Validation and Verification of a RNAS Solver with the Space-Time Gradient Method for the TUDa-GLR-Open Stage Transonic Axial Compressor

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GPPS CFD Workshop, Xi'an, Shaanxi

15th December, 2021

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CONTENT

1. Solver introduction

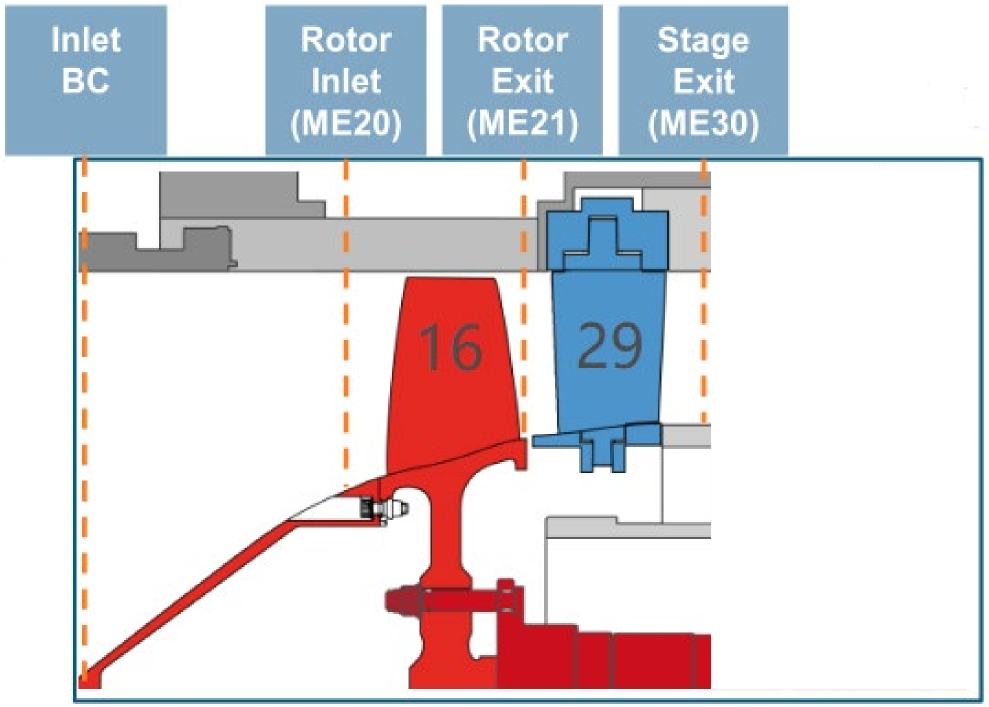
TurboXD[1-4] — an inhouse RANS solver

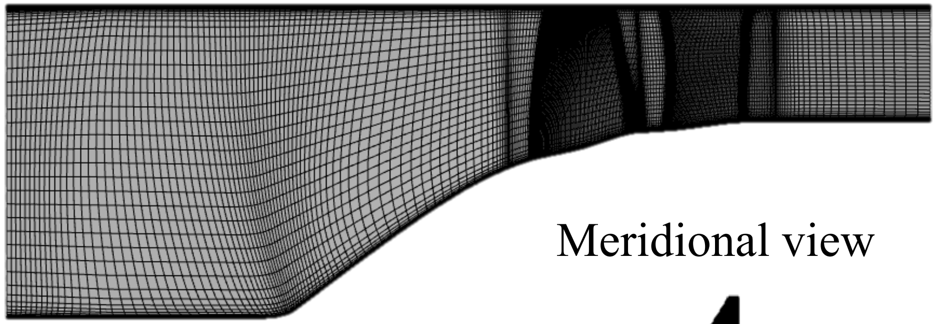
Method/model	Note
Finite volume approach	Cell centre
Turbulence model	Spalart-Allmaras
Spatial discretization	JST scheme with scaled numerical dissipation
Time integration in pseudo time	Hybrid five-stage Runge-Kutta method / Local time stepping
Residual smoother	LU-SGS method
Multigrid method	V type multi-grid method
Multi-row analysis	Steady: Mixing-plane approach Unsteady: (1)Space-time gradient method[4]/sliding plane method (the ninth order difference scheme is used for time discretization) (2)Time domain harmonic balance method/time and space mode decomposition and match method[3]

1. Wang D X, Huang X. Solution stabilization and convergence acceleration for the harmonic balance equation system. *Journal of Engineering for Gas Turbines and Power* 2017, 139(9).
2. Huang X, Wu H, Wang D. Implicit solution of harmonic balance equation system using the LU-SGS method and one-step Jacobi/Gauss-Seidel iteration. *International Journal of Computational Fluid Dynamics* 2018;32(4-5):218–32.
3. Wang D, Huang X. A complete rotor–stator coupling method for frequency domain analysis of turbomachinery unsteady flow. Aerospace Science and Technology, 2017;70:367-77.
4. Wang B, Wang D, Mohammad R and Huang X. Revisiting the Space-Time Gradient Method: A Time-clocking Perspective, High Order Difference Time Discretization and Comparison with the Harmonic Balance Method. *Chinese Journal of Aeronautics* (accepted).

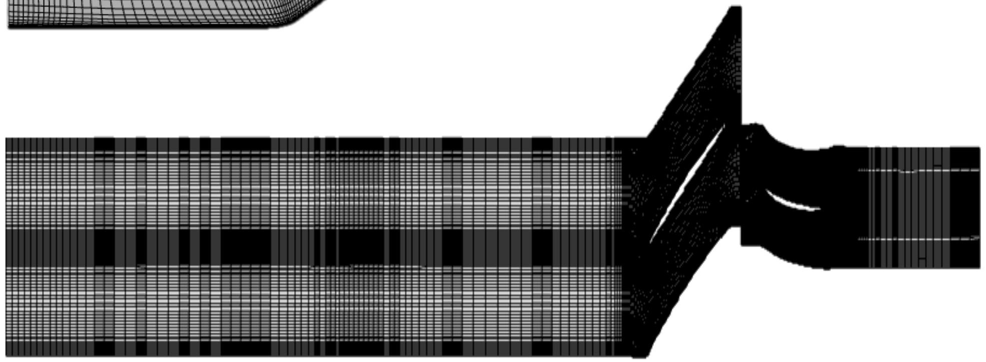
2.1 Mesh configuration

Row	Number of grid points (A*C*R = Total)
1	249*53*73 = 0.96 million
2	169*53*73 = 0.65 million





Meridional view

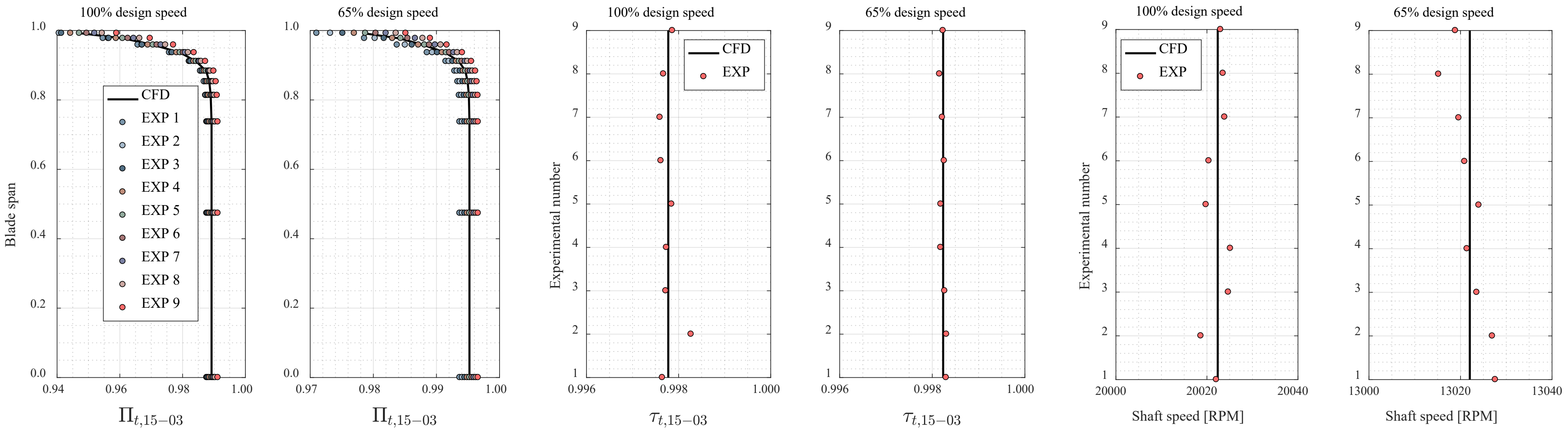


Blade to blade view (50% span)

2.2 Numerical settings

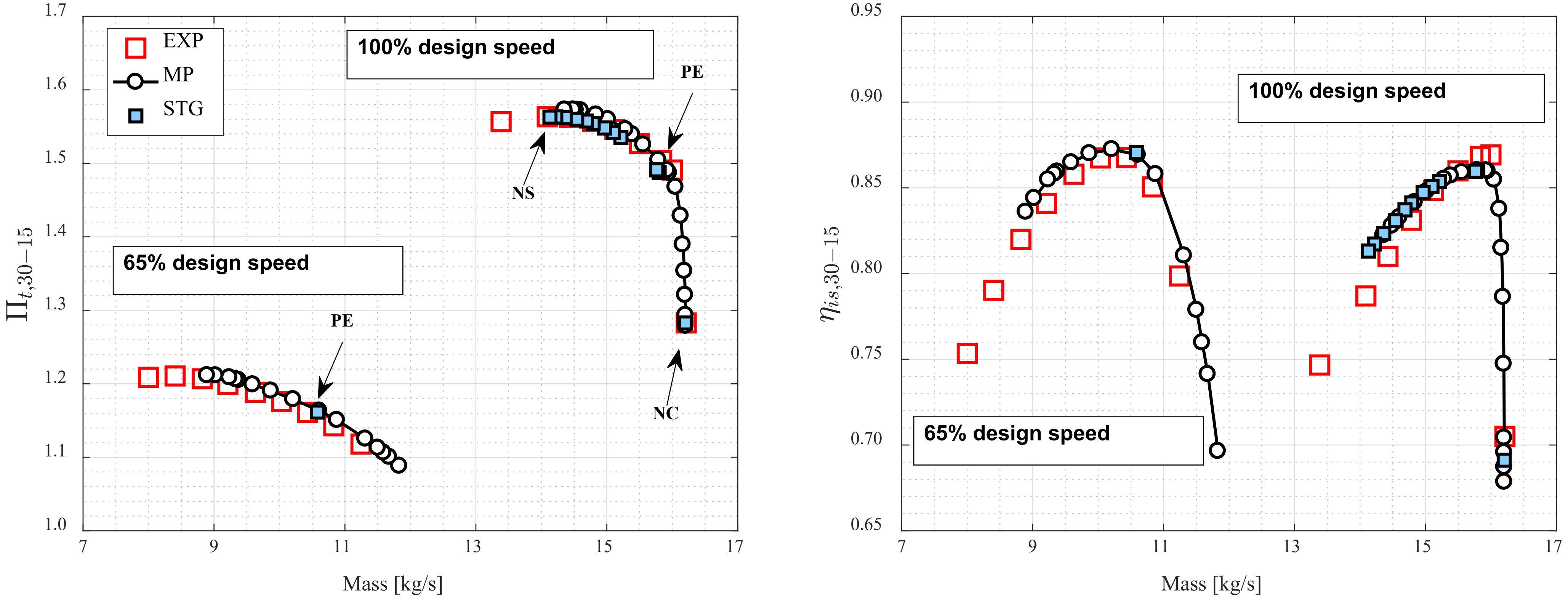
Inlet boundary (ME15) conditions: Pt, Tt, absolute flow angle, relative flow angle

Ideal gas model → Pt = 101325 Pa, Tt = 288.15 K ← Ambient parameters (ME03)



Performance map is obtained by increasing the back pressure

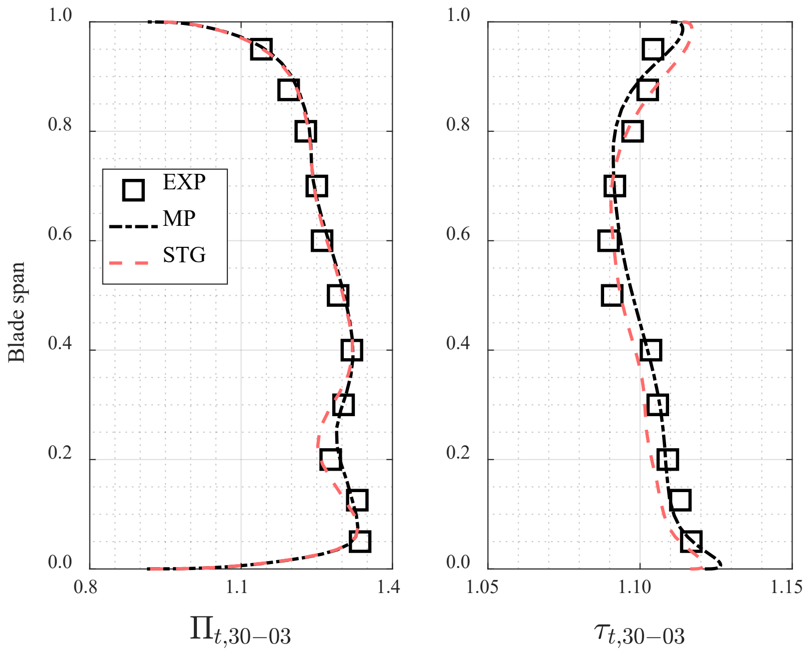
3.1 Performance maps



Improved pressure ratio and stall margin by the STG method

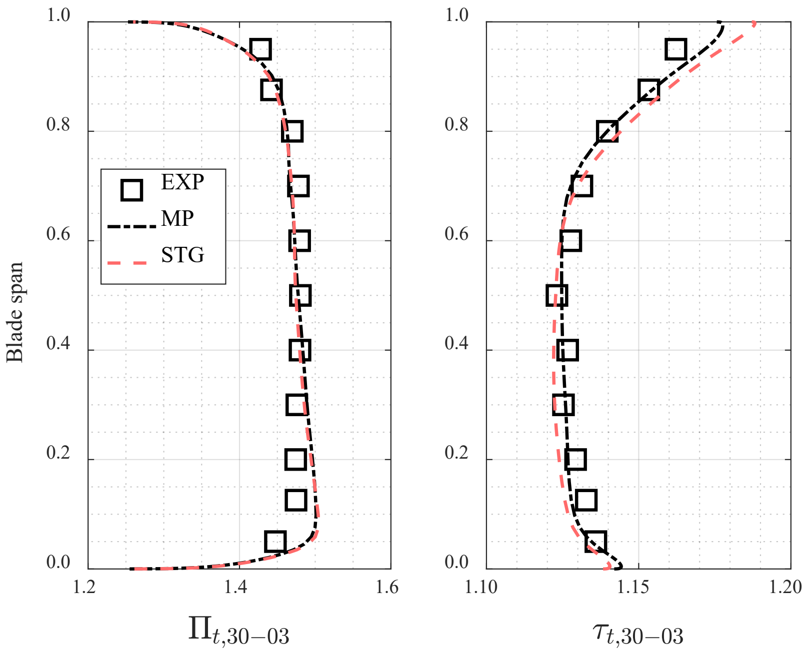
3.2 Radial profiles at stator exit (100% design speed)

Method	Mass	$\Pi_{t,30\text{-}15}$	$\eta_{is,30\text{-}15}$
EXP	16.2130	1.2828	0.7051
MP	16.2050	1.2836	0.6871
STG	16.2025	1.2828	0.6912



Near Choke

Method	Mass	$\Pi_{t,30\text{-}15}$	$\eta_{is,30\text{-}15}$
EXP	16.0000	1.4909	0.8692
MP	15.9255	1.4905	0.8601
STG	15.7630	1.4911	0.8597

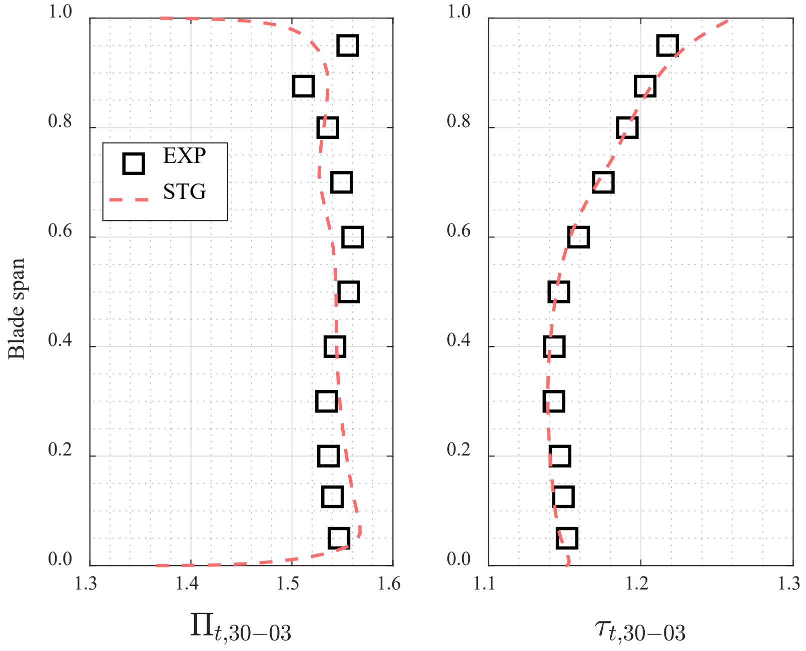


Peak Efficiency

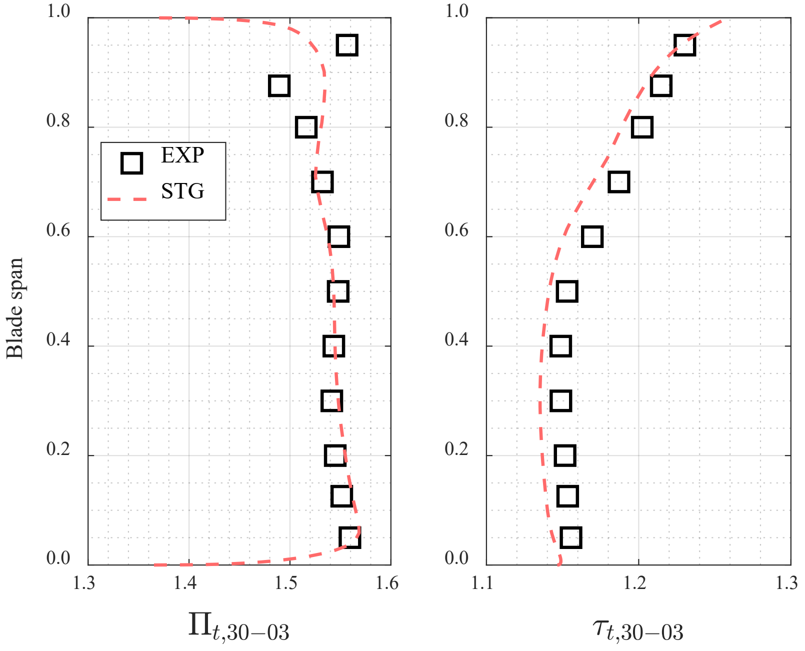
3.2 Radial profiles at stator exit (100% design speed)

Method	Mass	$\Pi_{t,30\text{-}15}$	$\eta_{is,30\text{-}15}$
EXP	14.09	1.5633	0.78693
STG	14.2205	1.5632	0.8172

Method	Mass	$\Pi_{t,30\text{-}15}$	$\eta_{is,30\text{-}15}$
EXP	13.385	1.5567	0.74667
STG	14.1315	1.5629	0.8131



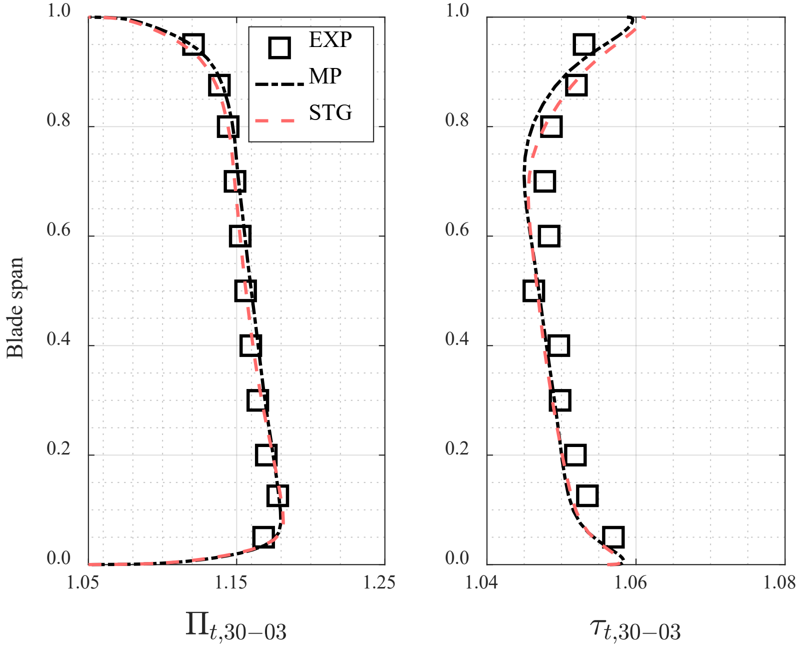
Experiment ID 8



Near Stall (Experiment ID 9)

3.2 Radial profiles at stator exit (65% design speed)

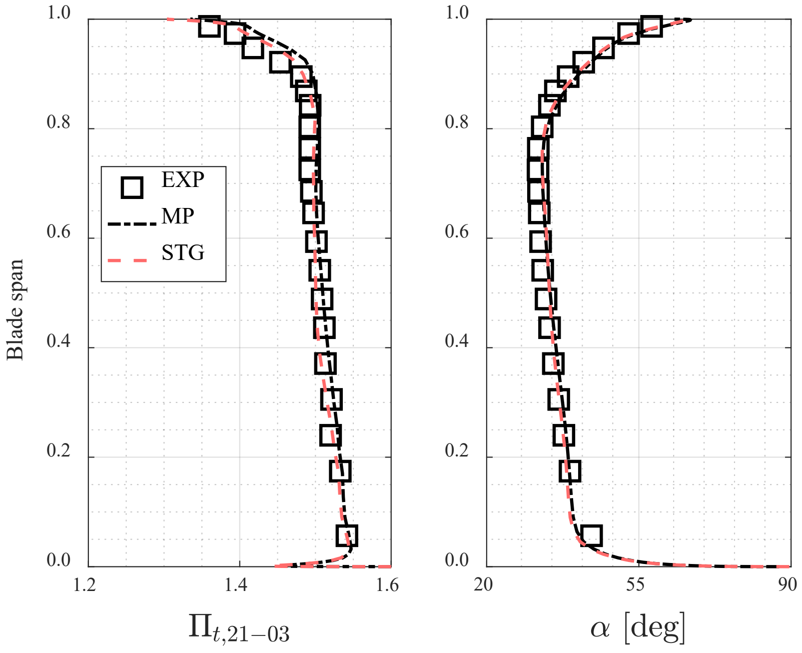
Method	Mass	$\Pi_{t,30\text{-}15}$	$\eta_{is,30\text{-}15}$
EXP	16.2130	1.2828	0.7051
MP	16.2050	1.2836	0.6871
STG	16.2025	1.2828	0.6912



Peak Efficiency

3.3 Radial profiles at rotor exit (100% design speed)

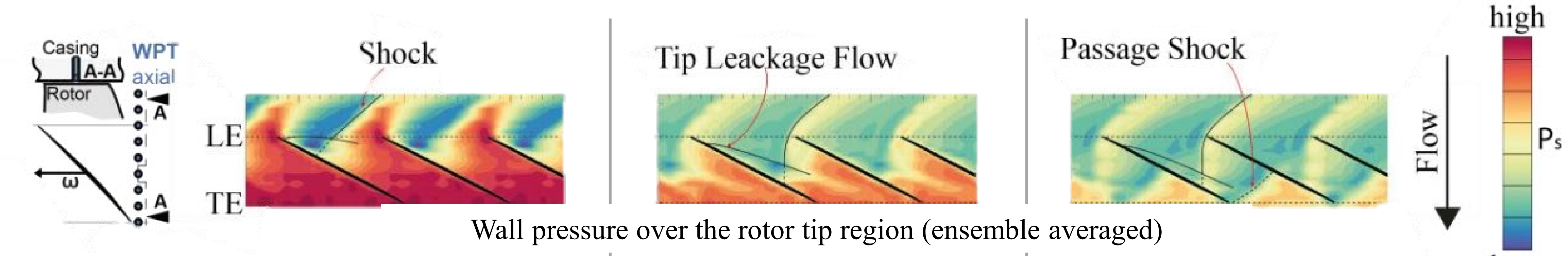
Method	Mass	$\Pi_{t,30\text{-}15}$	$\eta_{is,30\text{-}15}$
EXP	16.0000	1.4909	0.8692
MP	15.9255	1.4905	0.8601
STG	15.7630	1.4911	0.8597



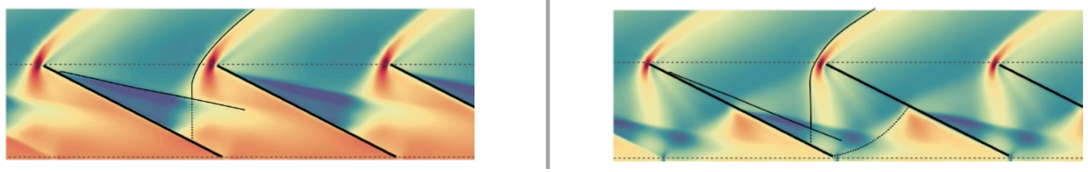
Peak Efficiency

3.4 Casing static pressure (100% design speed)

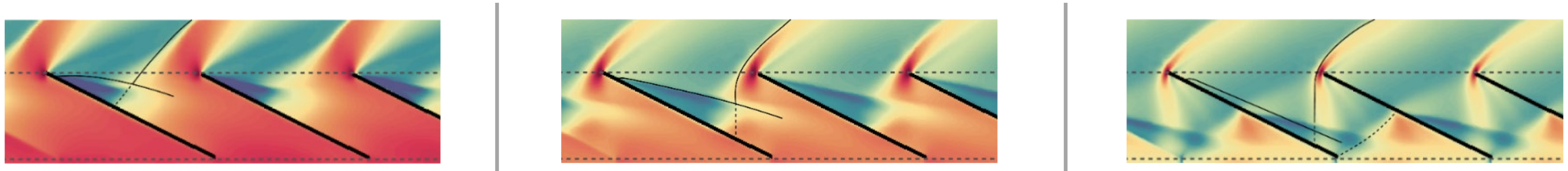
Near Stall | **Peak Efficiency** | **Near Choke**



Wall pressure over the rotor tip region (ensemble averaged)



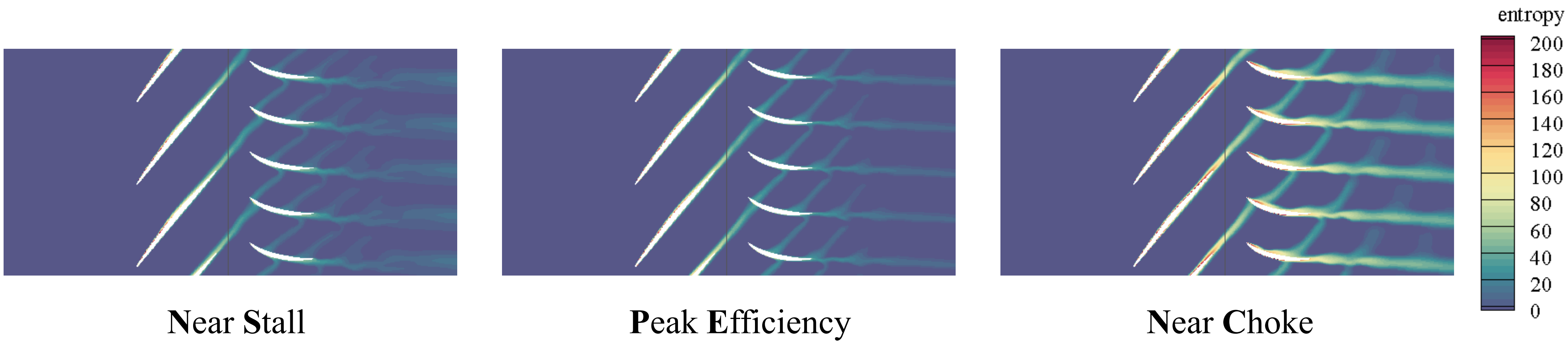
Pressure over the rotor tip region at 99.9% blade span (steady solution)



Pressure over the rotor tip region at 99.9% blade span (STG time averaged solution)

1. Fabian Klausmann et al. Transonic Compressor Darmstadt – Open Test Case GPPS-TC-2021-0029

3.5 Unsteady flows (100% design speed)



Entropy contours at 50% blade span

4 Conclusion

1 The results obtained by TurboXD has very good quantitative agreement with the experimental data

2 Compared with the steady analyses, the proposed STG method can obtain a larger stall margin and improve the solution accuracy

3 The STG method can predict blade row interaction unsteady flow field

Thanks for your attention