# Technical University of Darmstadt

## Institute of Gas Turbines and Aerospace Propulsion

TECHNISCHE UNIVERSITÄT DARMSTADT

GLR

MASCHINENBAU
We engineer future

GLR

# The Darmstadt Open Test Case - Introdcution

TECHNISCHE UNIVERSITÄT DARMSTADT

**Prof. Heinz-Peter Schiffer**

**Prof. Mehdi Vahdati**

Imperial College London

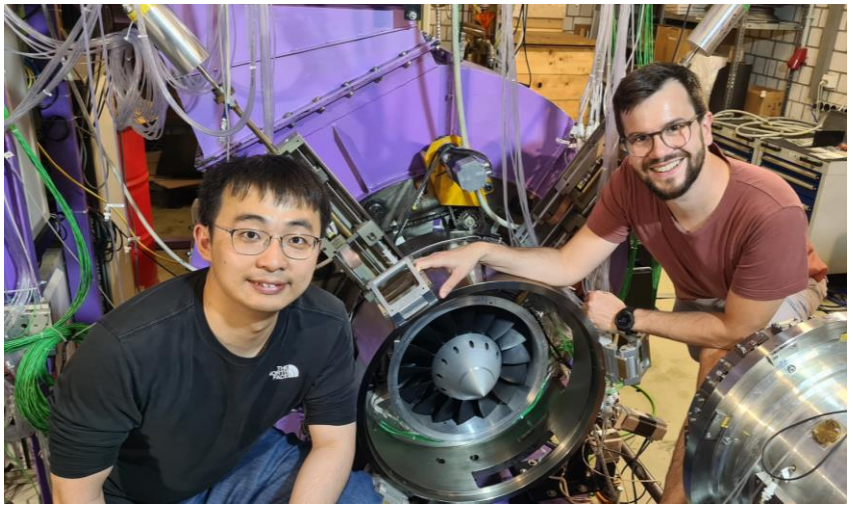
TECHNISCHE UNIVERSITÄT DARMSTADT

2019

# The Darmstadt Open Test Case - Introdcution

**Prof. Heinz-Peter Schiffer**

**Prof. Mehdi Vahdati**



**Xiao He**

**Fabian Klausmann**

2019

# The Darmstadt Open Test Case - Introdcution

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## Low availability of high speed test data

E.g.

NASA geometries

KHI multi-stage compressor

LMFA CREATE

# The Darmstadt Open Test Case - Introdcution

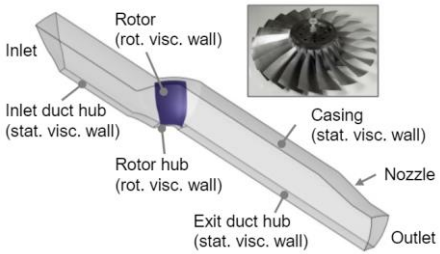
**Low availability of high speed test data**

NASA geometries

KHI multi-stage compressor

LMFA CREATE

NASA Rotor 67



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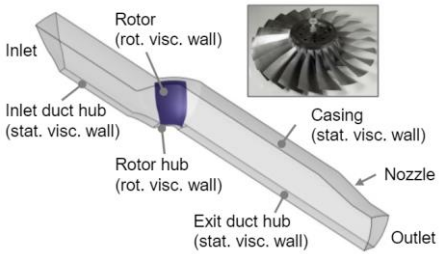


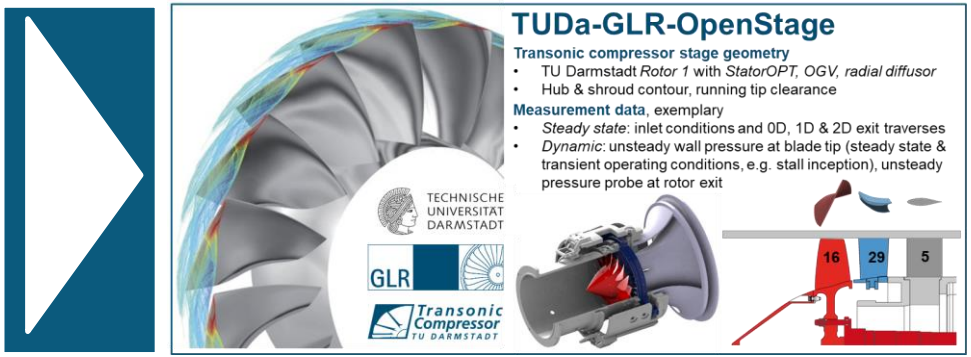


2020

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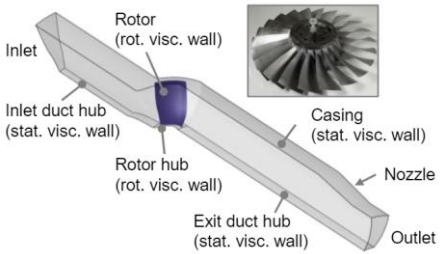
**Low availability of high speed test data**

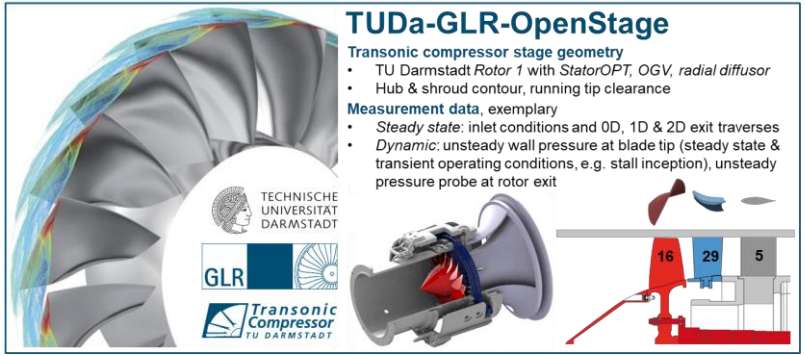
NASA geometries

KHI multi-stage compressor

LMFA CREATE

NASA Rotor 67




2020


2021

# The Darmstadt Open Test Case

## List of publications since test case release **April 11, 2023**

List of publications that used the TUDa-GLR-OpenStage, categorized according to the nature of the research. Results were based on Google Scholar database. Items in blue are contributed from groups other than TUD, IC and SJTU.(April 11, 2023)

**Experimental investigations of flow physics:**


[1] Klausmann, F., Kilian, N., He, X., Franke, D., Schmidt, B., & Schiffer, H. P. (2023). Transonic compressor Darmstadt open test case: experimental investigation of stator secondary flows and hub leakage. ASME Paper No. GT2023-103502. (accepted to journal of turbomachinery)

[2] Klausmann, F., Franke, D., & Schiffer, H. P. (2022). Transonic compressor Darmstadt open test case –unsteady aerodynamics and stall inception. GPPS Paper No. GPPS-TC-2022-0071.

[3] Klausmann, F., Franke, D., Foret, J., & Schiffer, H. P. (2022). Transonic compressor Darmstadt - Open test case Introduction of the TUDa open test case. Journal of the Global Power and Propulsion Society, 6, 318-329.


**Numerical investigations of flow physics:**


[4] Shao, R., He, X., Zhu, M., Klausmann, F., & Teng, J. (2023). Characterizing Shrouded Stator Cavity Flow on the Performance of a Single-Stage Axial Transonic Compressor. ASME Paper No. GT2023-101131.

[5] An, G., Kang, J., Zou, Y., Zhang, L., Lang, J., Yuan, W., & Zhang, Q. (2023). Investigation of the unsteady flow in a transonic axial compressor adopted in the compressed air energy storage system. Journal of Energy Storage, 63, 106928.

[6] Bode, C., Przytarski, P. J., Leggett, J., & Sandberg, R. D. (2022). Highly Resolved Large-Eddy Simulations of a Transonic Compressor Stage Midspan Section Part I: Effect of Inflow Disturbances. ASME Paper No. GT2022-81673.

[7] Przytarski, P. J., Leggett, J., Sandberg, R., & Bode, C. (2022). Highly Resolved Large-Eddy Simulations of a Transonic Compressor Stage Midspan Section-Part II: Effect of Rotor-Stator Gap. ASME Paper No. GT2022-82474.


**CFD validation and verification:**


[8] Yan, C., Wang, B., He, X., Zhao, F., Zheng, X., Vahdati, M., and Zheng, X. (2023). Extension and validation of the turbomachinery capabilities of SU2 open source CFD code. ASME Paper No. GT2023-103544. (accepted)

[9] Xia, K., He, X., Zhu, M., Klausmann, F. S., Teng, J., & Vahdati, M. (2023). Endwall geometric uncertainty and error on the performance of TUDA-GLR-OpenStage transonic axial compressor. Journal of the Global Power and Propulsion Society, 7, 113-126.

[10] He, X., Zhu, M., Xia, K., Fabian, K. S., Teng, J., & Vahdati, M. (2023). Validation and verification of rans solvers for tuda-glr-openstage transonic axial compressor. Journal of the Global Power and Propulsion Society, 7, 13-29.

[11 Hansen, T., Munktell, E., Scheuerer, G., & Zwiener, K. (2022). Single-Stage Axial Transonic Compressor Flow–CFD Simulations Including a Systematic Quality Assurance Procedure. GPPS Paper No. GPPS-TC-2022-0012.


**Development for numerical models:**


[12] He, X., Zhao, F., & Vahdati, M. (2022). A Turbo-Oriented Data-Driven Modification to the Spalart–Allmaras Turbulence Model. Journal of Turbomachinery, 144(12), 121007.

[13] Xu, S., Zhang, Q., Zhao, J., Qian, W., Li, W., & Wang, D. (2022). Implicit and Conservative Mixing-Plane Method for Multistage Turbomachinery Aerodynamic Analysis. AIAA Journal, 60(11), 6385-6403.

# CONTENT

## The Darmstadt Open Test Case

Related / future / unpublished experimental activities

Klausmann, F., Franke, D., Foret, J., and Schiffer, H. (2022). Transonic compressor Darmstadt - Open test case Introduction of the TUDa open test case.
*Journal of the Global Power and Propulsion Society*, 6, pp.318-329. https://doi.org/10.33737/jgpps/156120

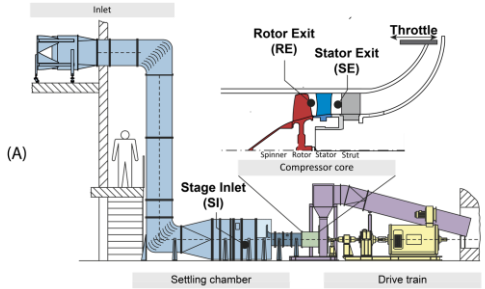
# Technology Readiness Level Classification

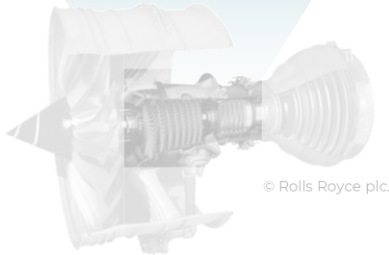
TECHNISCHE UNIVERSITÄT DARMSTADT

| TRL 1 | TRL 2 | TRL 3 | **TRL 4 - 5** | TRL 6 - 7 | TRL 8 - 9 |
|---|---|---|---|---|---|
| Basic Principles Observed and Reported | Potential Application Validated | Proof-of-Concept Demonstrated | **Component Test Facilities & Validation** | System Prototype Demonstration in Operation Environment | System Test, Launch & Operations |

- Good accessibility for instrumentation
- Isolated investigation
- Industrially relevant environment
- Focus on understanding the underlying phenomena


Transonic Compressor TU DARMSTADT



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# The Darmstadt Open Test Case
## Facility Design

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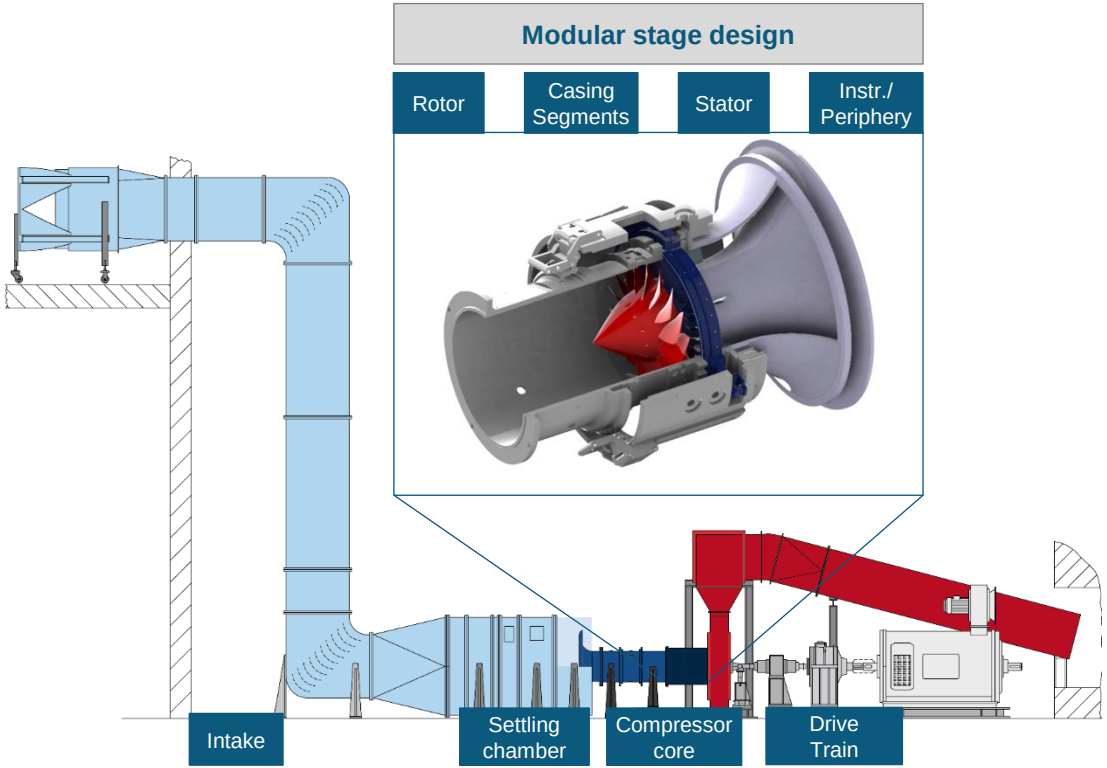


**Single-stage or 1.5-stage axial compressor setups (representative for a HPC front stage)**

| Capacity | |
|---|---|
| **In /out flow** | axial-axial |
| **Electr. Power** | 800 kW |
| **Max. Torque** | 350 Nm |
| **Max. speed** | 20 500 rpm |
| **Max. rotor diameter** | 0.38 m |
| **Hub to tip ratio** | ~ 0.5 |
| **Rel. Ma-Number @ tip** | ~ 1.4 |

Klausmann, F., Franke, D., Foret, J., and Schiffer, H. (2022). Transonic compressor Darmstadt - Open test case Introduction of the TUDa open test case.
*Journal of the Global Power and Propulsion Society*, 6, pp.318-329. https://doi.org/10.33737/jgpps/156120

# The Darmstadt Open Test Case

## Compressor Core (Open Test Case)

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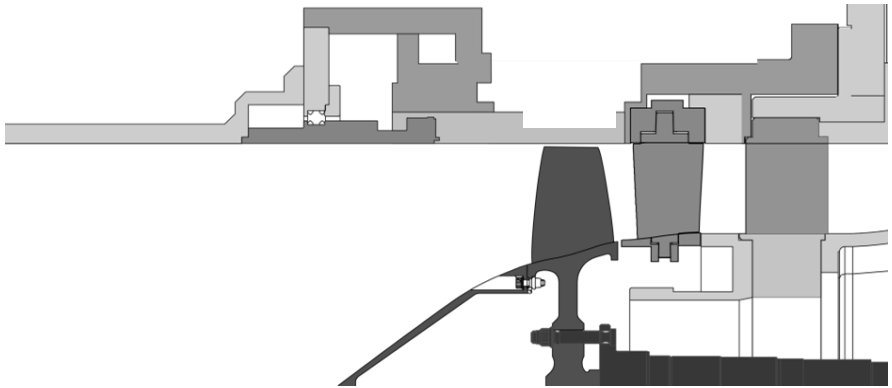


Rotor

**Rotor 1**

**Designed by *MTU Aero Engines***

- First run 1994
- Broad availability of literature
- open test case

Stator

**Stator opt.**

**CFD optimized Stator**

Klausmann, F., Franke, D., Foret, J., and Schiffer, H. (2022). Transonic compressor Darmstadt - Open test case Introduction of the TUDa open test case.
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# The Darmstadt Open Test Case

## Instrumentation – Compressor Core (Open Test Case)

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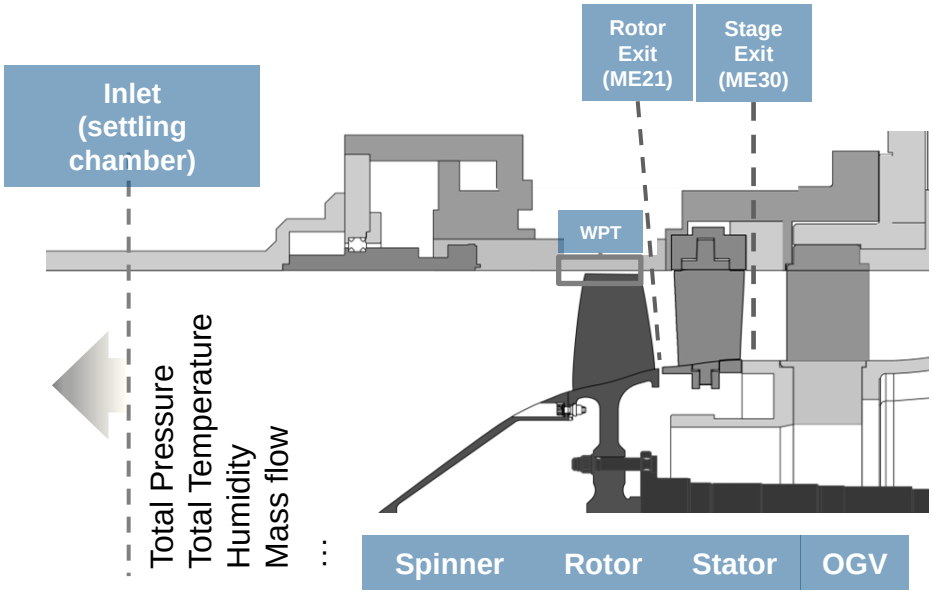


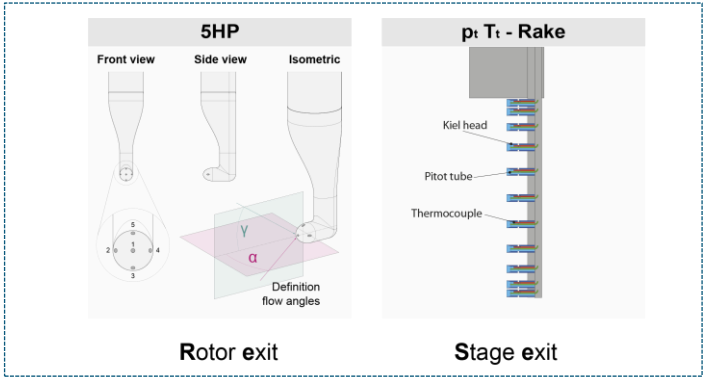


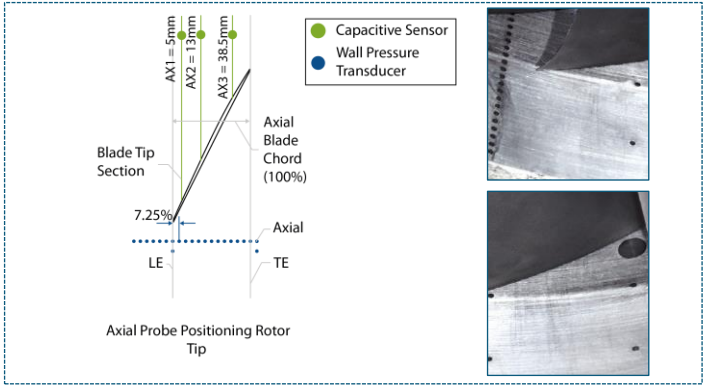

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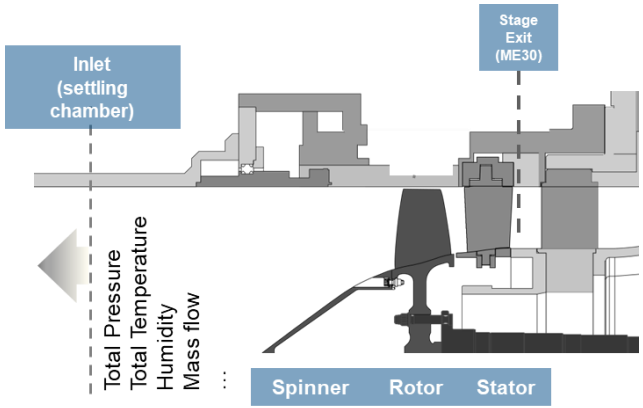
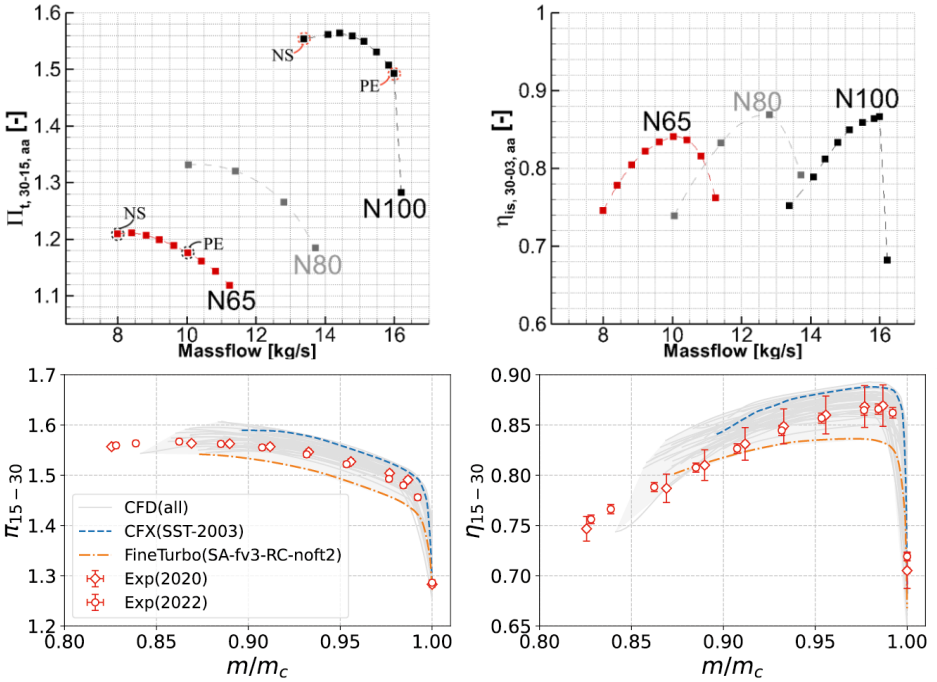
## Included data




Preprint: He, Xiao*, Klausmann F.: Capabilities of RANS CFD for Axial Compressor Flows: A Perspective from the GPPS CFD Workshop
*Corresponding author

Klausmann, F., Franke, D., Foret, J., and Schiffer, H. (2022). Transonic compressor Darmstadt - Open test case Introduction of the TUDa open test case.
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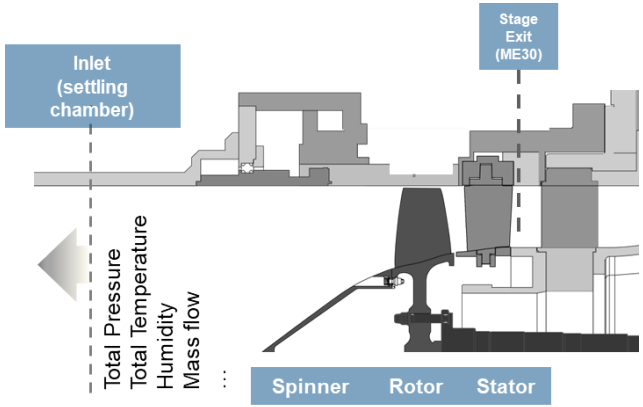
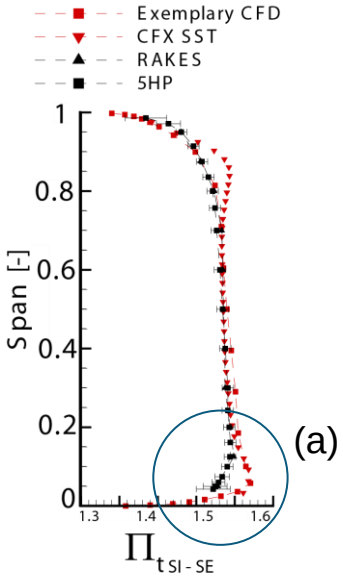
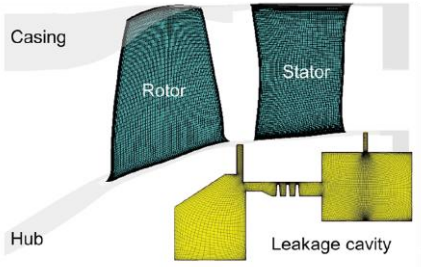



N100 PE
**S**tage **e**xit

(a) Overprediction at hub




**Shao, R., He, X., Zhu, M., Klausmann, F., and Teng, J., 2023. "Characterizing Shrouded Stator Cavity Flow on the Performance of a Single-Stage Axial Transonic Compressor". Journal of Turbomachinery, 08, pp. 1–23.**

**&**

**Klausmann, F., Kilian, N., He, X., Franke, D., Schmidt, B., and Schiffer, H.-P., 2023. "Transonic compressor Darmstadt open test case: experimental investigation of stator secondary flows and hub leakage". ASME Paper No. GT2023-103502**. *(accepted for journal)*

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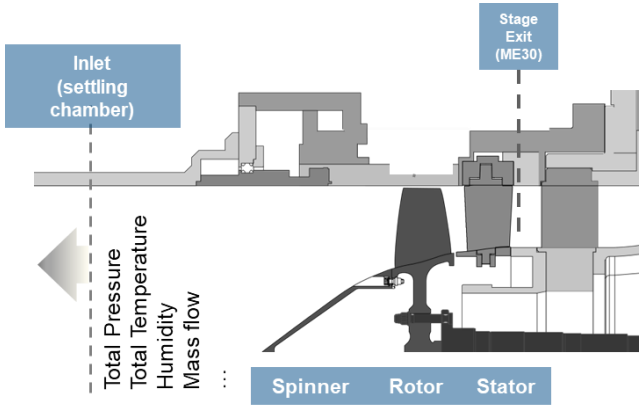


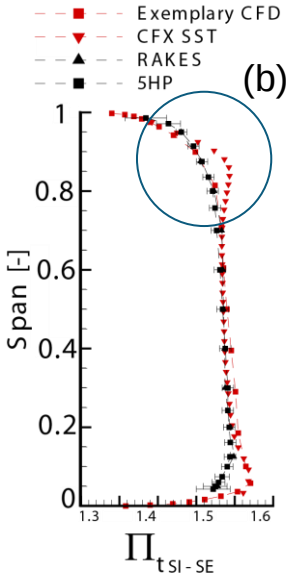


N100 PE
**S**tage **e**xit

(b) Overprediction at shroud

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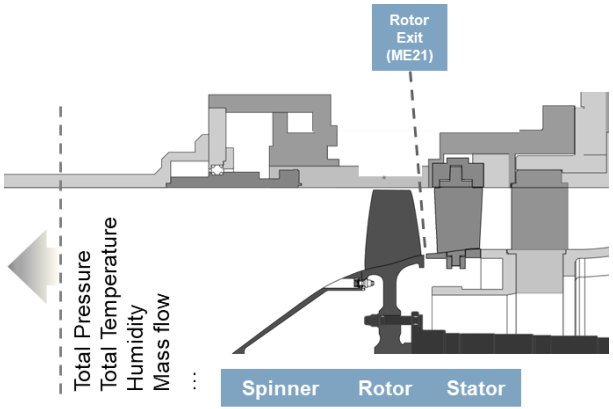
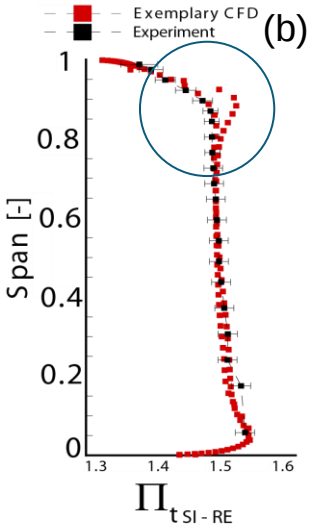
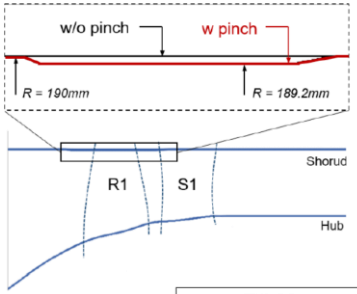



N100 PE
**R**otor **E**xit

(b) Overprediction at shroud

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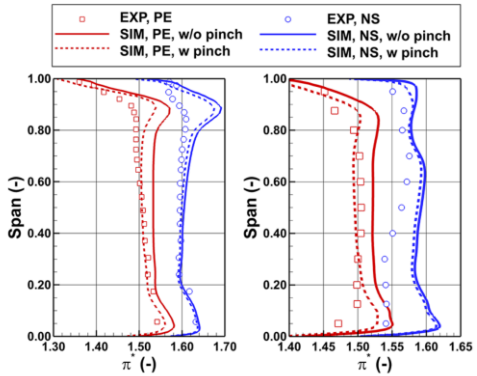

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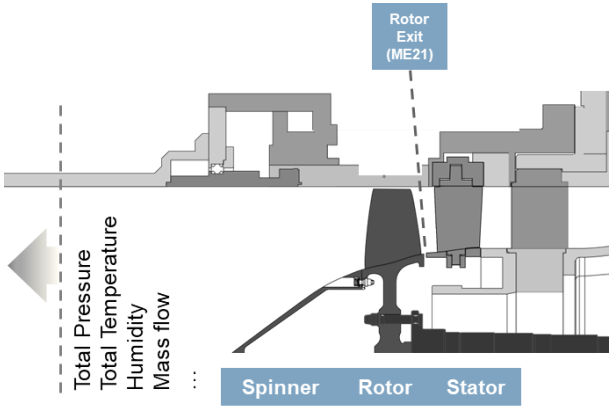


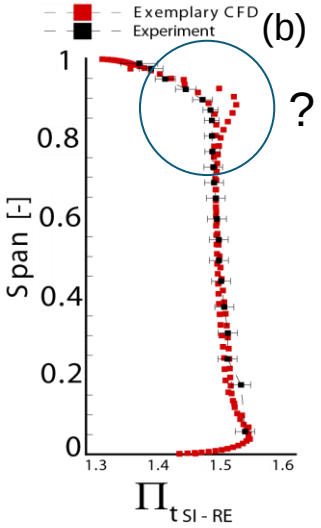


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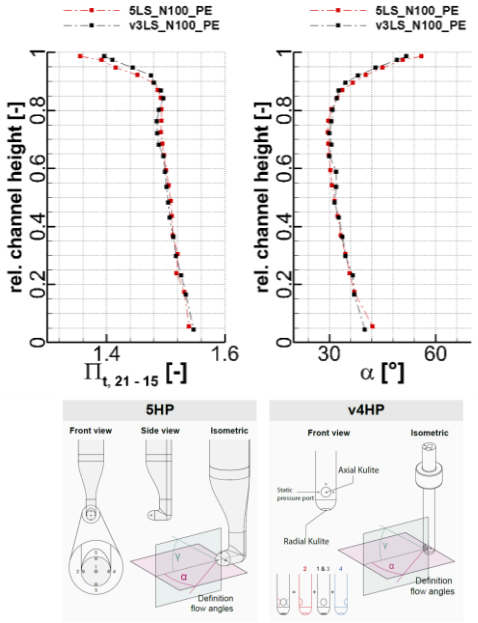
**R**otor **E**xit

(b) Overprediction at shroud



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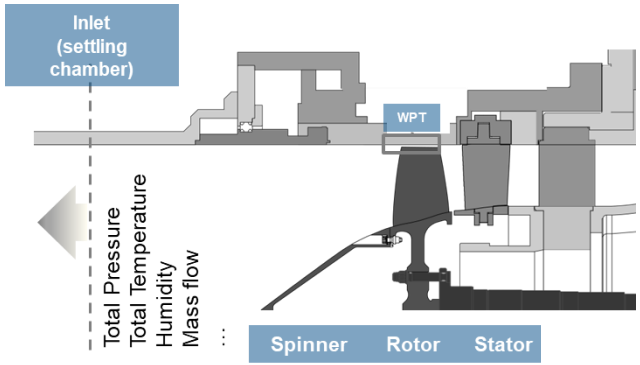


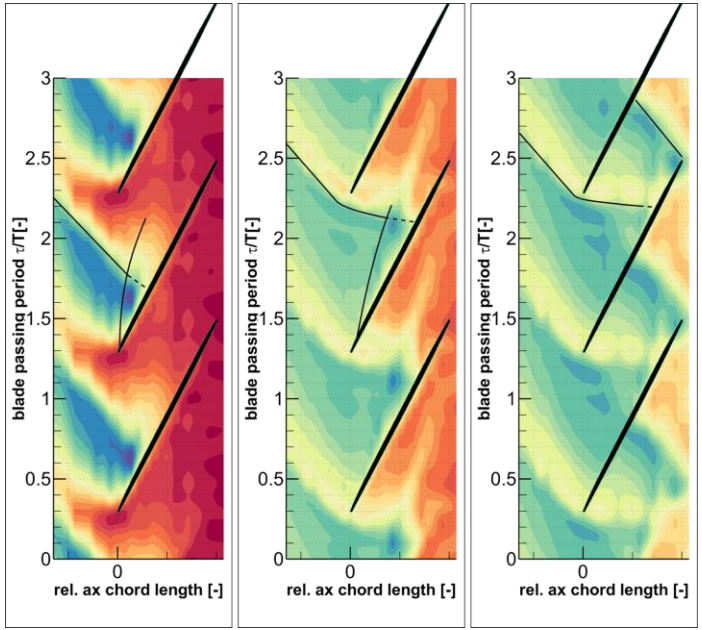


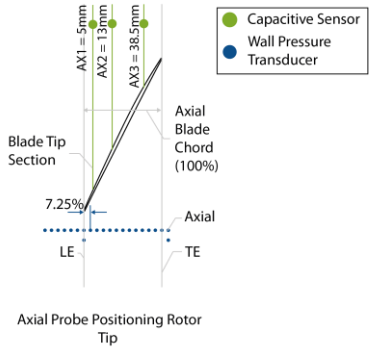

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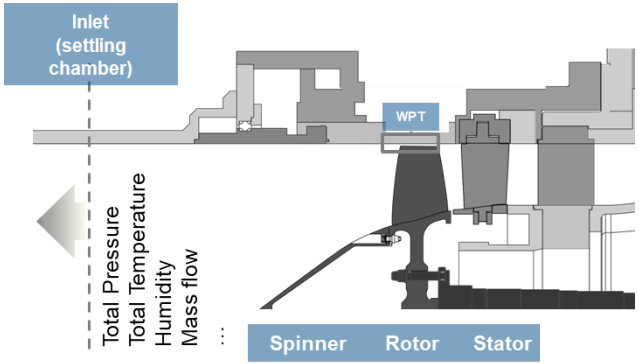


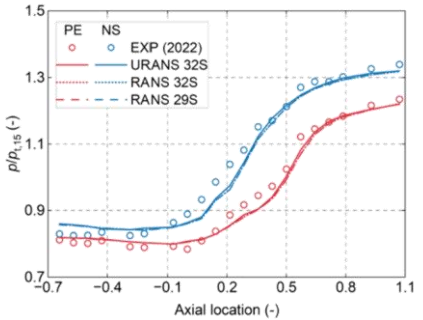


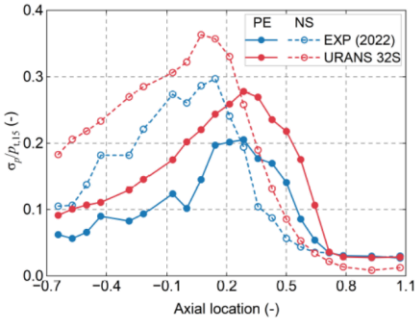


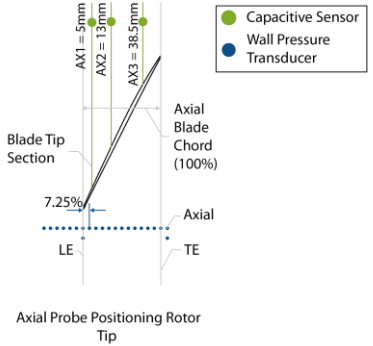


**UNSTEADY FLOW PHENOMENON IN THE TUDA-GLR-OPENSTAGE COMPRESSOR: URANS OBSERVATIONS**

**Hefang Deng, Xiao He∗, Mingmin Zhu, Fabian Klausmann, Jinfang Teng**

**Tuesday, October 17th 16:15**
**Room 1 (MB201)**

Klausmann, F., Franke, D., Foret, J., and Schiffer, H. (2022). Transonic compressor Darmstadt - Open test case Introduction of the TUDa open test case.
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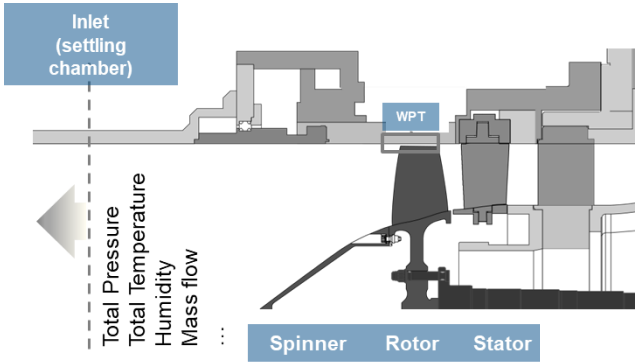
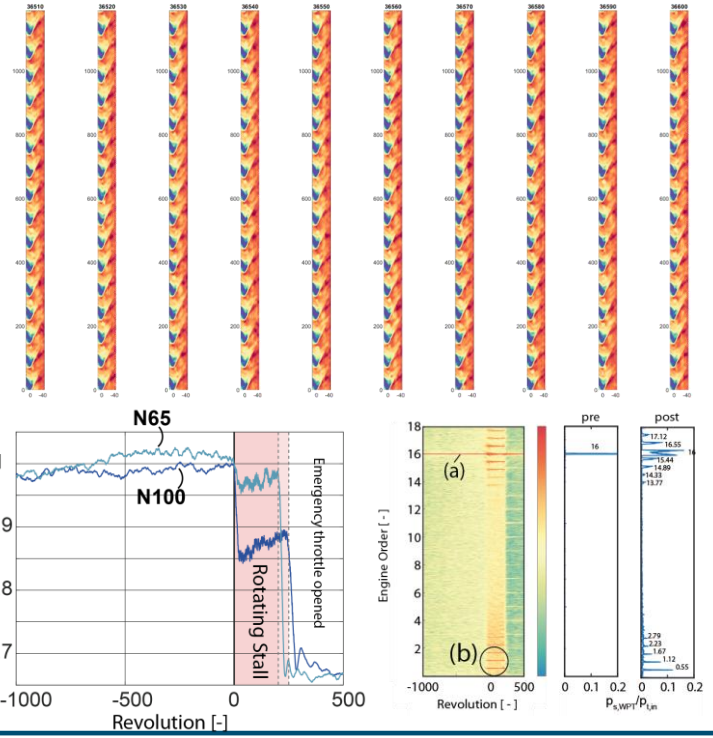
## Included data

TECHNISCHE UNIVERSITÄT DARMSTADT




Klausmann, F., Franke, D., Schiffer, H.-P.:
TRANSONIC COMPRESSOR DARMSTADT OPEN TEST CASE – UNSTEADY AERODYNAMICS AND STALL INCEPTION,
**GPPS-TC-2022-0071**



Klausmann, F., Franke, D., Foret, J., and Schiffer, H. (2022). Transonic compressor Darmstadt - Open test case Introduction of the TUDa open test case.
*Journal of the Global Power and Propulsion Society*, 6, pp.318-329. https://doi.org/10.33737/jgpps/156120

# The Darmstadt Open Test Case

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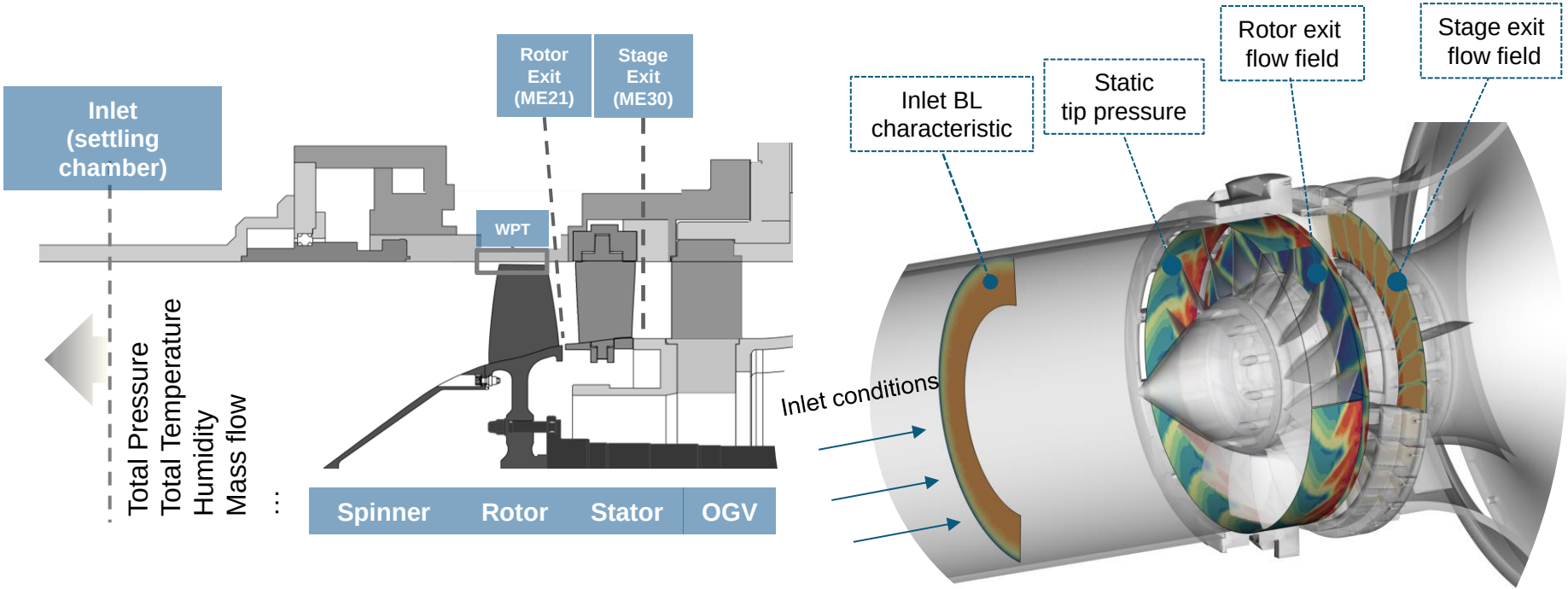

# CONTENT

The Open Test Case

**Related / future / unpublished experimental activities**

# The Darmstadt Open Test Case

## Repro measurements 2022

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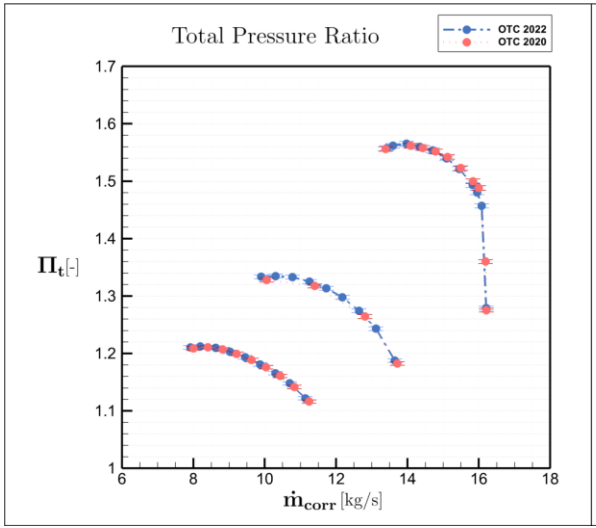
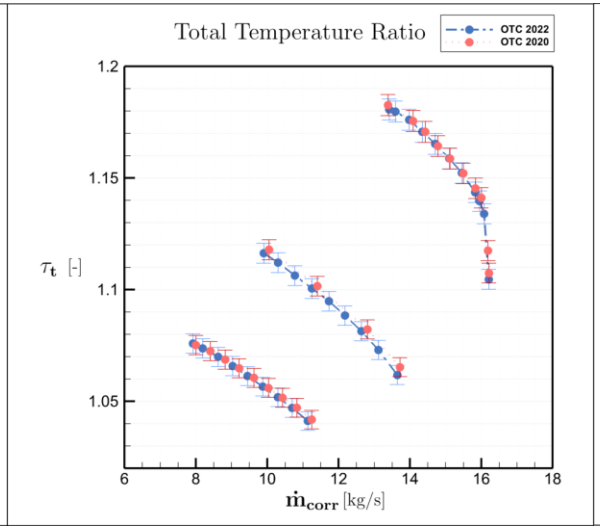
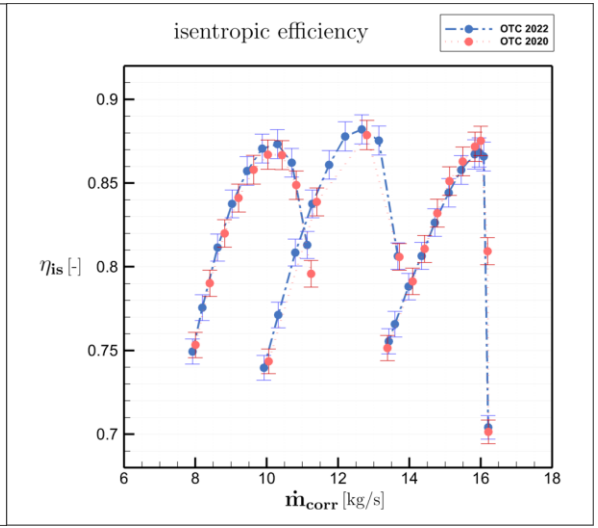
**How good can we reproduce the data with years apart? (consider unknown systematic errors)**

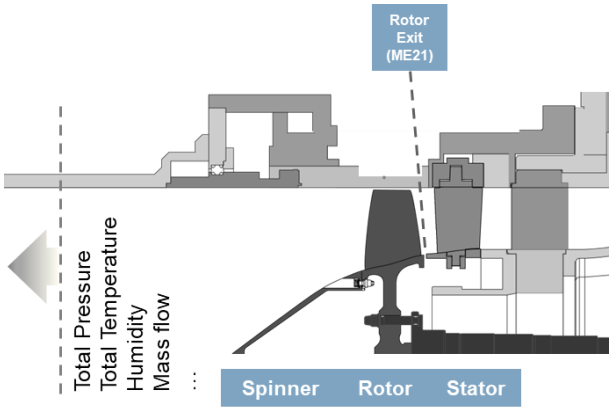


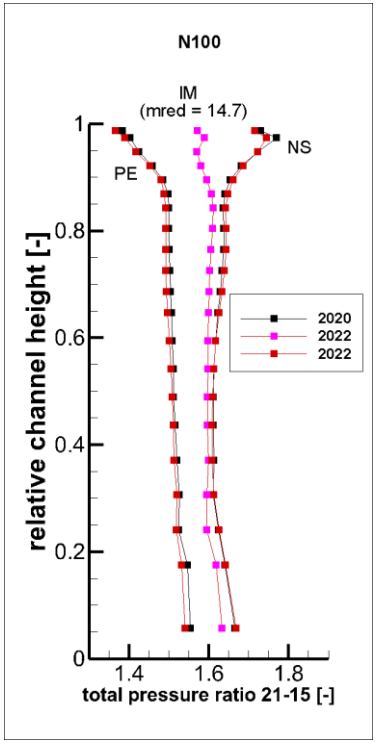



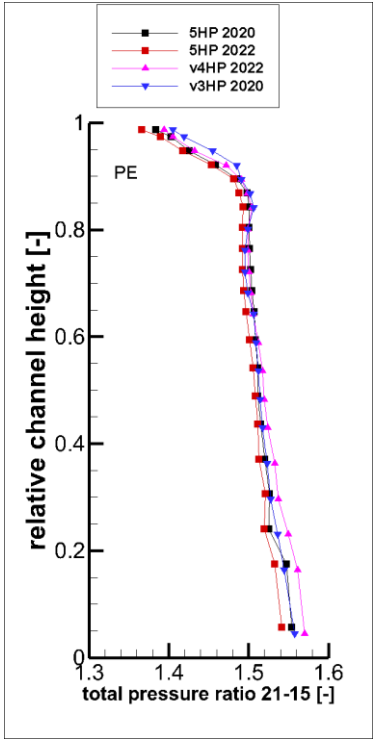



# The Darmstadt Open Test Case

## Repro measurements 2022



# The Darmstadt Open Test Case

## Influence of manufactured geometry

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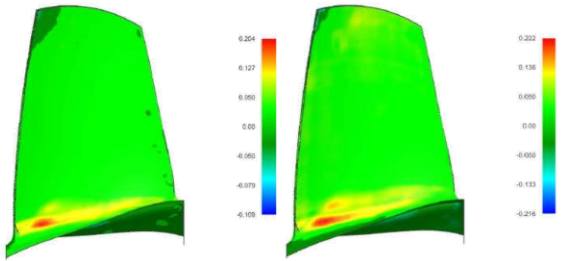
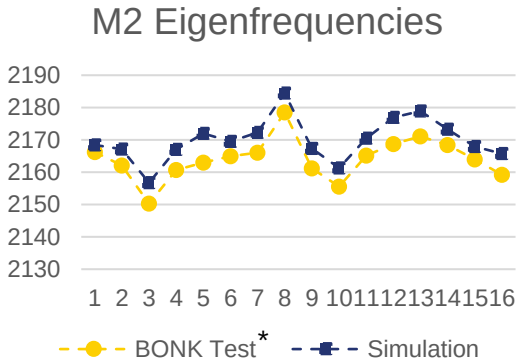
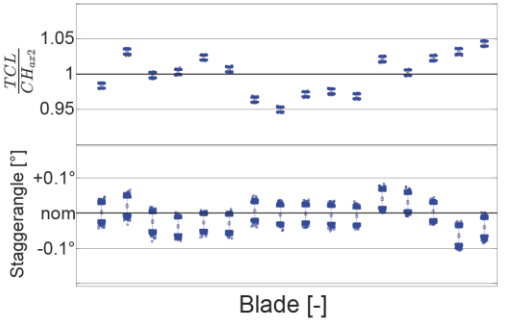
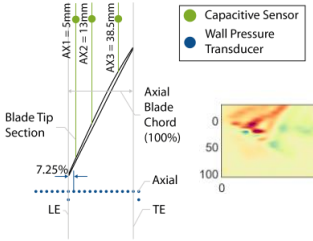
### Influence of blade-to-blade variations on flow

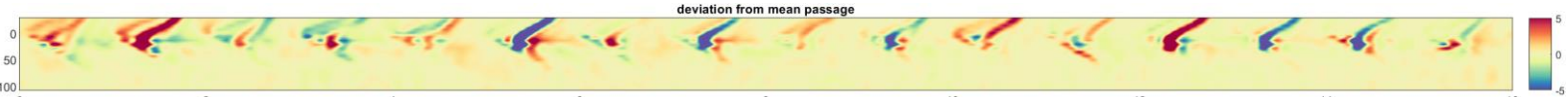


Blade 1 Blade 4




*Performend by BTU Cottbus

# The Darmstadt Open Test Case

## Blade row interaction and forced response

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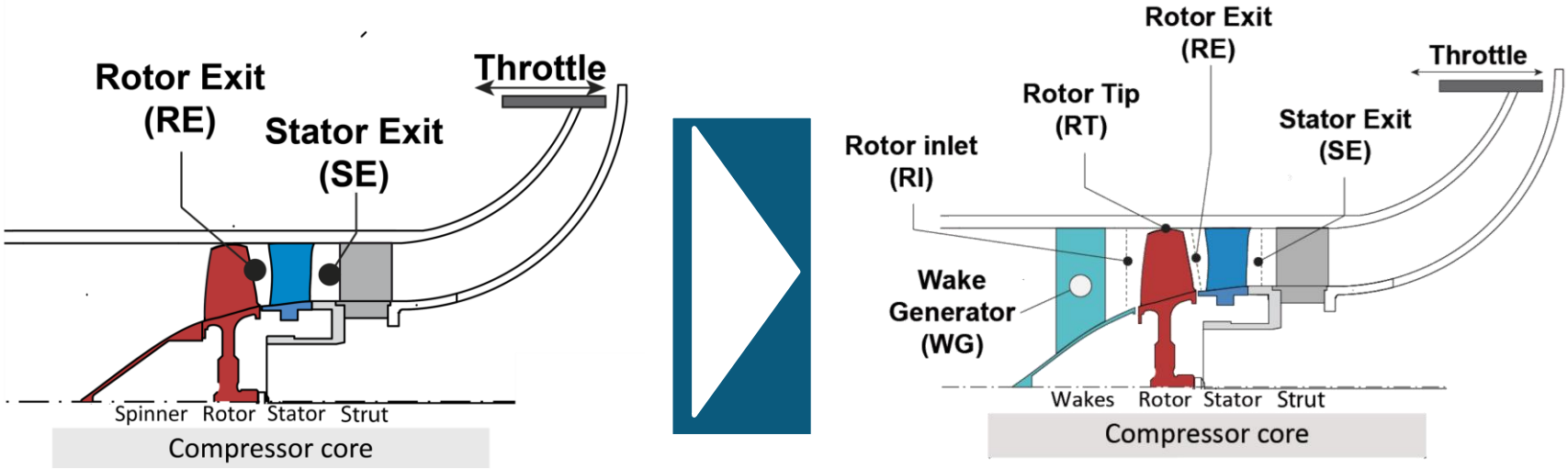
**„the original purpose“**




**GPPS-TC-2023-0210: Darmstadt Open Test Case: Experimental Investigation of Forced Response Phenomena in a Transonic Compressor Stage**

**Wednesday, October 18th, 15:10, Room 3**

# The Darmstadt Open Test Case
## Outlook

**GPPS 2021 Xi'an**

- 1st GPPS CFD Turbomachinery Workshop
- **After workshop** release of CFD data; submission of workshop summary to GPPS Journal
- **After conference** release of second part of dataset:

**GPPS 2023 Hong Kong**

- GPPS shared data becomes fully public before technical Conference in Hong Kong
- **After conference**: rework of unsteady data format
- **Consideration**: include repro measurements 2022

**2024** **2025** **2026**

Establish standard test case with reliable experimental and computational database

# The Darmstadt Open Test Case

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GLR

Transonic Compressor TU DARMSTADT

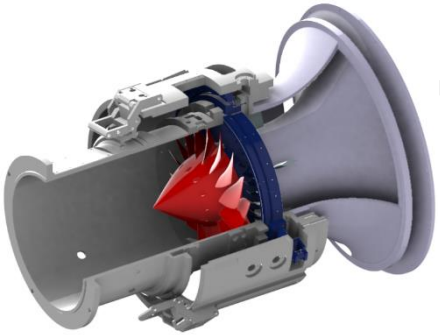
## TUDa-GLR-OpenStage

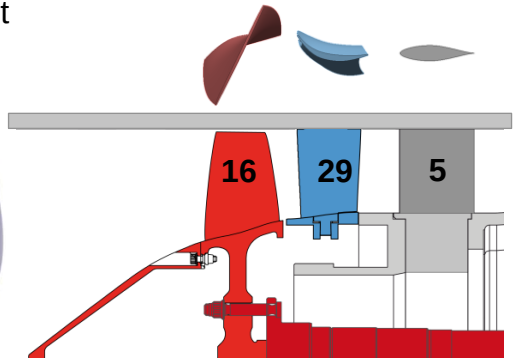
**Transonic compressor stage geometry**

- TU Darmstadt *Rotor 1* with *StatorOPT, OGV, radial diffusor*
- Hub & shroud contour, running tip clearance

**Measurement data**, exemplary

- *Steady state*: inlet conditions and 0D, 1D & 2D exit traverses
- *Dynamic*: unsteady wall pressure at blade tip (steady state & transient operating conditions, e.g. stall inception), unsteady pressure probe at rotor exit





# Thank you

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GLR