GPPS
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Workshop

XI'AN
2021

西北工業大學
NORTHWESTERN POLYTECHNICAL UNIVERSITY

Validation of a RANS Solver for the TUDa-GLR-Open-Stage

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2021/12/15

动力与能源学院
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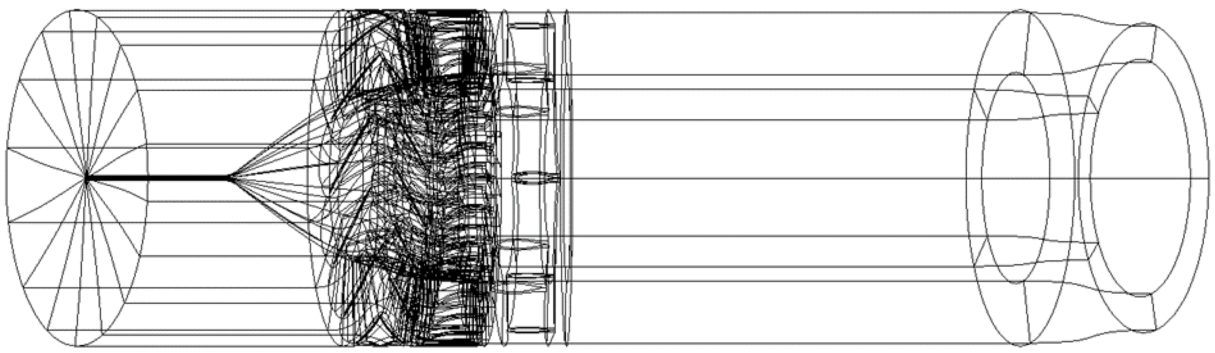
Content

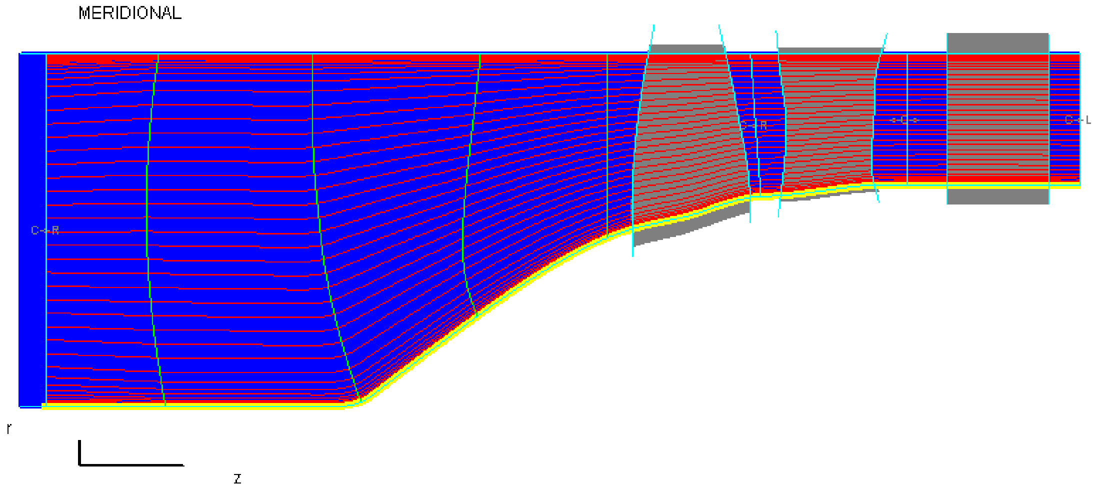
- Computational domain and mesh configurations
- Solver introduction
- CFD setup and overall performance
- Radial profiles
- Unsteady flow behaviors

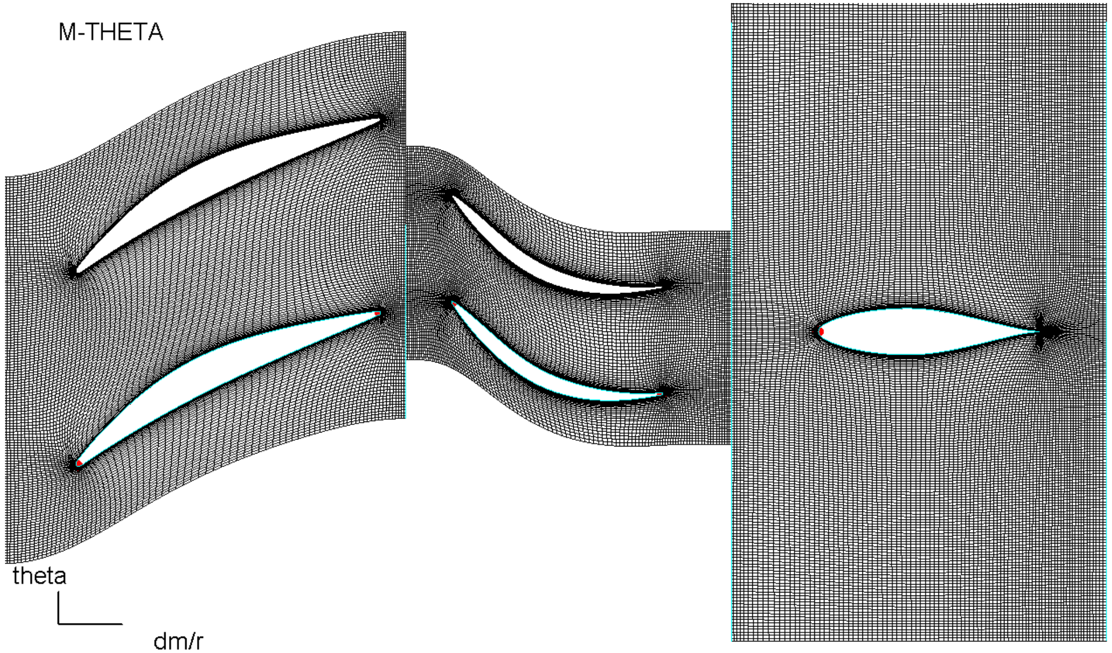
Computational domain and mesh configurations



First cell width: 5e-6m, with wall function used

Grid level	Coarse	Medium	Fine
Rotor	608872	1229652	2440380
Stator	291153	574209	1168873
Strut	929945	1838781	3627617
Full-annulus	~30million	~60million	~120million





Meridional view and b2b view of the medium grid

Solver introduction

Turbostream:

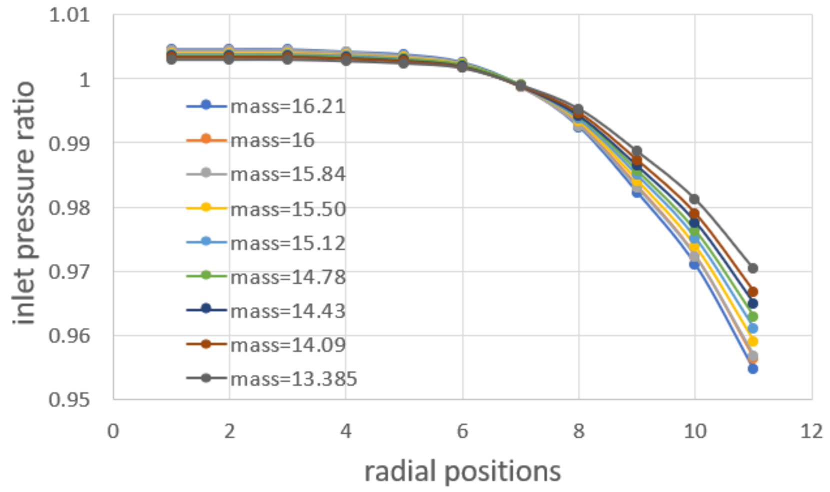
multi-block structured grids
Spalart-Allmaras turbulence model

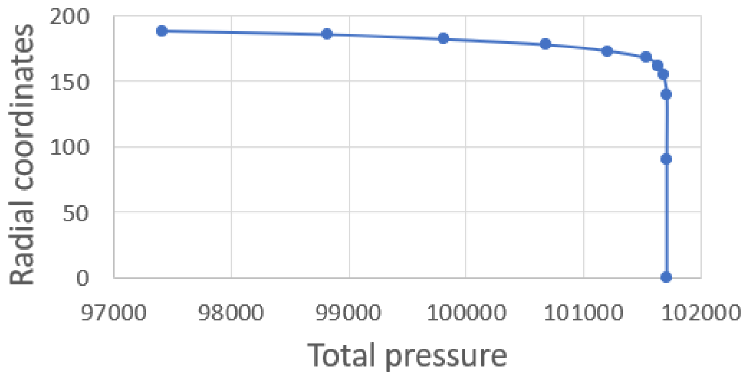
spatial discretization:
(1) Convective fluxes: take the average of the flow variables at the corner points of the cell face.
(2) Diffusive fluxes: evaluate the derivatives of velocity and temperature at the center of the cell using Gauss's theorem, and then average the cell values on either side of a cell face to get the face value.
(3) Artificial dissipation: a blend of second and fourth order.

Steady-state: explicit time-stepping, mixing plane.
Time-accurate: dual time-stepping, sliding plane.

CFD setup

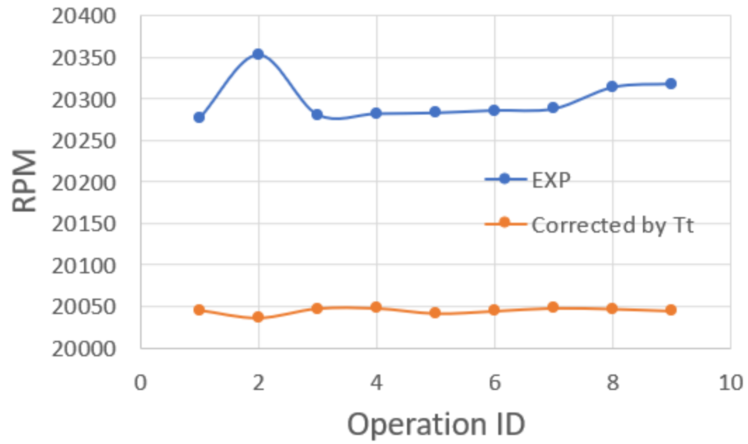
1. Inlet total pressure profiles are normalized by the total pressure at ME03
2. Average over different operating points
3. Multiply the total pressure at the ISO condition





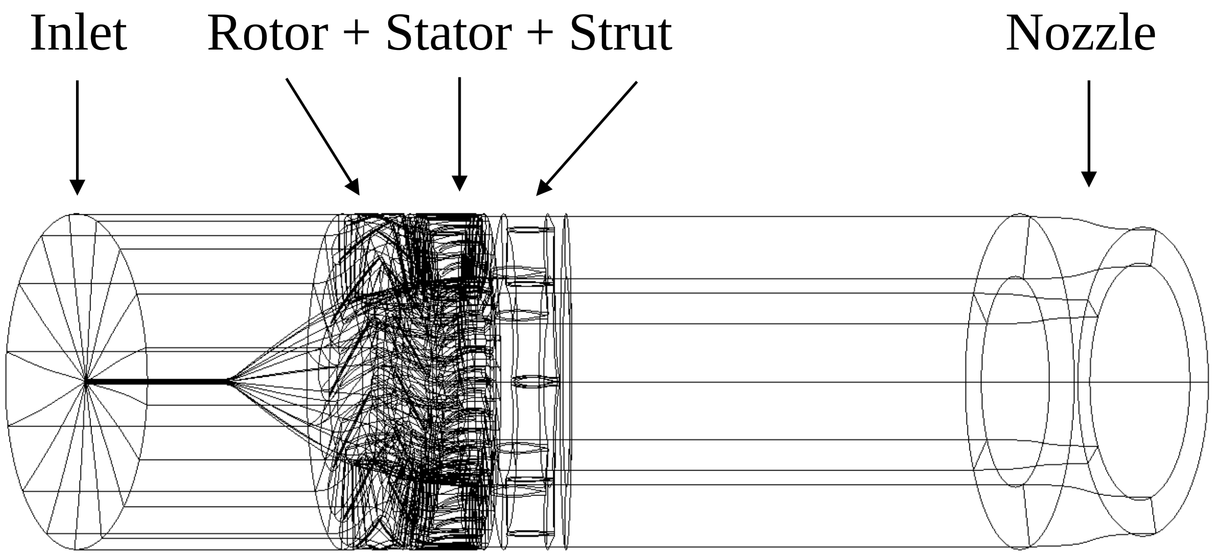
Inlet total pressure profile

1. Correct the rotating speed at different operating points
2. Average over different operating points



Averaged rotating speed

CFD setup



Constant total temperature,
Total pressure profile,
Axial flow direction.

Constant back pressure
(with a nozzle)

Steady computation domain(single passage)

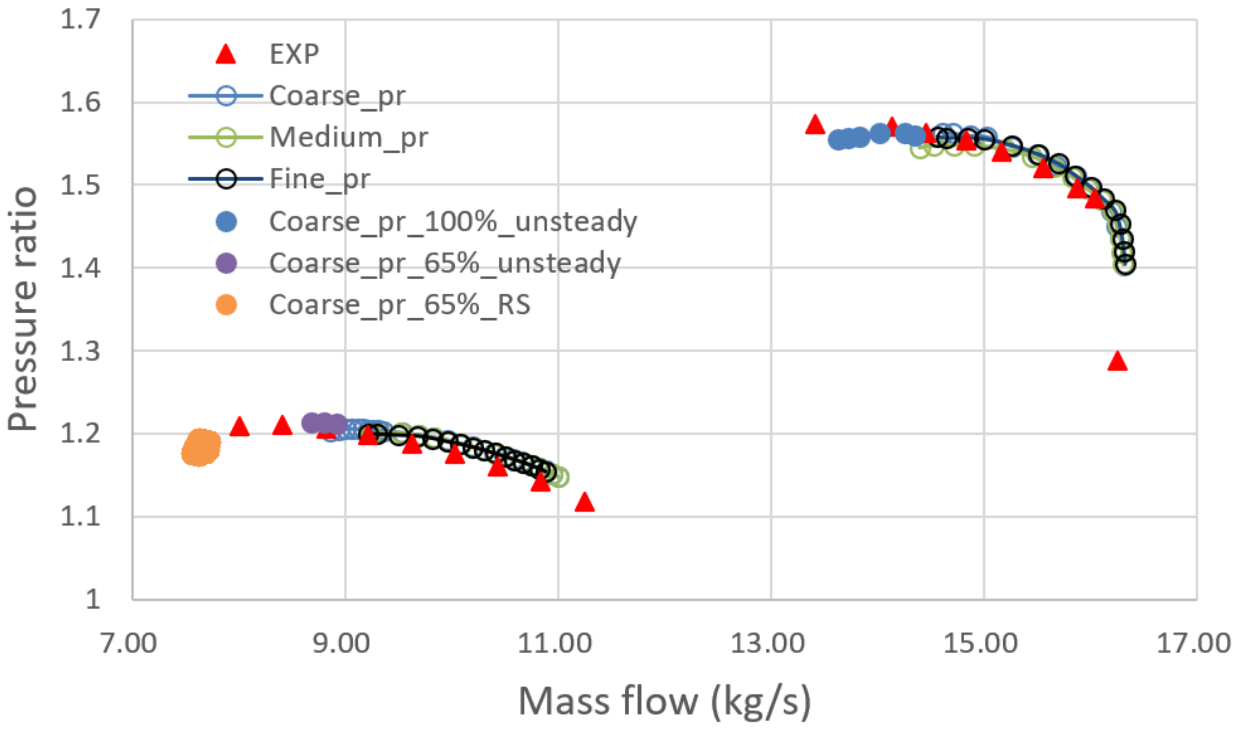
Steady computation domain(single passage)

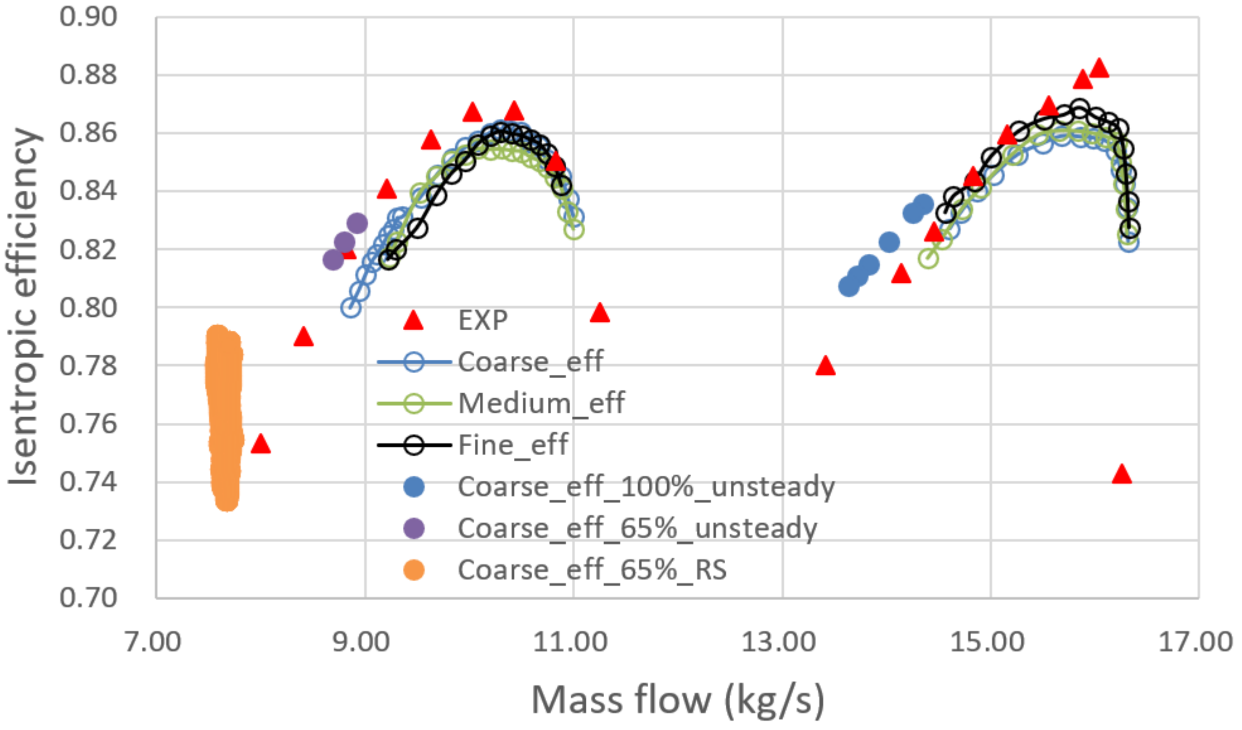
Unsteady computation domain(full annulus)

100(~156) physical time steps per rotor passing period at 100%(65%) of the design speed,
Physical time step: 1.8750e-06s

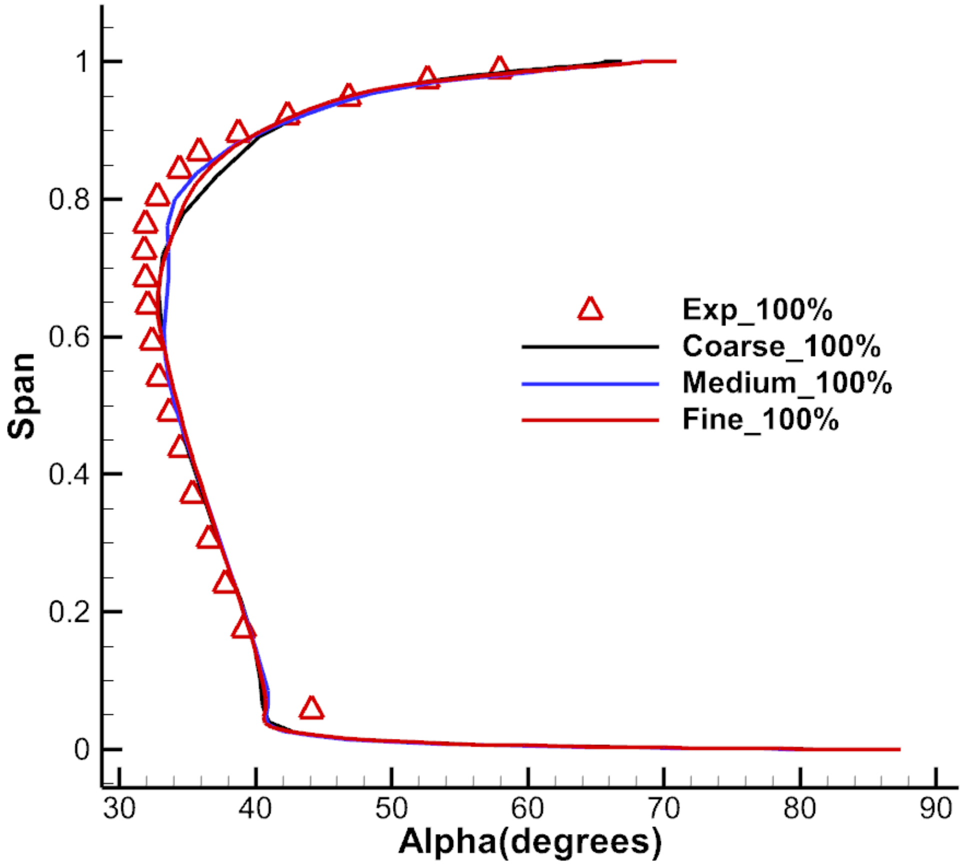
Overall performance

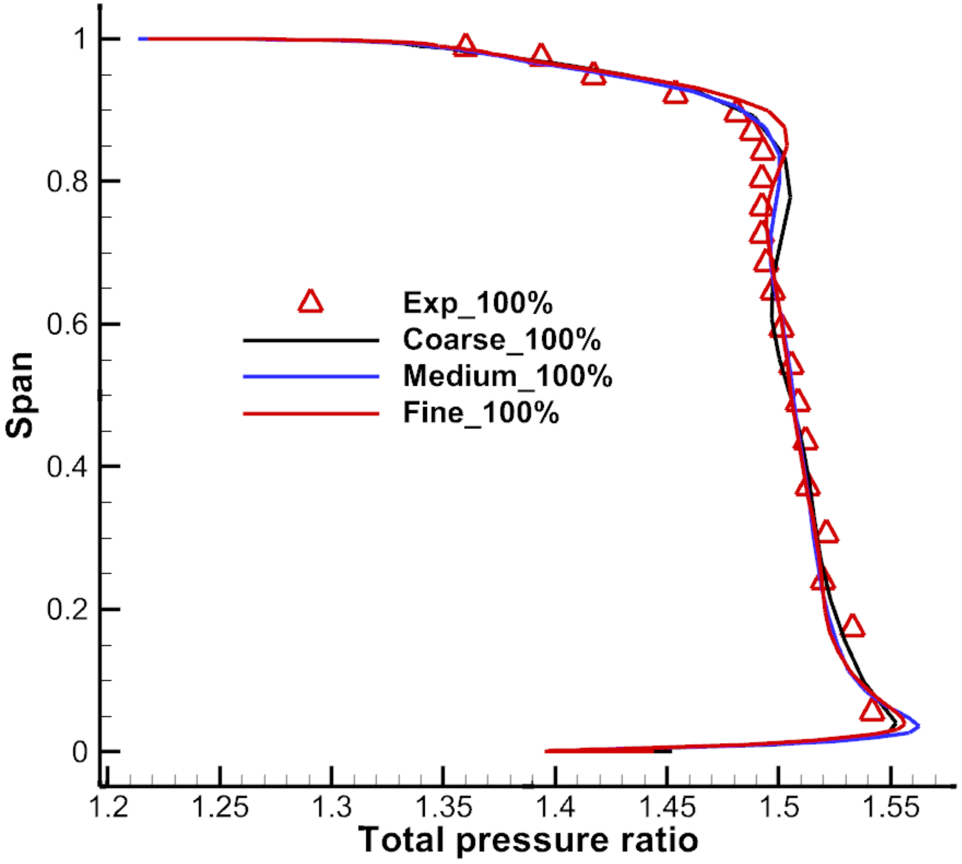
The performance is calculated based on the area-averaged data at ME15 and ME30.



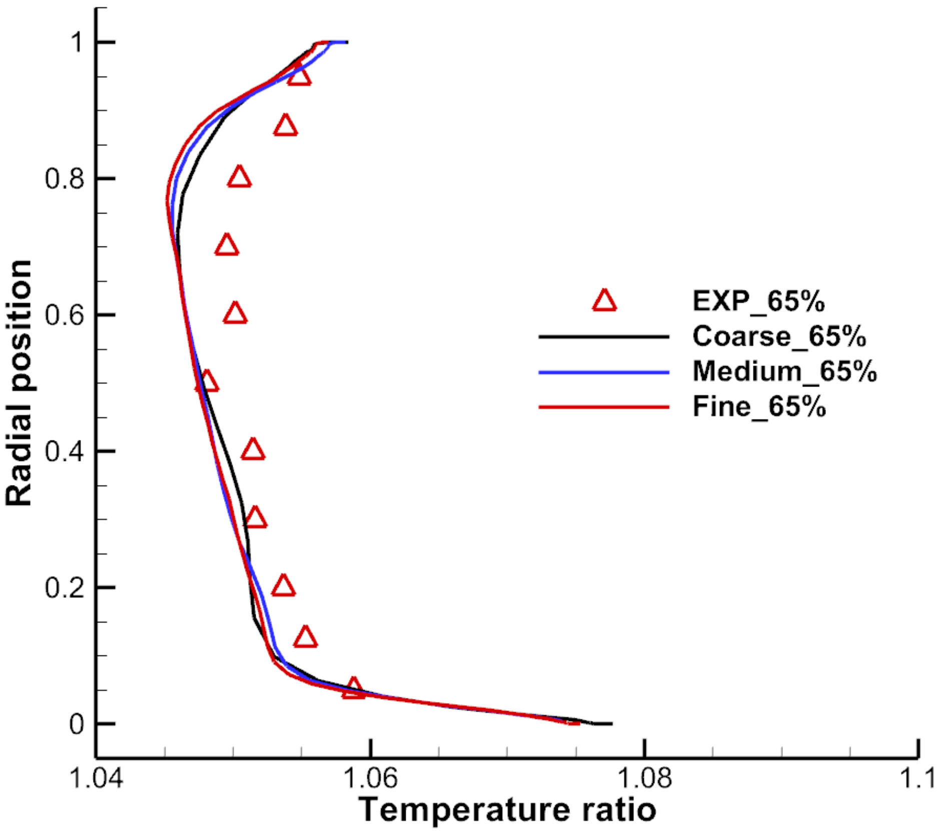


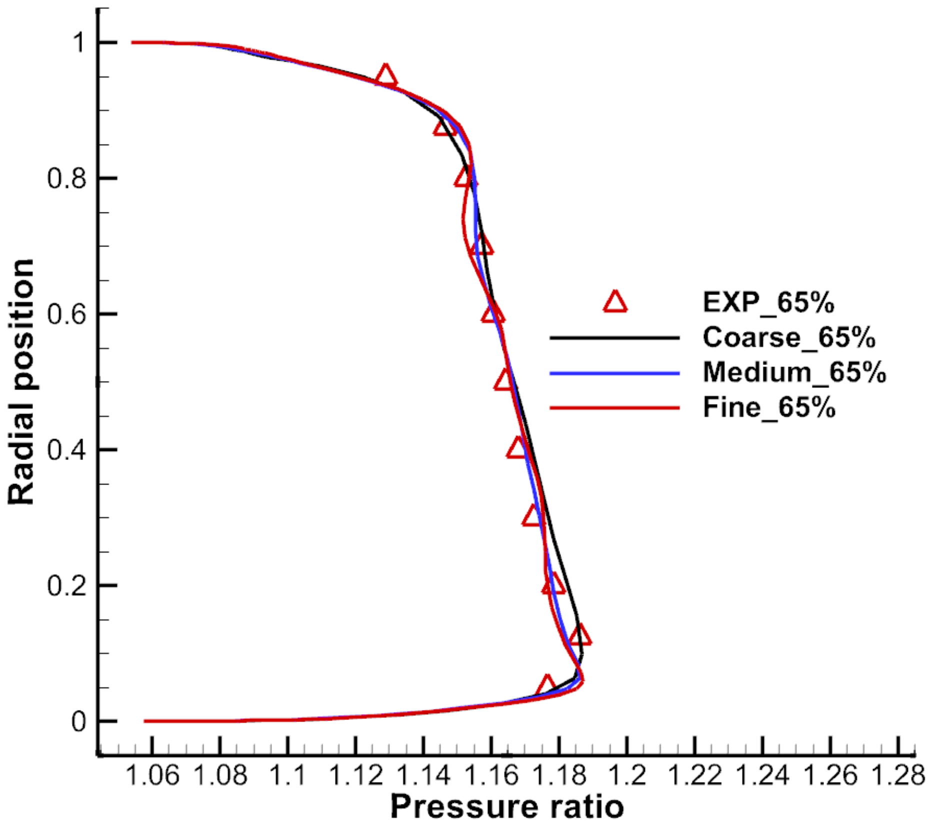
Flow angle(alpha) and total pressure ratio at ME21(rotor outlet).





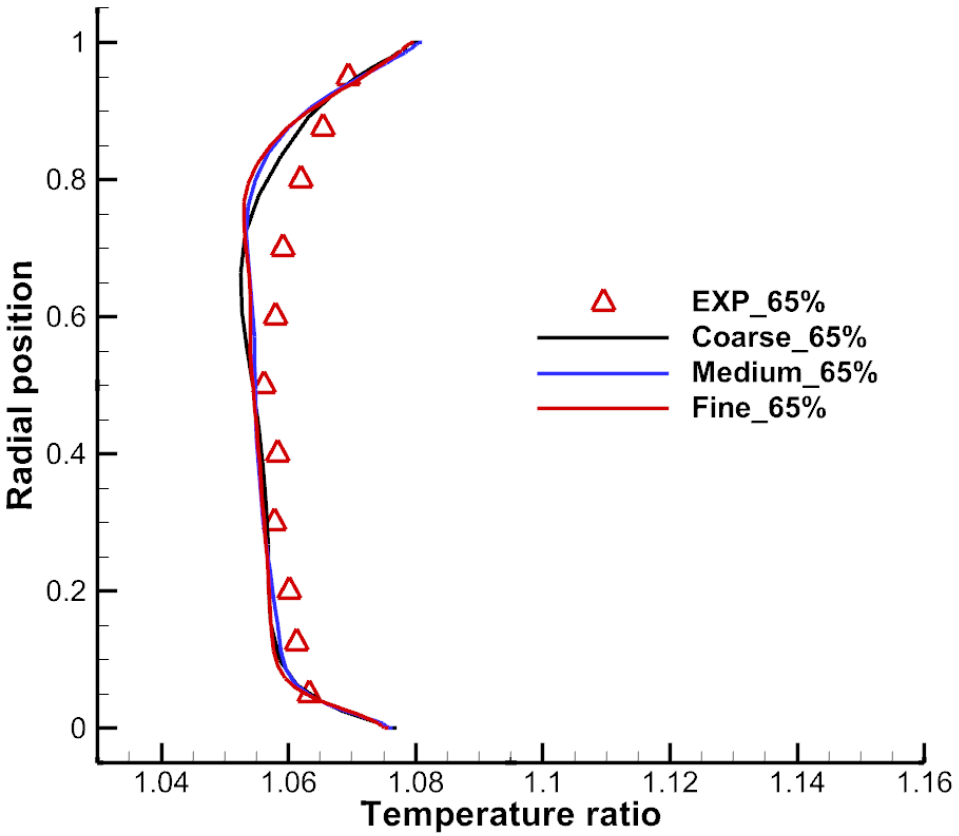
Total temperature ratio and total pressure ratio at ME30(stator outlet).

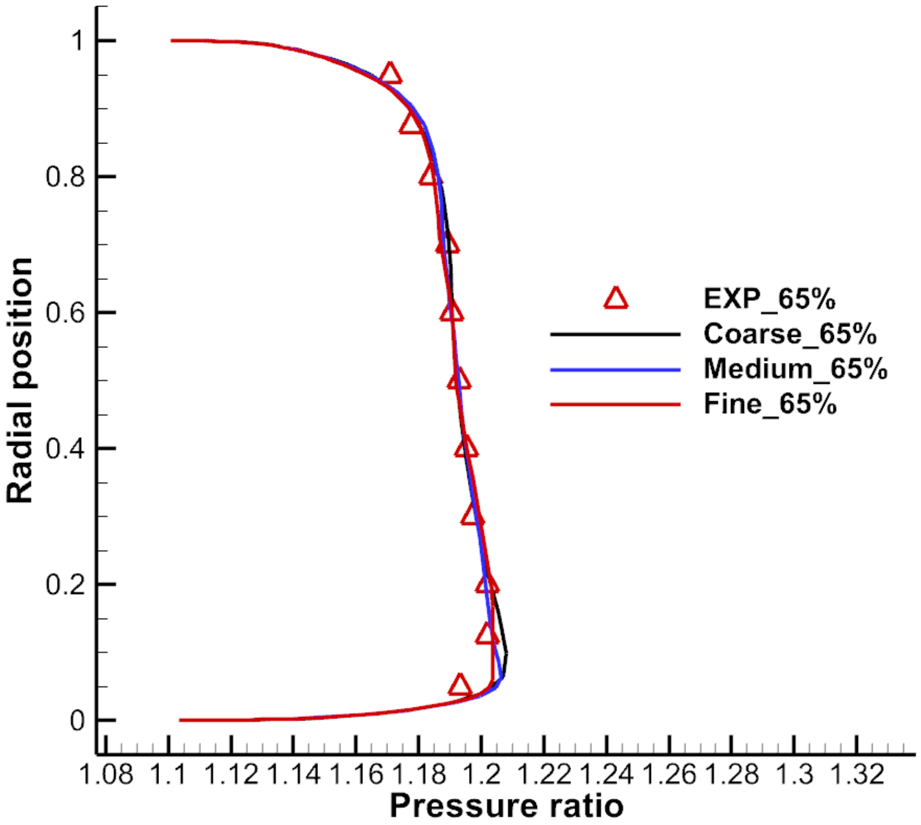




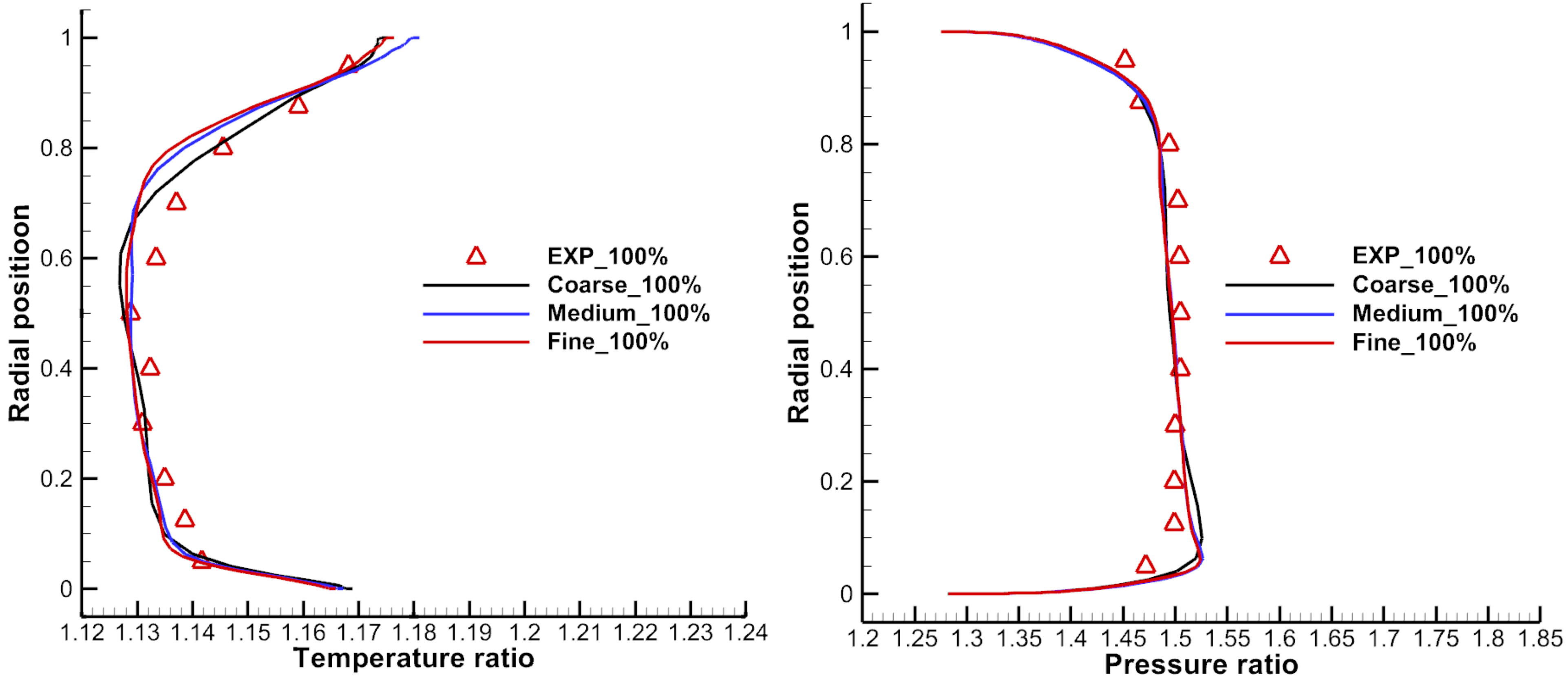
A near stall point, 65% speed

Total temperature ratio and total pressure ratio at ME30(stator outlet).





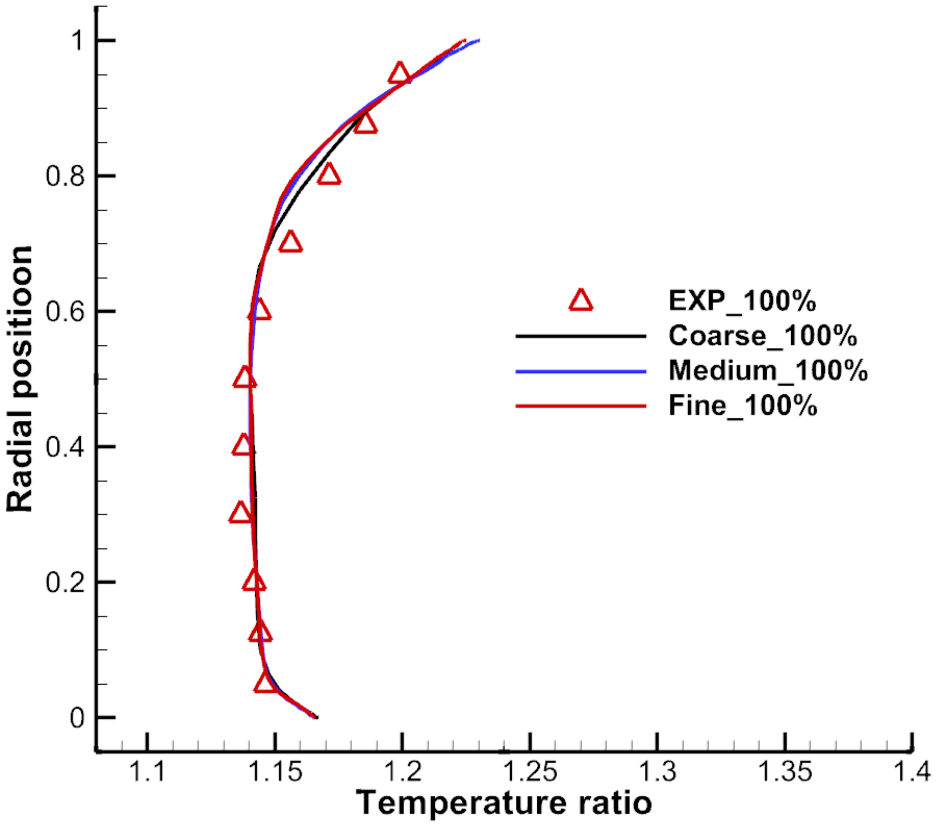
Total temperature ratio and total pressure ratio at ME30(stator outlet).

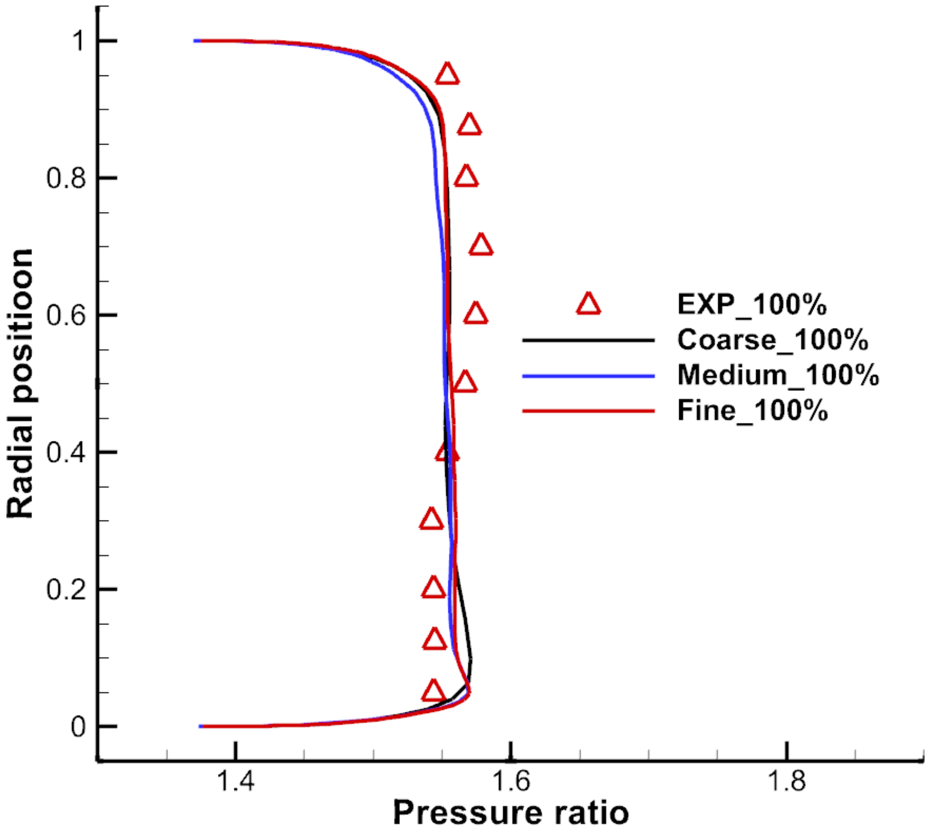


Radial profiles

A near stall point, 100% speed

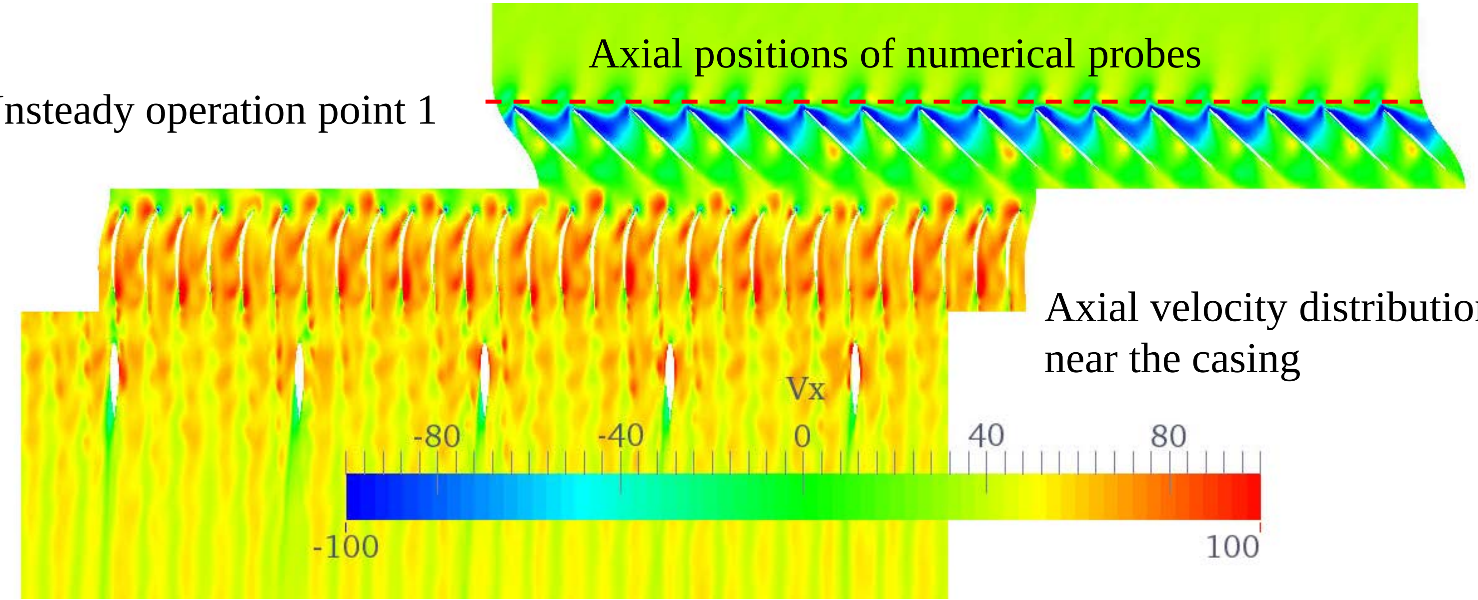
Total temperature ratio and total pressure ratio at ME30(stator outlet).



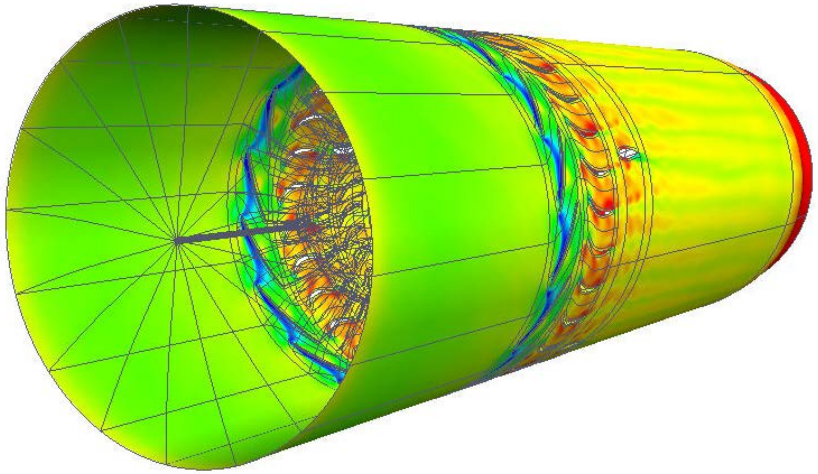


Unsteady results(65% speed)

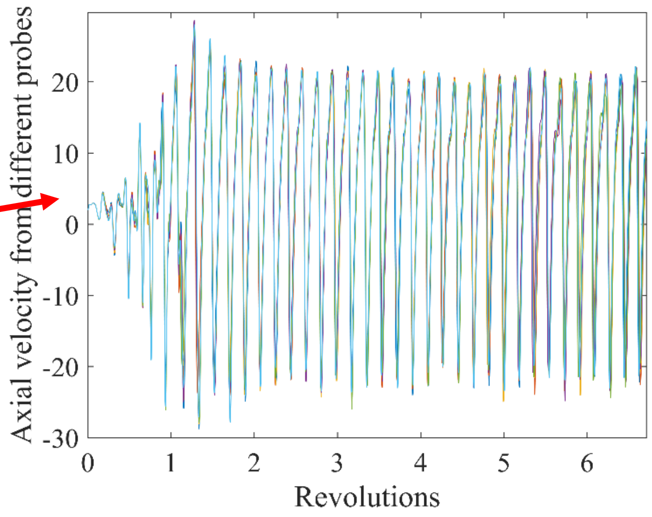
Unsteady operation point 1



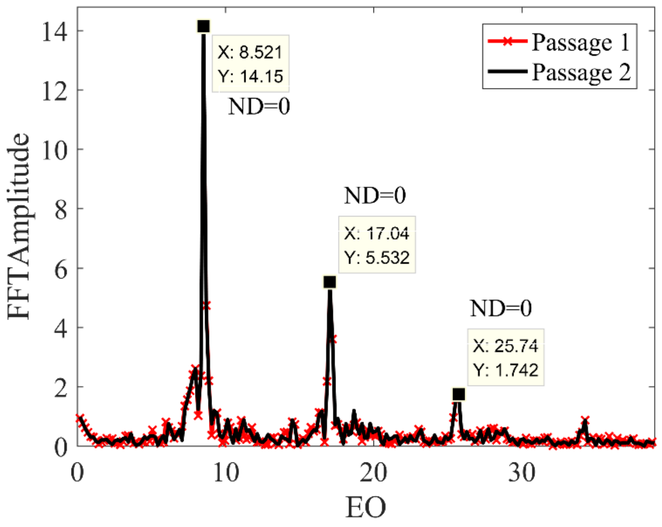
Axial velocity distribution near the casing



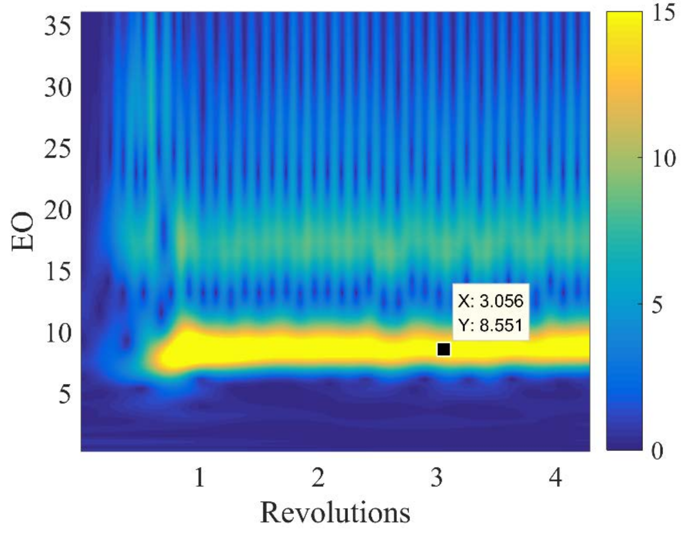
Initialized from the last steady solution



Axial velocity history

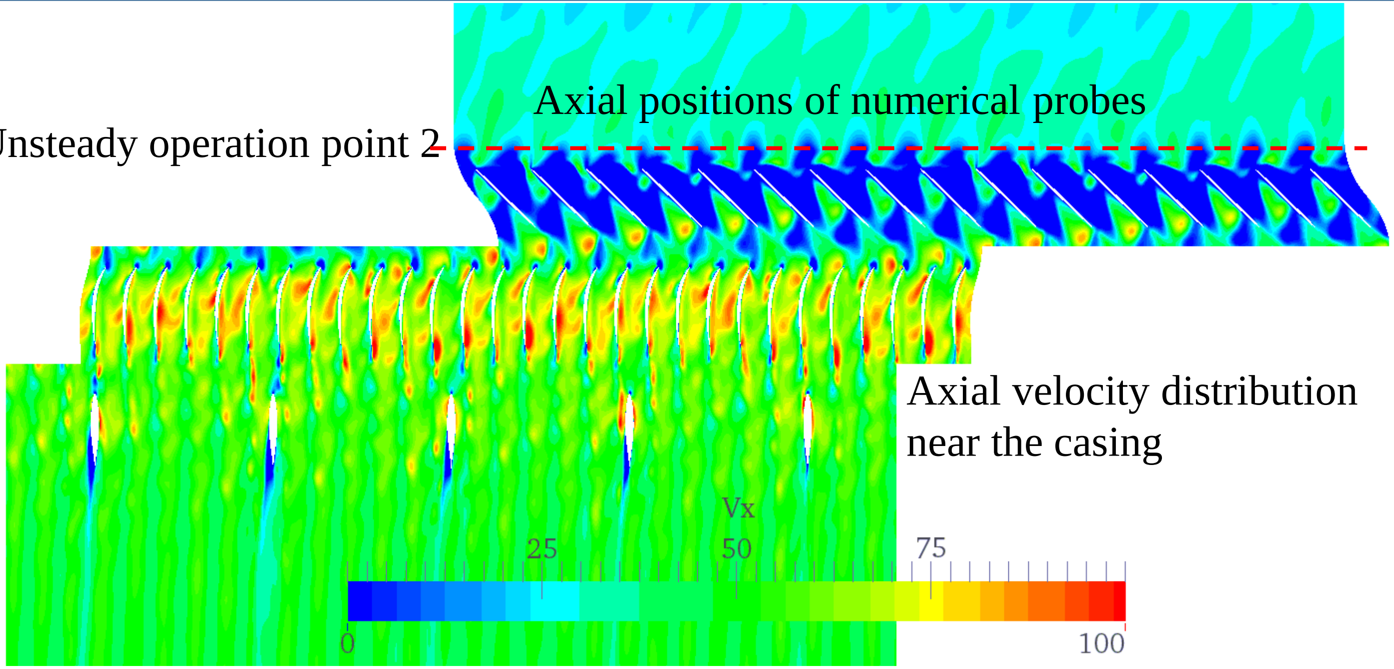


FFT results

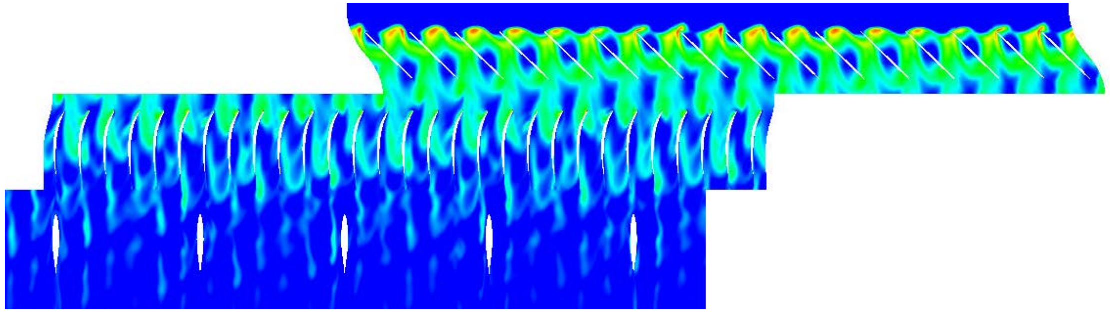


Wavelet analysis results

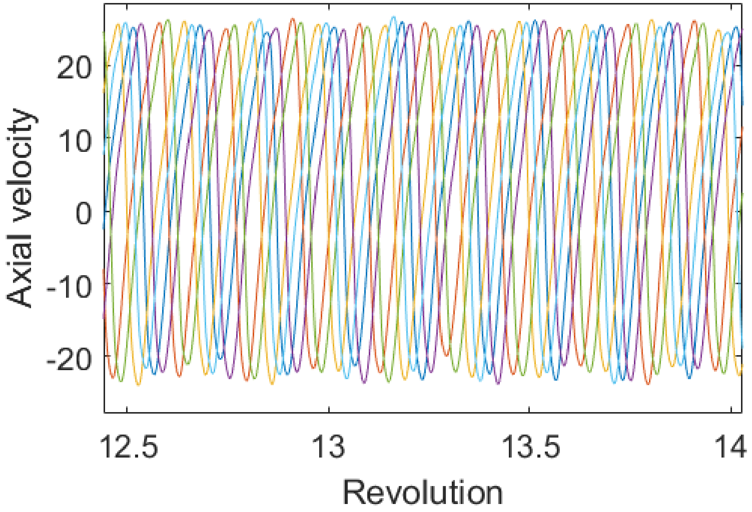
Rotating instability(65% speed)



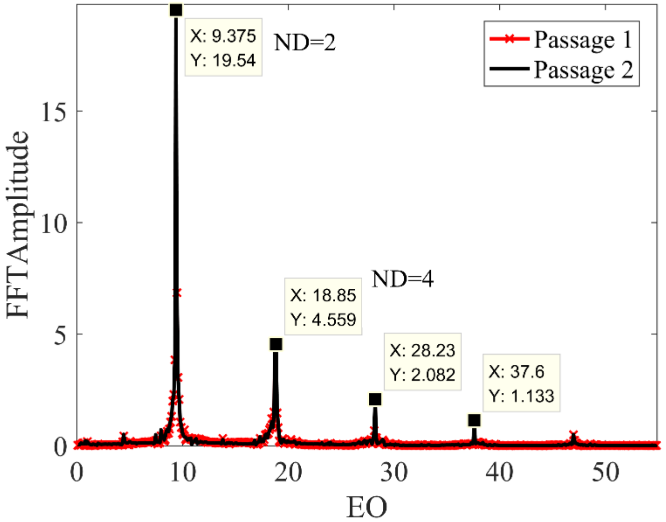
Axial velocity distribution near the casing



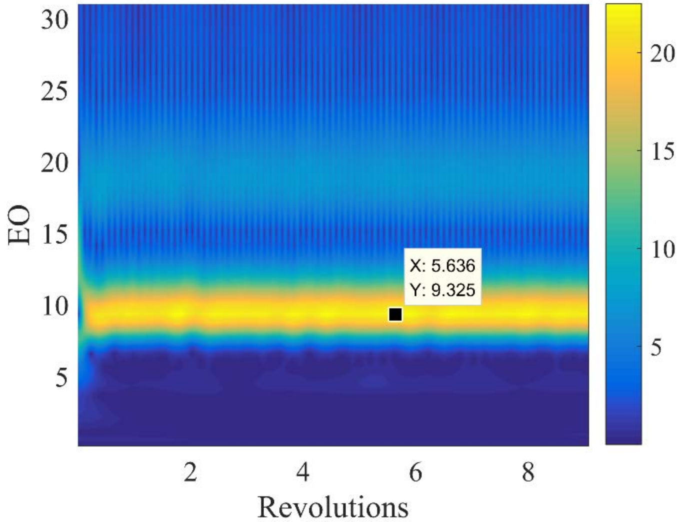
Entropy function distribution near the casing



Axial velocity history



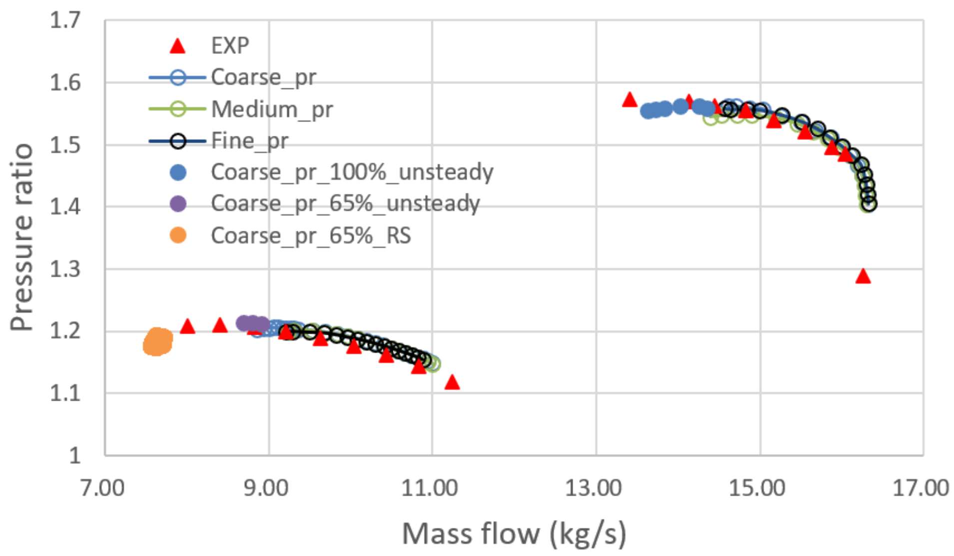
FFT results

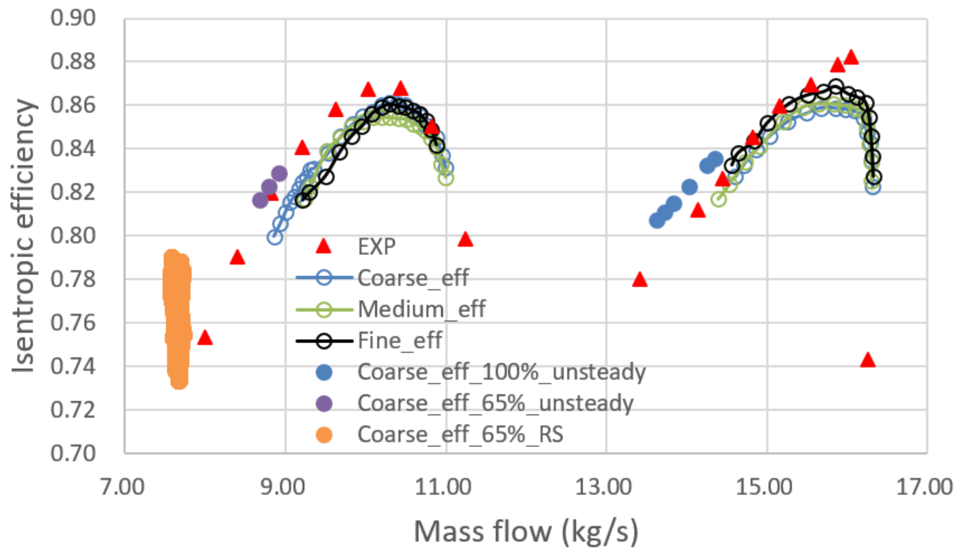


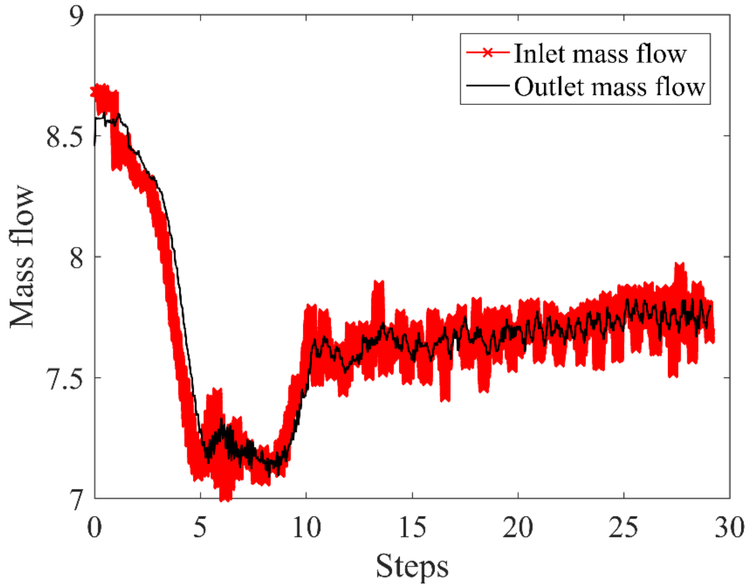
Wavelet analysis results

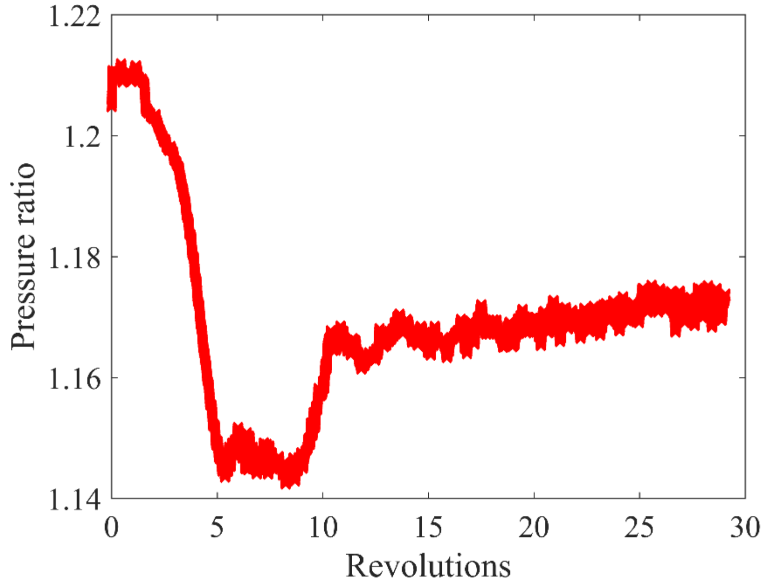
Rotating stall(65% speed, stable)

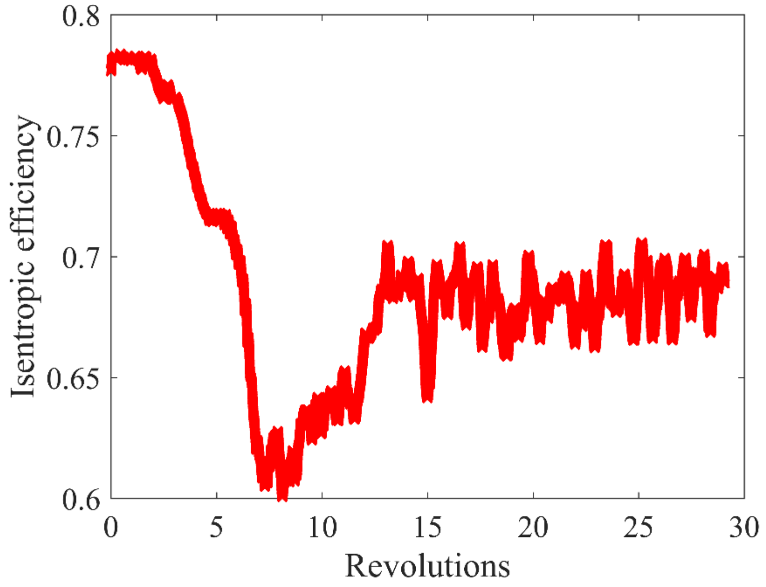
Performance



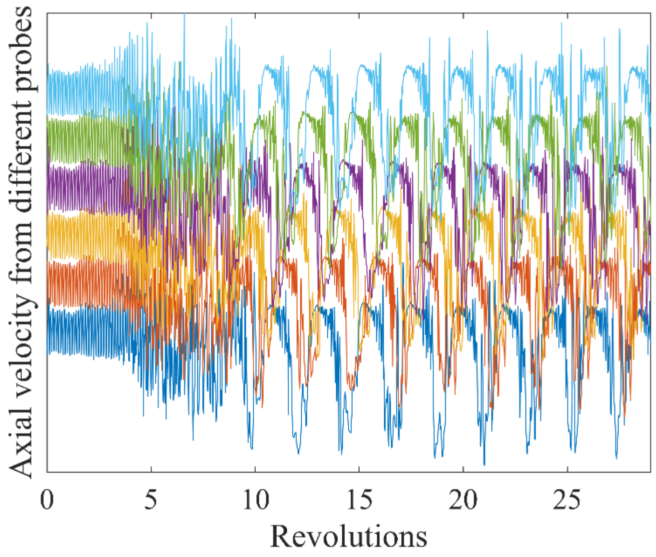


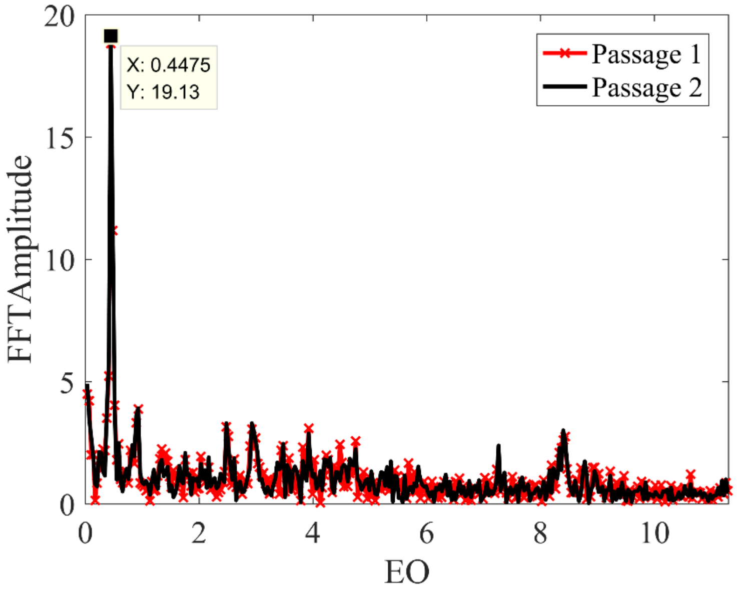


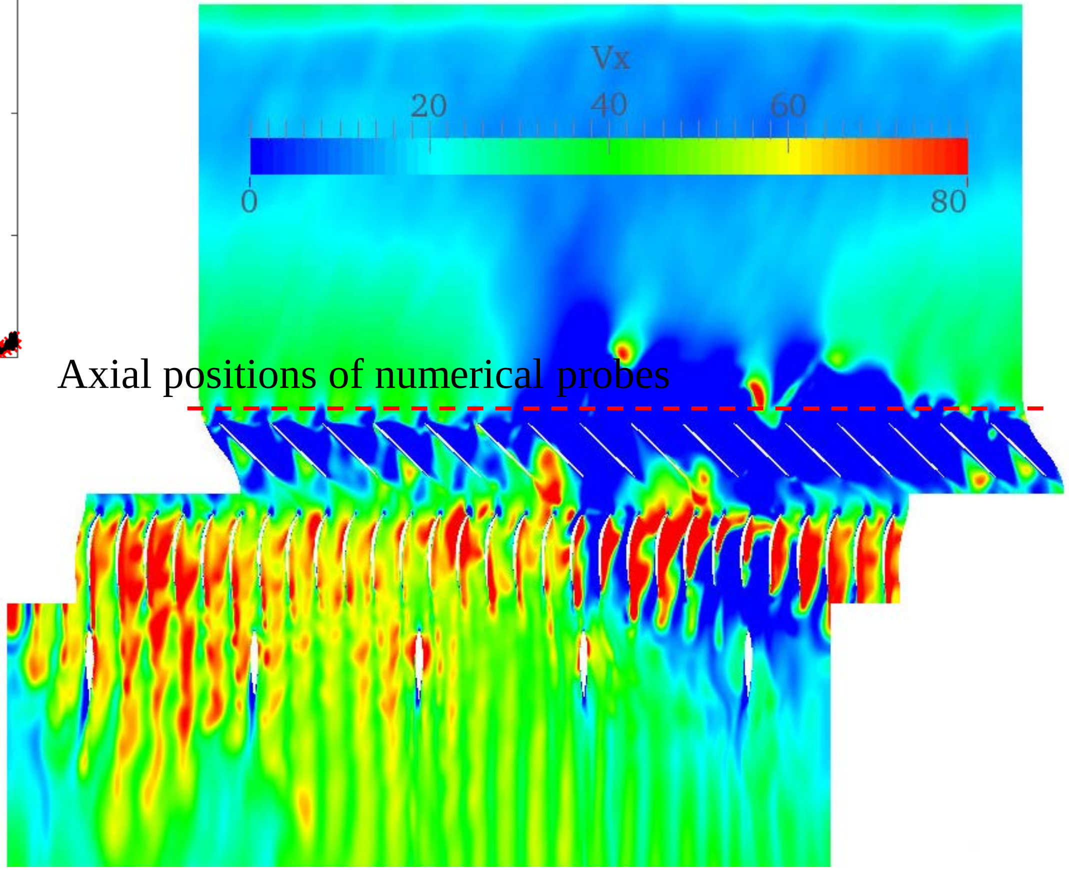




Rotating stall(65% speed, stable)

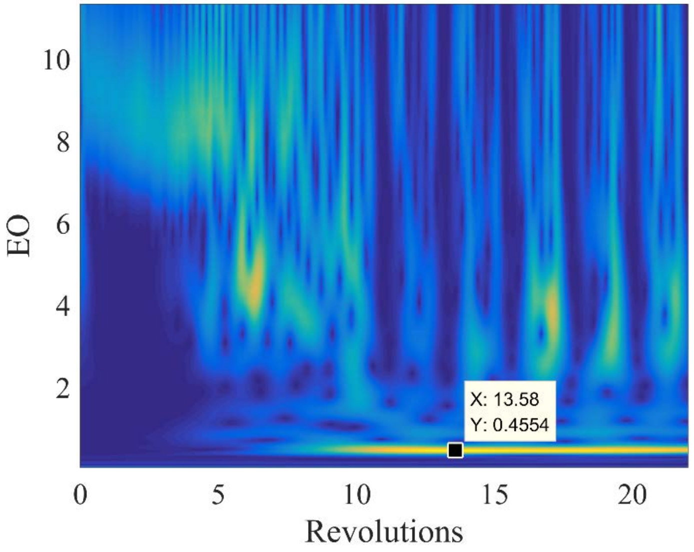






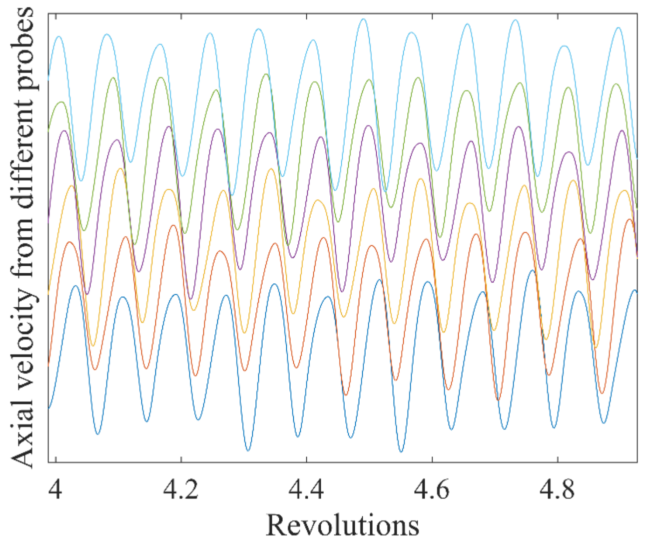
Axial positions of numerical probes

Axial velocity distribution near the casing

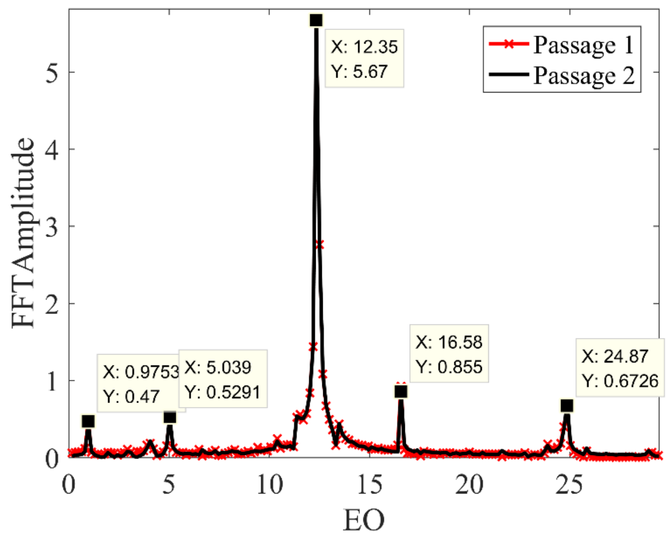


$$(1 - 0.4554) \times 100\% = 54.46\%$$
$$(1 - 0.4475) \times 100\% = 55.25\%$$

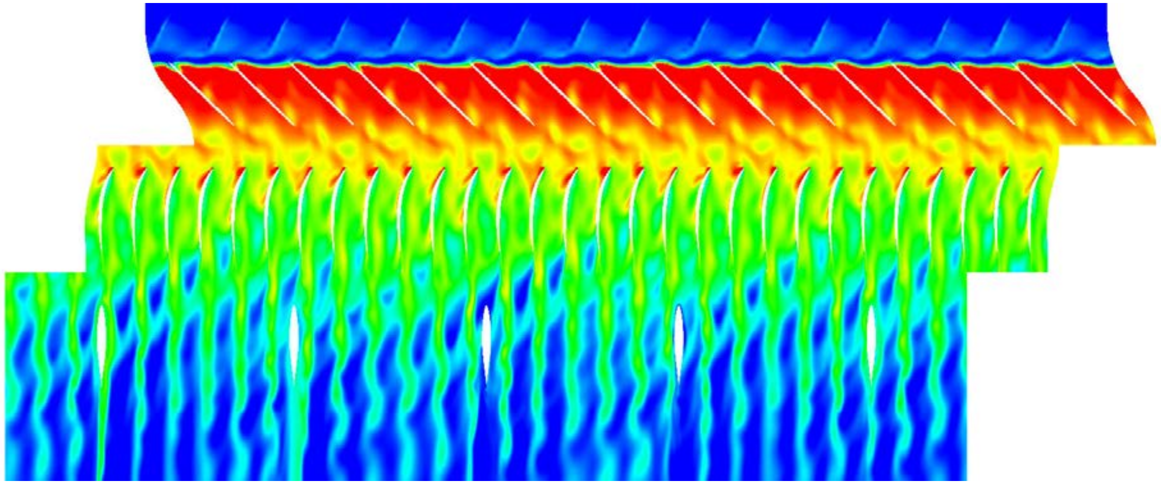
Rotating instability(100% speed)



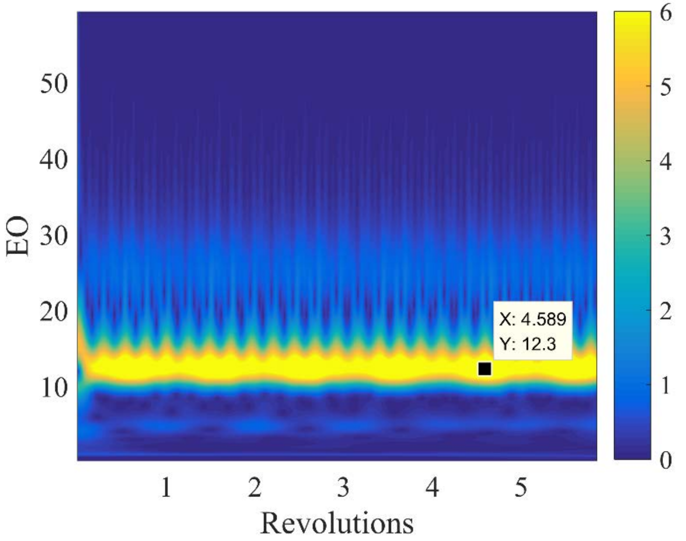
Axial velocity history



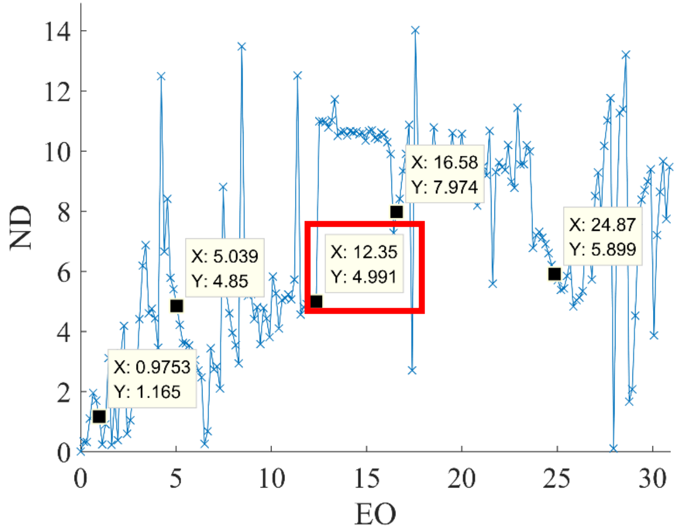
FFT amplitude



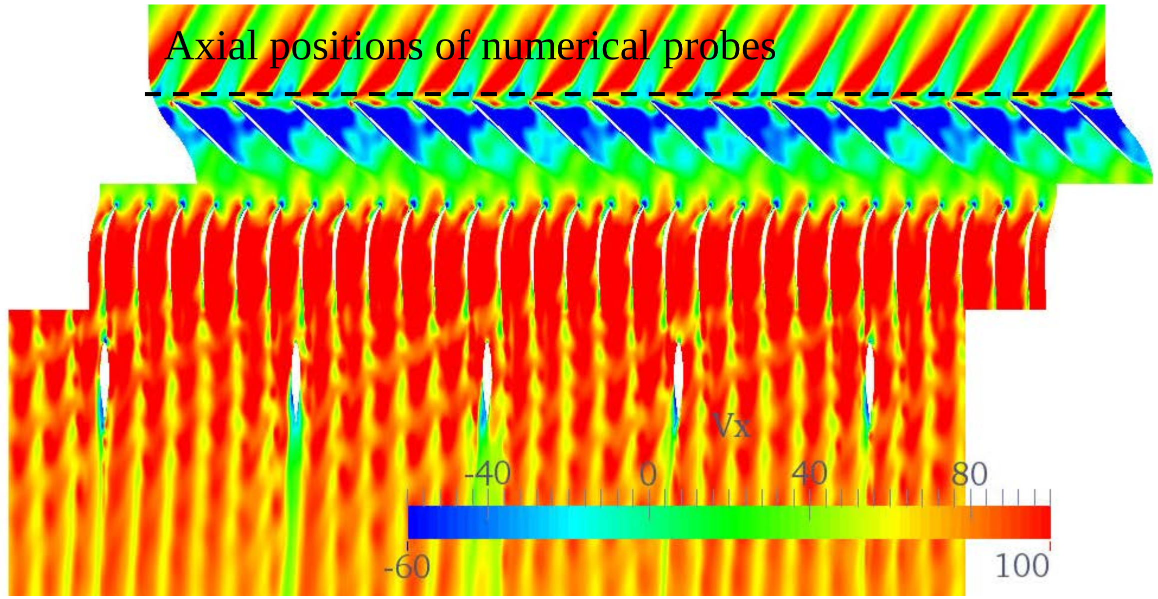
Entropy function distribution near the casing



Wavelet analysis



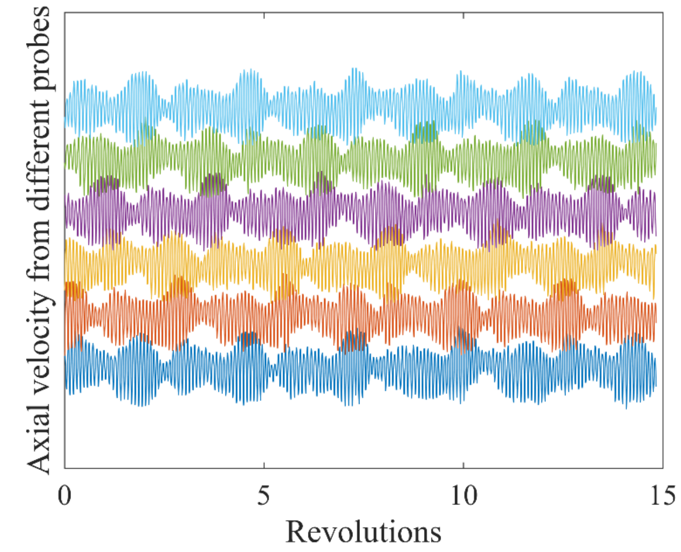
Nodal diameter



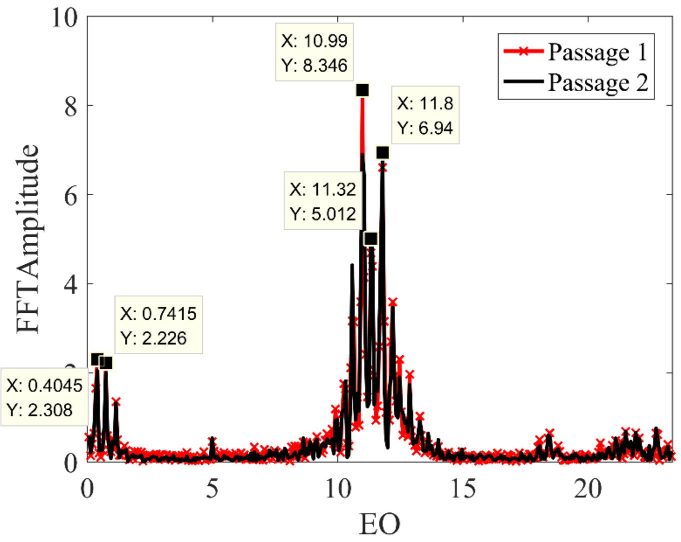
Axial velocity distribution near the casing

Rotating instability(100% speed)

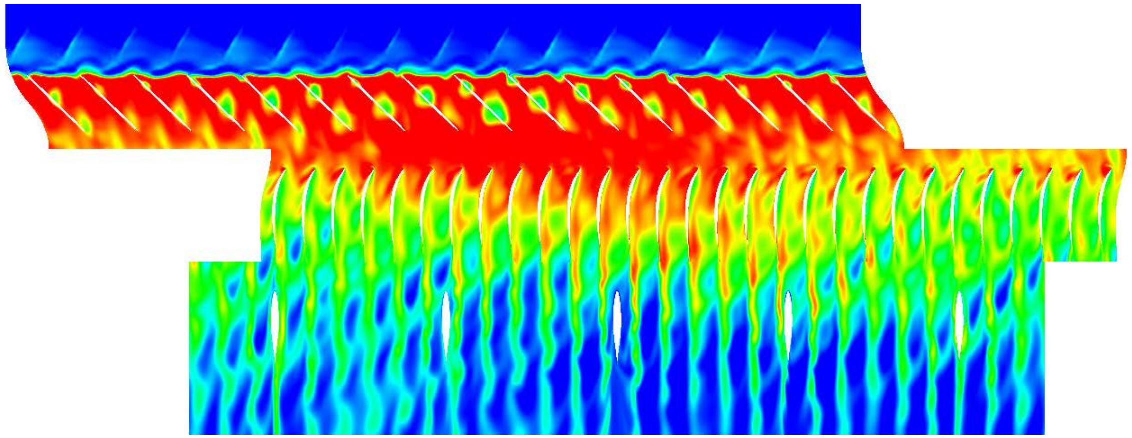
Unsteady operation point 2



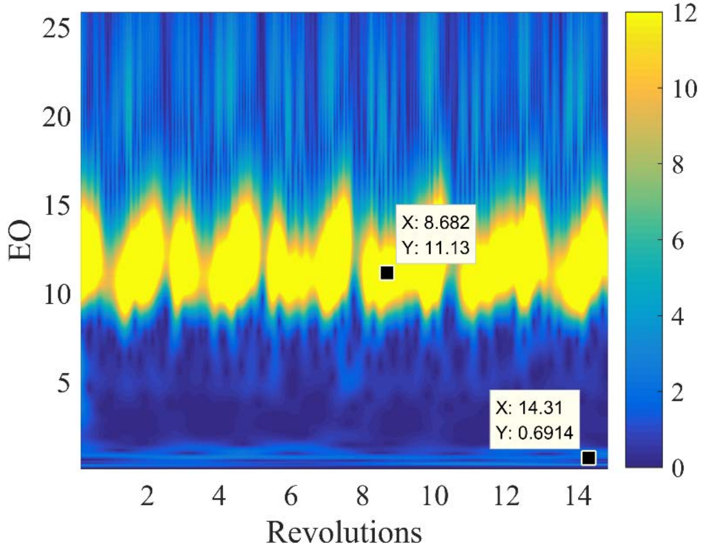
Axial velocity history



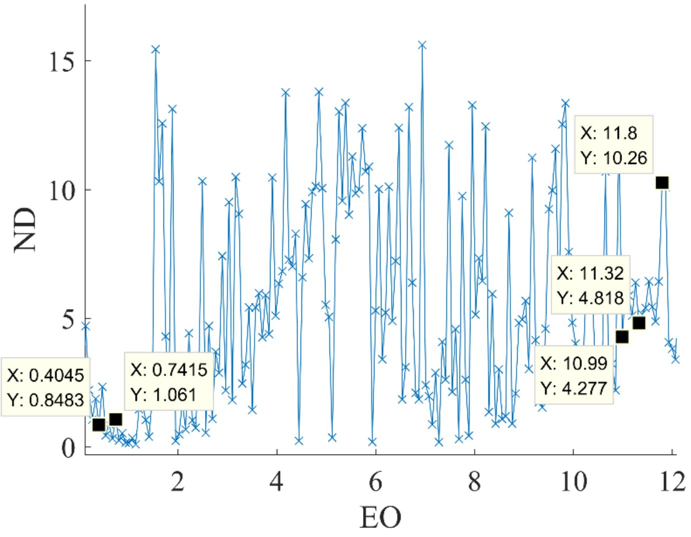
FFT amplitude



Entropy function distribution near the casing

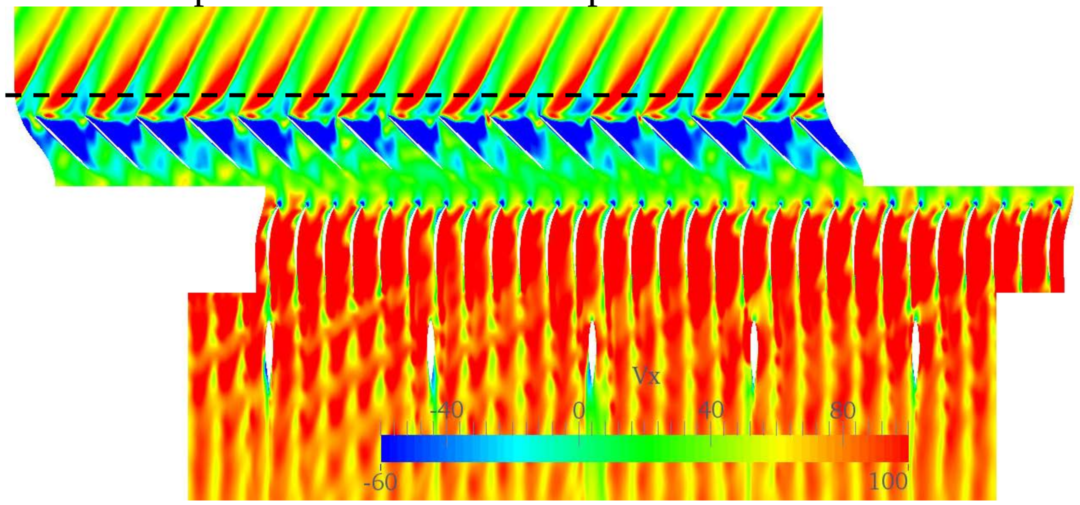


Wavelet analysis



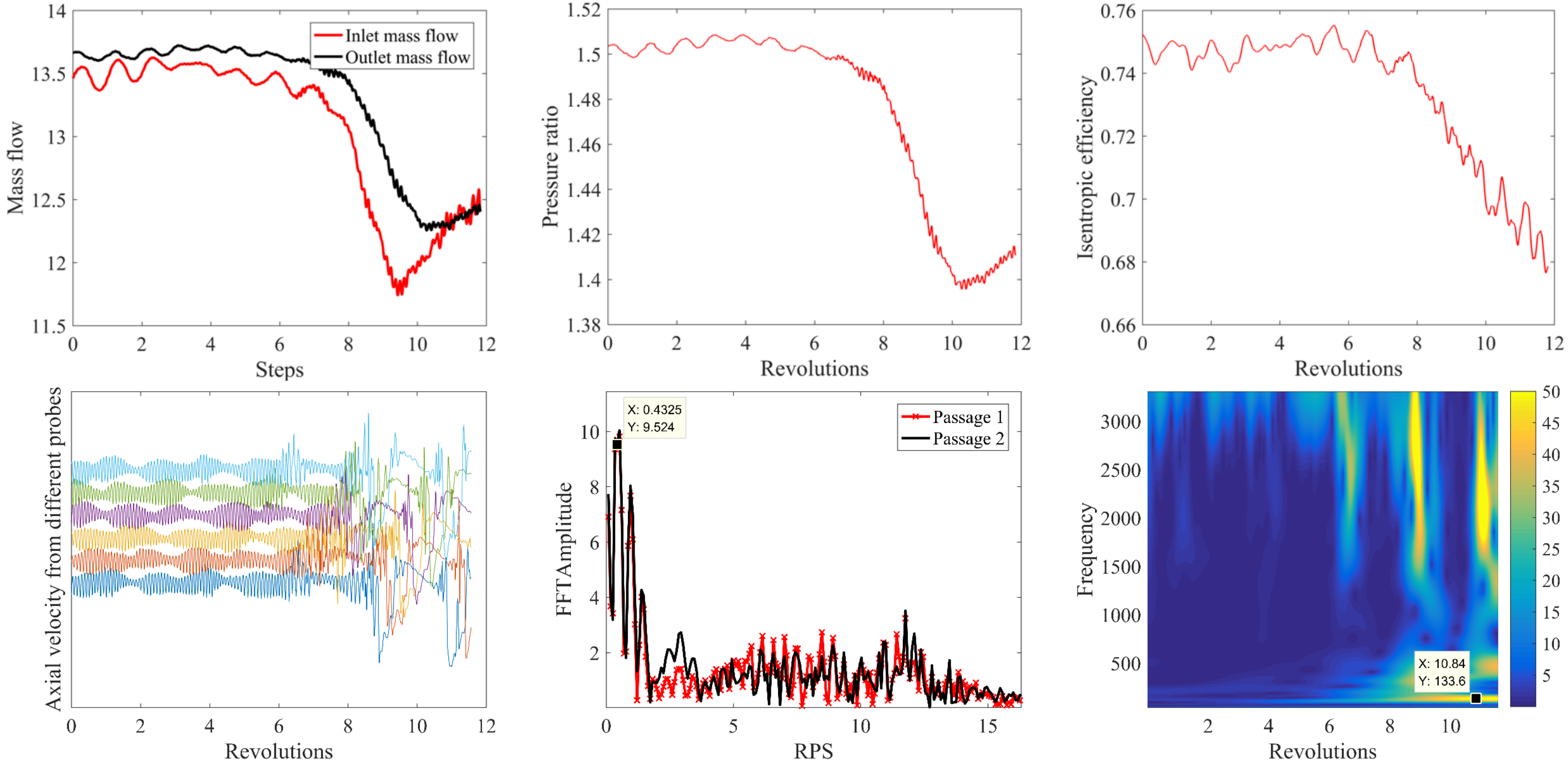
Nodal diameter

Axial positions of numerical probes



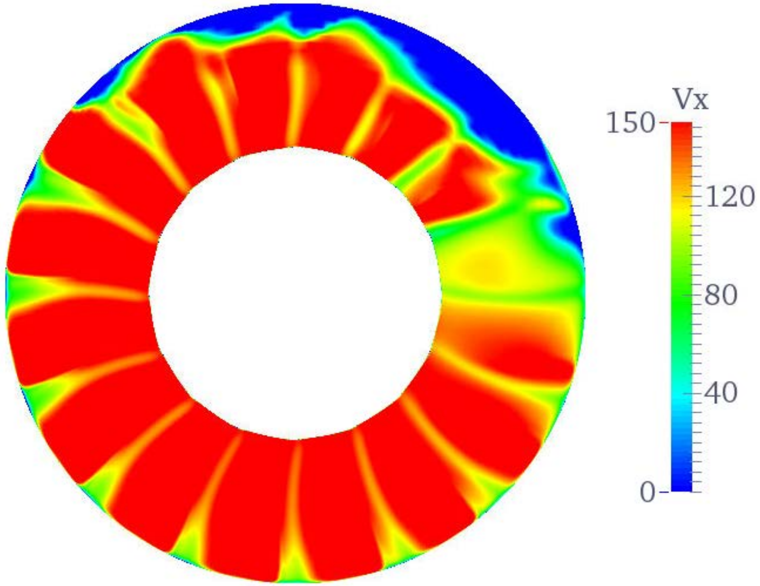
Axial velocity distribution near the casing

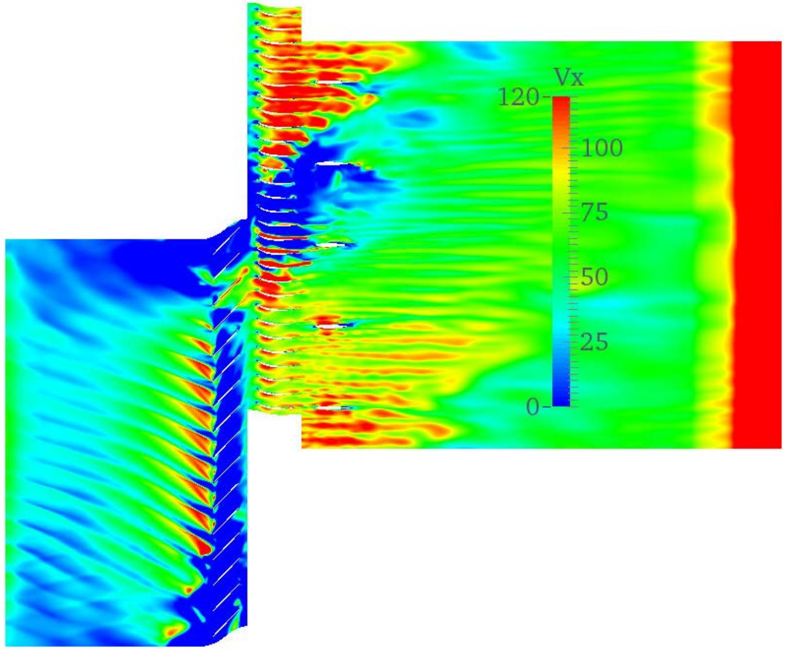
Rotating stall(100% speed, unstable)

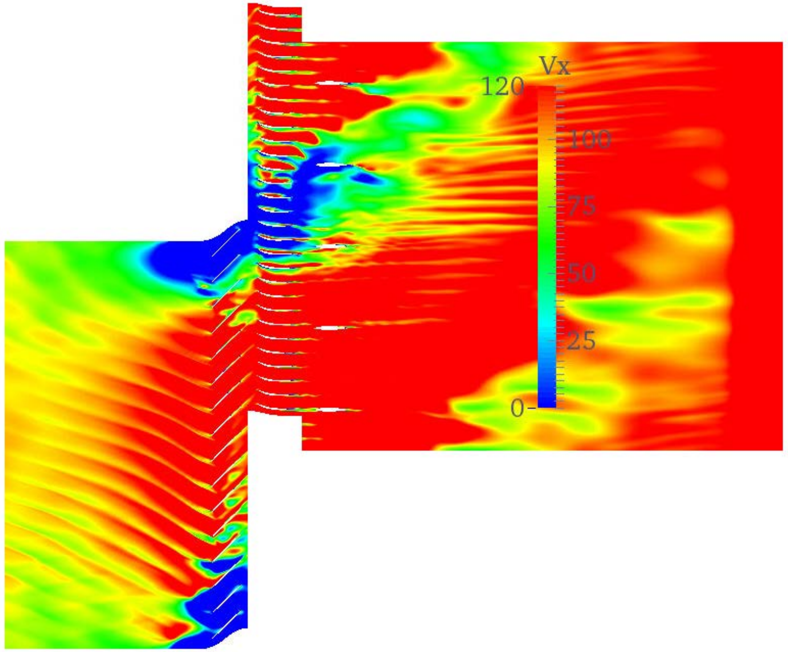


Rotating speed of the stall cell: 56.75% 60.00%

Rotating stall(100% speed, unstable)







Axial velocity distribution at the rotor inlet

Axial velocity distribution near the casing

Axial velocity distribution at 60% span

Conclusion

1. Calculated radial profiles of total pressure ratio, total temperature ratio and flow angle at a near choke and a near stall point match the test data well at both 65% and 100% of the design speed.
2. Total pressure ratio, efficiency and stall margin calculated from unsteady analyses at both 65% and 100% of the design speed match the test data well.
3. Unsteady flows at near stall conditions at 65% and 100% of the design speed are analyzed, with rotating stalls being found.

Thanks for your attention!