GPPS 1st Turbomachinery
CFD Workshop

GPPS-TC-2021-0050

Validation and Verification of RANS Solvers for TUDa-GLR-OpenStage Transonic Axial Compressor

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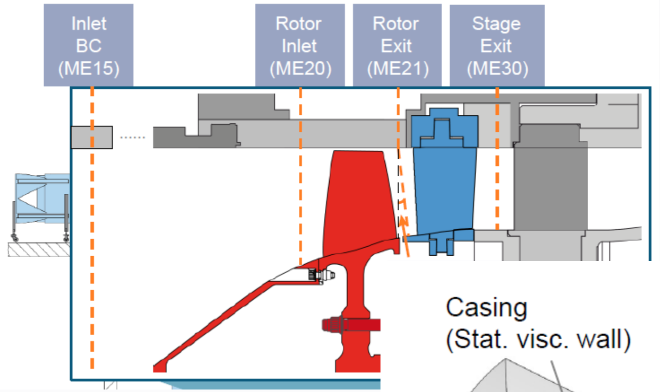
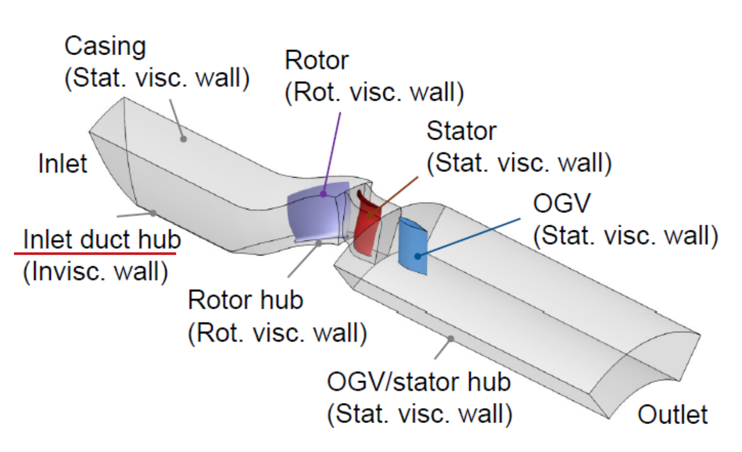
Contents

Methodology

CFD Solvers

- **ANSYS CFX** 20.1
  – Element-based finite volume method
- **Numeca FineTurbo** 14.1
  – Cell-centered control volume method





Boundary Conditions

Locations	Settings
Inlet	Axial direction / Measured P* and T* profiles
	Turbulence intensity / length scale: 4% / 0.09mm
Inlet duct hub	Inviscid wall
R / S and S / OGV	Mixing plane
Outlet	1.5 times the compressor core axial length downstream of OGV
	Constant backpressure

Methodology

Grids

- Numeca AutoGrid v5
- Hexahedron grids / O4H topology
- $y^+ < 3$
- **OGV** remain the **Medium** density

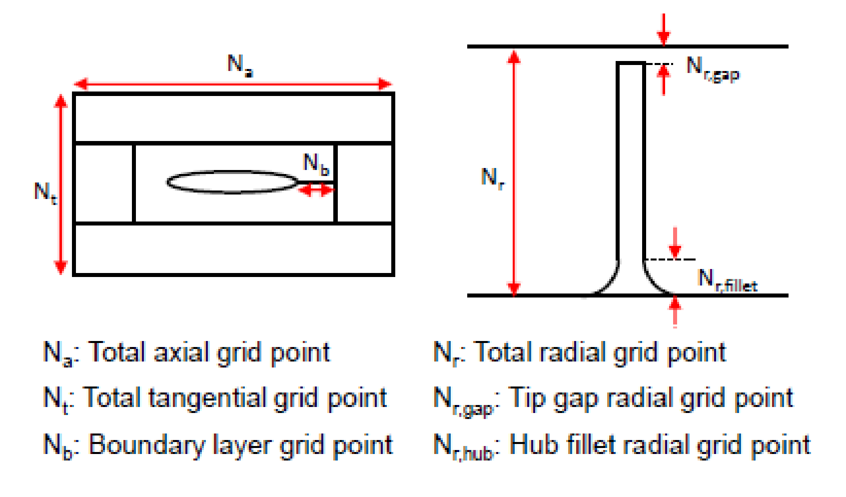


Illustration of grid topology

Grid density	Grid Points (mil.)			
	Rotor	Stotor	OGV	Total
UltraCoarse	0.12	0.04	0.85	1.01
Coarse	0.28	0.16	0.85	1.29
Medium	1.08	0.53	0.85	2.46
Fine	3.36	1.8	0.85	6.01
UltraFine	11.8	5.81	0.85	18.43

Results

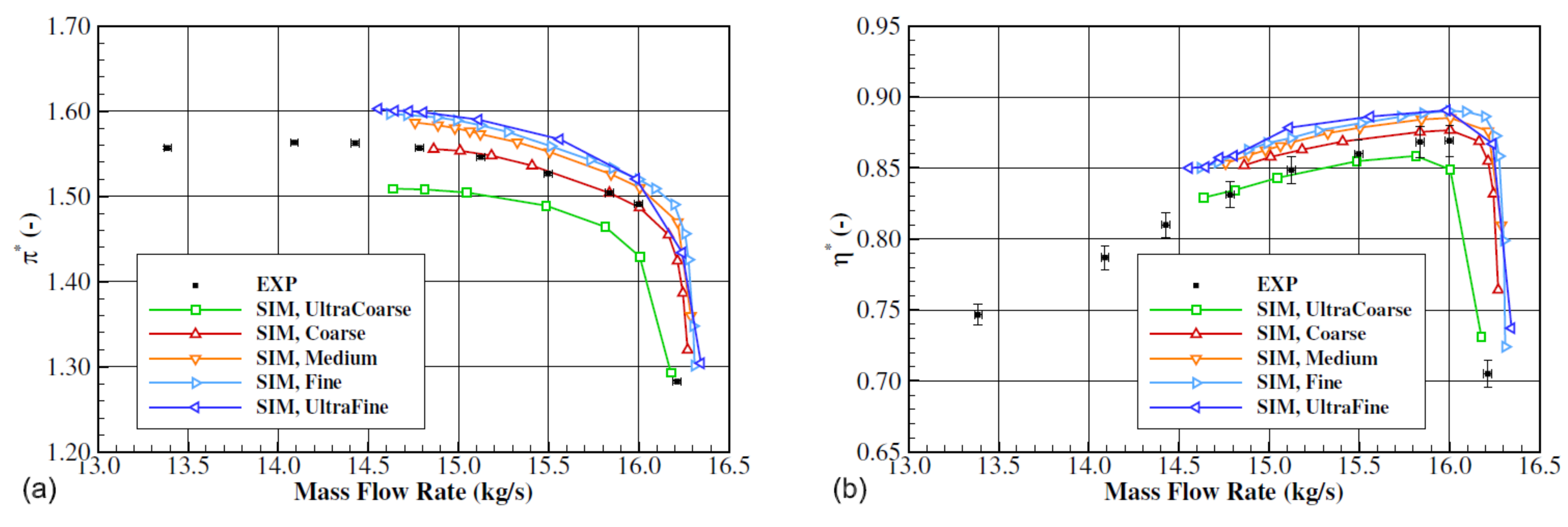
- **Computation Results**
  - **Effect of Numerical Settings**
    - **Grid Density**
      - CFX — Five Sets of Grids
      - Numeca — Five Sets of Grids
    - **Advetion Scheme**
      - CFX — High Resolution
      - Numeca
        - Central
        - Upwind
    - **Turbulence Model** — Numeca
      - SST
      - SA
      - SARC
      - EARSM
    - **Rotor-Stator Interface** — CFX
      - Mixing Plane
      - Sliding Interface
  - **Effect of Geometric Uncertainty and Error**
    - **Rotor Running Tip Gap Shape** — Numeca
      - PE, uniform
      - NS, uniform
      - PE, non-uniform
      - NS, non-uniform
    - **Stator Hub Cavity** — Numeca
      - Without Cavity
      - With Cavity
    - **Stage Throat Area Change** — CFX
      - 15.86 kg/s
      - 16.00 kg/s
      - 16.09 kg/s

- 100% speed
- Characteristic curves of π^* & η^*
- Radial profiles at rotor outlet (ME21) & stage outlet (ME30)

Results

Effect of Grid Density – Compressor Maps at 100%N

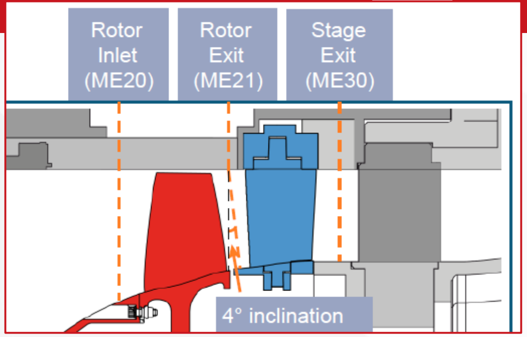
- CFX, SST
- Grid density ↑ → Curves towards top right corner
- Fine→UltraFine: 0.01 and 0.1% variation of π^* & η^*

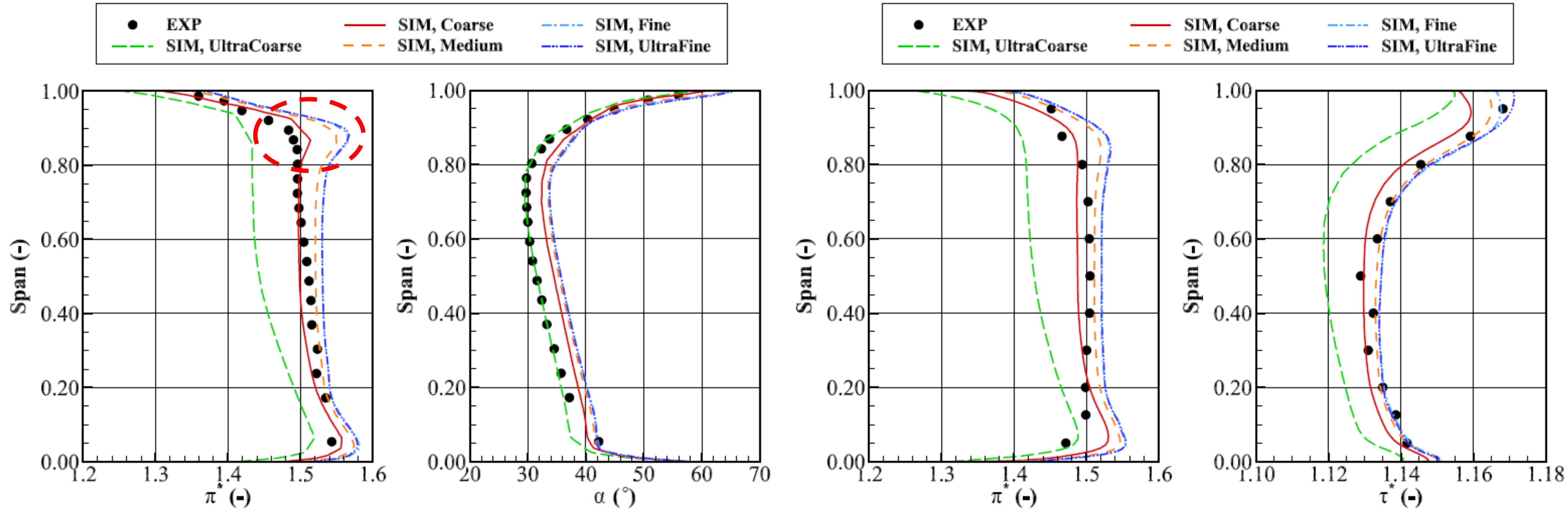


Results

Effect of Grid Density – Radial Profiles

- Grid density ↑ → π^*, α, η^* ↑
- Fine & Ultrafine: Overprediction above 80% span





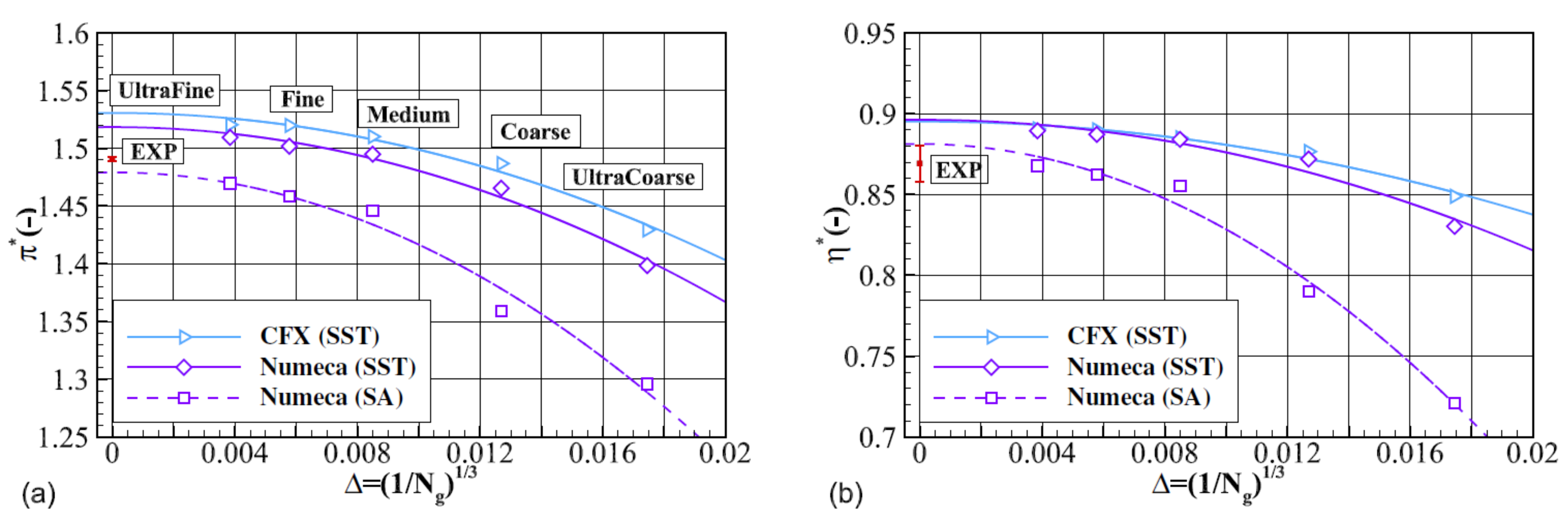
(a) rotor exit (ME21).

(b) stage exit (ME30).

Effect of Grid Density – Quantity v.s. Nominal grid spacing

- π^* & η^* v.s. $\Delta = (1/N_g)^{1/3}$ (PE condition)
- Curves: Least-squares fits of parabolas
- CFX (SST)
  - Discretization error (q_{ideal} - q_{Fine}): 0.01 in π^* and 0.5% in η^*

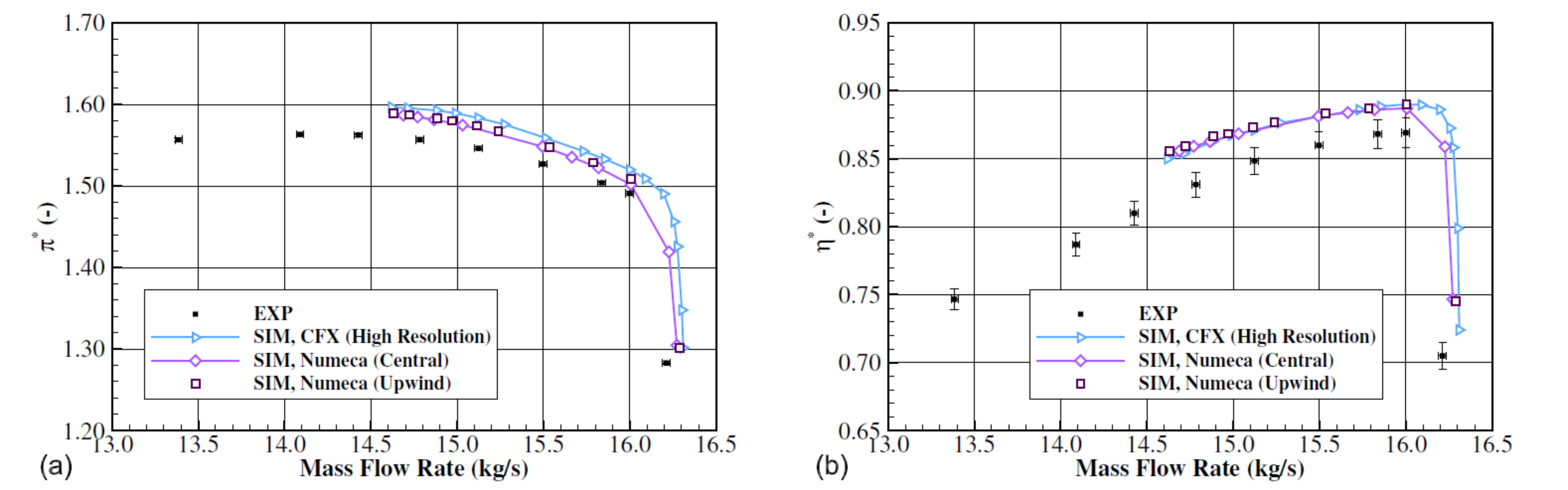
- The Fine grid is adopted for all the simulations in later calculations



Results

Effect of Advection Scheme

- Overlapping results are expected
- Numeca(Central) & Numeca(Upwind): almost overlapping
- CFX(High Resolution): slightly higher m_c, π^* & η^*



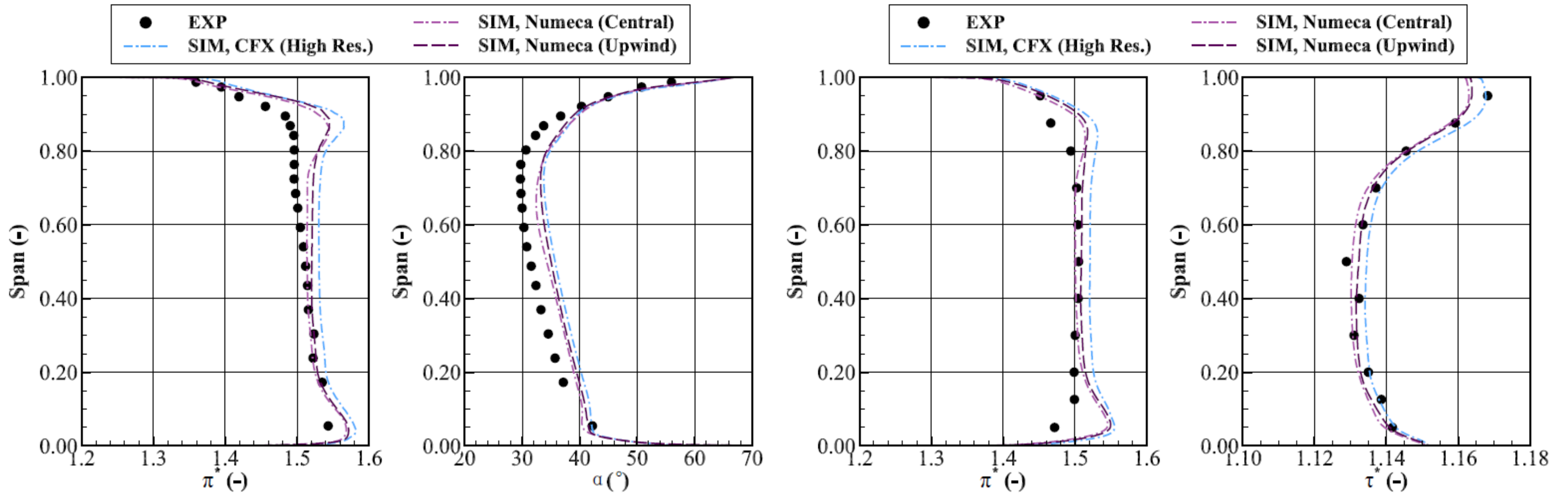
Results

Effect of Advection Scheme – Radial Profiles

- CFX: higher than Numeca results
- Minor difference → numerical settings

Difference in numerical settings

Solver	SST Model	Wall function
CFX	2003 version	Scalable wall function
Numeca	1994 version	No wall function

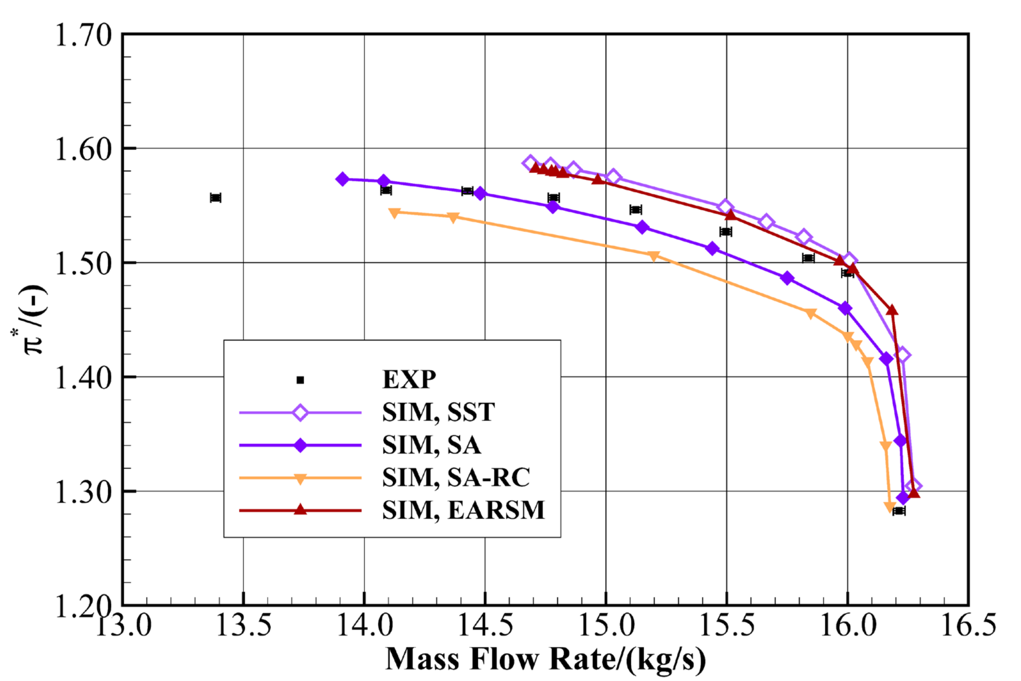


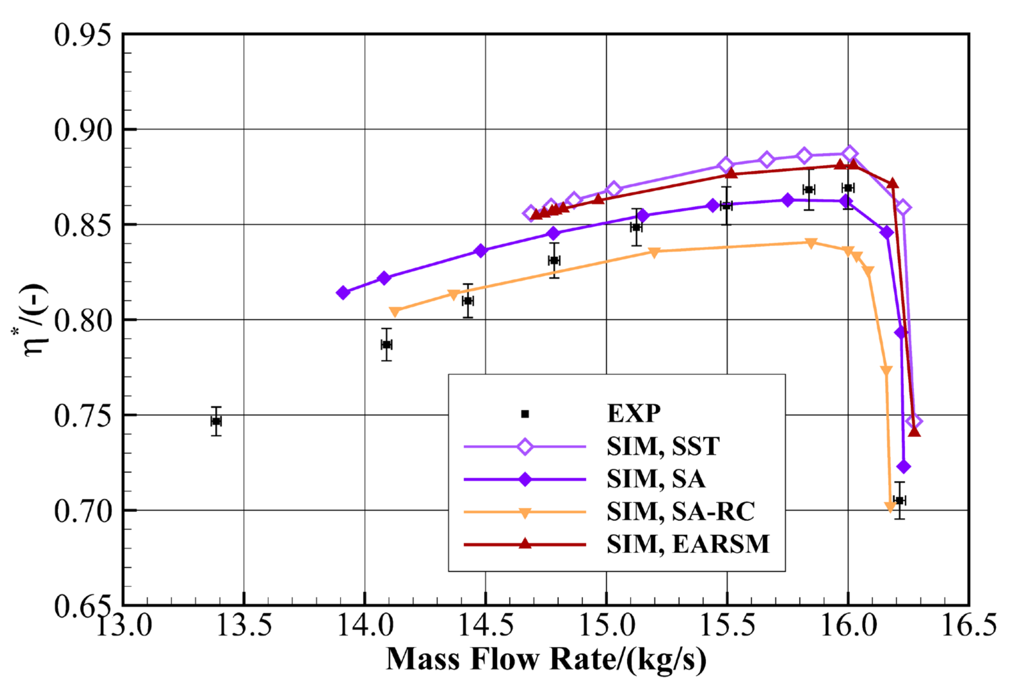
(a) rotor exit (ME21). (b) stage exit (ME30).

Results

Effect of Turbulence Model

- Numeca, Fine grid
  - SST, SA, SARC, EARSM
- Turbulence model has a great influence



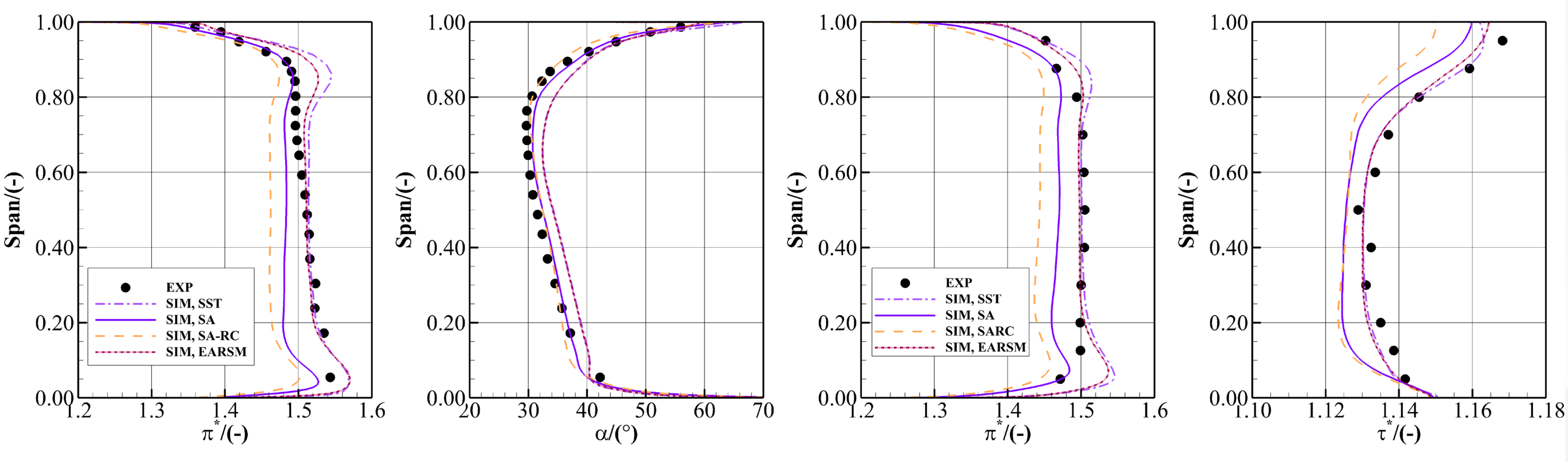


Results

Effect of Turbulence Model – Radial Profiles

- SA & SARC: underpredict the pressure ratio below 80% span
- Results of SST and EARSM are close

- The choice of turbulence model remains an open option for the users.



(a) rotor exit (ME21).

(b) stage exit (ME30).

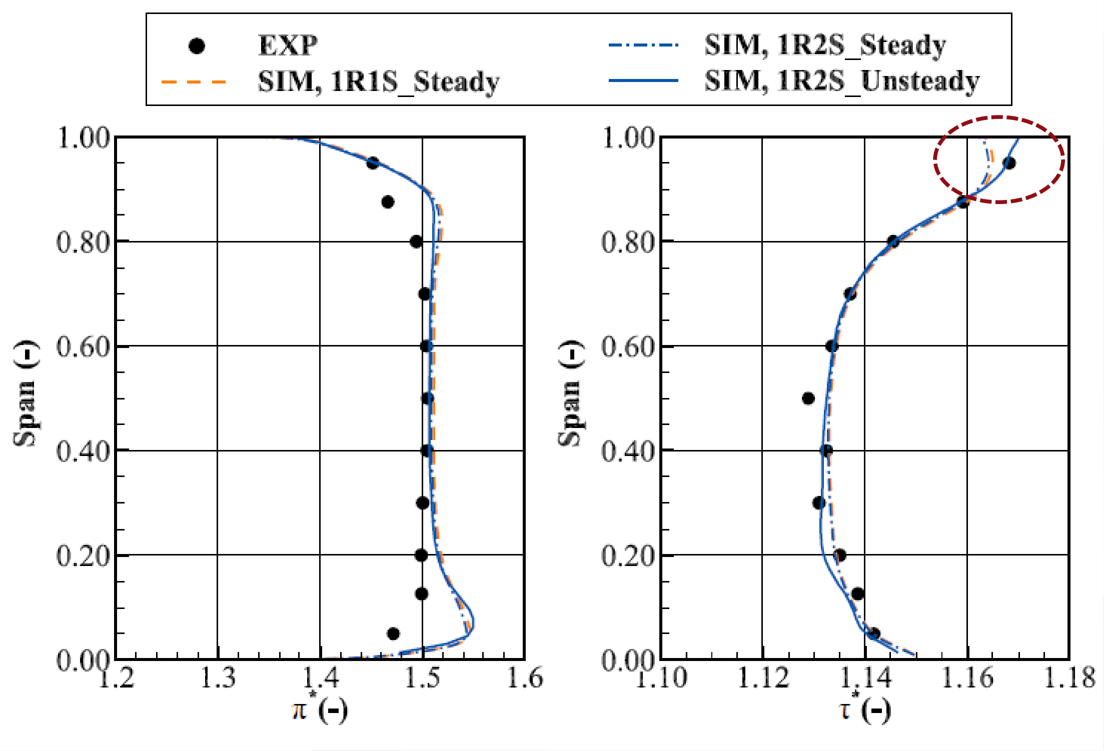
Results

Effect of Rotor-Stator Interface Model

- Mixing Plane v.s. Sliding Interface
- CFX, Medium grid, SST, PE condition
- Stator Blades: 29 to 32 → 1R2S
- 10 revolutions (Time step: Δt·BPF = 50)

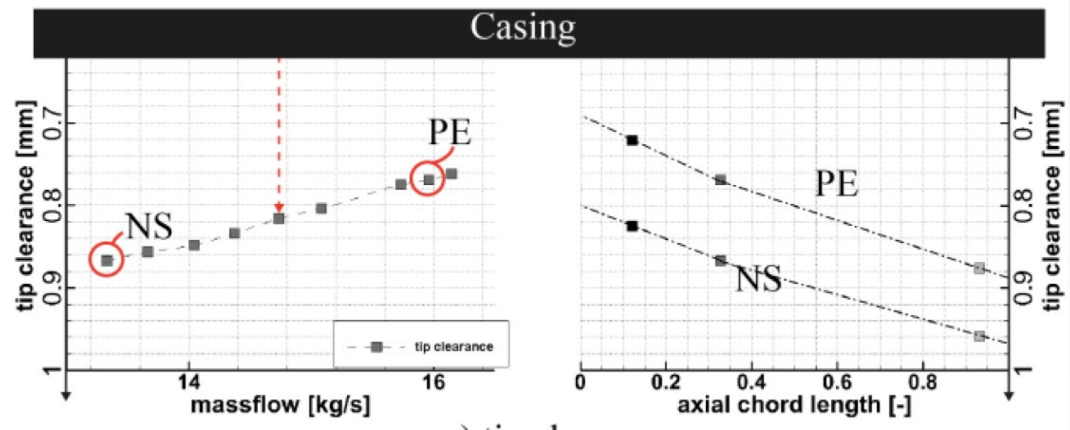
- Mixing Plane is sufficient for the simulation at PE condition

Case	Peak efficiency		
	m (kg/s)	π^* (-)	η^* (%)
Experiment	16.00	1.49	86.9
1R1S, steady	16.01	1.51	88.5
1R2S, steady	16.02	1.51	88.4
1R2S, unsteady	15.98	1.50	87.7



Discussions on Geometric Uncertainty and Error

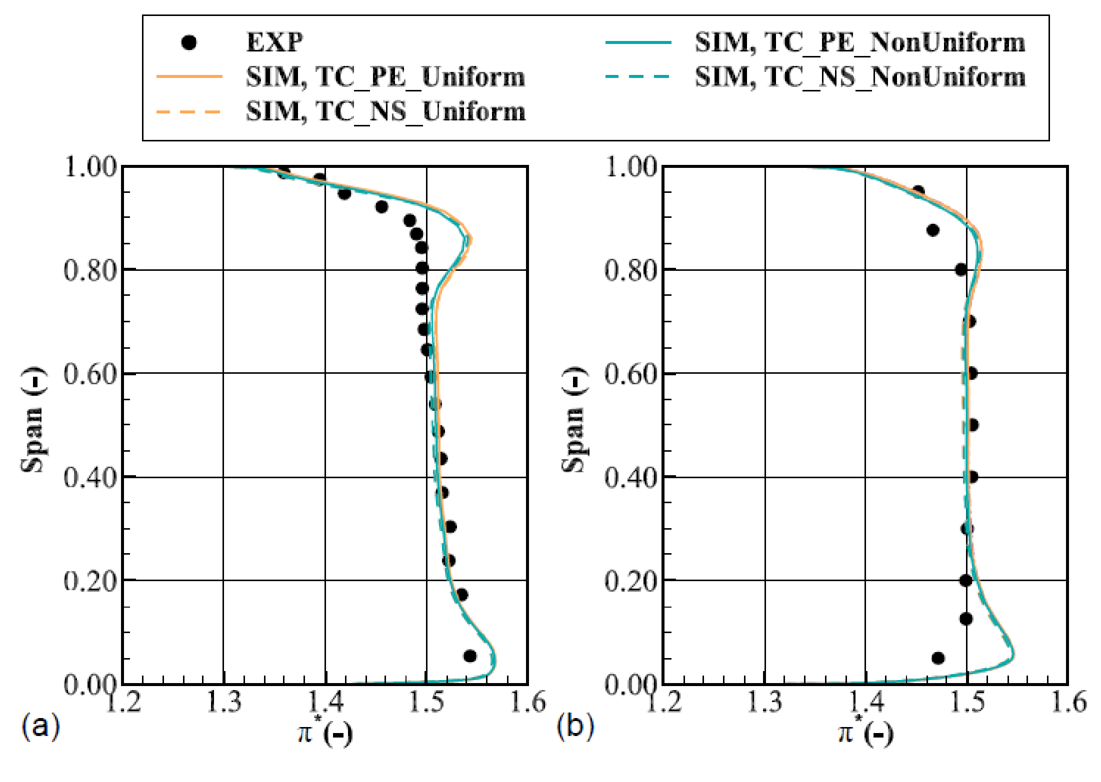
Effect of Rotor Running Tip Gap Shape



c) tip clearance

Case	Tip gap size (mm)		
	$13\% \, c_t$	$32\% \, c_t$	$93\% \, c_t$
Datum	0.75	0.75	0.75
TC, PE, uniform	0.77	0.77	0.77
TC, NS, uniform	0.87	0.87	0.87
TC, PE, non-uniform	0.72	0.77	0.78
TC, NS, non-uniform	0.83	0.87	0.96

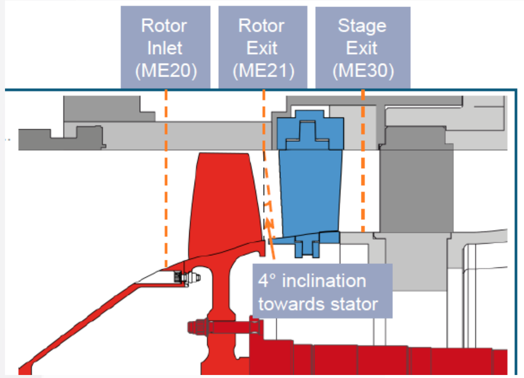
- Such a small change in tip gap size has negligible effects on the compressor performance

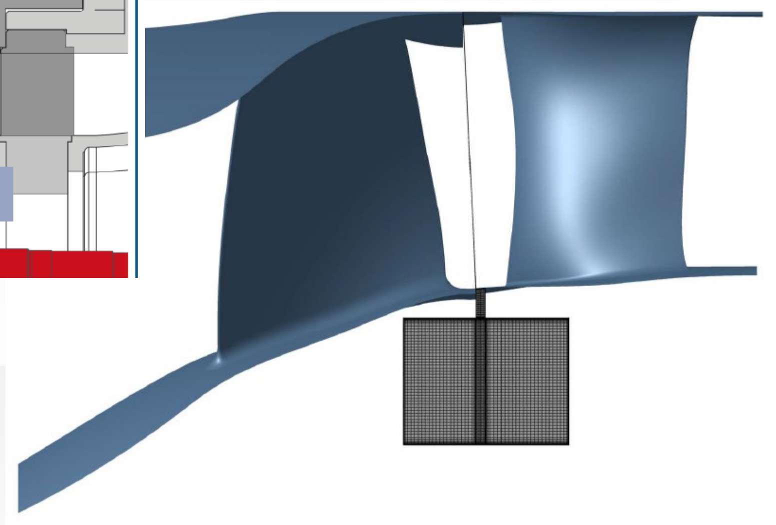


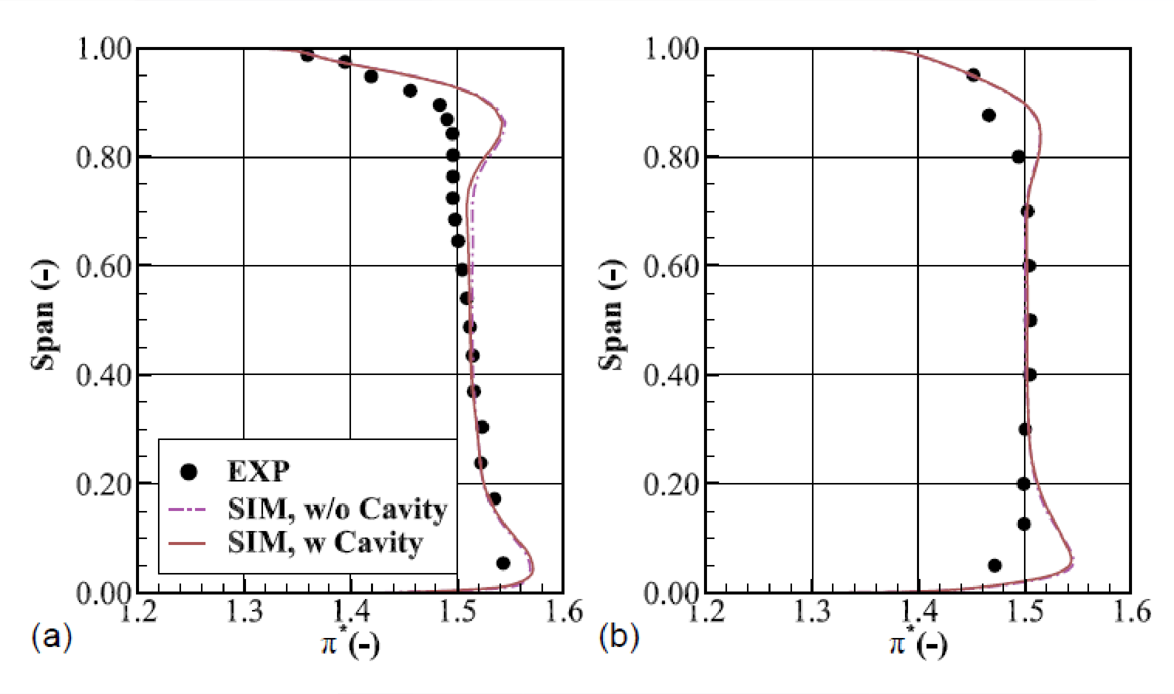
Effect of Stator Hub Cavity

- A secondary flow passage that connects the stator inlet hub to the stator outlet hub
- Overprediction below 20% ?
- Numeca, Fine grid, SST

- The cavity domain with zero leakage flow has a negligible effect on the main flow;
- A non-zero leakage flow can potentially lead to an evident difference.







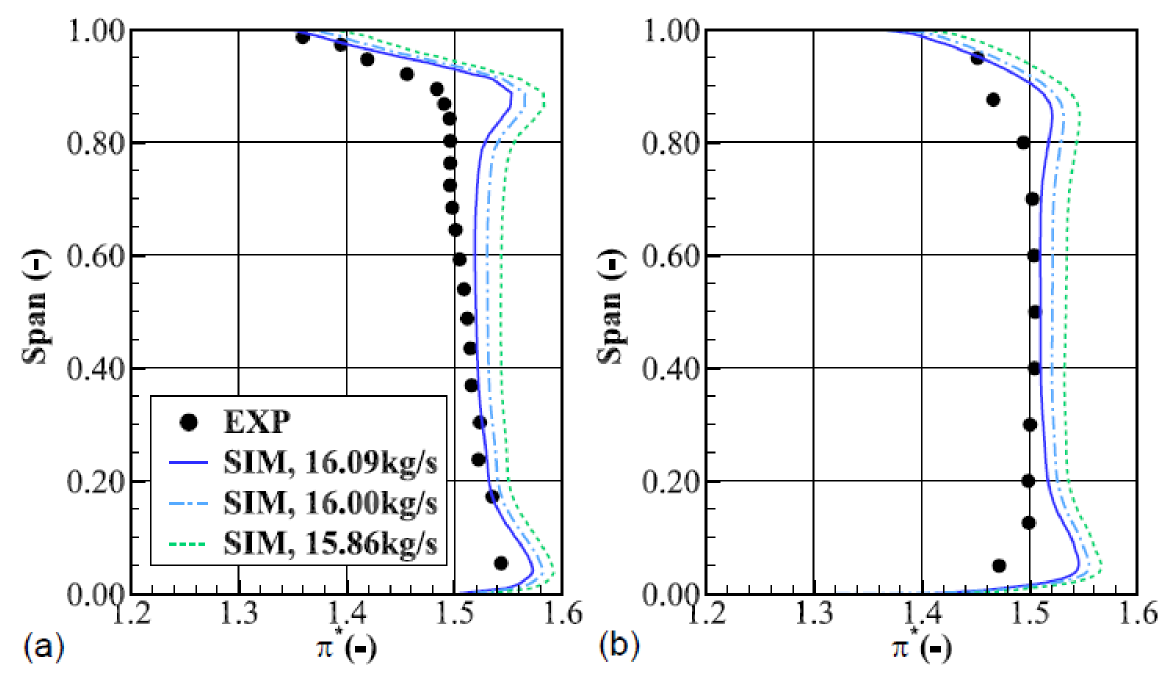
ME21 ME30

Discussions on Geometric Uncertainty and Error

Effect of Stage Throat Area Change

- Slight difference in the throat area → an evident change in the inflow incidence
- Normalized mass flow rate m/m_c
  - 16.09 kg/s
  - 16.00 kg/s
  - 15.86 kg/s
- CFX, Fine grid, SST
- 16.09 kg/s: better agreement between 30% and 70% span.

- The inconsistency near both endwalls comes from other uncertainties and errors, rather than throat area.



ME21 ME30

Conclusions and Future Works

The Differences Between EXP and SIM:

- Rotor near-tip flow / Stator near-hub flow

→
- Turbulence models
- Real geometric effects

Grid Density

- Fine(1.8 - 3.4 mil./passage): in-depth flow field analysis
- Medium(0.5 - 1.1 mil./passage): optimization and full-annulus

→
- Recommended grid points can be used as a reference

Advection Scheme

- Inconsistent numerical settings:
  Turbulence model version / wall function

→
- More RANS solvers to understand the effects of these settings

Turbulence Models

- The choice among turbulence models remain an open option

→
- More RANS flow solvers with more turbulence models

R/S Interface

- Mixing Plane is sufficient at PE condition

→
- Effect of R/S interface model at NS condition

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Thanks！

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