Experimental Measurement of Transonic Fan Wake Response to Uniform and Simulated Boundary Layer Ingesting Inlet Flows

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Research in partnership with NASA and the United Aircraft Research Laboratories
Introduction

- BWB Aircraft with embedded engines and BLI inlets offer attractive advantages in terms of reduced noise from engines and increased range and fuel economy.
- The BLI inlet produces inlet distortion patterns that can reduce fan performance and stall margin, and can produce undesirable forced responses.
Introduction

• Knowledge of the dynamic response of fan flow when subjected to flow distortions of the type produced by BLI inlets is important for the design of distortion tolerant fans

• This project is investigating fan response to flow distortion by measuring the response of the fan of a JT15D engine to a flow pattern following the results of the NASA “Inlet A” BLI wind tunnel tests

Ref. -Berrier et. al. “High Reynolds Number Investigation of a Flush-Mounted S-Duct Inlet with Large Amounts of Boundary Layer Ingression” NASA/TP-2005-213766
Research Plan

• Construct an inlet system and flow measurement apparatus for the Virginia Tech JT15D
  – Impose the desired flow distortion on the fan
  – Measure the dynamic effects of distortion on the fan flow
    • Blade wake structure
    • Flow turbulence level
• Perform research program to construct the required rig and make measurements

Research Plan Details
1. Measure clean inlet fan response
2. Develop $P_0$ distortion screen
3. Measure distorted inlet fan response
4. Data processing
   • Fan blade wake structure
   • Flow turbulence level
Initial clean inlet experiments have shown uniform flow entering the engine and measured unsteady fan blade wake details.
Flow Probe and AIP Rake

- Traversing Kulite Probe
- Fan OGVs
- AIP Measurement Rake
- P&W JT5D Fan
Distorted Inlet Experiment

- Tunnel Inlet
- Screen Rotator
- Distortion Screen
- AIP Measurement Rake
- Traversing Kulite Probe
- P&W JT15D Engine
Typical Serpentine Inlet Distortion Patterns

CAD model of UTRC BLI S-Duct

CAD model of NASA BLI S-Duct

Measured S-Duct distortions

Ref. - Ferrar et. al. “Active Control of Flow in Serpentine Inlets for Blended Wing-Body Aircraft” AIAA-2009-4901
Screen Construction and Calibration Method

• Single-layer screen consisting of varying density sections with supporting grid
  • Performance of multi-layer screens is difficult to predict
  • Each screen section is welded to adjacent sections

Ref. —Overall, B. W., ‘A Procedure for the design of complex distortion screen patterns for producing specified steady-state total pressure profiles at the inlet of turbine engines,” AEDC-TR-72-10, 1972
Screen Design Methodology

- Uses a pattern of varying density screens to generate desired $P_0$ profile
- Iterative development process:
  - Compute ideal screen design
  - Measure profile created by screen and compare to desired profile
  - Iterate on screen design until desired profile is achieved

Design Method Details:
1. Contour plot of desired profile determines outline of each screen section
2. Porosity of each screen section is determined using mass flow and desired $P_0$ to compute required area blockage
3. Construct screen as a single-layer, supported by a backing grid
AIP Steady $P_0$ Measurement System

Experiment
- 60 probe AIP rake
- Various static taps

(80x) Omega PX139
- 5psi transducers

NI-SCB68 Pin Block

NI-PXI 6225 DAQ
- 40 Differential Channels
- 16-bit, 250 kS/s

NI LabView VI
AIP Rake in JT15D Engine

• 60 Probe pressure rake currently installed on VT P&W JT15D

• Installed in Nov. 2010 and has successfully completed 7 engine runs up to full speed
High-Response Kulite $P_0$ Measurement System

- **Experiment**
  - JT15D Fan

- **Kulite Total Pressure Probe**
  - (1x) Kulite LE-062
  - (3x) Kulite LQ-062

- **NI-SCB68 Pin Block**

- **NI-PXI 6254 DAQ**
  - 1 MS/s, 16-bit
  - 16 differential ch.

- **NI LabView VI**

- **Eddy Current Sensor and optical key-phasor**
High Response Total Pressure Probe Behind Fan

- JT15-D Fan
- Kulite Probe
- Fan Bypass OGV
- Fan Core OGV
- Kulite Probe Detail
# Preliminary High Response Flow Measurements

<table>
<thead>
<tr>
<th>Test Cases</th>
<th>Tunnel Inlet</th>
<th>JT15-D Engine</th>
<th>60 Probe AIP Rake</th>
<th>Probe Traverse System</th>
</tr>
</thead>
<tbody>
<tr>
<td>34%</td>
<td>2495</td>
<td>50000</td>
<td>20.0401</td>
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<tr>
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<td>100000</td>
<td>14.6071</td>
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<tr>
<th>Fan Speed (% of maximum)</th>
<th>Blade Passing Frequency (Hz)</th>
<th>Sample Frequency (Hz)</th>
<th>Samples Per Blade Passing</th>
</tr>
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Average Total Pressure Measurements

Average Total Pressure vs Blade Passing Frequency (Engine Speed)
Dynamic Pressure Measurements

Raw Data Total Pressure

- 4133 blades/second
- 6846 blades/second
Dynamic Pressure Measurements

Total Pressure Averaged and Resampled

- Blue line: 4133 blades/second
- Gray line: 6863 blades/second

Axes:
- Y-axis: Total Pressure, Psia
- X-axis: Time, seconds

Data points for each line are shown on the graph.
Dynamic Pressure Measurements

Raw and Blade-Averaged Total Pressure, 55%

4133 Blades per second

10^{-3} x 10^{-3}
Dynamic Pressure Measurements

Raw and Blade-Averaged Total Pressure, 92%

6863 Blades per second
Progress and Future Plans

• Clean Inlet Test
  → Inlet
  → AIP rake
  → JT15D engine
  → Traversing high-response total pressure probe
    → Kulite Transducers

• Screen Development
  → Extended wind tunnel
  → Design/Construct screen
    – Measure screen performance
    – Modify screen

• Distorted Inlet Test
  – Screen close to fan
  – AIP rake
  – JT15D engine
  – Traversing high-response total pressure probe

• Data processing
Summary

• Research Program is on track to provide new insights into fan response to distorted inflows as produced by BLI inlets
• Supports UTRC and NASA efforts in distortion-tolerant fan design and tests.