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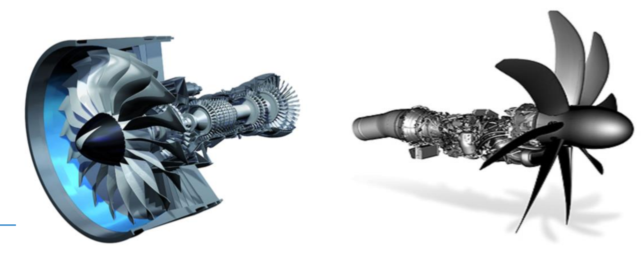

Development and Validation of a Methodology for Numerical Calibration of Five-Hole Probes

Introduction

Objectives

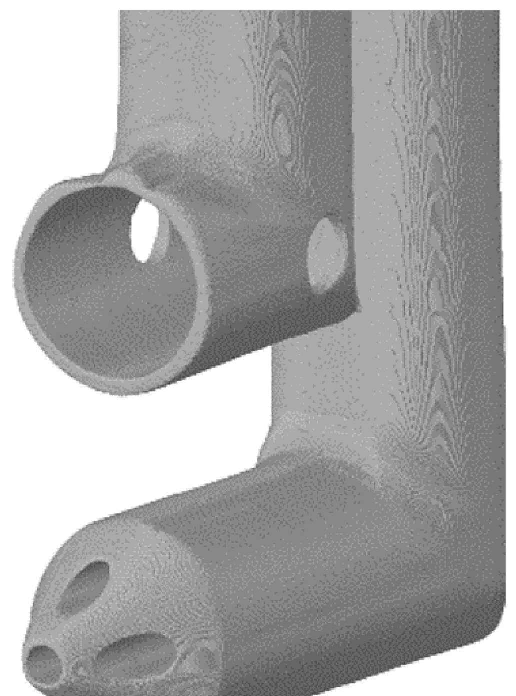

Fig. 1 CT-Scan of Five Hole Probe.

Numerical methods are continuously improving and advancing in accuracy. Since experimental measurements are used to validate numerical methods, the demand for higher accuracy in experimental data is increasing. CFD simulations could be employed to further investigate uncertainties in turbomachinery measurements using pressure probes.

Measurement Errors in Turbomachinery

Pressure probes, such as Five-Hole Probes (5HP), are widely used in turbomachinery applications and are generally considered accurate. However, deviations from calibration conditions can introduce significant errors, caused by:

- Shear flows
- High turbulence intensity
- Unsteadiness
- Variations in Reynolds number

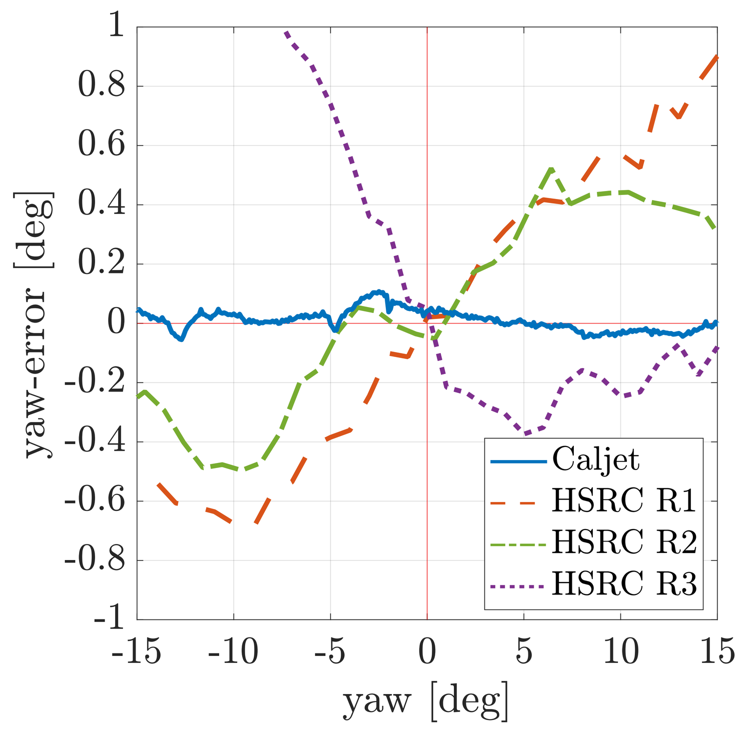

Fig. 2 Angle Errors in Turbomachinery.

Methodology

Geometry Analysis

Initial investigations showed that multiple probes of nominally identical geometry behave differently during calibration. To understand the requirements for numerical investigations, different degrees of abstraction of probe head geometry are studied, including:

- **wo PH** – Modeling probe head without PH (scientific standard).
- **w PH** – Adding probe holes (PH) to the model.
- **w PH pos** – Positioning probe holes at the exact location.
- **Scan** – Using microCT scans of probe heads.

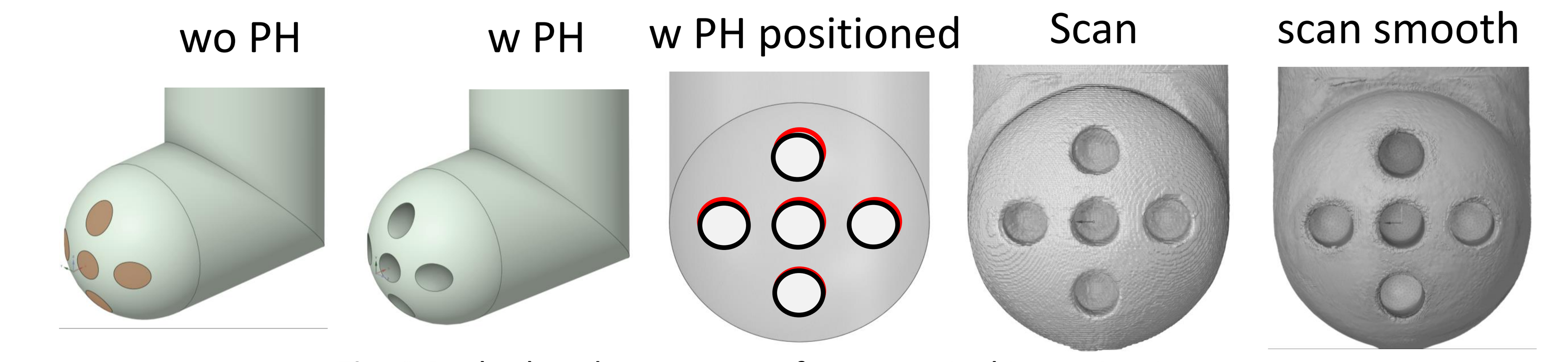

Fig. 3 Probe head geometries for numerical investigations.

Numeric Approach

The numerical setup is described in the following:

Mesh:
– Fluent Meshing – Ploy-Hex-Core Mesh – 10-40 Mio cells –

Boundary Condition:
– Pressure Far Field – derived from experiment –

Fluid: ideal Gas
Solver: Fluent
Turbulence Model: GEKO
Convergence: PH-pressure

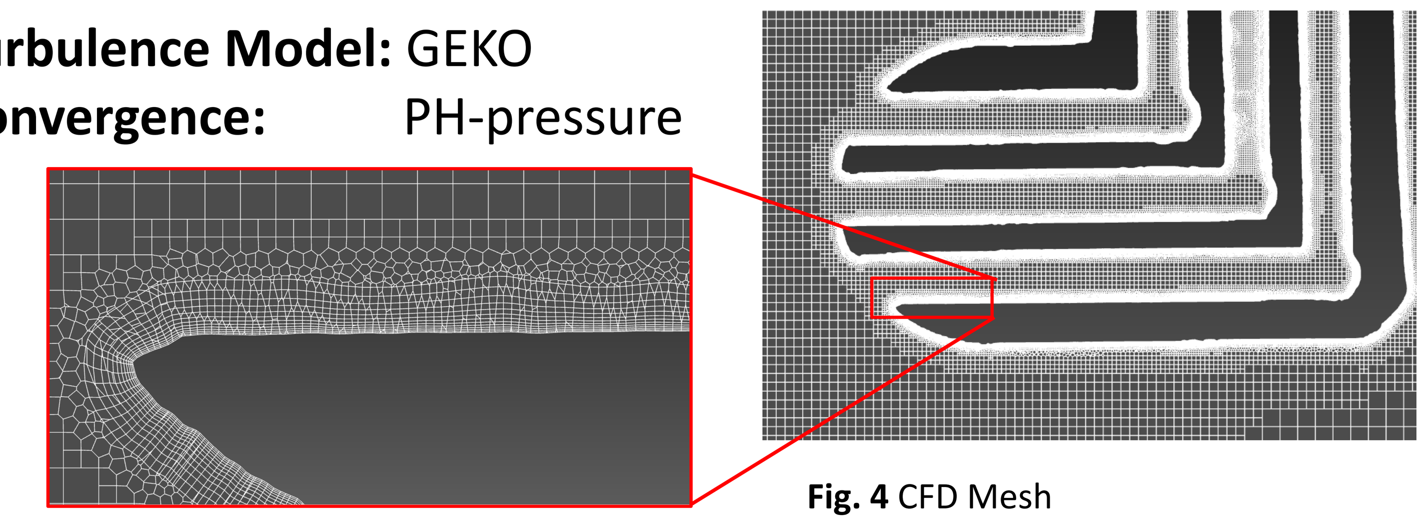

Fig. 4 CFD Mesh

Results

Geometry Study

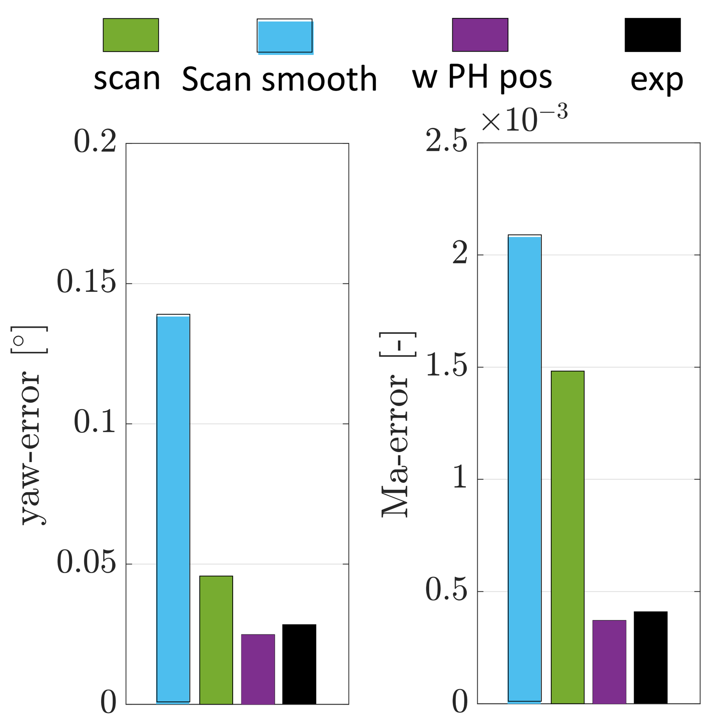

Fig. 5 Comparison of Experimental and Numerical Error.

Results obtained:

- Modelling of PH is essential.
- Positioning of PHs improves the results a lot.
- More complexity does not improve the results (scan vs. w PH pois).
- Depending on the approach, experimental accuracy can be reached.

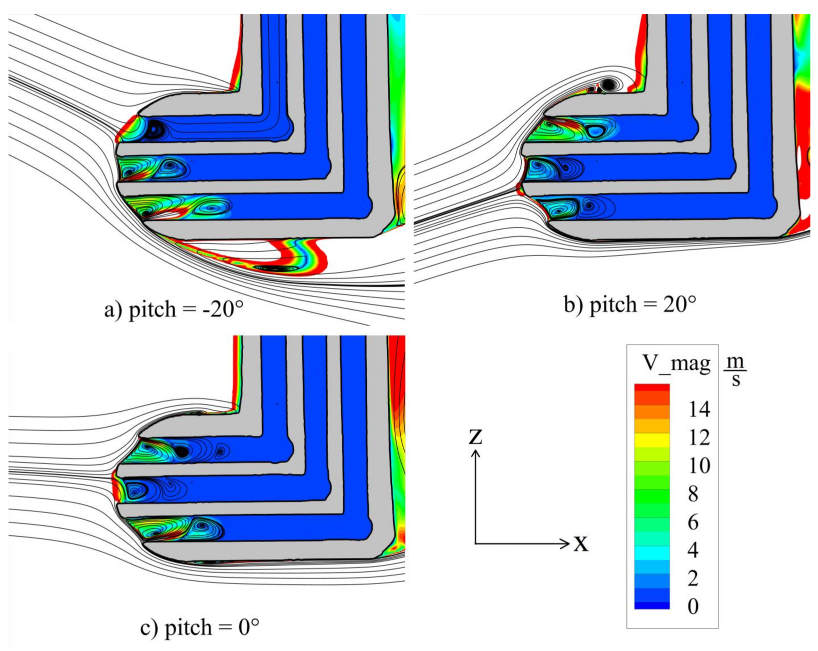

Fig. 6 Velocity-field around probe head.

Key Findings:

- Multiple regions of flow separation at the probe head.
- Formation of vortex structures inside the probe holes.
- Significant shift of the stagnation point depending on the flow angle.
- Some probes exhibit small geometric features.

Outlook

- Numerical calibration of pressure probes is possible but very costly (num: 60 CPU*h vs. exp: 6s).
- However, numerical methods can be used to analyze flow conditions that cannot be experimentally investigated due to limitations at calibration wind tunnels or non-existing measurement techniques, such as:
  - Shear flows
  - High turbulence
  - Changes in Reynolds numbers
  - Unsteadiness

Therefore, a new tool has been developed to better understand measurement errors in turbomachinery flow conditions.

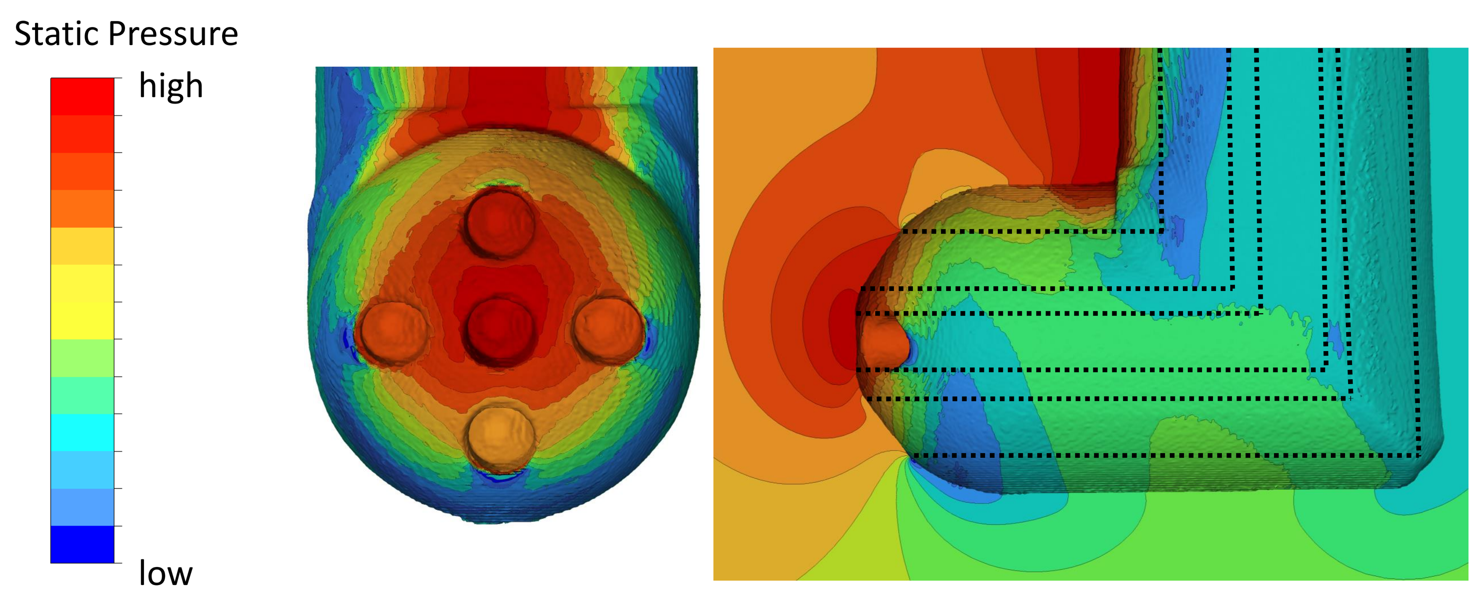

Fig. 7 Pressure distribution at probe head.

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