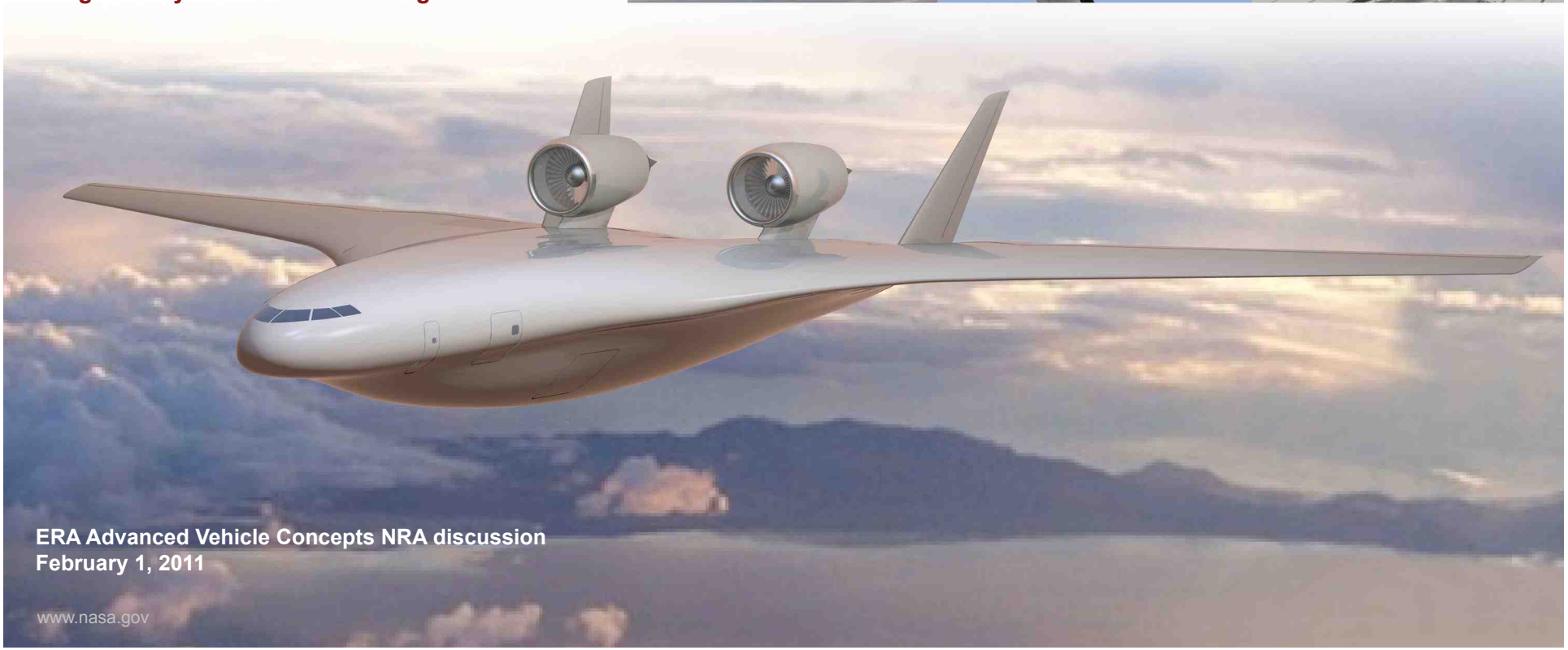
Open Rotor Research at NASA Glenn

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 as well as installation effects such as pylon integration. The research program in both the low and high-speed wind tunnels is reviewed. Some detailed flowfield and acoustics measurements acquired for an internal NASA program are highlighted. The publically available research data is presented also.

National Aeronautics and Space Administration

Open Rotor Research at NASA Glenn

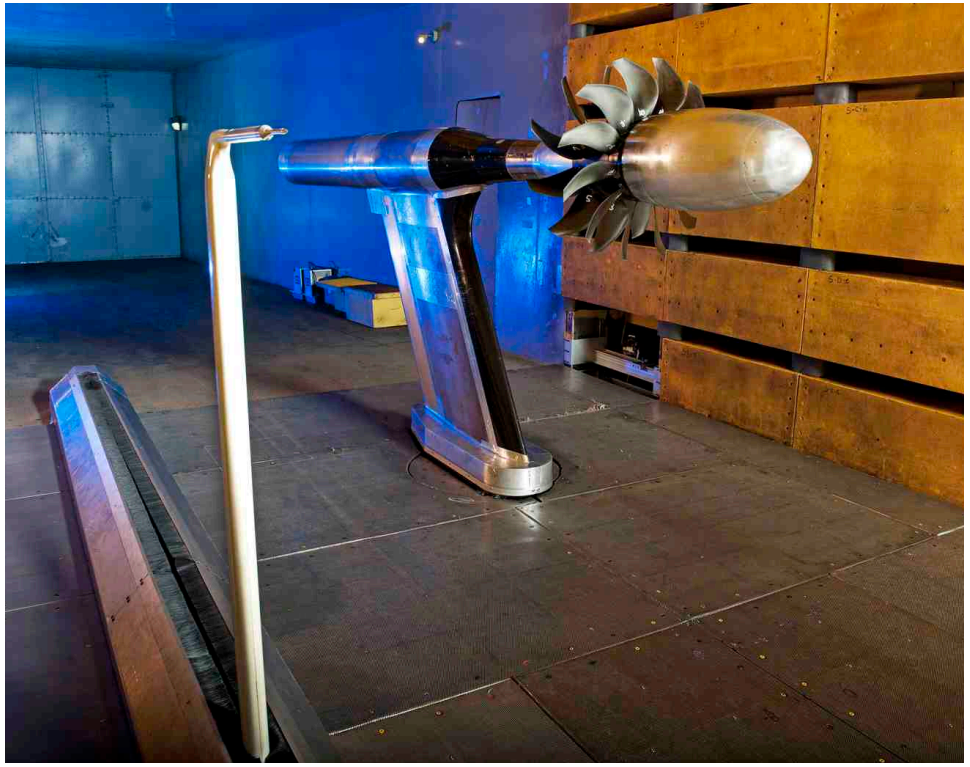
Dale Van Zante
Propulsion Sub-Project Engineer
Environmentally Responsible Aviation
Integrated Systems Research Program



ERA Advanced Vehicle Concepts NRA discussion
February 1, 2011

Outline

- The Open Rotor test program
- Rig and facility details
- Low speed isolated/installed data
- Status



Testing is supported by the Environmentally Responsible Aviation Project
Data analysis efforts are supported by the Subsonic Fixed Wing Project
Facility support is from the Aeronautics Test Program

The NASA/GE 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 as well as installation effects such as pylon integration.

Historical Baseline Blade Set
12 x 10 blade count
Non-proprietary geometry/data
Export controlled

Test Program Overview

NASA/GE 9x15 Low Speed Wind Tunnel		**NASA/GE 8x6 High Speed Wind Tunnel**	**NASA/GE/FAA (CLEEN) 8x6/9x15**
GE Gen-1 Blade Designs			GE Gen-2 Blade Designs
Takeoff and Approach Conditions	ERA Diagnostics	Cruise Conditions	TO/Approach and Cruise Conditions
•Aerodynamic performance •**Acoustics** •Hot Film flowfield measurements	•Acoustic phased array •Farfield Acoustics with Pylon •Pressure Sensitive Paint •Stereo Particle Image Velocimetry •Acoustic Shielding	•**Aerodynamic performance** •Near field unsteady pressure	• Aero and acoustic performance of optimized blade designs at low and high speed.

Glenn Research Center
Cleveland, Ohio

8x6 SWT/9x15 LSWT Wind Tunnel Complex

Operating mode: Aerodynamic–Closed loop
Propulsion–Open loop

9ft. x 15ft.
Low Speed Test Section
MACH NO.: 0–0.2

Muffler

Cooler

Flexible nozzle

Air Dryer

Compressor

Drive motors

8ft. x 6ft.
Supersonic Test Section
MACH NO.: 0.25–2.0
Altitude: Sea level to 35,000 ft.
Tunnel pressure: 2400 to 3700 lb/ft^2
Temperature: 80 to 200 °F
Drive motors 87,000 HP

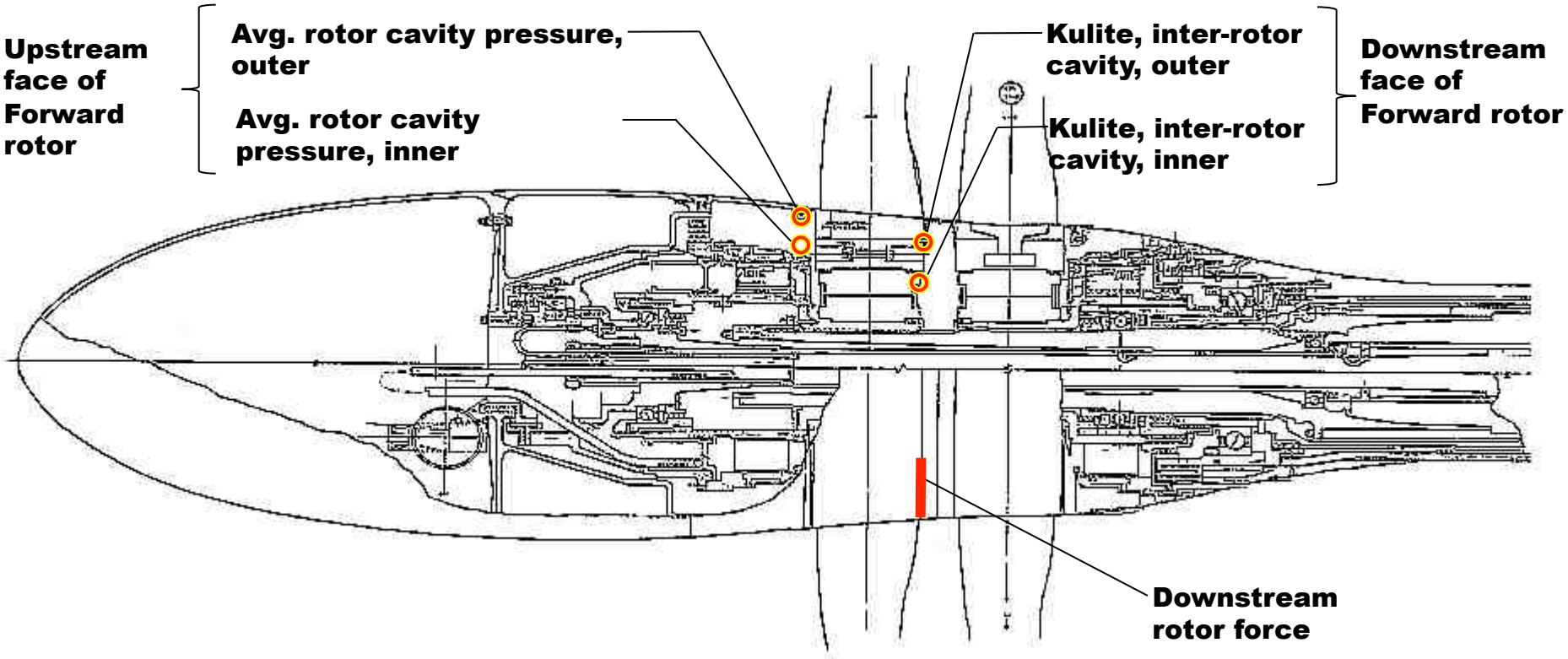
CD-98-77052

The Open Rotor Propulsion Rig (ORPR)

750 SHP per rotor
Rotating force balance:
  430 Lbf thrust per rotor
  550 ft-lb torque per rotor

1/5 to 1/7 of Full Scale
Independently controlled rotor speeds
Digital telemetry units for and aft
12 strain gage channels per rotor
Adjustable rotor spacing

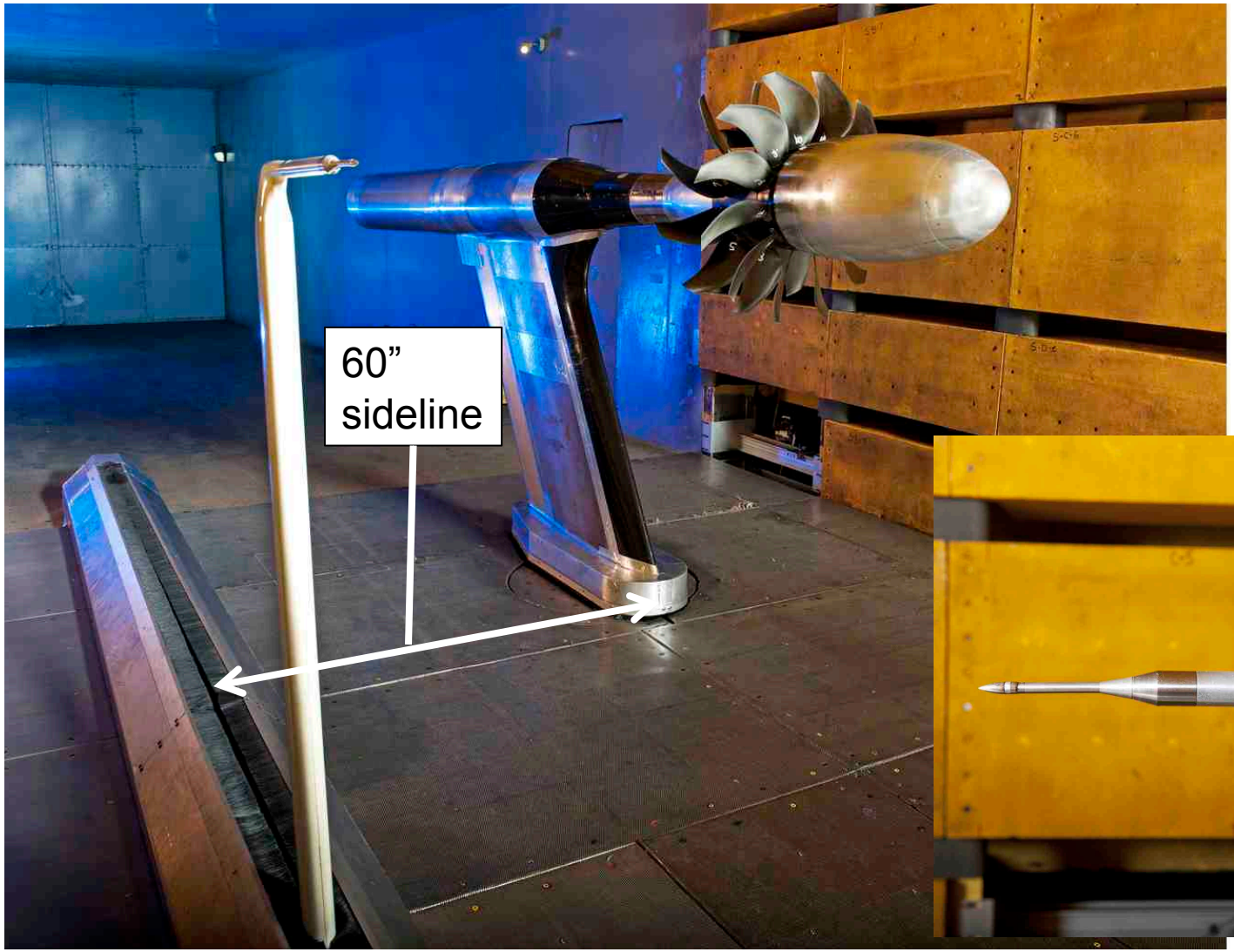
Tare corrections to force balance data

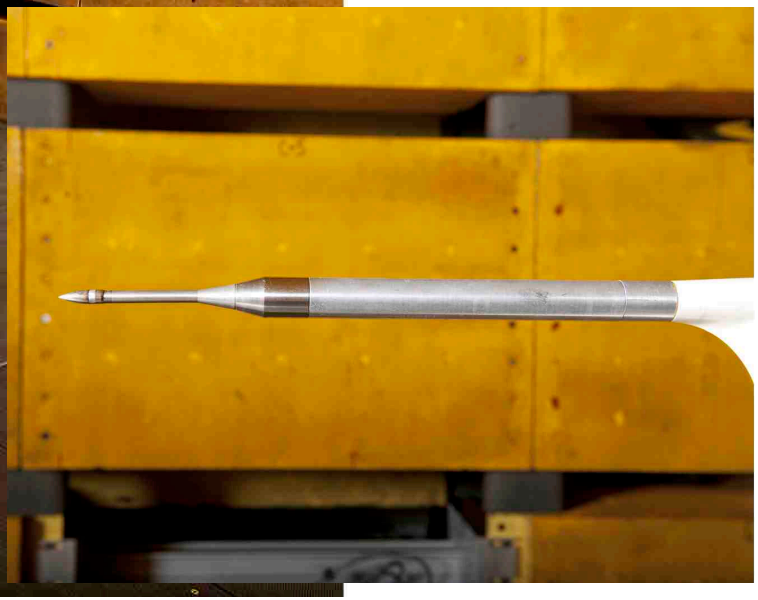


Forward Rotor Downstream Force

The downstream rotor force, frdf, is calculated by multiplying the delta pressure term (delta from the freestream static pressure, pso) by the particular inter-rotor cavity pressure.

Acoustic Configuration





18° forward to
140° aft angles

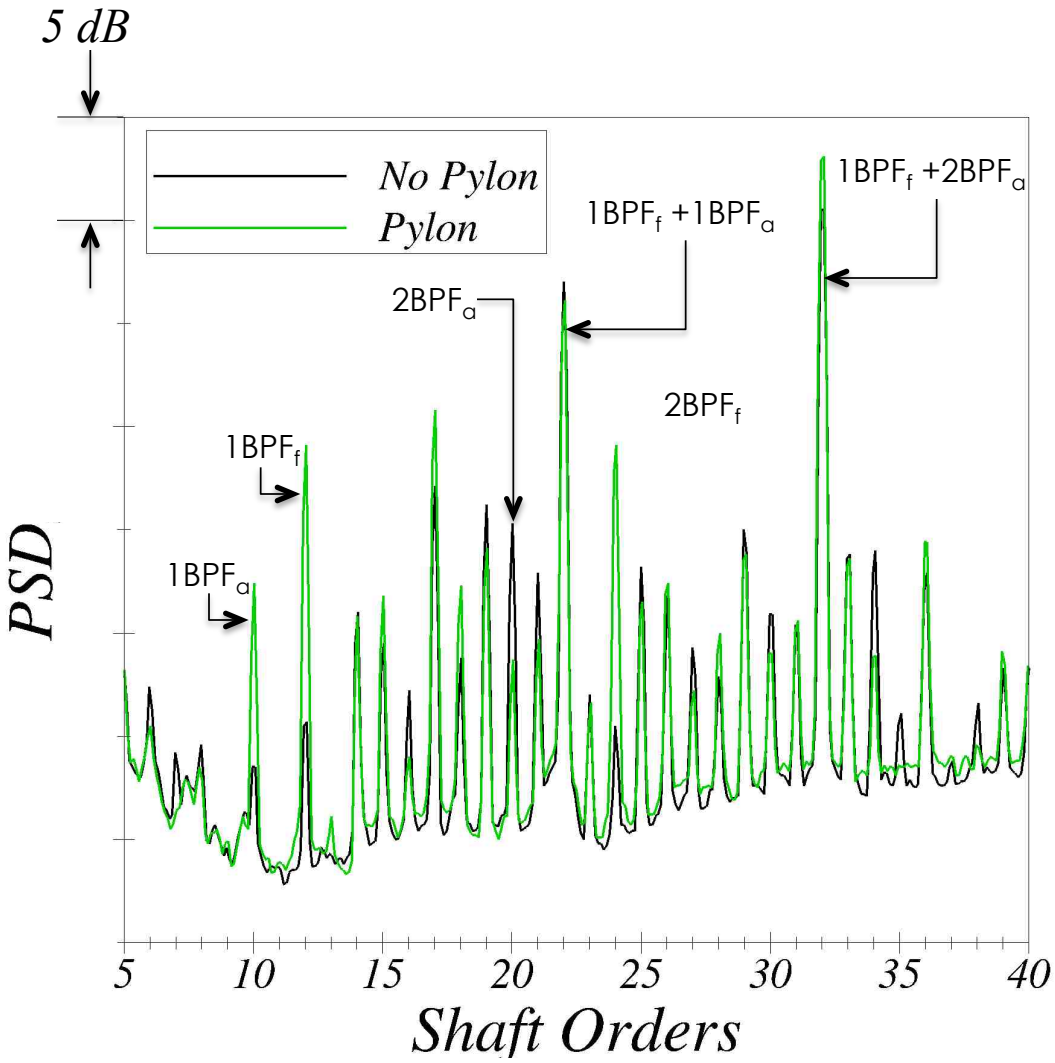
NASA/GE Collaboration
9x15 Low Speed Wind Tunnel test

Test Matrix
Freestream Mach number variation
Blade pitch angle setting variation
Series of RPMs at a set pitch
Model angle of attack

A detailed aerodynamic performance data set was acquired for all blade sets as well as acoustic measurements at 18 axial locations.

Primary NASA researcher: John Gazzaniga

ERA Diagnostics:
Historical Baseline Installation effects (2)



The presence of the CFMI pylon induces distortions into blade rows causing noticeable increase in the levels of the individual rotor harmonics.

NASA Researcher: David Elliott

Data Summary for Historical Baseline

Run No.	Config No.	MO	AoA	Fwd Rotor β ang	Aft Rotor β ang	Exhaust Treatment	Test Date
4	12A	0.2	0	43	43.5	None	28-Oct-09
5	12B	.18,.2,.22	-3,0,3,8	40.1	40.8	None	28-Oct-09
67	12C	0.2	0	40.1	40.8	Duct	9-Mar-10
68b	13A	0.2	0	33.5	35.7	Duct	9-Mar-10
69	12D	0.2	0	43	43.5	Duct	10-Mar-10
213	FF PYL	0.2, 0.22	0,3,8	40.1	40.8	Muffler	2-Aug-10
214	FF PYL	0.2, 0.22	0,3,8	33.5	35.7	Muffler	3-Aug-10
215	FF ISO	0.2, 0.22	0,3,8	33.5	35.7	Muffler	3-Aug-10
216	FF ISO	0.2, 0.22	0,3,8	40.1	40.8	Muffler	4-Aug-10
217	FF ISO WALL FWD	0.2	0	40.1	40.8	Muffler	5-Aug-10
218	FF ISO WALL AFT	0.2	0	40.1	40.8	Muffler	5-Aug-10
230	FF ISO WALL FWD	0.2	0	40.1	40.8	Muffler	7-Sep-10
231	FF ISO WALL AFT	0.2	0	40.1	40.8	Muffler	7-Sep-10

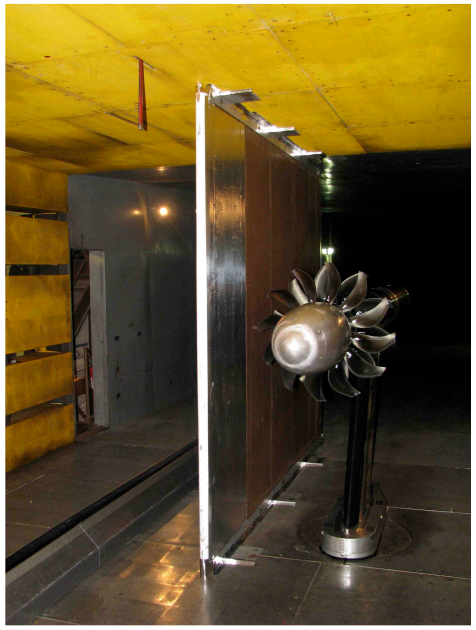
3 blade pitches: TO Nom, Scaled TO, Approach

Work is going on now to apply the tare corrections to this data.

ERA Diagnostics:
Historical Baseline Acoustic Shielding

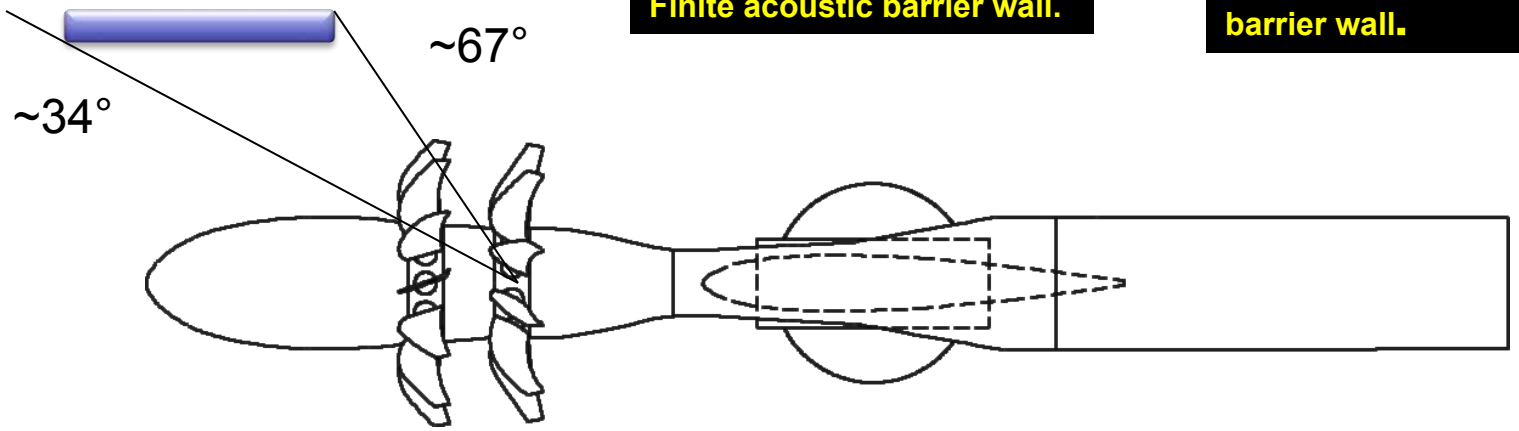
Test Matrix
2 Barrier wall lengths
2 Barrier wall positions Forward and Aft
2 Rotor speeds
2 Freestream Mach numbers

Finite acoustic barrier wall.

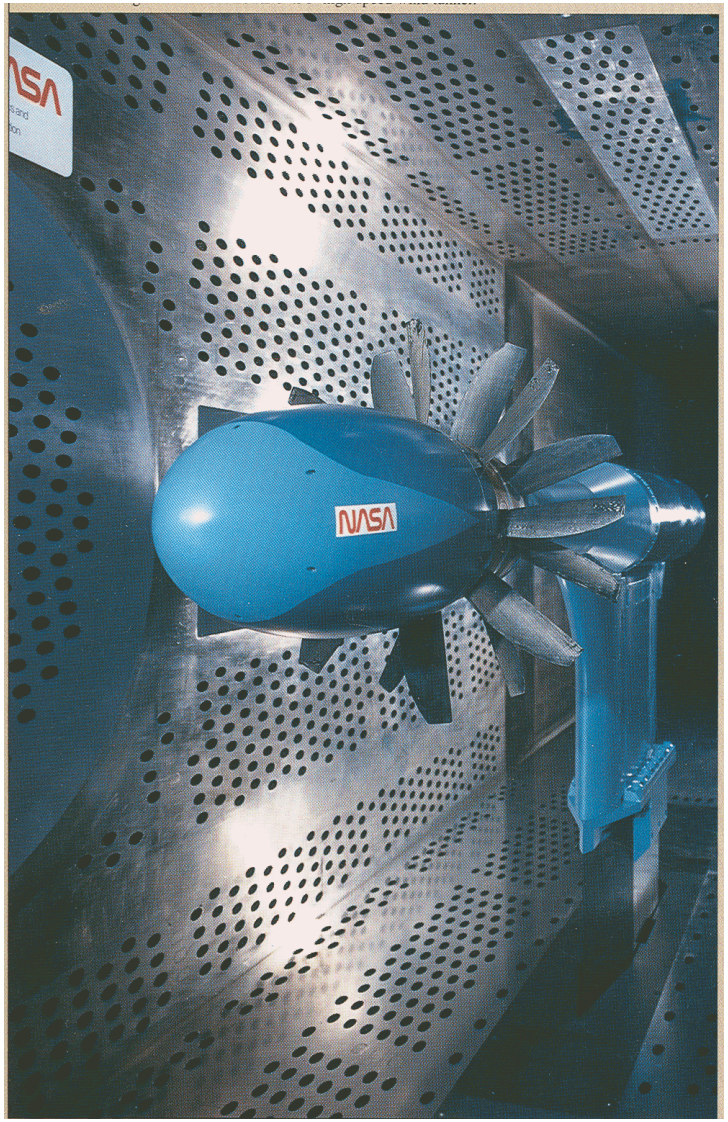


Semi-infinite acoustic barrier wall.

Short barrier, Forward position



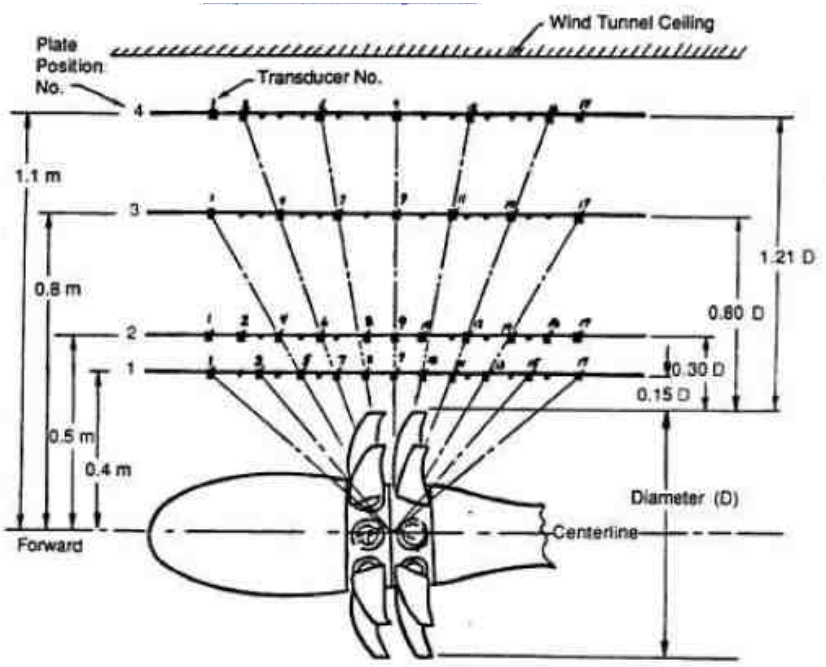
NASA/GE Collaboration
8x6 High Speed Wind Tunnel test



NASA C85-6031

Objectives: Aerodynamic performance and near field unsteady pressure measurements at cruise Mach number.

Installation of ORPR into the 8x6 began in December.

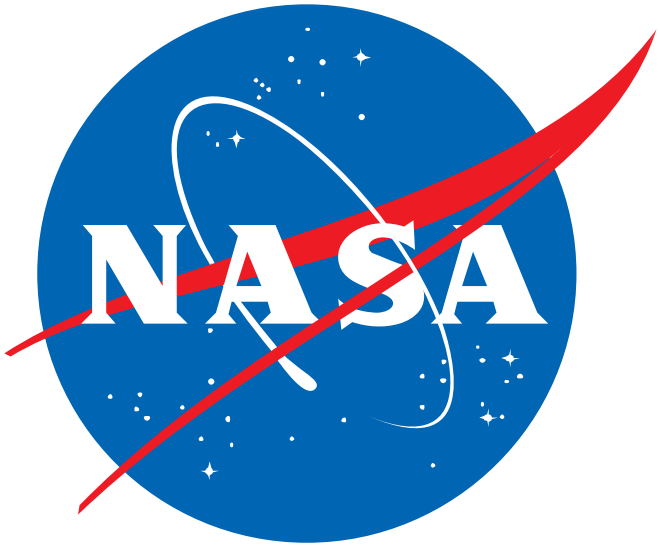


NASA NAS3-24080, Task V Final Report

Status

- Isolated and pylon installed aero and acoustic data exist for the Historical Baseline Blade Set (F31/A31).
- Tare corrections are being applied to the data now.

- This constitutes that data set needed for system analysis.



Federal Aviation Administration: CLEEN program

Publications

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,” to be presented at AIAA Aeroacoustics Conference, Portland, Oregon, June 2011.

Stephens, David and Envia, Edmane, “Acoustic Shielding for a Model Scale Counter-rotation Open Rotor,” to be presented at AIAA Aeroacoustics Conference, Portland, Oregon, June 2011.

Berton, Jeffery J., “Empennage Noise Shielding Benefits for an Open Rotor Transport,” to be presented at AIAA 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, to be presented at Turbo Expo 2011, Vancouver, BC, June 2011.

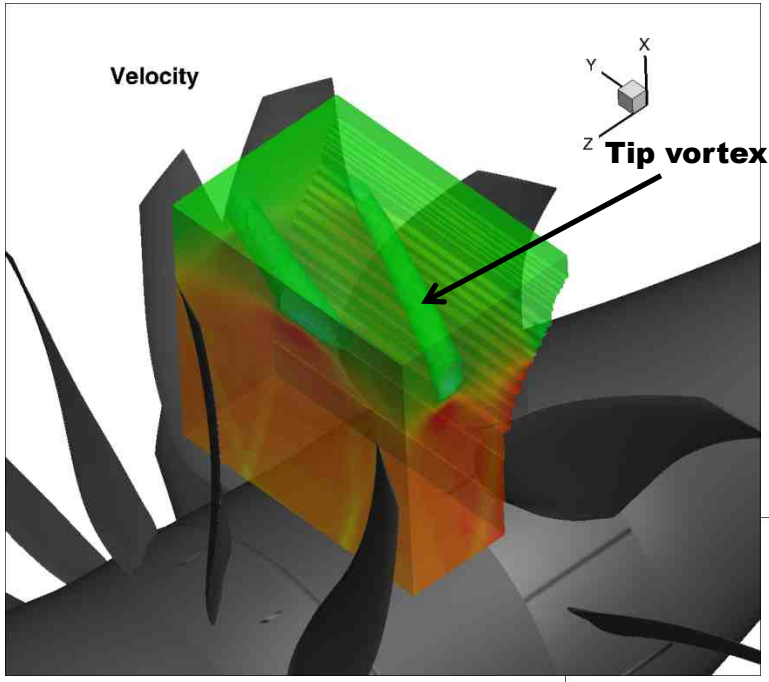
Van Zante, Dale, Gazzaniga, John, Eliott, David, and Woodward, Richard, “An Open Rotor Test Case: F31/A31 Historical Baseline Blade Set,” to be presented at ISABE 2011, Gothenburg, Sweden. September 2011.

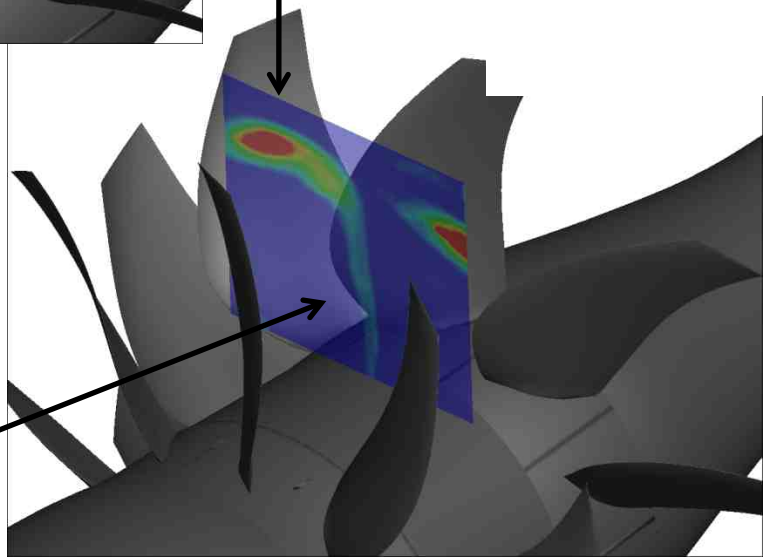
The ERA Diagnostics Program

Acoustic Phased Array	**Farfield acoustics with Pylon**	**Pressure Sensitive Paint**	**Stereo Particle Image Velocimetry**	**Acoustic Shielding**

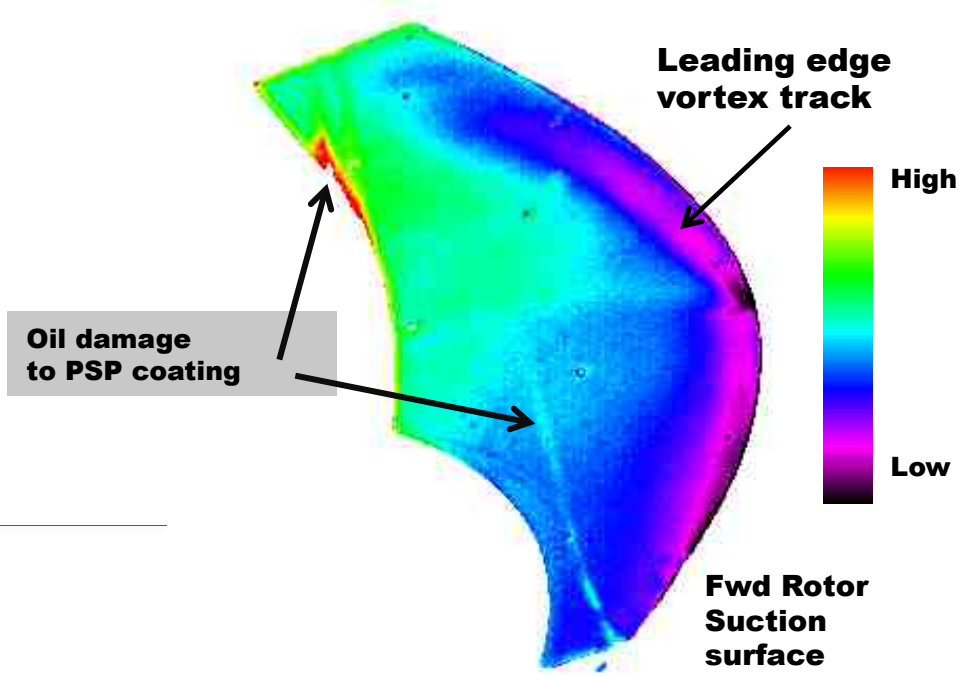
The goal is a comprehensive data set that will identify noise sources and enable improved performance and acoustic modeling of open rotor systems.

ERA Diagnostics:
Detailed Historical Baseline flowfield measurements





The 3D **PIV** measurements provide a wealth of information about the blade wakes and vortex track.
NASA Researcher: Mark Wernet



The **Pressure Sensitive Paint** measurements show phase locked static pressure on the surface of the rotating blade.
NASA Researcher: Tim Bencic

ERA Diagnostics:
Historical Baseline Installation effects (1)

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.

NASA Researcher: Gary Podboy