Product - Regeneration
Regeneration of complex capital goods

Probabilistic Analysis of Regeneration-Induced Geometry Variances in a Low-Pressure Turbine

8. Dresdner-Probabilistik-Workshop
TU Dresden, 8 – 9 October 2015

Benedikt Ernst
Florian Herbst
Jörg Seume

Leibniz Universität Hannover

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Outline

Product-Regeneration
Regeneration of complex capital goods

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CRC 871 - Regeneration of Complex Capital Goods

Scientific basis for maintaining complex capital goods to…

- recondition and improve the functional properties
- refurbish high-value components
- reduce scrap rates


source: MTU


source: Siemens


source: ENERCON


source: Deutsche Bahn

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Project Areas and Subprojects

Project Area A
„Inspection and Diagnostics“

Project Area B
„**Interaction of** the Production Process with Functional Product Properties“

Project Area C
„Production and Material **Variance** in Regeneration“

Project Area D
„Integral **Control** of the Regeneration Process”

- 19 subprojects and 1 transfer project
- Participating disciplines: Mechanical Engineering, Construction Engineering, Industrial Engineering
- Cooperation of the Institutions: Leibniz Universität Hannover, Laser Zentrum Hannover, TU Braunschweig
- Funded by the DFG (German Research Foundation) since 2010
- 2nd funding period (2014 till 2017)

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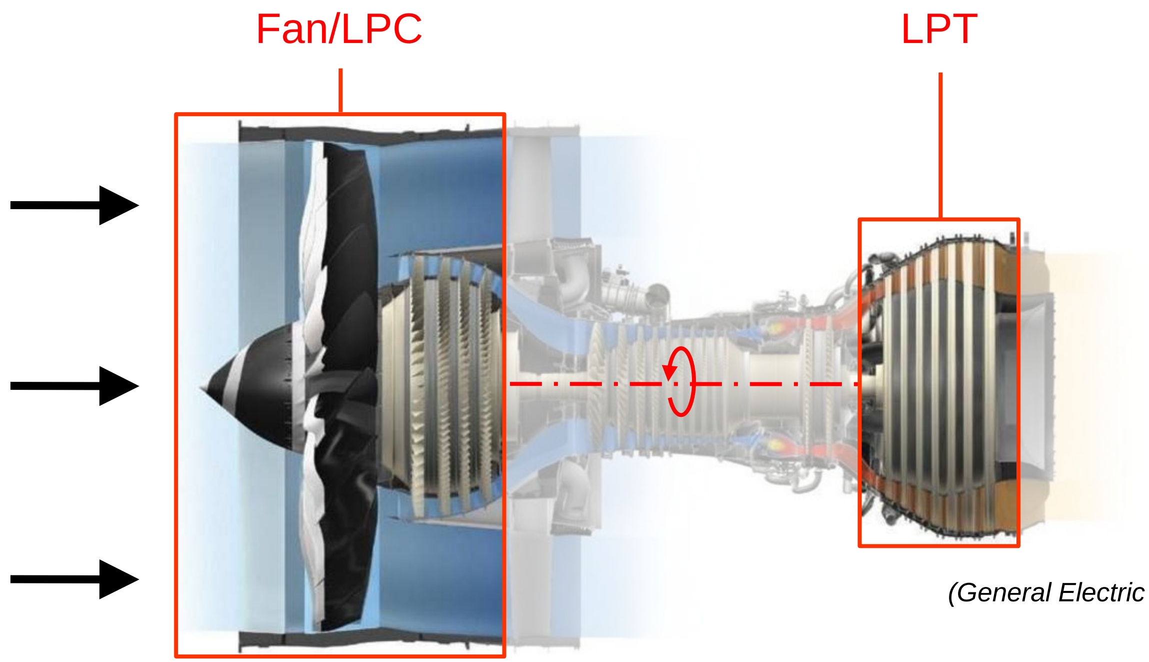
Motivation and Objective of the Present Study

- High aerodynamic, mechanical, and thermal loads cause substantial wear
- Regular overhaul and repair of turbine blades
  - ➔ Higher variance after regeneration compared to new engines
  - ➔ Modified aerodynamic and aeroelastic performance
- Efficiency changes in a low pressure turbine (LPT)
  LPT: $\Delta\eta_{LPT} = 1\%$ ➔ Overall: $\Delta\eta_{overall} \approx 0.7\%$



(General Electric Aviation)

Analysis of regeneration induced geometry variances on the aerodynamic performance of a LPT

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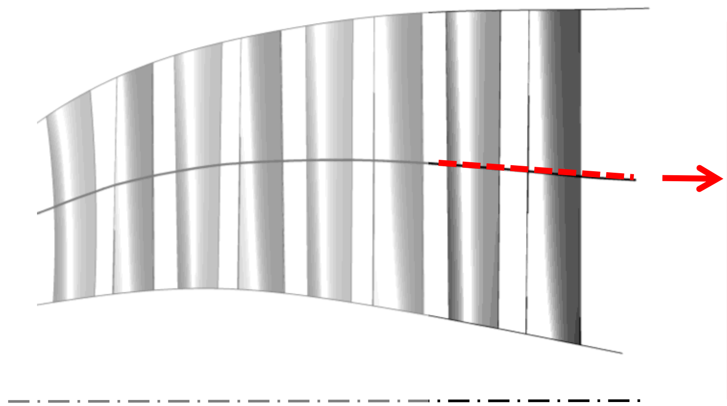
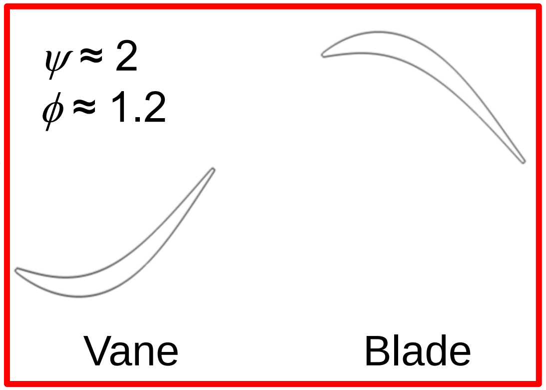
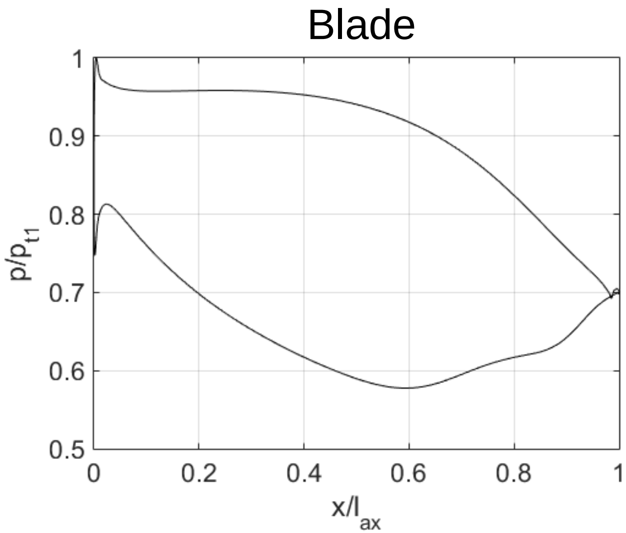
Test-Case: Final Stage of a LPT at Cruise







- Low Re: Profile aerodynamics dominated by boundary layer transition
- Laminar separation bubble at aft-part of suction side
- High sensitivity to geometrical variances can be expected.

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Determination of Regeneration-Induced Variances

Optical 3D measurements of regenerated turbine blades

↓

Alignment of the measured blades with the reference CAD-model

↓

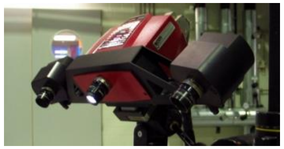
Extraction of blade profiles over the entire span

↓

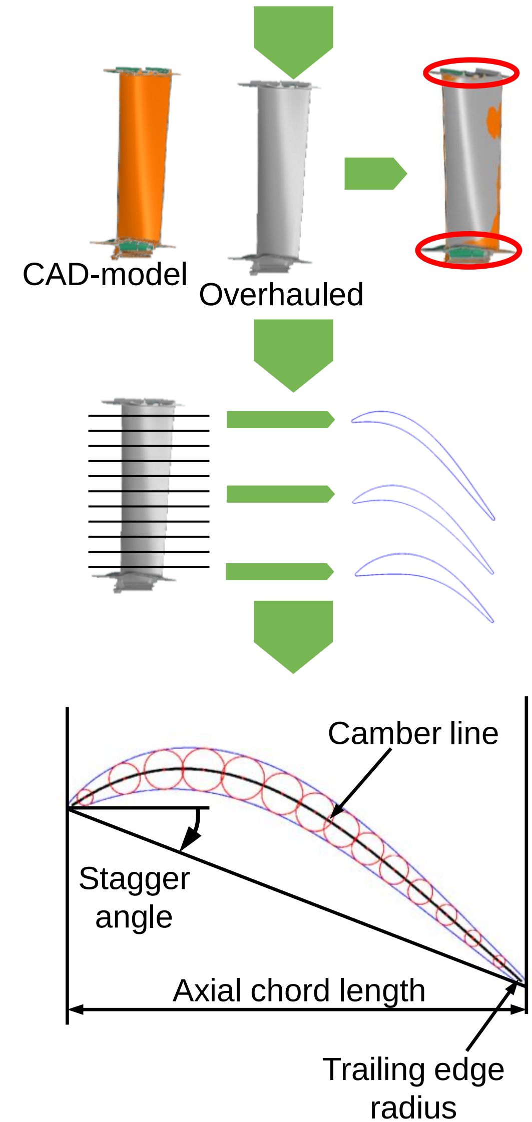
Determination of characteristic profile parameters

- Axial chord length
- Stagger angle
- Maximum thickness
- Trailing edge radius
- ...

(based on Aschenbruck et al. 2013)



Source: www.trimetric.com



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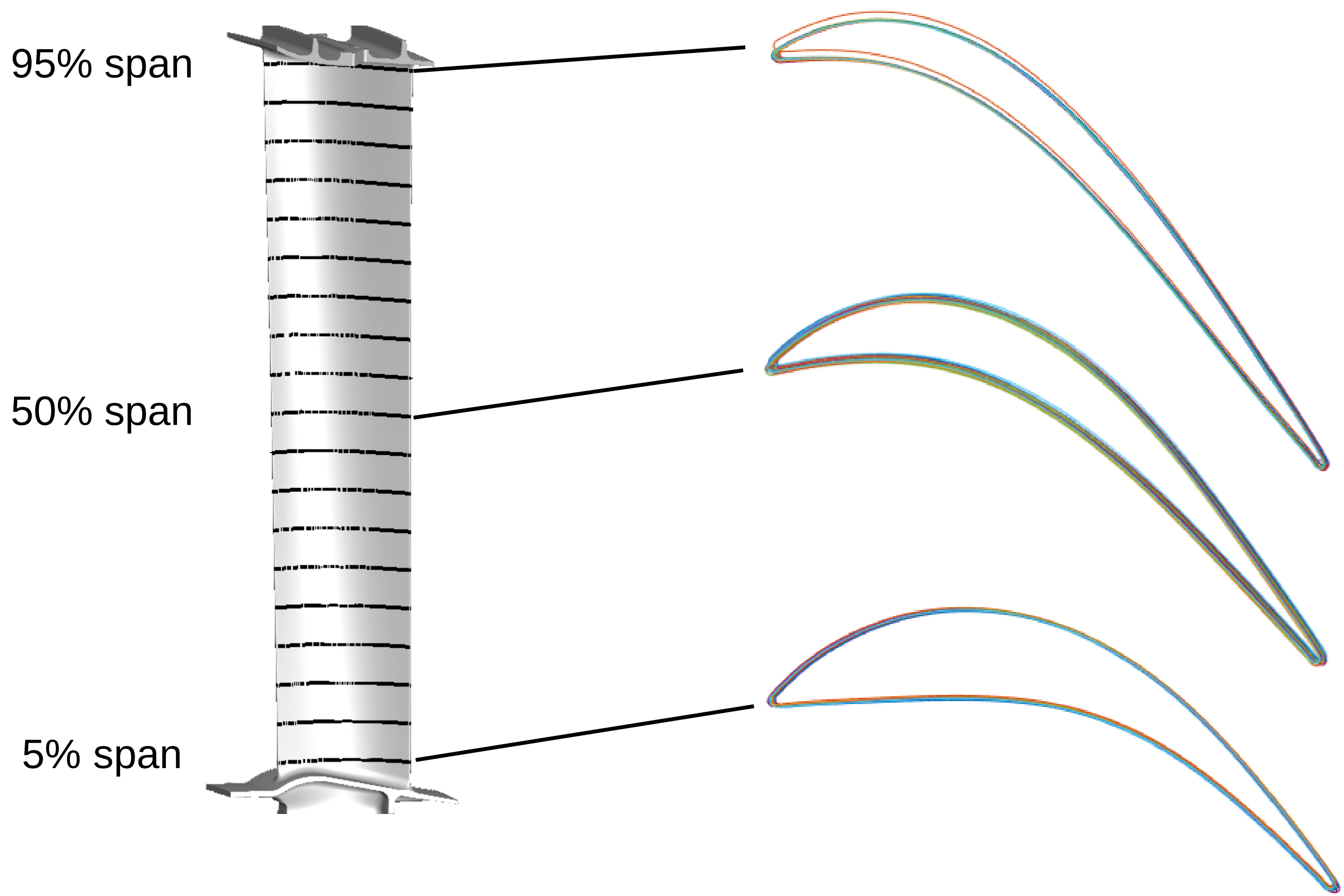
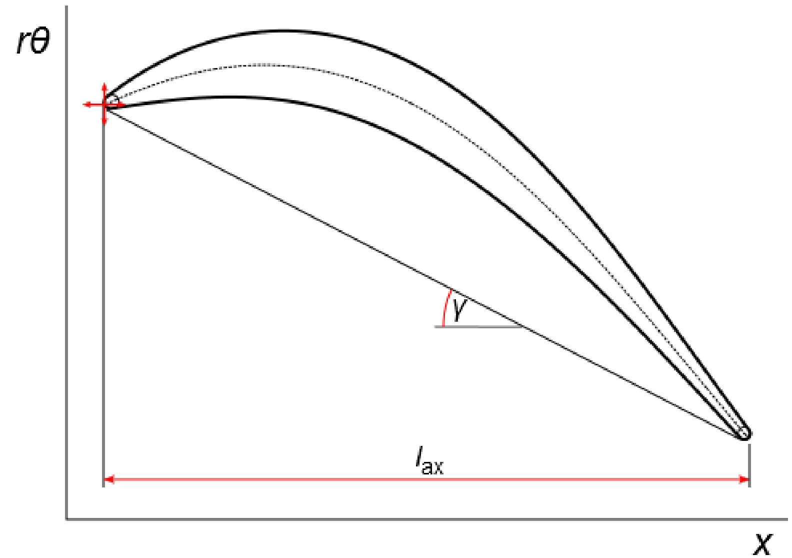
Measured Blade Geometries

- Database with 20 regenerated blades
- Data include geometry variances caused by manufacturing, operation, and repair
- 19 extracted profiles at different span locations of each blade

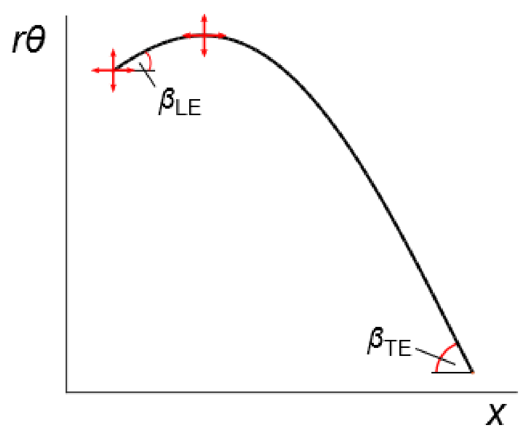


Parameterization to Characterize the Profile Geometry

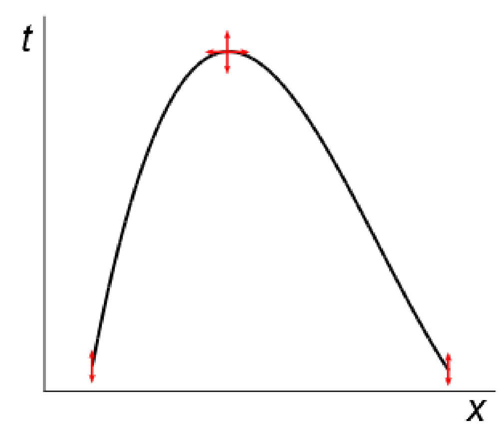
- 12 parameters are used to describe the profile geometry.
- Camber line and thickness distribution are modeled by polynomials.



Camber line



Thickness distribution



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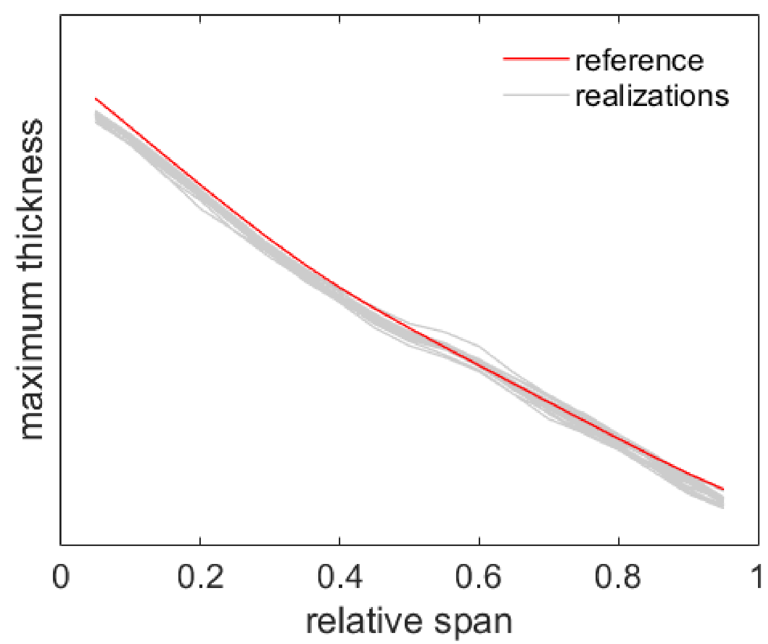
Geometry Parameter Deviation

- Nominal design geometry is used as reference (CAD-model).
- Deviations are referred to the parameters of the reference geometry.
- Delta-parameter / parameter deviation:

$$\Delta P_{\text{realization}} = P_{\text{realization}} - P_{\text{reference}}$$

- Excluding leading edge position and angles, all parameter deviations are normalized with respect to their reference value.



Geometry Parameter Variances at Different Span Locations

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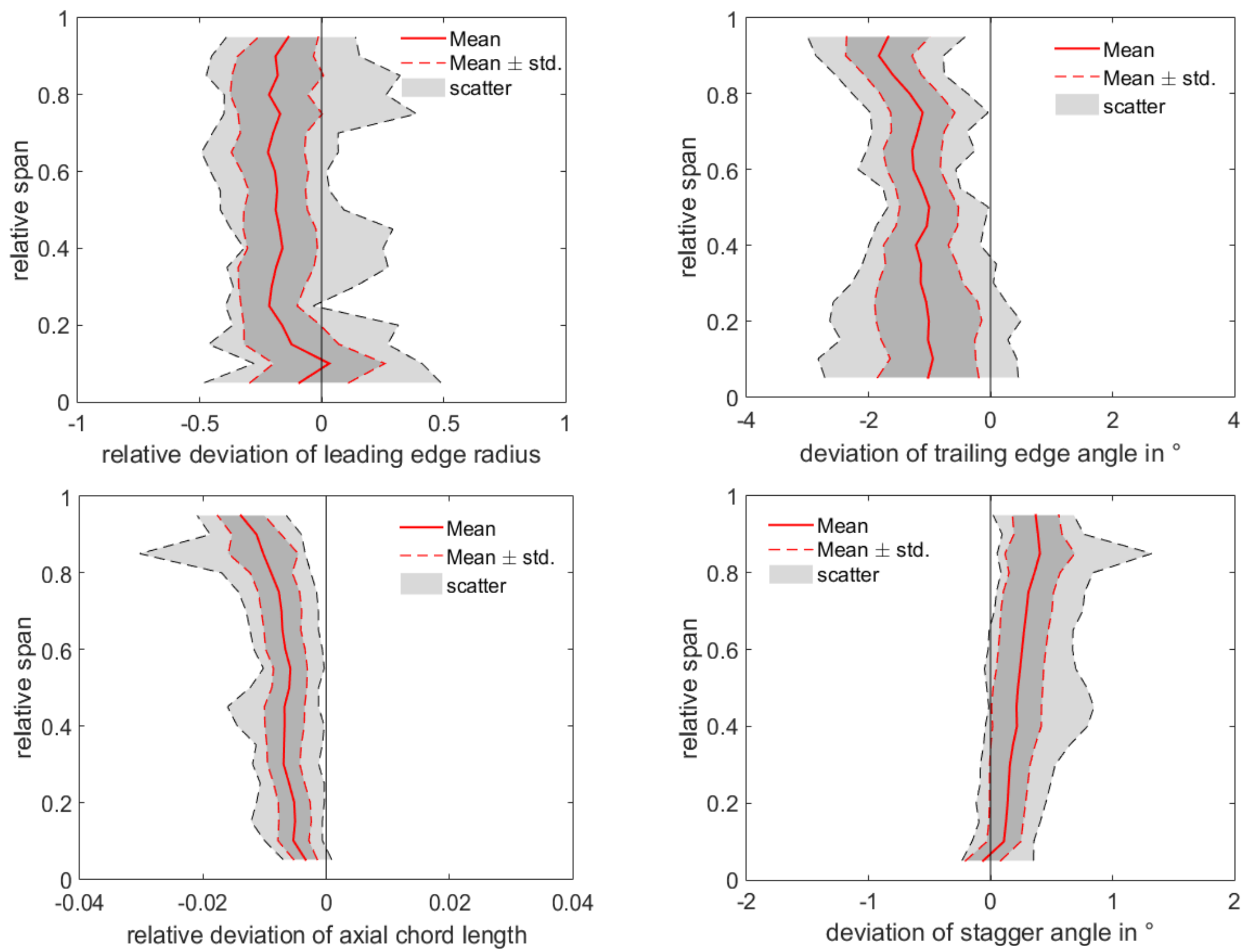

- Large scatter range e.g. of leading edge radius and trailing edge angle
- Maximum deviation of axial chord and stagger angle at 85% span due to blend repair

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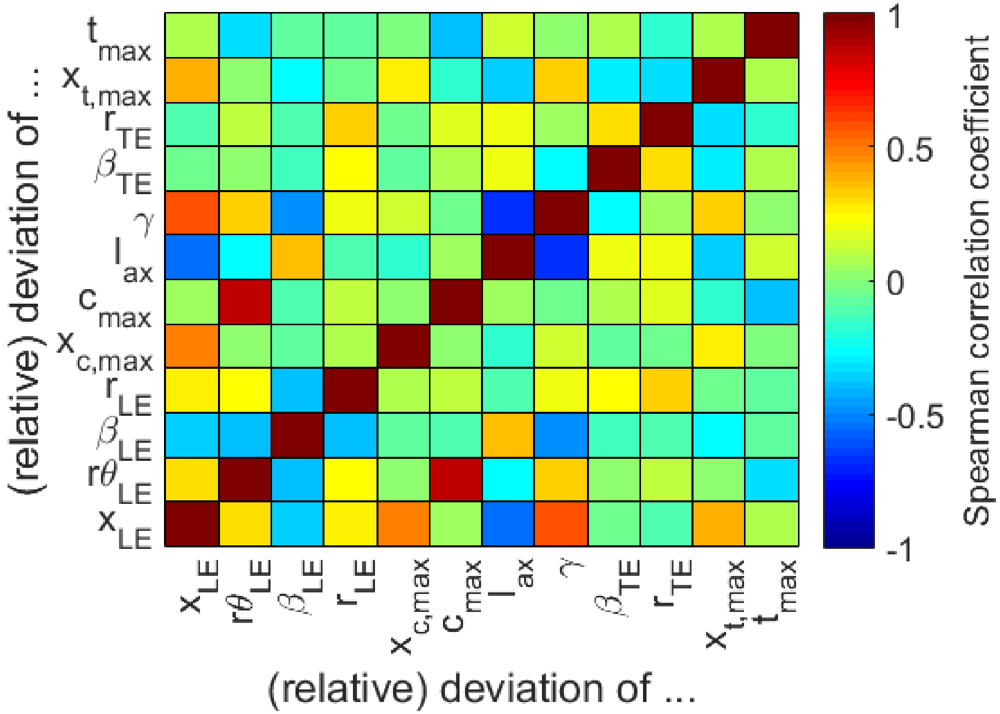
Correlations of Profile Parameter Deviations



Significant correlation e.g. between…

- stagger angle γ and axial leading edge position x_{LE} (positive)
- stagger angle γ and axial chord length l_{ax} (negative)
- axial chord length l_{ax} and axial leading edge position x_{LE} (negative)
- max. camber c_{max} and circumferential leading edge position $r\theta_{LE}$ (positive)

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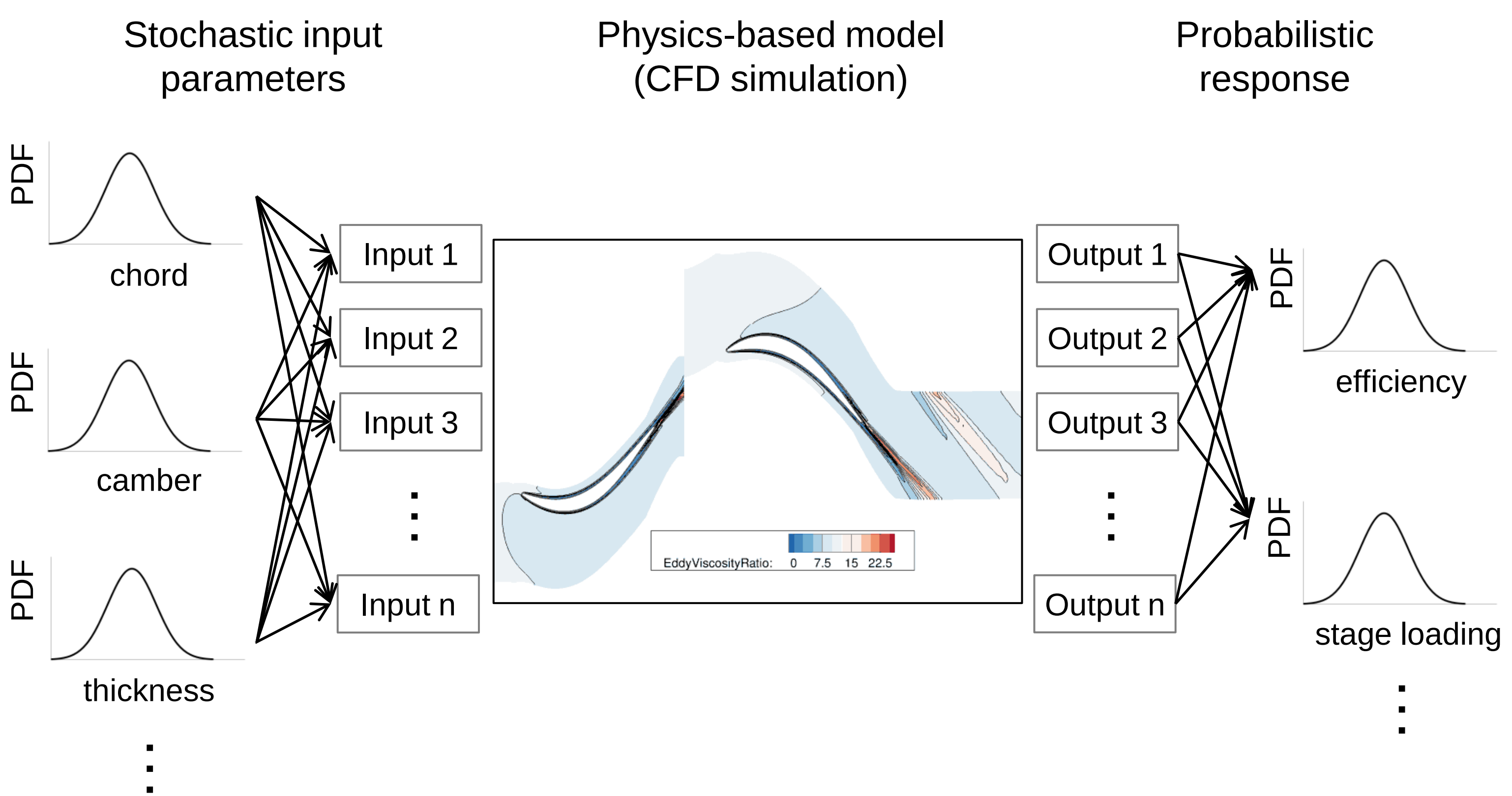
Scheme of the Probabilistic Model



- Latin Hypercube Sampling (LHS) with 100 designs
- Consideration of input parameter correlation
- Nominal vane design used for all simulations

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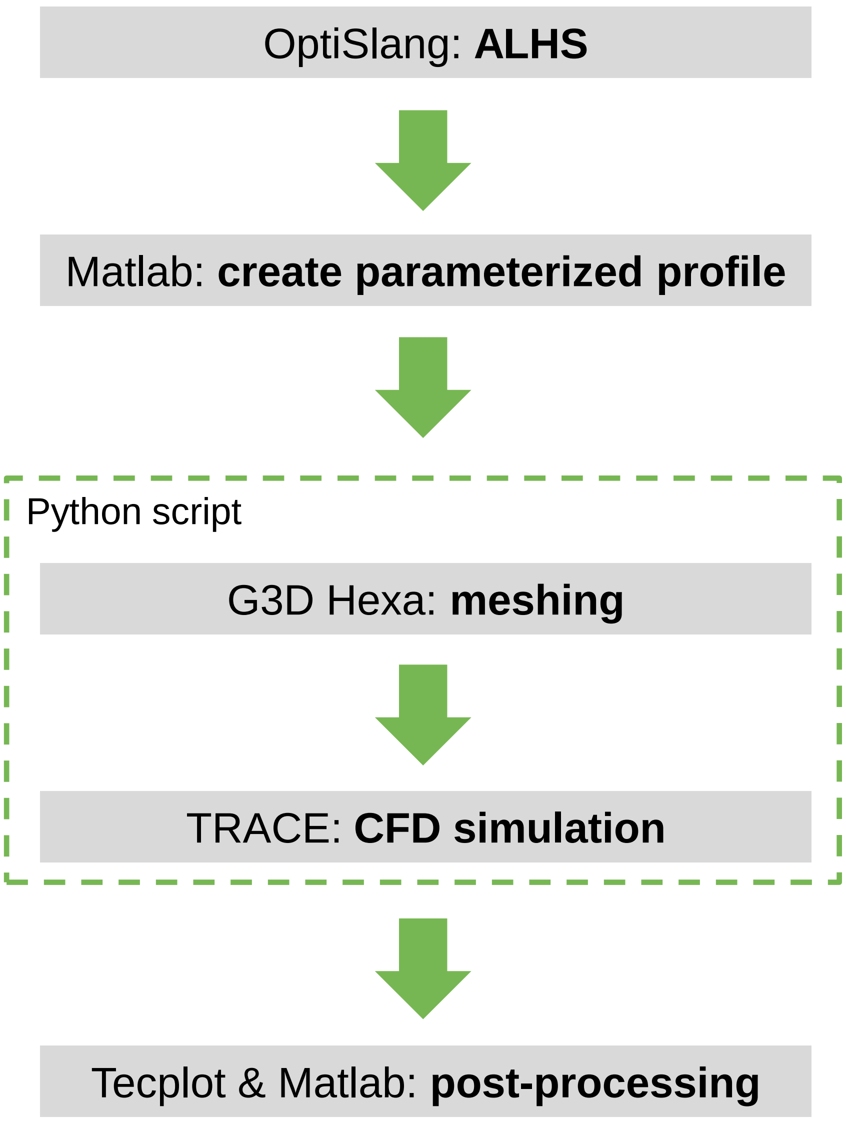
Tool Chain



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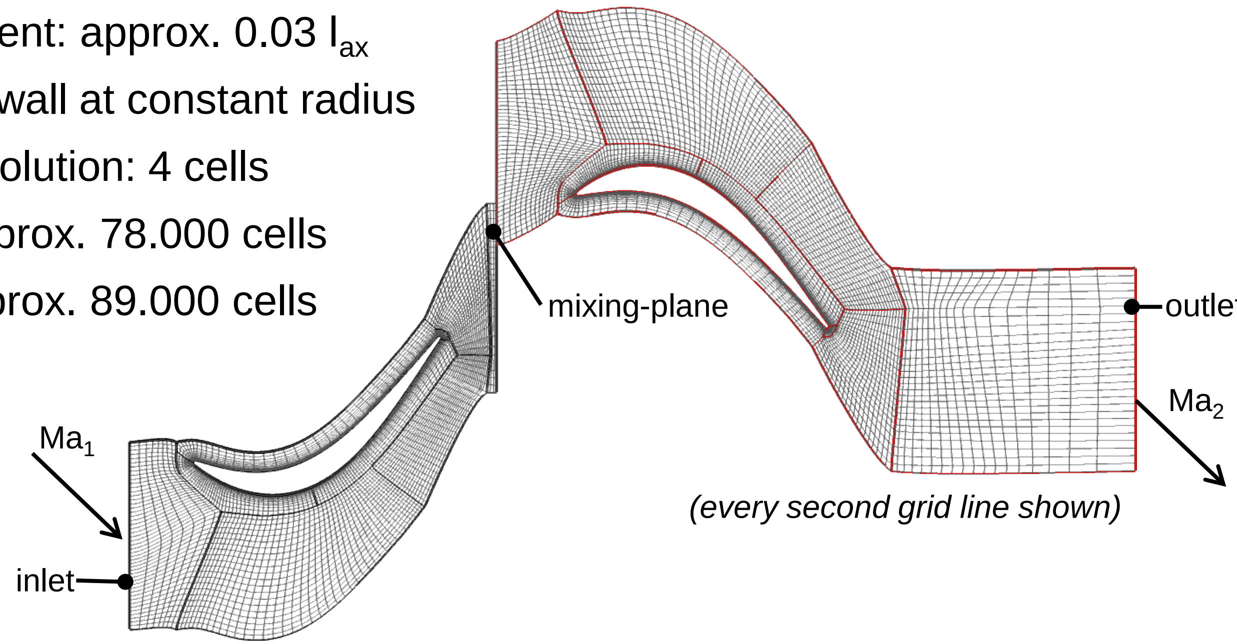
CFD Setup of the Final Stage

Computational domain

- Quasi3D(Q3D)-grid at half-span
- Radial extent: approx. 0.03 l_{ax}
- Each sidewall at constant radius
- Radial resolution: 4 cells
- Stator: approx. 78.000 cells
- Rotor: approx. 89.000 cells
- $y^+ < 1$



(every second grid line shown)

Finite volume code TRACE of the DLR

- 2nd order accuracy
- RANS turbulence closure: Wilcox‘ (1988) k-ω turbulence model
- Including modification for stagnation point (acc. to Kato and Launder)
- Non-local correlation-based multimode transition model by Kozulovic (2007)
- Only steady computations performed

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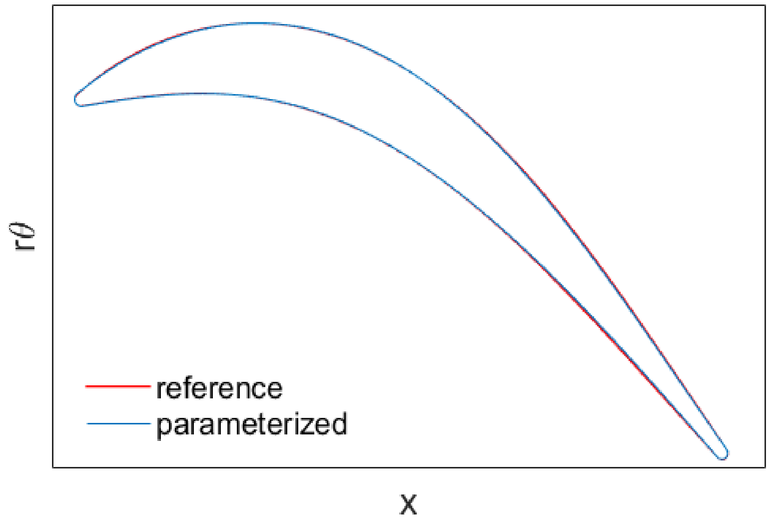
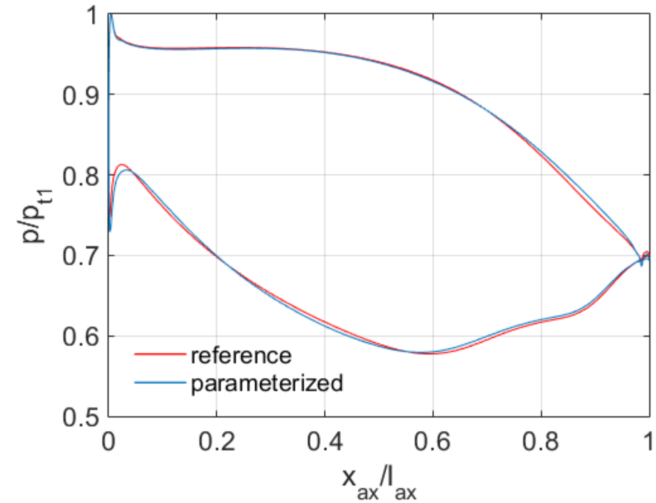
Comparison of the Original and Parameterized Blade Profile





Isentropic efficiency

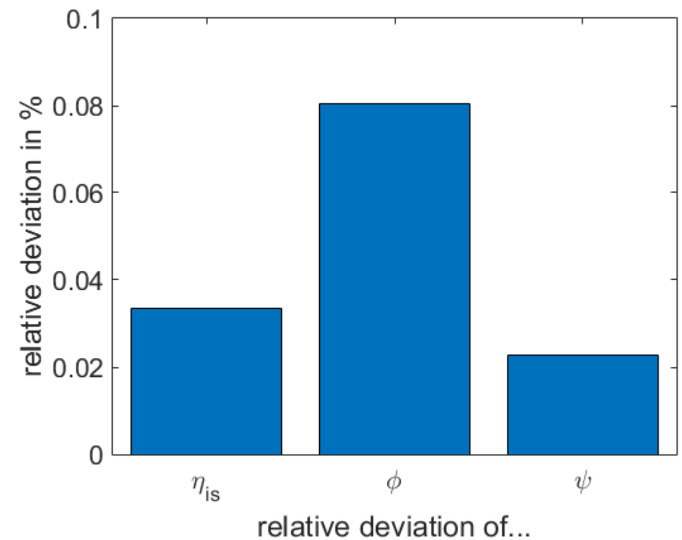
$$\eta_{is} = \frac{1 - \frac{T_2}{T_0}}{1 - \left(\frac{p_2}{p_0}\right)^{(\kappa-1)/\kappa}}$$

Flow coefficient

$$\phi = \frac{c_{ax,2}}{U}$$

Stage loading coefficient

$$\psi = \frac{\Delta h_t}{U^2}$$



➔ Good agreement between the nominal and the parameterized reference

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Motivation

Geometry Variances

Probabilistic Model

Results

Conclusions

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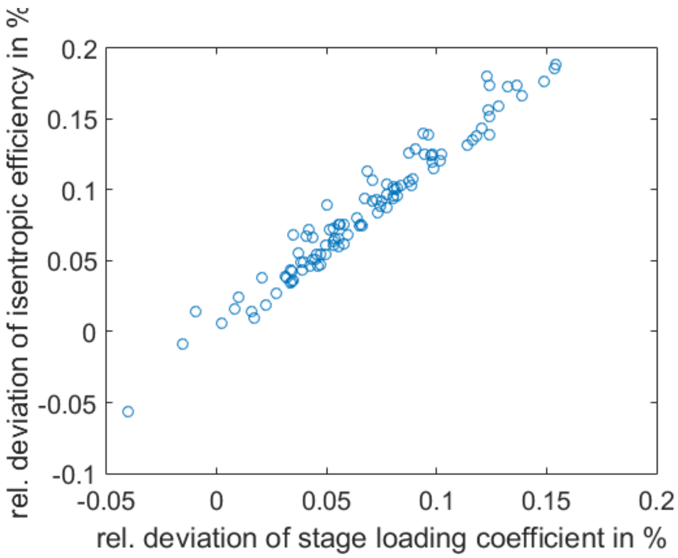
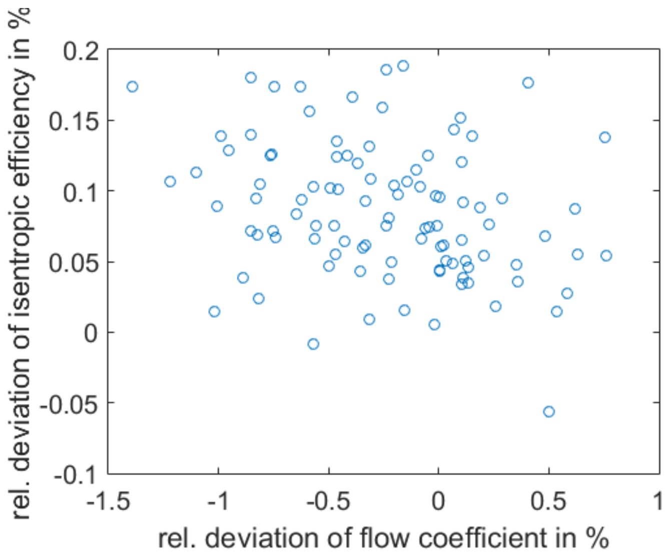
Scatter of Output Parameters

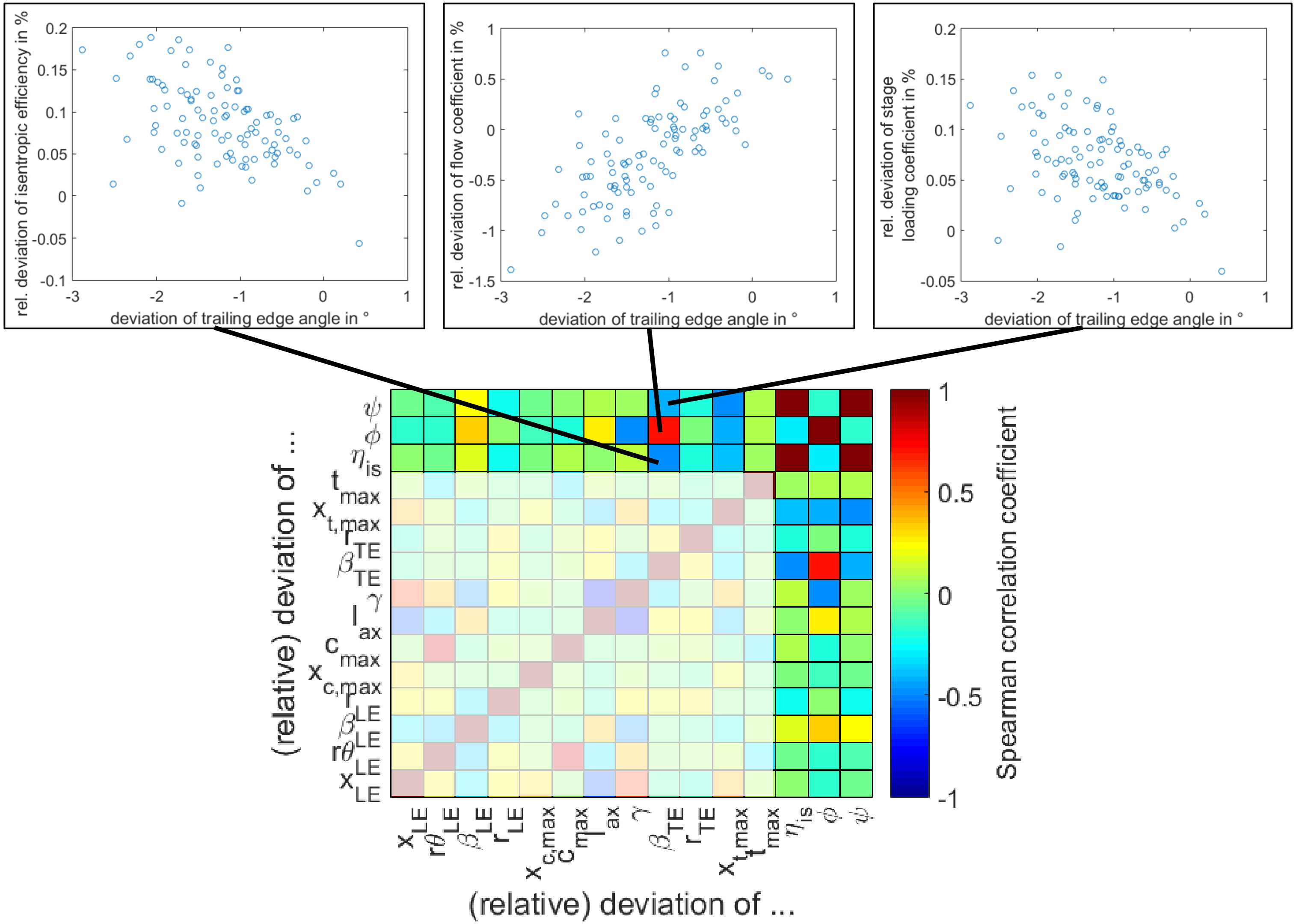
Deviations of isentropic efficiency, flow coefficient and stage loading coefficient are shown relative to the reference.





- Scatter range of isentropic efficiency $\Delta\eta_{is,max}$ - $\Delta\eta_{is,min} \approx 0.25\%$
- Linear correlation between stage loading and isentropic efficiency
- No significant correlation between flow coefficient and isentropic efficiency

Correlation between Input and Output Parameters



- Significant correlation between trailing edge angle and output parameters
- No correlation between max. thickness and output parameters

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Conclusions and Outlook

Conclusions

- Profiles are well characterized by means of 12 geometric parameters.
- Significant deviations of geometric parameters are found.
- High negative correlation between stagger angle and axial chord length of measured LPT blades
- Significant correlation between leading edge angle and
  - isentropic efficiency (negative)
  - flow coefficient (positive)
  - stage loading coefficient (negative)
- Geometry variances of most designs lead to an increase in efficiency

Outlook

- Increase the number of measured LPT blades in our database
- Further improvement of the CFD model and automation of the tool chain
- Analysis of local flow-related parameters
- Variation of operation points

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Thank you for your attention!

Benedikt Ernst
Institute of Turbomachinery and Fluid Dynamics
ernst@tfd.uni-hannover.de

Leibniz Universität Hannover