Experimental Results of the First Two Stages of an Advanced Transonic Core Compressor Under Isolated and Multi-Stage Conditions

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Outline

• Introduction

• Objective

• Facility and Rig Overview

• Results

• Conclusion
• NASA Environmentally Responsible Aviation Project (ERA) goal: Identify and mature technologies that together can simultaneously meet the metrics above (noise, emissions, and fuel burn) in the N+2 timeframe

• ERA system studies have shown potential for up to 2.5% reduction in Thrust Specific Fuel Consumption by increasing core compressor pressure ratio by 30%
Introduction

• Increased loading of the core compressor introduces aerodynamic losses and decreased efficiency in the front stages

• NASA partnered with General Electric to test the front stages of a legacy advanced, highly loaded, transonic core compressor to identify loss mechanisms

• Previous test experience of a compressor which included these front stages indicated a performance deficit relative to design at high speed which was not captured by RANS/URANS CFD
Introduction

• Potential explanations of the previously measured performance deficit:

  - Unanticipated loss through the gooseneck inlet/strut/IGV
  - Rotor 1 wake mixing loss
  - Rotor 2 shock loss
  - Rotor 2 bow shock interaction with Stage 1
Objective

- Document high-speed performance of a highly loaded front block core compressor under isolated and multi-stage conditions to understand any differences
  - Provide detailed aero data for CFD validation

- Rig was operated in 1-stage and 2-stage configurations in separate tests to isolate the effect of the Rotor 2 bow shock on Stage 1
Facility and Rig Overview

- Testing was conducted at NASA Glenn Research Center in the W-7 High Speed Multi-Stage Axial Compressor Facility.
- Atmospheric inlet and exhaust were used during testing.
- ESP data acquisition system for steady state pressures up to 150 PSIA.
- ESCORT data recording system to obtain and display steady state parameters.
- GE supplied proprietary data acquisition and probe actuation systems were used for traversing probe data, dynamic pressure data, and rotor tip clearance measurements.

### W-7 Facility Capabilities

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Operating value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet air pressure</td>
<td>atm to 20 psig</td>
</tr>
<tr>
<td>Inlet airflow</td>
<td>10-100 lbₘ/ₜ,s</td>
</tr>
<tr>
<td>Atmospheric exhaust</td>
<td>0.8 psid blowers</td>
</tr>
<tr>
<td>Altitude exhaust</td>
<td>26 in. Hg (vacuum)</td>
</tr>
<tr>
<td>Rotor speed</td>
<td>0-18,700 ± 0.5 rpm</td>
</tr>
<tr>
<td>Rotor size</td>
<td>20 to 22 in.</td>
</tr>
<tr>
<td>Drive motor</td>
<td>15,000 hp</td>
</tr>
</tbody>
</table>
Facility and Rig Overview

• 1-stage configuration
  – Strut, IGV, Rotor 1, Stator 1, de-swirl vane

• 2-stage configuration
  – Strut, IGV, Rotor 1, Stator 1, Rotor 2, Stator 2

• IGV, Stator 1, and Stator 2 are variable stagger vanes
  – Data was acquired at off-schedule vane angles but the current work is focused on nominal vane settings
Inlet and Exit Rakes: 5 circumferential positions with 5 radial locations
Vane Leading Edges: 2 vanes/stage with P0 probes, 2 vanes/stage with T0 probes at 5 radial locations
Casing and hub static pressures along the flow path
Detailed traverses at 4 positions shown above: 5-hole probe, Kulite, hot wire
Inlet and Exit Rakes: 5 circumferential positions with 5 radial locations
Vane Leading Edges: 2 vanes/stage with P0 probes, 2 vanes/stage with T0 probes at 5 radial locations
Casing and hub static pressures along the flow path
Detailed traverses at 4 positions shown above: 5-hole probe, Kulite, hot wire
Results: Inlet P0 Profile

- Inlet total pressure profile aft of inlet screen (within strut passage) below was typical for all run conditions.
- Radial-circumferential 5-hole probe survey characterizing IGV wake (black) and strut+IGV wake (red) is shown below.
- These data ruled out unanticipated loss due to inlet conditions.

![Graph showing normalized inlet total pressure and percent span vs pitch %]
Results: 97% Nc Speedlines

1-stage configuration

2-stage configuration
2-stage config. chokes at lower flow than 1-stage config.
Results: Peak Efficiency

Rotor 1 throttled past peak efficiency in 2-stage config.
National Aeronautics and Space Administration

Results: Near-Stall

Stage 2 stalls before Stage 1
Results: Rotor 1 Performance

• 2-stage config. choked at lower flow than 1-stage config.
  – Rotor 1 does not reach peak efficiency in 2-stage config.
• Negligible change in Rotor 1 performance between 1-stage and 2-stage configs.
Results: 5-Hole Probe Traverse Aft Stator 1

- Stage 1 efficiency (1-stage config.) is low relative to design intent
Conclusion

• Data collected upstream of Rotor 1 did not indicate sources of unanticipated loss

• Stage 2 choked at a mass flow rate which prevented Stage 1 from reaching its peak efficiency point, causing a stage mismatch

• Level of Rotor 1 performance is otherwise unaffected by presence of the Stage 2
  – i.e. Losses due to Rotor 2 shock loss or bow shock interaction with Stage 1 is unlikely

• Stage 1 performance is down relative to design intent
Following Papers

• GT2015-42526: Lurie and Breeze-Stringfellow present GE interpretation of the data at the 1-stage peak efficiency point

• GT2015-43389: Hah presents LES results of the 1-stage configuration
Backup Slides
Over Rotor Tip Pressure Blocks

Rotor 1

Rotor 2

FWD

AFT

Top case inside looking up