ERA's open rotor studies including shielding for noise reduction

Environmentally Responsible Aviation Project

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Additional system analysis provided by the Subsonic Fixed Wing Project

Progress Towards Open Rotor Propulsion Technology
Royal Aeronautical Society Headquarters
No. 4 Hamilton Place, London, UK
November 21, 2012
Outline

• NASA/Boeing PAA with an Open Rotor
• The GE/NASA/FAA Open Rotor Test Campaign
• Systems Analysis of an Advanced Single Aisle Aircraft
• The ERA Diagnostics Test at NASA Glenn
• Simplified shielding configurations
• Outlook
NASA/Boeing Open Rotor Propulsion Airframe Aeroacoustic Integration Effects Test in 2010
NASA/Boeing Open Rotor Propulsion Airframe Aeroacoustic Integration Effects Test in 2010

Heritage Eight by Eight F7/A7 Rotor

Conventional Airframe:
- U-tail and T-tail
- Multiple rotor/main wing positions
- Angle of attack
- Fuselage boundary layer variations
- Takeoff and Approach flaps

HWB Planform Model:
- Derived from a Boeing BWB Configuration
- NACA airfoil leading and trailing edges
- Vertical surface variations
- Elevon variations
- Instrumentation including surface unsteady pressures

Shielding of Five Tones

B7, Rotor at 1D

Solid Line is Isolated
Dashed Line is Shielded
Red = m(1,0)
Blue = m(0,1)
Black = m(1,1)
Orange = m(2,0)
Green = m(0,2)

Isolated

Installed

SPL (dB)

Engine order (FWD)

Engine order (AFT)

AZI@090°

EMANG (°)

10dB

90°
NASA HWB Open Rotor Noise Assessment

- NASA Glenn projection of best open rotor source levels in 2025

- NASA Langley/Boeing Experimental Data for Key Installation Effects Including:
  - rotor speed variation
  - wind tunnel Mach variation
  - rotor to airframe relative position, axial and vertical
  - off-center and centerline positions
  - inboard verticals, size and cant angle
  - elevon deflection

- Boeing Vehicle Model and a NASA Glenn Engine Model

- All Elements Combined in a NASA Noise Assessment of Open Rotor HWB (papers planned for 2013 Aeroacoustics Conference)
The GE/NASA/FAA Collaboration on Open Rotor Testing

• **Objective:** Explore the design space for lower noise while maintaining the high propulsive efficiency from a counter-rotating open rotor system.

• **Approach:** A low-noise open rotor system is being tested in collaboration with General Electric and CFM International, a 50/50 joint company between Snecma and GE. Candidate technologies for lower noise will be investigated. Installation effects such as pylon integration will be investigated in partnership with GE and the FAA.

Gen-1 Blade Sets (NASA/GE)
- Historical Baseline
- Modern Baseline
- 2 GE Advanced Designs
- 2 Snecma Designs

Gen-2 Blade Sets (NASA/FAA/GE)
- 6 GE Advanced Designs
- Pylon wake mitigation

Historical Baseline Blade Set
- 12 x 10 blade count
<table>
<thead>
<tr>
<th>Month</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug</td>
<td>Drive rig rehab and installation</td>
</tr>
<tr>
<td>Sep</td>
<td>First research run. Oct 28</td>
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<tr>
<td>Oct</td>
<td>Linear array checkout. Dec 7-11</td>
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<tr>
<td>Nov</td>
<td>Airframer entry 1 start Dec 14</td>
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<tr>
<td>Dec</td>
<td>Drive rig checkout. Sep 24 – Oct 27</td>
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History (2/3)

GE/Airbus test complete. Feb 12


ERA Diagnostics Test. Jul 19 – Sep 7

2010

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

Drive rig muffler implementation.

Open Rotor Install in the 8x6
**History (3/3)**

<table>
<thead>
<tr>
<th>Month</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb</td>
<td>8x6 Tare Runs Feb 9</td>
</tr>
<tr>
<td>Mar</td>
<td>Gen-1 8x6 Test Feb 28 – Aug 25</td>
</tr>
<tr>
<td>Jun</td>
<td>Gen-2 8x6 Test Aug 26 – Sep 9</td>
</tr>
<tr>
<td>Nov</td>
<td>Gen-2 9x15 Test Nov 10 – Jan 19</td>
</tr>
<tr>
<td>Jan. 19</td>
<td>End of Gen-2 Test</td>
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</tbody>
</table>

**2011**

| Jan     | Feb   | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|

Jan. 19, 2012
End of Gen-2 Test
Systems Analysis of an Advanced Single Aisle Aircraft
**NASA Study Results – Fuel Burn vs. Noise**

- **Advanced UHB Turbofan**
  - Fuel burn: 27%
  - Noise: 25 dB cum margin to CH4

- **Open Rotor (modern blade set)**
  - Fuel burn: 36%
  - Noise: 13 dB cum margin to CH4

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**NASA modern airplane**
- 162 pax, 3250nm mission
- Cruise M= 0.78, 35kft (FL350)
- Rear mount Turbofan

**Open rotor version** has +2100lbs (953 kg) weight penalty

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**NASA modern airplane**
- 162 pax, 3250nm mission
- Cruise M= 0.78, 35kft (FL350)
- Rear mount Open Rotor

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**1998 technology reference vehicle**
- 162 pax, 3250nm mission

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**% Fuel Burn Benefit**

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The ERA Diagnostics Test at NASA Glenn
ERA Diagnostics: Detailed Historical Baseline flowfield measurements

The 3D PIV measurements provide a wealth of information about the blade wakes and vortex track.

A canonical shielding configuration provides code validation data.

The Pressure Sensitive Paint measurements show phase locked static pressure on the surface of the rotating blade.

The location of peak noise level in the phased array map changes in the presence of the CFMI pylon indicating a change in the relative strength of sources.
Test Geometry

1. Rotor sound should be unaffected by the wall
2. Should be useful for validation of prediction methods
3. Useful for estimation of noise reduction in system level studies
Shielding Experiment: Realistic Source, Simplified Shield
**Simplified Shield Results**

- Up to 10 dB OASPL peak attenuation with short barrier
  - Enough to meet noise goals?

- Simplified prediction methods over-predict shielding: advanced methods needed
  - Source distribution may be complicated


Prediction of Open Rotor Acoustic Shielding Benefits

**PROBLEM**
- Prediction and optimization of canonical shielding configurations for advanced low-noise open rotor installations

**OBJECTIVE**
Assess capability of LINPROP code for predicting acoustic benefits of open rotor tone noise shielding by airframe components such as wing or U-tail
- Realistic three-dimensional open rotor geometries and operating conditions
- Representative canonical shielding configurations

**APPROACH**
Assess accuracy of LINPROP code using wind tunnel acoustic test data
- F31/A31 sideline acoustic data for free-field and shielded configurations
- 3D aerodynamic simulation of unsteady loading on F31/A31 blade rows
- 3D acoustic field calculations for configurations of interest using LINPROP code

**RESULTS**
**Technical Progress:**
- Demonstrated fairly good agreement between LINPROP predictions and measured acoustic benefits of finite shields representative of U-Tail installations

**Paper, Presentation, etc.:**
Presented highlights at the 2012 Annual Fundamental Aeronautics Meeting in Cleveland, OH in March

**POC:** Ed Envia, NASA

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**A Conceptual Open Rotor Installation Offering Potential Acoustic Shielding Benefits by the U-Tail**

**Predicted and Measured Acoustic Shielding Benefits (i.e., Reduction in Tone SPL) for Two Canonical Shielding Configurations for F31/A31 Open Rotor**
Outlook

• The progress in source noise reduction has been remarkable.

• System analysis (TRL 4) has shown promise for new aircraft designs.

• Next steps are installation effects.
Abstract

The Open Rotor is a modern version of the UnDucted Fan (UDF) that was flight tested in the late 1980’s through a partnership between NASA and General Electric (GE). Tests were conducted in the 9’x15’ Low Speed Wind Tunnel and the 8’x6’ Supersonic Wind Tunnel starting in late 2009 and completed in early 2012. Aerodynamic and acoustic data were obtained for takeoff, approach and cruise simulations. GE was the primary partner, but other organizations were involved such as Boeing and Airbus who provided additional hardware for fuselage simulations. This test campaign provided the acoustic and performance characteristics for modern open rotor blades designs.

NASA and GE conducted joint systems analysis to evaluate how well new blade designs would perform on a B737 class aircraft, and compared the results to an advanced higher bypass ratio turbofan.

Acoustic shielding experiments were performed at NASA GRC and Boeing LSAF facilities to provide data for noise estimates of unconventional aircraft configurations with Open Rotor propulsion systems.

The work was sponsored by NASA’s aeronautics programs, including the Subsonic Fixed Wing (SFW) and the Environmentally Responsible Aviation (ERA) projects.