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 Configuration
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

IGV wake phasing

Unsteady loss generation

Analysis domain
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\textsuperscript{rd}-order scheme for convection terms.
- 2\textsuperscript{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 56 S1.
- 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

flow

IGV  Rotor 1  Stator 1
Overall compressor flow field from LES
Instantaneous pressure distribution at mid-span
Instantaneous vorticity distribution at mid-span
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

R1 exit

S1 exit

Tt

1 psi

5 R
Comparison of total pressure at IGV exit

Contours at 0.2psi Increments

5-hole traverse

LES
Comparison of IGV exit swirl angle

H

2 deg
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
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

Rotor Wake
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


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

Convex curvature (stable effect)

Concave curvature (unstable effect)

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.