OPEN ROTOR TEST STATUS

Testing of low noise, counter-rotating open rotor propulsion concepts has been ongoing at Glenn Research Center in collaboration with General Electric Company. The presentation is an overview of the testing that has been completed to date and previews the upcoming test entries. The NASA Environmentally Responsible Aviation Project Diagnostics entry is the most recent to finish. That test entry included acoustic phased array, pressure sensitive paint, particle image velocimetry, pylon installed measurements and acoustic shielding measurements. A preview of the data to be acquired in the 8x6 high-speed wind tunnel is also included.

Open Rotor Test Status

Dale Van Zante
Dale.E.VanZante@nasa.gov

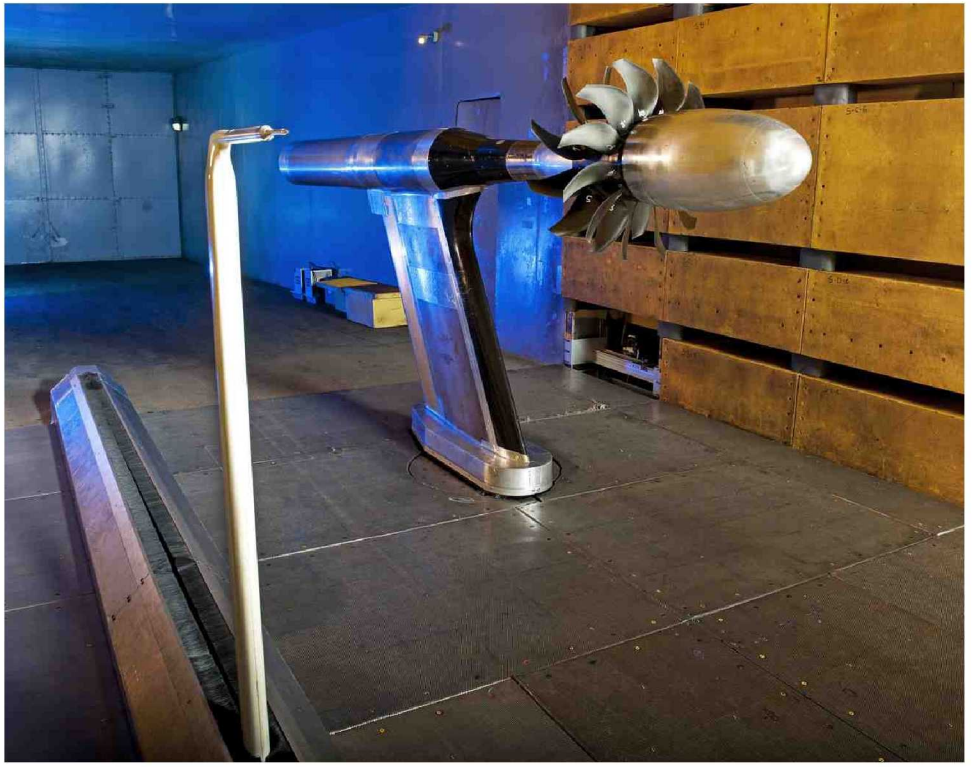
Acoustics Branch
NASA Glenn Research Center
Cleveland, OH

Acoustics Technical Working Group
Hampton, VA
October 21-22, 2010

Outline

The Open Rotor test program
- Low speed testing: 9x15 LSWT
- ERA Diagnostics Program
  - Phased Array
  - Pylon installed acoustics
  - Pressure Sensitive Paint
  - Particle Image Velocimetry
  - Barrier wall acoustics
- High speed testing: 8x6 SWT
- FAA/CLEEN test

- Numerical simulations
- Noise prediction status



Testing is supported by the Environmentally Responsible Aviation Project
Data analysis efforts are supported by the Subsonic Fixed Wing Project

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 and fuselage integration.

Historical Baseline Blade Set
12 x 10 blade count
Non-proprietary

Test Program Overview

9x15 Low Speed Wind Tunnel		8x6 High Speed Wind Tunnel	FAA/CLEEN
Takeoff and Approach Conditions	ERA Diagnostics	Cruise Conditions	Gen 2 Blade Designs
•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	• Test plan is in formulation

9x15 Low Speed Wind Tunnel Test Setup

Open Rotor Propulsion Rig (ORPR)

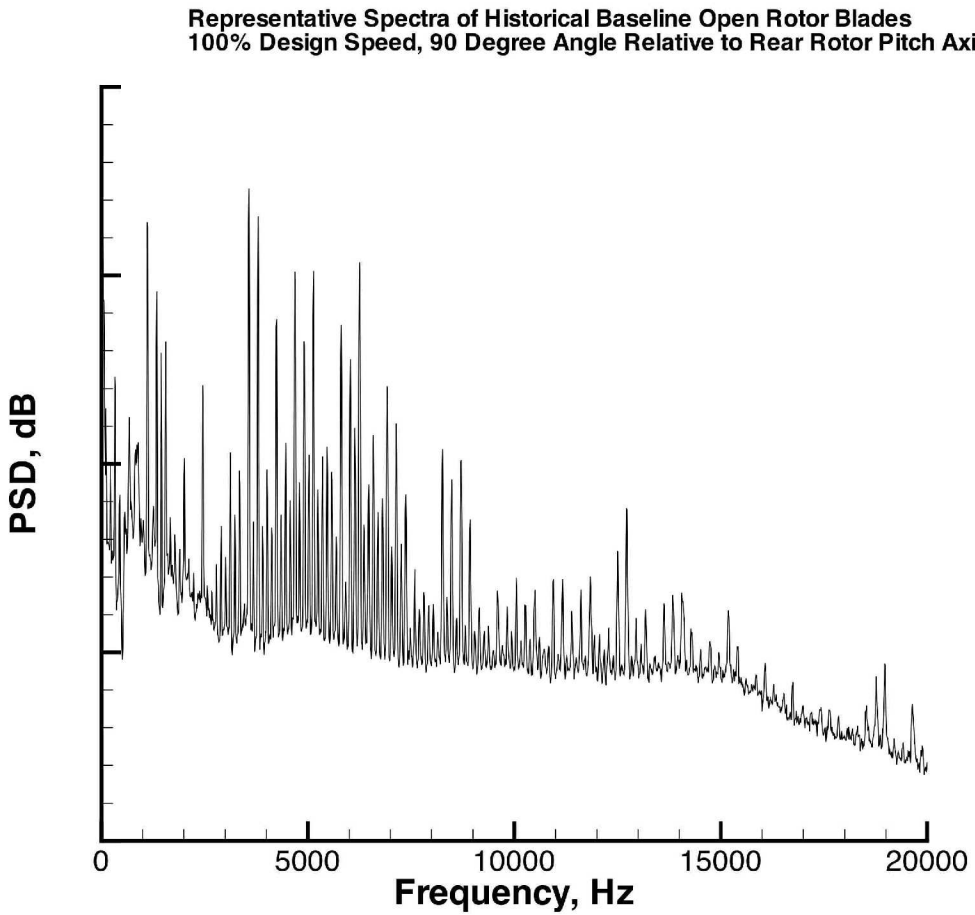
Operating Limits	Single Rotation Propeller (SRP) Drive Rig	Open Rotor Propulsion Rig (ORPR)
		
Turbine/Motor Power (SHP)	950	750/rotor
Shaft RPM	12,200	10,000/rotor
Turbine Inlet/Plenum Pressure (psia)	400	315
Turbine Inlet/Plenum Temperature (deg F)	200	160 min 250 max
Turbine Inlet/Plenum Flow (lbm/sec)	15	33
Rotating Balance Forces, thrust (lbs)/torque (ft-lbs)	800/600	400/500 per rotor
Static Balance Forces, thrust (lbs)/torque (ft-lbs)	N/A	N/A
Comments	- Himmelstein transformer for relaying rotating signals	- Counter rotation - Data telemetry units fwd and aft - 12 strain gages available per rotor - Independently controllable rotor speed

9x15 Low Speed Wind Tunnel Results to Date

Preliminary analysis of the data shows progress has been made over 1980's era designs. Modern designs have demonstrated acoustics margin versus GE36 while maintaining efficiency.

Generation 1 test:
5 sets of forward and aft blades, each set a distinctly different configuration, designed via 3D aero design technology in an effort to achieve optimum acoustic and performance efficiency. Three of the sets were GE-designed, and two were designed by Snecma.

Successful implementation of a muffler onto the ORPR.



The ERA Diagnostics Program

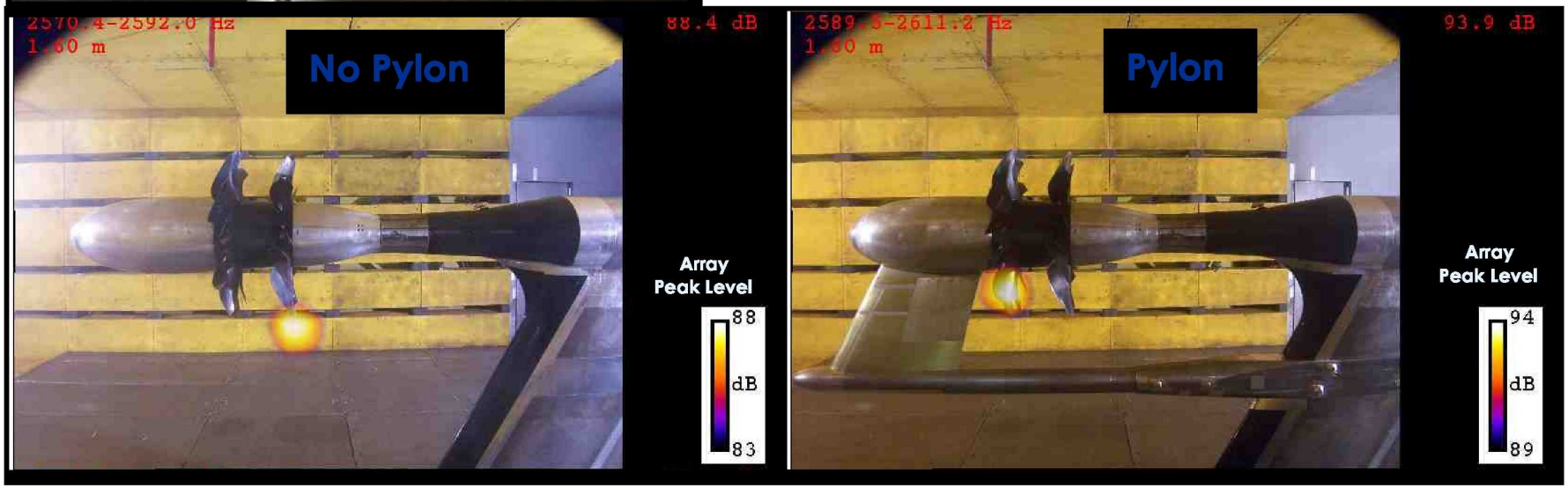
Acoustic Phased Array	**Farfield acoustics with Pylon**	**Pressure Sensitive Paint**	**Stereo Particle Image Velocimetry**	**Acoustic Shielding**

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

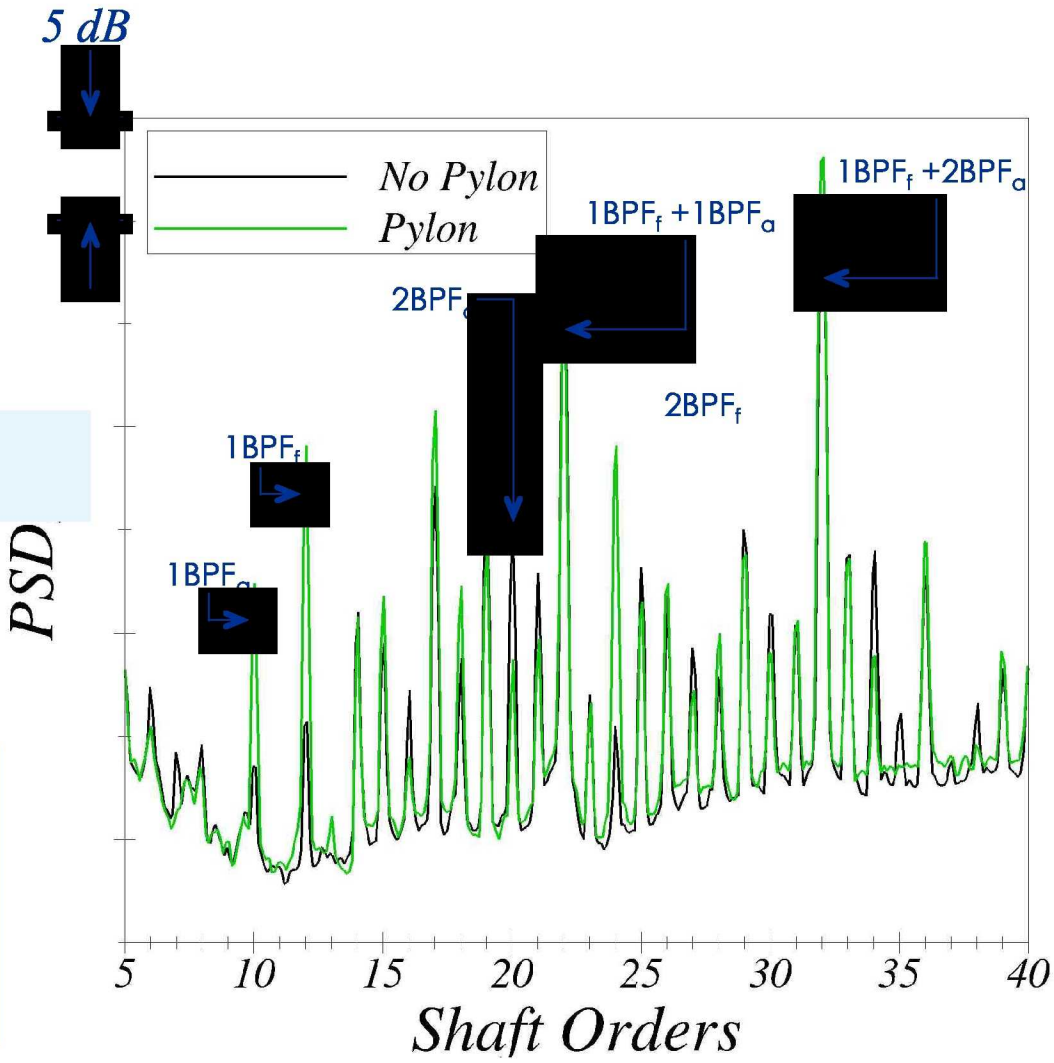
The ERA Diagnostics Program
Acoustic Phased Array

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

Researcher: Gary Podboy



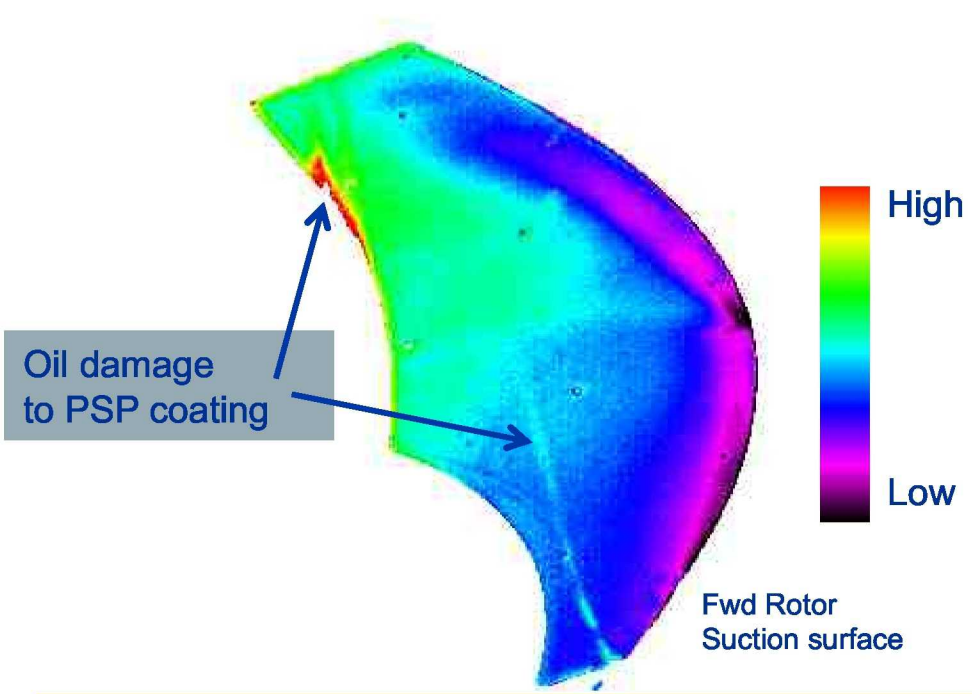
The ERA Diagnostics Program
Farfield Acoustics with Pylon

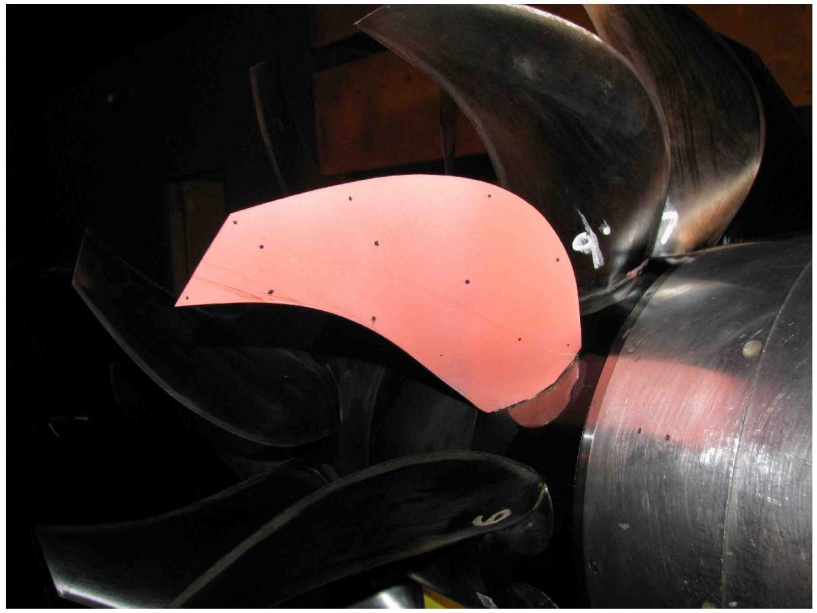


The presence of the pylon induces distortions into blade rows causing noticeable increase in the levels of the individual rotor harmonics.

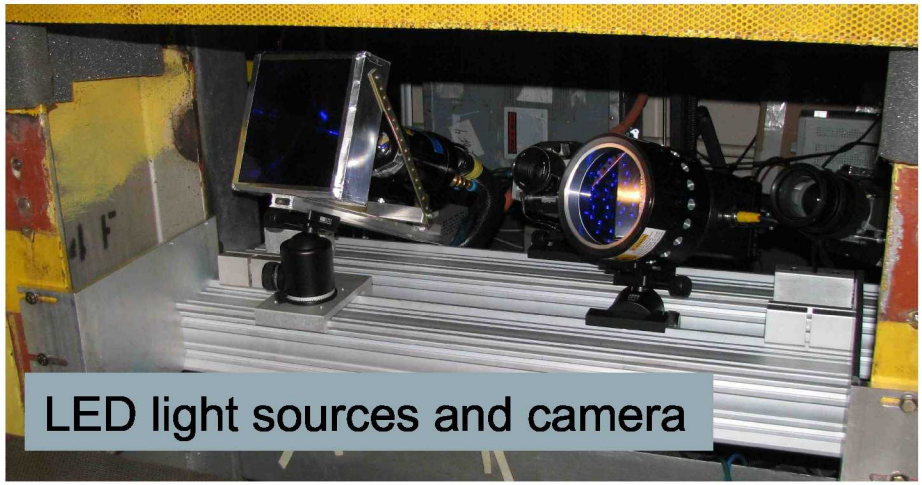
Researcher: David Elliott

The ERA Diagnostics Program
Pressure Sensitive Paint: Forward Rotor



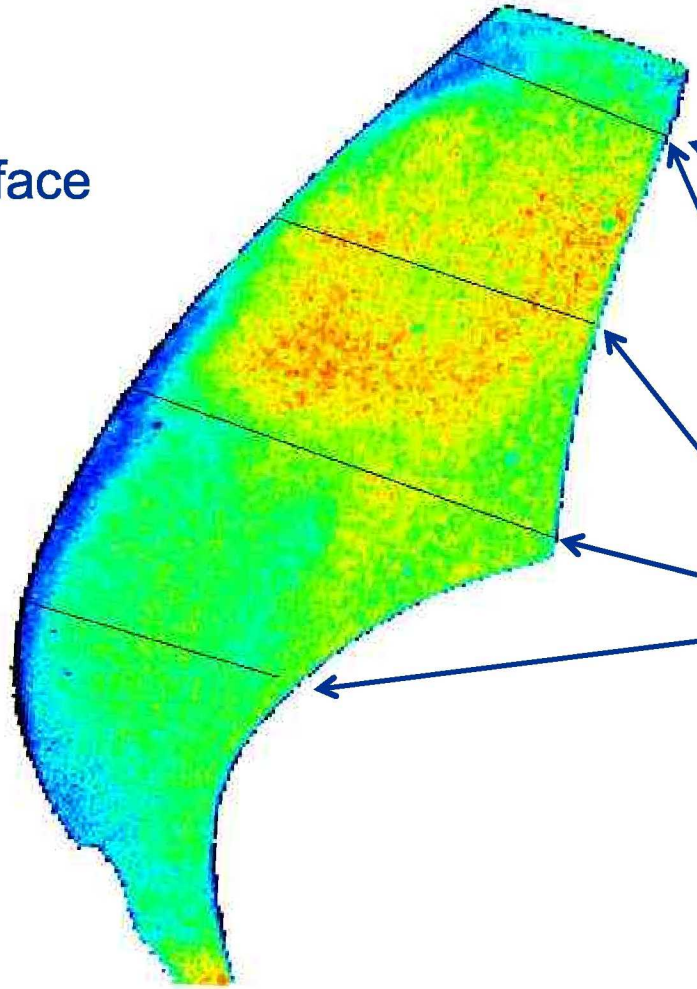


Forward Rotor instantaneous suction side pressure acquired with PSP lifetime acquisition technique synchronized to a rotor/pylon orientation.
Dataset:
-Aft blade PS and SS sync'd through fwd rotor wake.
-Fwd blade SS sync'd through pylon wake.
Issues:
-Illumination intensity, oil contamination.
Researcher: Tim Bencic



The ERA Diagnostics Program
Pressure Sensitive Paint: Aft Rotor

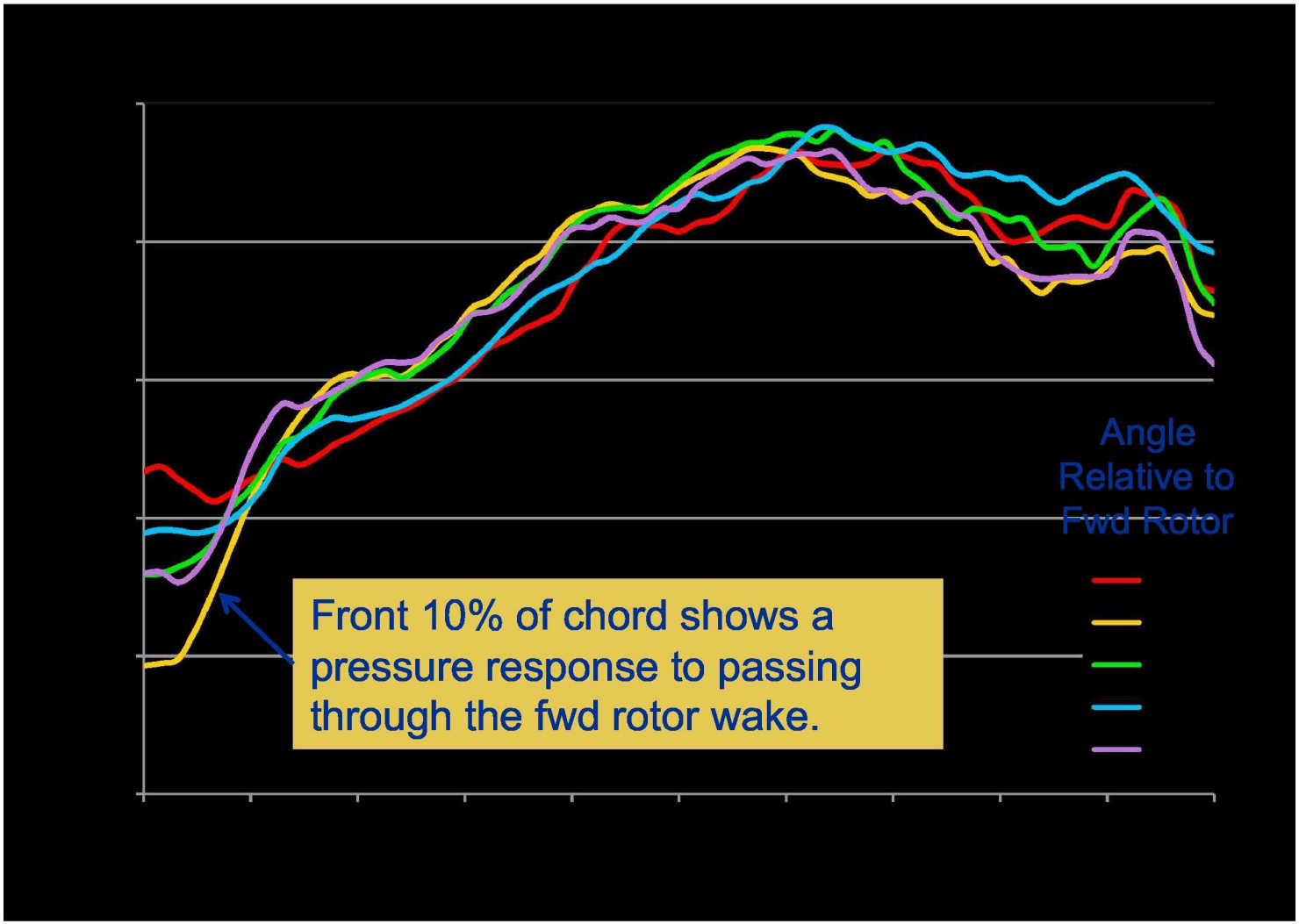
Aft rotor suction surface



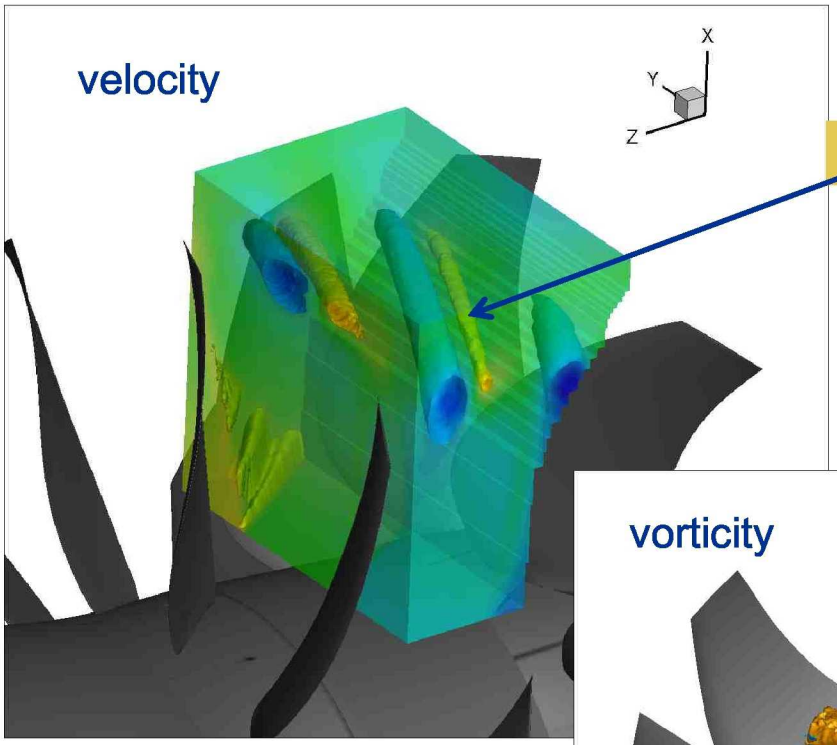
Data from this location is shown on the next slide.

Line plots were done at these spans as the forward rotor was indexed past the aft.

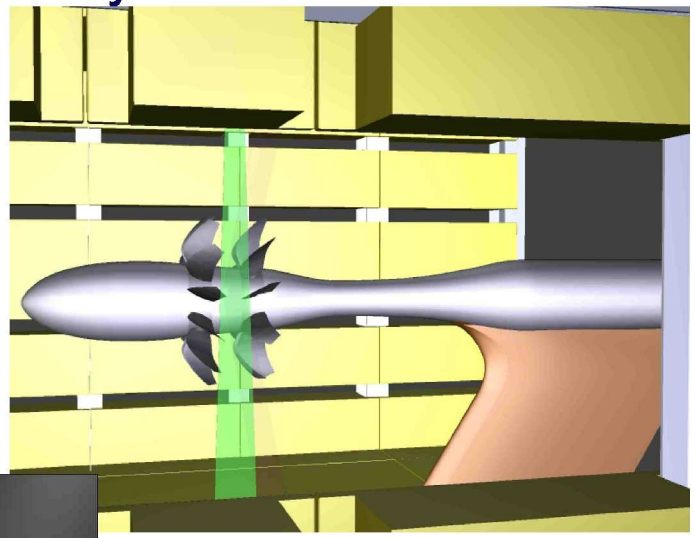
The ERA Diagnostics Program
Pressure Sensitive Paint: Aft Rotor

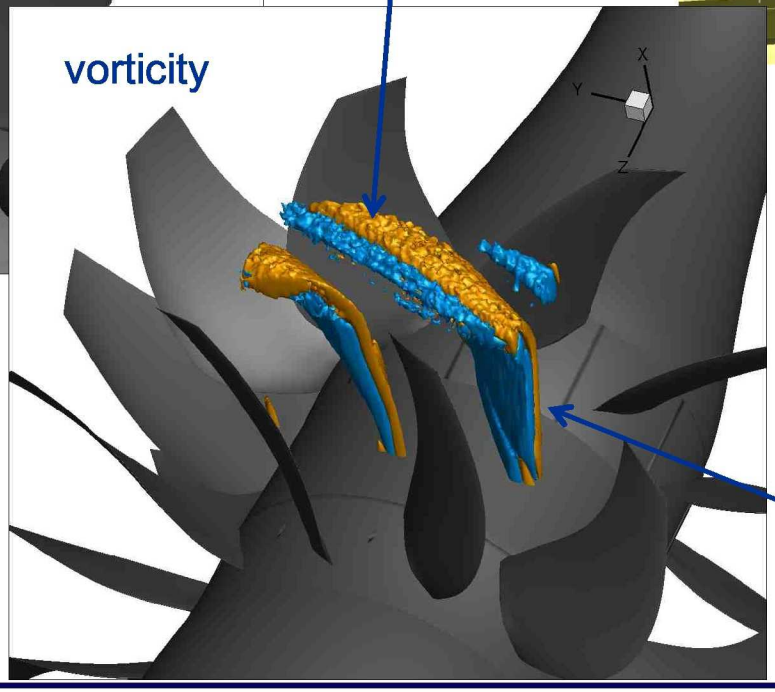


The ERA Diagnostics Program
Stereo Particle Image Velocimetry



Tip vortex track



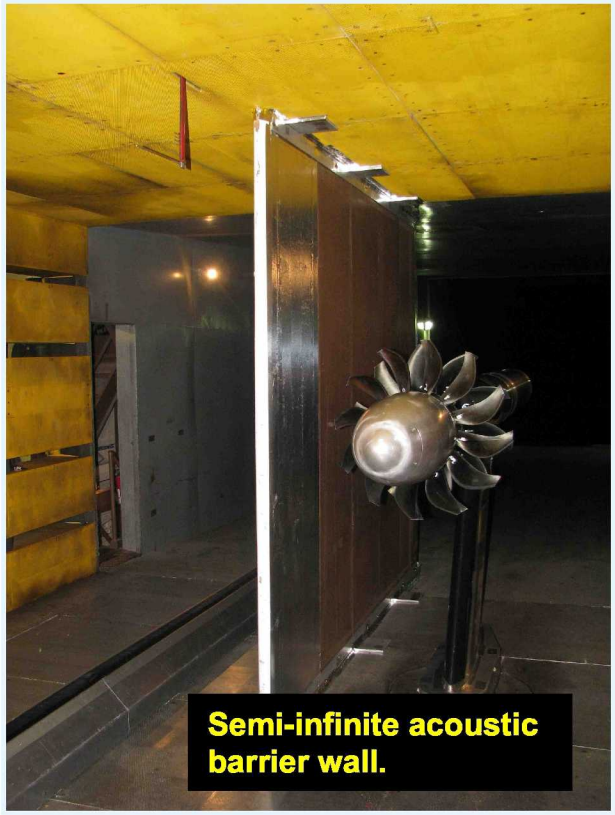


Researchers:
Mark Wernet
Adam Wroblewski
Randy Locke

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

Blade wake

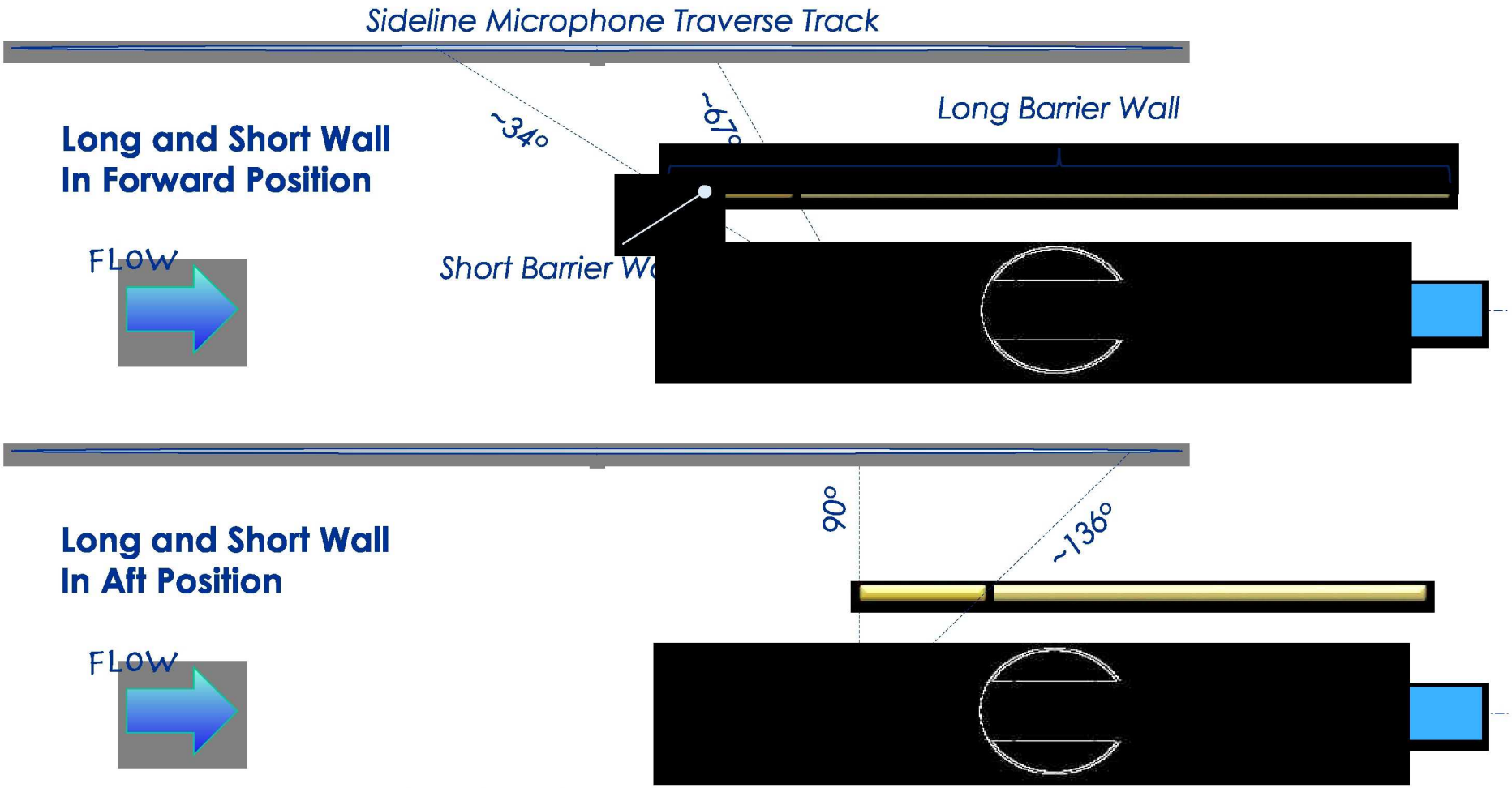
The ERA Diagnostics Program
Acoustic Shielding



Acoustic shielding: Simple shielding configurations provide basic acoustic data for model validation.

Researchers: David Stephens and Dave Elliott

The ERA Diagnostics Program
Acoustic Shielding

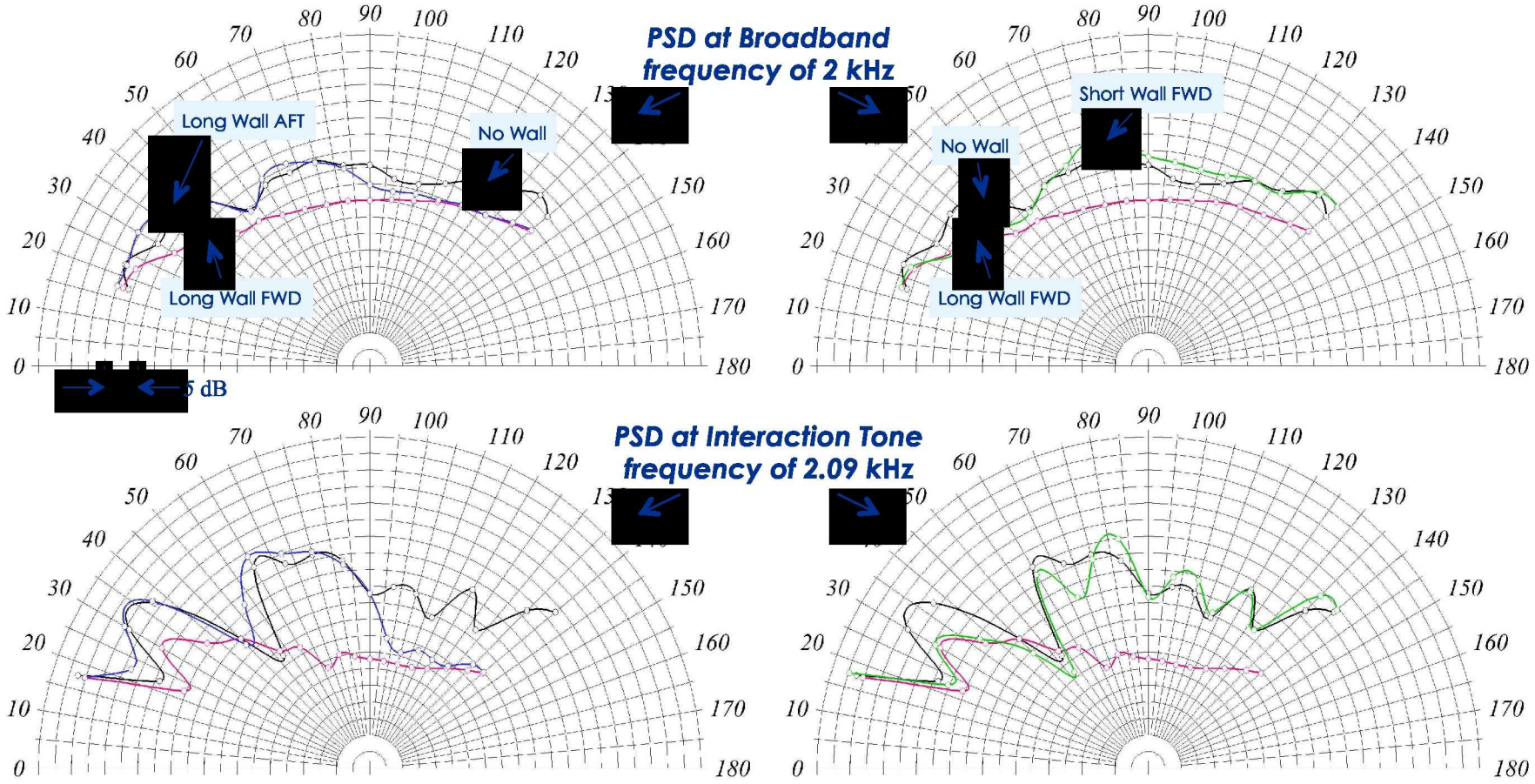


Acoustic shielding Analysis:

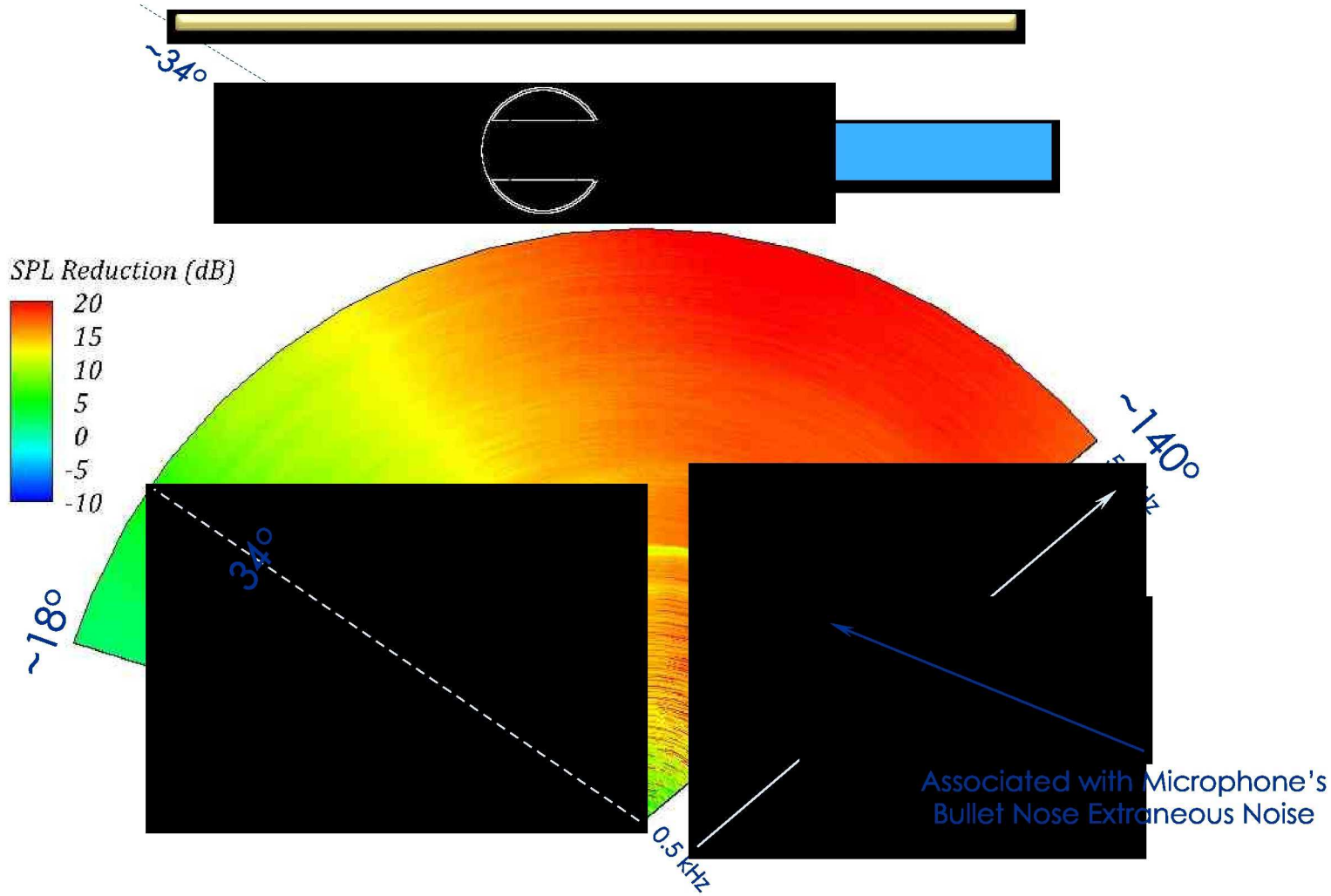
Researcher: Ed Envia

The ERA Diagnostics Program
Acoustic Shielding: 60 inch arc

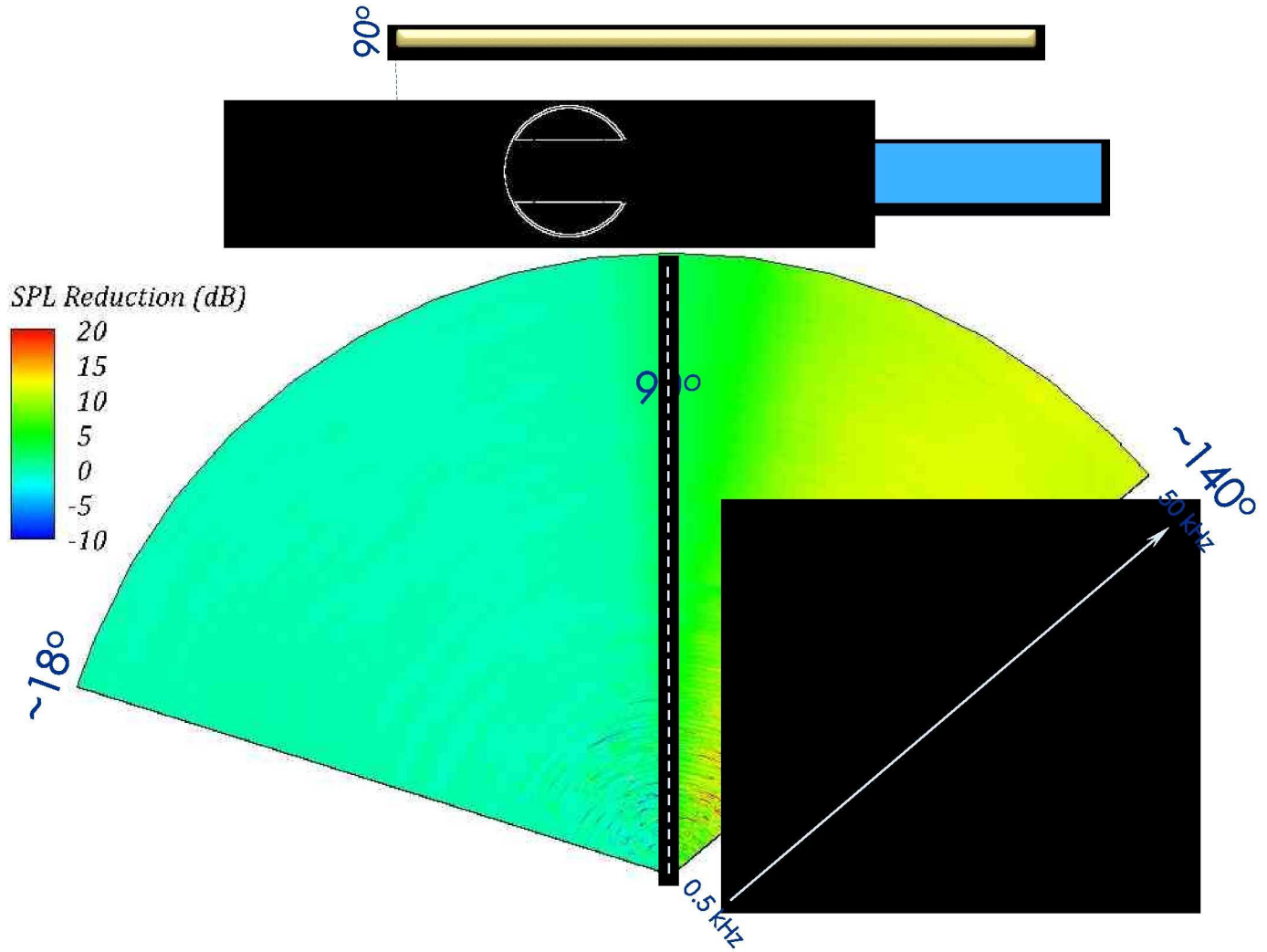
There is substantial difference between the shielding benefits of tone and broadband Noise.



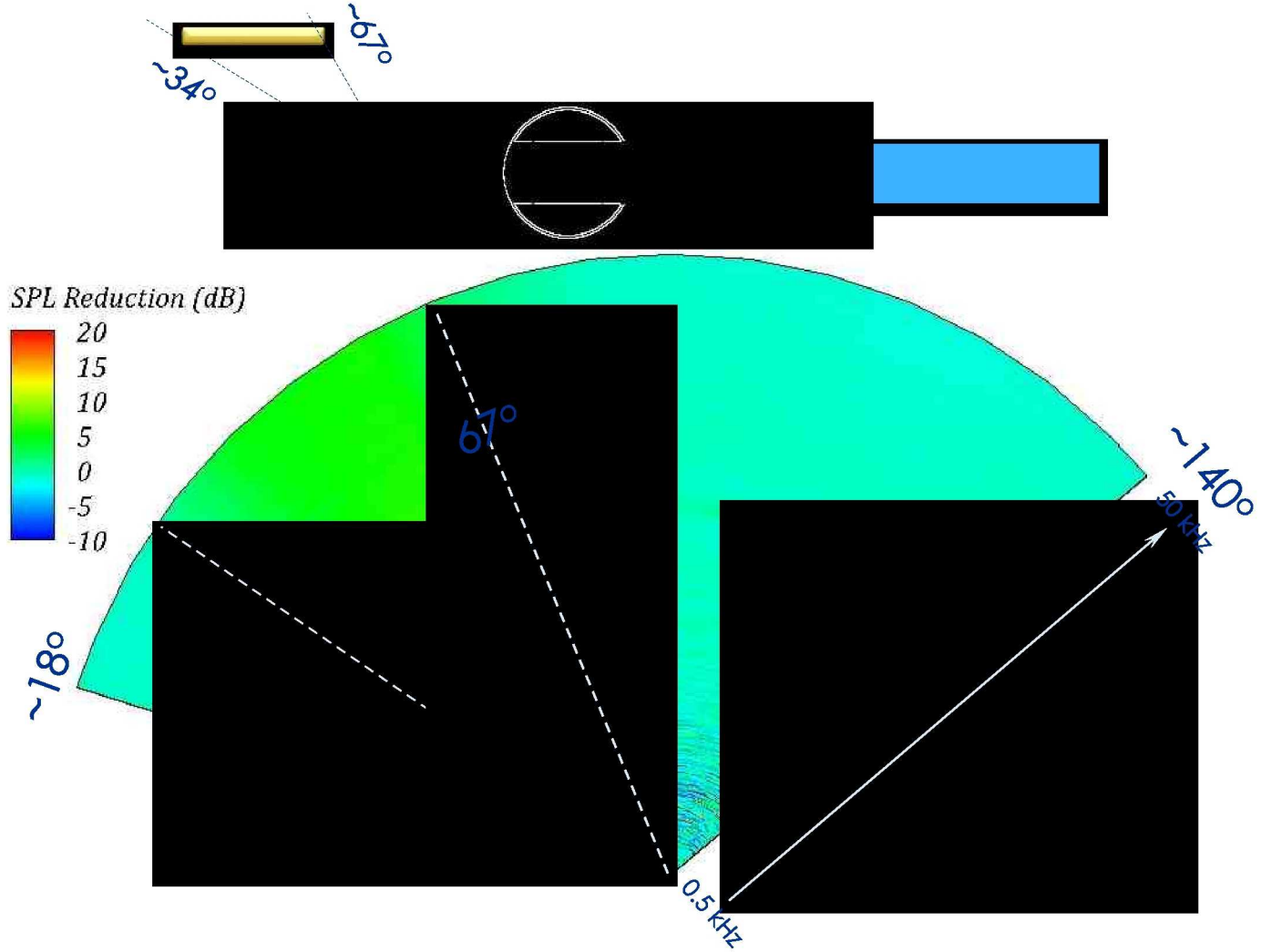
The ERA Diagnostics Program
dB Reduction = Freefield – Configuration 1



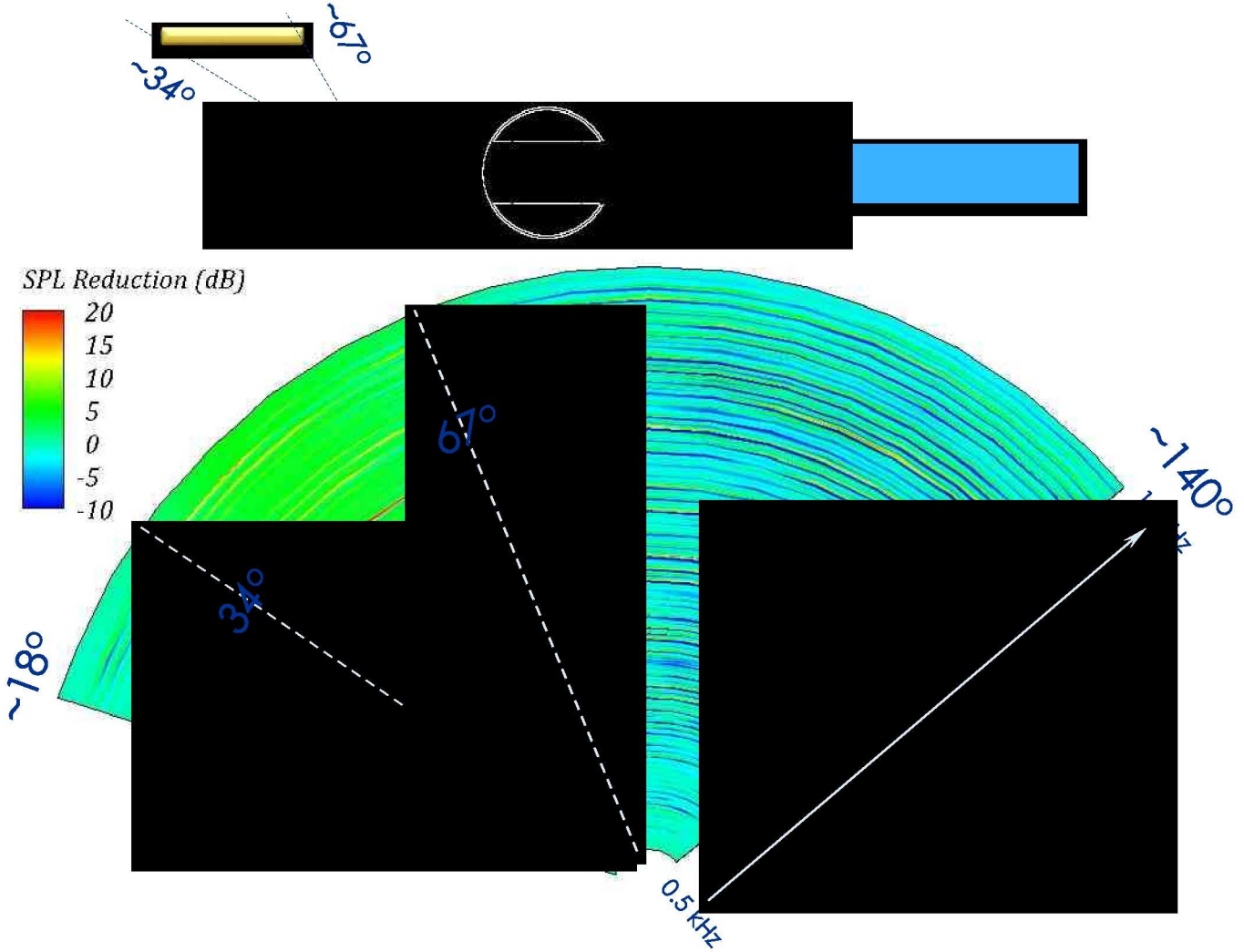
The ERA Diagnostics Program
dB Reduction = Freefield – Configuration 2



The ERA Diagnostics Program
dB Reduction = Freefield – Configuration 3



The ERA Diagnostics Program
dB Reduction = Freefield – Configuration 3

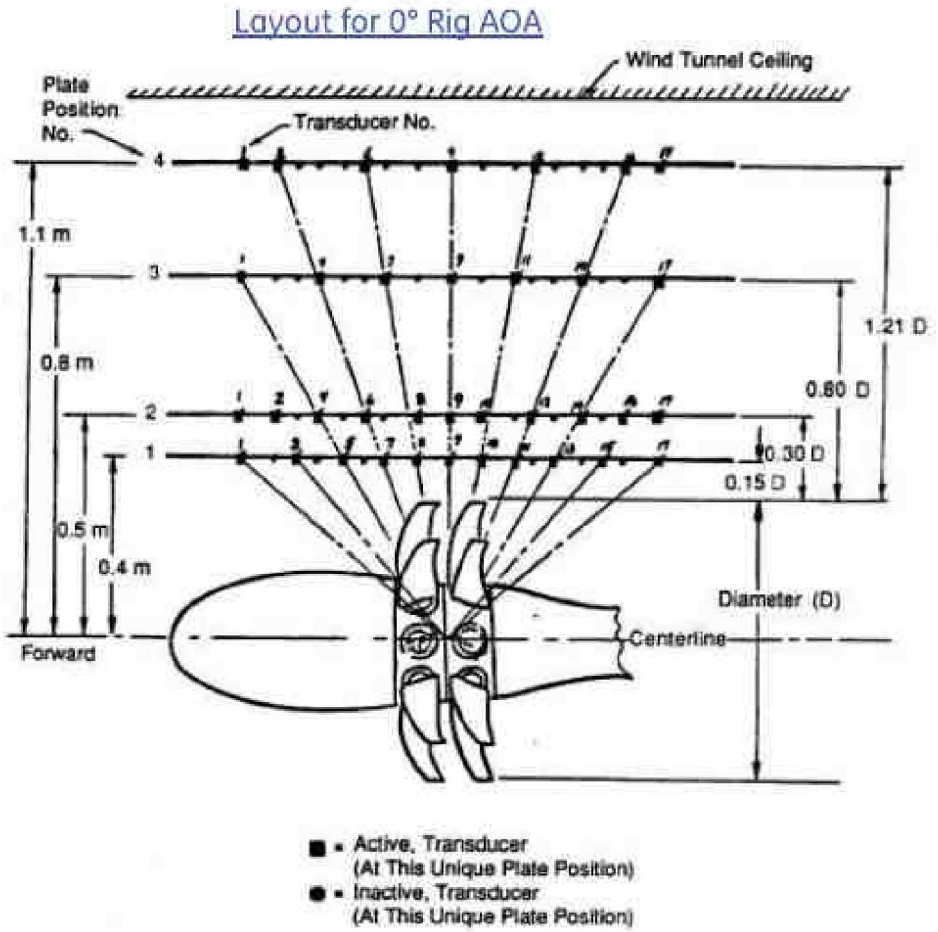


8x6 Cruise Performance Testing

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

Installation of ORPR into the 8x6 will begin in November.

8x6 Cruise Performance Testing
Acoustic Plate

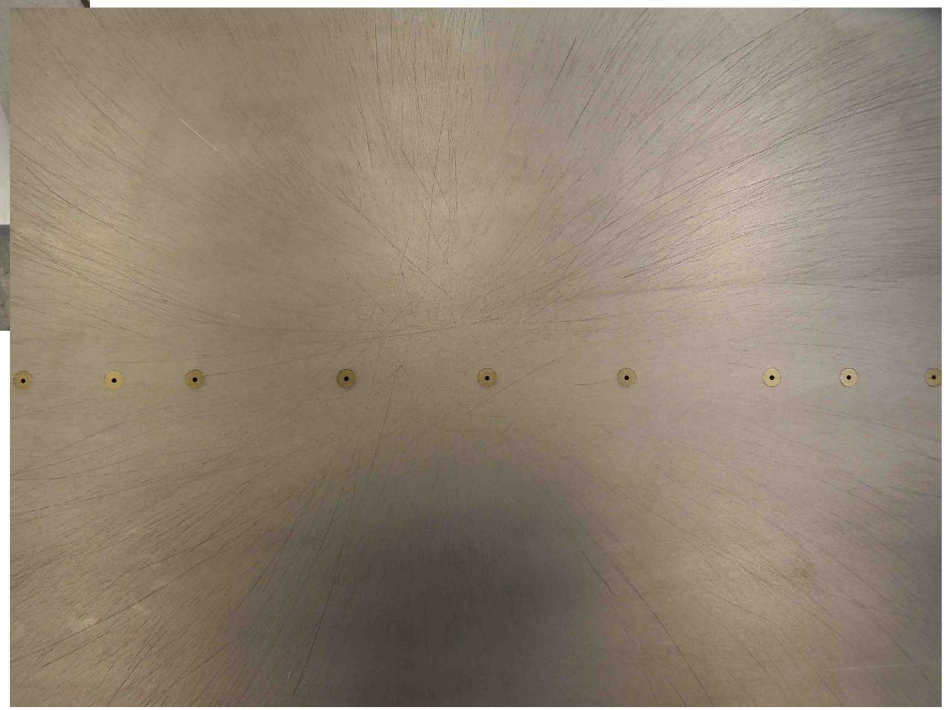


NAS3-24080, Task V Final Report

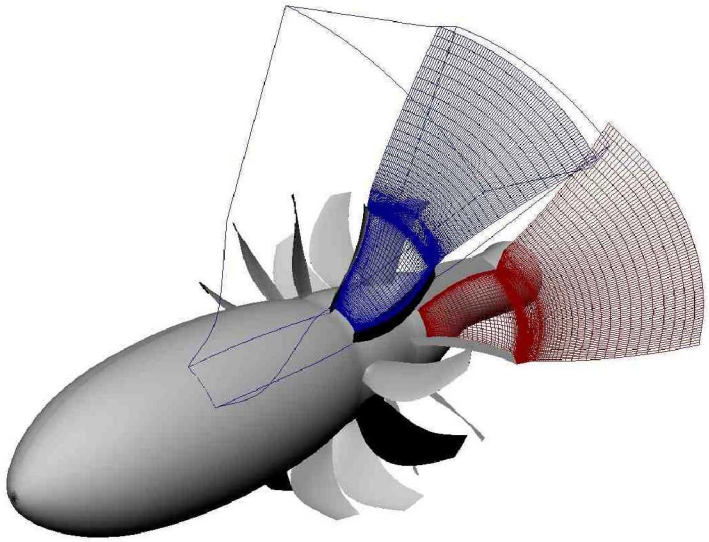
8x6 Cruise Performance Testing
Acoustic Plate

The plate has been resurfaced.

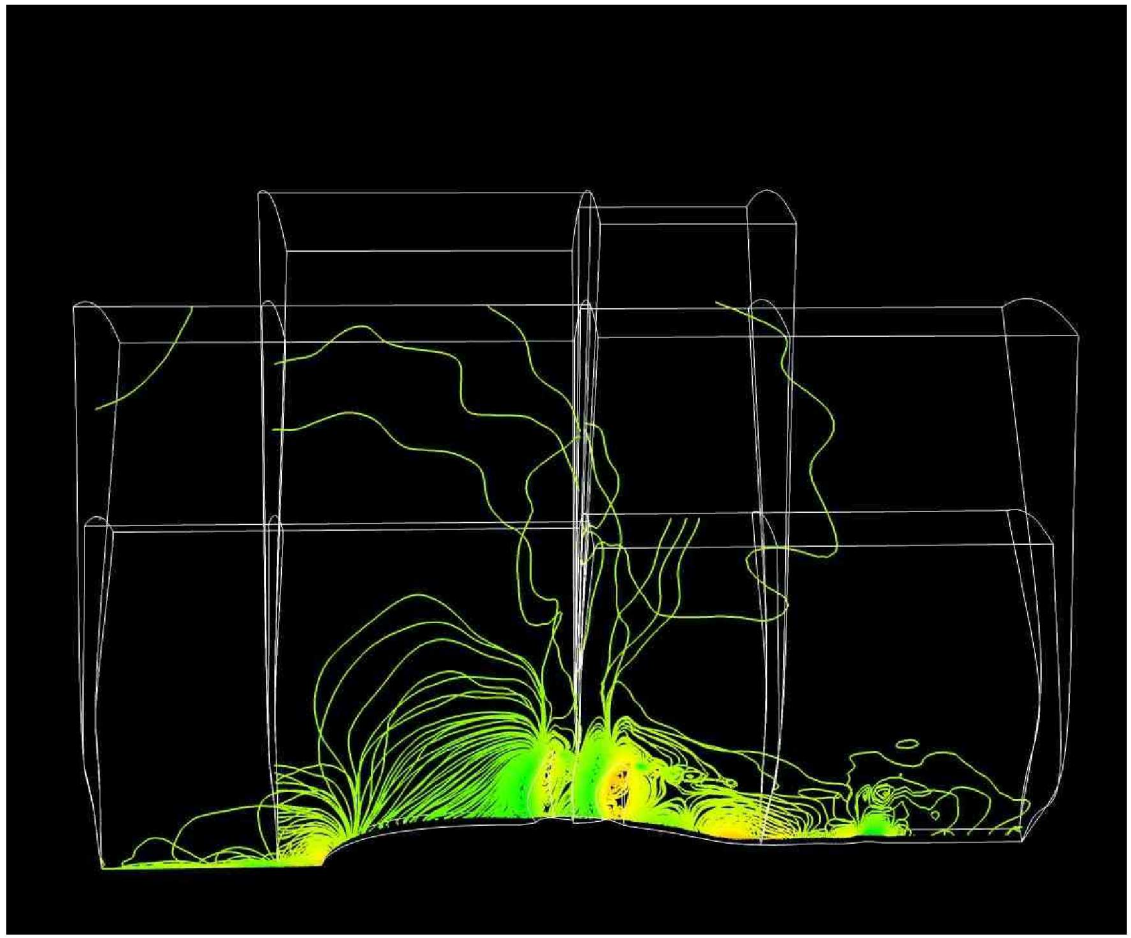
17 Kulites will be flush mounted.



Open Rotor Meshing/Simulation status



Tim Beach has developed the mesh generation capability.



Csaba Horvath (summer employee) completed ADPAC and TURBO simulations include a domain size study with ADPAC.

Open Rotor Noise Prediction Plan/Status
Ed Envia

Plan

- Perform unsteady CFD analysis on 2 open rotor configurations and provide input to acoustic prediction tools for assessment.
- Initial coarse grid for process development; fine grid for final assessment.
- GRC to use LINPROP and QPROP; LaRC to use ASSPIN

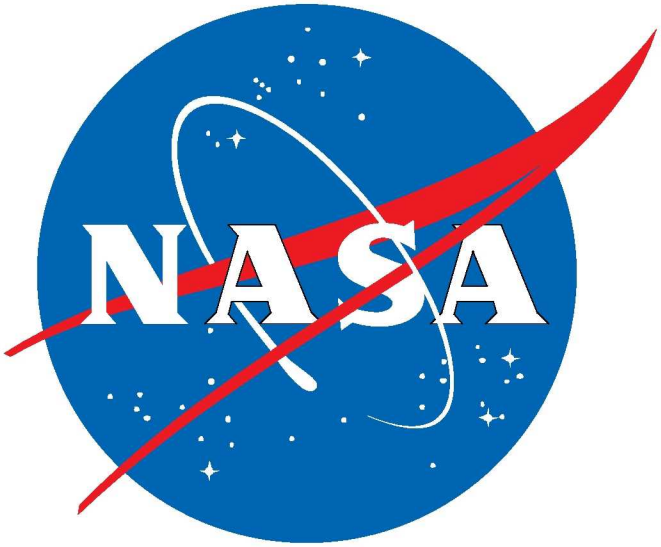
Status

- Initial coarse grid complete; ADPAC complete; TURBO complete.
- LINPROP and QPROP capabilities have been extended to account for counter-rotating rotors and installation effects.
- Data from a coarse mesh TURBO simulation is being used to exercise the new capabilities.
- Fine mesh grid in process.

Summary

- Isolated testing in the 9x15 for the GE SAA finished in May.
- ERA Diagnostics acquired a comprehensive, detailed data set finishing on Sept 7.
    - NASA TM for shielding data before end of year.
    - Open Rotor Test Case publication for ISABE 2011.
- 8x6 Installation begins at the end of October.
- Open Rotor meshing and domain sizing study complete with ADPAC. Initial URANS simulation complete with TURBO.

Acknowledgements to the NASA Acoustics Team:
Dick Woodward, Dave Elliott, John Gazzaniga, David Stephens, Rick Bozak, Ashlie McVetta, Cliff Brown, Gary Podboy, Ed Envia, Chris Miller, Dan Sutliff, Brian Fite, Chris Hughes, Dennis Huff, Abbas Khavaran, Lennart Hultgren
The 9x15 Wind Tunnel Team


NASA