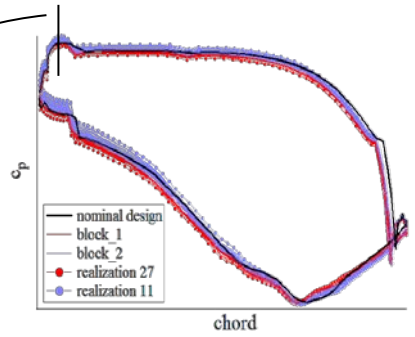
1D:

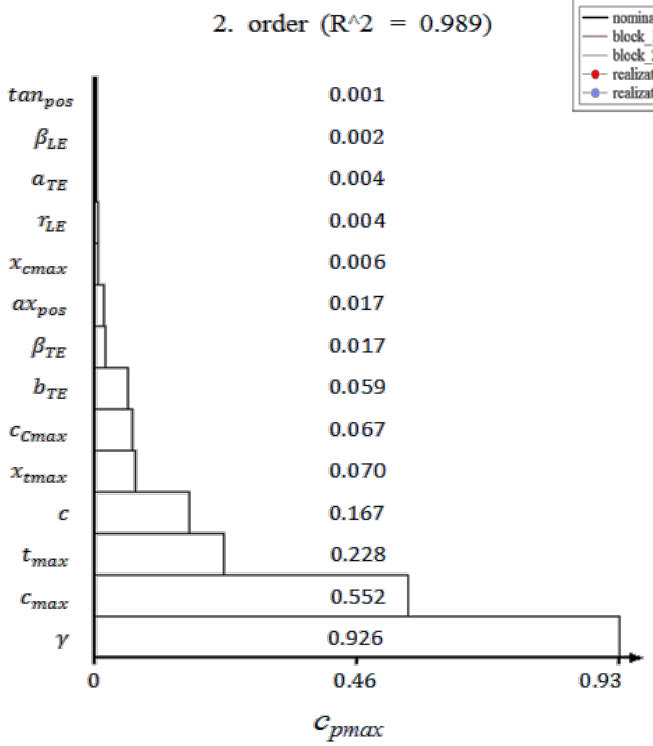
M_{tot} at rotor exit



COI of: c_{pmax}

c_p at 50% span

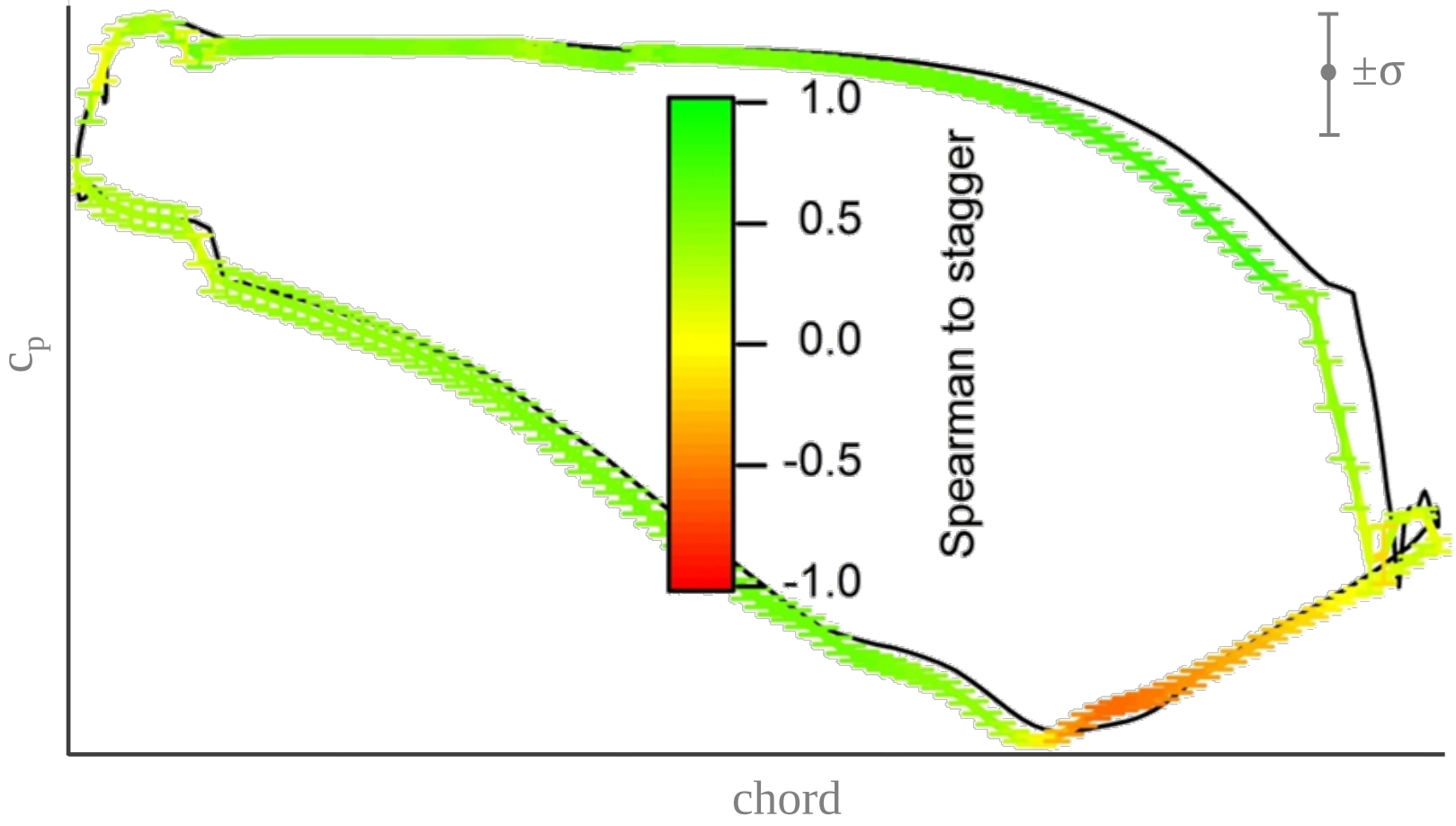




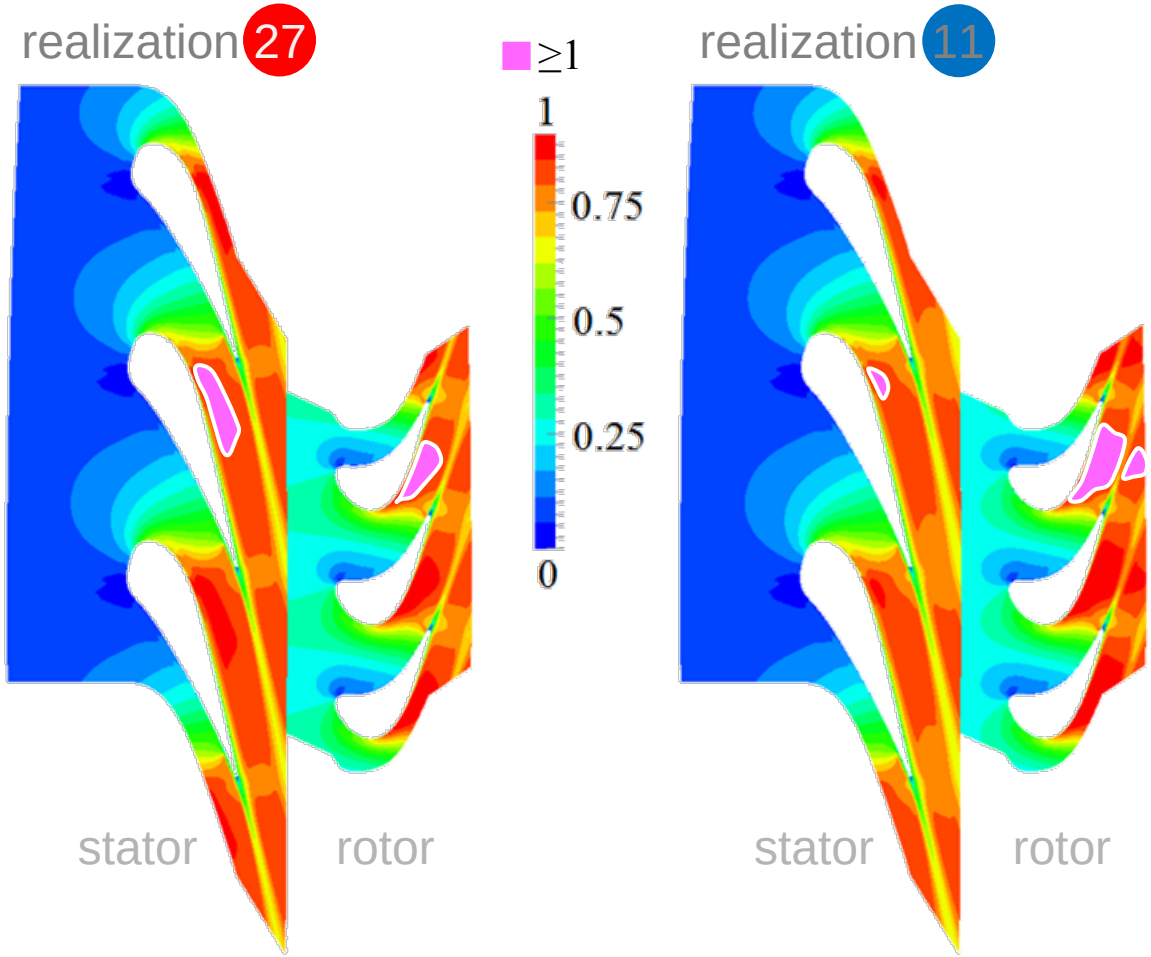
Spearman at 50% span

c_p of nominal design c_p of realizations

c_p - γ

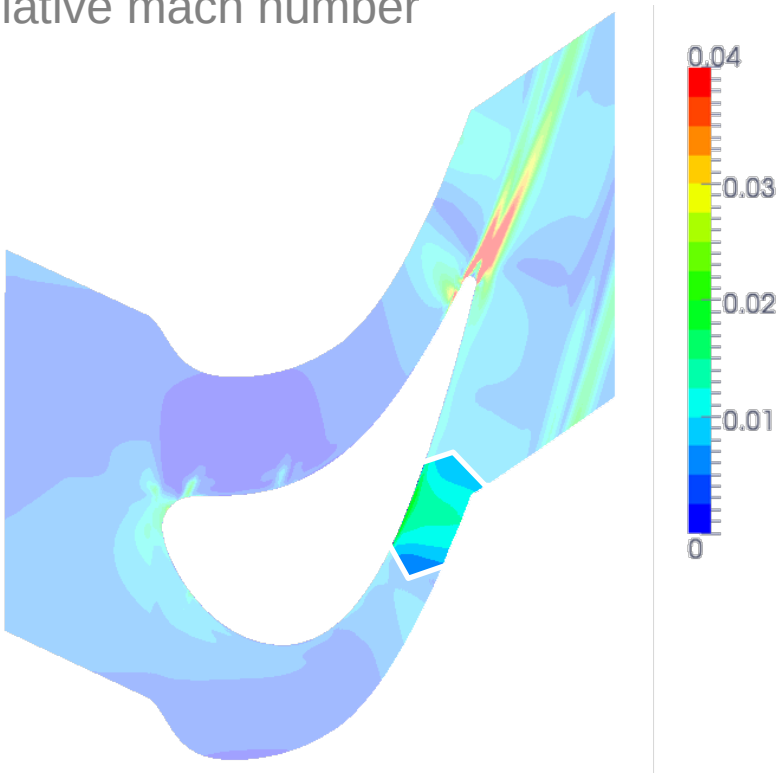


relative Mach number (50% rotor span):

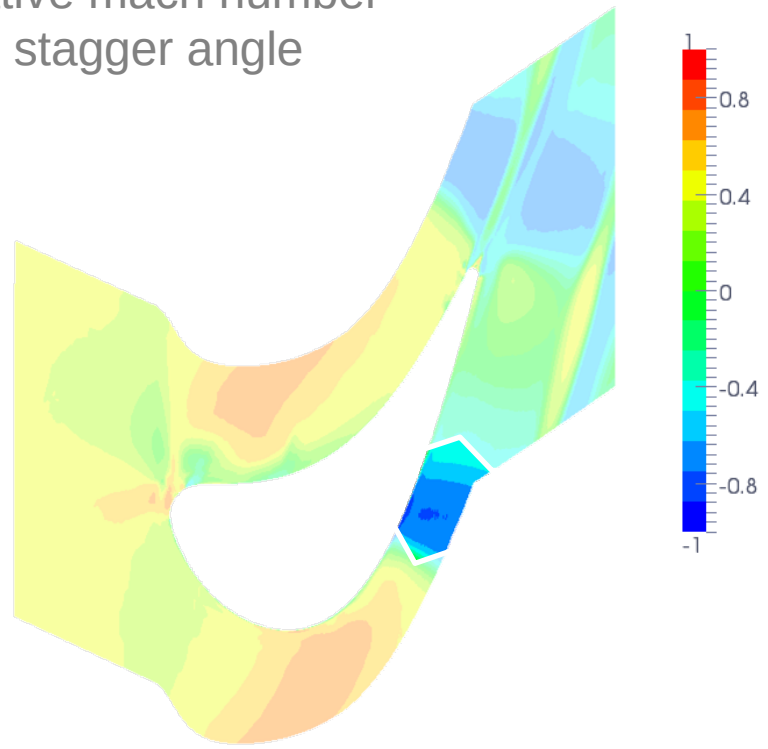


SoP – Statistics on Passage at 50% span

standard deviation of relative mach number



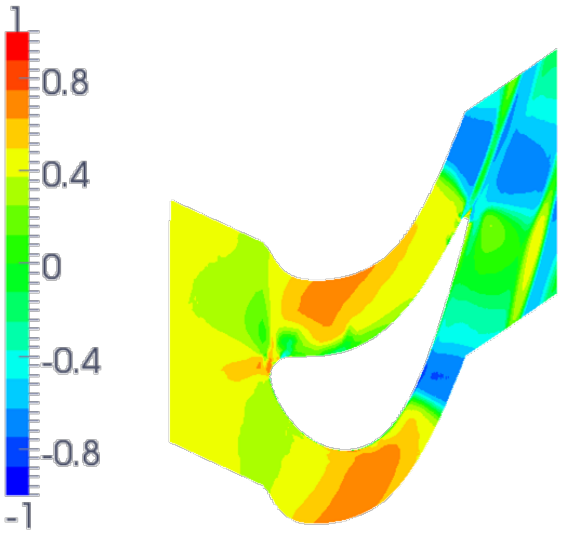
correlation between relative mach number and stagger angle



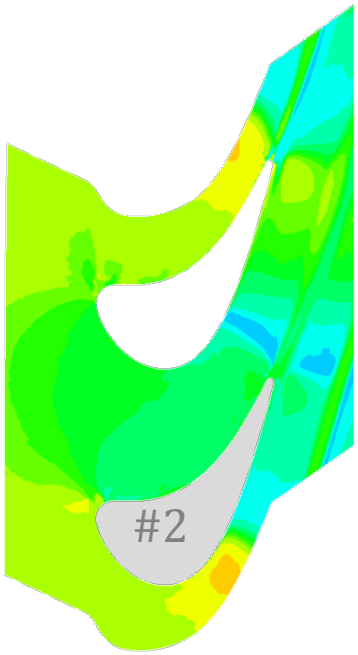
SoP – Statistics on Passage at 50% span

non-axisymmetric assembling

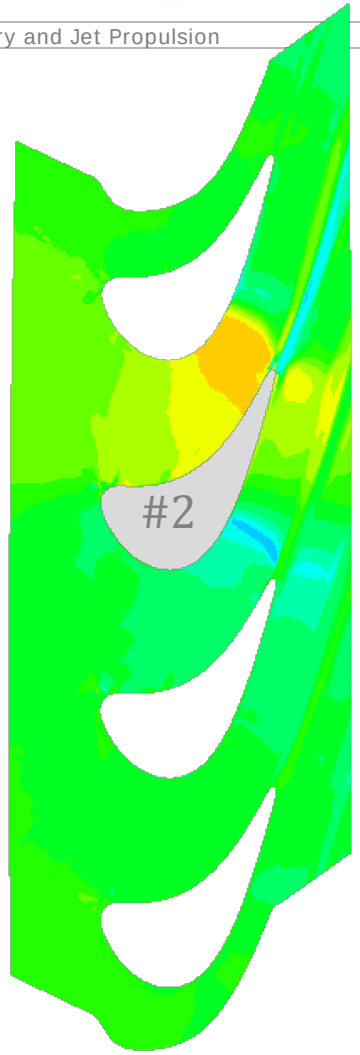
correlation between relative mach number and stagger angle



1 - Passage



2 - Passages



4 - Passages

PROBABILISTIC CFD ANALYSIS OF HPT-BLADES CONSIDERING REAL GEOMETRIC EFFECTS

- deterministic 1.5 HPT stage CFD-model
- 500 real manufactured HPT-blades were digitised and parameterised
- rebuild of probabilistic HPT-blades to describe real produced parts
- MCS → scatter: input vs. output
  - → very potential tool that brings real life into computer
  - → enables target-oriented analyses
  - → statistical analyses across entire CFD-mesh
- results → stagger most important regarding capacity and rotor reaction
  - → thickness of trailing edge influences efficiency mostly
  - → non-axisymmetric effects: impact of parameter more local & less strong

Questions??

HolisTurb / InterTurb - Project financing within the scope of *Luftfahrtforschungsprogramm Call IV* (2009- 2013)

Gefördert durch:
Bundesministerium für Wirtschaft und Technologie
aufgrund eines Beschlusses des Deutschen Bundestages

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur