UNSTEADY LOSS IN THE STATOR DUE TO THE INCOMING ROTOR WAKE IN A HIGHLY LOADED TRANSONIC COMPRESSOR

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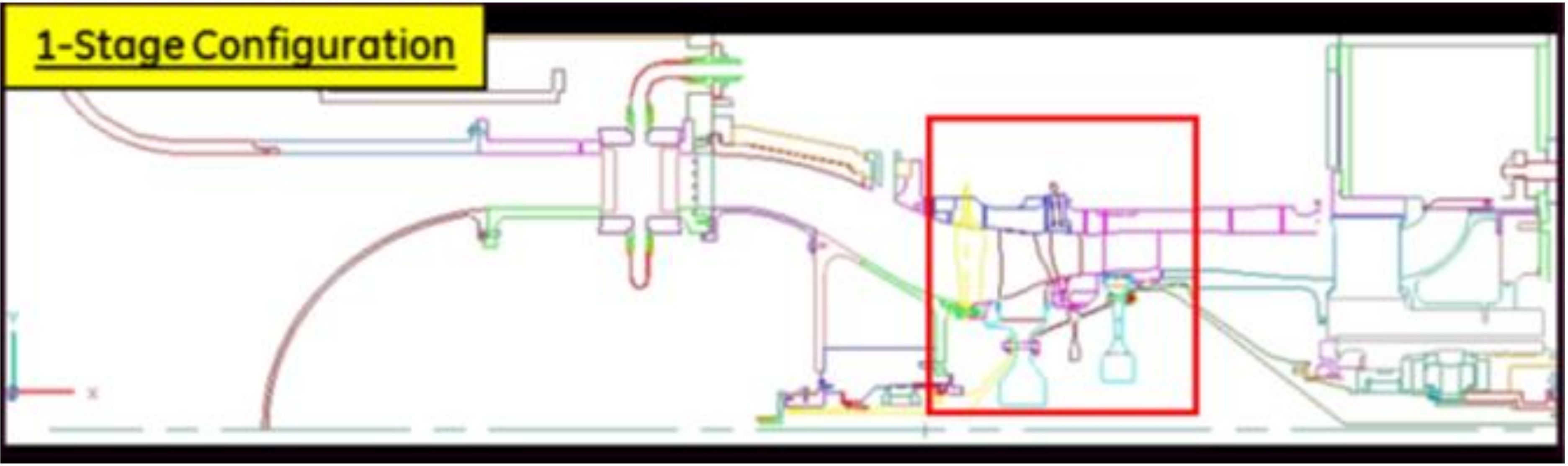
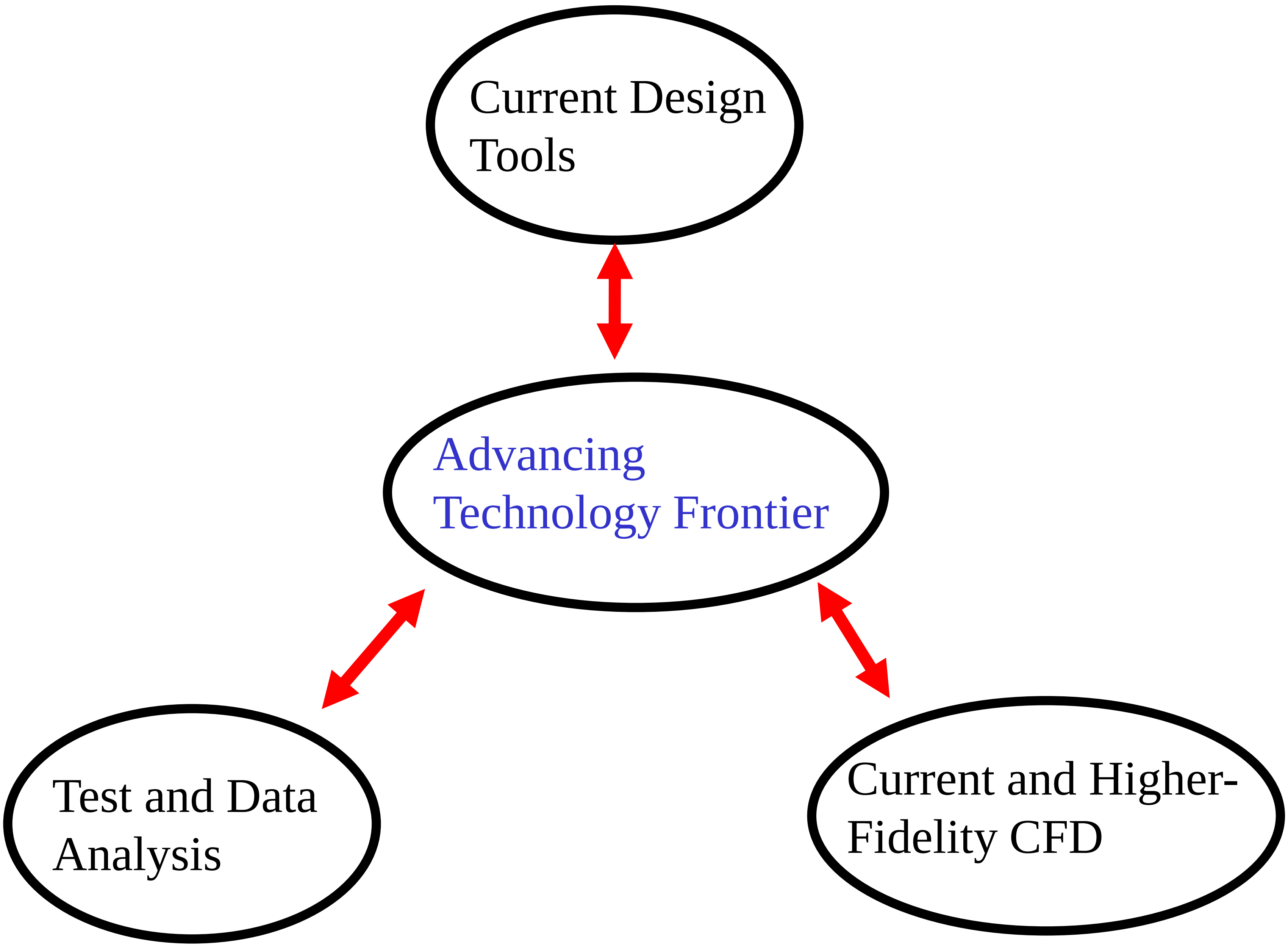
Background

- NASA ERA Program
  - Physics of Loss Generation in a GE Highly Loaded Transonic Compressor.
  - Aero Testing at NASA/Glenn W7 facility.
  - NASA Internal CFD study with RANS, URANS, LES.

1-Stage Rig Configulation




Current Design Tools
Advancing Technology Frontier
Test and Data Analysis
Current and Higher-Fidelity CFD

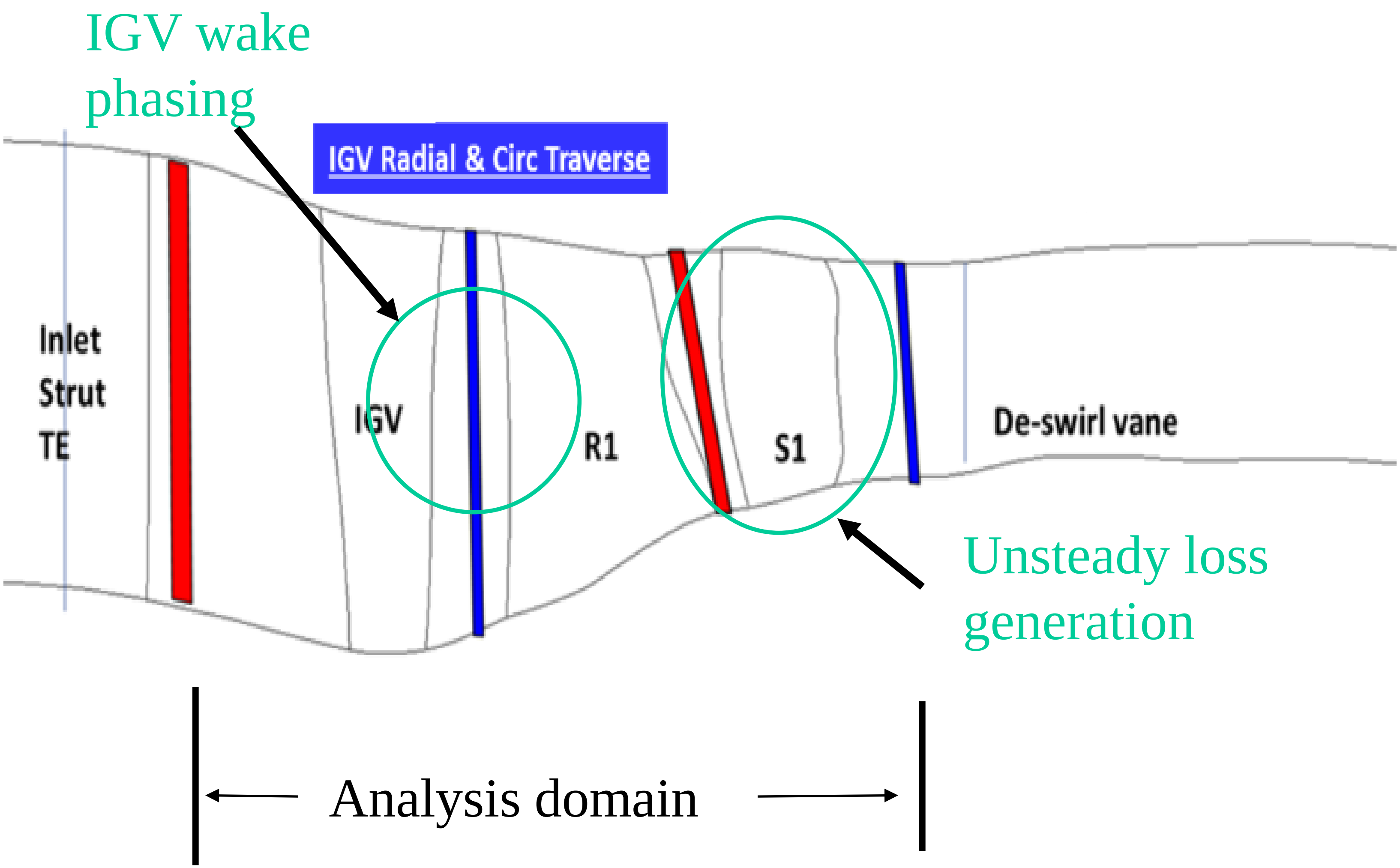
Objectives

- Application of a LES to investigate loss generation in a highly loaded compressor.
- Possible ways to reduce loss generation ?

Order of presentation

- LES set-up and CFD grids.
- Compressor characteristics from LES.
- Effects of spacing between IGV and R1.
- Unsteady loss generation in the stator passage.
- Effects of spacing between R1 and S1.
- Concluding remarks.

CFD analysis of the first stage



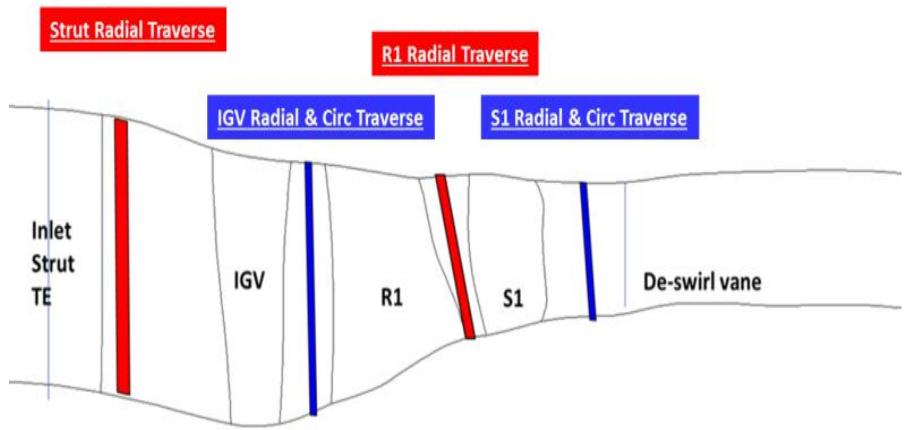
LES for turbomachinery application

- To address some shortcomings of RANS/URANS (vortex interaction, flow separation, wake development. Etc.)
- Significant increase in computing cost with large size computational grid.
- Solution depends on CFD grid.
- Good insight and knowledge required to extract physics (needs further development).

Applied LES procedure

- 3^{rd}-order scheme for convection terms.
- 2^{nd}-order central differencing for diffusion terms.
- Sub-iteration at each time step.
- Dynamic model for sub grid stress tensor.

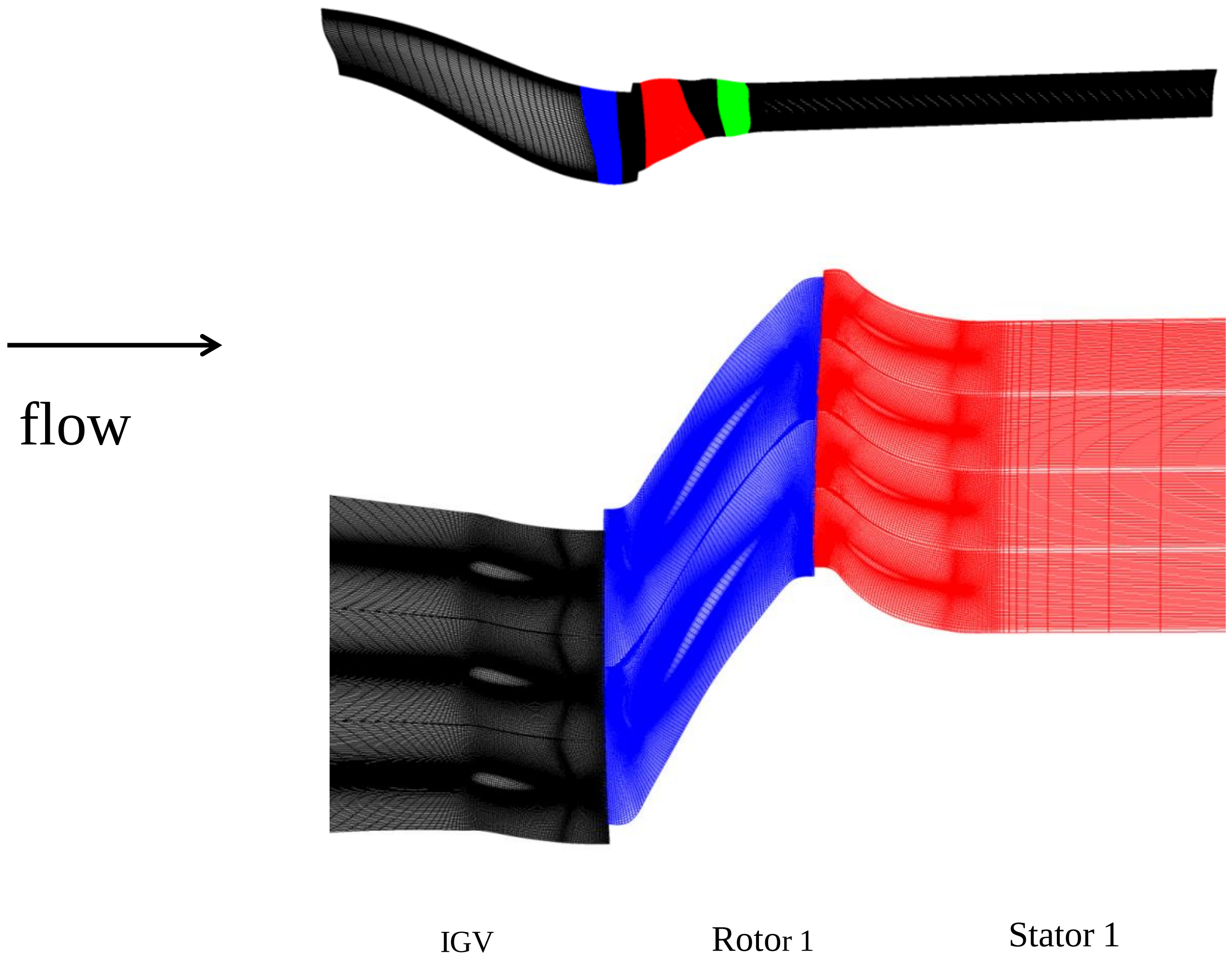
LES Set-Up



- Original Blades : 42 IGV, 28 R1, and 58 S1.

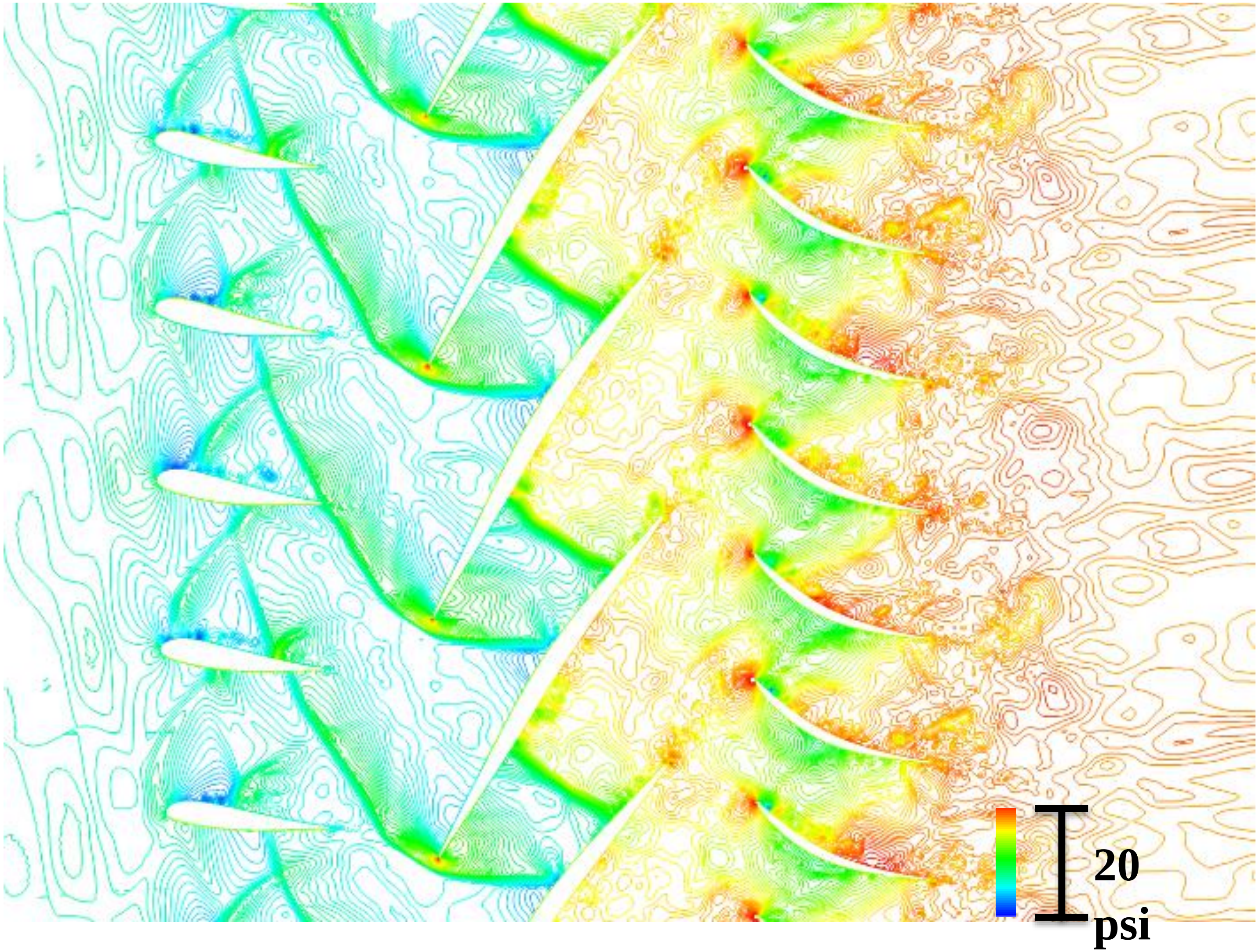
  Scaled to 42 IGV, 28 R1, and 56S1.
- 3 IGV , 2 R1 , and 4 S1 passages analyzed with periodicity condition.
- 500 million CFD nodes for 9 passages (for S1, 384x356x650 in B to B, Spanwise, axial direction for each passage)

Computational grid and domain

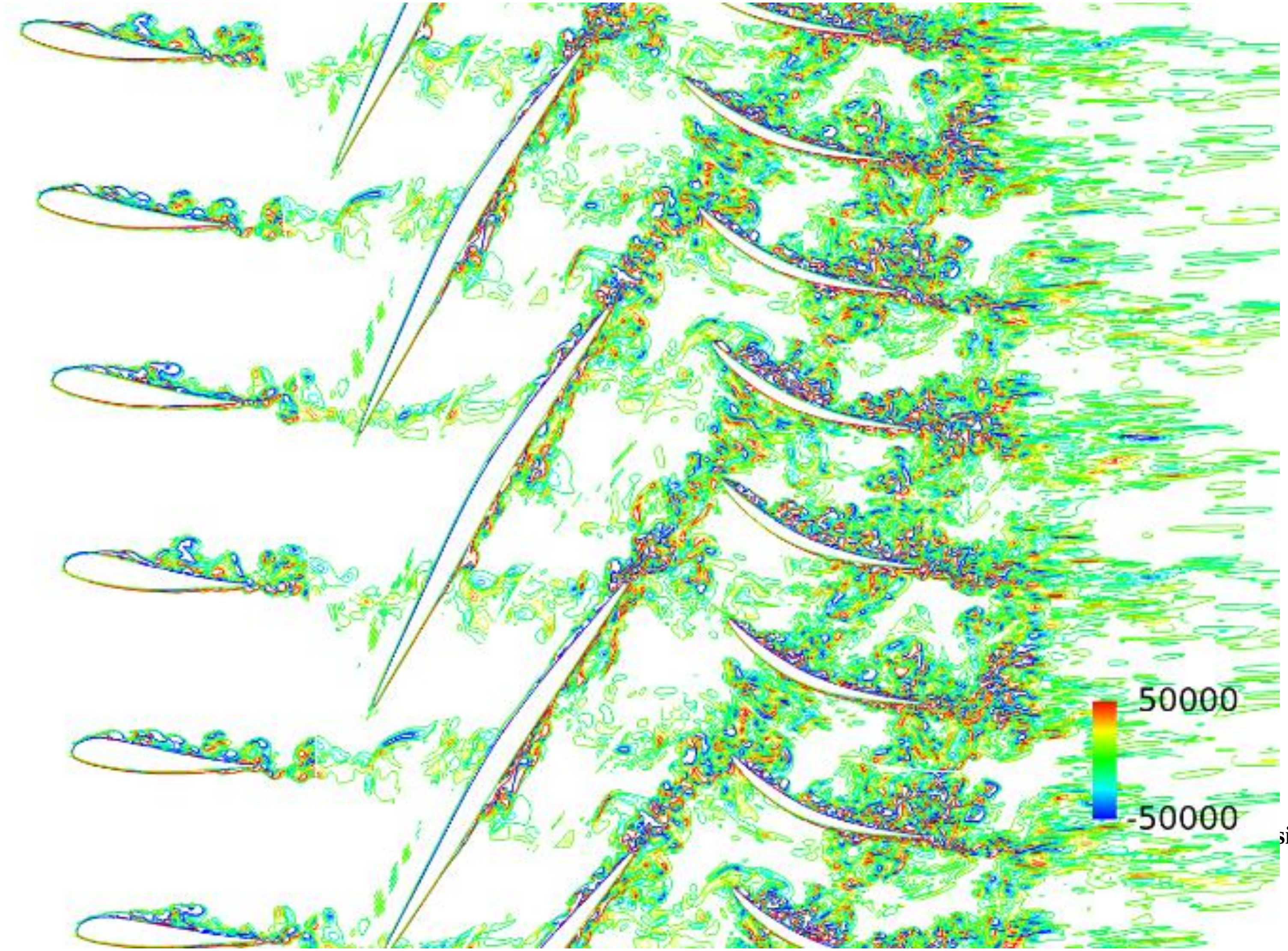


Overall compressor flow field from LES

Instantaneous pressure distribution at mid-span



Instantaneous vorticity distribution at mid-span



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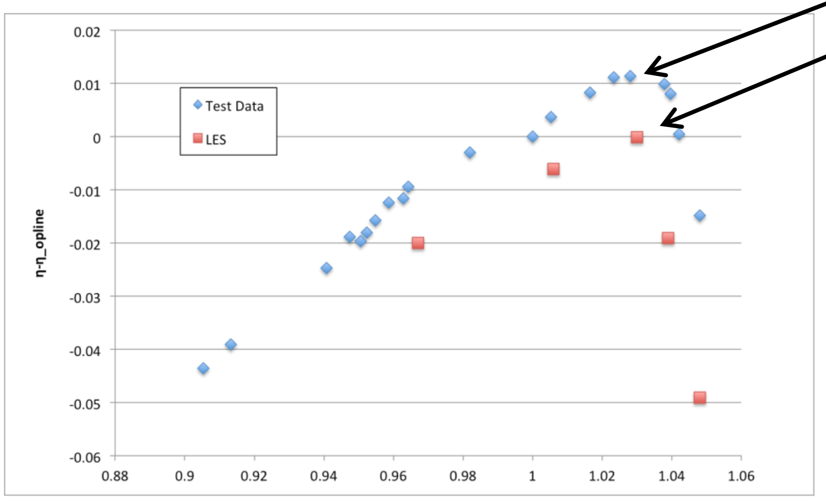
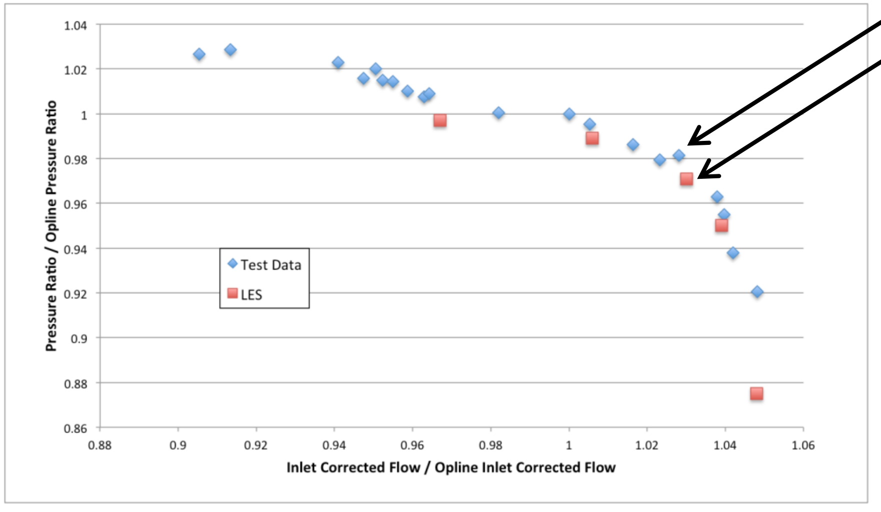
Comparison of corrected speedline relative to multi-stage compressor opline

Peak efficiency point

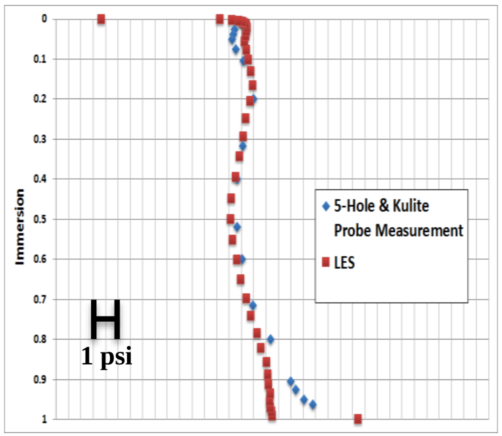


Peak efficiency point

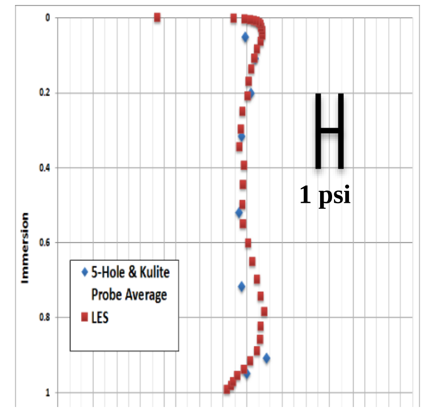


Comparison of Pt and Tt at exit of R1 and S1

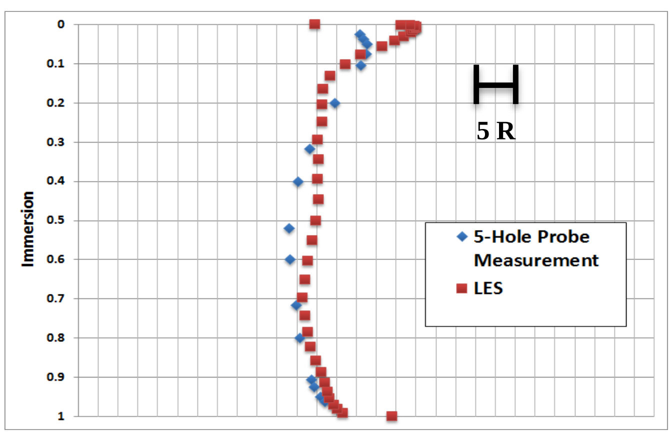
Pt



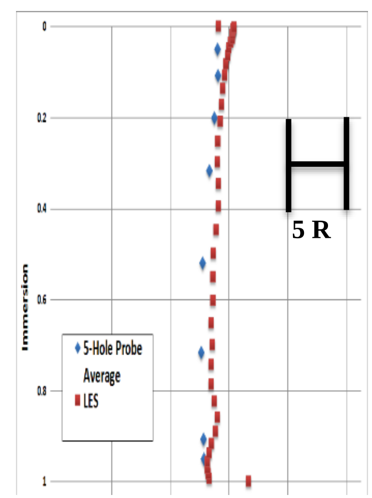
Pt



Tt



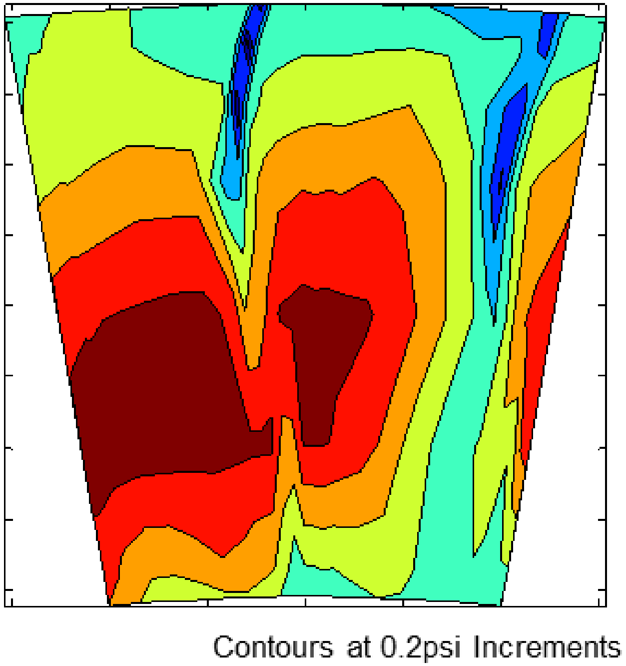
Tt



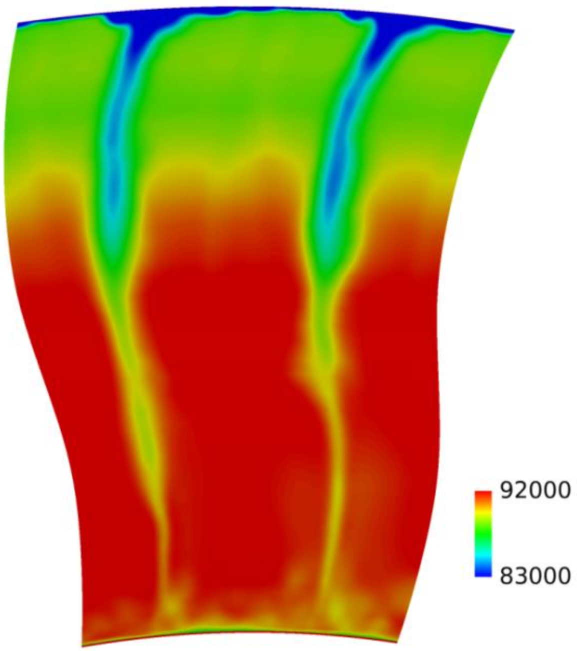
R1 exit

S1 exit

Comparison of total pressure at IGV exit

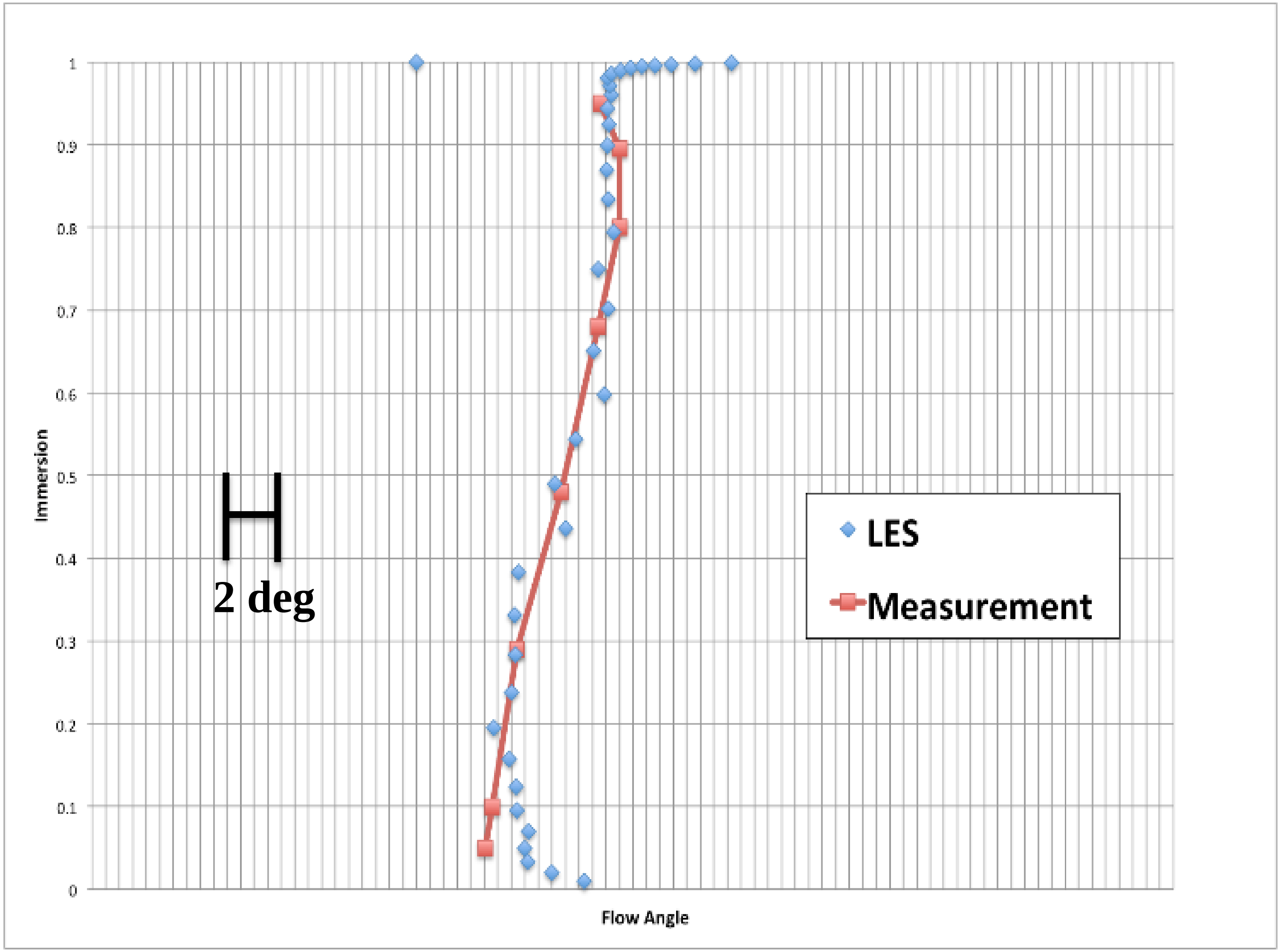


5-hole traverse



LES

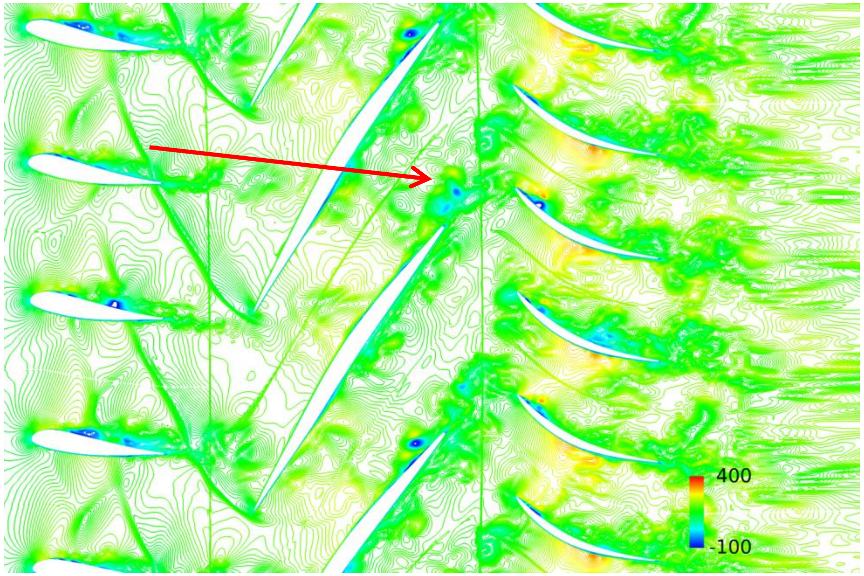
Comparison of IGV exit swirl angle



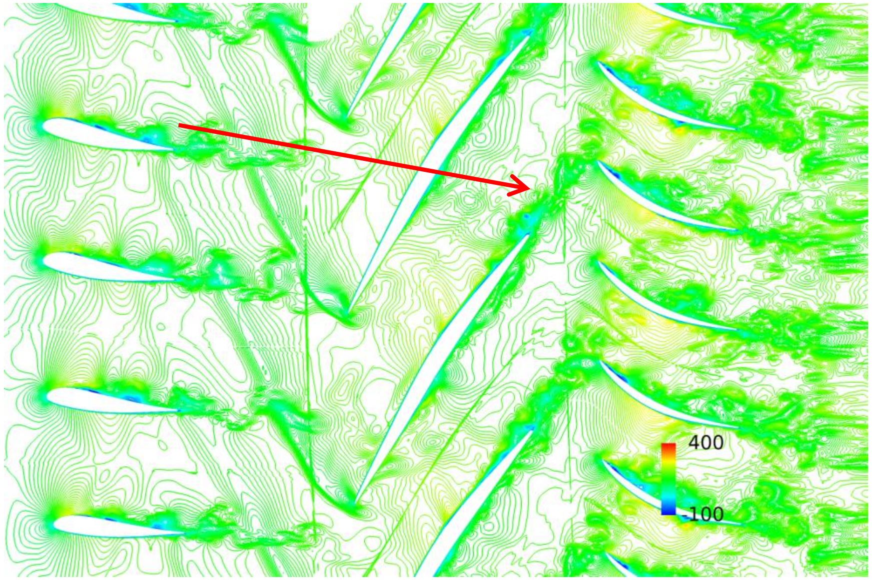
IGV wake phasing study

- Effects of IGV wake phasing on the stage efficiency.
- Axial gap between IGV and R1 increased twice.
- Very little effects on the efficiency.

Instantaneous axial velocity, mid-span



Original design

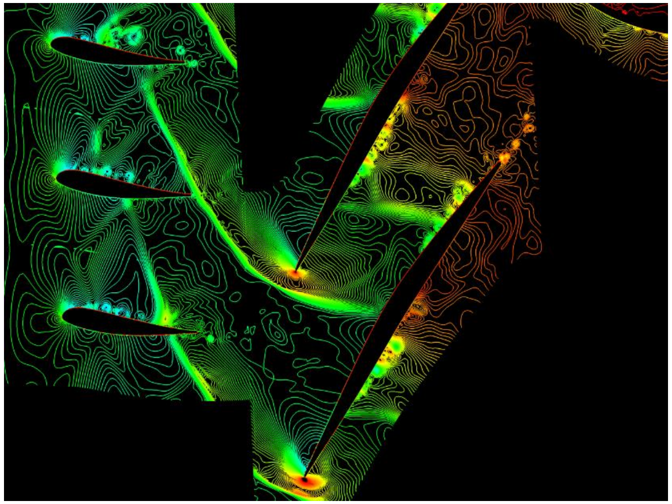


Wider igv/r1 spacing

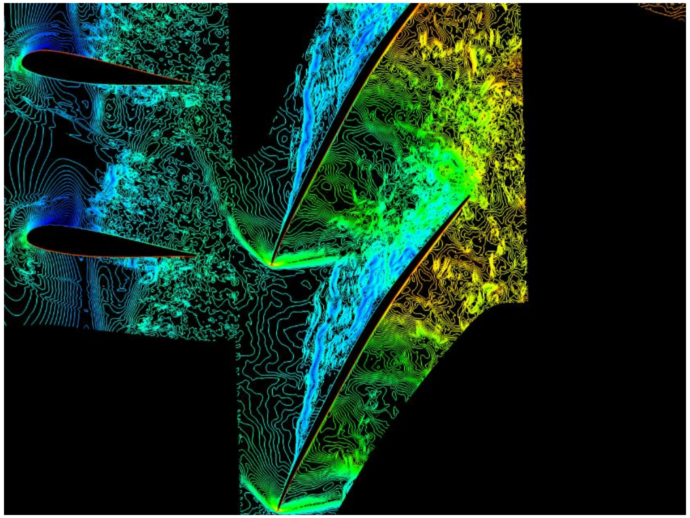
R1 shock structure from LES

- Detached shock at mid-span and attached shock at rotor tip (Forward swept rotor characteristics).
- Shock structure agrees with high frequency pressure data.

Comparison of rotor shock structure



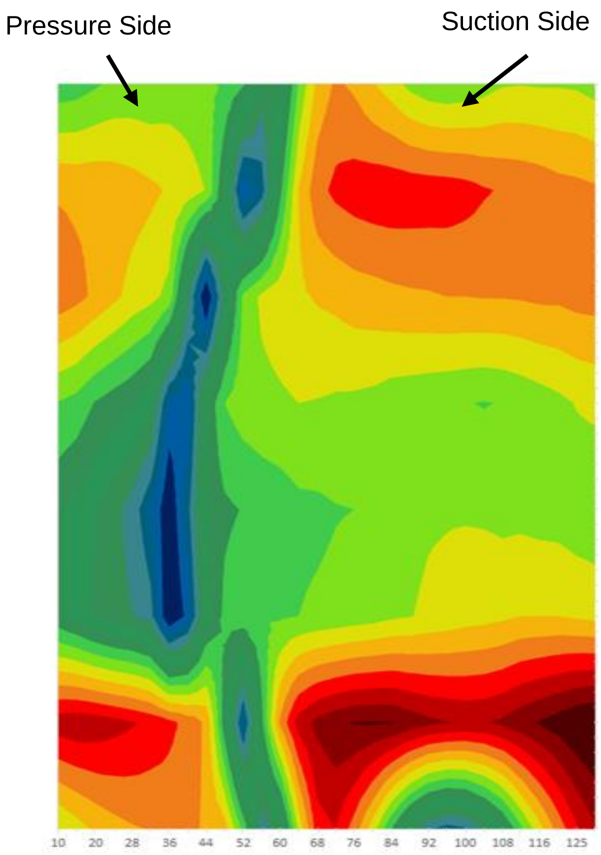
Mid-span

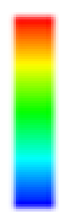


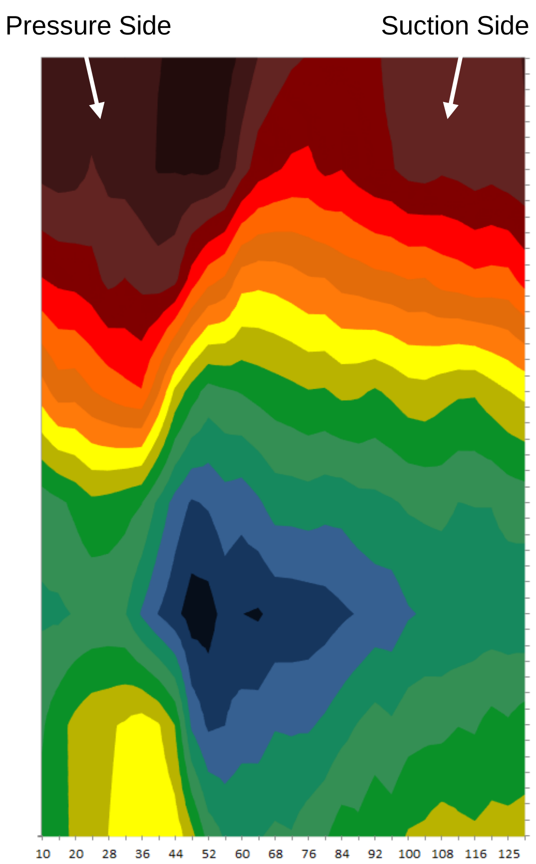
Rotor tip

Unsteady loss generation in the stator due to incoming rotor wake

Measured Pt and Tt at stator exit



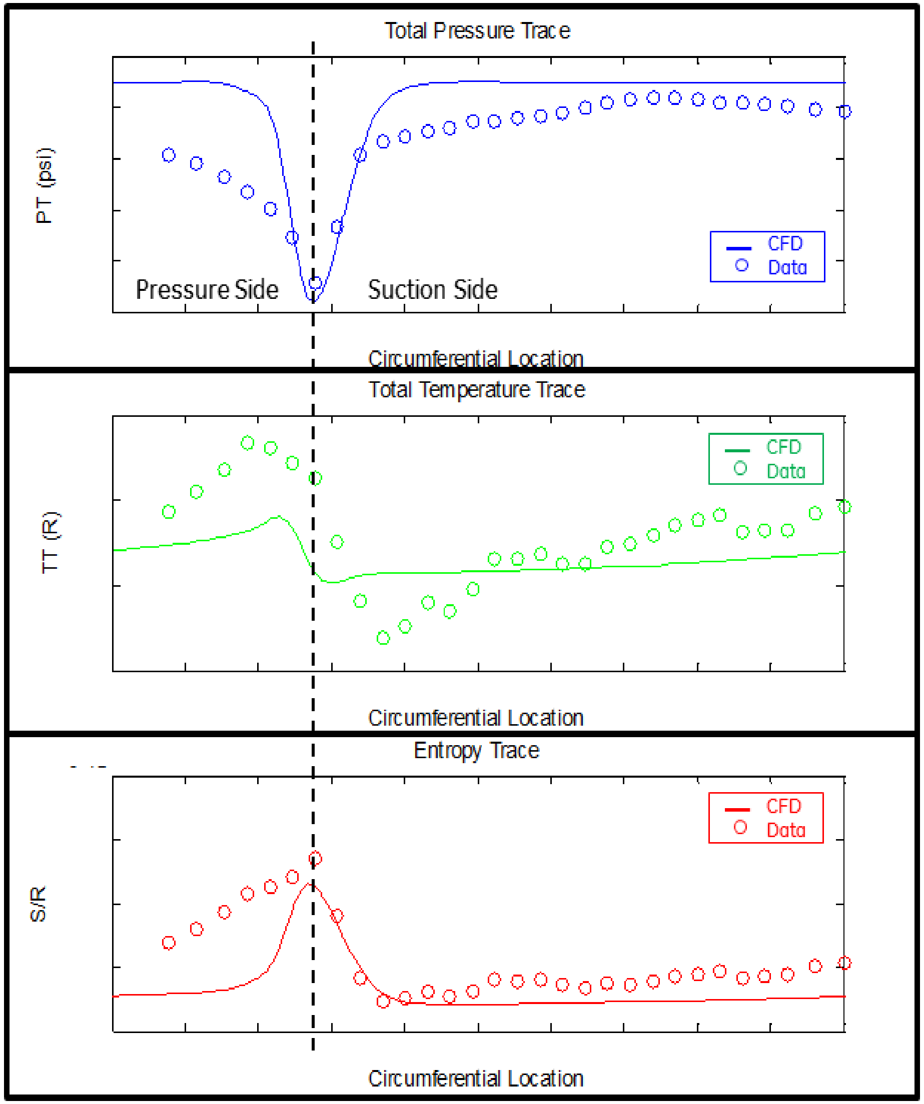




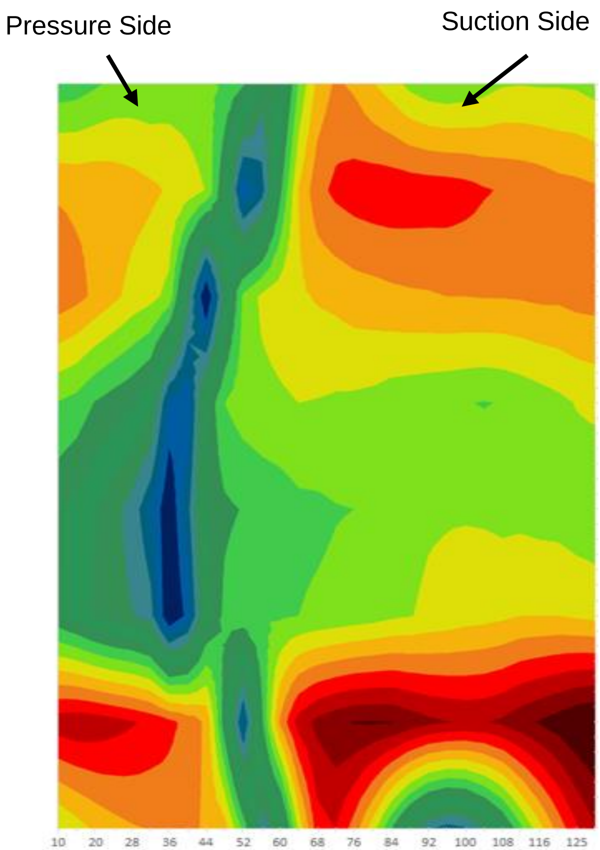
Pt

Tt

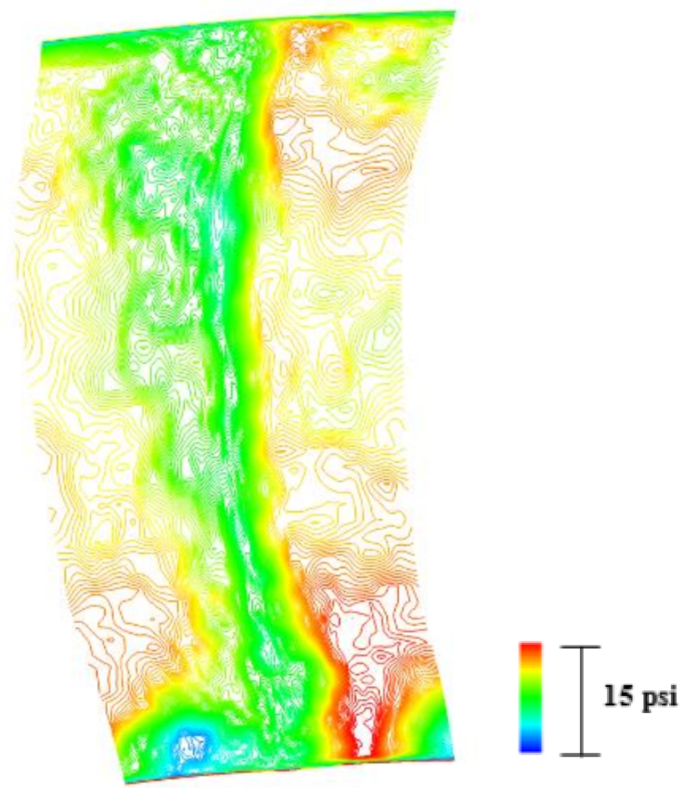
Measured Pt, Tt, and entropy at 48.1 % span (Lurie and Breeze-Stringfellow[GT2015-42526])



Comparison of Pt from LES, S1 exit

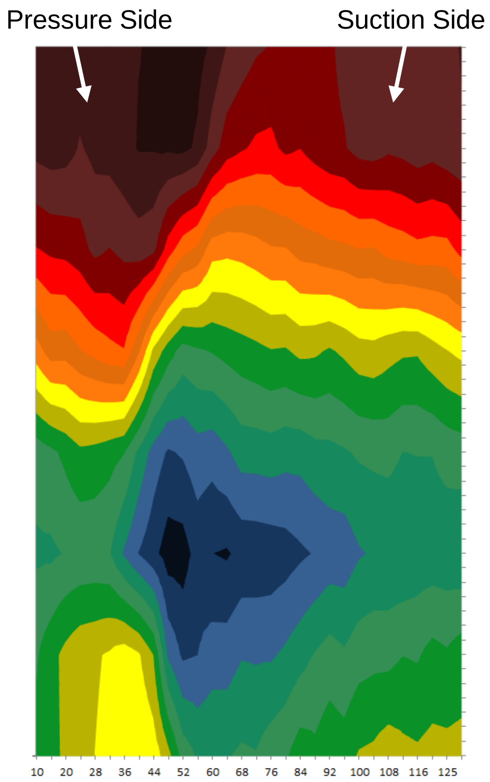


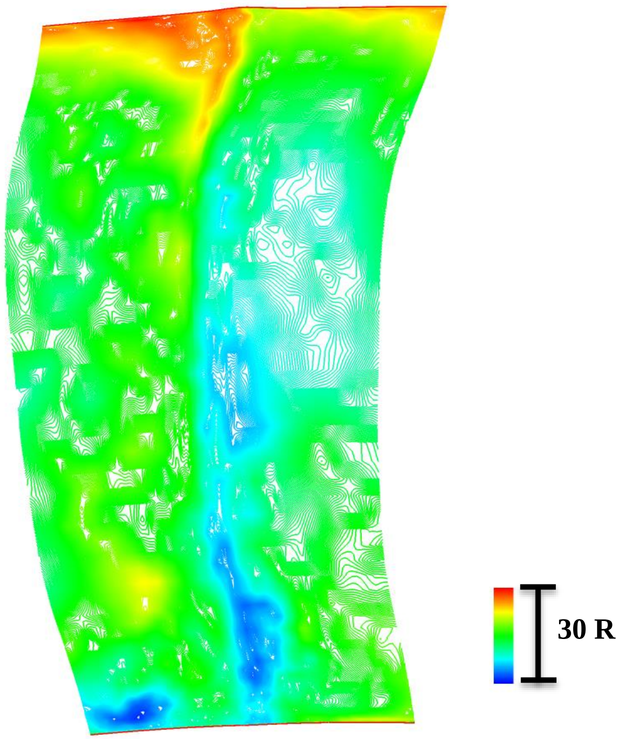
Five hole probe



LES

Comparison of Tt from LES, S1 exit

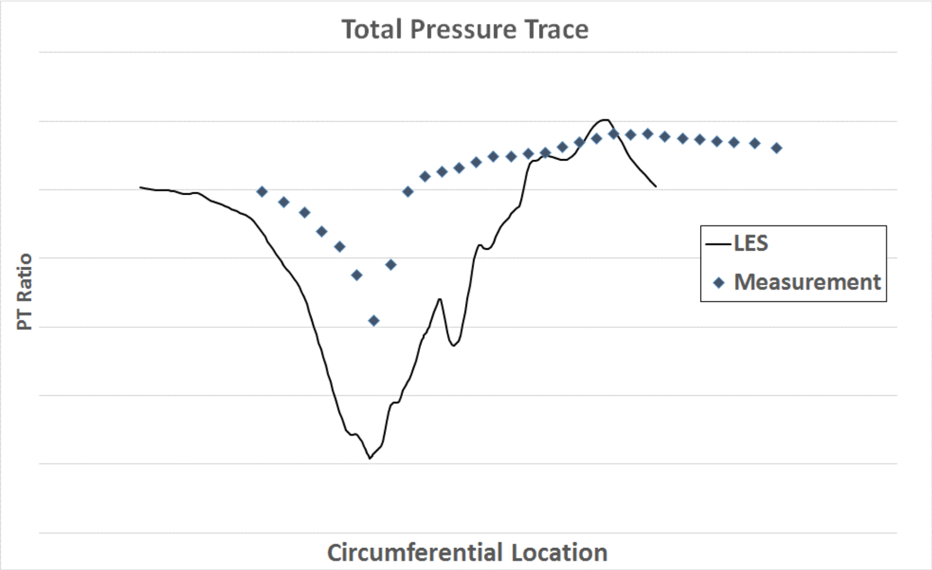


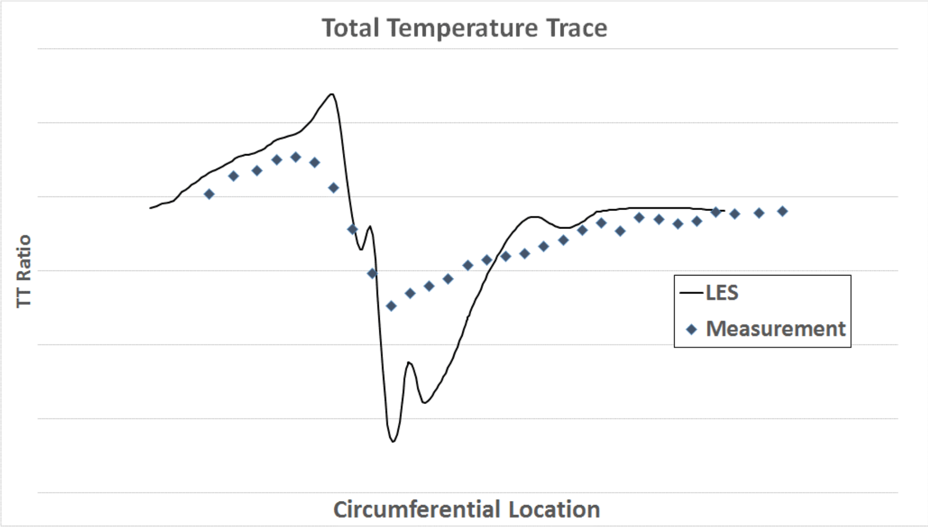


Measurement

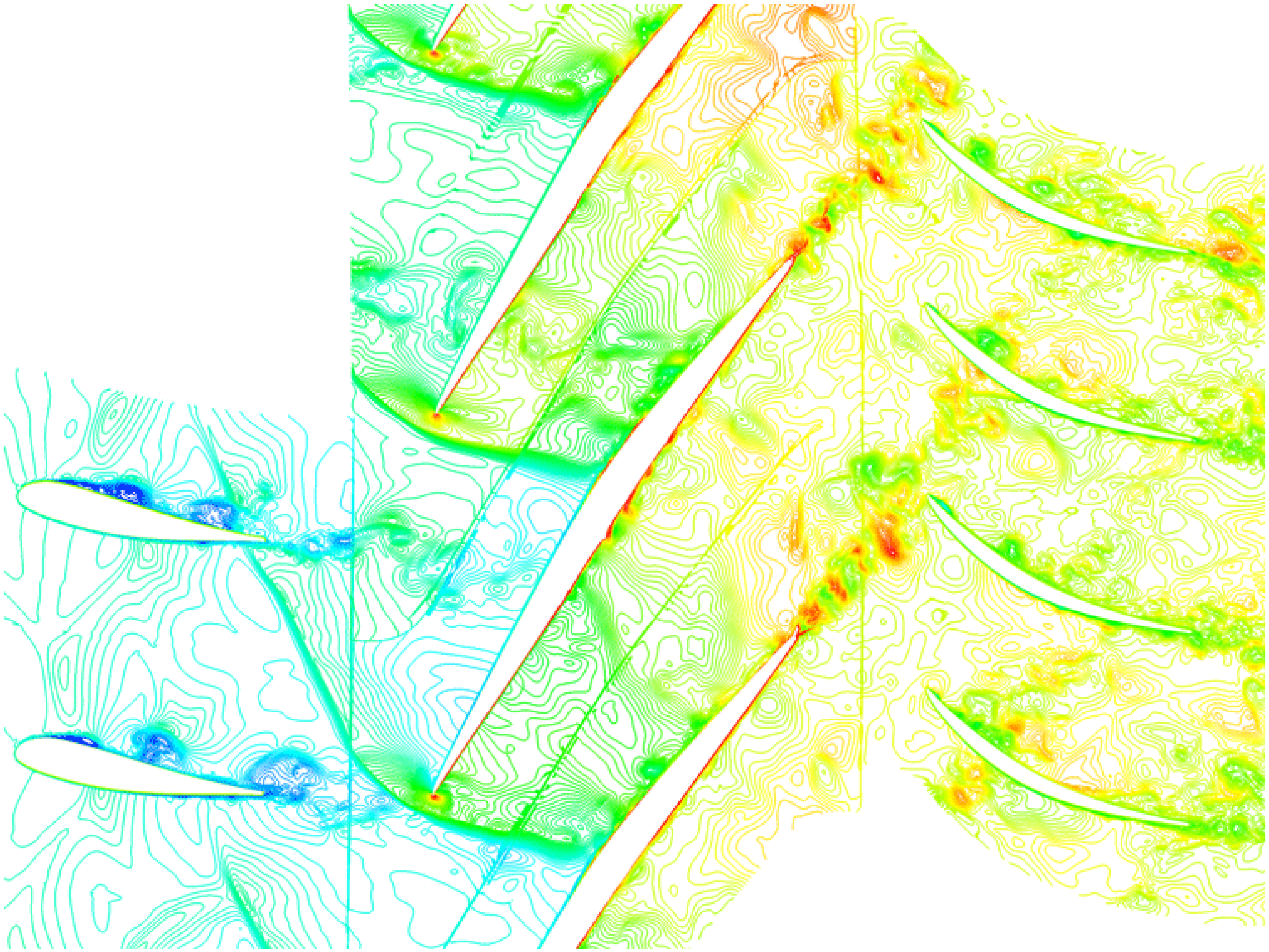
LES

Comparison of Pt and Tt at mid-span

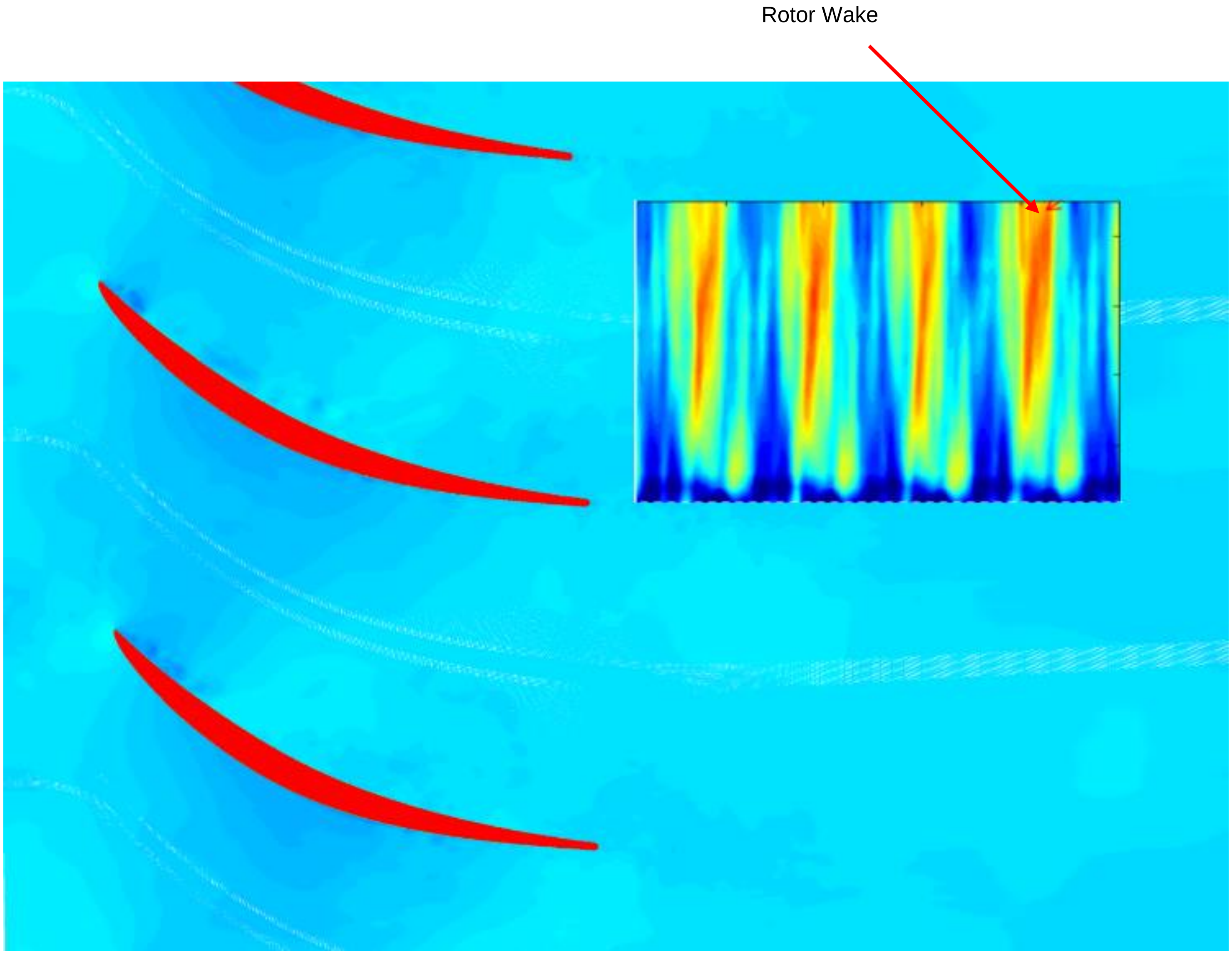




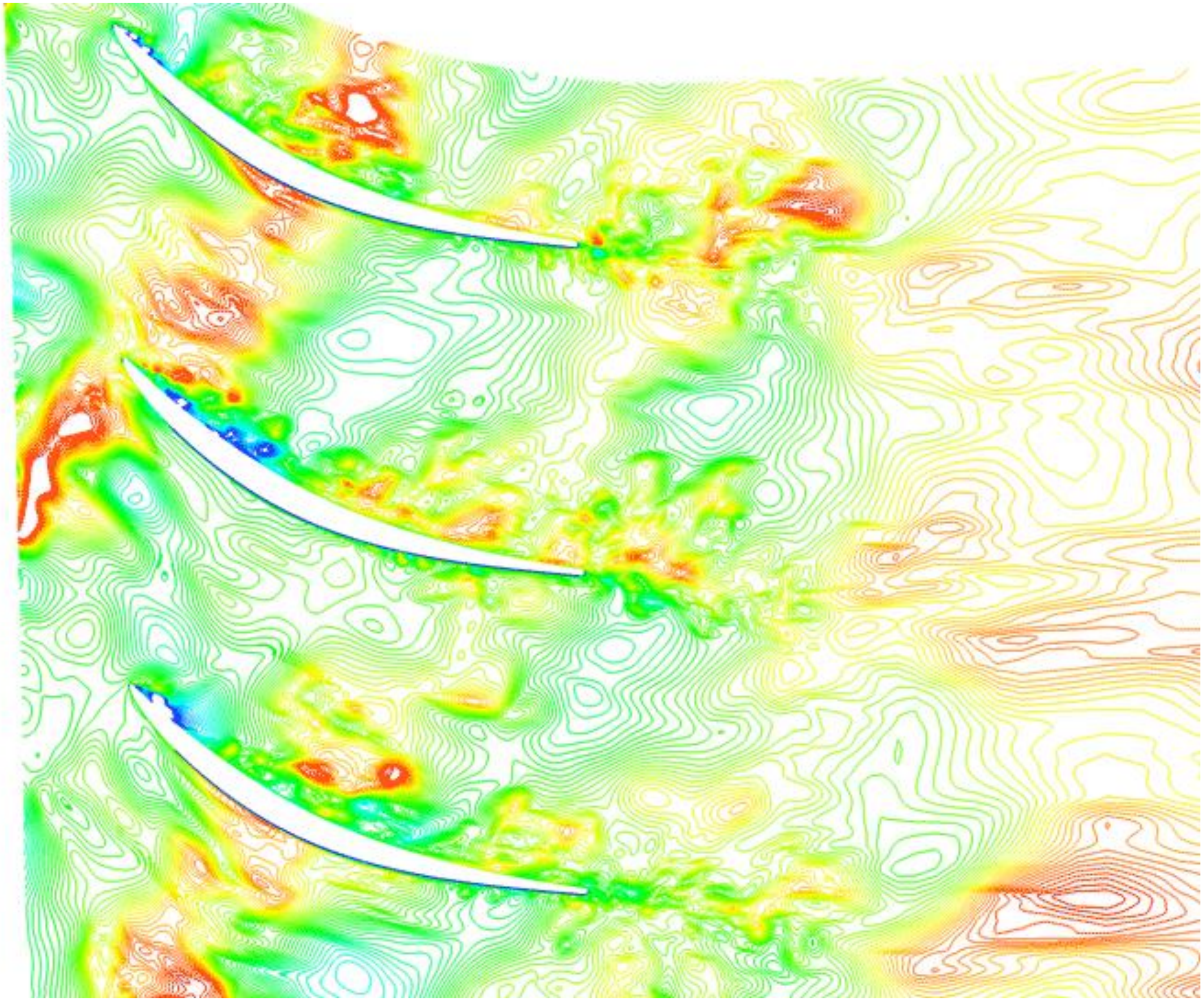
Instantaneous Pt distribution



Pt time-space plot at S1 exit



Instantaneous distribution of Tt from LES



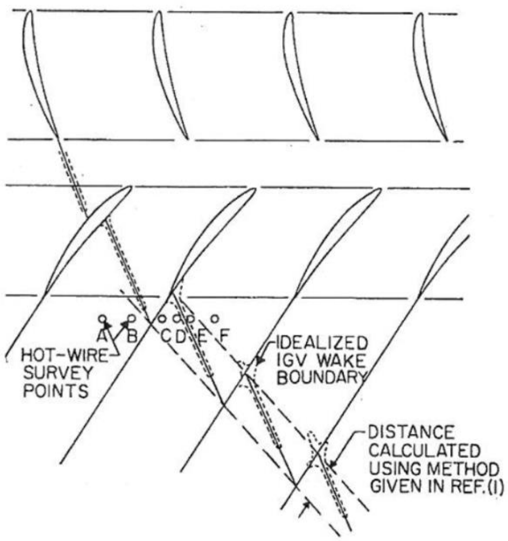
Why higher Tt and lower Pt on the pressure side of the stator ?

Why URANS does not pick up this trend ?
Why LES shows the correct trend ?

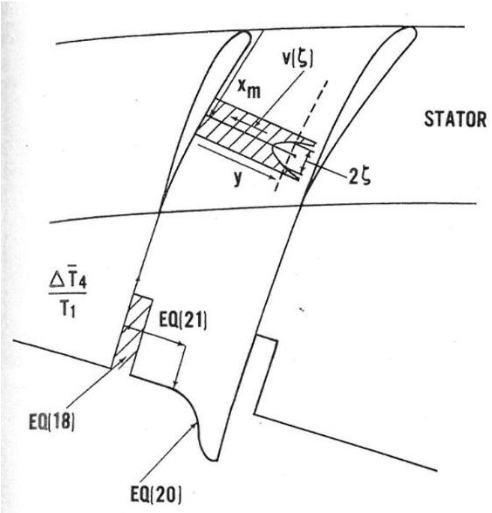
Flow mechanism for unsteady loss generation

Loss generation in multi-stage compressors

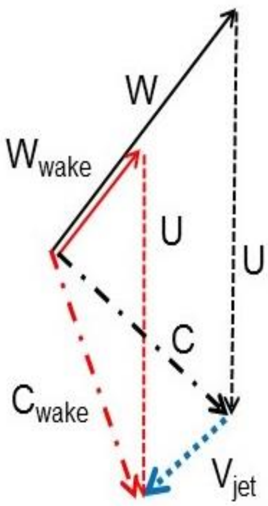
Smith, L.H. Jr. : Wake Dispersion, 1966.

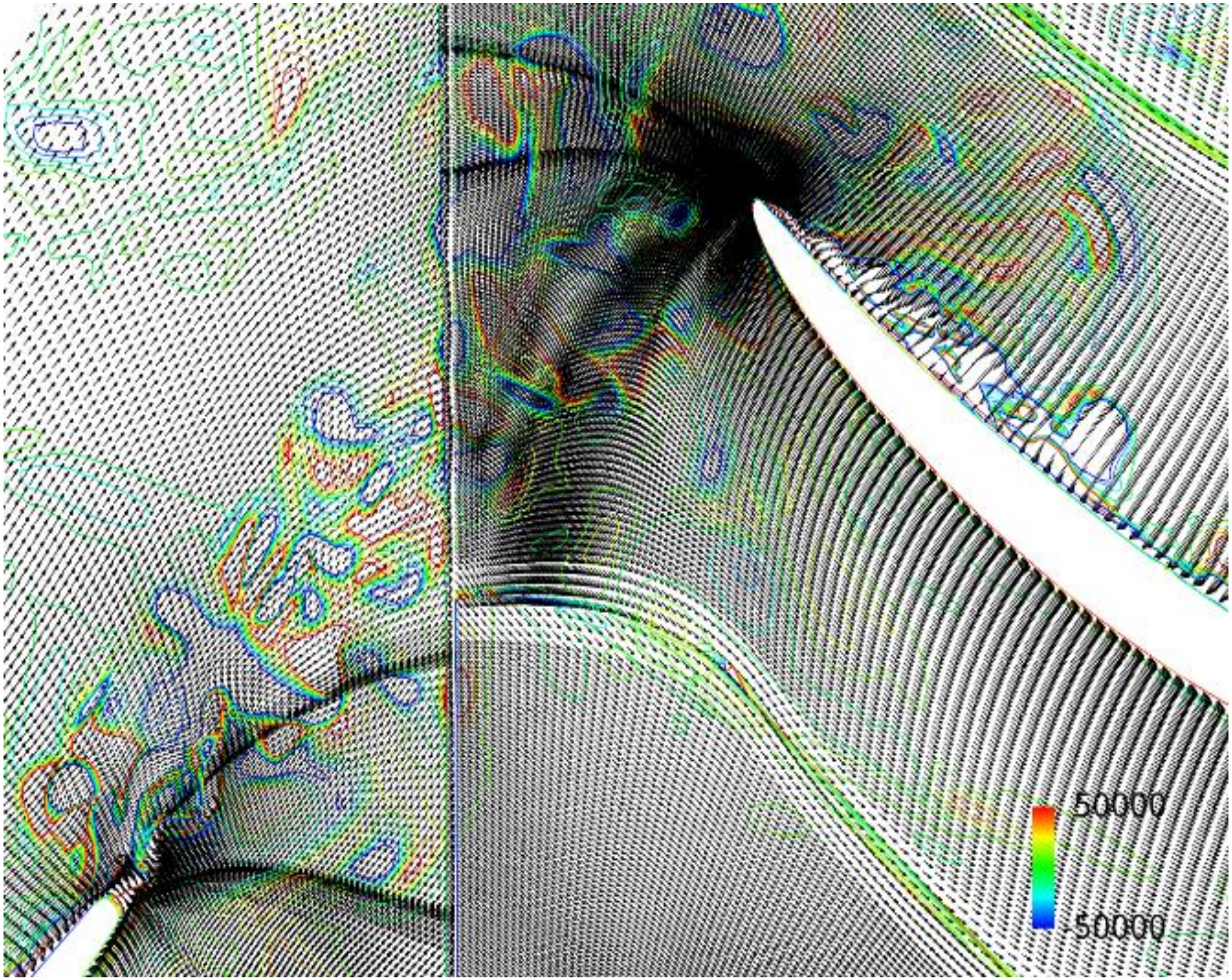


Kerrebrock, J.L. and Mikolajczk, A.A. :
Intra-Stator transport of rotor wakes, 1970

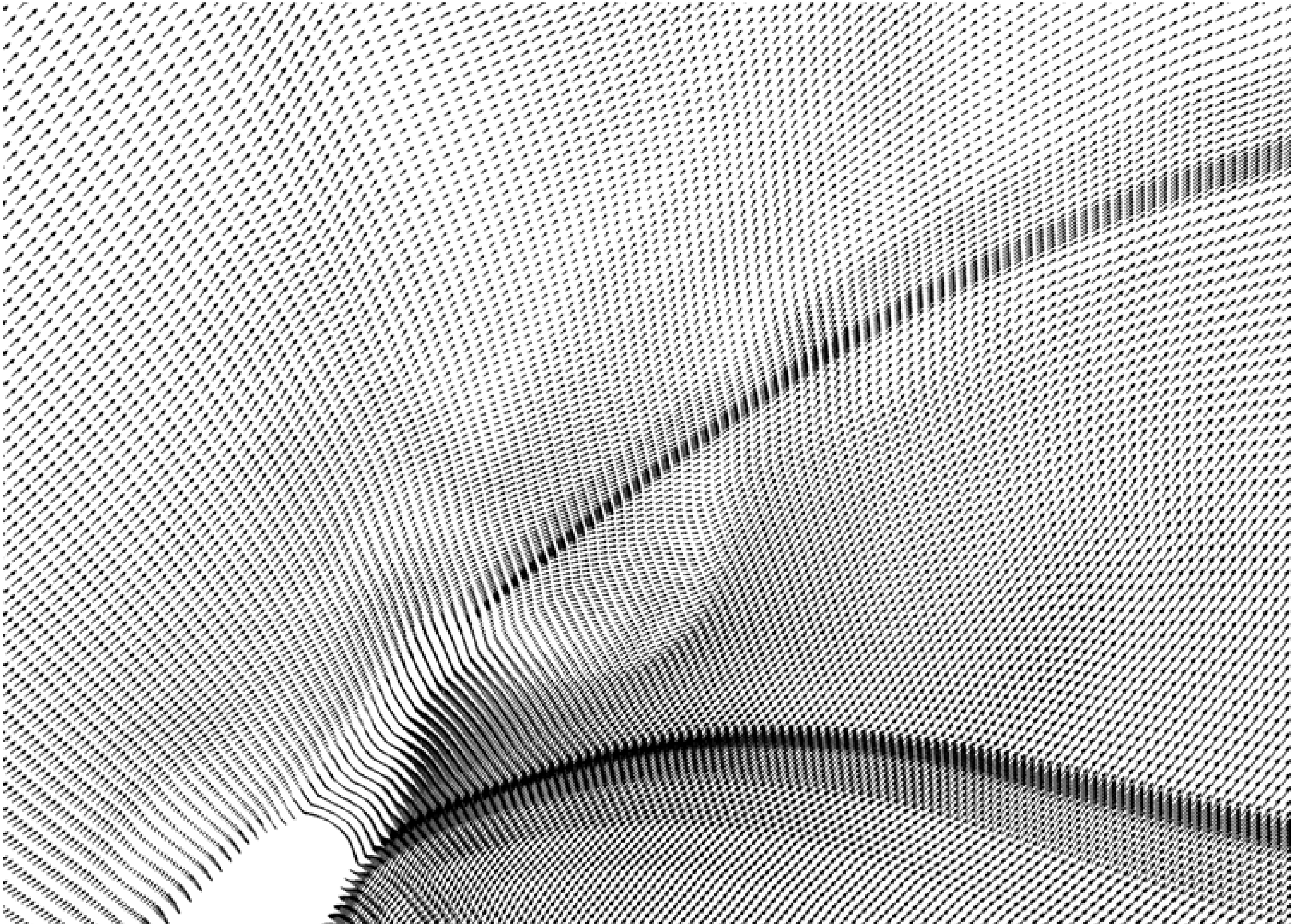


Instantaneous velocity vectors at mid-span

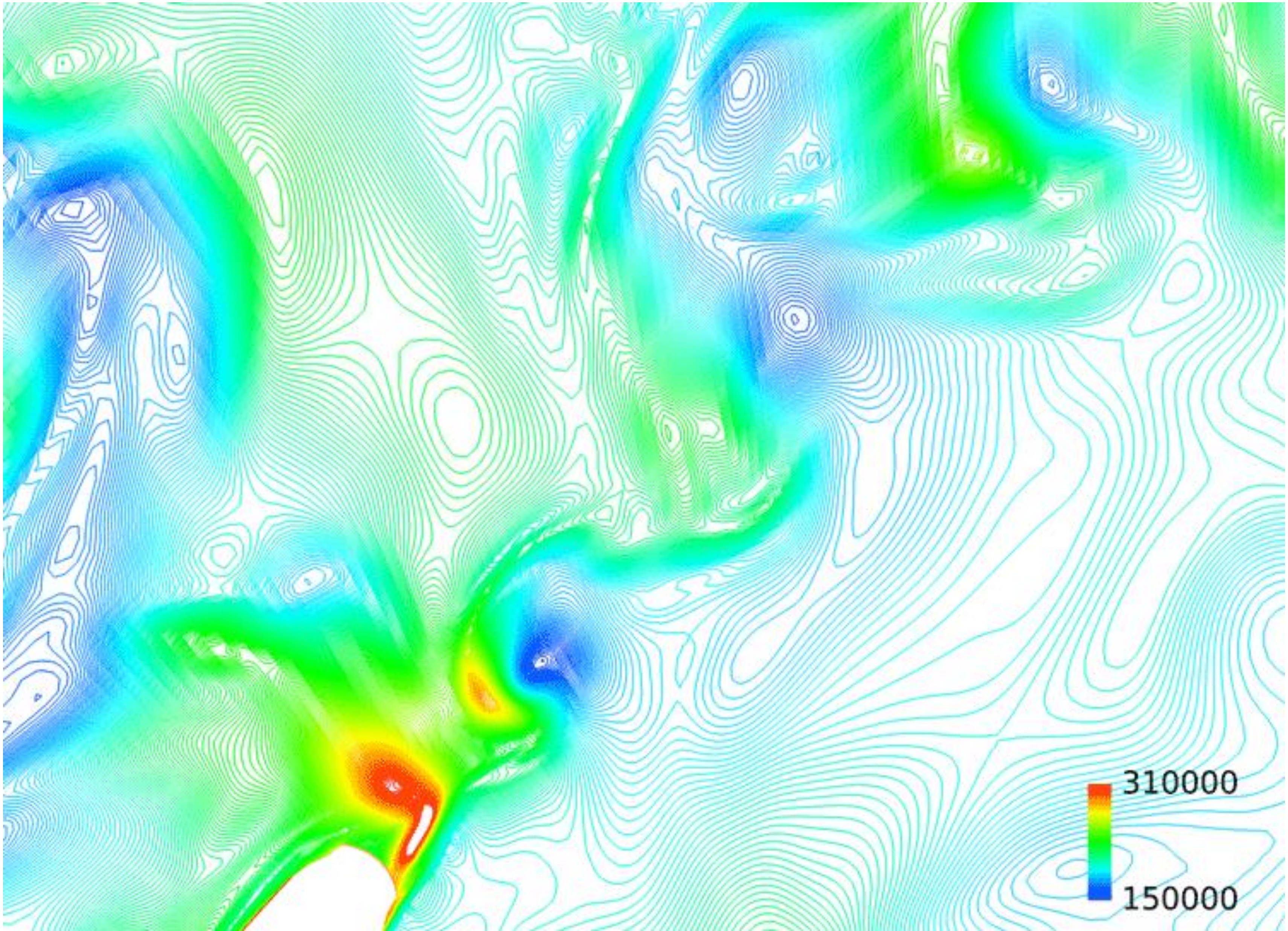




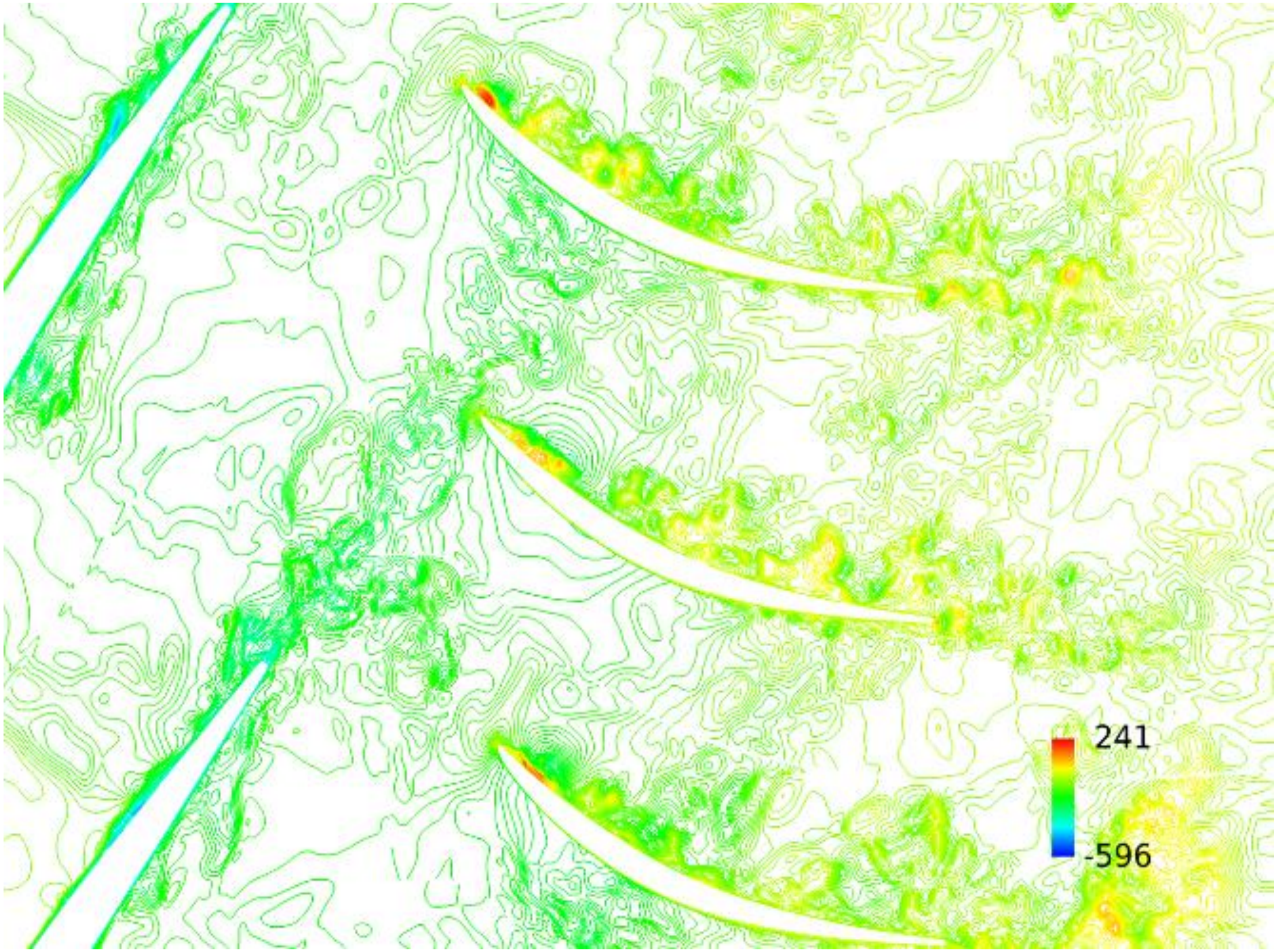
Velocity vectors in rotor wake



Absolute Pt in the rotor wake



Instantaneous tangential velocity component in stator frame



Intra-stator transport of rotor wake for high Tt on PS

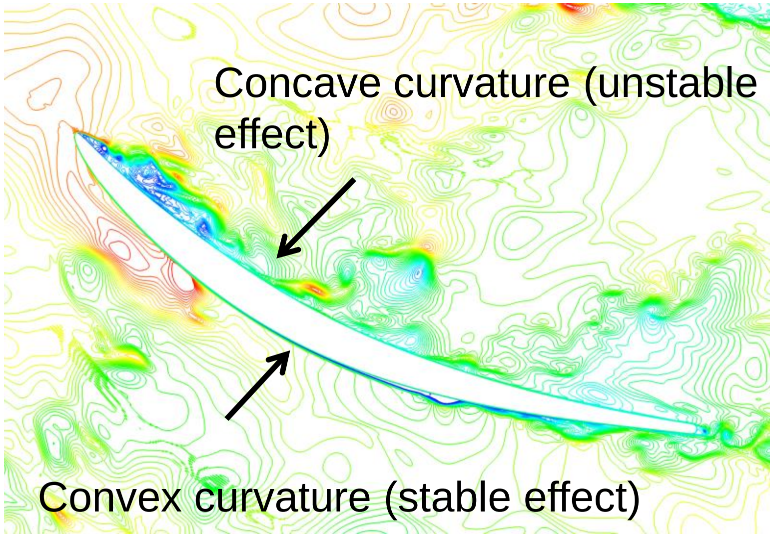
Both Tt and Pt are higher in rotor wake for the current compressor.

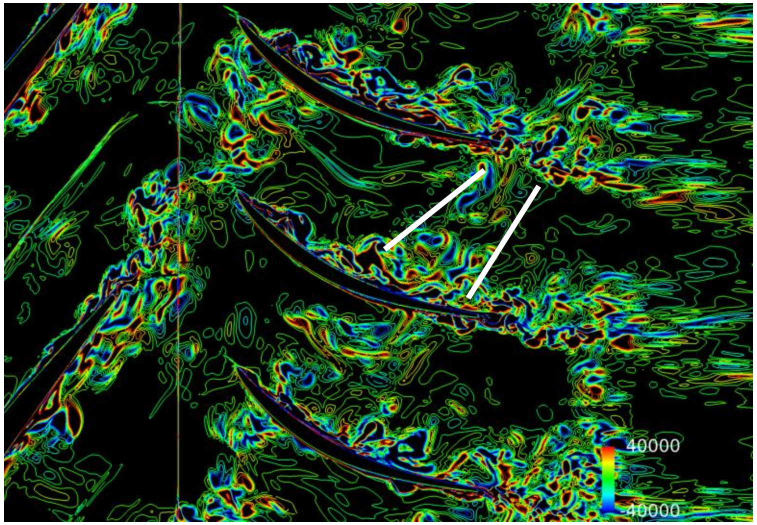
Jet velocity in the rotor wake decays very fast and The rotor wake is not like 2-D inviscid wake.

What makes Tt higher on pressure side of S1 ?

Why Pt is lower on pressure side of S1 ?

Mechanisms of unsteady loss generation





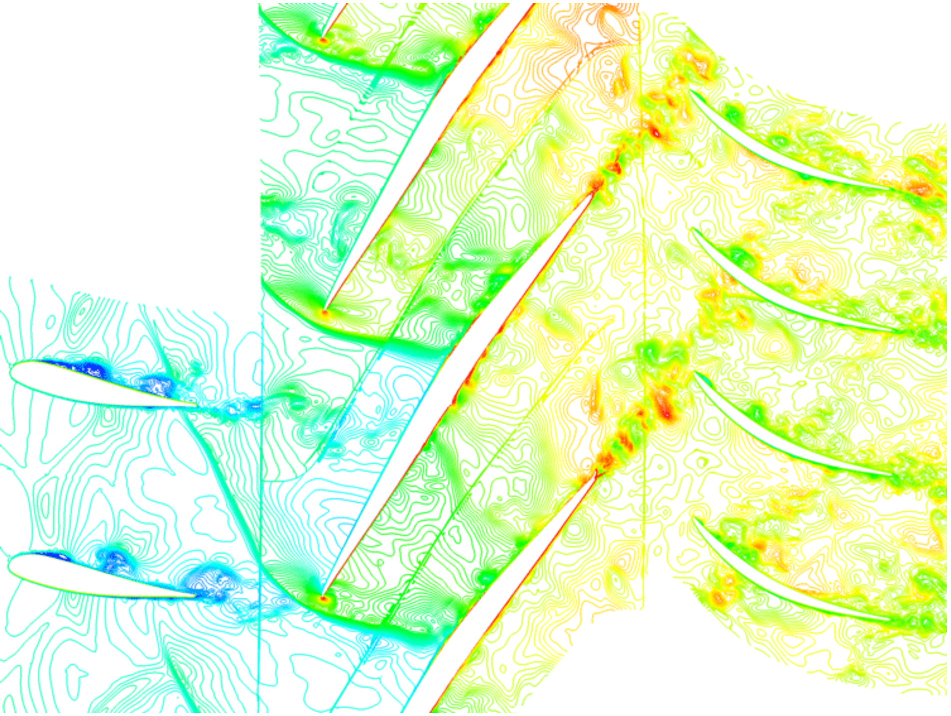
Curvature effects

Wake stretching

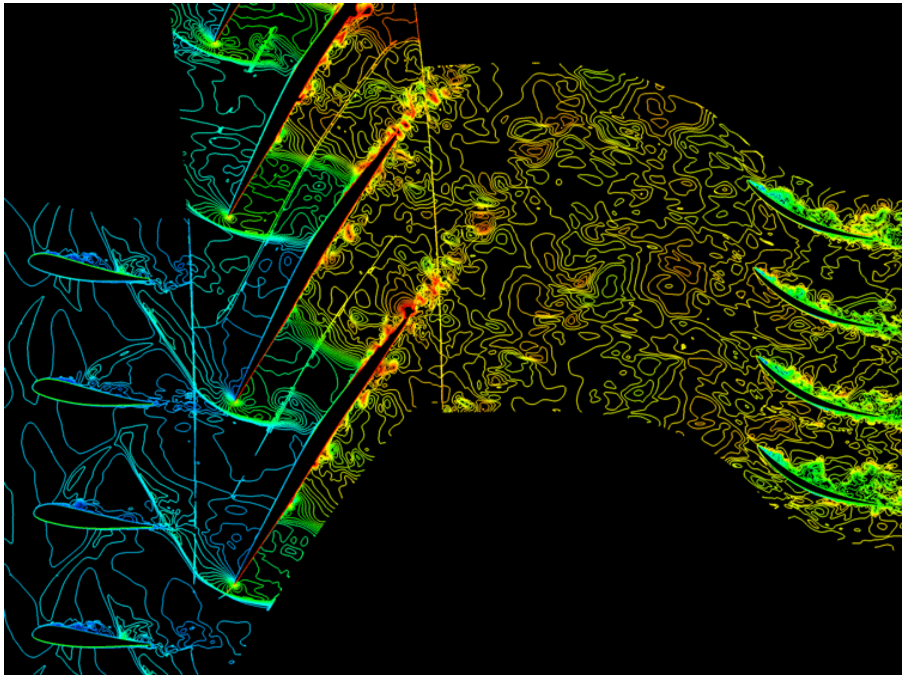
Effects of axial gap between R1 and S1

- Axial gap between R1 and S1 increased twice.
- Higher Pt and Tt observed with the increased gap.
- Further analysis are being performed.

Instantaneous Pt distribution (larger space between R1 and S2)



Original spacing



Increased spacing

Concluding remarks

- Investigated unsteady loss generation in the stator passage due to incoming rotor wake.
- Three-dimensional unsteady vortex interaction seems to be the main reason for the high loss near the pressure side of the stator.
- Further study being performed to develop ways to reduce the overall loss generation.