Analyses of Flow Field Within the TUDa Compressor

Boqian Wang, Dingxi Wang

School of Power and Energy, Northwestern Polytechnical University

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动力与能源学院
SCHOOL OF POWER AND ENERGY

西北工業大學
NORTHWESTERN POLYTECHNICAL UNIVERSITY

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- Computational domain and numerical settings
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Solver introduction

AeroX:

Multi-block structured mesh
Spalart-Allmaras turbulence model

Spatial discretization:
- Convective fluxes: JST scheme with the scaled numerical disspation
- Diffusive fluxes: evaluate the gradient of the velocity, temperature and turbulence quantity at cell centers using the Gauss's theorem, then use a central scheme to face values

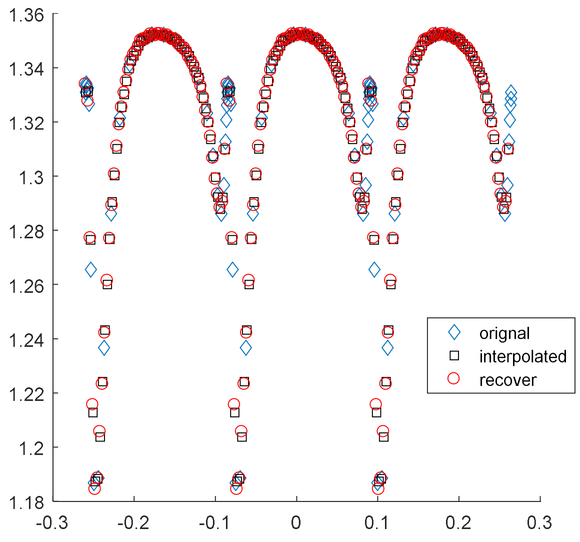
Time integration in pseudo time:
- Local time stepping
- Hybrid method combining an explicit five stage Runge-Kutta method and the implicit LU-SGS method

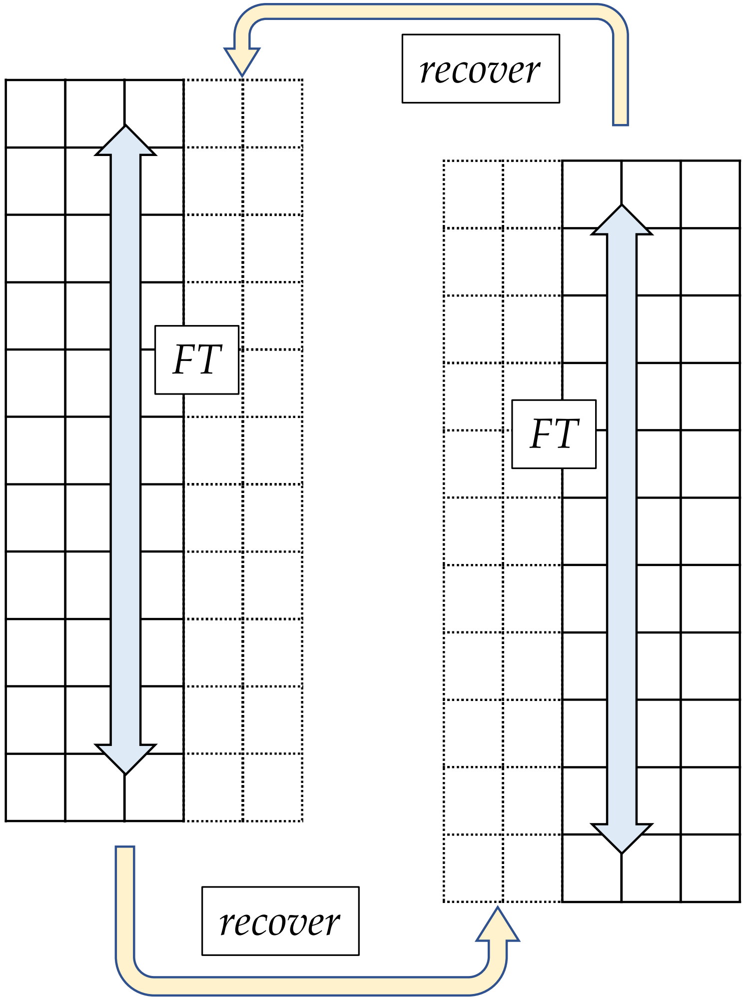
Row interface method
- Steady state: mixing plane method
- Unsteady state: Fourier transformation based method

Solver introduction

Fourier transformation based method (+DTS method)

1. Uniform resample to account for a non-uniform mesh along the circumferiential direction
2. Rotational Fourier transformation
3. Recover the distribution at ghost cells of the other side of an interface

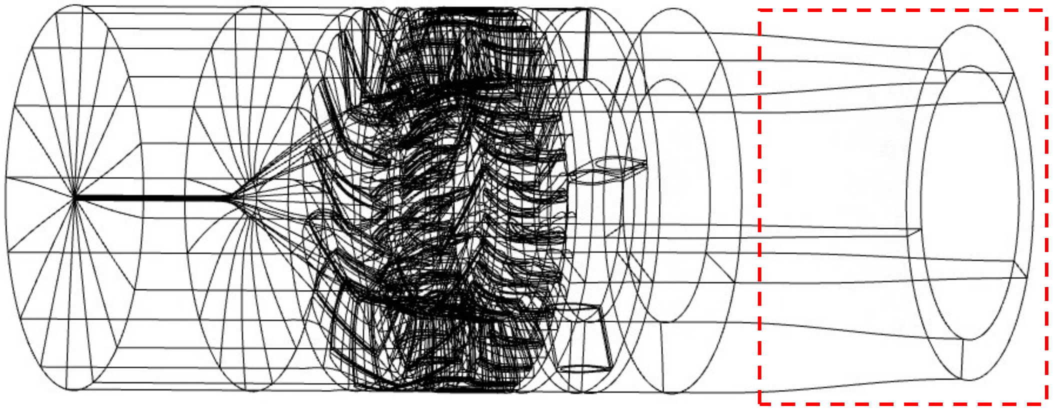




Computational domain and grid

The officical medium mesh with the rotor casing pinch is adopted

The computational domain is extended for analyzing rotating instability and rotating stall

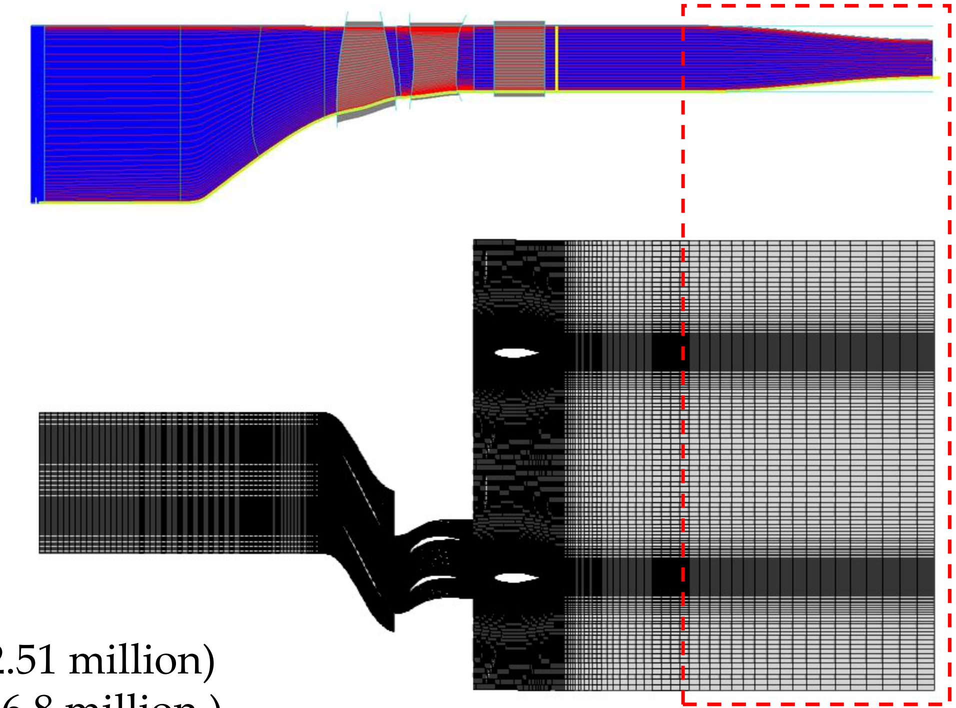


Computational domain of the official medium mesh

Extended computational domain

Single passage for steady analyses (number of the grid points: 2.51 million)

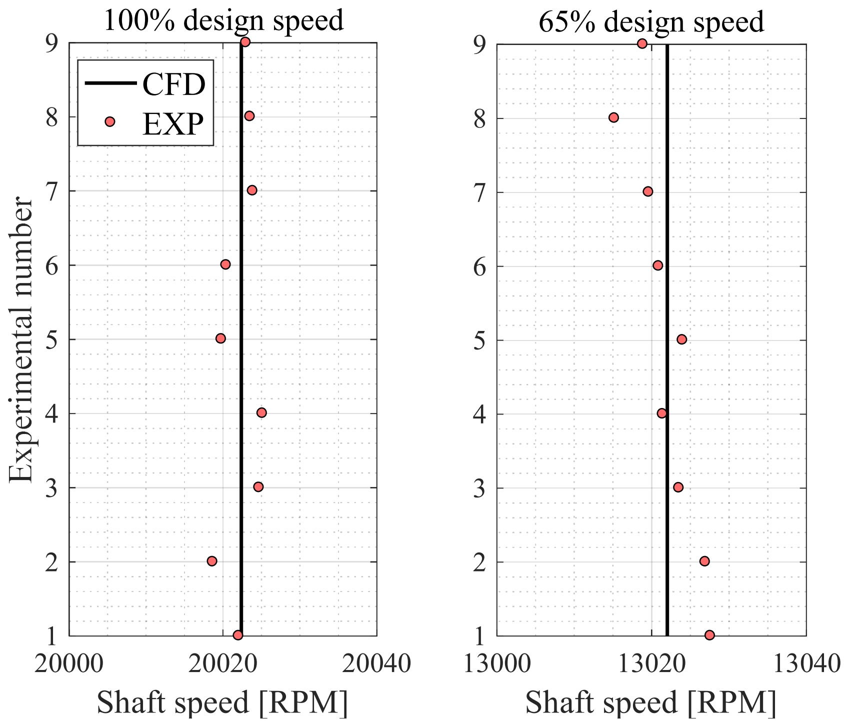
Full annulus for unsteady analyses (number of the grid points: 36.8 million)



Convergent nozzle

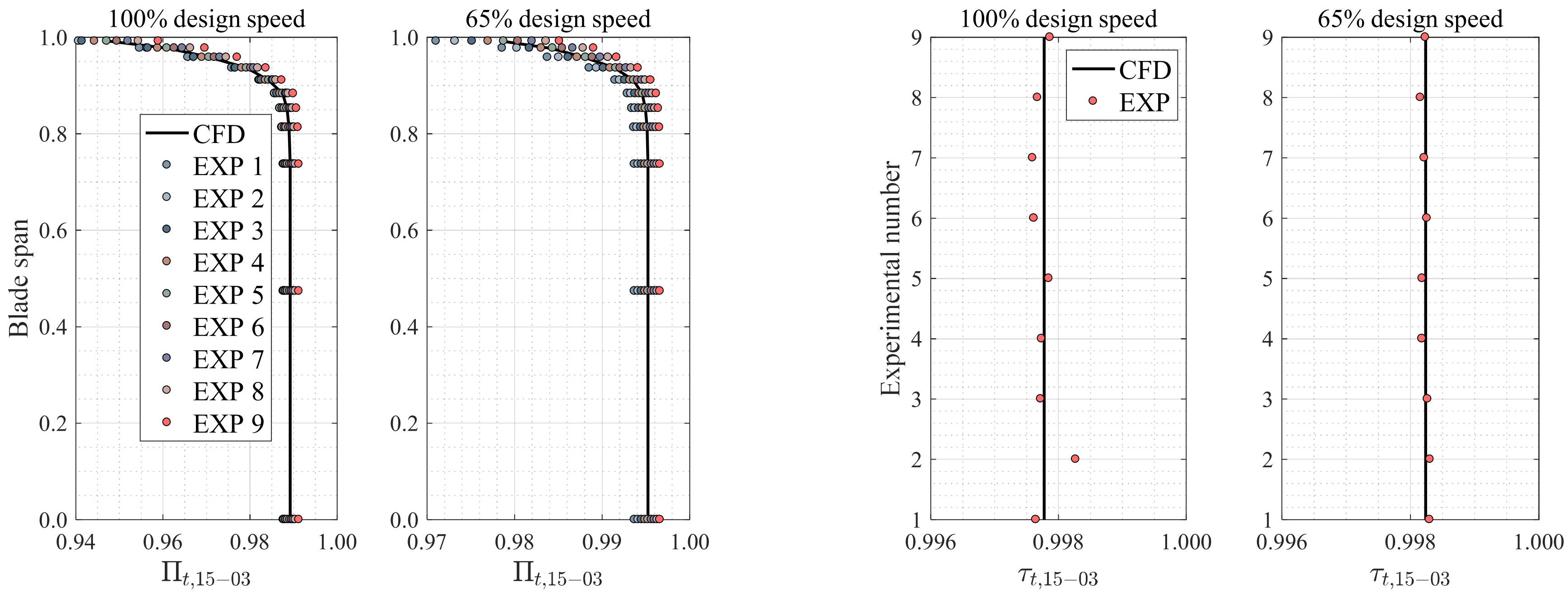
Numerical settings

Shaft speed:arithmetic average of measured data



Numerical settings

Inlet boundary (ME15) condition



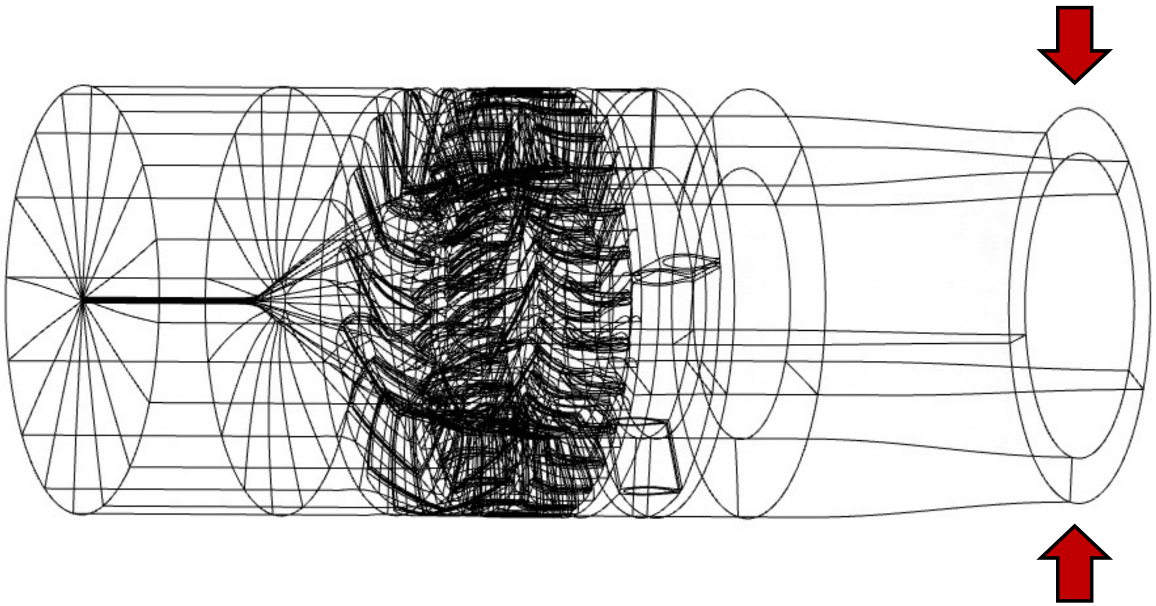
Numerical settings

Performance map is obtained by

- ☐ Increasing back pressure, constant nozzle outlet area (100%)

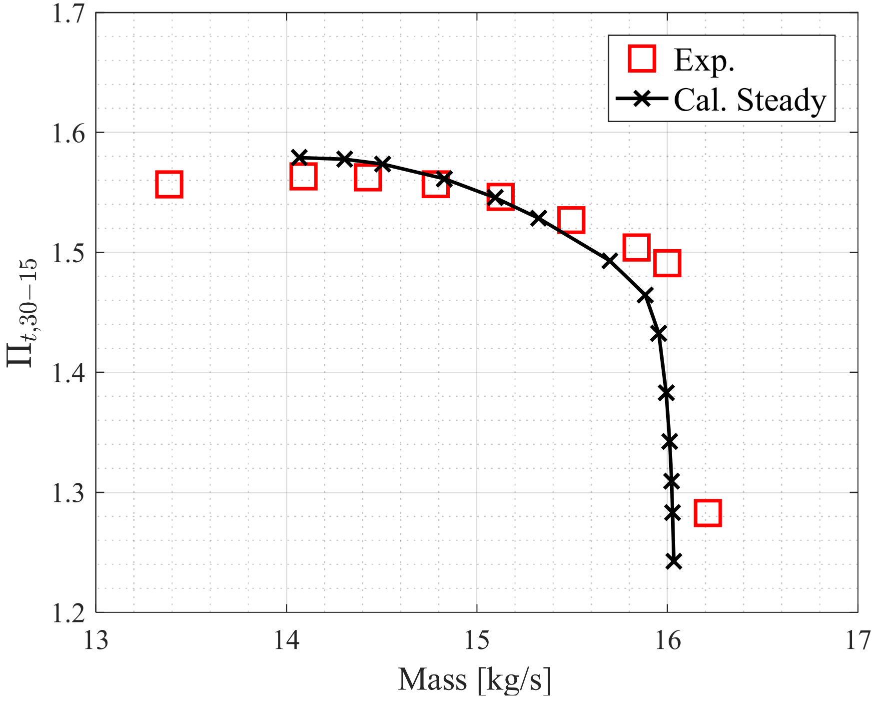
- ☐ Decreasing nozzle outlet area, constant back pressure (1 atm)

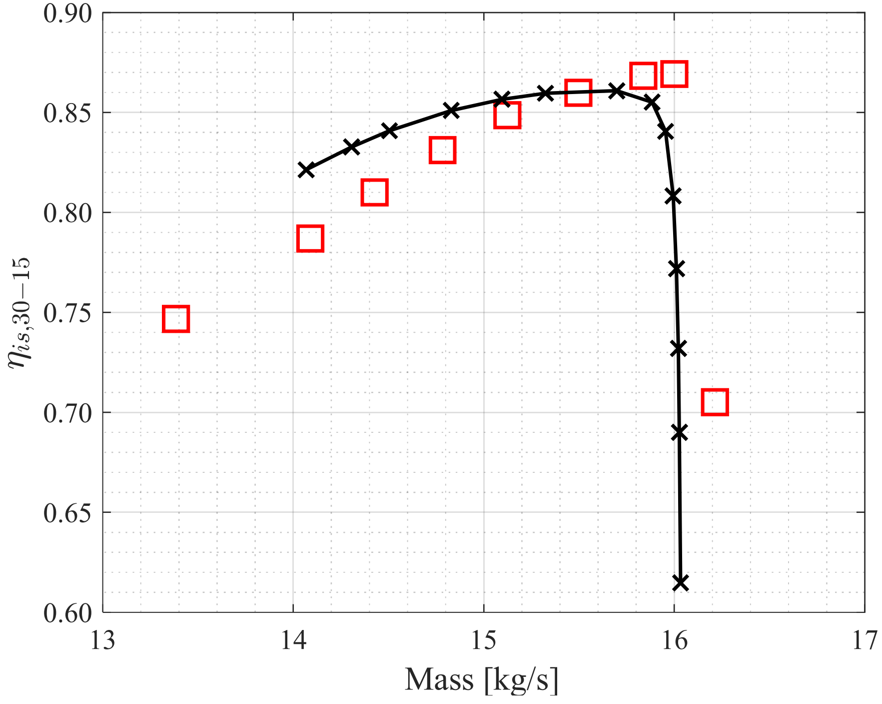
$$Ar = \frac{Area_{nozzle}}{Area_{channel}} \in [57\%, 100\%]$$



Flow field analyses (N100)

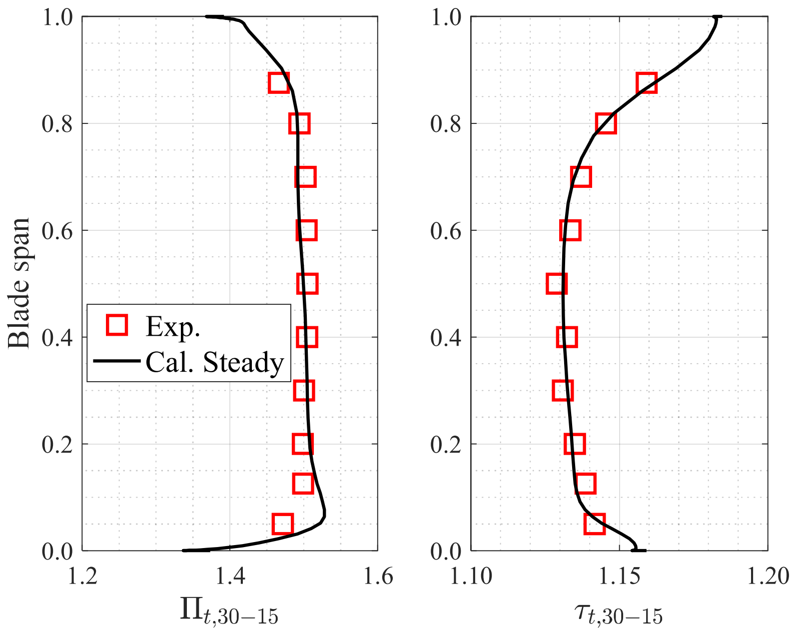
Performance map



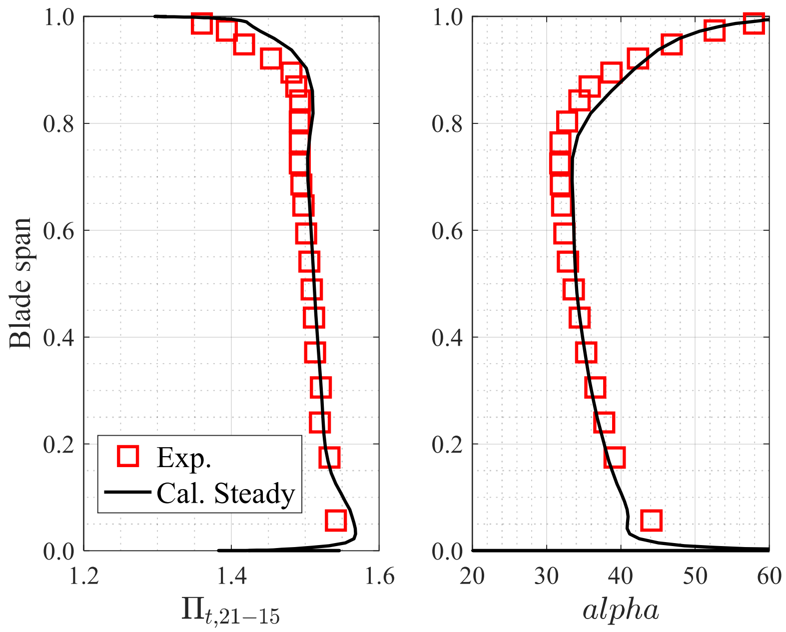


Flow field analyses (N100)

Radial profile at a near peak efficiency point



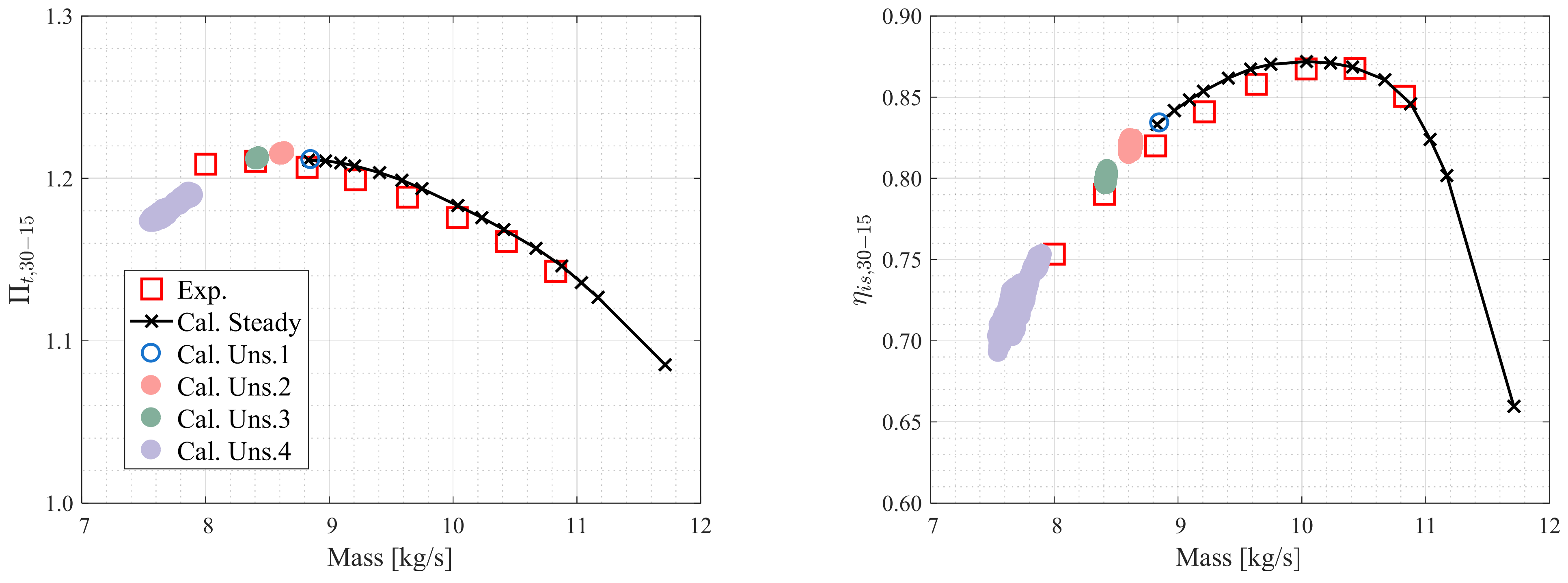
ME30 (Stator exit)



ME21 (Rotor exit)

Flow field analyses (N65)

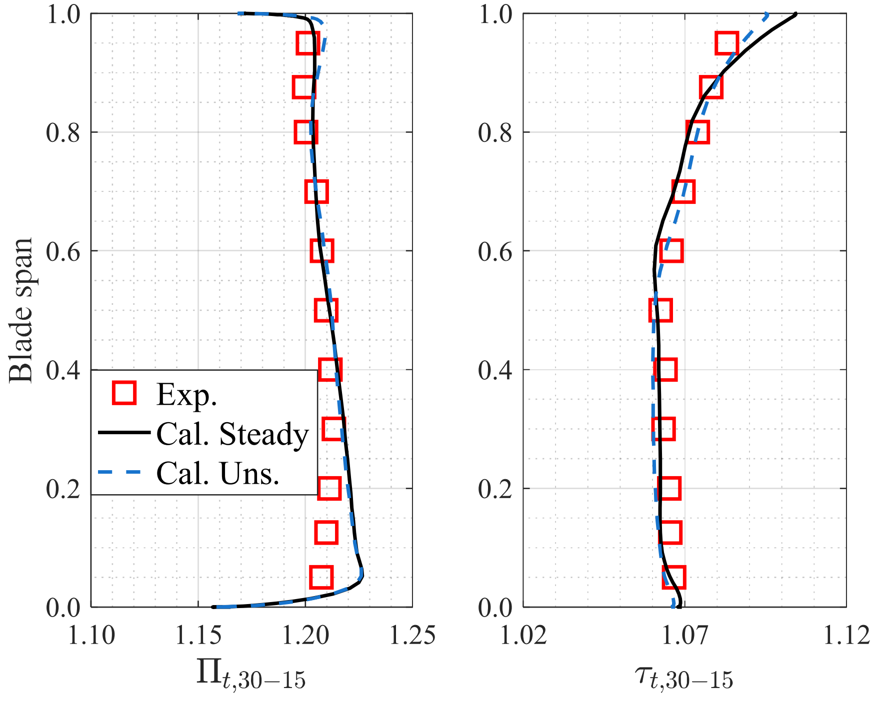
Performance map



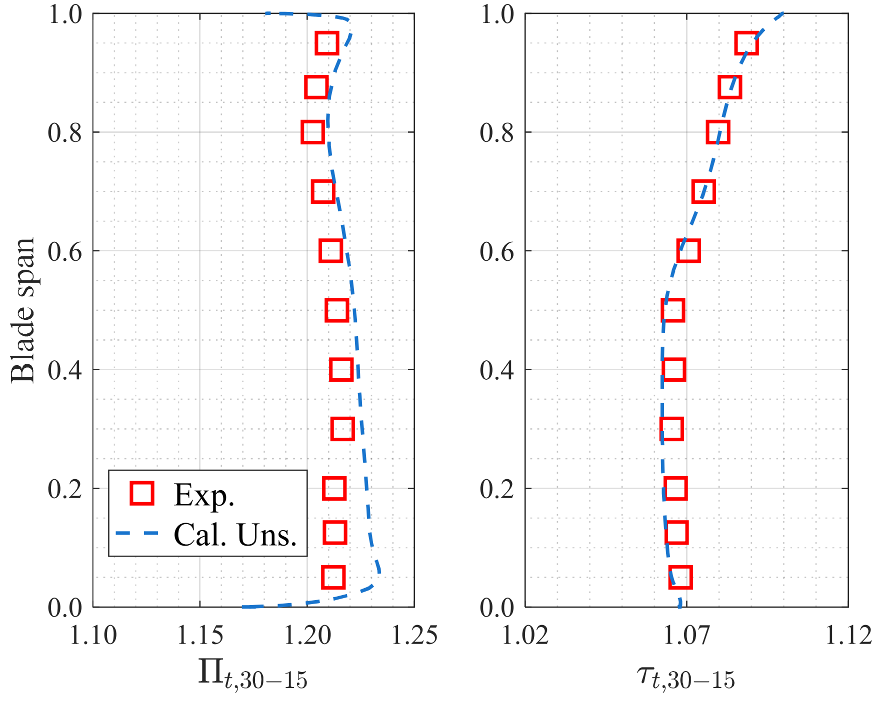
Time step for an unsteady solution: T/100 (T is blade passing period)

Flow field analyses (N65)

Radial profile at ME30 (Stator exit)



Exp. ID 6



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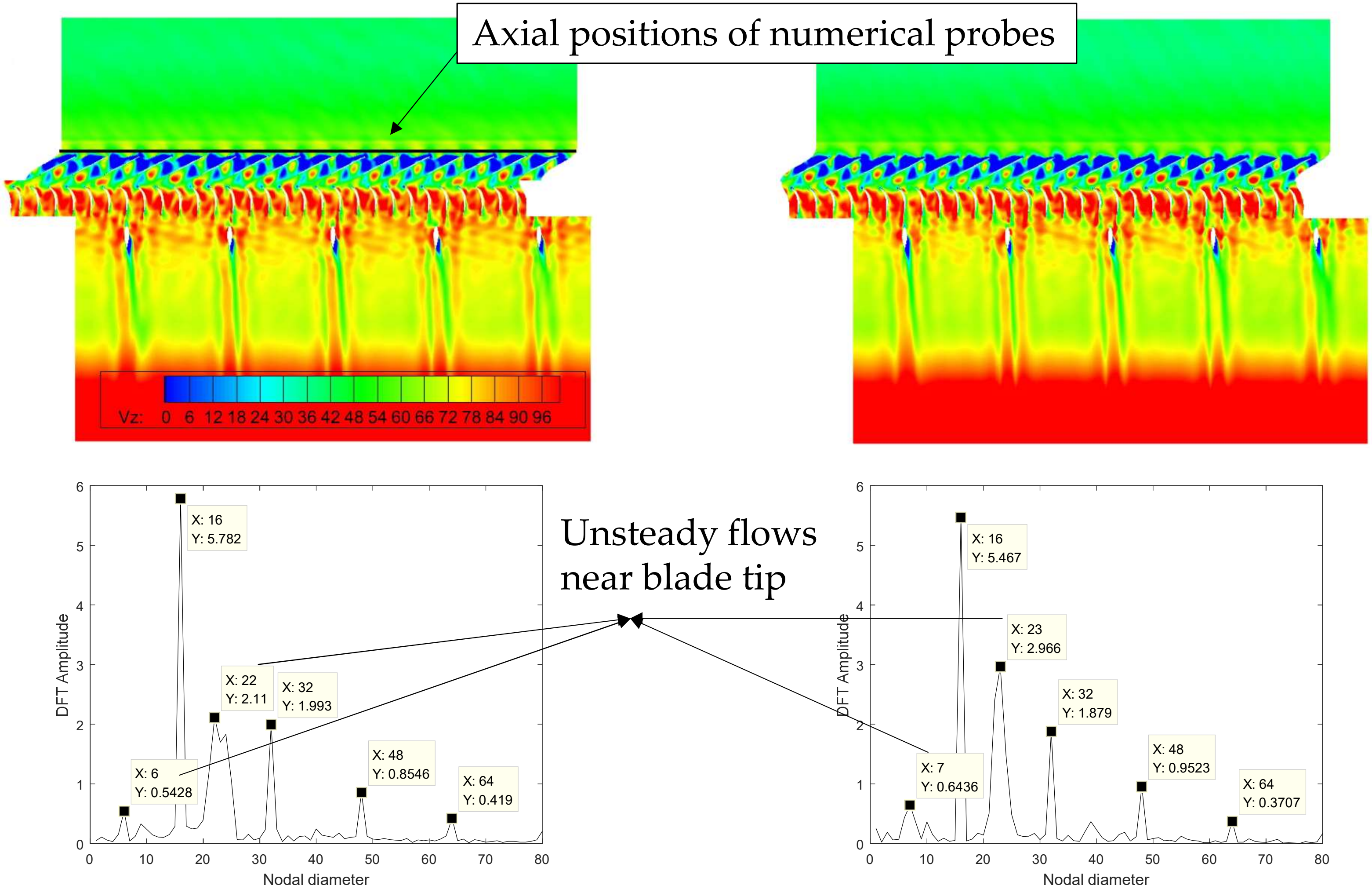
Flow field analyses (N65)

Axial velocity distribution near the casing

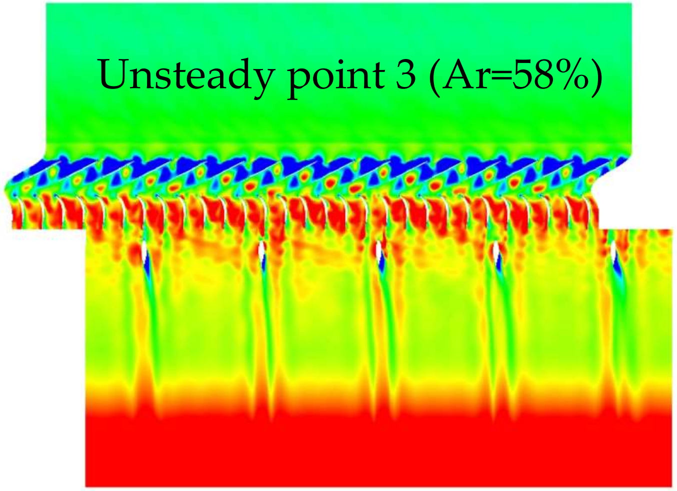
Spatial FT results of the numerical probes

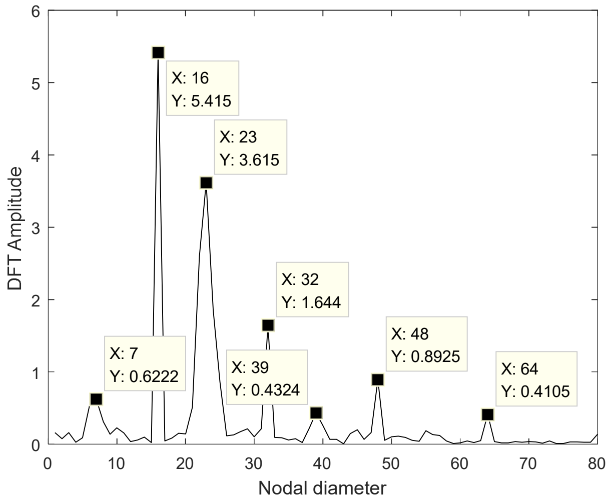


Unsteady point 1 (Ar = 61%)

Unsteady point 2 (Ar = 59%)

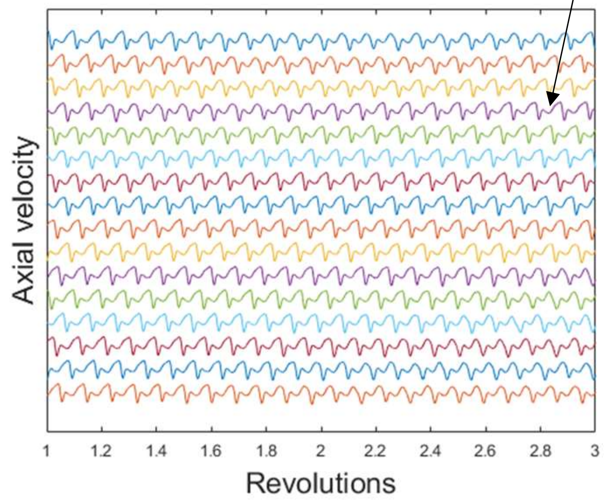
Flow field analyses (N65)

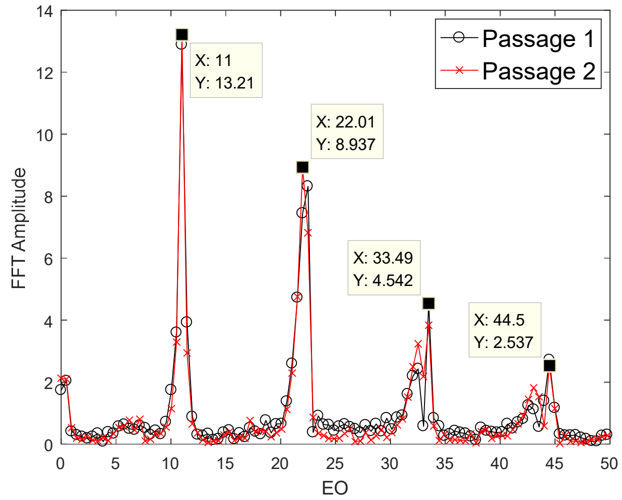




Spatial FT

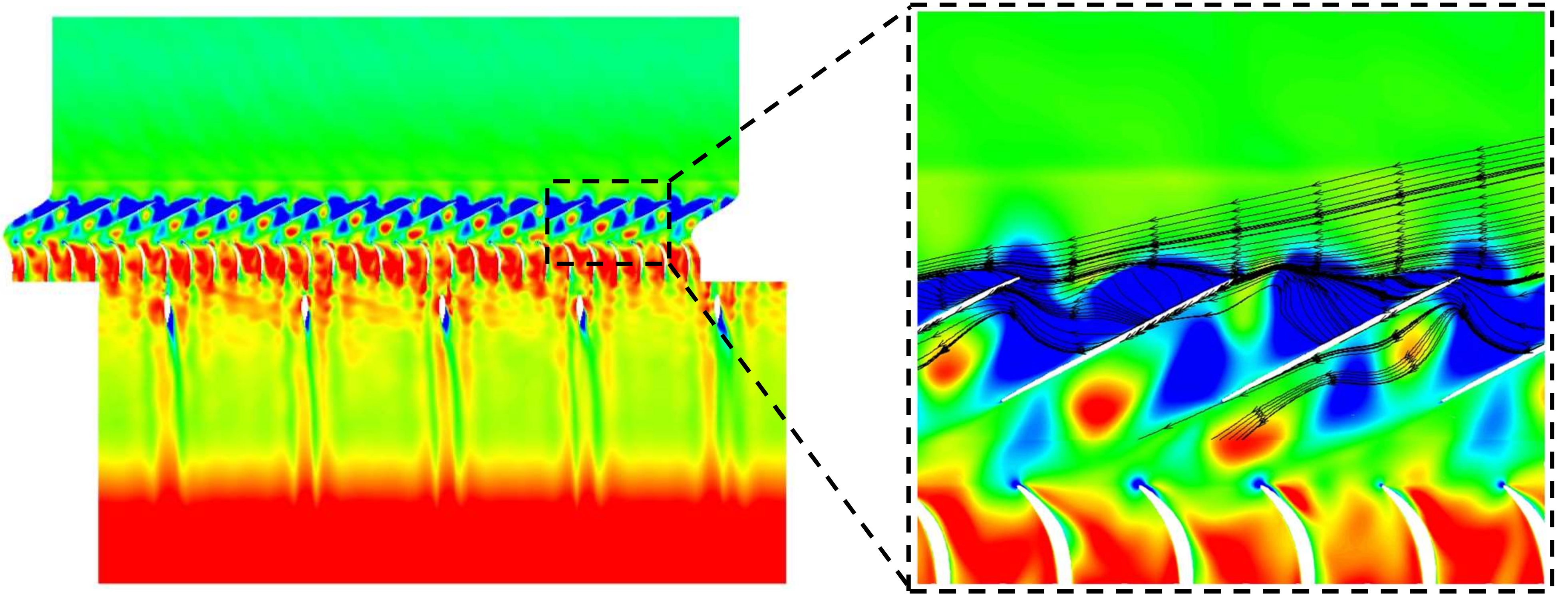
Numerical probes around L.E. at the blade tip
(attached to the rotor)





Temporal FT

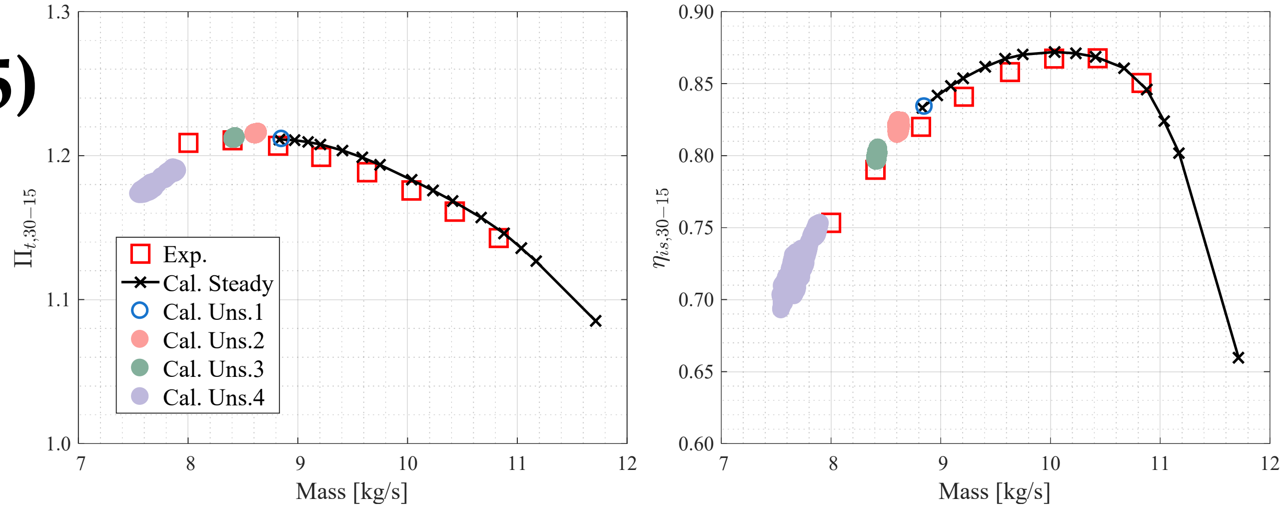
Flow field analyses (N65)

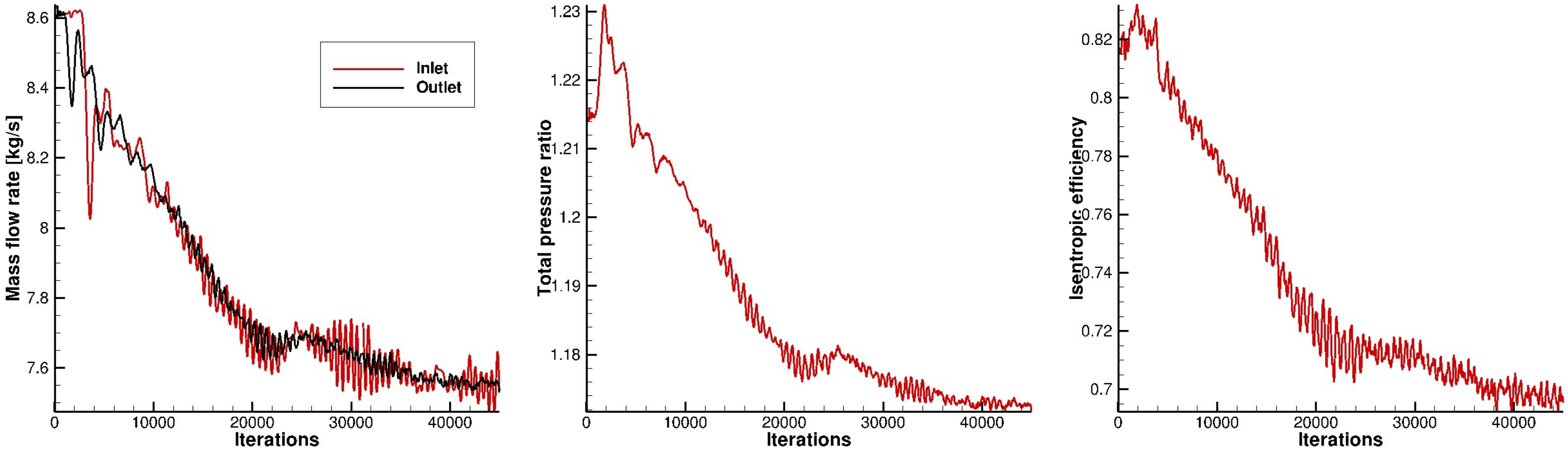


The leakage flow/main flow interface has developed to the leading edge of the blade

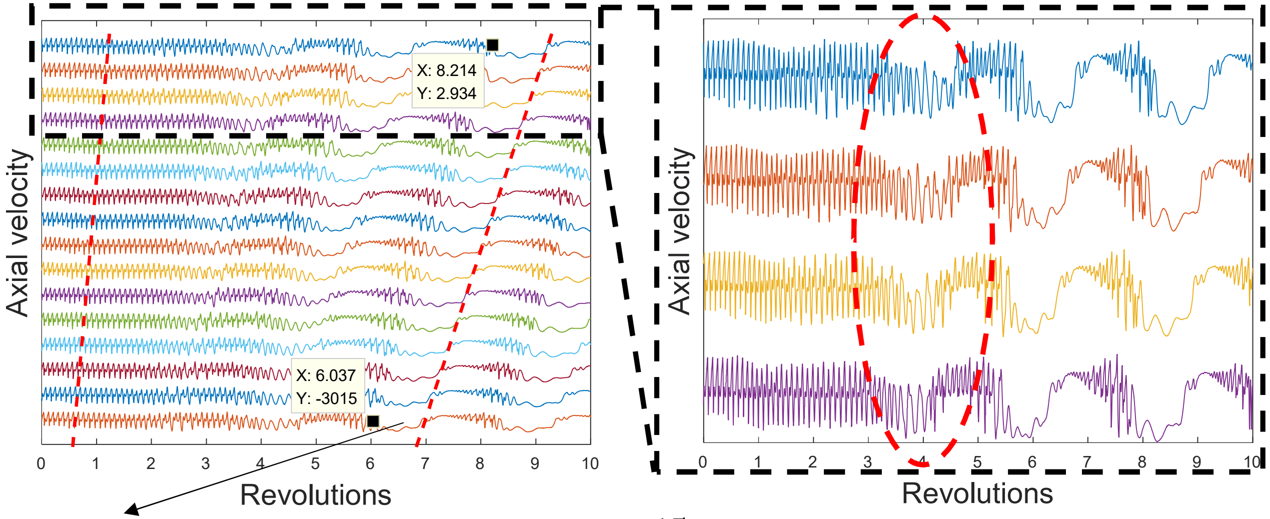
Flow field analyses (N65)

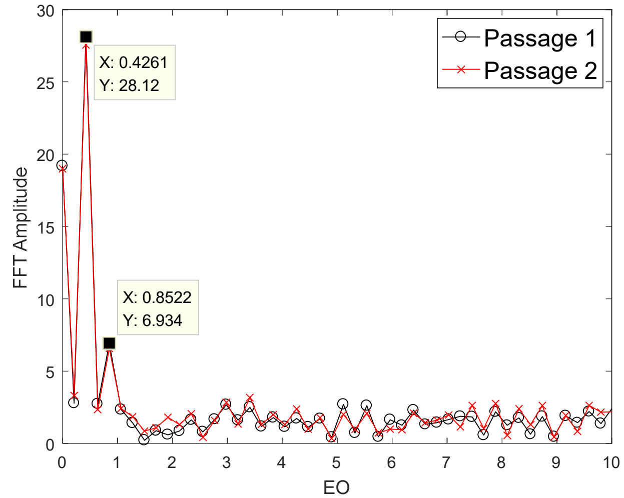
Unsteady point 4 (Ar=57%)





Flow field analyses (N65)

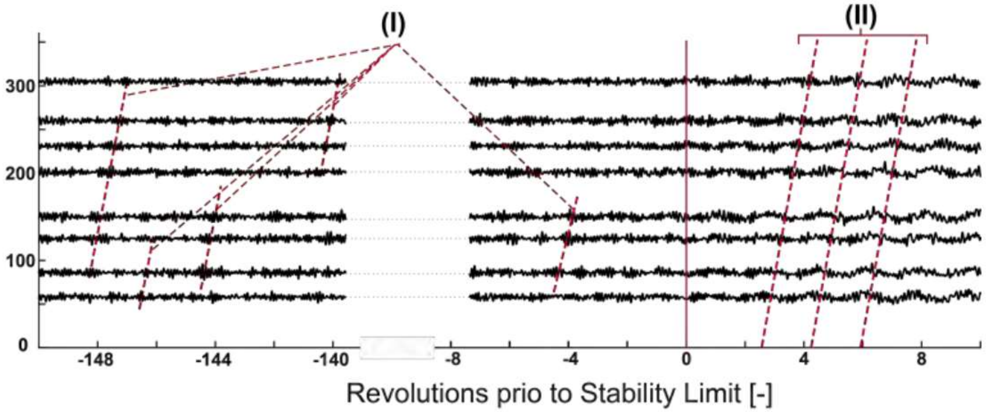




Spatial propagation of rotaing stall

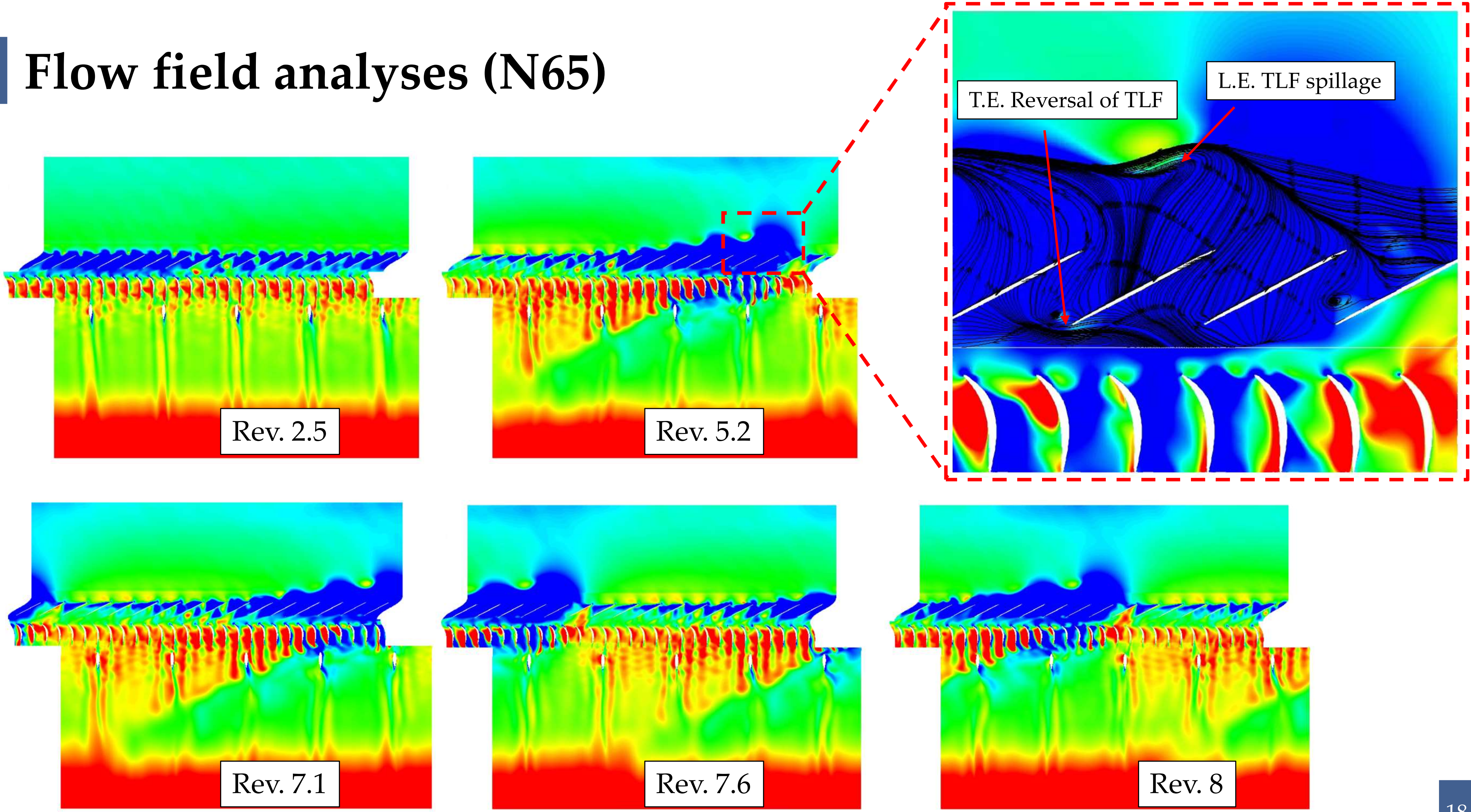
$$\left(1 - \frac{15}{(8.214 - 6.037) \times 16}\right) \times 100\% = 56.94\%$$

$$(1 - 0.4261) \times 100\% = 57.39\%$$



Fluctuations of axial velocity due to the stall cell is less pronounced

Flow field analyses (N65)



Conclusion

- The calculated radial profiles of total pressure ratio, total temperature ratio and flow angle show good agreement with the experimental data for both 65% and 100% of the design speed

- Unsteady flows at near stall conditions of the 65% design speed are analyzed. The rotating stall is detected and the speed of the rotating cell is about 57% of the shaft speed

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