EU Export Controls and IP Classification		
Technology Classification (Ref. Work Instructions 011-04226)	AL: N	ECCN: N
Classification of IP in Systems (Ref. Work Instructions 011-04284)	IP: S00	IP: R00

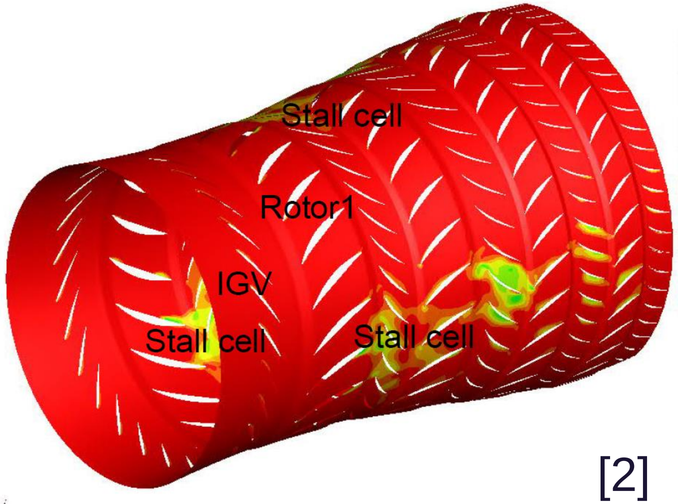
GPPS CFD Workshop TUDa test case

Giuseppe Bruni

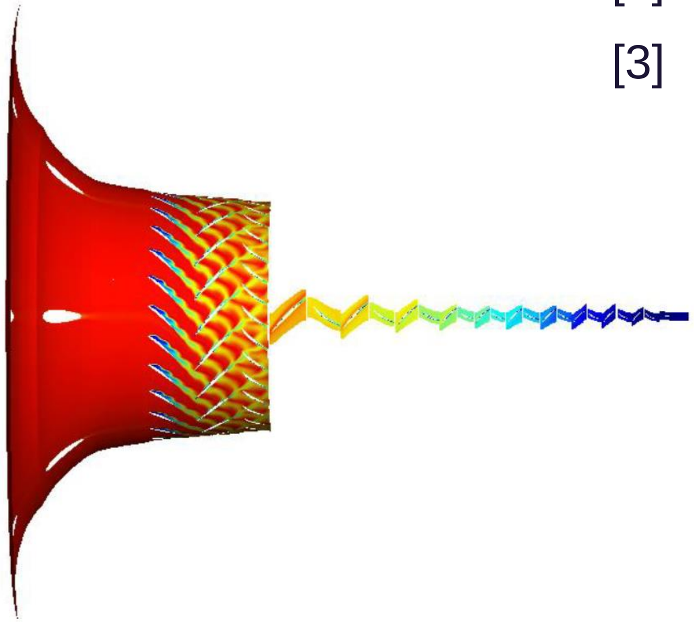
TUDa test case
Introduction

- Results presented using GPU solver - **TurboStream** [1]:
  - Up to an order of magnitude faster than traditional CPU solvers
  - Allows large scale simulations to be used as part of the design process
    - Prediction of rotating stall and surge [2]
    - Forced response calculations for LEOs and NSVs [3]

  - Summary of the solver settings, further details can be found in [1]
    - Advection Scheme: JST
    - Linear system solver: Jacobi
    - Second order spatial discretisation
    - Standard Mixing-Plane implementation
    - Adaptive wall functions
    - Fully turbulent boundary layers
    - Ideal Gas properties
    - Turbulence model: *SAnoft2-Helicity model*
      - Helicity correction for improved near stall predictions [4]



[2]

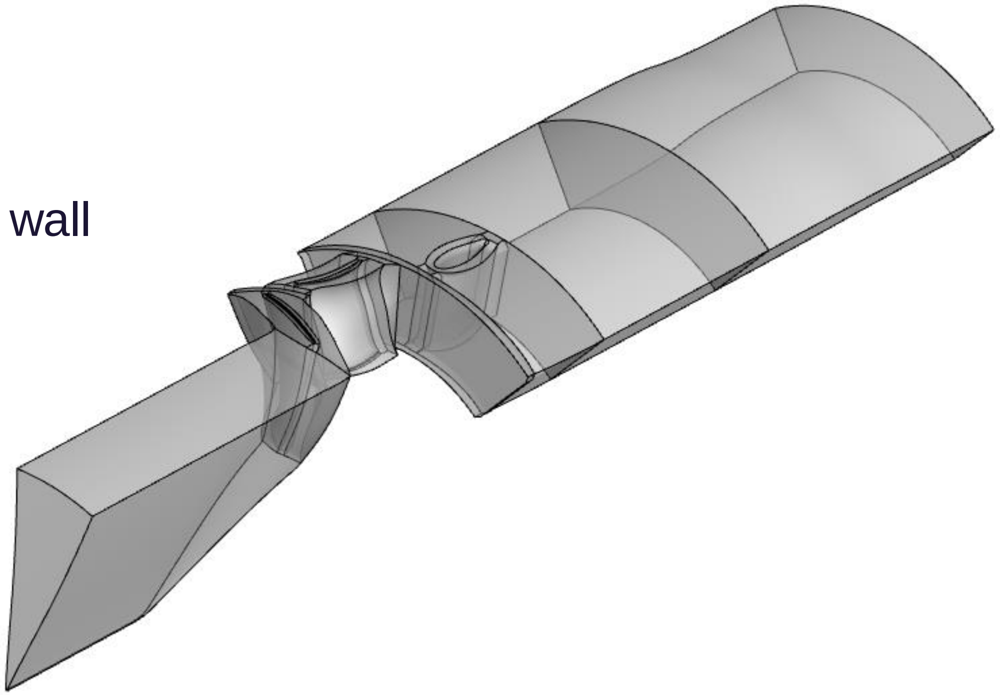


[3]

TUDa test case
CFD Setup

- Inlet boundary conditions:
  - Converted from *InletBC.input*
- Outlet boundary conditions :
  - Nozzle with atmospheric back pressure, PR controlled by increasing nozzle contraction ratio
    - Aids convergence when the slope of the characteristic approaches zero

- Geometry based on TUDa specs:
  - Single passage model
  - Inviscid wall in inlet duct up to spinner, spinner set to rotating wall
  - Location of mixing planes based on measurement planes
  - Stator geometries based on CAD: Real fillet geometry used
  - No geometrical simplifications compared to standard grids

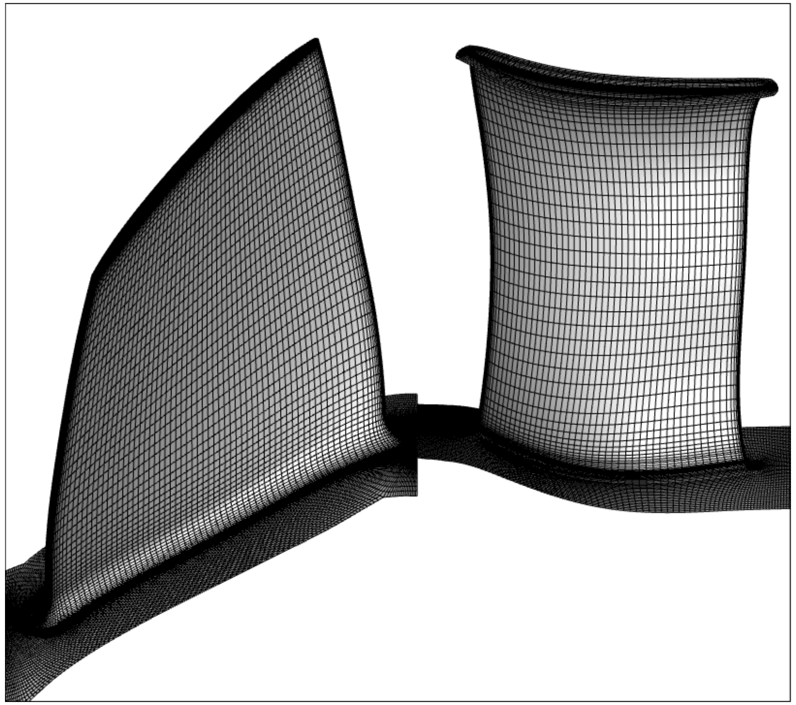


- Convergence criteria:
  - Solver ran for 50k timesteps for each OP
  - CPU time with 4 GPUs and 50k timesteps: ~20 min

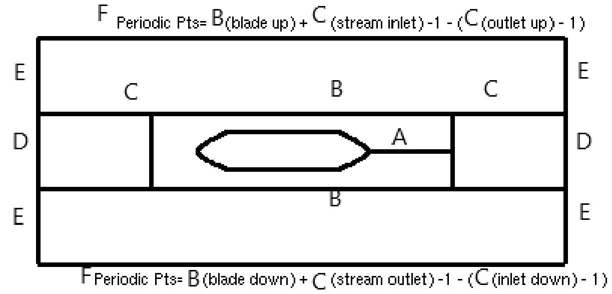
TUDa test case
Mesh

- Resulting mesh is an example of what can be used for **practical applications** to multi-stage industrial axial compressors

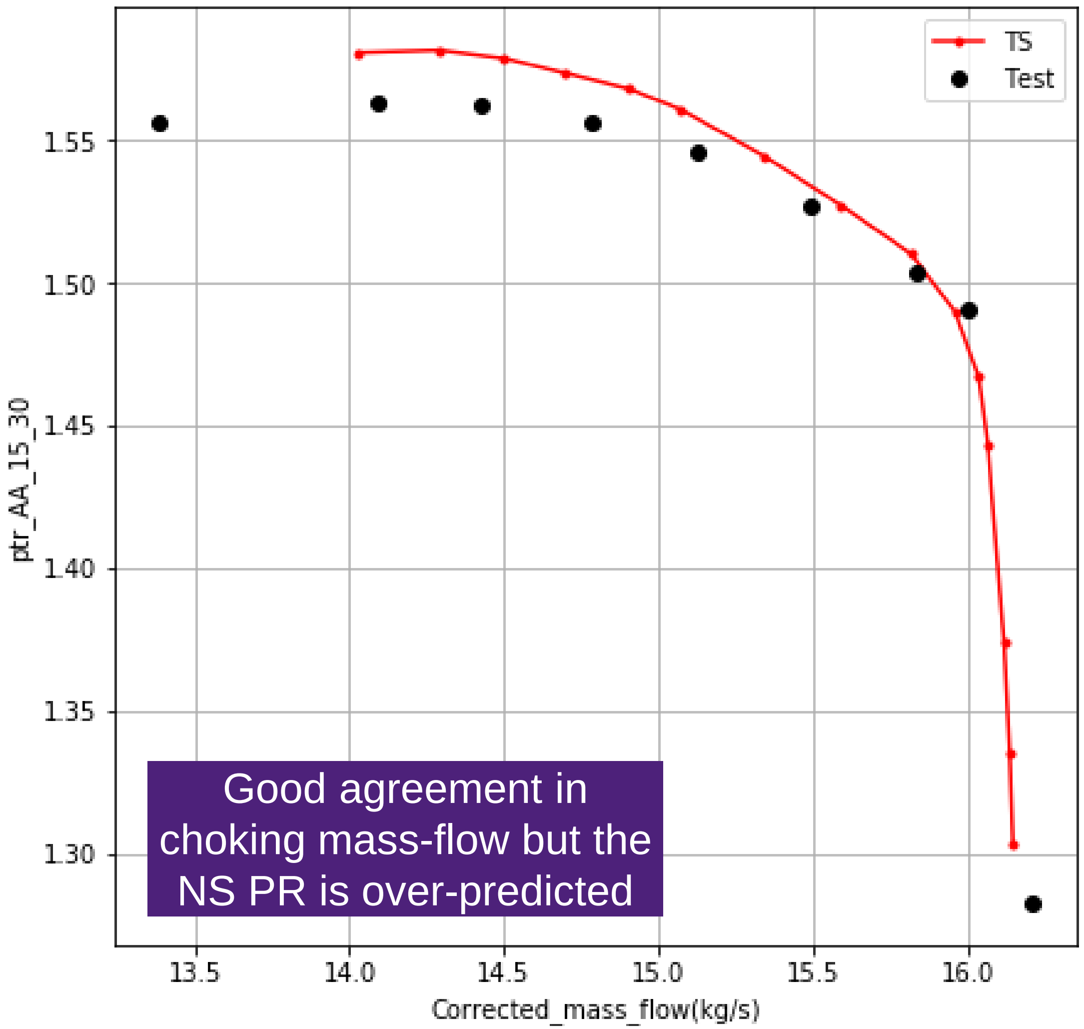
- Numeca Autogrid5 mesh
  - Structured mesh: HOH topology
  - ~2.7 million nodes overall
    - Rotor 1.28M, Stator 0.78M, OGV 0.66M
  - Average y^+ of the first layer grid:
    - ~1 blade surface
    - >30 end-walls
- Fillets meshed with butterfly topology, 17 points
- 13 rotor tip gap points

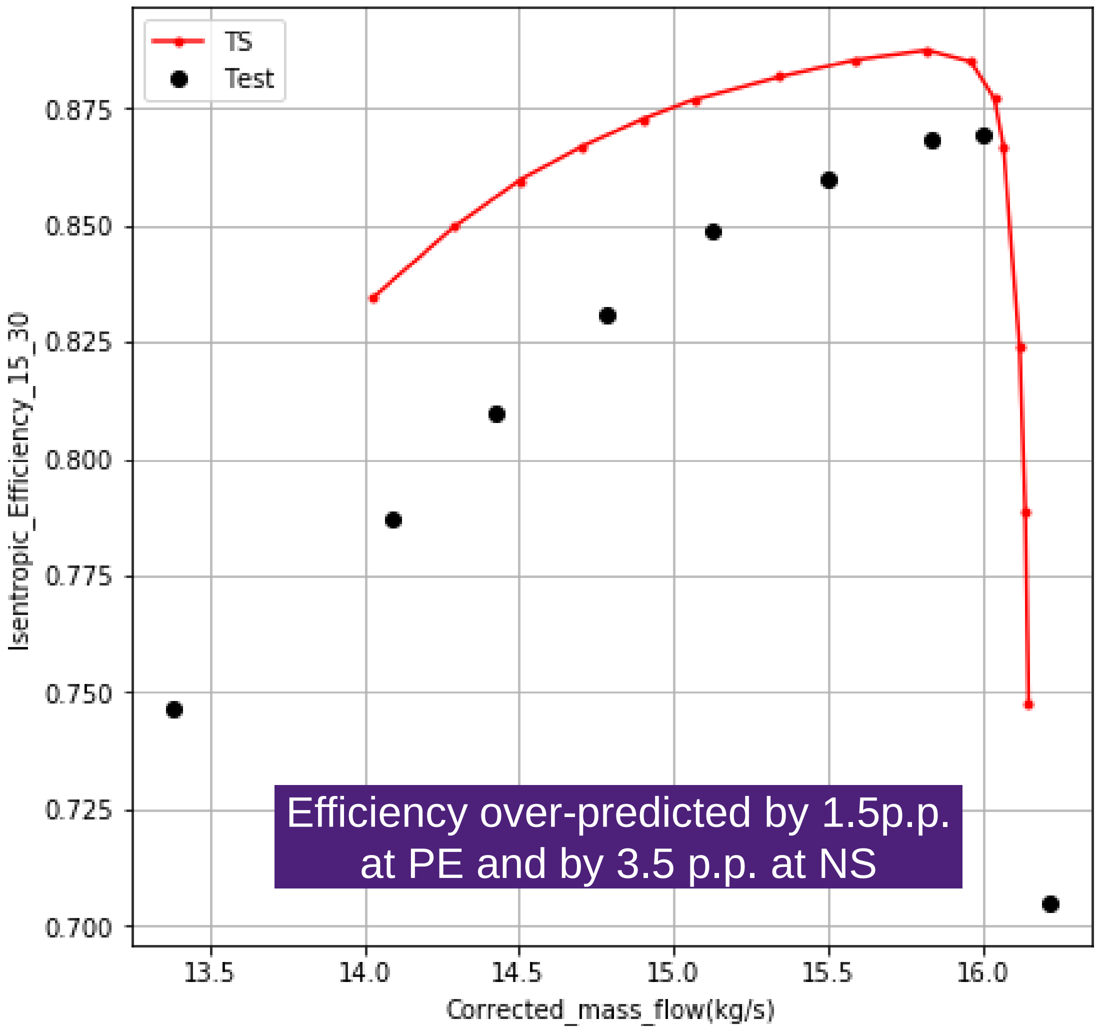


	Flow Paths	Cell width		% mid-flow cells	B2B Mesh						Points in clearance O-mesh	Exp. Ratio	y
		Hub	Shroud		A	B	C	D	E	F			
Rotor	73	5.0E-05	5.0E-05	50	28	81	21	13	21	81	13	1.2	1.6E-06
Stator	73	5.0E-05	5.0E-05	50	28	61	17	17	21	93	13	1.2	1.6E-06
OGV	61	5.0E-05	5.0E-05	50	17	53	17	9	21	93	13	1.2	5.0E-05



TUDa test case
Overall Performance





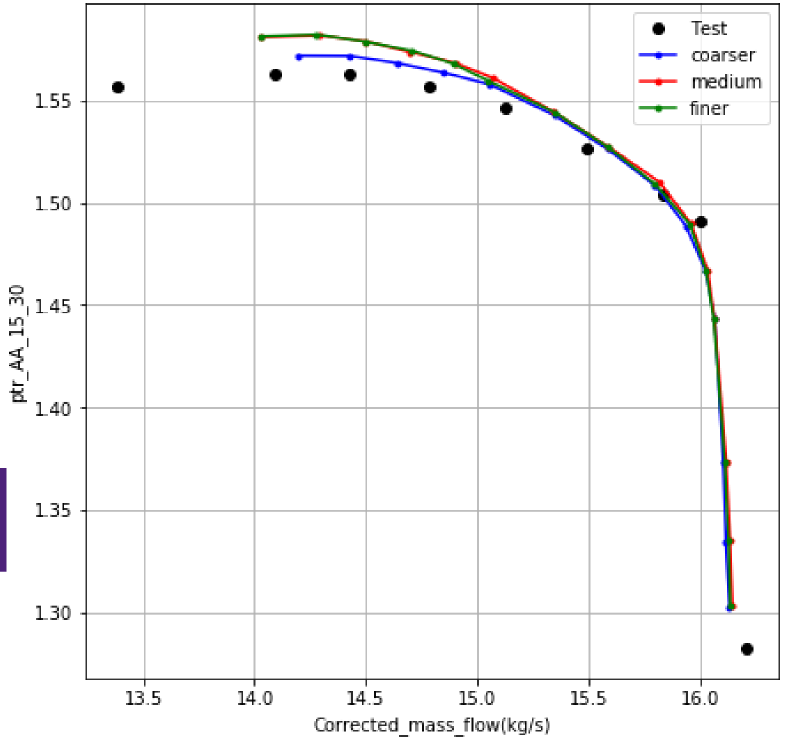
TUDa test case
Mesh Independence

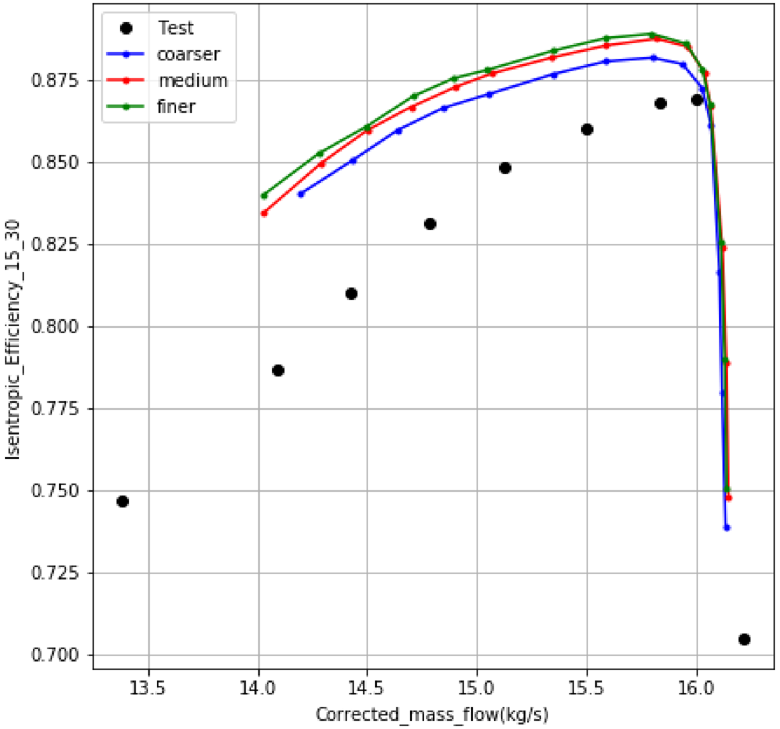
- Results shown are a summary of a wider mesh independence study considering the effect of:
  - HOH mesh resolution
  - O-grid points [17 to 33] and expansion ratio [1.2 to 1.4]
  - Spanwise mesh resolution [61 to 85 points]
  - Tip gap mesh resolution [5 to 17 points]

Guidelines updated based on the trade-off between agreement with test data and computational cost

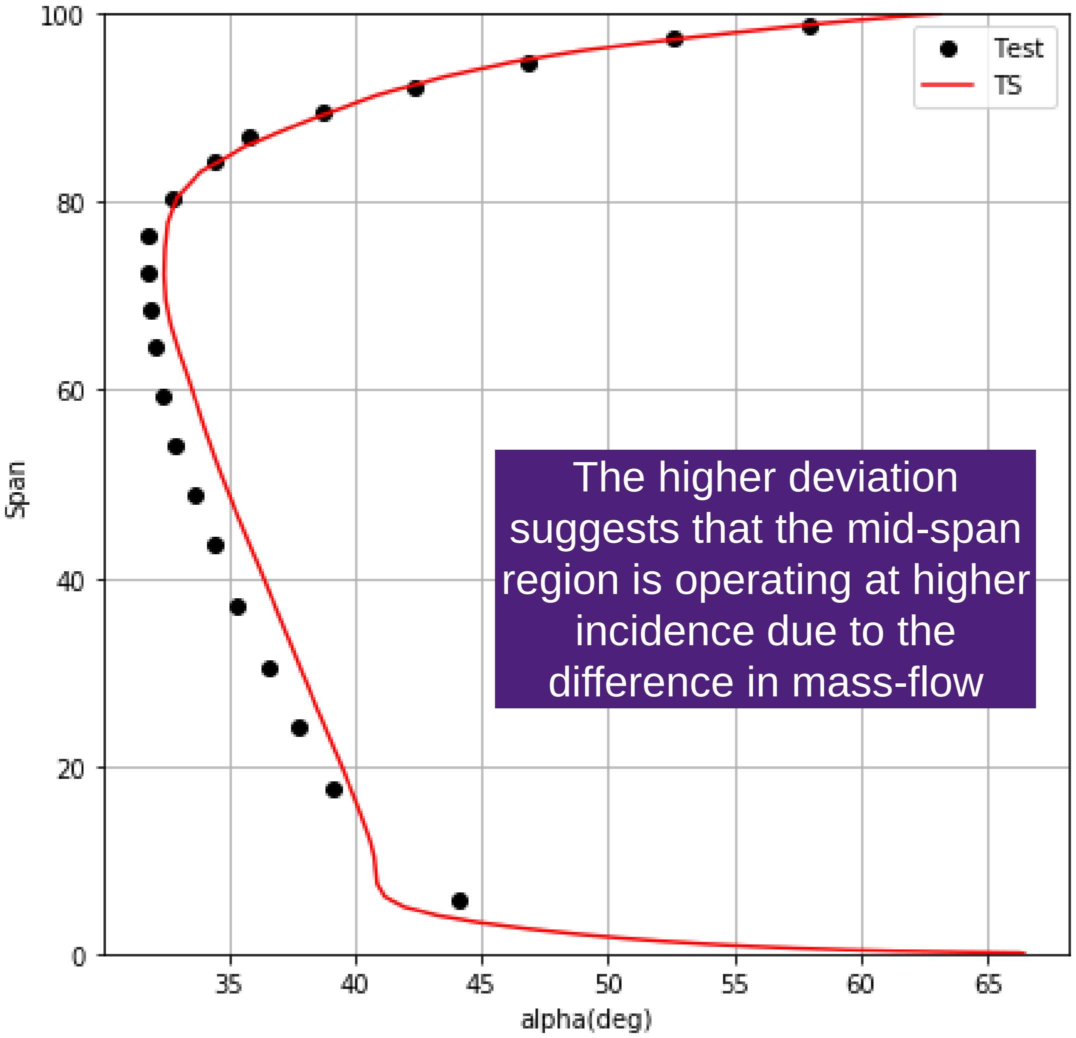
Number of Grid Points (M)			
Mesh	**Rotor**	**Stator**	**OGV**
coarser	0.564	0.395	0.66
medium	1.283	0.782	0.66
finer	1.920	1.146	0.66

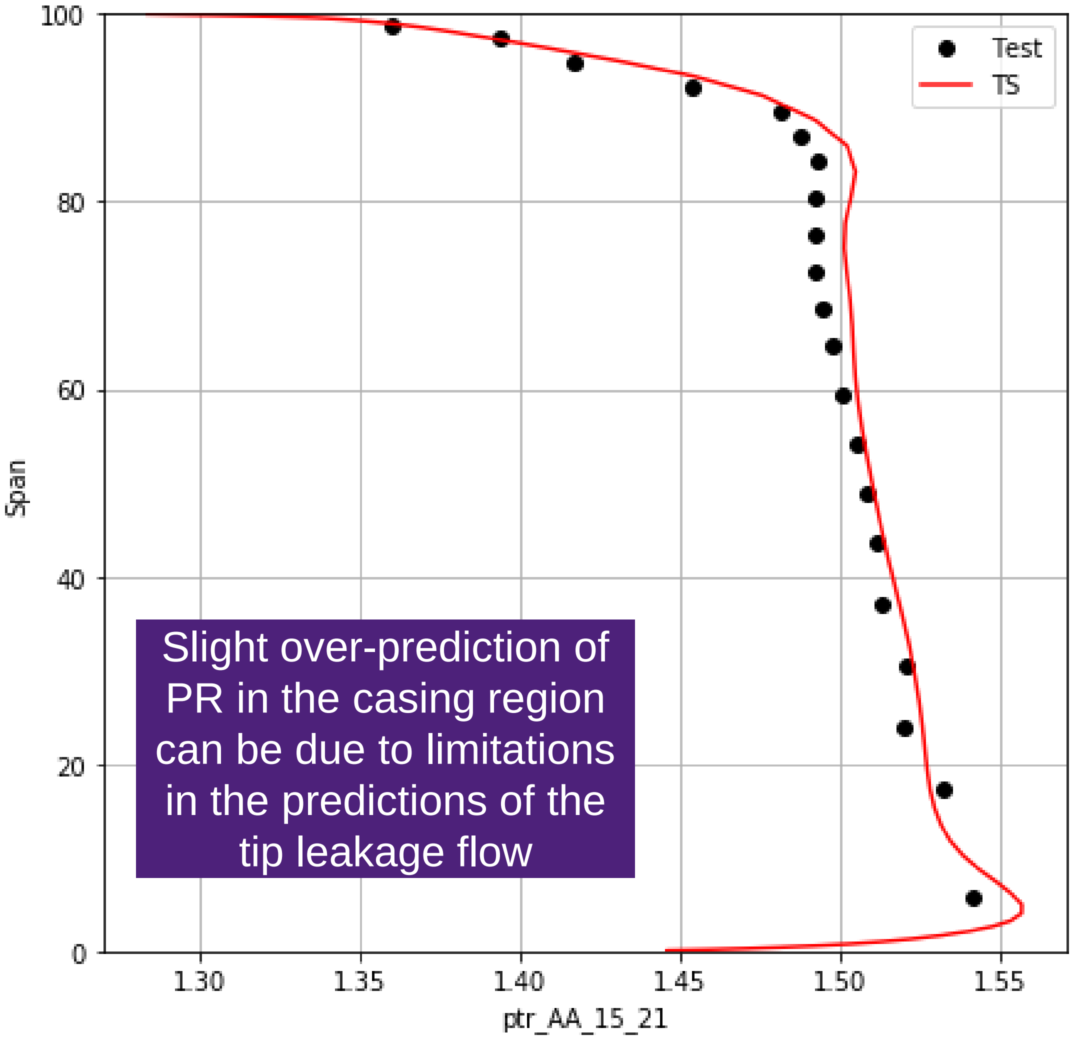
Medium mesh acceptable compromise between accuracy and computational cost





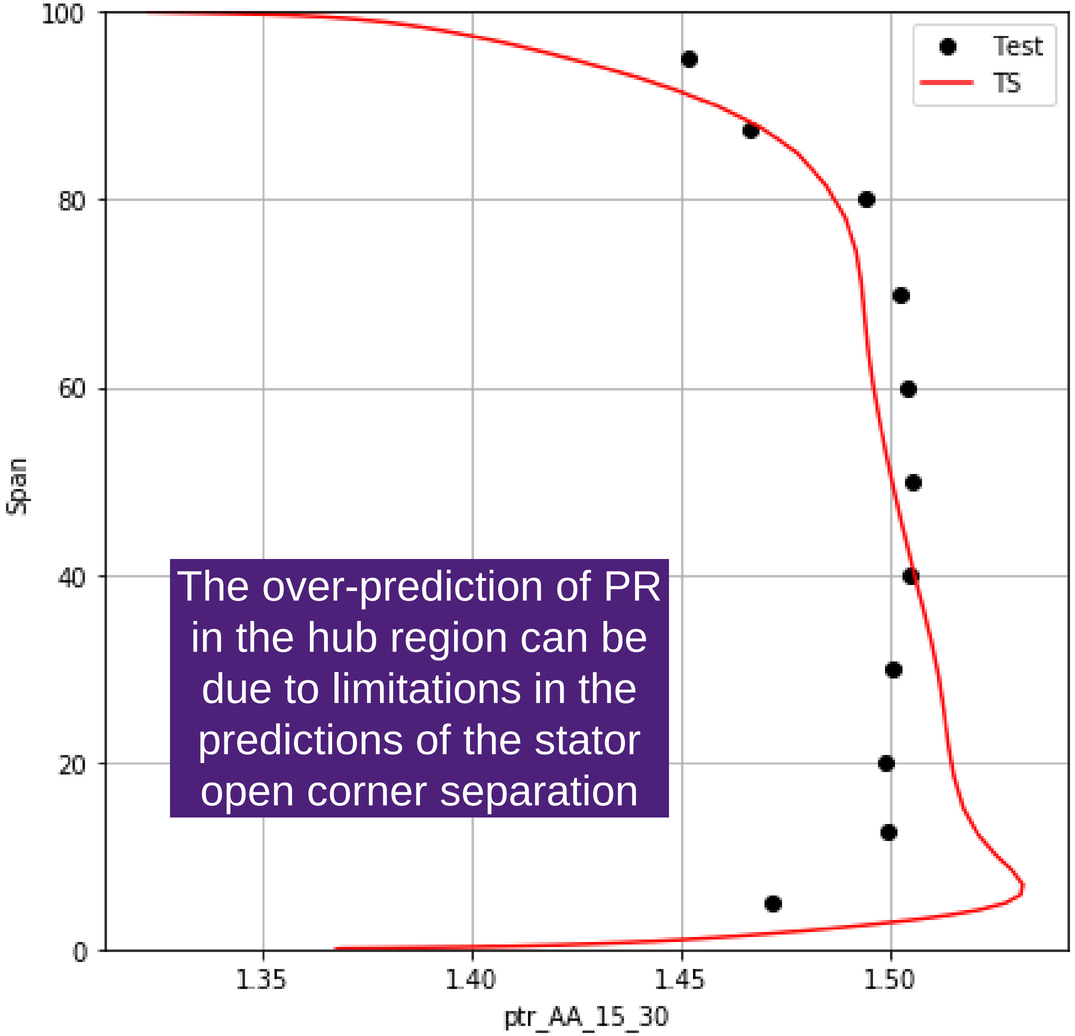
Design Point
ME21 Rotor Outlet



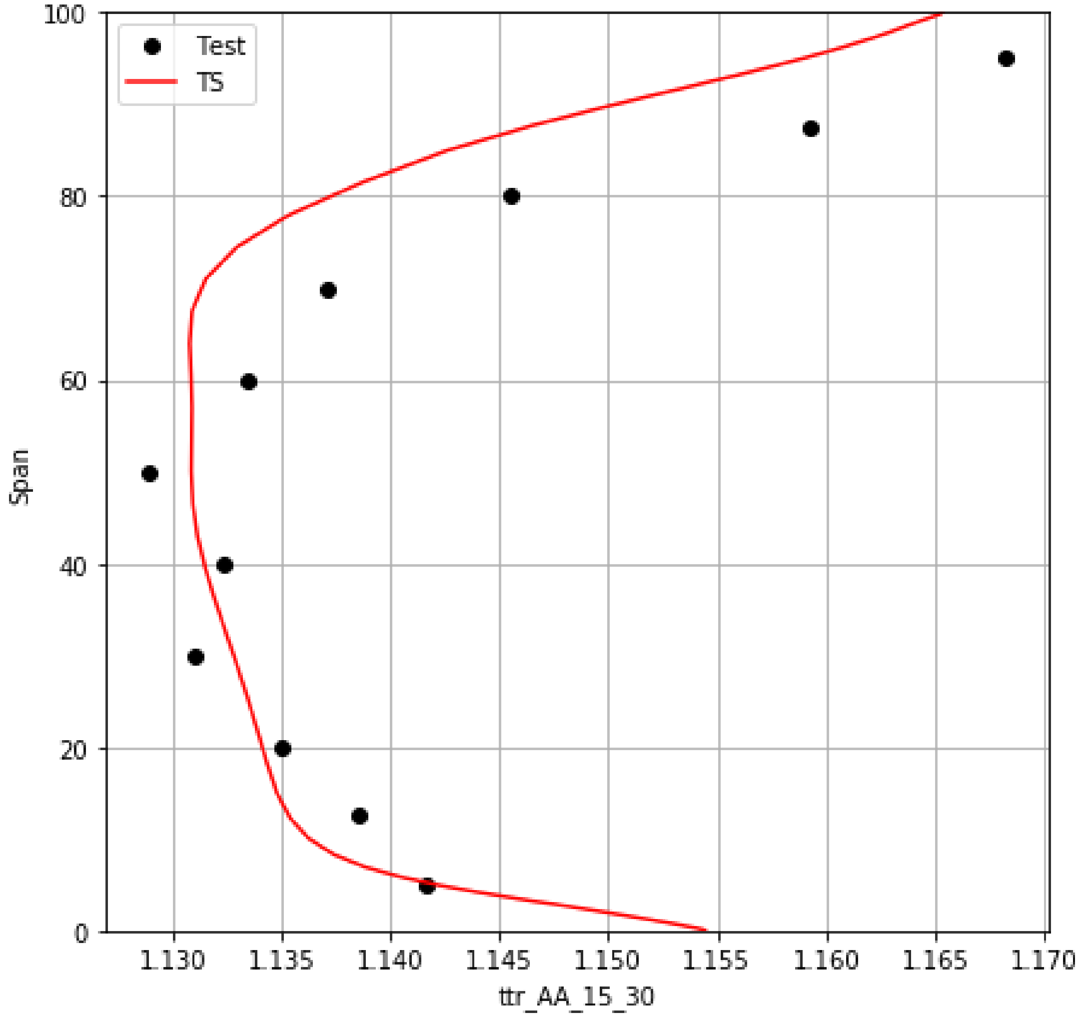


Design Point
ME30 Stator Outlet

SIEMENS energy

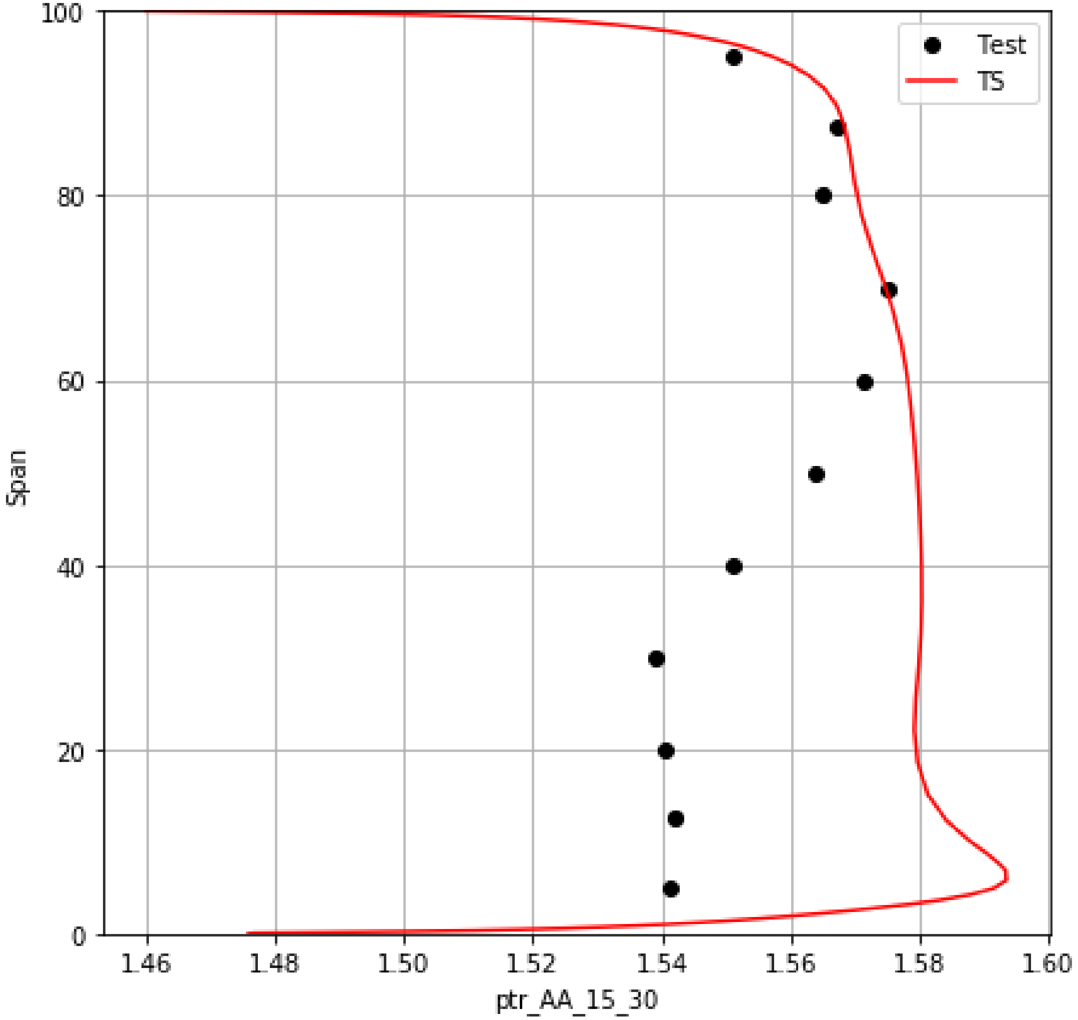


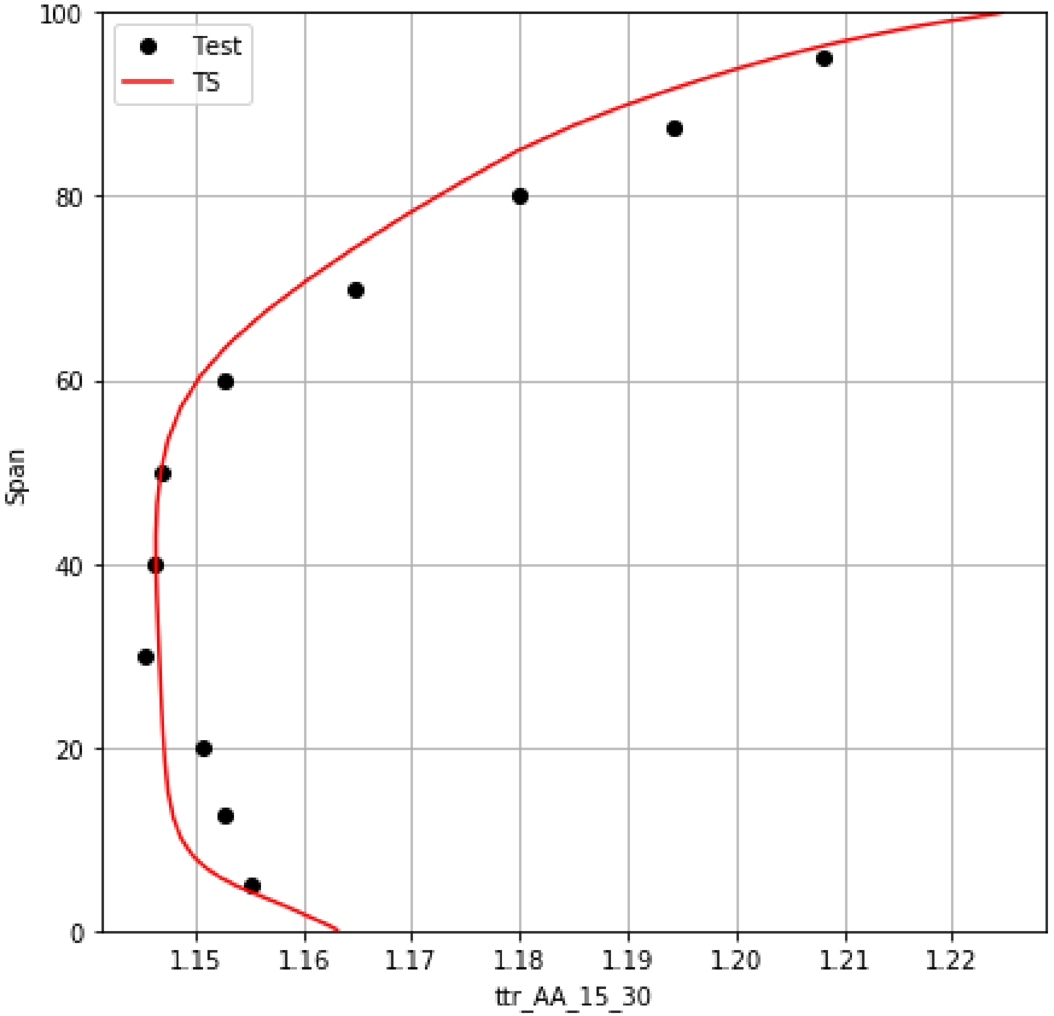
The over-prediction of PR in the hub region can be due to limitations in the predictions of the stator open corner separation



Near Stall Point
ME30 Stator Outlet

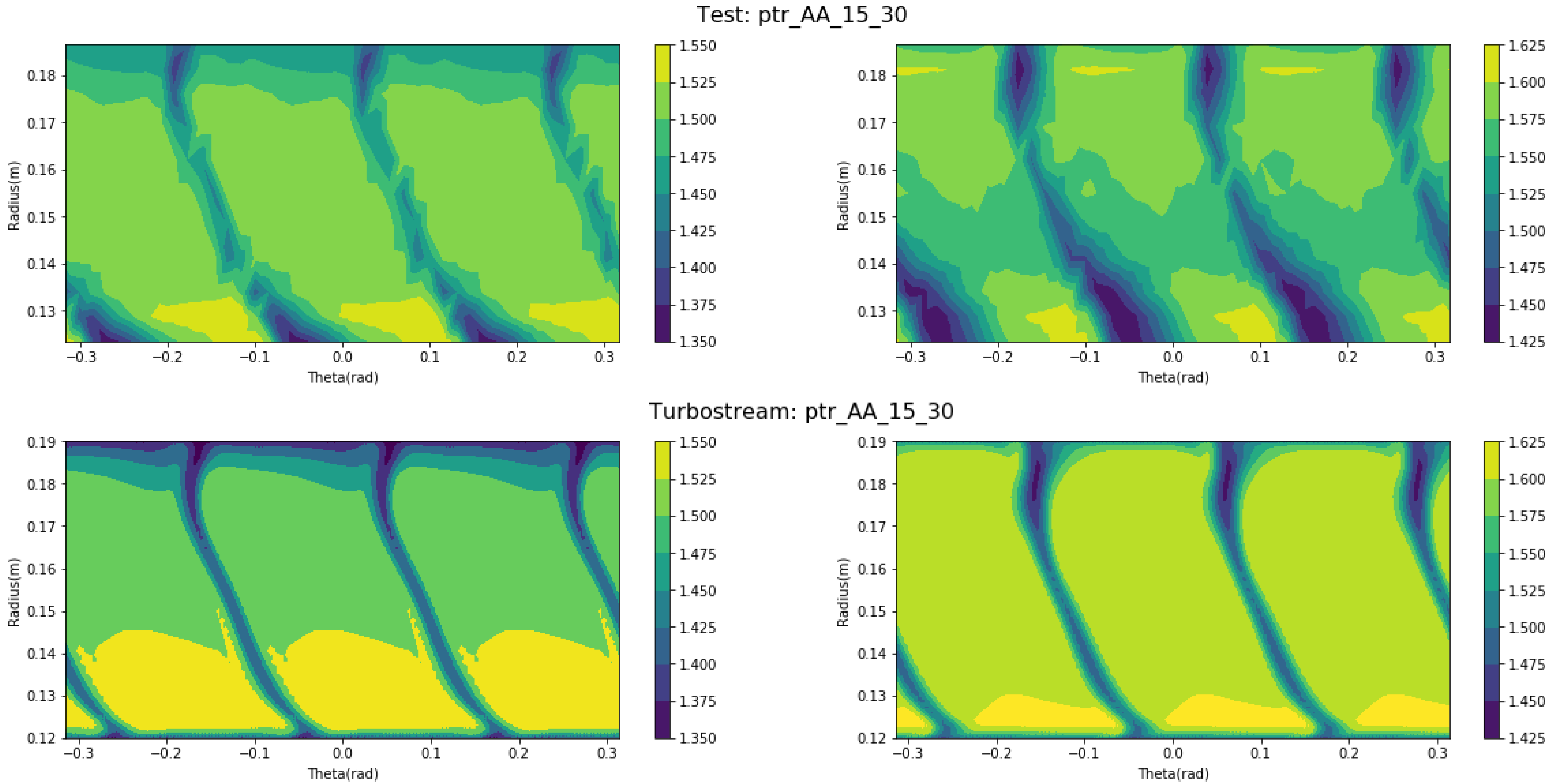
- The under-prediction of the stator open corner separation becomes more apparent approaching stall
- This is potentially due to a stator hub leakage flow which is not modelled





Pressure Ratio Contours ME30 Stator Outlet

- The under-prediction of the stator open corner separation becomes more apparent approaching stall
- This is potentially due to a stator hub leakage flow which is not modelled



TUDa test case
Conclusions

- The overall performance can reasonably be captured with the CFD setup presented

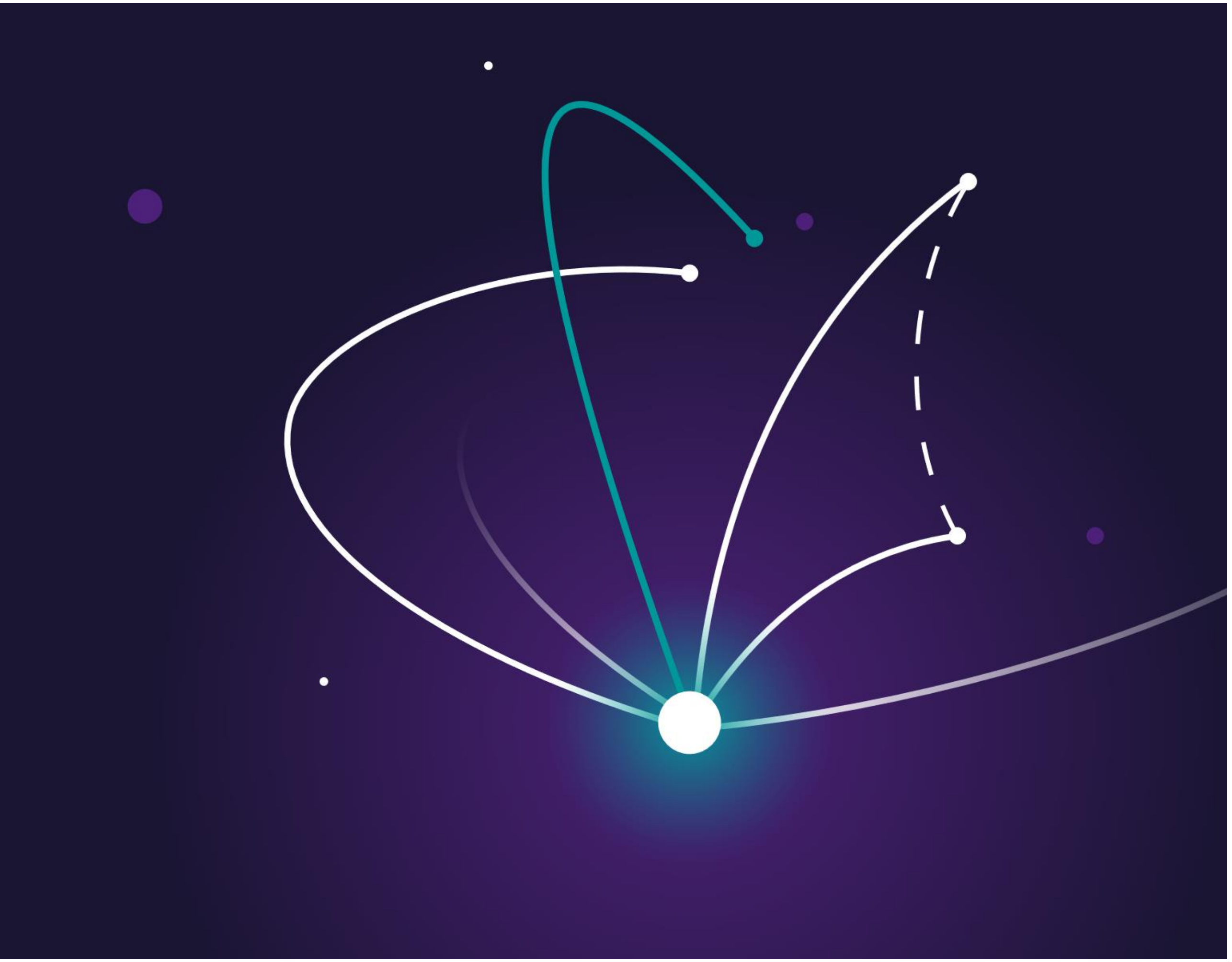
- The discrepancies with the test data can be attributed to:
  - Limitations of the turbulence models
  - Trade-off between computational cost and mesh resolution
  - Real-geometry effects not being modelled

- Future work to improve the CFD setup can include:
  - Consider different turbulence models
    - SST or more sophisticated if required
  - Increase the mesh resolution to address specific discrepancies
    - Tip leakage flow and stator open corner separation
  - Include a realistic amount of stator hub leakage flow to replicate the test configuration
  - The resulting guidelines can then be translated back for the relevant application

References

1. Brandvik, T., and Pullan, G. (October 27, 2010). "An Accelerated 3D Navier–Stokes Solver for Flows in Turbomachines." ASME. *J. Turbomach*. April 2011; 133(2): 021025. https://doi.org/10.1115/1.4001192
2. Krishnababu, SK. "On the Prediction of Rotating Stall in an Industrial Gas Turbine Compressor." *Proceedings of the ASME Turbo Expo 2020*. Virtual, Online. September 21–25, 2020. V02ET41A027. ASME. https://doi.org/10.1115/GT2020-15330
3. Krishnababu, S, Bruni, G, & Frach, A. "On the Forced Response Predictions and Life Improvements of an Industrial Axial Compressor Rotor Blade." *Proceedings of the ASME Turbo Expo 2021*. Virtual, Online. June 7–11, 2021. V09AT23A007. ASME. https://doi.org/10.1115/GT2021-58923
4. Kim, S., Pullan, G., Hall, C. A., Grewe, R. P., Wilson, M. J., and Gunn, E. (February 22, 2019). "Stall Inception in Low-Pressure Ratio Fans." ASME. *J. Turbomach*. July 2019; 141(7): 071005. https://doi.org/10.1115/1.4042731

Contact



Giuseppe Bruni

Senior Aerodynamicist

Compressor Engineering Department
Siemens Industrial Turbomachinery Ltd.

1 Waterside South
Lincoln LN5 7FD, United Kingdom

Phone: +44 1522 583191
giuseppe.bruni@siemens-energy.com

siemens-energy.com