Comparison of Probabilistic Assessments utilizing Geometric Inputs of Different Quality

Dresden

10/11/2019 - Philip Magin

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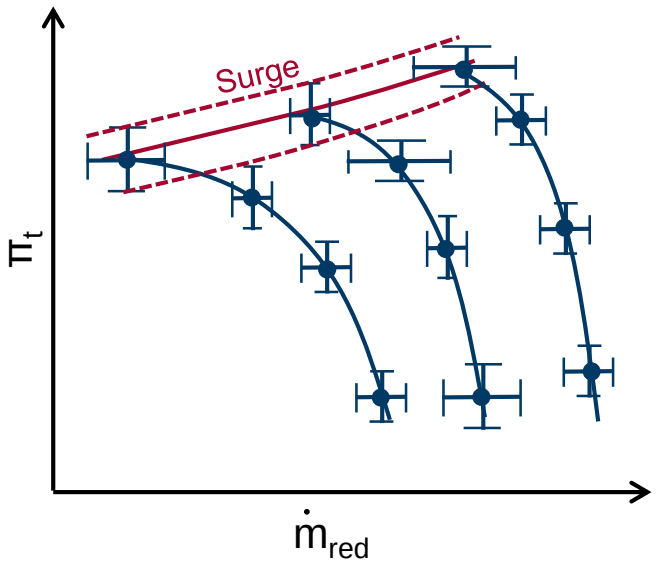
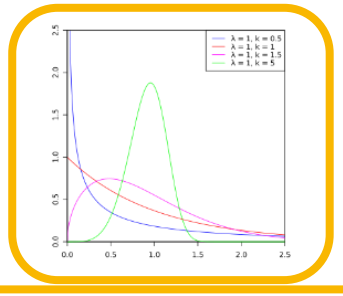
Probabilistic Assessment of Turbomachinery Design

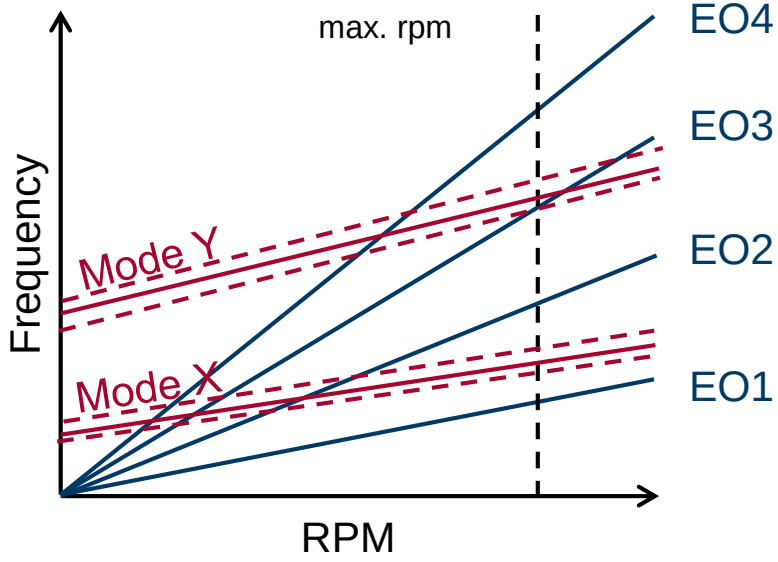
Performance Map





Need for
probabilistic design process
to assess uncertainties

Campbell-Diagram



- **Intended** operating point / **design** geometry → **deterministic** system **response**
- Introducing **uncertainties** → knowledge of design **environment** → **probabilistic design**
  - **geometric uncertainties** (manufacturing scatter, deterioration)
  - **operational uncertainties** (pressure, temperature, rpm, etc.)

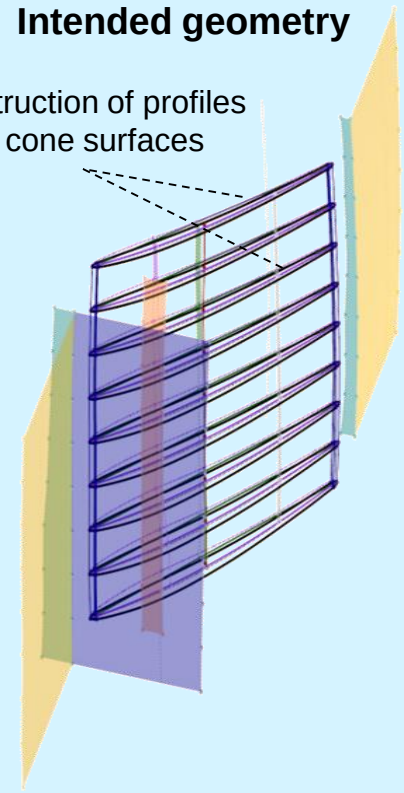
Blade Design vs. Data Sources available

Blade design system

Quality control

Intended geometry

Construction of profiles on cone surfaces

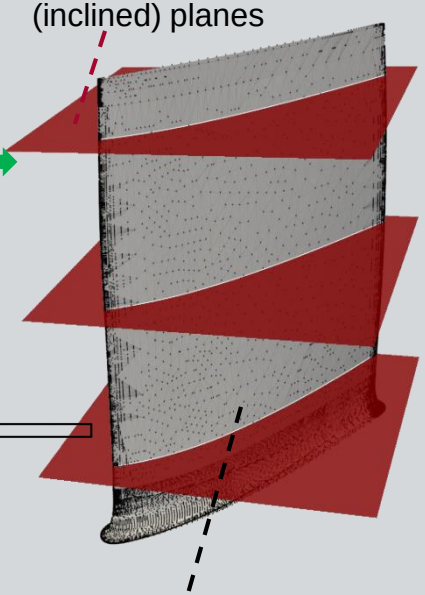


Definition and analysis of sections according to drawing

Transfer of **quality control** data to **design** system **parametric**

Real geometry

Tactile measurements on (inclined) planes



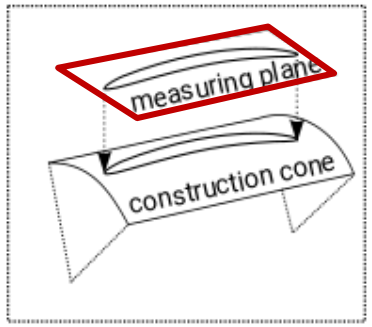
optical 3D Measurement

→ **Mapping** and **modelling** of Blades **challenging.**

Comparison of available Measurement Methods

Optical Measurements:
- **3D** data available
- Analyzation of **conical surfaces** from hub to tip

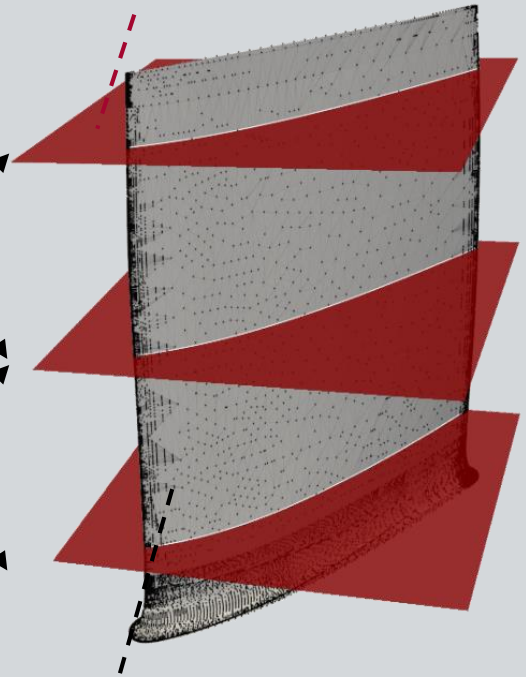
Tactile Measurements:
- **2D** data on limited radial measurement planes only
- Introduce **Mapping:**
  - **Project** Parameter onto **Cones**
  - **Interpolate** between **Construction Cones**



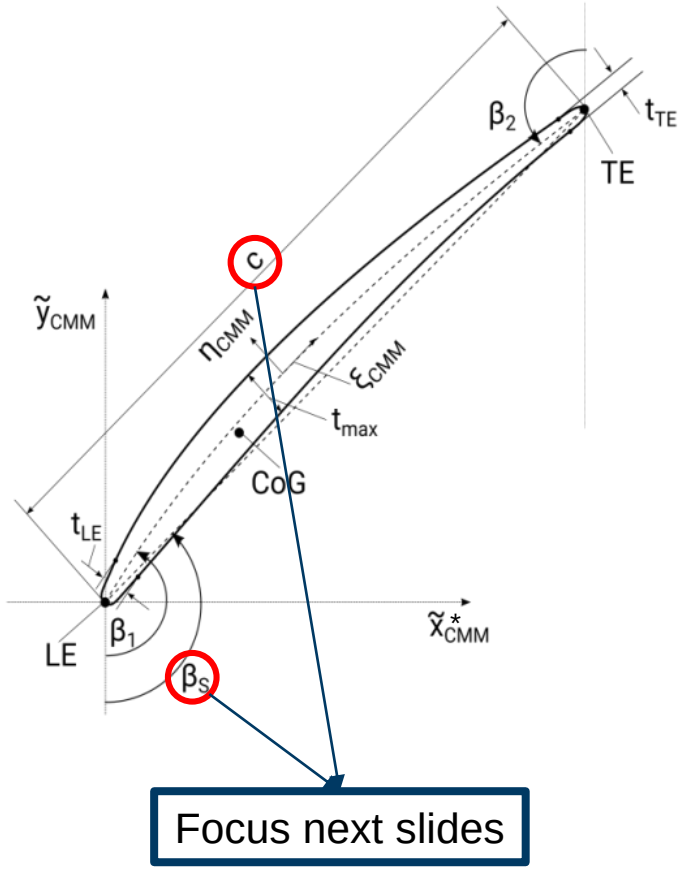
$$\Delta P = P_{real} - P_{Design\ Intent}$$

Real geometry

Tactile measurements on (inclined) planes



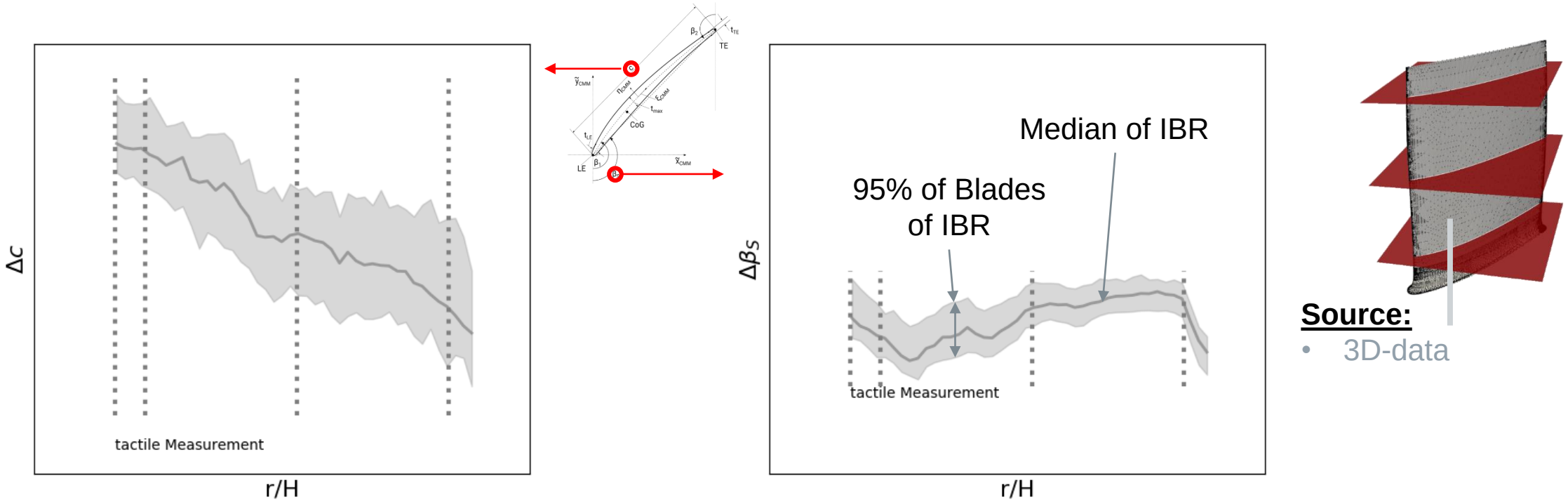
optical 3D Measurement



Focus next slides

* Coordinate Measurement Machine

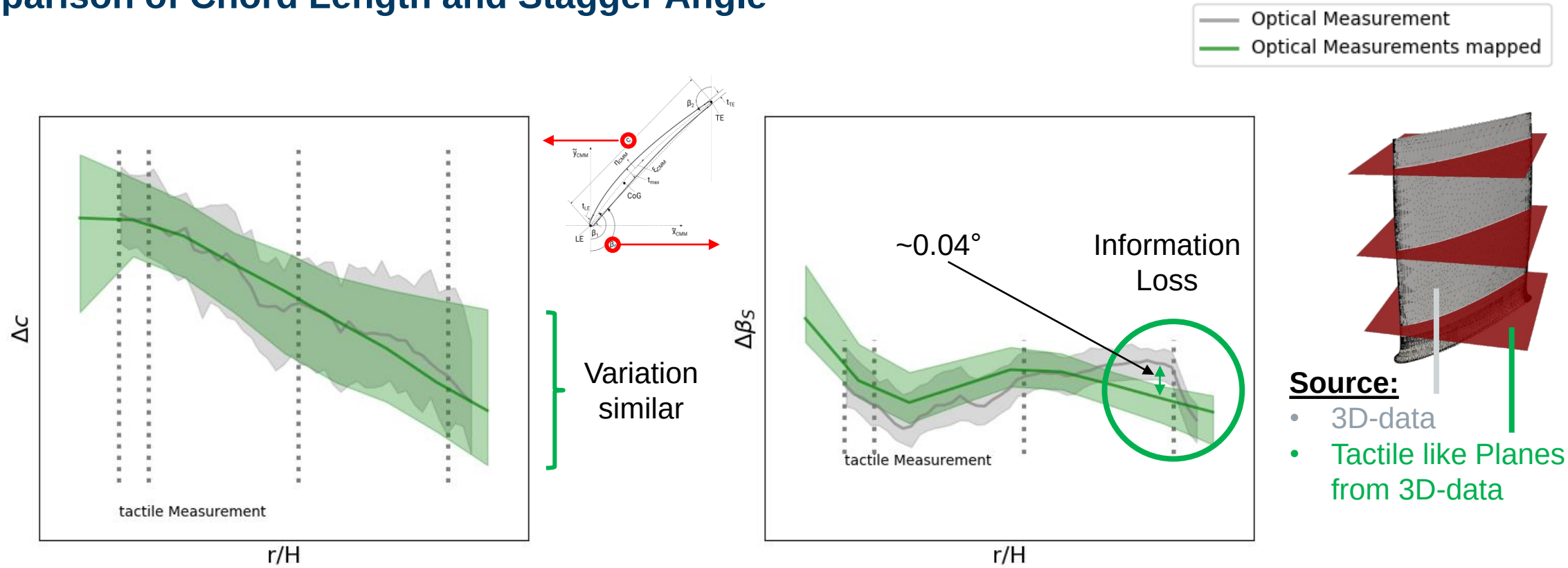
Comparison of Chord Length and Stagger Angle



Source:
- 3D-data

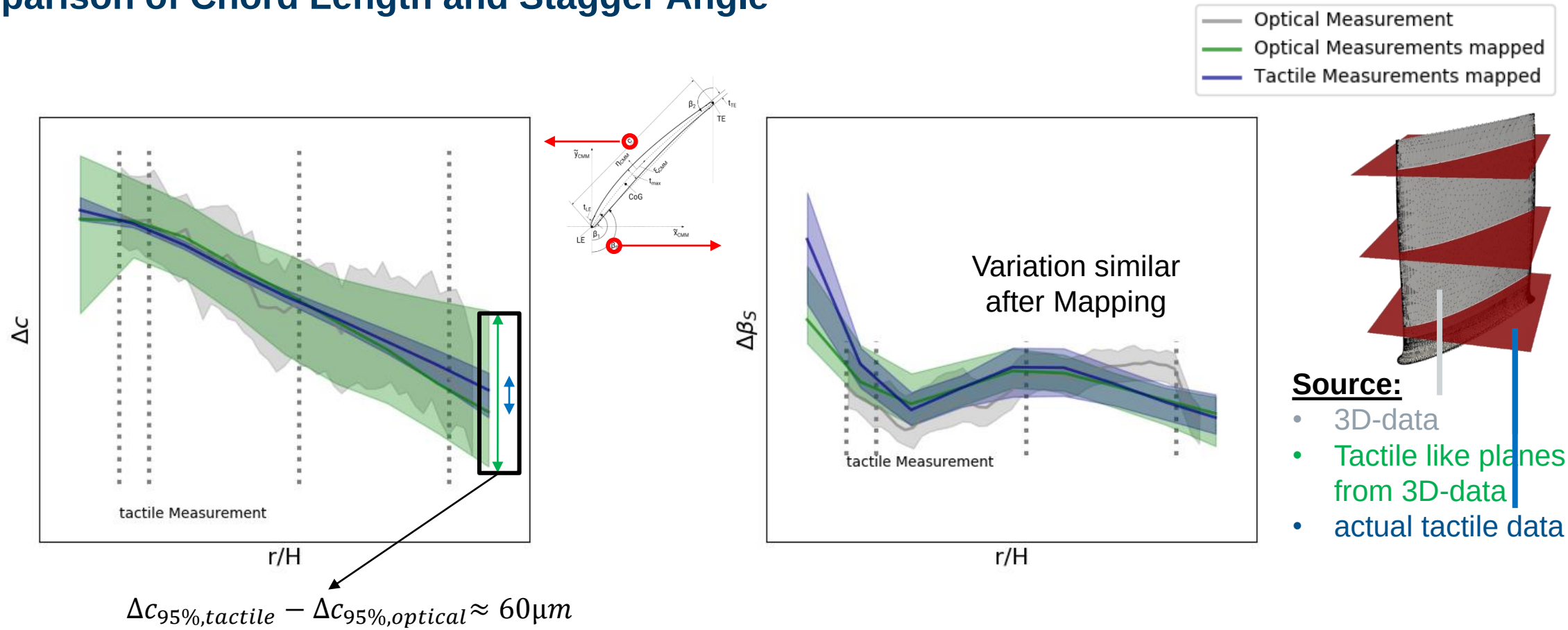
→ **Data** taken from **single Integrally Bladed Rotor (IBR).**
→ **Not representative** of whole manufacturing scatter.

Comparison of Chord Length and Stagger Angle



→ **Mapping** reproduces **spread.**
→ **Loss** in **Information** due to local effects.

Comparison of Chord Length and Stagger Angle

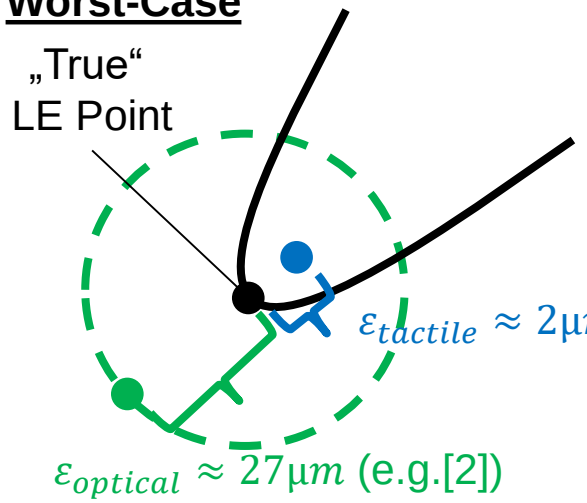


$$\Delta c_{95\%,tactile} - \Delta c_{95\%,optical} \approx 60\mu m$$

→ **Measurement Uncertainty** causes **difference** in spread for **linear measures**.
→ **Stagger Angle** rather insensitive.

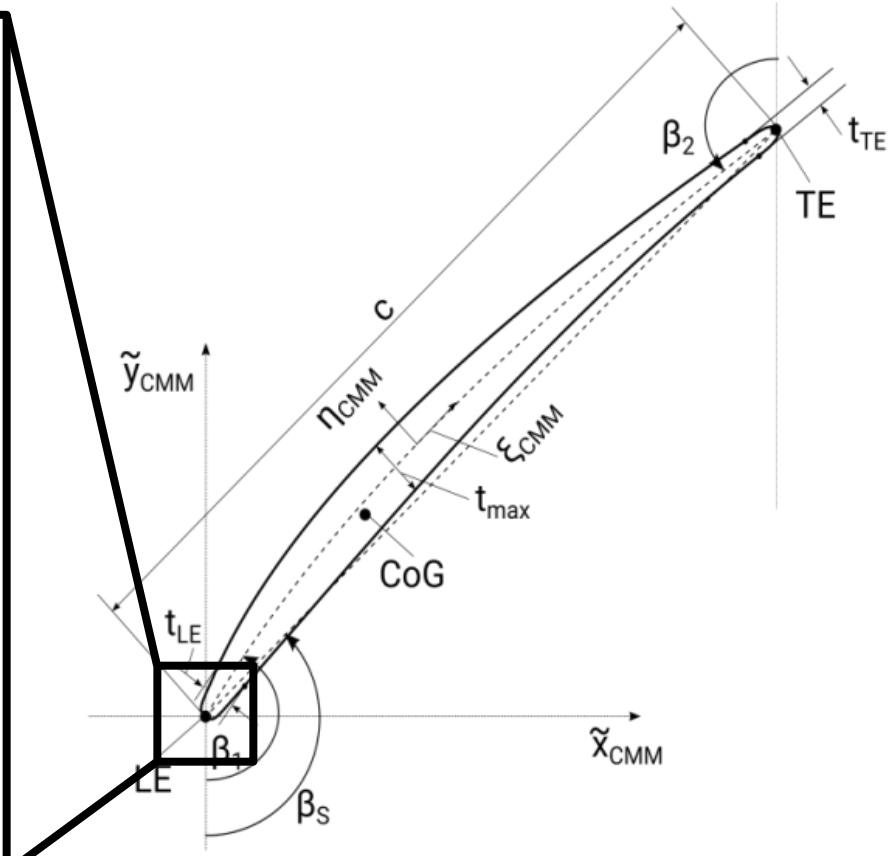
Measurement Uncertainty Comparison

Worst-Case



$$\Delta c_{\varepsilon,Worst-Case} = 2 * \left(\varepsilon_{tactile} + \varepsilon_{optical}\right) = 58\mu m \approx 60\mu m$$

$$\Delta\beta_{S\,\varepsilon,Worst-Case} = \arctan\frac{58\mu m}{c} \ll 0.04°$$



→ **Worst-Case** measurement error explains difference in spread.
→ **Stagger Angle** insensitive because of ratio chord length-to-measurement uncertainty.

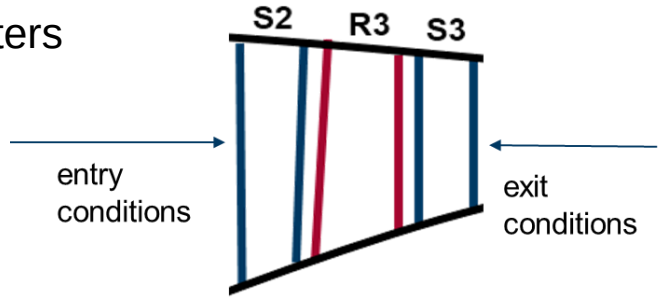
Uncertainty Quantification of Loss of Coefficient

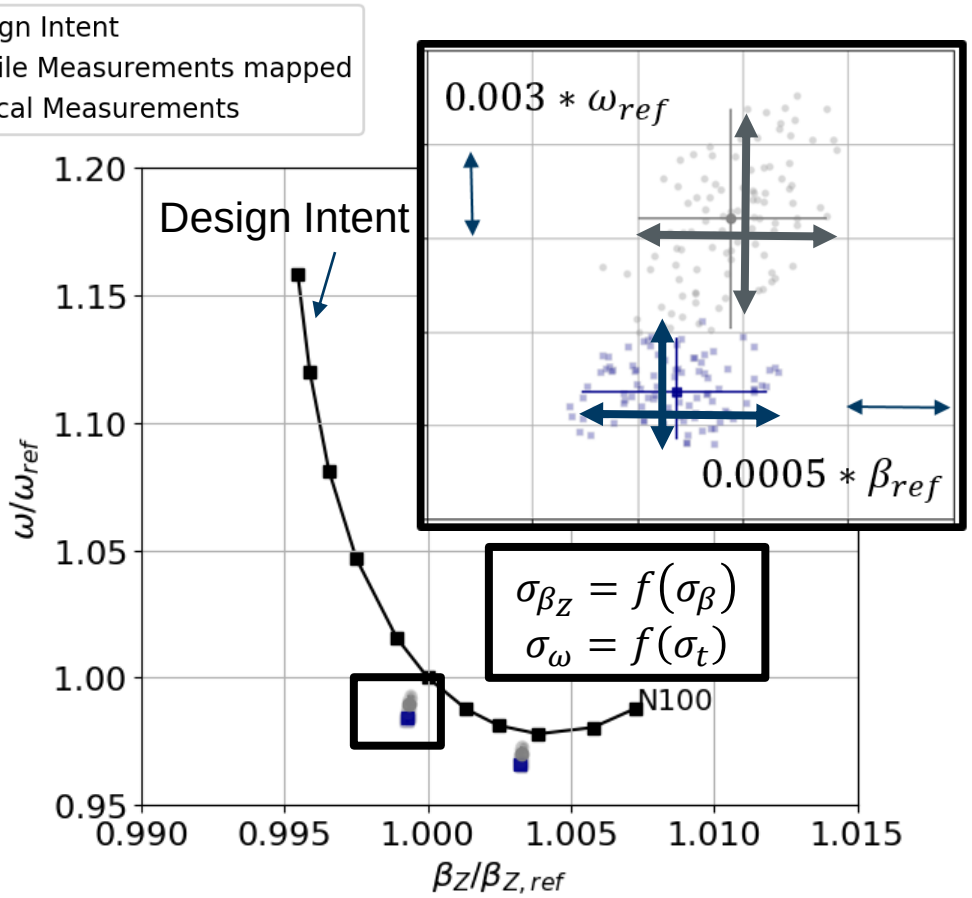
CFD-Model:

- 1.5 Stages, Stator-Rotor-Stator
- **Golden Masters** created by modifying Design Intent with **Median Values**
- TRACE steady state RANS flow solver

UQ-Model:

- **Geometric Model**
  - Profile deviations, Positioning error
  - Correlations between parameters
  - **9 Parameters total**
- **Monte-Carlo-Simulation:**
  - Latin Hypercube Sampling
  - 100 Samples





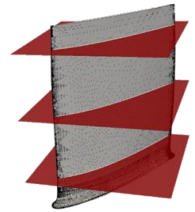
→ **Variation** in **flow angle** similar.
→ **Difference** in **variation** in **Loss Coefficient** caused by **measurement uncertainty**.

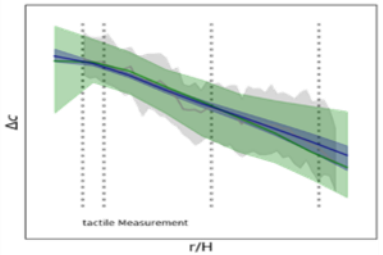
Conclusion

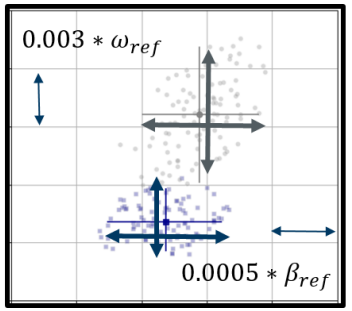
- Measurement Data of **single IBR analyzed**
  - **Optical Measurements**
  - **Tactile Measurements** on (inclined) planes
  - **Differences** due to **measurement uncertainty**
  - **Geometric deviations** of **milled IBR** small

- **Golden Master** built from **both** Datasets

- **Probabilistic Assessment** of both Golden Masters using Latin-Hypercube-Sampling
  - Variation in **Loss Coefficient** very small
  - Differences caused by **measurement uncertainty**
  - **Variation** in flow angle similar in **both cases**







→ **Tactile Measurements** can be **utilized** for **probabilistic assessment** of **aerodynamic performance**

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Literature

[1] Aggogeri, F. Barbato G., Barini E. M., and Genta, G., 2011. „Measurement uncertainty assessment of Coordinate Measuring Machines by simulation and planned experimentation“. In CIRP Journal of Manufacturing Science and Technology, pp. 51-56.

[2] Heinze, K, 2016. „Eine Methode für probabilistische Untersuchungen zum Einfluss von Fertigungsstreuungen auf die hochzyklische Ermüdung von Verdichterschaufeln.“ PhD-Thesis, Dresden.