National Aeronautics and Space Administration

# The NASA Environmentally Responsible Aviation Project/General Electric Open Rotor Test Campaign

*Environmentally Responsible Aviation Project*

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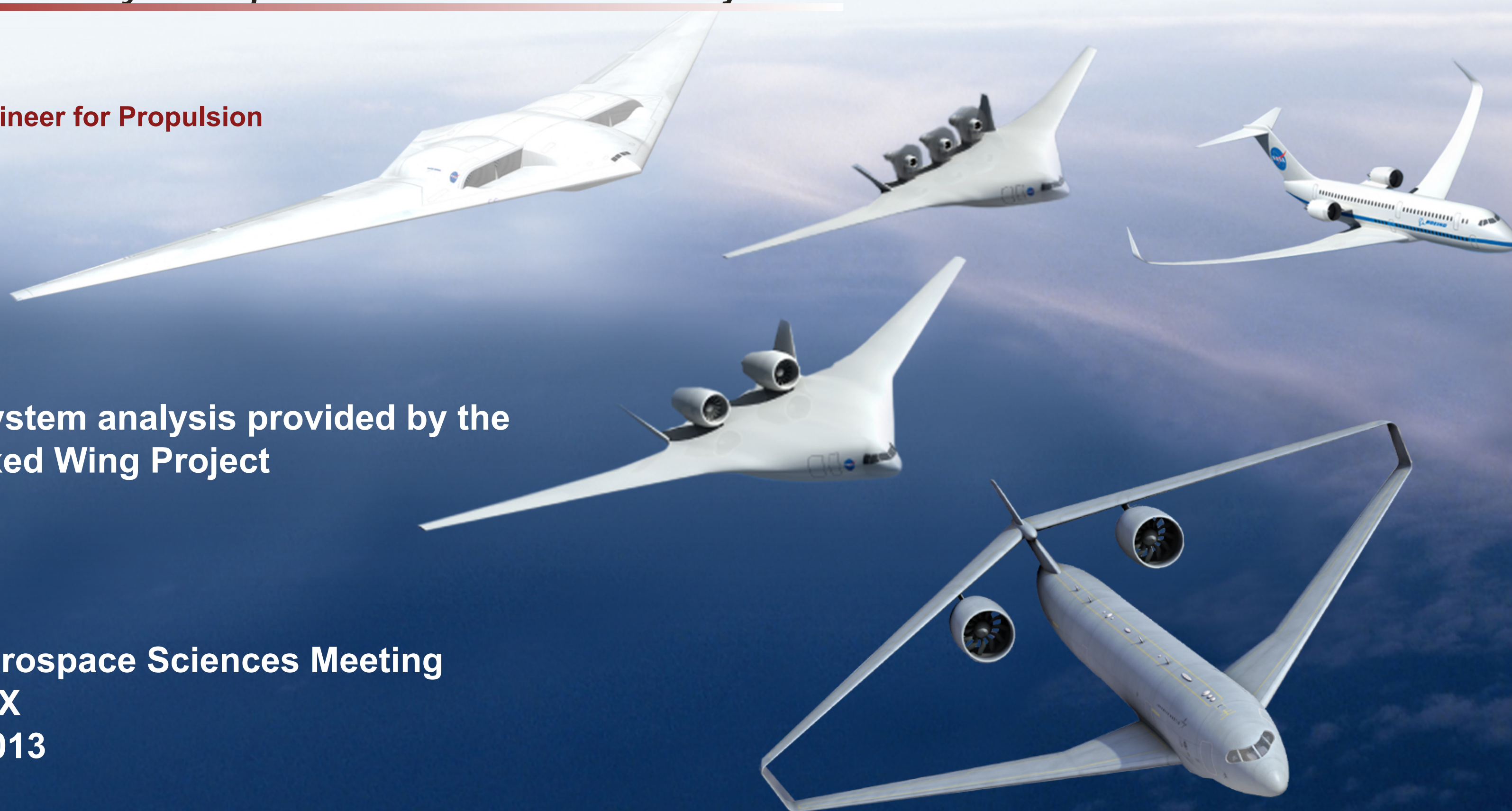
**Sub-Project Engineer for Propulsion**



**Additional system analysis provided by the Subsonic Fixed Wing Project**

**51st AIAA Aerospace Sciences Meeting**
**Grapevine, TX**
**January 8, 2013**

# Outline

- Objective
- The Open Rotor Propulsion Rig (ORPR)
- The Test Campaign
- Systems Analysis of an Advanced Single Aisle Aircraft
- The ERA Diagnostics Test at NASA Glenn
- Simplified shielding configurations
- Outlook
- Acknowledgements

## 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 series of low-noise open rotor systems were tested in collaboration with General Electric and CFM International, a 50/50 joint company between Snecma and GE. Candidate technologies for lower noise were investigated. Installation effects such as pylon integration were investigated in partnership with GE and the FAA.

"Can Open Rotors ever by quiet enough to be practical?"

# Open Rotor Propulsion Rig (ORPR)


NASA C-1985-6030

Three Model Propulsion Simulator (MPS) rigs were fabricated in the 1980s.
MPS SN001- Used at Boeing.
MPS SN002- Used at GE Cell 41.
MPS SN003- Used at NASA Lewis.

MPS SN003 was refurbished and is now called ORPR.

- New digital telemetry system
- Updated/upgraded rotating force balances.

Table 1: Open Rotor Propulsion Rig (ORPR) capabilities.

| Parameters | Operating Limits |
|---|---|
| Turbine Power (SHP) | 750/rotor |
| Shaft RPM | 10,000/rotor |
| Turbine Inlet/Plenum Pressure (psia) | 315 |
| Turbine Inlet/Plenum Temperature (deg F) | 160 min 250 max |
| Turbine Inlet/Plenum Flow (lbm/s) | 33 |
| Rotating Balance Forces, thrust (lbs)/torque (ft-lbs) | 430/550 per rotor |

Chris Hughes of the GRC Acoustics branch oversaw the ORPR rehab.

# The Test Campaign

- **The test program characterized the aerodynamic and acoustic performance of Generation-1 and Generation-2 blade sets.**

Gen-1 Blade Sets (NASA/GE)
- Historical Baseline (F31/A31, 1980s best aero)
- Modern Baseline (2000s CFD+CAA design)
- 2 GE Advanced Designs
- 2 SNECMA Designs

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

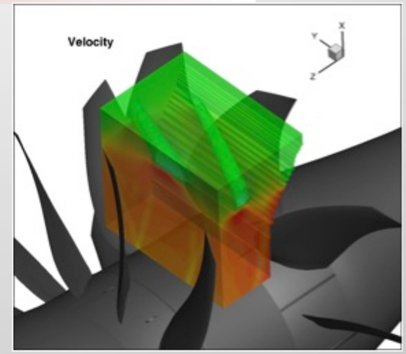
Historical Baseline Blade Set
12 x 10 blade count

# The Gen-1 test series

Drive rig rehab and installation

First research run.
Oct 28

GE/Boeing test.
Apr 5 – 28.




ERA Diagnostics Test.
Jul 19 – Sep 7

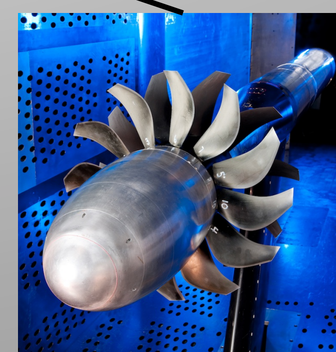
| 2009 | 2010 | 2011 |
|---|---|---|

Drive rig checkout.
Sep 24 – Oct 27

Linear array checkout.
Dec 7-11

GE/Airbus test.
Dec 14 – Feb 12

Gen-1 designs demonstrated significant noise reduction with high aero efficiency.



Gen-1 8x6 Test
Feb 28 – Aug 25

# The Gen-2 test series

Gen-2 8x6 Test
Aug 26 – Sep 9

| 2011 | | | | 12 |
|---|---|---|---|---|
| | | | | |

Gen-2 9x15 Test
Nov 10 – Jan 19

Linear Array development
in the 9x15

Jan. 19, 2012
End of Gen-2 Test

Systems Analysis of an Advanced Single Aisle Aircraft

# NASA Study Results – Fuel Burn vs. Noise

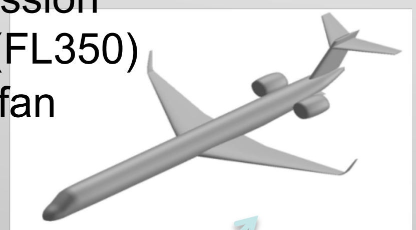
NASA modern airplane:
15% structural weight reduction from composites, etc.
Open rotor version has +2100lbs (953 kg) weight penalty

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

N+1 Tech
UHB TF
BPR ~14

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

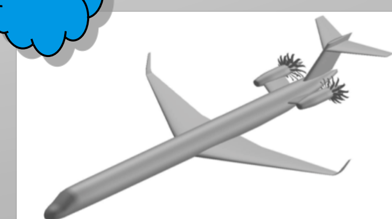
NASA modern airplane
162 pax, 3250nm mission
Cruise M= 0.78, 35kft (FL350)
Rear mount Turbofan



N+1 Tech
Open Rotor
BPR >30

**Guynn, M., Berton, J., Hendricks, E., Tong, M., Haller, W., & Thurman, D. (2011). "Initial Assessment of Open Rotor Propulsion Applied to an Advanced Single-Aisle Aircraft," 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, AIAA-2011-7058. Virginia Beach, VA.**

**Guynn, M.; Berton, J.; Haller, W.; Hendricks, E.; and Tong, M.: Performance and Environmental Assessment of an Advanced Aircraft with Open Rotor Propulsion. NASA TM-2012-217772, 2012.**



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

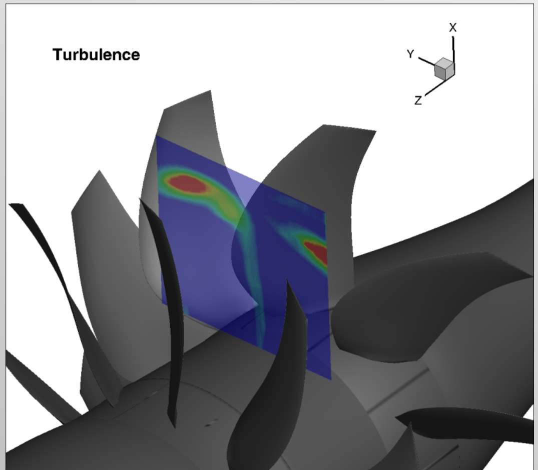
1998 technology reference vehicle
162 pax, 3250nm mission

**Noise Margin**

**% Fuel Burn Benefit**

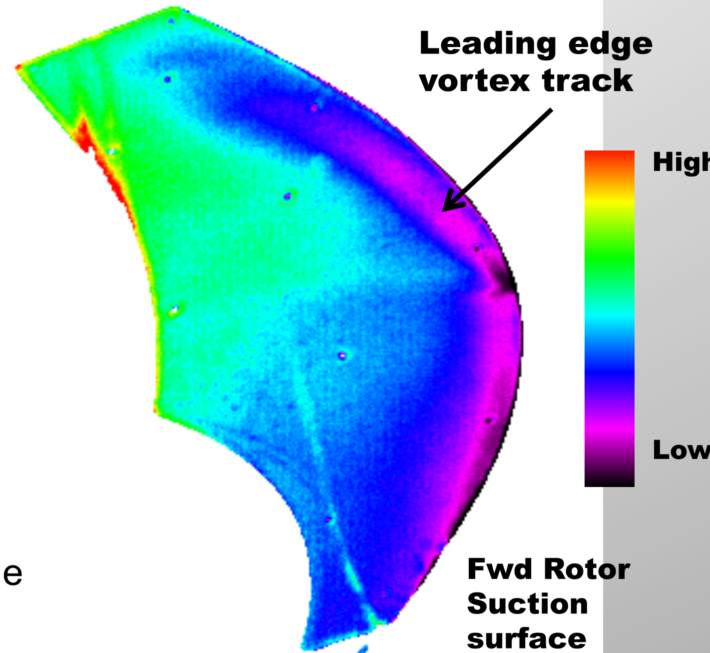
# The ERA Diagnostics Test at NASA Glenn

# 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.

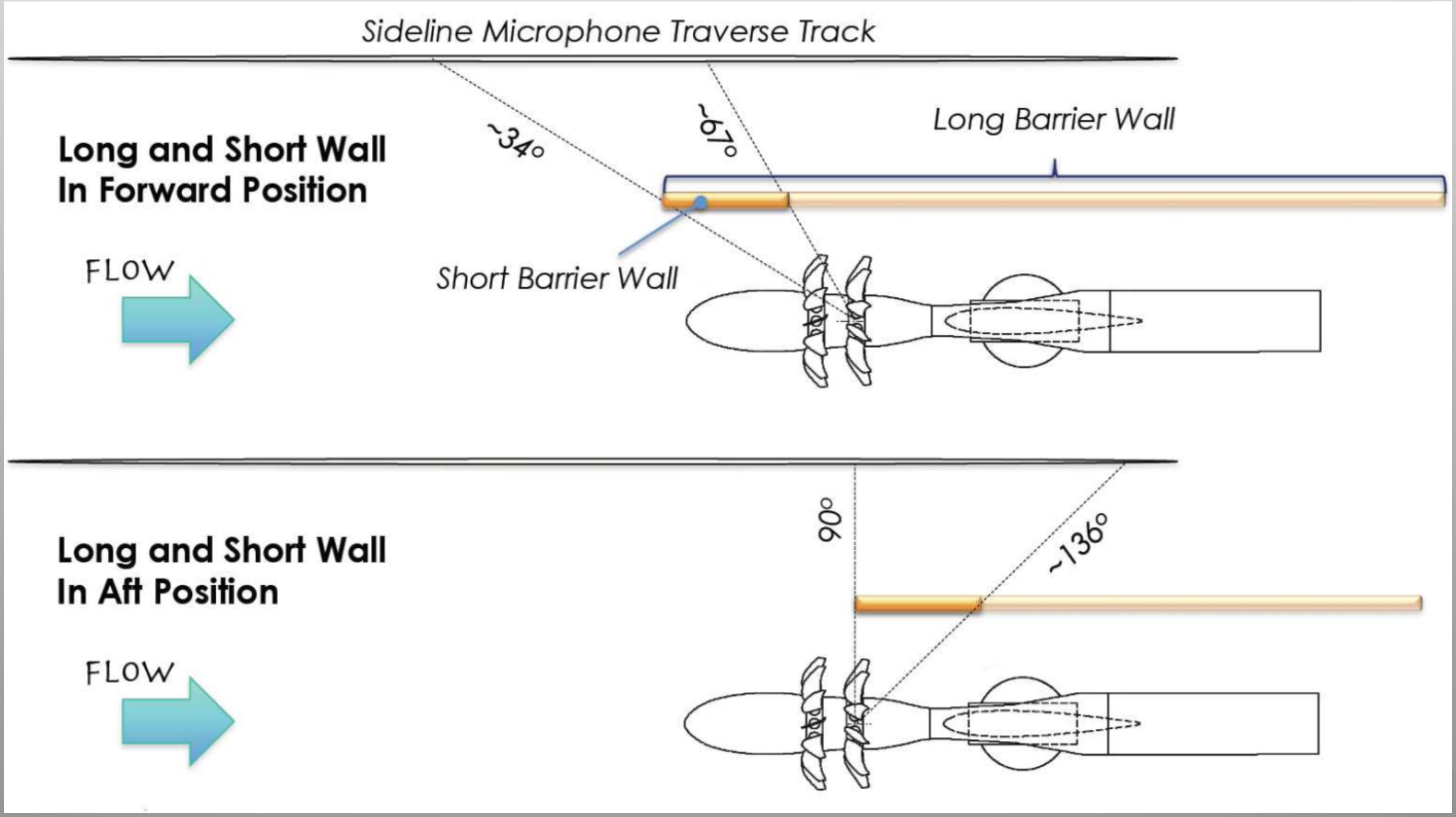



The **Pressure Sensitive Paint** measurements show phase locked static pressure on the surface of the rotating blade.

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.

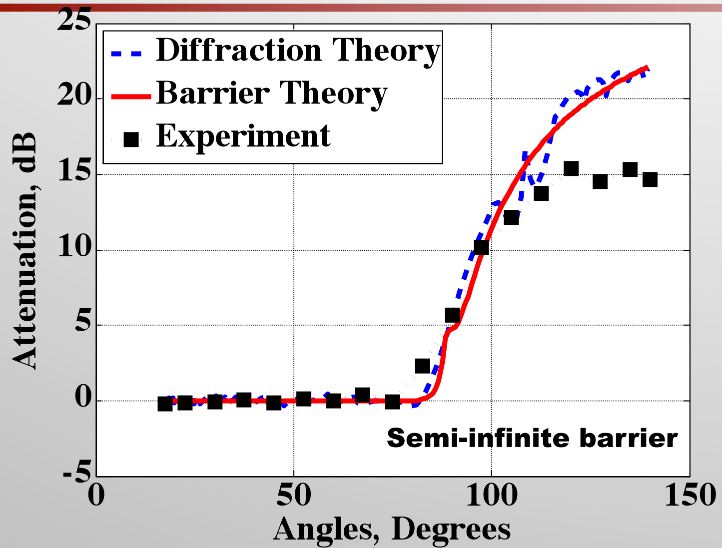
# Test Geometry

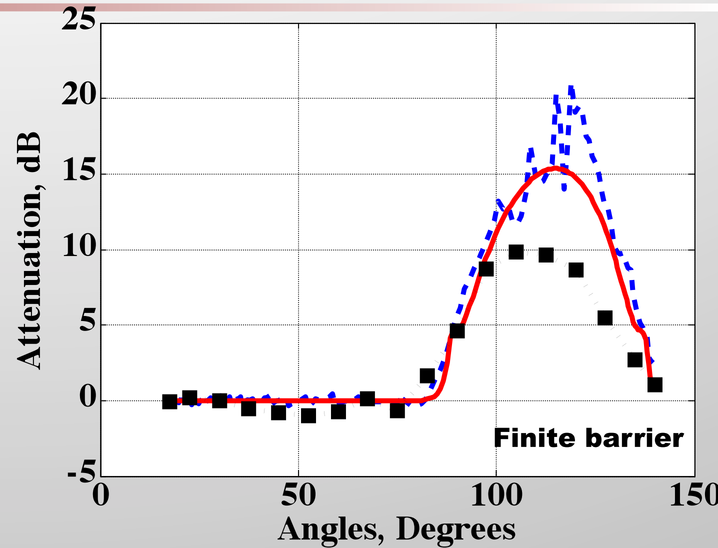
1. Rotor sound should be unaffected by the wall
2. Should be useful for validation of prediction methods
3. Useful for estimation of noise reduction in system level studies



# 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


Stephens, David and Envia, Edmane, “Acoustic Shielding for a Model Scale Counter-rotation Open Rotor,” AIAA 2011-2940, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, June 2011.

Berton, Jeffery J., “Empennage Noise Shielding Benefits for an Open Rotor Transport,” AIAA 2011-2764, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, June 2011.

# Summary

- The test program required a substantial commitment from the research/facilities organizations.
  - Double shift operations, 5 days a week since Sept 2009
  - 1142 hours of run time on the open rotor rig

- A collaboration between all partners (ERA, SFW, FAA and GE) was necessary for the success of the test and ongoing data analysis.

- ***Low-noise, high-efficiency Open Rotor systems have been demonstrated. The progress in source noise reduction has been remarkable. (10+ EPNdB Cum. in a single generation)***

- System analysis (TRL 4) has shown promise for substantial acoustic margin for new aircraft designs based on Gen-1 data.

- Gen-2 test series focused on pylon installation effects. System studies with the Gen-2 data are ongoing.

# Acknowledgements


NASA

- Environmentally Responsible Aviation Project
- Subsonic Fixed Wing Project
- Aeronautics Test Program

FAA

- Continuous Lower Energy, Emissions and Noise Program

General Electric Co. and CFMI

- and partners Boeing and Airbus

# Open Rotor papers based on the GE/NASA work at Glenn Research Center.

**Elliott, David M., “Initial Investigation of the Acoustics of a Counter Rotating Open Rotor Model With Historical Baseline Blades in a Low Speed Wind Tunnel,” AIAA 2011-2760, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, June 2011.**

**Stephens, David and Envia, Edmane, “Acoustic Shielding for a Model Scale Counter-rotation Open Rotor,” AIAA 2011-2940, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, June 2011.**

**Berton, Jeffery J., “Empennage Noise Shielding Benefits for an Open Rotor Transport,” AIAA 2011-2764, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, June 2011.**

**Hendricks, Eric, “DEVELOPMENT OF AN OPEN ROTOR CYCLE MODEL IN NPSS USING A MULTI-DESIGN POINT APPROACH,” GT2011-46694, ASME Turbo Expo 2011, Vancouver, BC, June 2011.**

**Van Zante, Dale, Gazzaniga, John, Eliott, David, and Woodward, Richard, “An Open Rotor Test Case: F31/A31 Historical Baseline Blade Set,” ISABE-2011-1310, Gothenburg, Sweden, September 2011.**

**Van Zante, Dale E. and Wernet, Mark P., “Tip Vortex and Wake Characteristics of a Counterrotating Open Rotor,” AIAA-2012-4039, 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Atlanta, GA, 29 July – August 1, 2012.**

**Hendricks, Eric S. and Tong, Michael T., “Performance and Weight Estimates for an Advanced Open Rotor Engine,” AIAA-2012-3911, 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Atlanta, GA, 29 July – August 1, 2012.**

**Stephens, David B., “Nearfield Unsteady Pressures at Cruise Mach Numbers for a Model Scale Counter-Rotation Open Rotor,” AIAA-2012-2264, 18th AIAA/CEAS Aeroacoustics Conference, Colorado Springs, CO, June 2012.**

**Guynn, M., Berton, J., Hendricks, E., Tong, M., Haller, W., & Thurman, D. (2011). Initial Assessment of Open Rotor Propulsion Applied to an Advanced Single-Aisle Aircraft. 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, AIAA-2011-7058. Virginia Beach, VA.**

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**Hendricks, E. and Tong, M. "Performance and Weight Estimates for an Advanced Open Rotor Engine." AIAA-2012-3911. NASA/TM-2012-217710. 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Atlanta, GA, 30 July-1 August 2012.**

**Envia, Edmane, “Open Rotor Aeroacoustic Modelling,” presented at the Conference on Modelling Fluid Flow, Budapest, Hungary, Sept. 4-7, 2012.**

# 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.