Reestablishing Open Rotor as an Option for Significant Fuel Burn Improvements

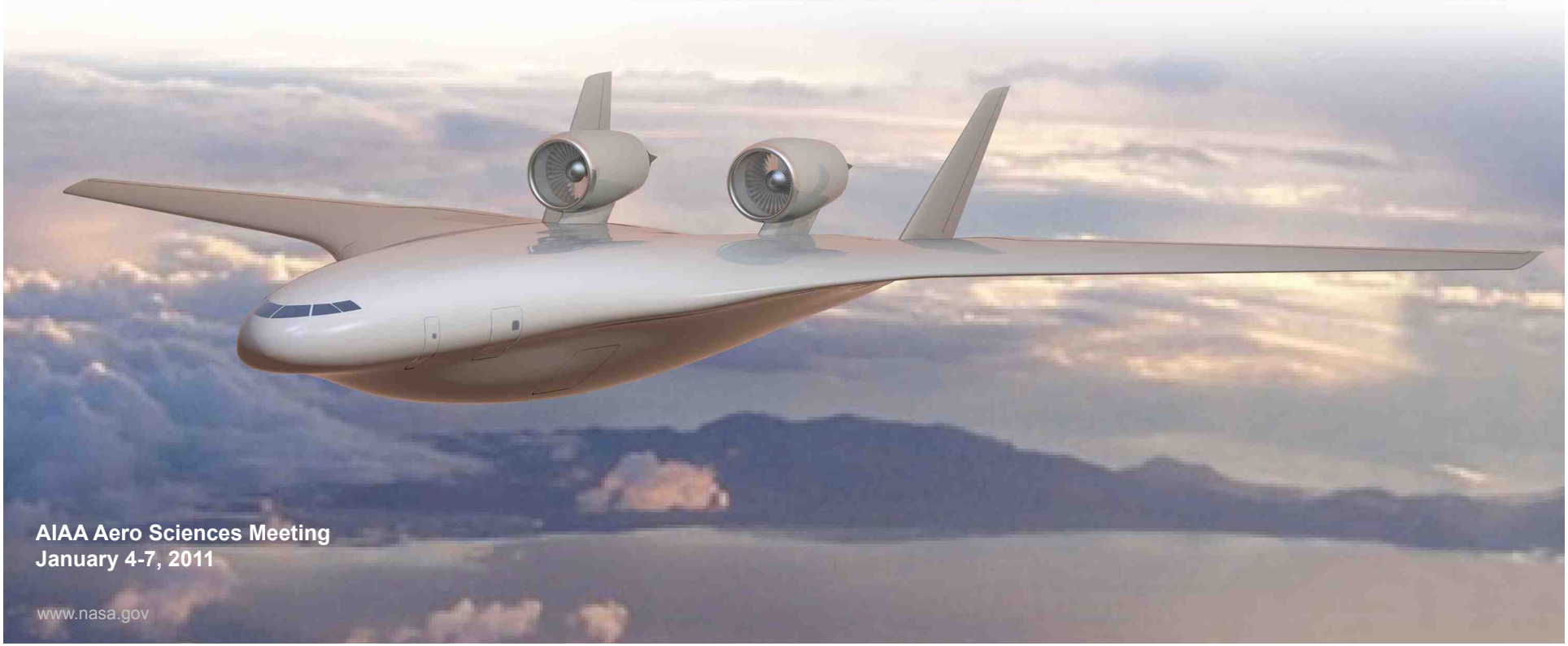
A low-noise open rotor system is being tested in collaboration with General Electric and CFM International, a 50/50 joint company between Snecma and GE. Candidate technologies for lower noise will be investigated as well as installation effects such as pylon integration.

Current test status is presented as well as future scheduled testing which includes the FAA/CLEEN test entry. Pre-test predictions show that Open Rotors have the potential for revolutionary fuel burn savings.

National Aeronautics and Space Administration

Reestablishing Open Rotor as an Option for Significant Fuel Burn Improvements

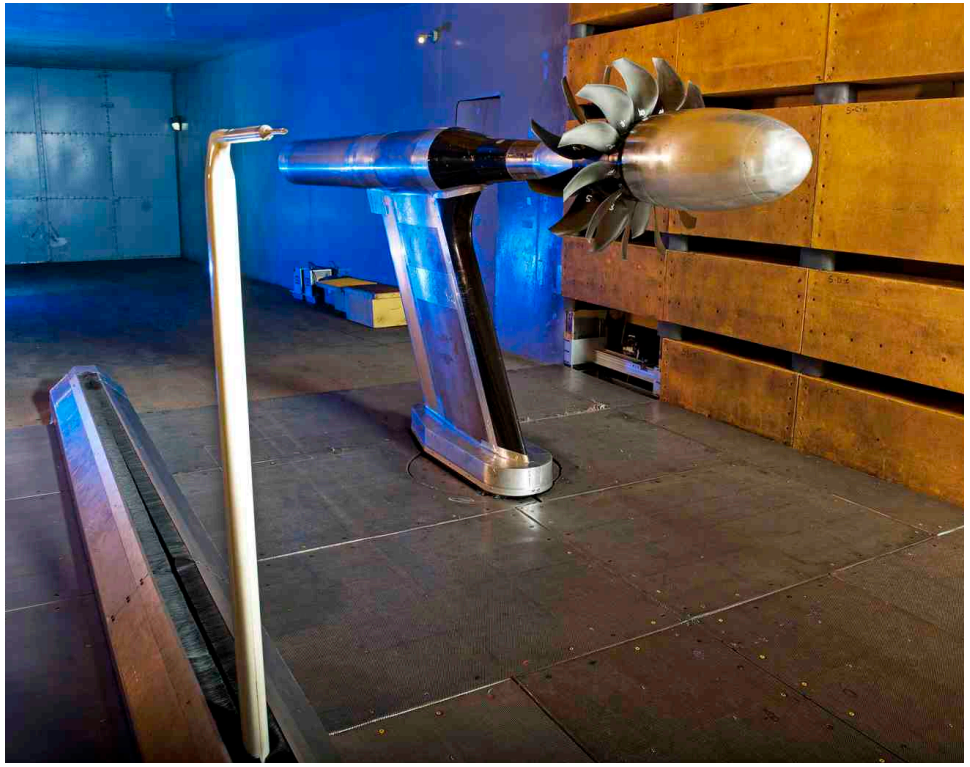
Dale Van Zante
Open Rotor Technical Lead
Environmentally Responsible Aviation
Integrated Systems Research Program



AIAA Aero Sciences Meeting
January 4-7, 2011

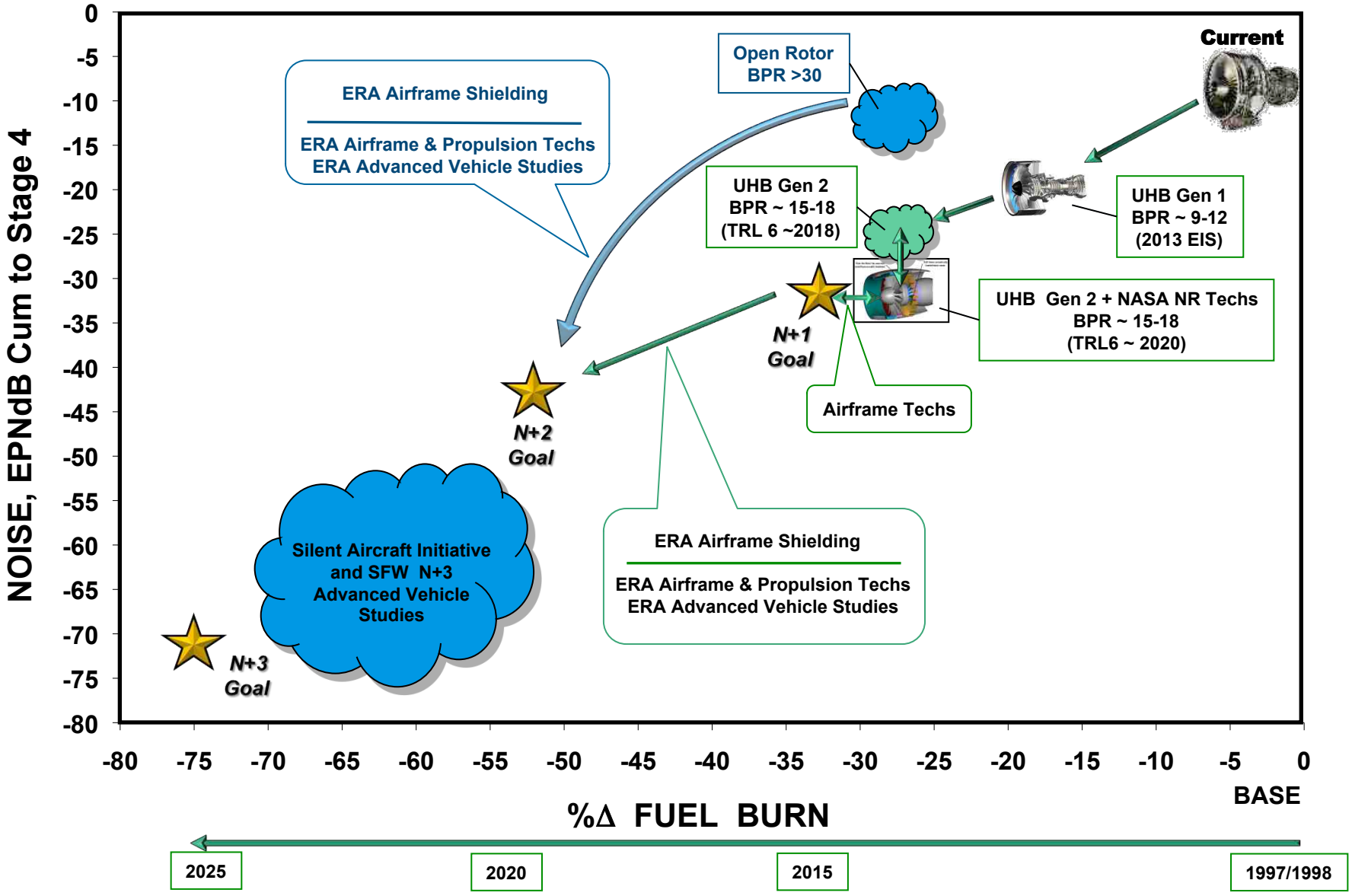
Outline

- Why Open Rotor?
- The Open Rotor test program
  - The NASA/GE Collaboration
  - ERA Diagnostics Program
- CFMI projection of modern open rotor performance
- The path forward
- Summary



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

Why Open Rotor? Technology Development

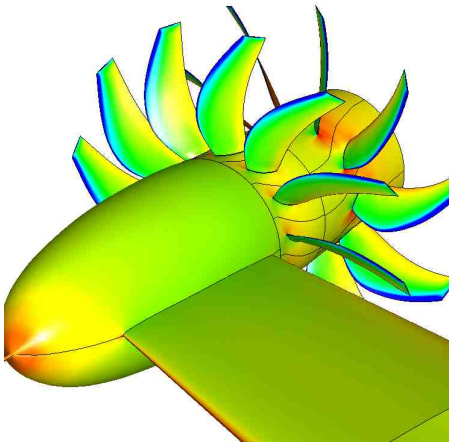


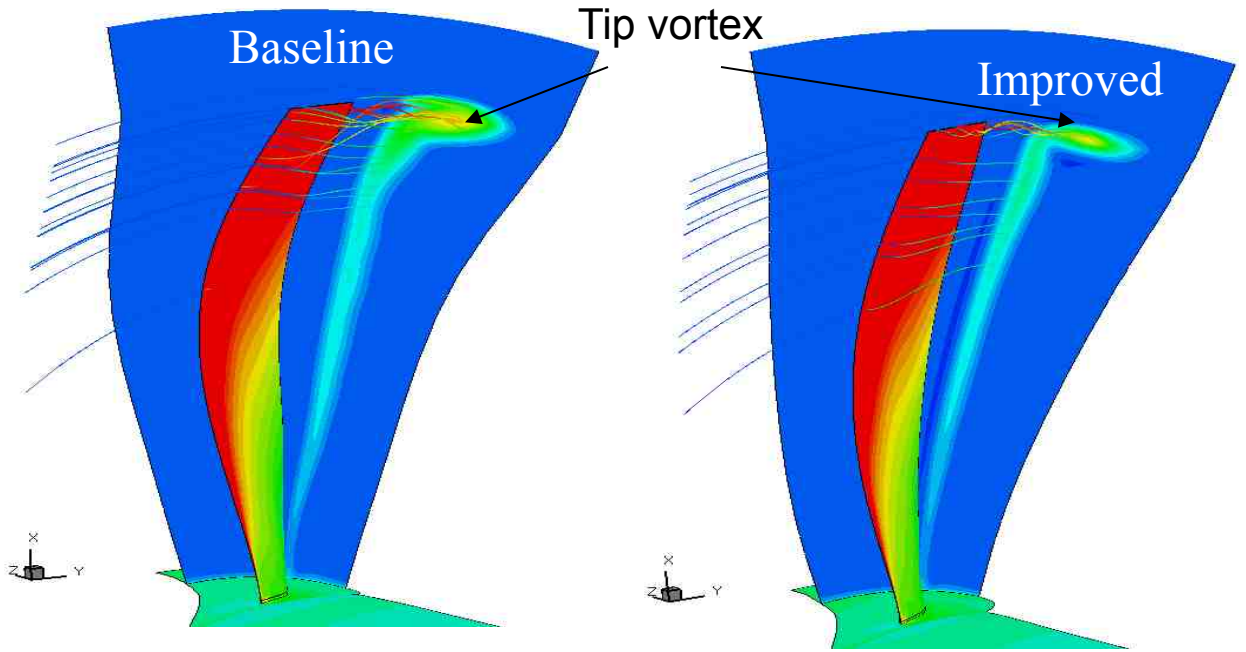
The NASA/GE Collaboration on Open Rotor Testing

- **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

GE Open Rotor Blade Designs





At take-off open rotors have high rotor lift coefficients and strong tip vortices.

Front rotor tip vortex interacting with aft rotor blade is a dominant noise source.

State of the art CFD is being used to modify the open rotor tip vortex at take-off conditions to reduce the noise generation.

- Modern analytical tools shedding light on open rotor source noise
- Advanced designs showing good promise in aero-acoustic wind tunnel tests

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.

NASA/GE Collaboration
9x15 Low Speed Wind Tunnel test

Test Matrix
Freestream Mach number variation
Blade pitch angle setting variation
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.

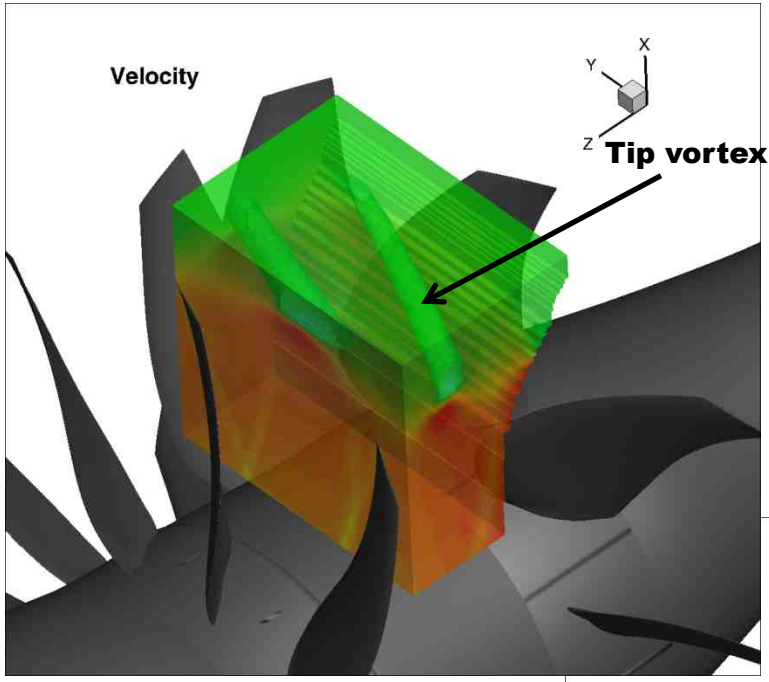
Primary NASA researcher: John Gazzaniga

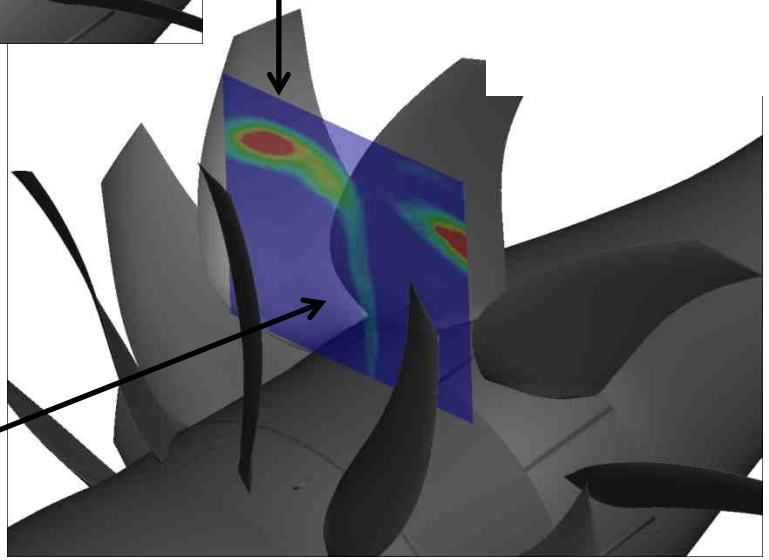
The ERA Diagnostics Program

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

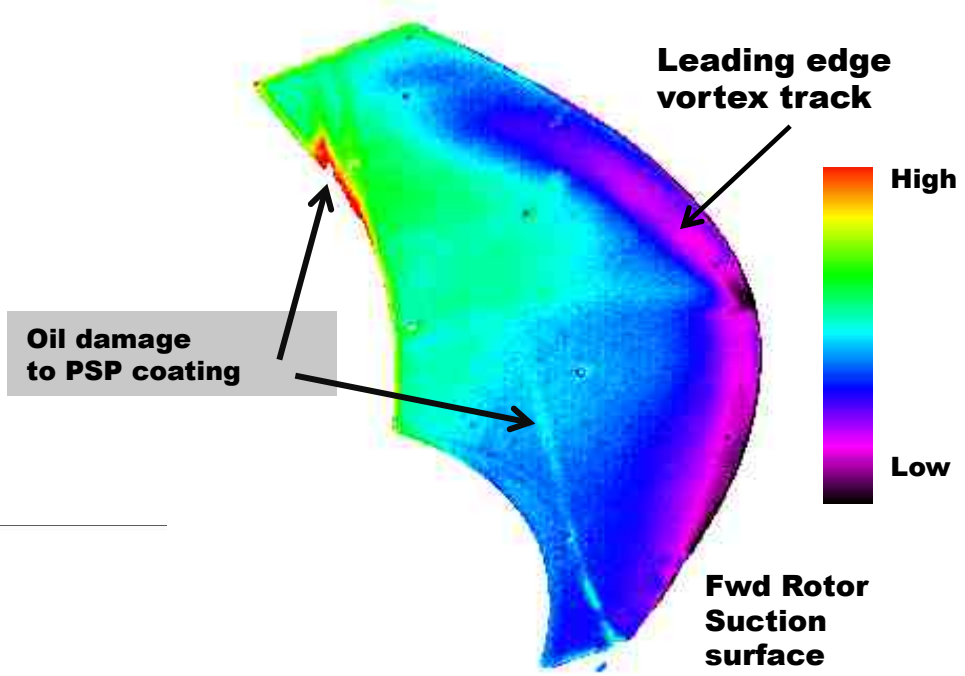
The goal is a comprehensive data set that will identify noise sources and enable improved performance and acoustic modeling of open rotor systems.

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

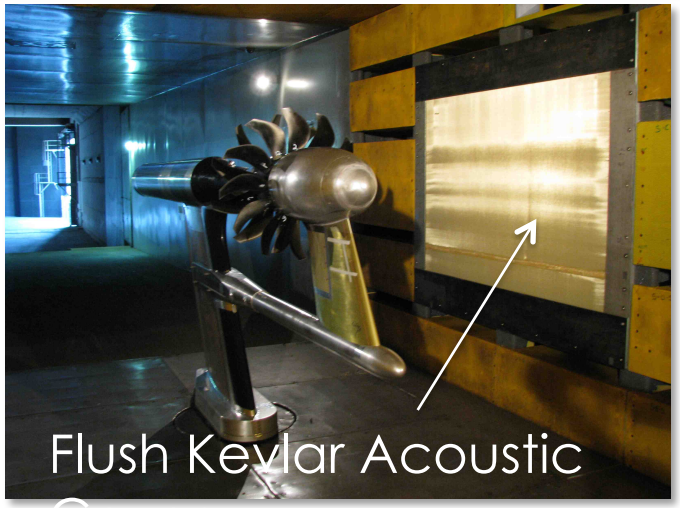


The **Pressure Sensitive Paint** measurements show phase locked static pressure on the surface of the rotating blade.
NASA Researcher: Tim Bencic

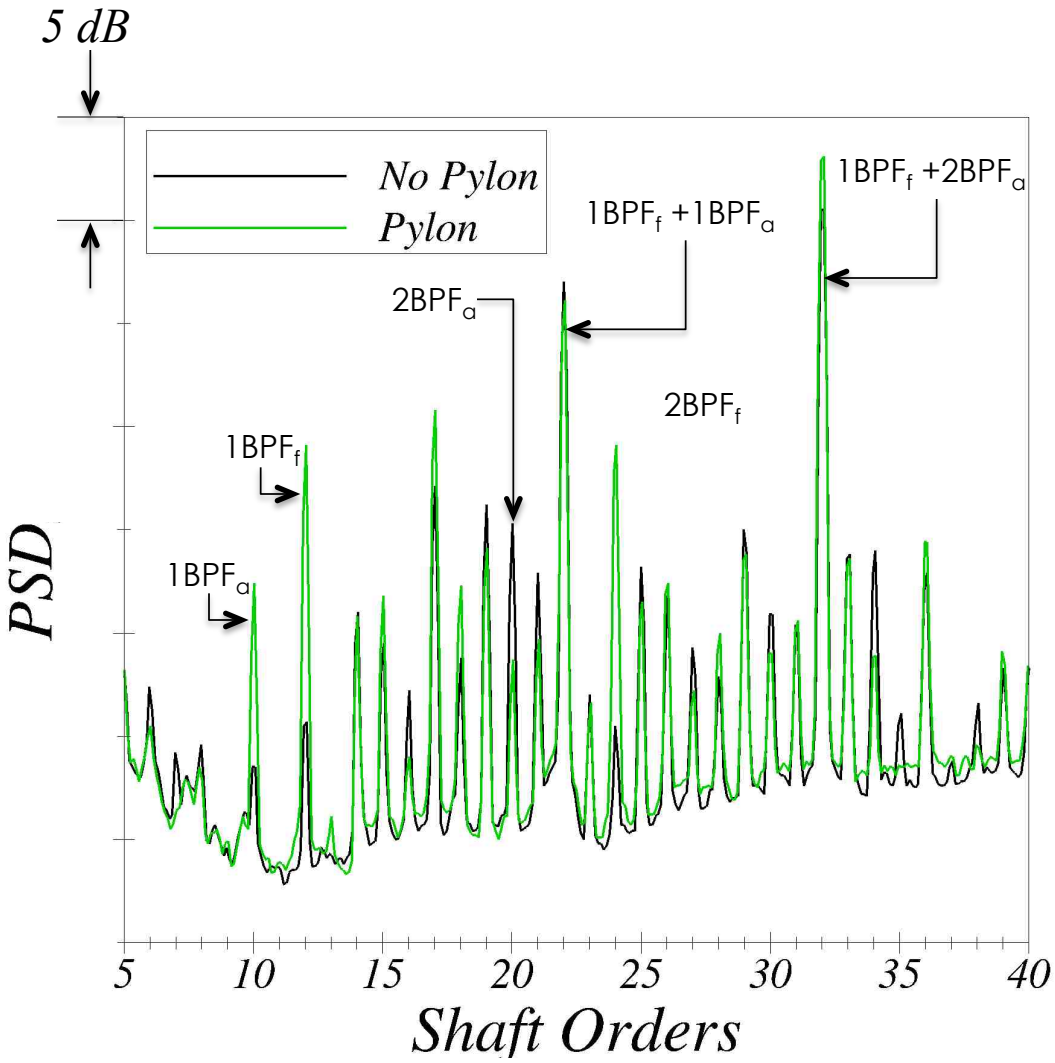
ERA Diagnostics:
Historical Baseline Installation effects (1)

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



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

ERA Diagnostics: Acoustic Shielding (1)

Strategies in addition to propulsion system noise reduction are needed to meet the N+2 goals. An example is acoustic shielding by tail or wing surfaces.

Within the ERA Diagnostics testing canonical shielding configurations were measured to provide basic acoustic data for model validation.

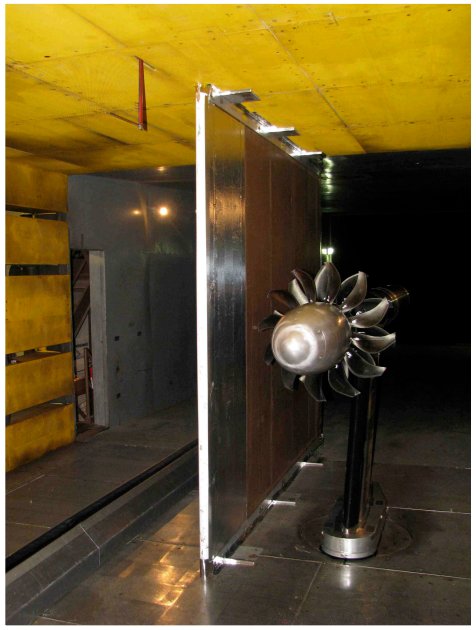
NASA Researchers: David Stephens and Dave Elliott

NASA Analysis: Ed Envia

ERA Diagnostics:
Historical Baseline Acoustic Shielding (2)

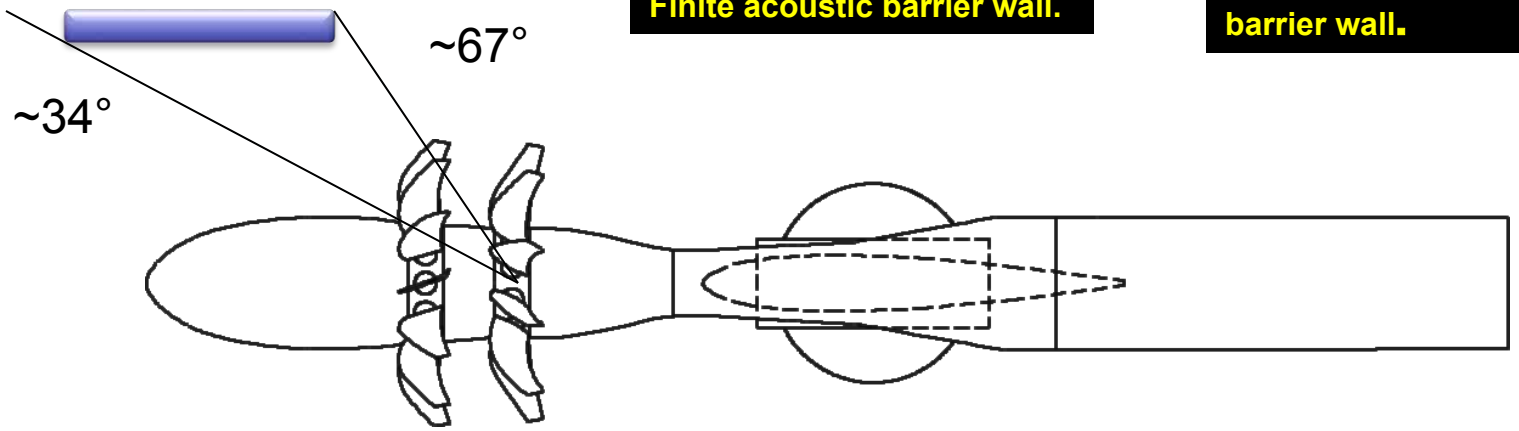
Test Matrix
2 Barrier wall lengths
2 Barrier wall positions Forward and Aft
2 Rotor speeds
2 Freestream Mach numbers

Finite acoustic barrier wall.

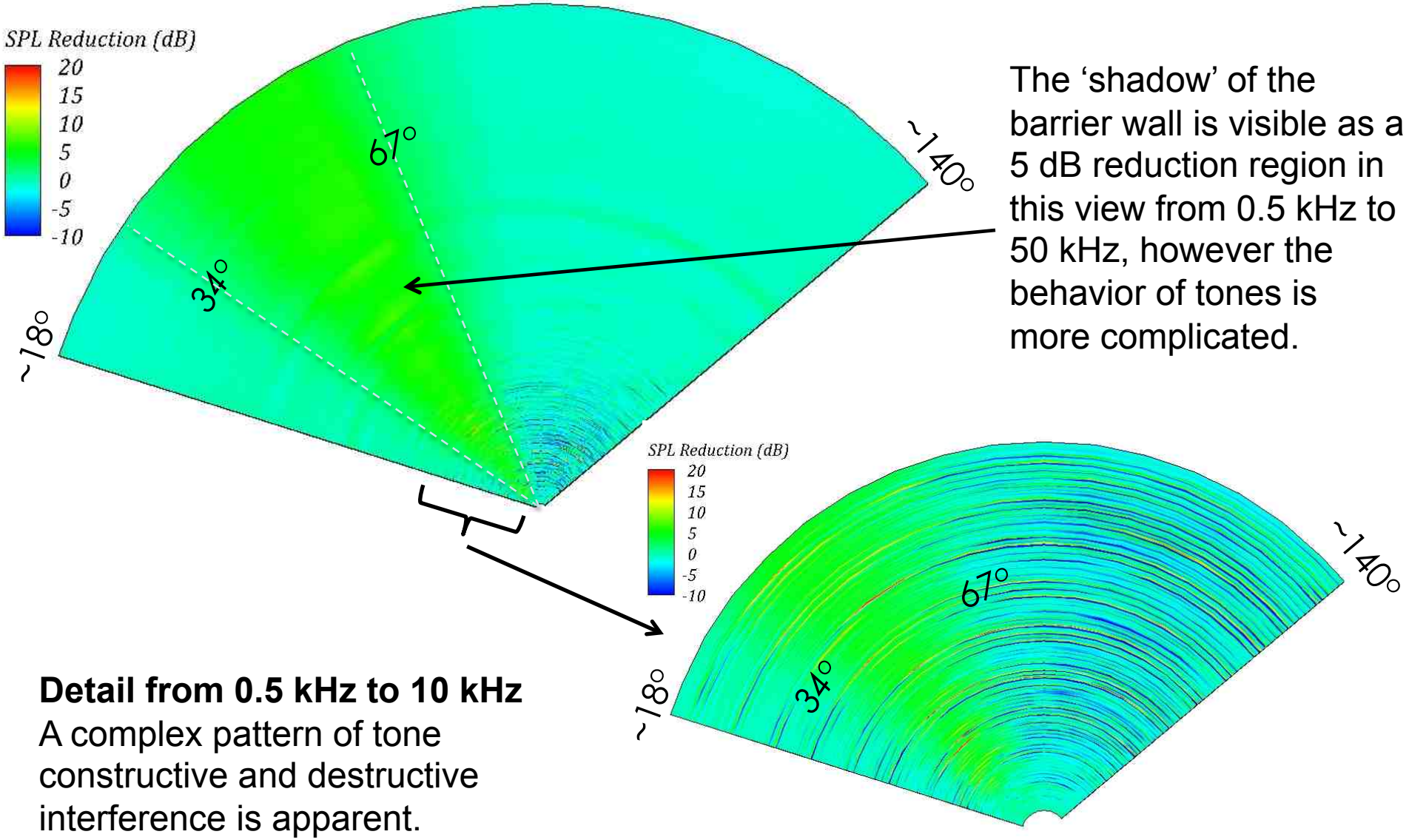


Semi-infinite acoustic barrier wall.

Short barrier, Forward position



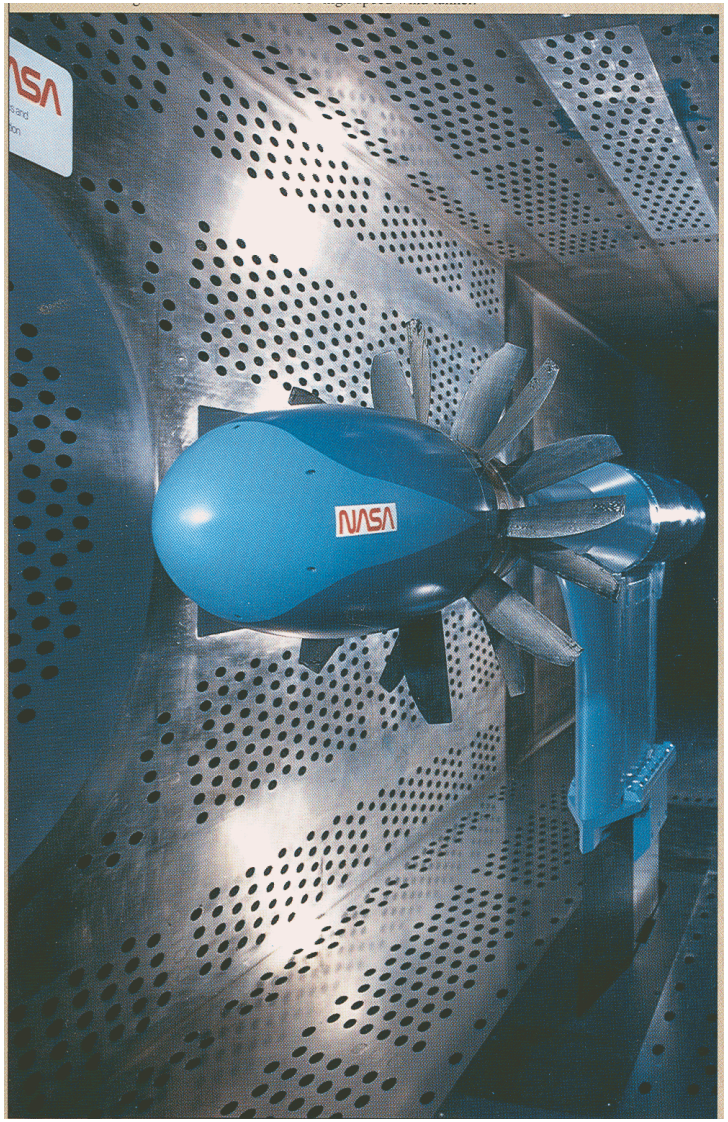
ERA Diagnostics:
Historical Baseline Acoustic Shielding (3)



The ‘shadow’ of the barrier wall is visible as a 5 dB reduction region in this view from 0.5 kHz to 50 kHz, however the behavior of tones is more complicated.

Detail from 0.5 kHz to 10 kHz
A complex pattern of tone constructive and destructive interference is apparent.

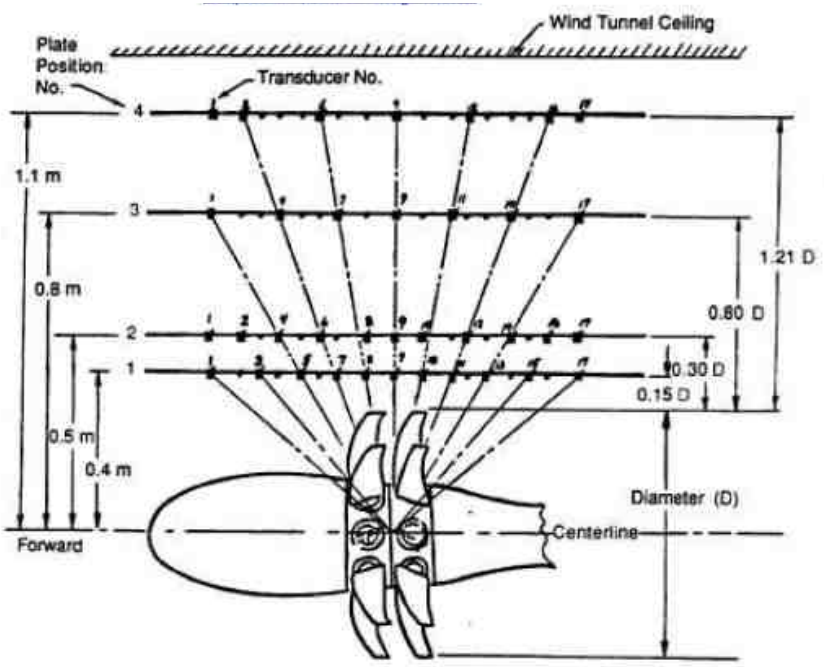
NASA/GE Collaboration
8x6 High Speed Wind Tunnel test



NASA C85-6031

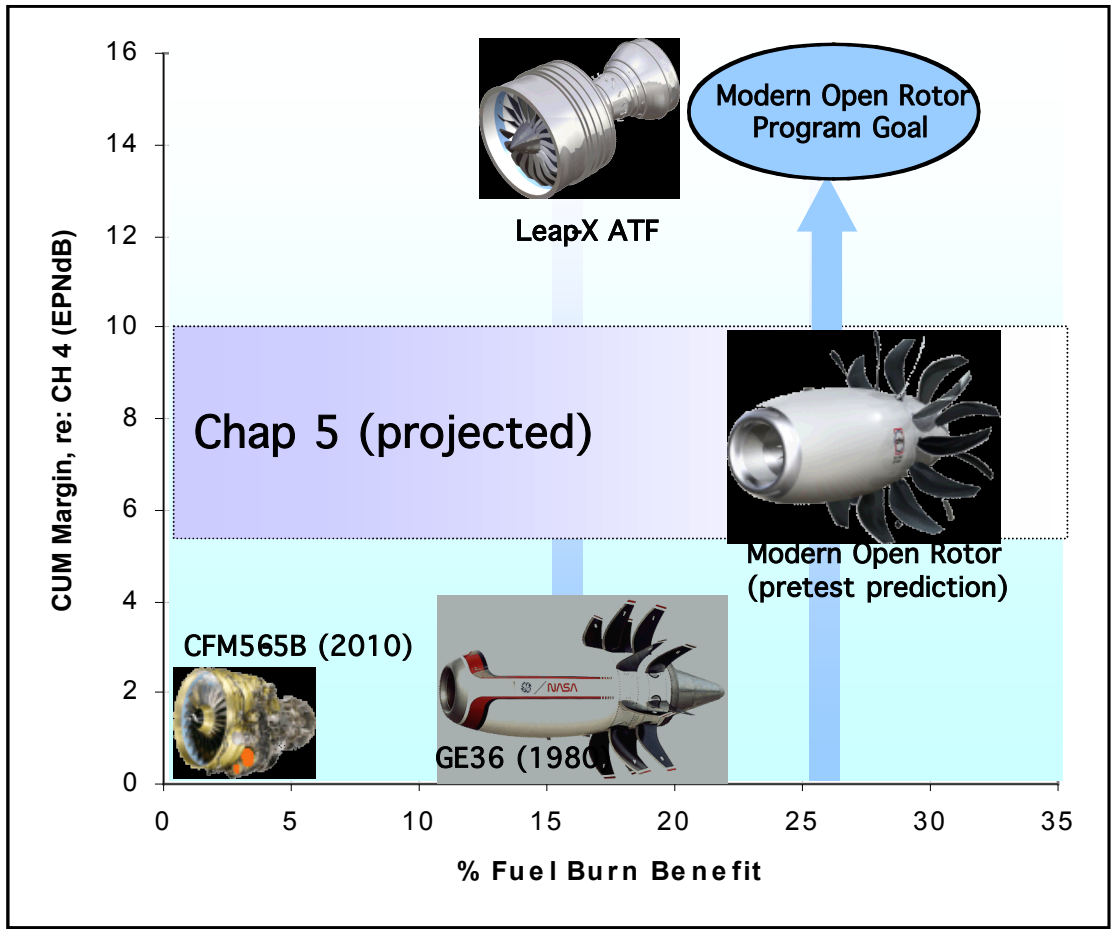
Objectives: Aerodynamic performance and near field unsteady pressure measurements at cruise Mach number.

Installation of ORPR into the 8x6 began in December.



NASA NAS3-24080, Task V Final Report

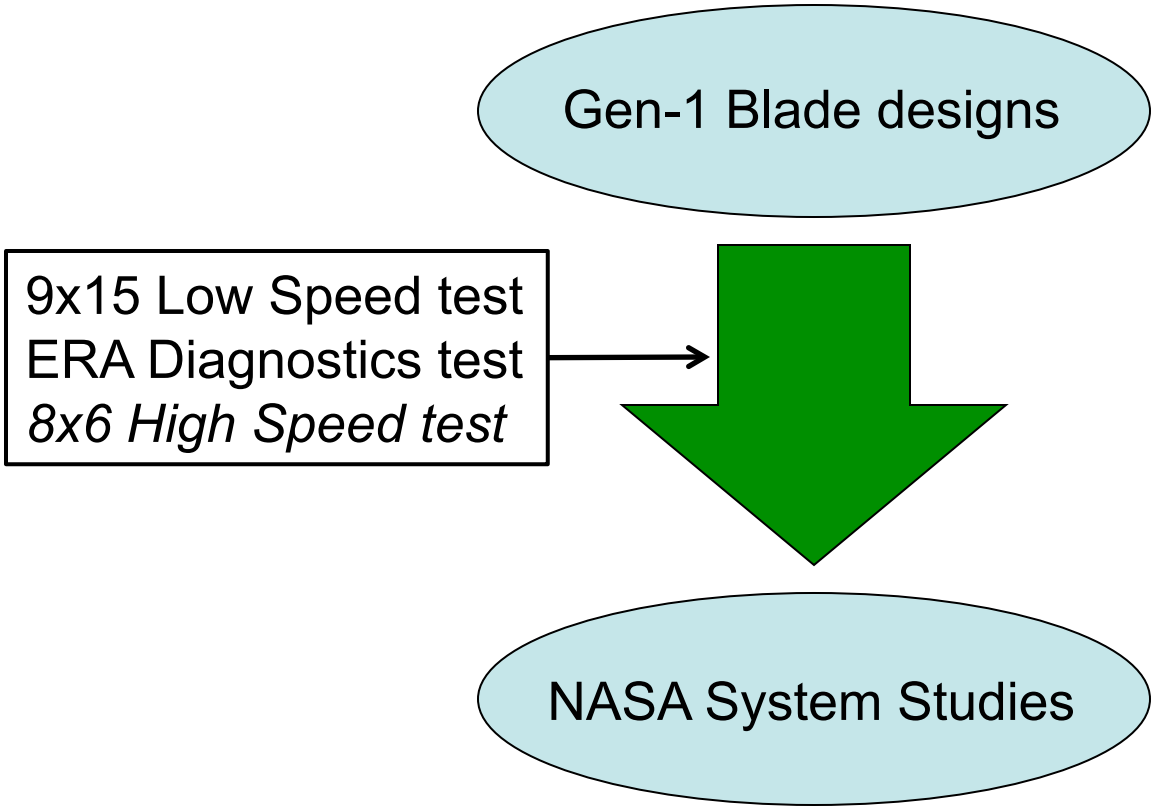
CFMI Projection of Modern Open Rotor Performance



GE FAA/CLEEN Consortium presentation. October 2010.

Open Rotor based propulsion systems provides revolutionary fuel burn advantages.

The Path Forward

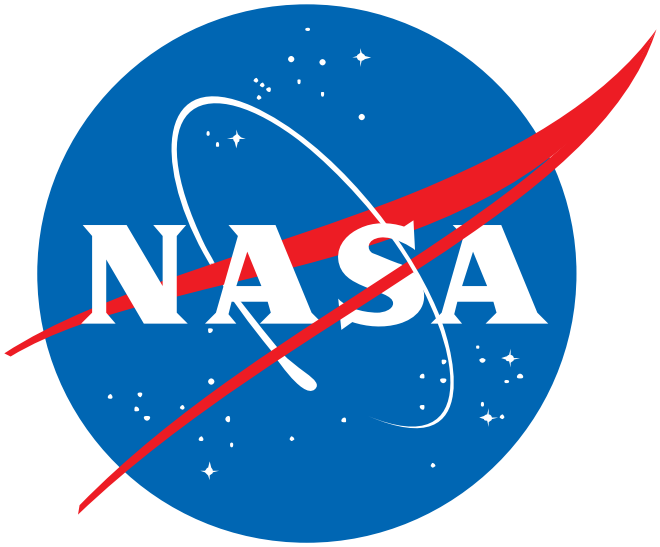


NASA system studies will help guide future research investment.

FAA CLEEN/NASA/GE Gen-2 blade testing to follow.

Summary

- GE Gen-1 Blade designs have demonstrated noise reduction relative to 1980s designs.
- Confirmation of predicted cruise efficiency is pending with the 8x6 test.
- FAA CLEEN/NASA/GE Gen-2 blade testing to follow.
- The ERA Diagnostics testing added design method validation data.



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.