TECHNISCHE UNIVERSITÄT DRESDEN

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

A parametric model for probabilistic analysis of turbine blades considering real geometric effects

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

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Gefördert durch:

Bundesministerium für Wirtschaft und Technologie

aufgrund eines Beschlusses des Deutschen Bundestages

DRESDEN concept Exzellenz aus Wissenschaft und Kultur

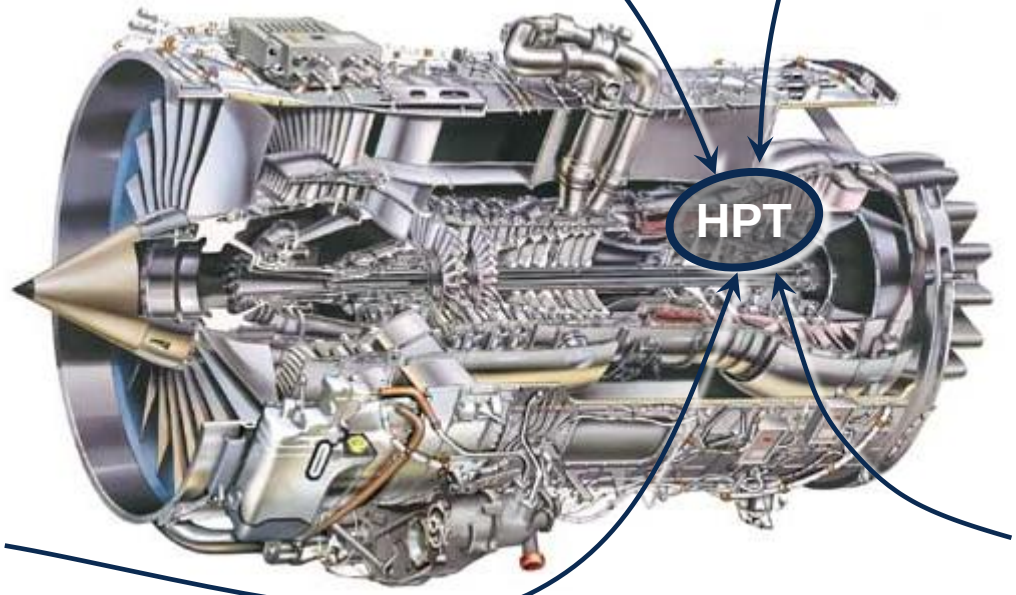
Geometric scatter driven by:

supplier 1
supplier 2

- know-how
- quality standard
- …

processing 1
processing 2

- workman
- machine pool
- …



Rolls-Royce

BR715 Engine

airline 1
airline 2

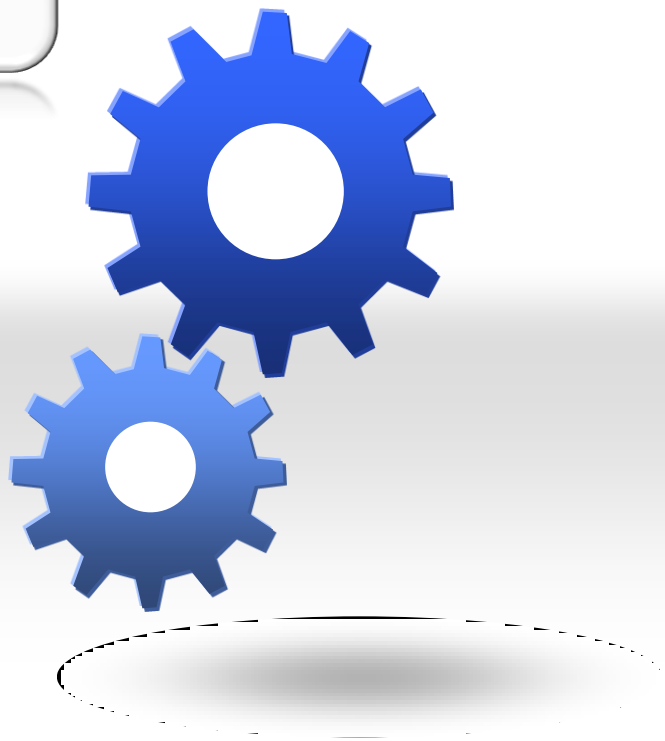
- location
- cycles
- services

reconditioning 1
reconditioning 2

- philosophy
- time managment
- …

Effects due to geometric scatter?

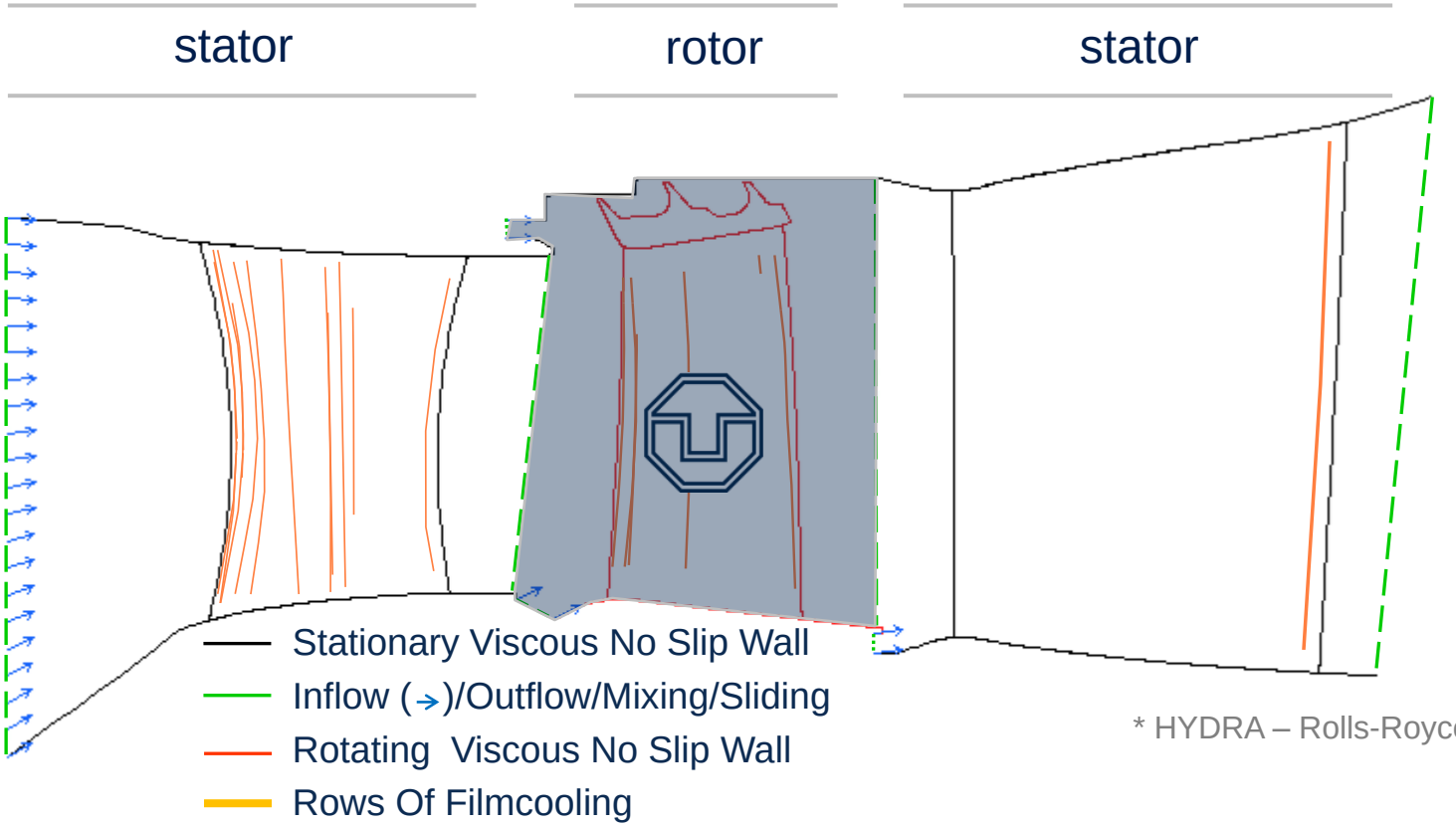
Probabilistic Simulation considering real geometric effects



Deterministic Model

- a validated model to simulate the process

BR715 high pressure turbine - 1.5 stage



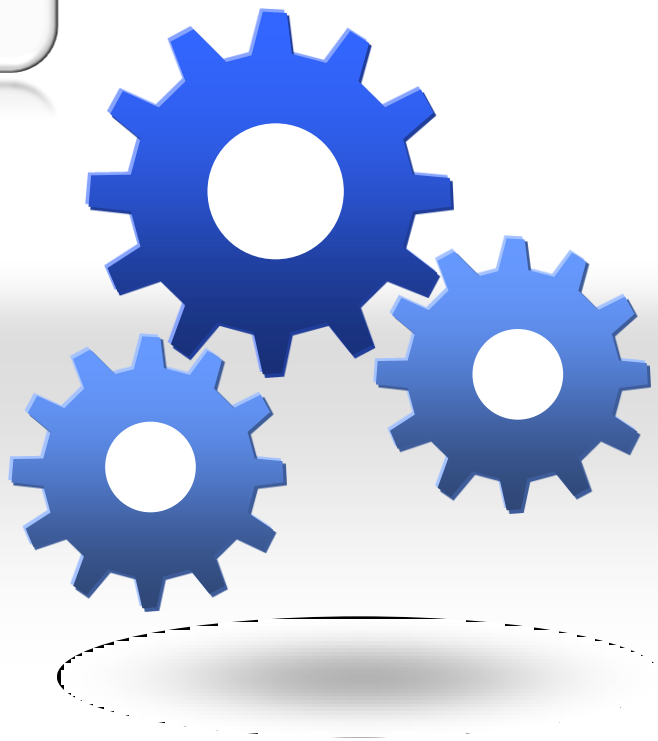
* HYDRA – Rolls-Royce CFD-code

→ validated CFD-mesh allready provided by Rolls-Royce

BR715 high pressure turbine - 1.5 stage

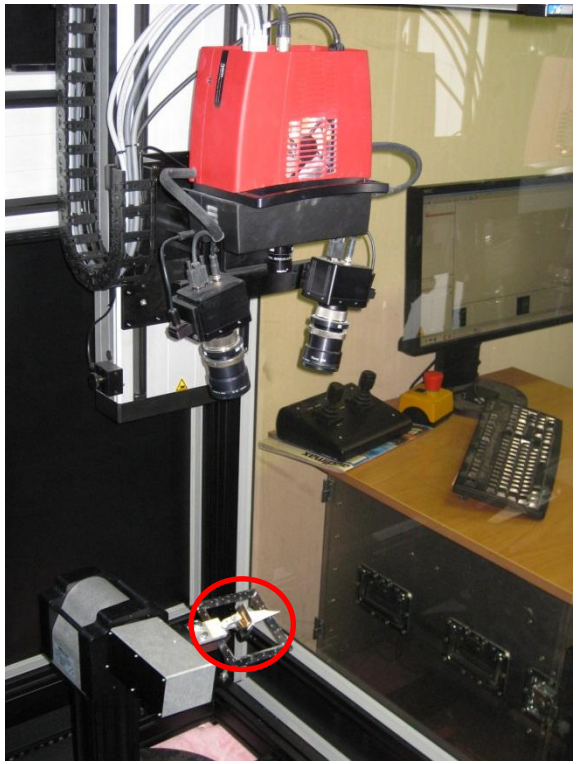
	stator	rotor	stator	
node quantity	1 021 840	2 482 900	1 315 266	/ 4 820 006
fillet	no	no	no	
coolant	yes	yes - flexible	yes	
model	stationary, real gas, Spalart-Allmaras			
input	nominal design	nominal design & scatter of used delta parameters	nominal design	
action		rebuilt aerofoil & shroud		

Probabilistic Simulation considering real geometric effects



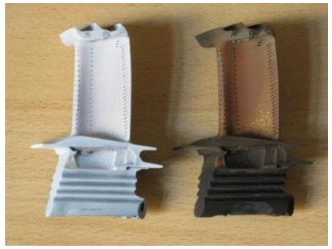
Deterministic Model
- a validated model to simulate the process

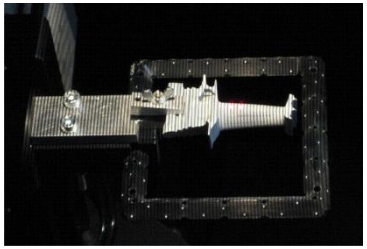
Input Parameter
- distribution function and corresponding parameters of real geometric parameters
- correlations between the real input parameters

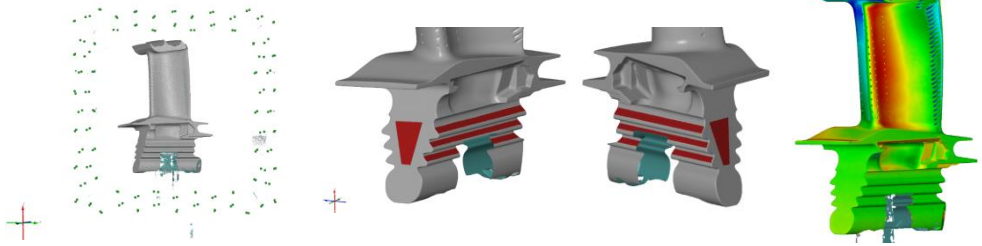


GOM ATOS SO 4M

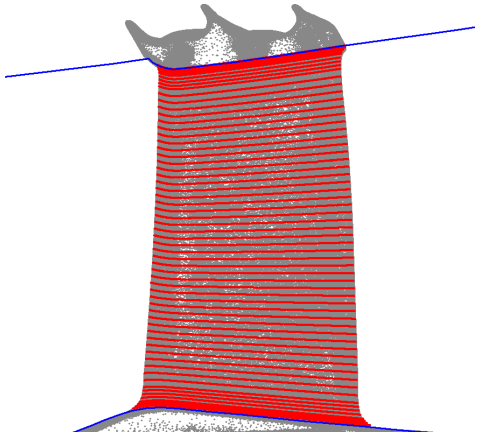
- Measurement accuracy of 0.005 mm according to VDI 2634 Part III
- Blade specific measurement accuracy of 0.008 mm at planar faces and 0.027 mm at areas with high curvature (e.g. cooling holes)
- Measurement area up to 300 mm x 300 mm
- automation unit with 6 degrees of freedom
- application of reference frame to combine the scanned views
- additional quality control algorithms integrated

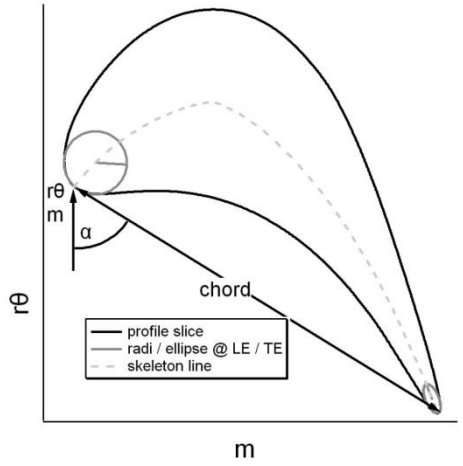


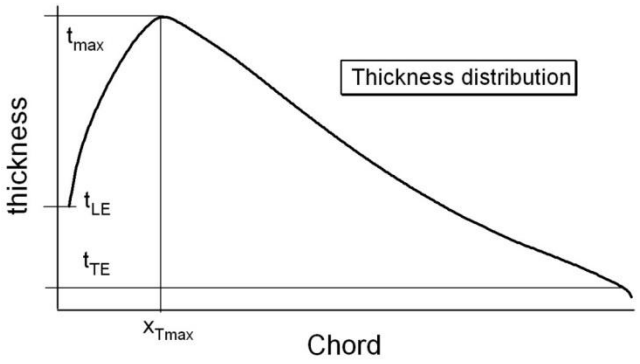


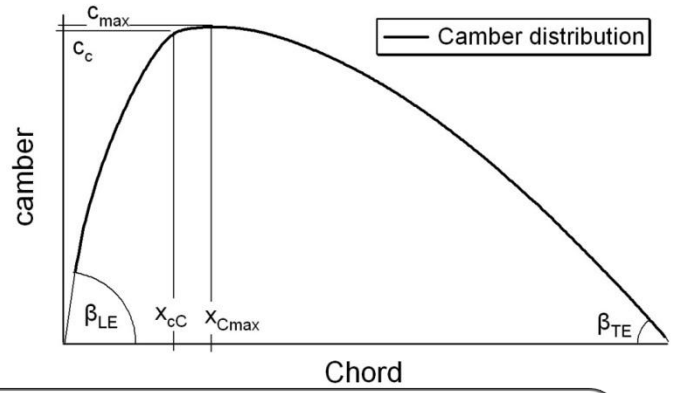


Input for Probabilistics

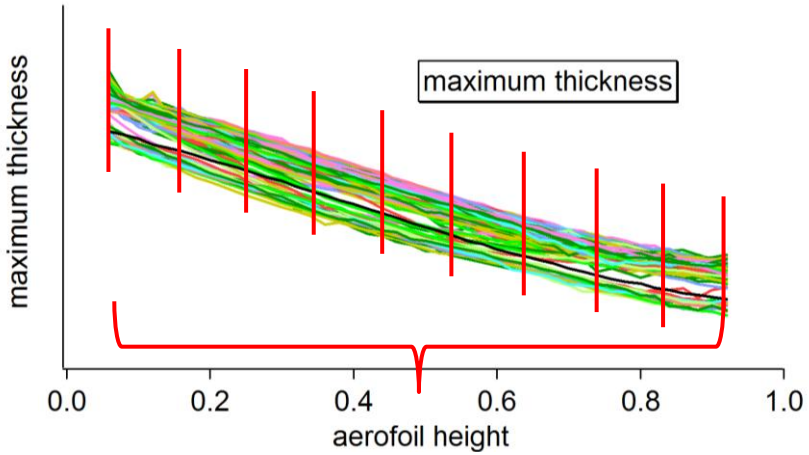


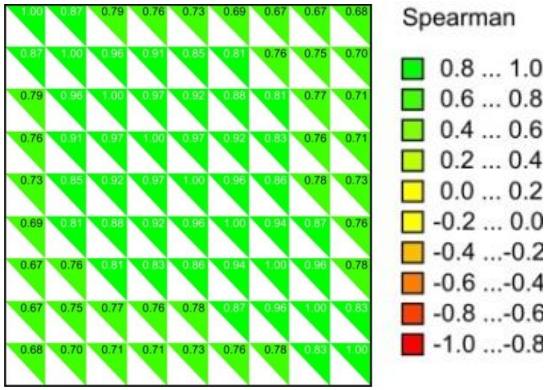


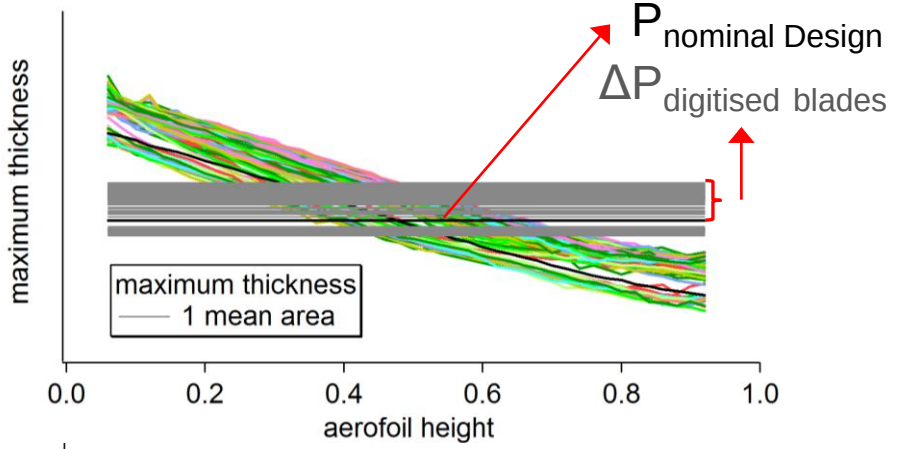


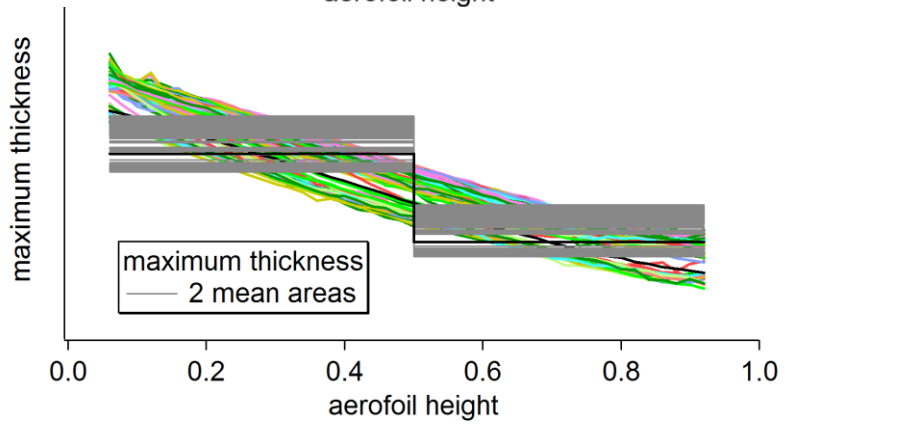


- 61 profile slice extraction according to the streamlines
- 15 parameters to describe the profile slice geometry



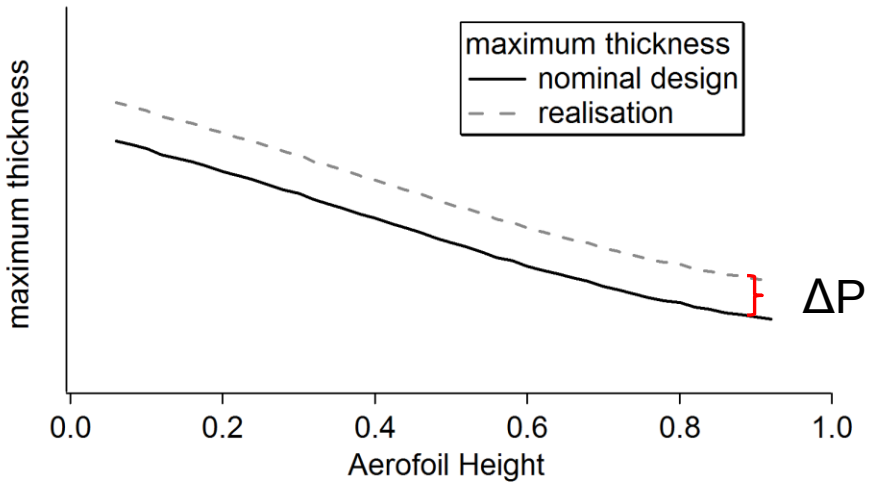


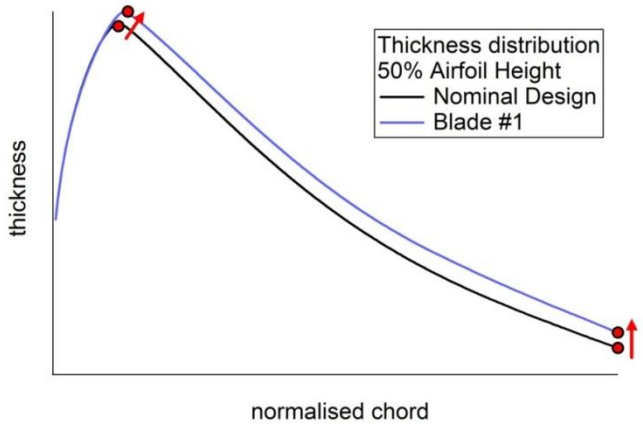




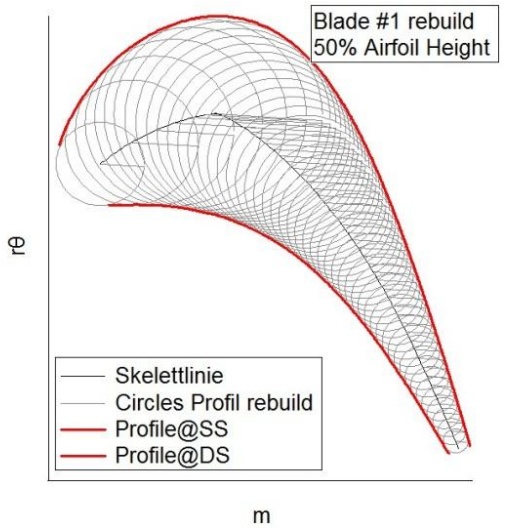
- high correlations between different areas of parameter maximum thickness

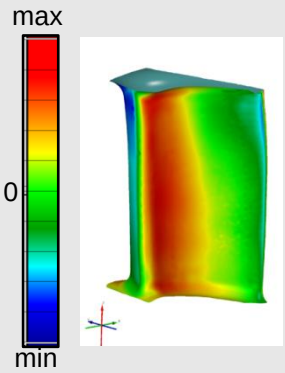
- delta model applied





- $P_{nominal\ Design} + \Delta P_{digitised\ blades} = P_{realisation}$
- figure on the top right shows nominal design and realisation thickness distributions
- nominal design thickness distribution will be morphed according to the geometric parameters at the anchor points



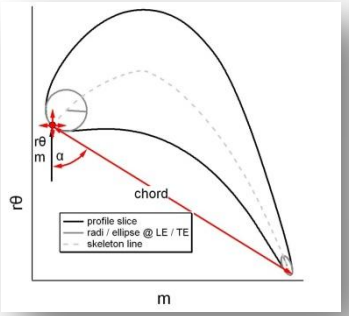
method	original
parameters	-
deviation plot profile setup vs. digitised aerofoil	

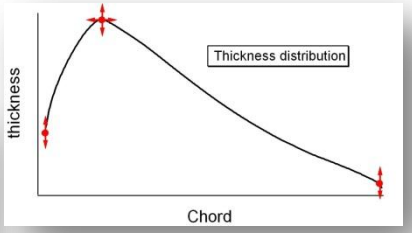
- profile setup method shows small deviations to the digitised aerofoil compared to the nominal design aerofoil
- more geometric effects can be considered with an increased number of parameters

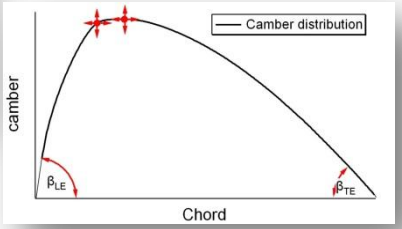
Introduction of geometric variability to CFD-model

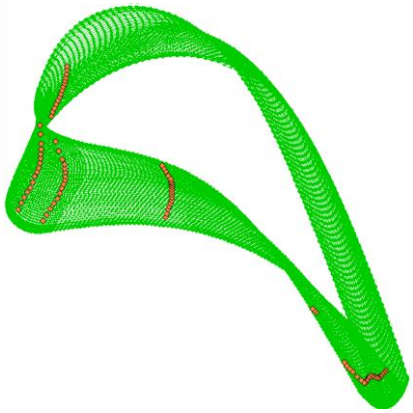
measurement vs. nominal design delivers delta parameters

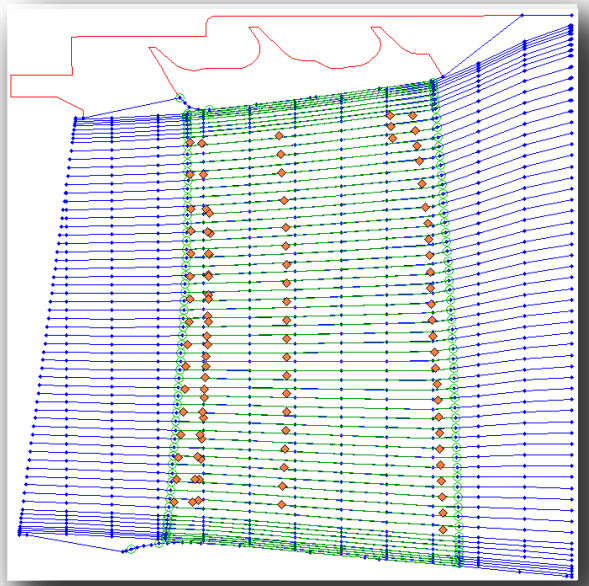
- 61 slices
- 61 flexible profiles
- shroud adapt to aerofoil
- coolant follows aerofoil











Probabilistic Simulation considering real geometric effects

Probabilistic Method

- depends on the investigations e.g. Monte-Carlo-Simulation (MCS) or Response Surface Method (RSM)

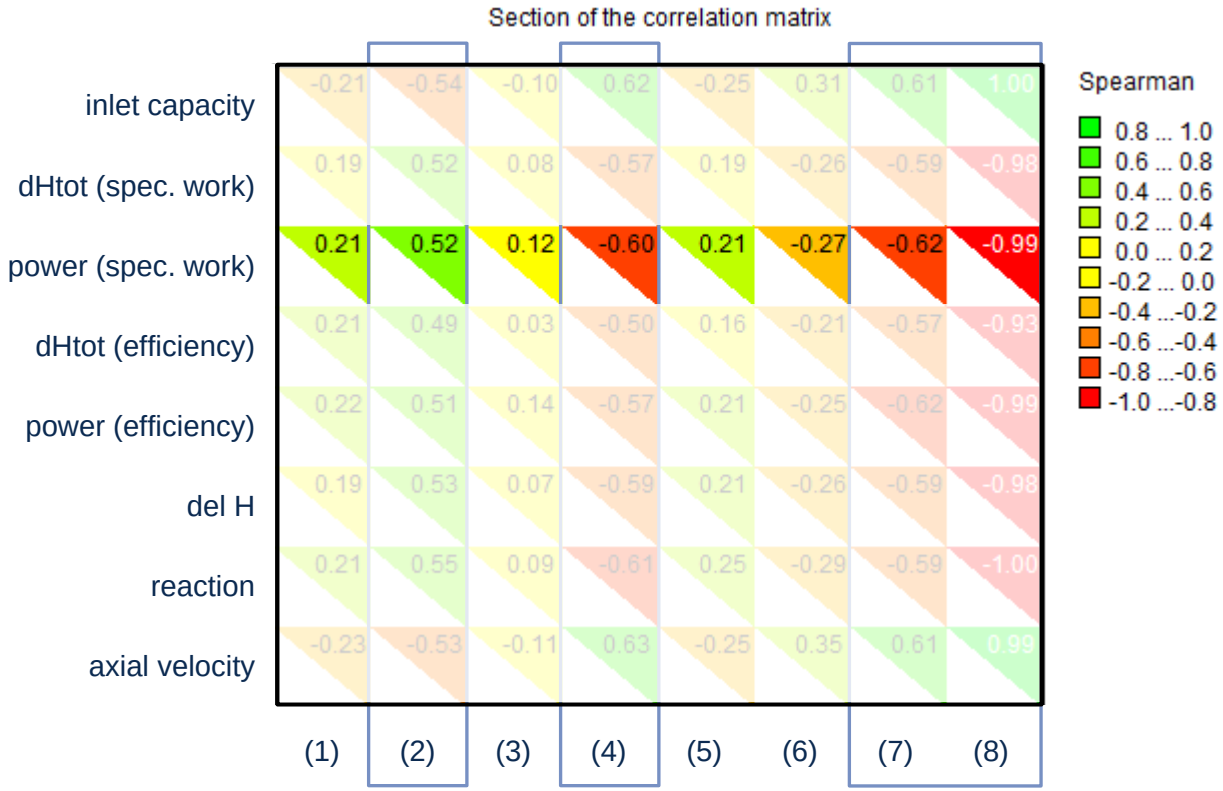
Deterministic Model

- a validated model to simulate the process

Input Parameter

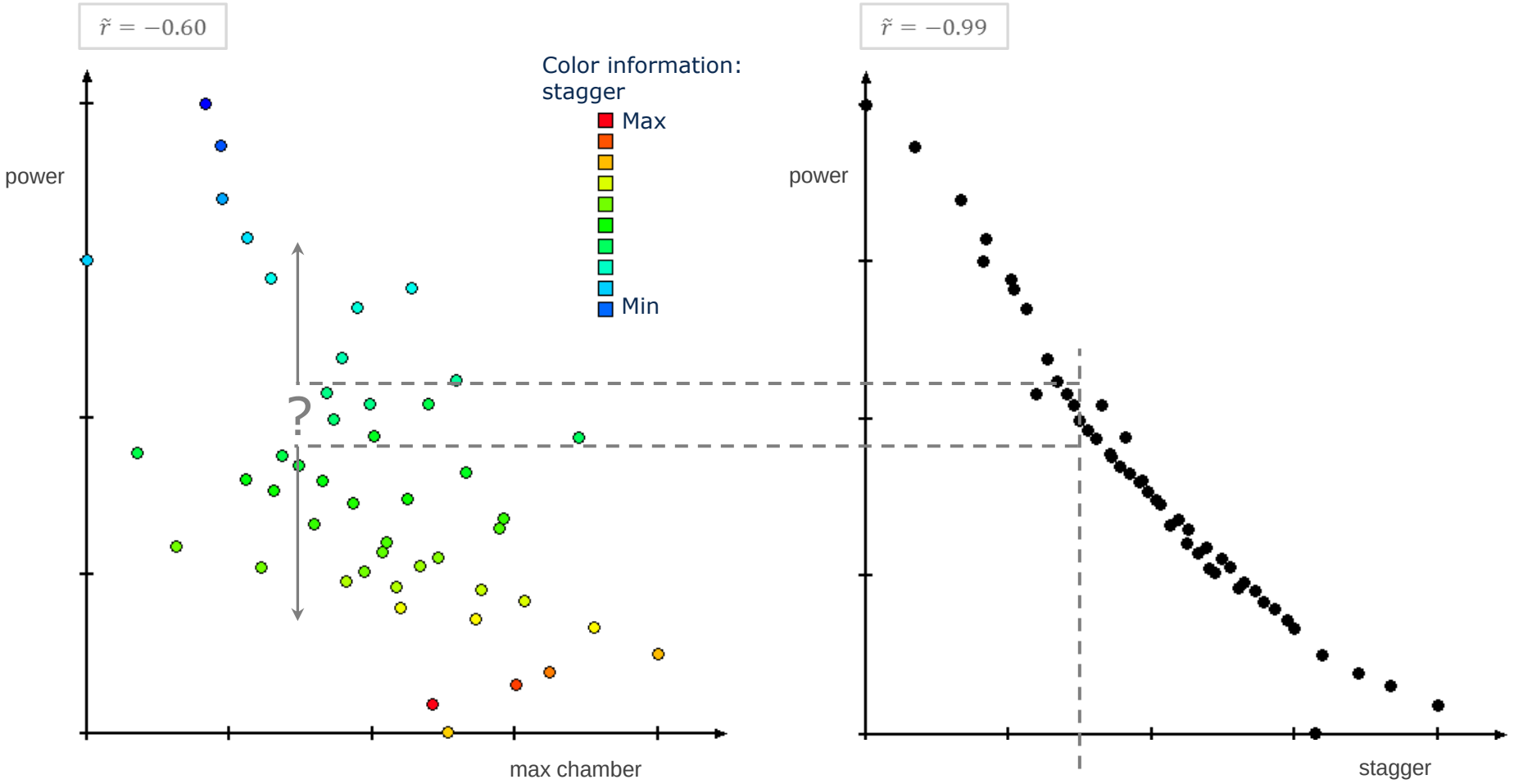
- distribution function and corresponding parameters of real geometric parameters
- correlations between the real input parameters

Look for correlations: $n_{sim} = 50$



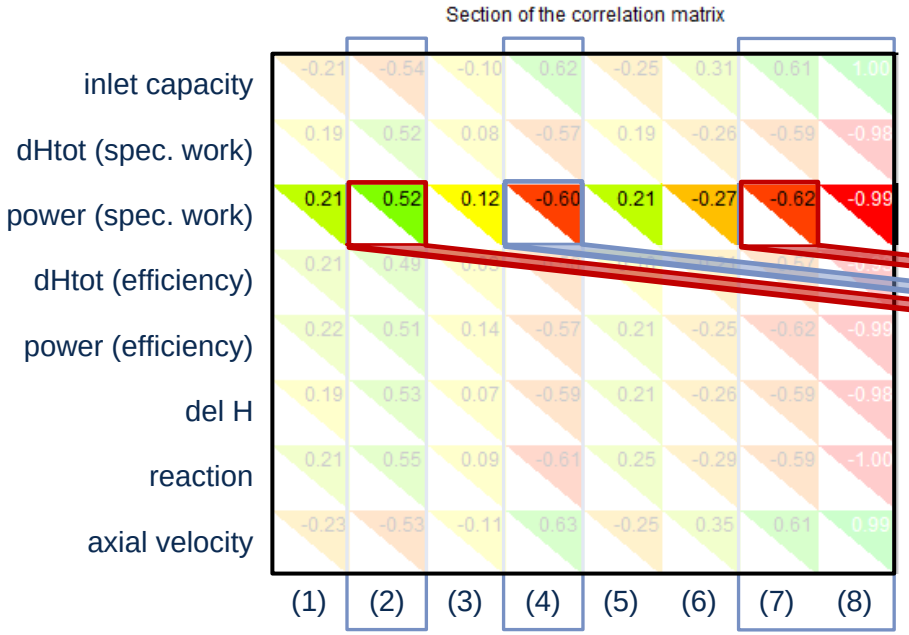
chord	(1)
LE tan Pos	(2)
LE ax Pos	(3)
max chamber	(4)
Pos max chamber	(5)
max thickness	(6)
Pos max thickness	(7)
stagger	(8)

Look for correlations:

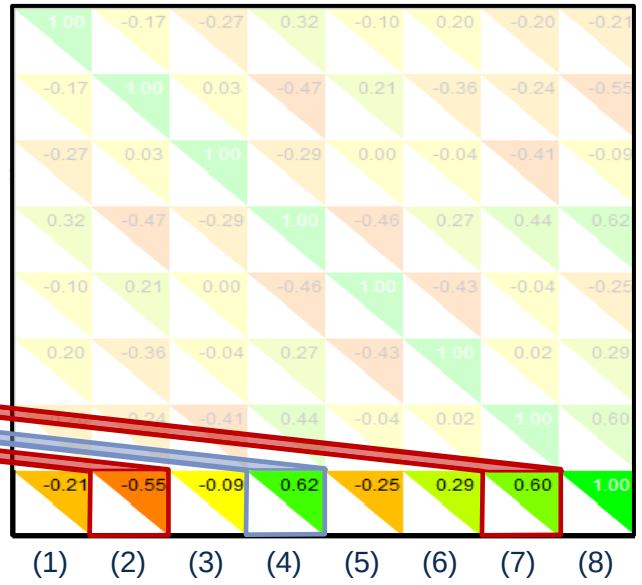


Spurious correlations :

results vs. input



input



(1) chord
(2) LE tan Pos
(3) LE ax Pos
(4) max chamber
(5) Pos max chamber
(6) max thickness
(7) Pos max thickness
(8) stagger

Spearman
0.8 ... 1.0
0.6 ... 0.8
0.4 ... 0.6
0.2 ... 0.4
0.0 ... 0.2
-0.2 ... 0.0
-0.4 ...-0.2
-0.6 ...-0.4
-0.8 ...-0.6
-1.0 ...-0.8

Coefficient of Importance (CoI):

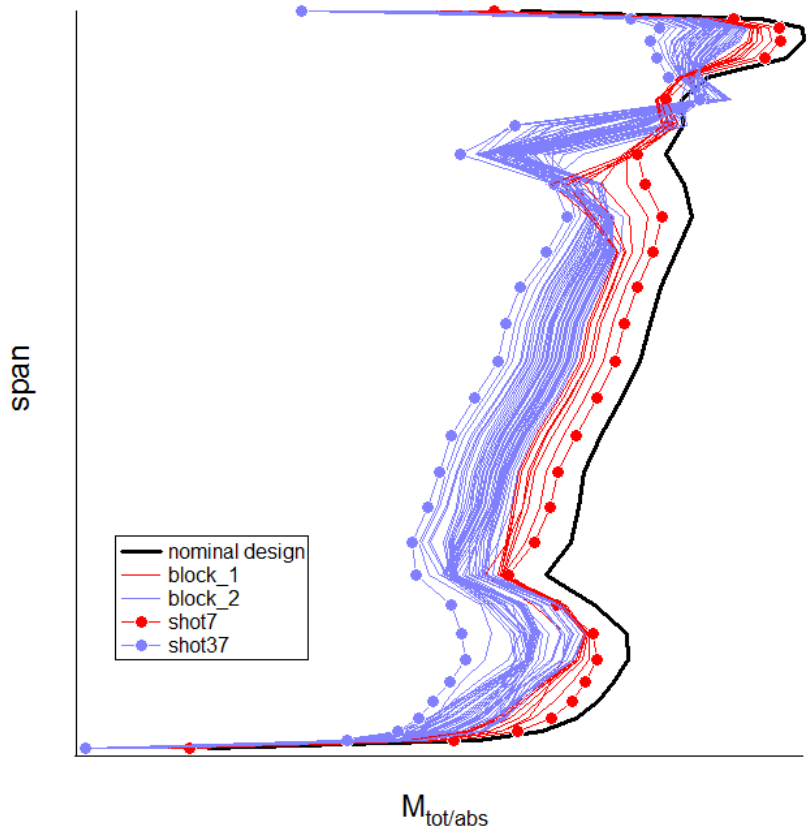
Section of the CoI-matrix

	R²	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
inlet capacity	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94
dHtot (spec. work)	0.95	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.95
power (spec. work)	0.99	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.98
dHtot (efficiency)	0.84	0.00	0.01	0.04	0.01	0.00	0.01	0.00	0.84
power (efficiency)	0.96	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.94
del H	0.95	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.95
reaction	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89
axial velocity	0.99	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.75

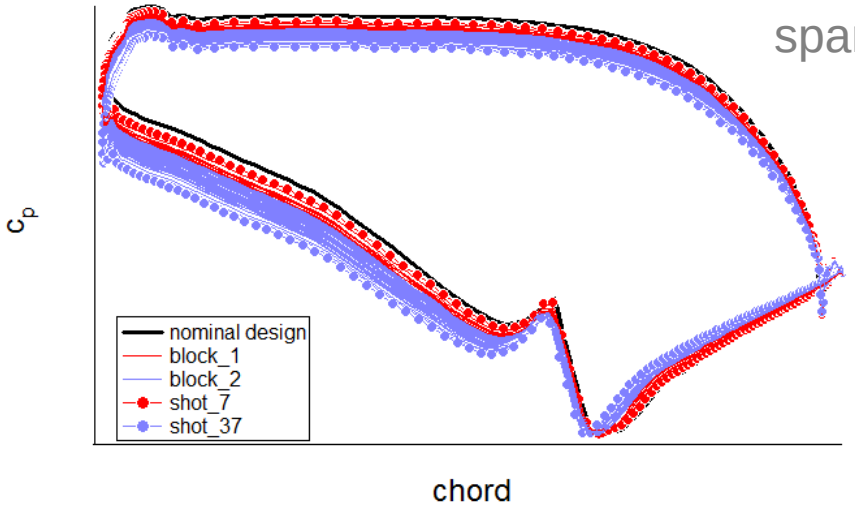
Coefficient
- 0.8 ... 1.0
- 0.6 ... 0.8
- 0.4 ... 0.6
- 0.2 ... 0.4
- 0.0 ... 0.2

chord	(1)
LE tan Pos	(2)
LE ax Pos	(3)
max chamber	(4)
Pos max chamber	(5)
max thickness	(6)
Pos max thickness	(7)
stagger	(8)

diverse plots



span 80%



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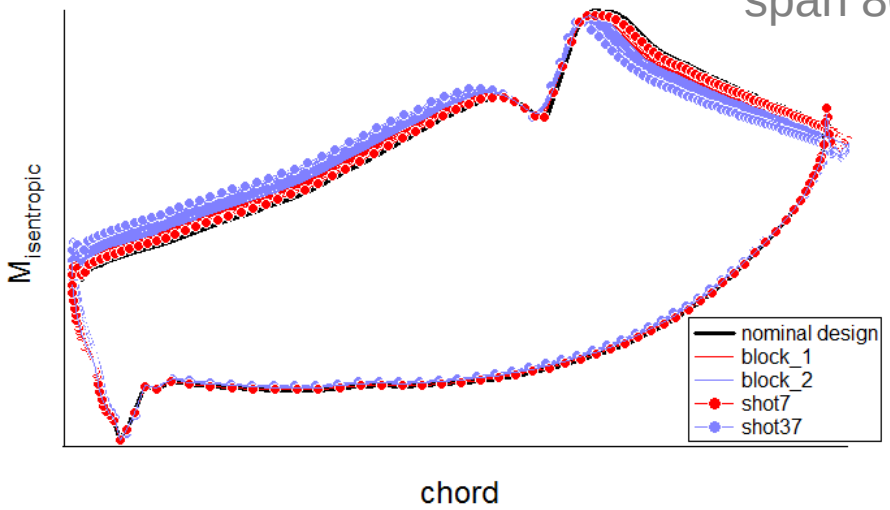
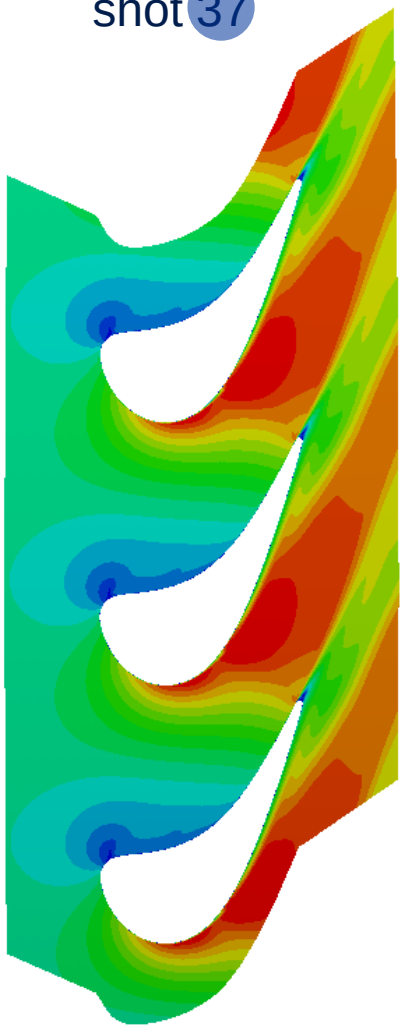


shot 37



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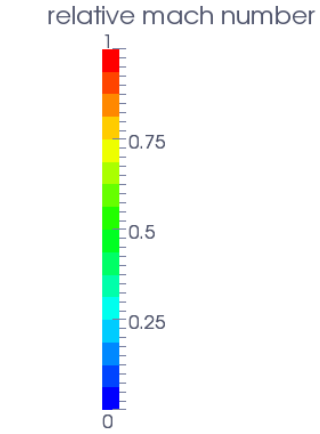
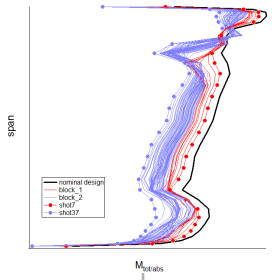
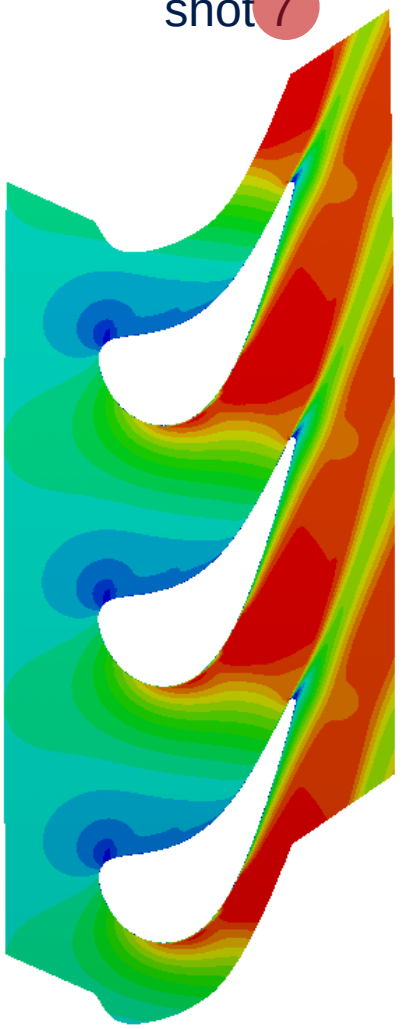




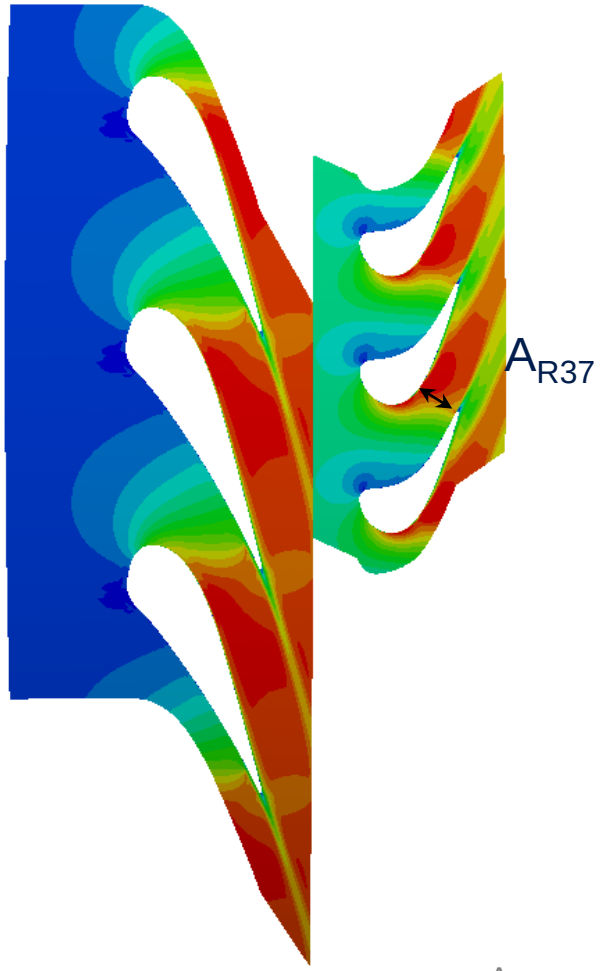
shot 7

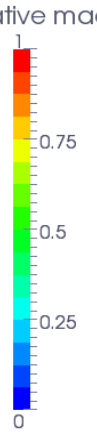


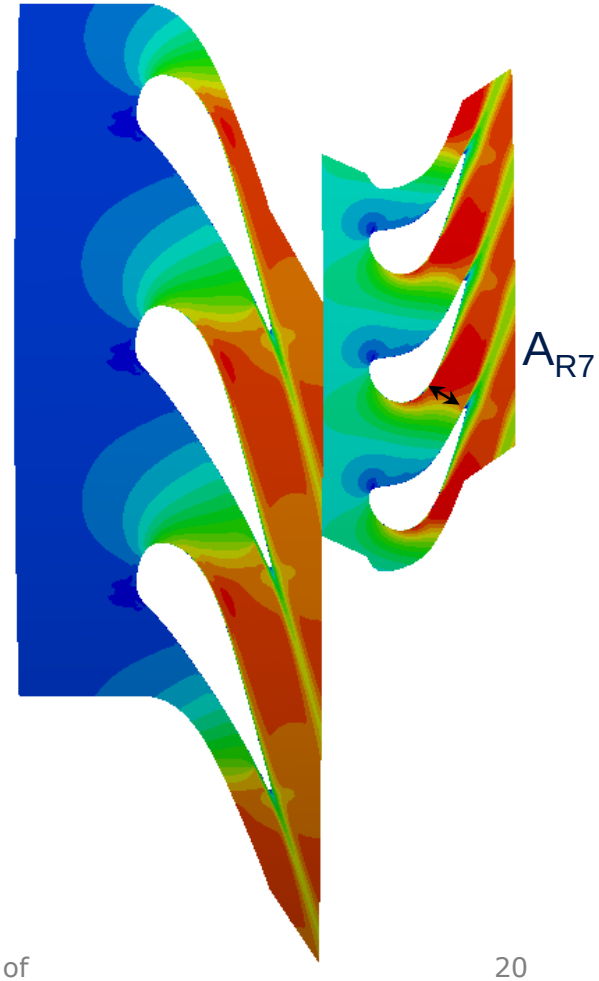
shot 37

span 80%

shot 7



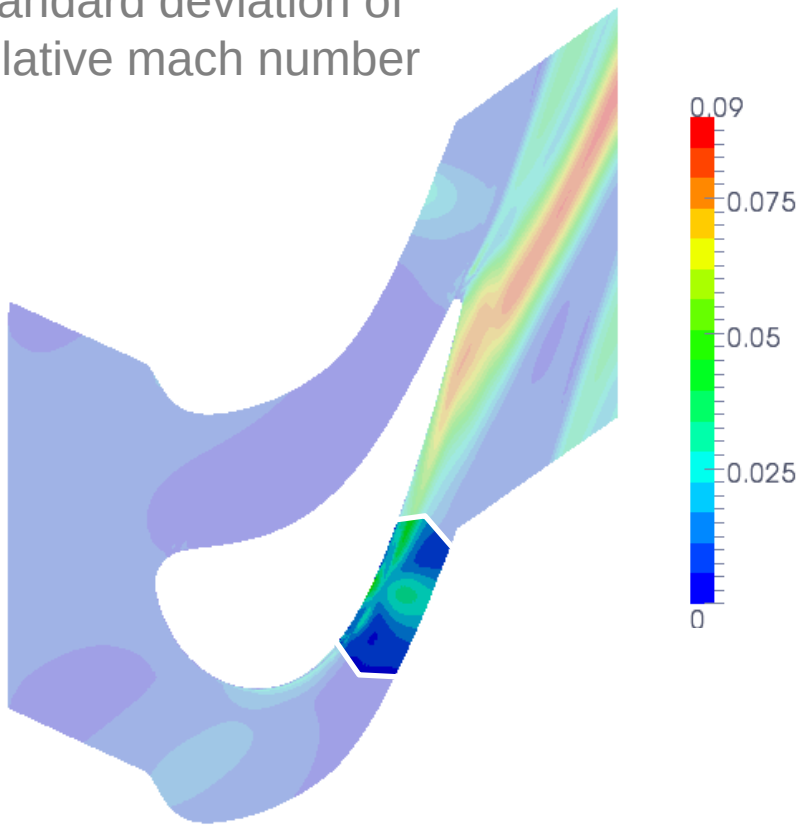




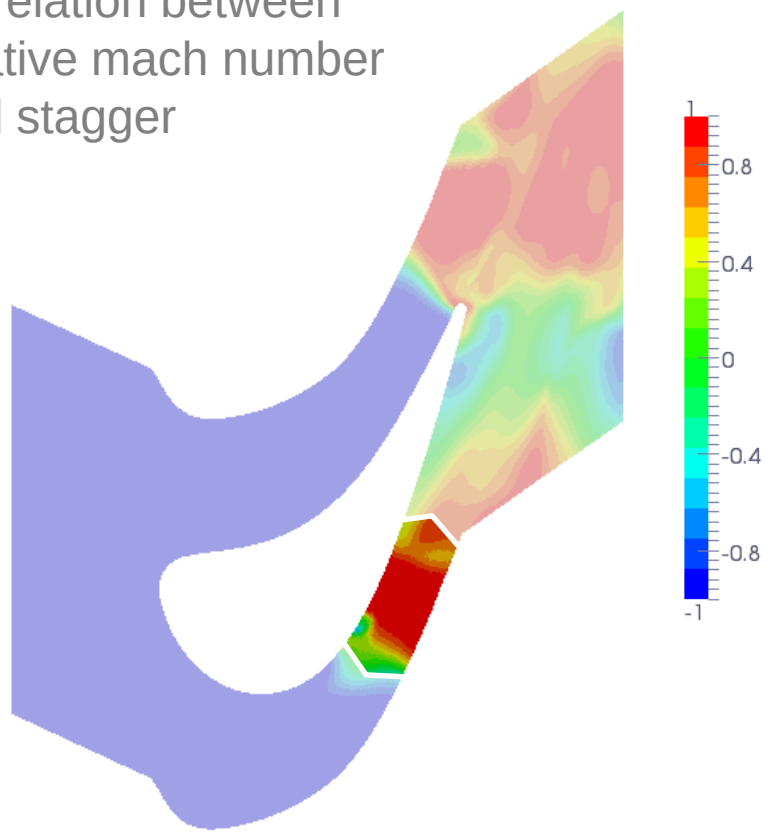
$A_{R37} > A_{R7}$

SoP – Statistics on Passage at 80% span

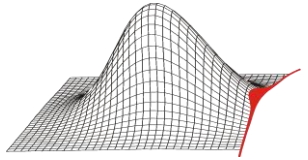
standard deviation of relative mach number



correlation between relative mach number and stagger



Conclusion



- 500 real manufactured turbine blades have been digitised
- probabilistic investigations are based on a geometric parameter set with appropriated pdf‘s and correlations
- without input correlations there are no useful results reachable

- variable CFD model for HYDRA where
  - coolant position & shroud geometry follows aerofoil shape
  - prepared to increase parameter driven flexibility (coolant, hub, shroud, …)
  - using Padram for meshing

- sensitivity analyses by spearman can cause spurious correlations
- investigation of CoI leads to meaningful results,
  e.g. if stagger increases the throat area increases too

Outlook

- currently `worst case scenario` caused by duplication of same blade (single passage CFD setup)
- probabilistic investigation with a more realistic CFD model & multi-passage setup (increase computational effort!)

A parametric model for probabilistic analysis of turbine blades considering real geometric effects

Speakers: Jens Scharfenstein *

Kay Heinze *

Co-Authors: Matthias Voigt *, Konrad Vogeler *

Marcus Meyer **

(* Technische Universität Dresden, ** Rolls-Royce Deutschland GmbH & Co KG)

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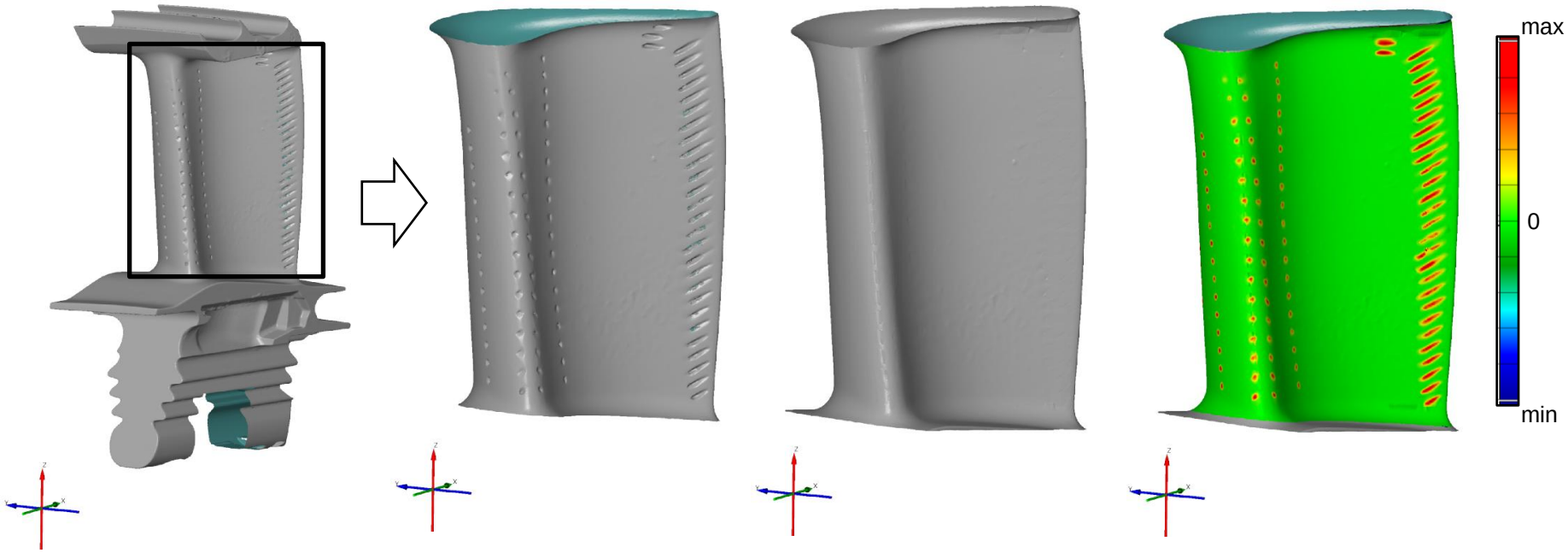
11.09.2012

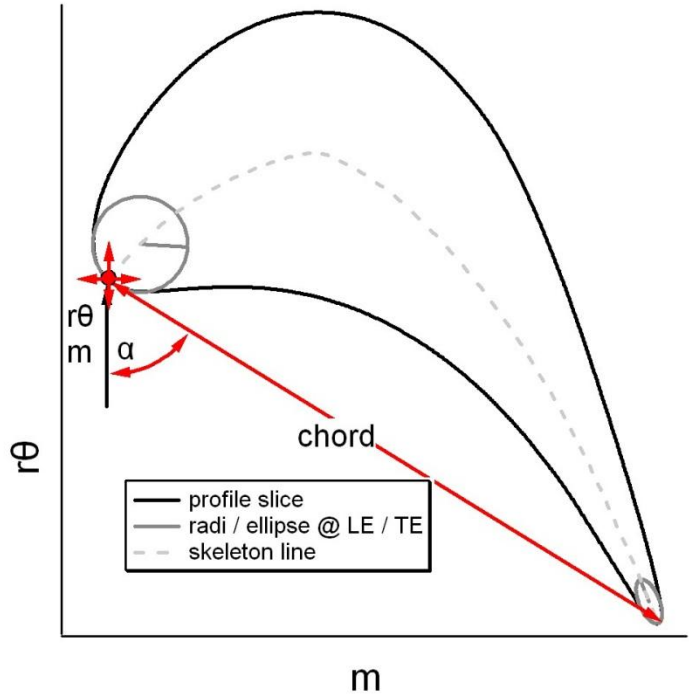


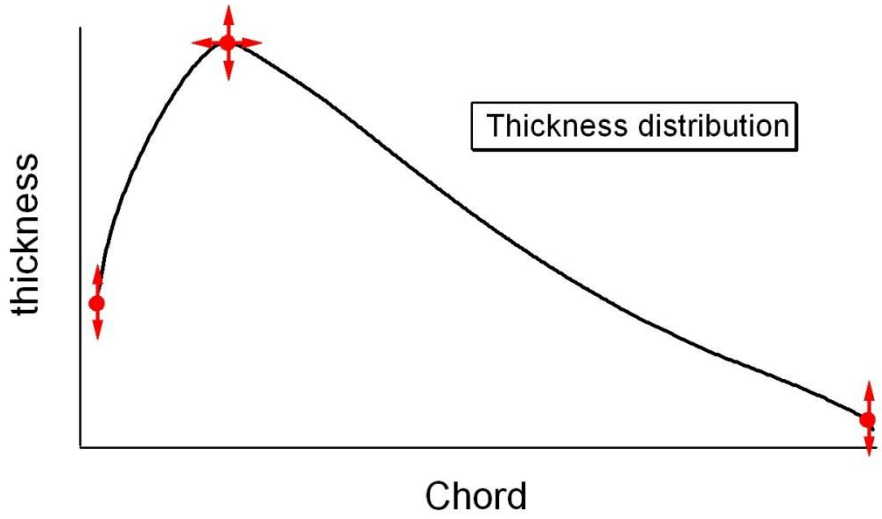
- results of the cooling hole smoothing algorithm based on a 3D-NURBS
- deviation plot on the right clarifies the local smoothing of the cooling holes

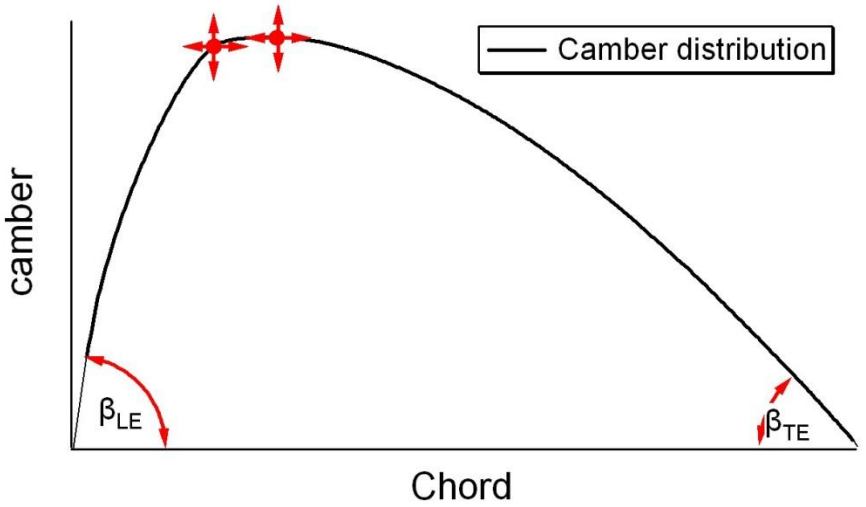
parameterisation method target:

- capture as much as possible geometric variability with as less as possible parameters
- use well known parameters that ease the interpretation of the probabilistic results
- enable automatic parameterisation and profile setup

method	pros	cons
aerofoil parameterisation with free form curves	• analytical model for 3D geometry • same model as for the design process	• large parameter set • control point based (NURBS); difficult to understand for non-involved engineers

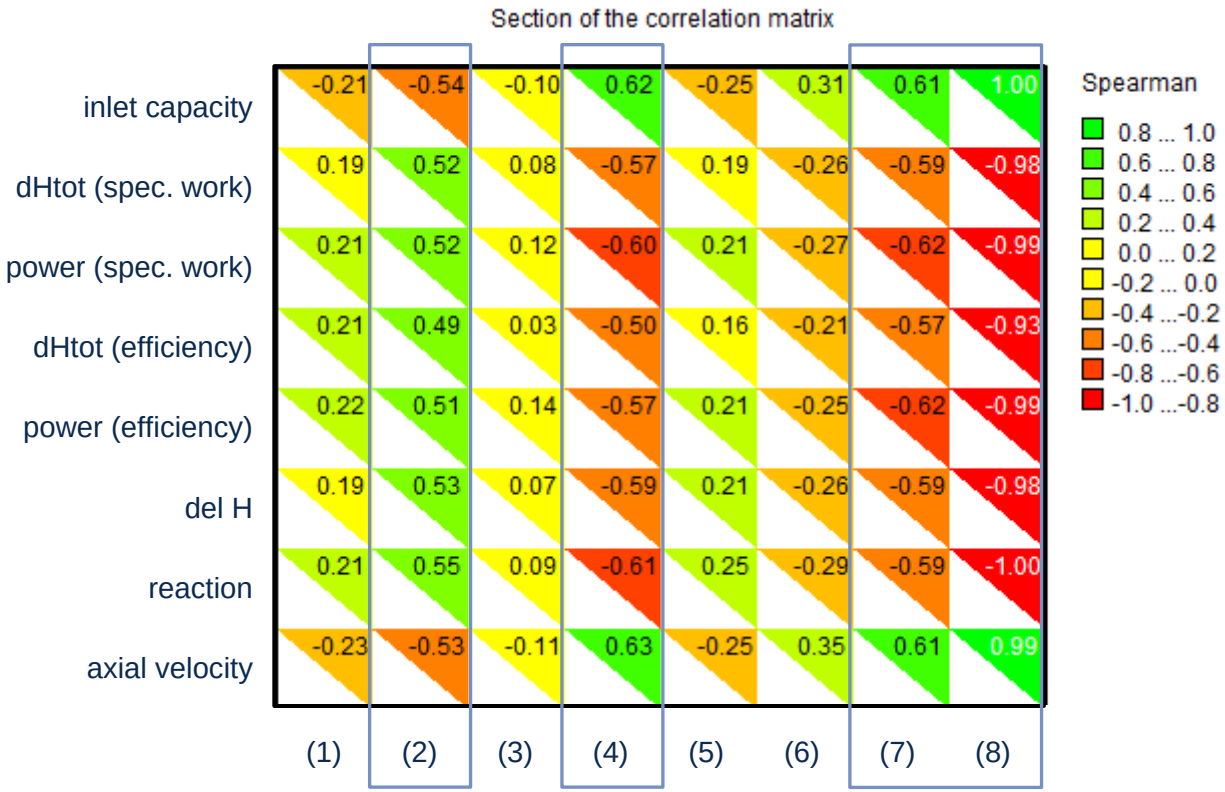






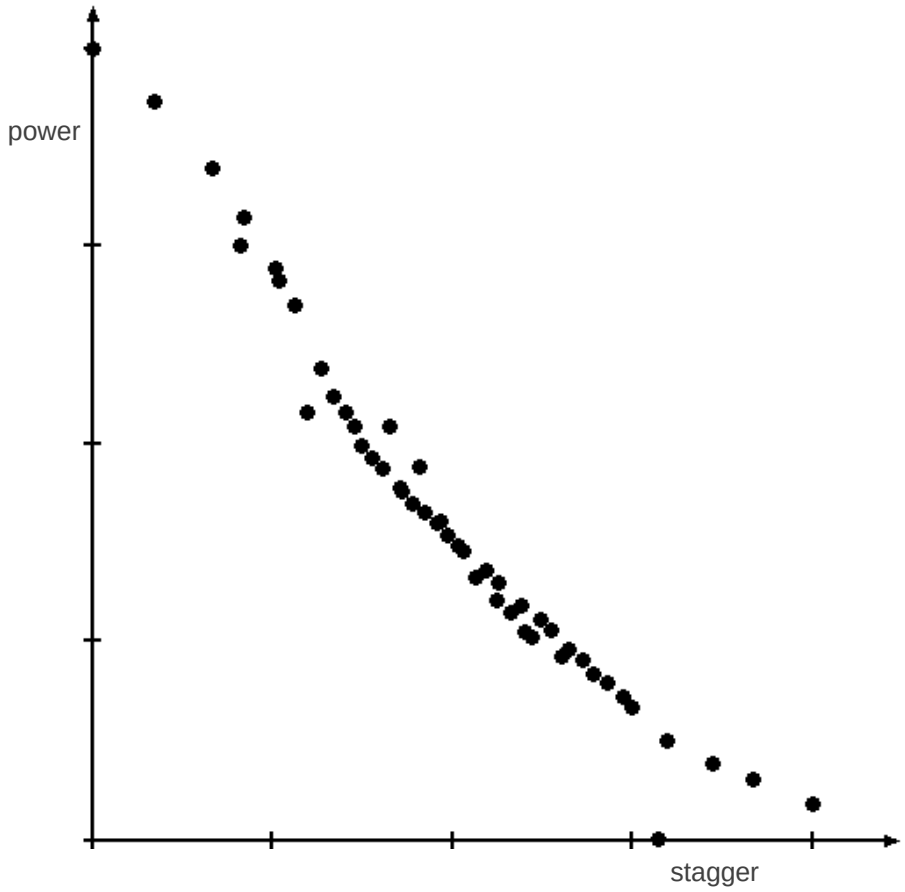
Profile variation at displayed anchor points and at three parameters leading and trailing edge (small and large semi axis ellipse and angle).

Look for correlations:

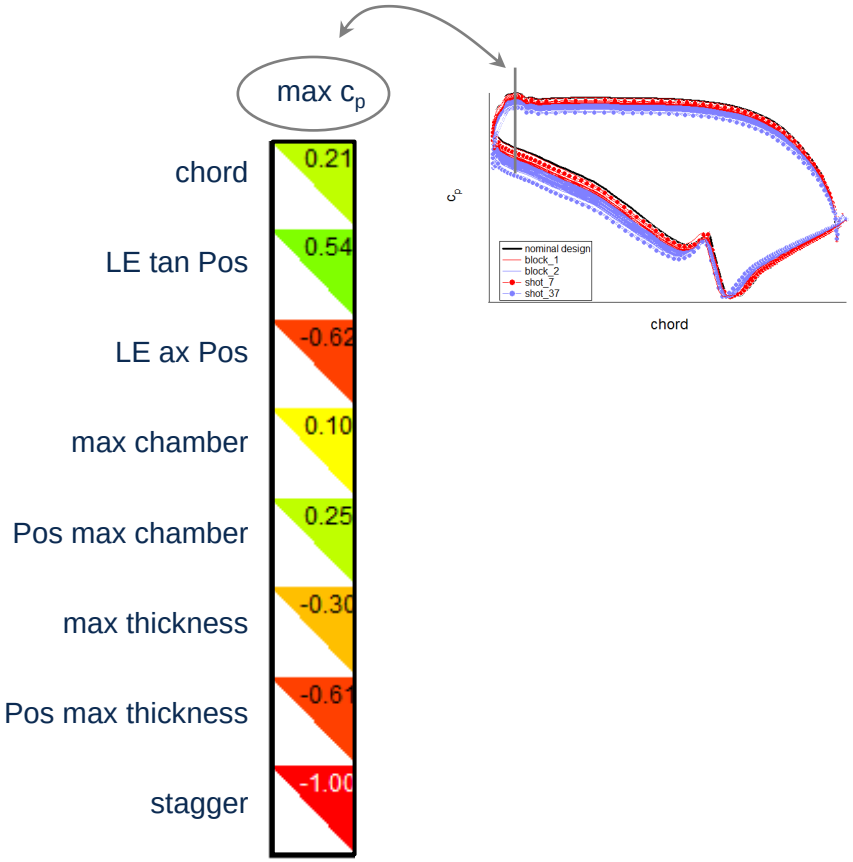


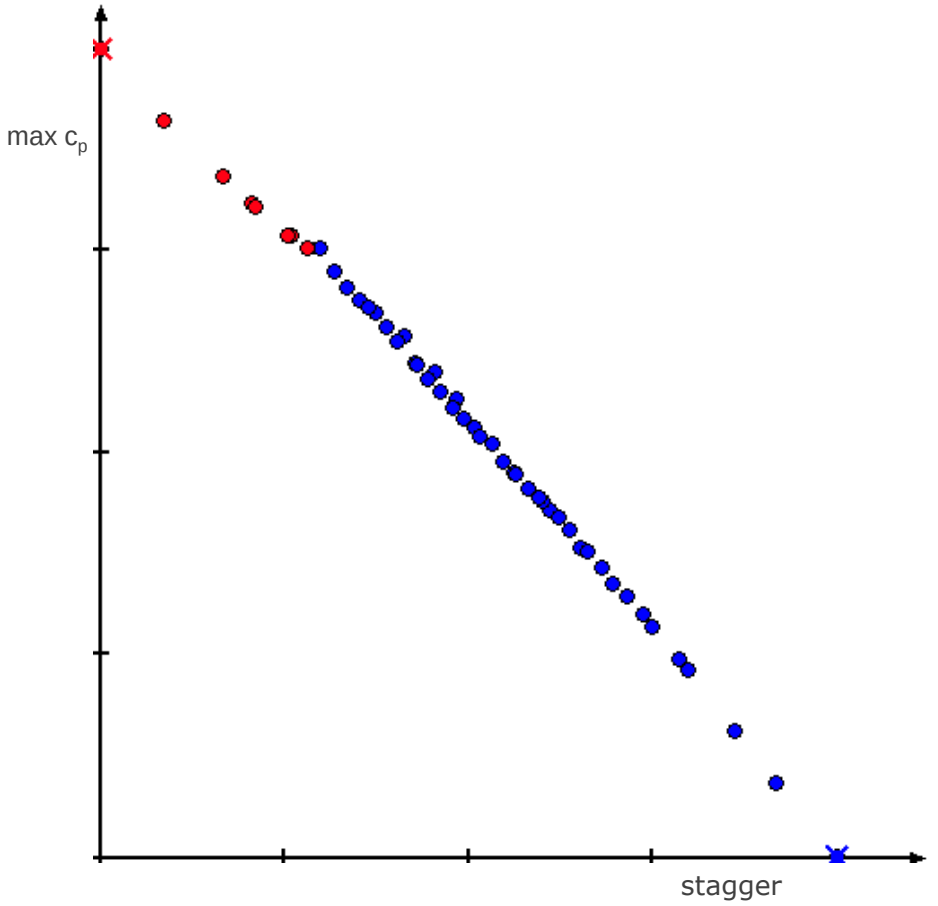
chord	(1)
LE tan Pos	(2)
LE ax Pos	(3)
max chamber	(4)
Pos max chamber	(5)
max thickness	(6)
Pos max thickness	(7)
stagger	(8)

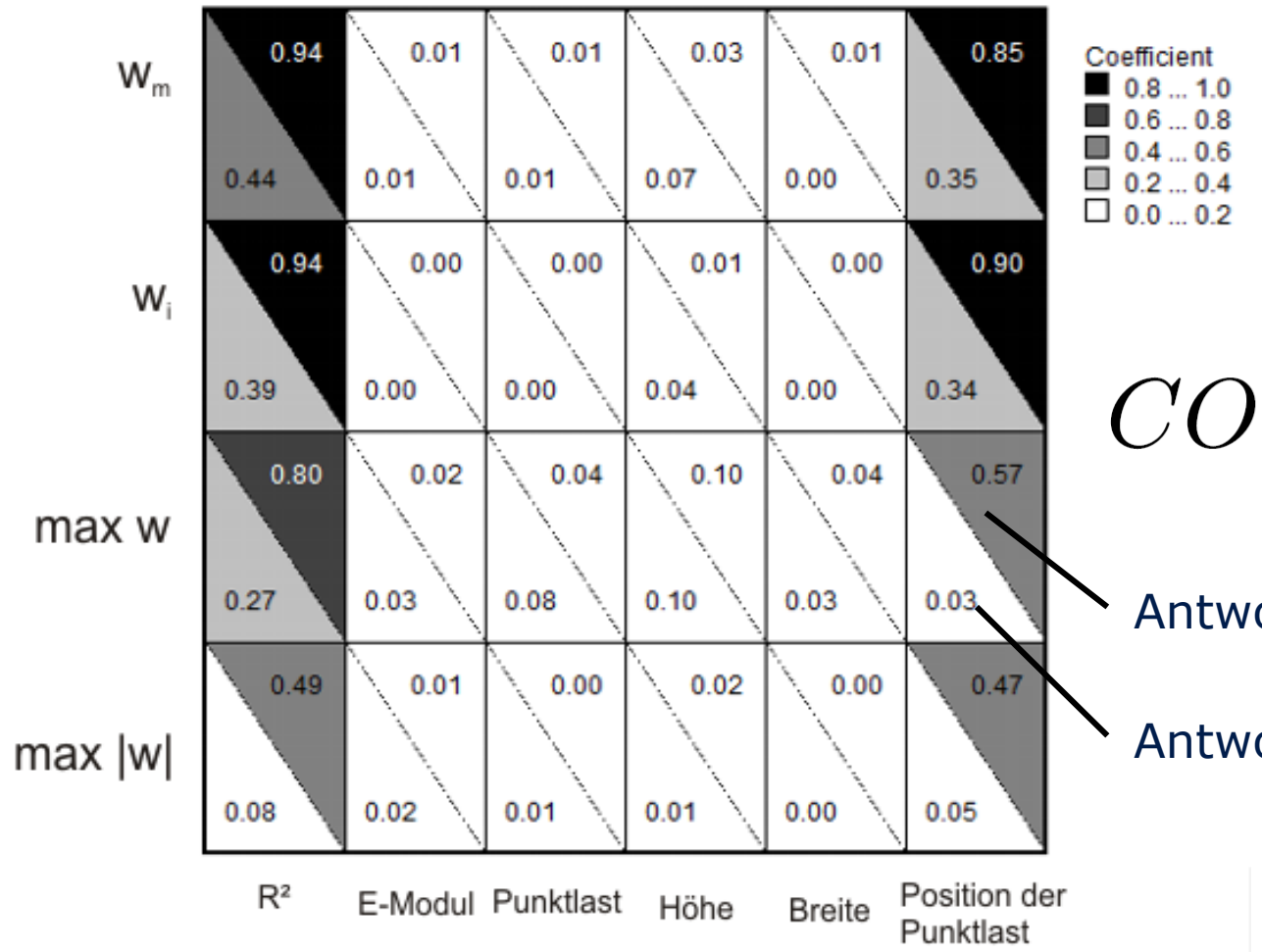
Look for correlations:



detailed investigation of max c_p







$$COI_e = R^2 - R_e^2$$

Antwortfläche dritter Ordnung

Antwortfläche erster Ordnung