Study of Unsteady Flow in Transonic Compressors at Near Stall Operation With a Large Eddy Simulation

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Objectives

• Current RANS with various Turbulence models does not calculate unsteady flow features in transonic compressor adequately for many applications.

• LES can be applied for better calculation.

• Flow fields in two transonic compressors are used for evaluation.
Order of presentation

• Flow field in the Darmstadt’s Rotor 1.
• NASA Rotor 37 Flow field.
• Concluding Remarks.
Numerical 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 scheme for subgrid-scale model.
Computational grid

Single passage LES. (198x77x200)
Full annulus LES. (16x100x77x200)
NASA Columbia Cluster used.
Full annulus grid near the rotor
Flow characteristics in transonic compressors at near stall operation

- Tip leakage vortex, passage shock, vortex shedding.
- Self-induced unsteady flow due to interactions among these.
- Non-synchronous frequencies/vibrations due to unsteadiness and instability observed.
Cross section of Darmstadt’s compressor test rig
Darmstadt Rotor1
### Darmstadt Rotor 1 design parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure ratio</td>
<td>1.5</td>
</tr>
<tr>
<td>Corrected mass flow rate</td>
<td>16.0 kg/s</td>
</tr>
<tr>
<td>Corrected tip speed</td>
<td>398 m/s</td>
</tr>
<tr>
<td>Inlet relative Mach number at tip</td>
<td>1.35</td>
</tr>
<tr>
<td>Inlet relative Mach number at hub</td>
<td>0.70</td>
</tr>
<tr>
<td>Shaft speed</td>
<td>20,000 rpm</td>
</tr>
<tr>
<td>Tip diameter</td>
<td>0.38 m</td>
</tr>
<tr>
<td>Rotor mean aspect ratio</td>
<td>0.94</td>
</tr>
<tr>
<td>Rotor solidity (hub/mid/tip)</td>
<td>1.9/1.5/1.2</td>
</tr>
</tbody>
</table>
Pressure rise characteristics of the rotor

![Graph showing pressure rise characteristics](image)

- **Measurements**
- **LES Single Passage Calc.**
- **LES Full Annulus Calc.**
Casing static pressure near stall

measurement

calculation
Velocity vectors at rotor tip, near stall, averaged LES

- Induced vortex
- Low momentum area
Particle traces at rotor tip

Induced vortex

Core vortex
Measured endwall pressure variation
Calculated instantaneous casing pressure
Pressure contours at blade tip (LES)
Instantaneous velocity vectors at blade tip (LES)
location of pressure difference

number of occurrence

pressure [kPa]

low pressure difference appears too often
Wall pressure spectrum from full annulus LES

Tip vortex oscillation and vortex shedding

110 Hz

BPF
Wall pressure spectrum from single passage LES

Tip vortex oscillation and vortex shedding
Instantaneous Mach number distribution at mid-span
Instantaneous pressure distribution, blade tip, time 1

Large induced vortex

Small induced vortex
Instantaneous Mach Number from LES
Instantaneous velocity vectors

Induced vortex
NASA Rotor 37

- Transonic flow field with passage shock over the full span.
- Used as a blind test case by ASME in 1992.
- Many flow features are not fully understood yet.
Computational grid
Instantaneous Mach number
Comparison of average Mach Number, near Peak effi.

RANS

LES
Comparison of Pt distribution
Comparison of Tt distribution

![Graph showing comparison of Tt distribution]

- LES 98.45% choke mass
- Measurement at 98.3%
Observations and future research

• Promising results for simulation of transonic compressor flow field with LES.

• Further validations planned.