THE NASA/GE COLLABORATION ON OPEN ROTOR TESTING

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Outline

- Background: Why Open Rotors?
- The Open Rotor test program
  - Low speed testing: 9x15 LSWT
  - ERA Diagnostics Program
  - High speed testing: 8x6 SWT
- Challenges
- Other related activities
- System Studies

UDF on B727

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

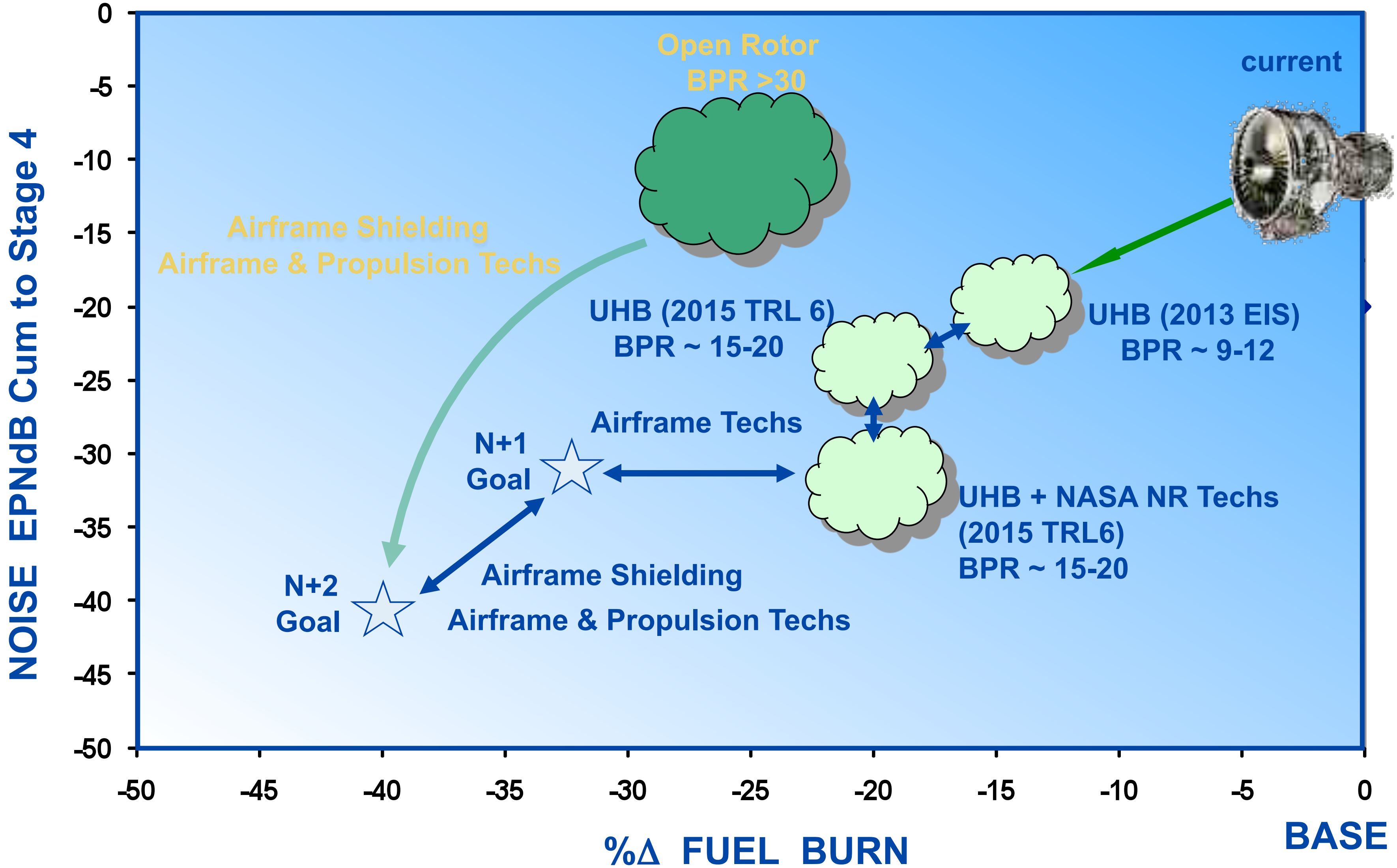
Current Ultra-High Bypass Systems

GE/CFM Open Rotors

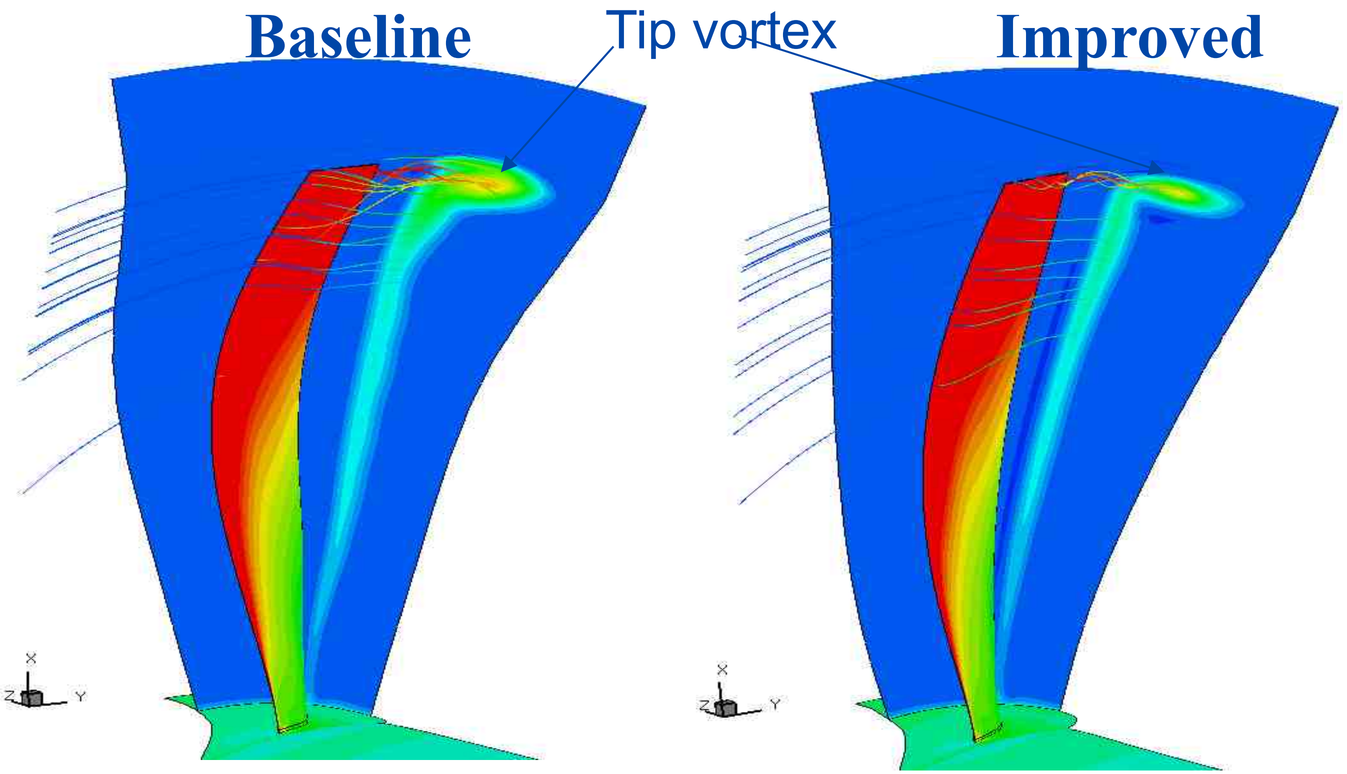
P&W Geared Turbofan (GTF)

Open Rotors have the potential for game changing fuel burn savings.
A challenge will be to make them acoustically acceptable.

Propulsor Technology Roadmap



What is different than the early 1990's?

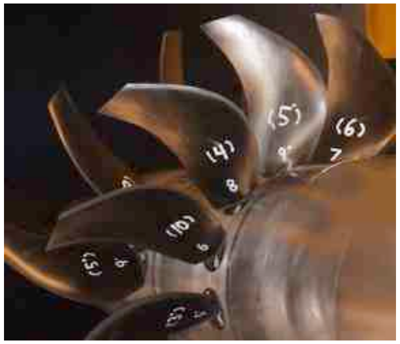


State of the art CFD being used to modify the open rotor tip vortex at take-off conditions to reduce the noise generated.

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.



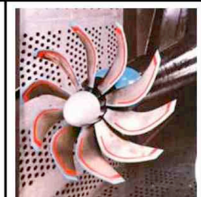
Historical Baseline Blade Set
12 x 10 blade count
Non-proprietary

Test Program Overview

9x15 Low Speed Wind Tunnel		8x6 High Speed Wind Tunnel
Takeoff and Approach Conditions	ERA Diagnostics	Cruise Conditions
•Aerodynamic performance •**Acoustics** •Hot Film flowfield measurements	•Acoustic phased array •Farfield Acoustics with Pylon •Pressure Sensitive Paint •Stereo Particle Image Velocimetry	•**Aerodynamic performance** •Near field unsteady pressure

9x15 Low Speed Wind Tunnel Test Setup

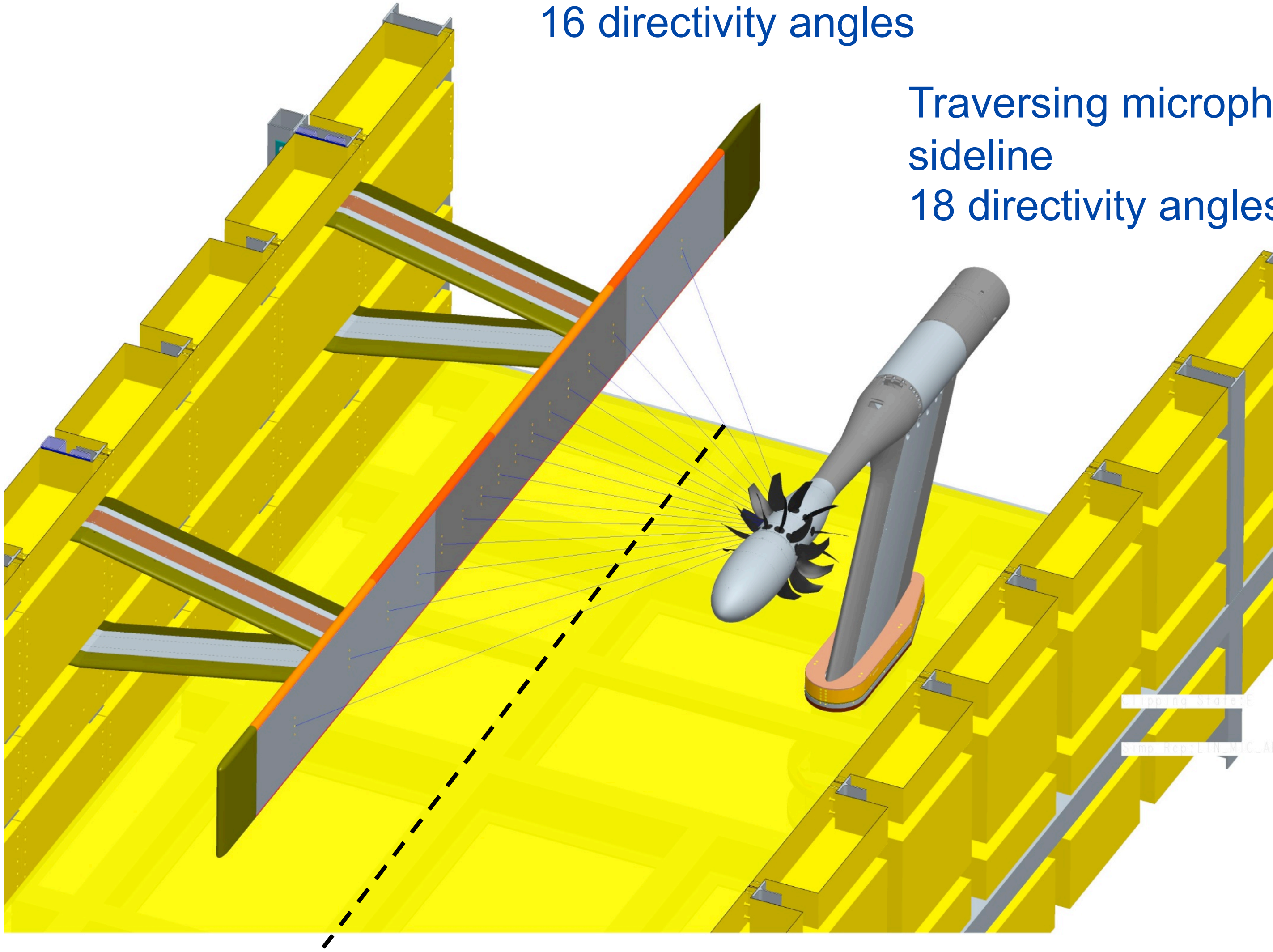
Open Rotor Propulsion Rig (ORPR)

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 Test Setup

Linear array at 60” sideline
16 directivity angles

Traversing microphone at 60” sideline
18 directivity angles

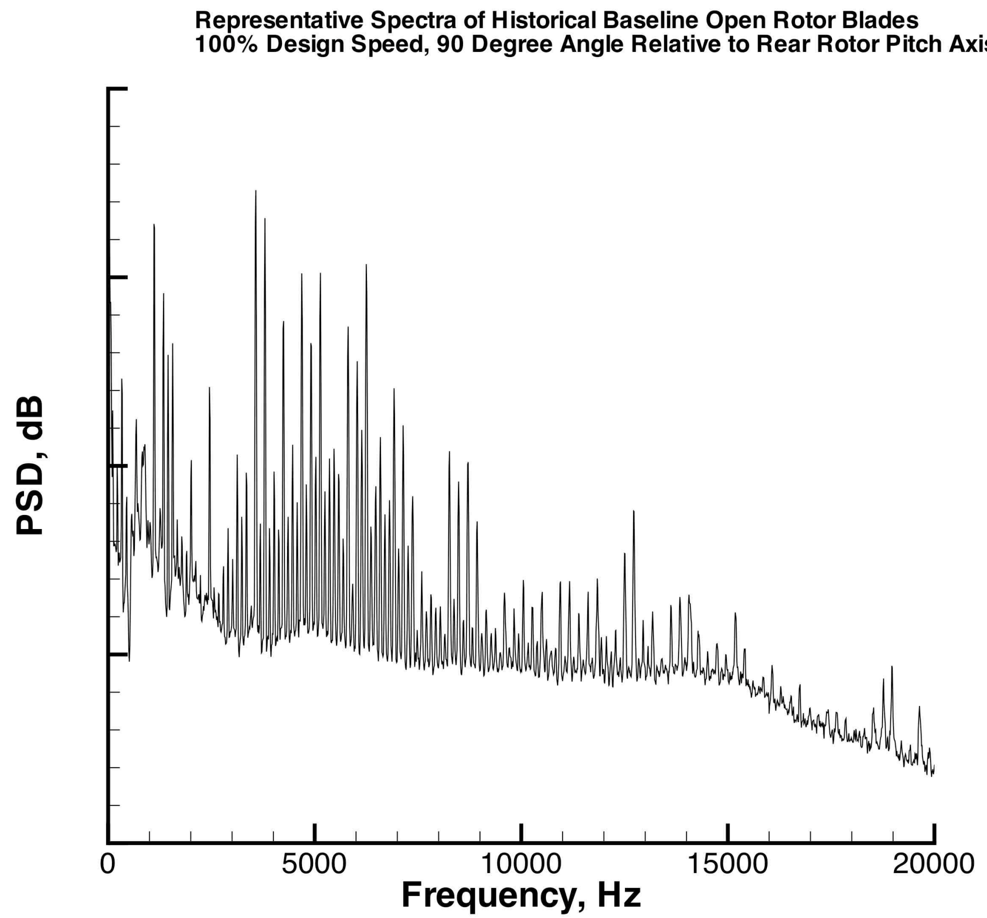


9x15 Low Speed Wind Tunnel Results to Date

Aerodynamic and acoustic performance testing for Approach and Takeoff set points in an isolated configuration.

Aerodynamic performance:
- rotating thrust/torque balance measurements through digital telemetry
- fore/afterbody and rotor cavity pressures for effective thrust

Acoustics:
- traversing microphone
- linear array



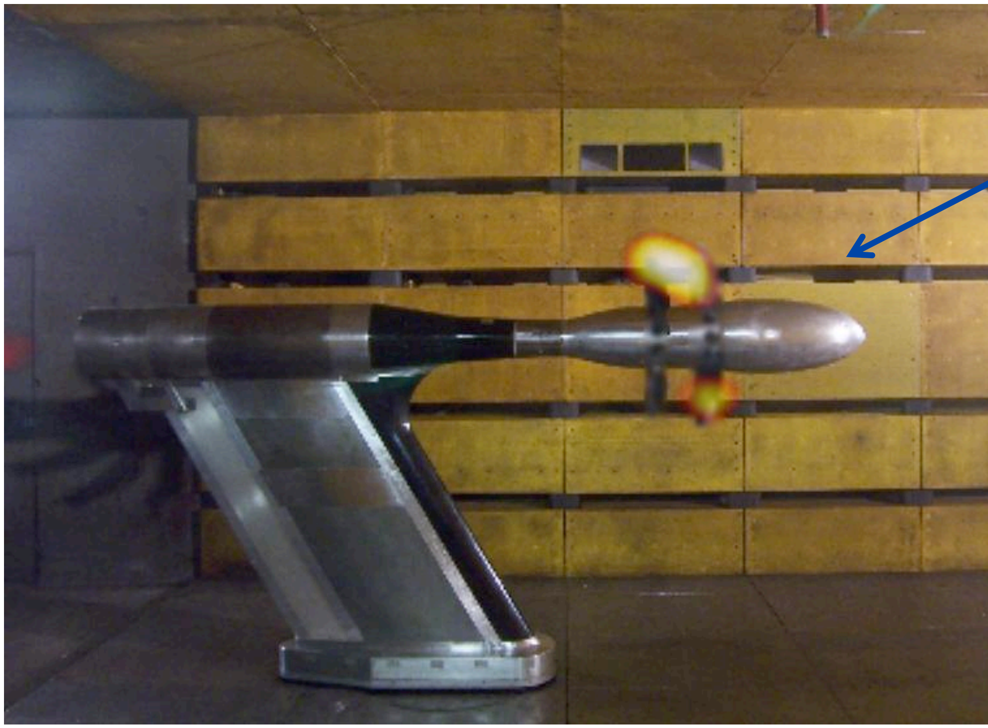
The Low Speed testing was completed May 14. Data is being analyzed now.

The ERA Diagnostics Program

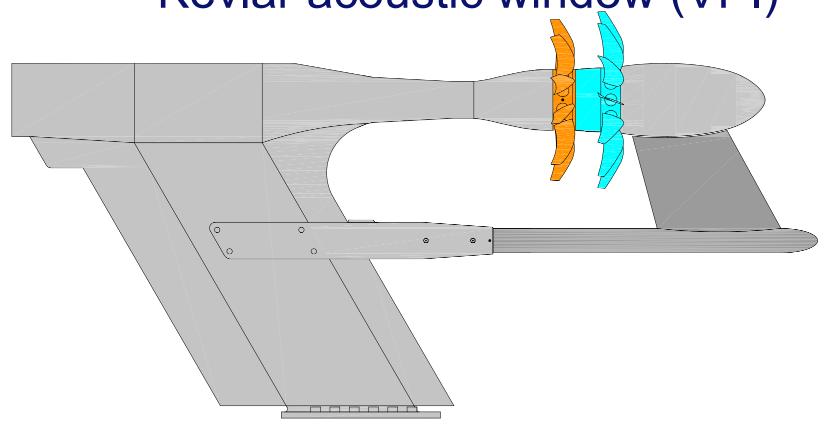
Acoustic Phased Array	Farfield acoustics with Pylon	Pressure Sensitive Paint	Stereo Particle Image Velocimetry

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



Kevlar acoustic window (VPI)



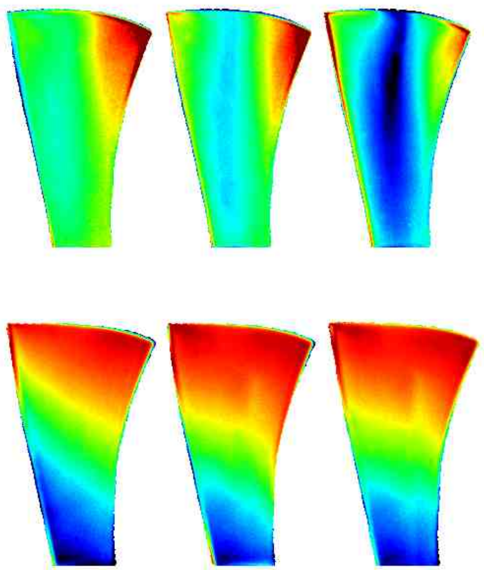
Researcher: Gary Podboy

Objective: identify noise source locations on the model for isolated and pylon installed conditions.

The ERA Diagnostics Program
Farfield Acoustics with Pylon

Objective: Quantify aero and acoustic impact of pylon upstream of rotor system.

The ERA Diagnostics Program
Pressure Sensitive Paint



Steady state pressure and temperature of ducted fan blades in 9X15

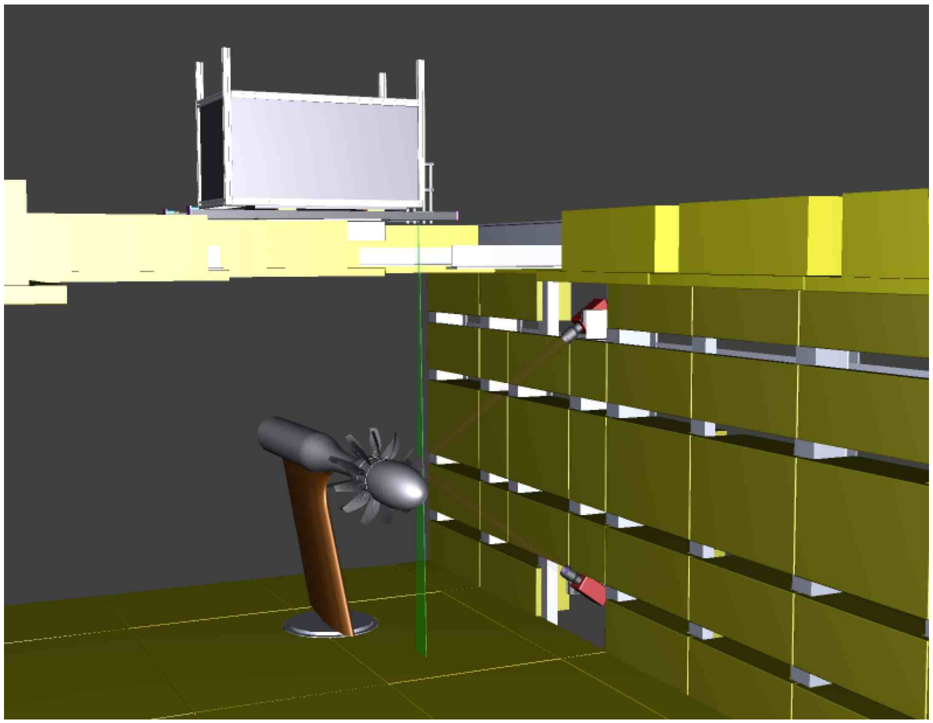
Researcher: Tim Bencic

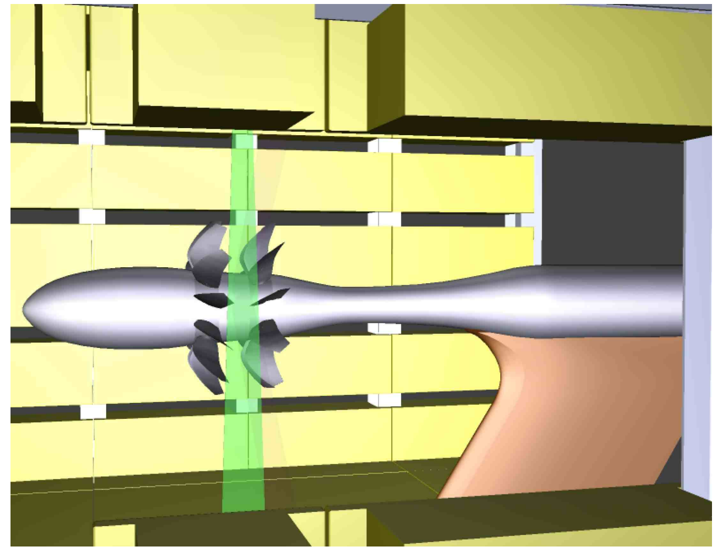
Unsteady PSP Characteristics

- •Response > 20KHz
- •Typical Pressure range: 0-25psia, (low pressure is the brightest and dims with increasing pressure)
- •Excitation source: pulsed LED <10μsec (405nm or 460nm)
- •Signal > 580nm (depending on pressure sensor)
- •Use a porous coating to allow fast interchange of air in and out of coating (ceramic particles in a very thin binder)
- •Delta P Acquisition Technique will utilize the ratio of a time averaged or a non-wake influenced pressure field and an instantaneous pressure field with wake present

Objective: quantify the magnitude and infer information about the time history of static pressure fluctuations on the forward and aft rotor airfoils as well as the trailing edge of the generic pylon.

The ERA Diagnostics Program
Stereo Particle Image Velocimetry

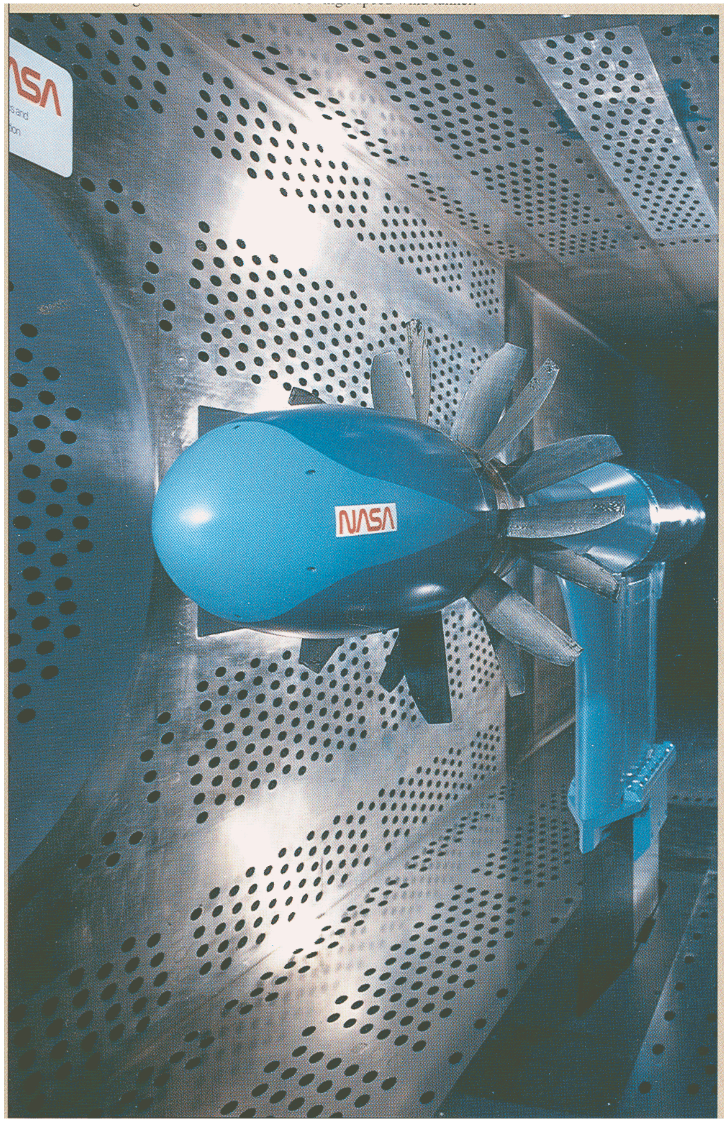




Objective: quantify the velocity characteristics and trajectory of the forward rotor wakes and tip vortex in support of tone noise predictions. In addition, second order statistics (Tu%) will be determined from the measurements in support of broadband noise predictions.

Researchers: Mark Wernet
Adam Wroblewski
Randy Locke

8x6 Cruise Performance Testing



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

Challenges

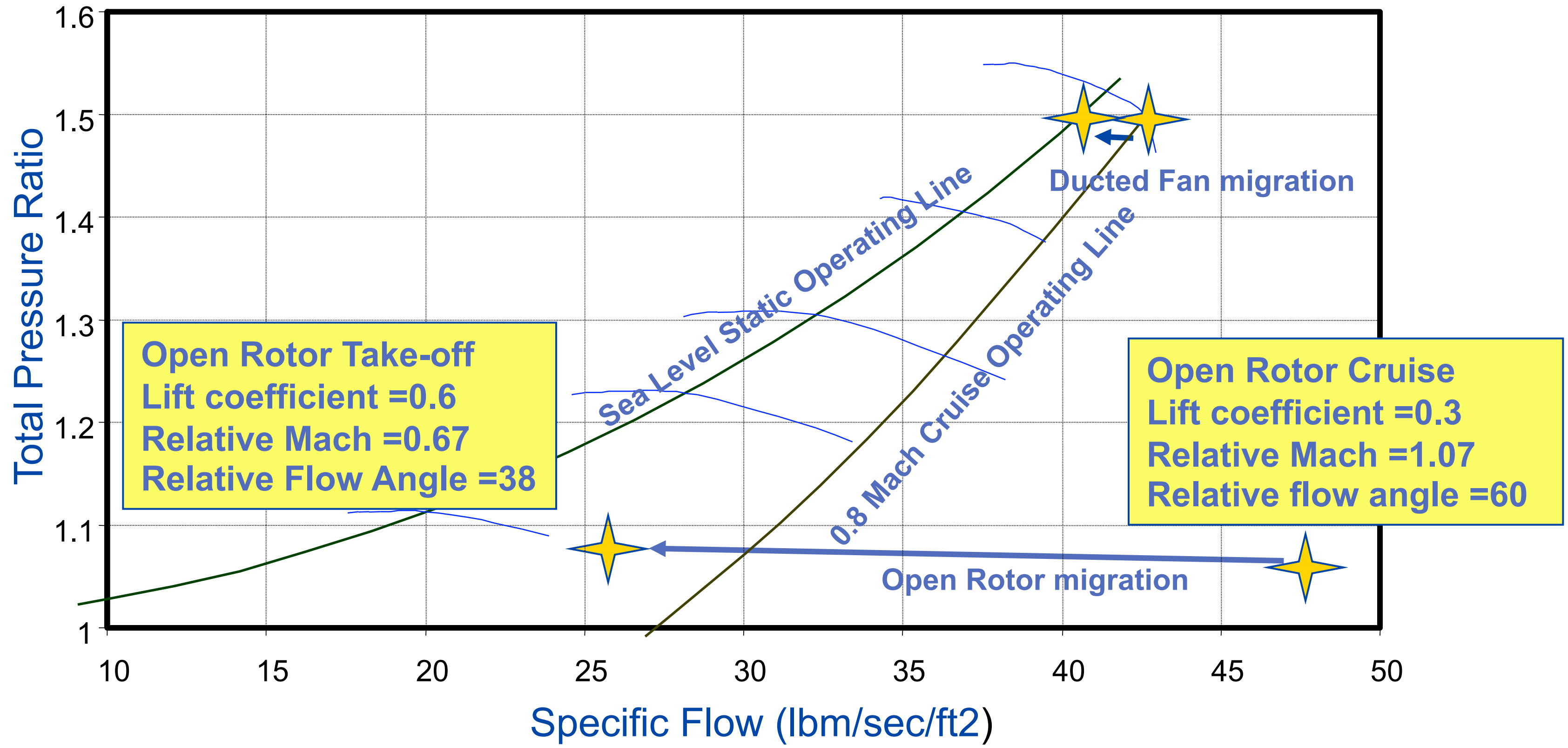
Installation effects:

- Much of the noise and performance development testing is being done for an isolated fan/nacelle.
- Noise and performance impact of the pylon and fuselage are to be measured in test.
- Future design intent to mitigate any significant penalties. Modern aero/acoustic tools will aid greatly.

Pitch change mechanism:

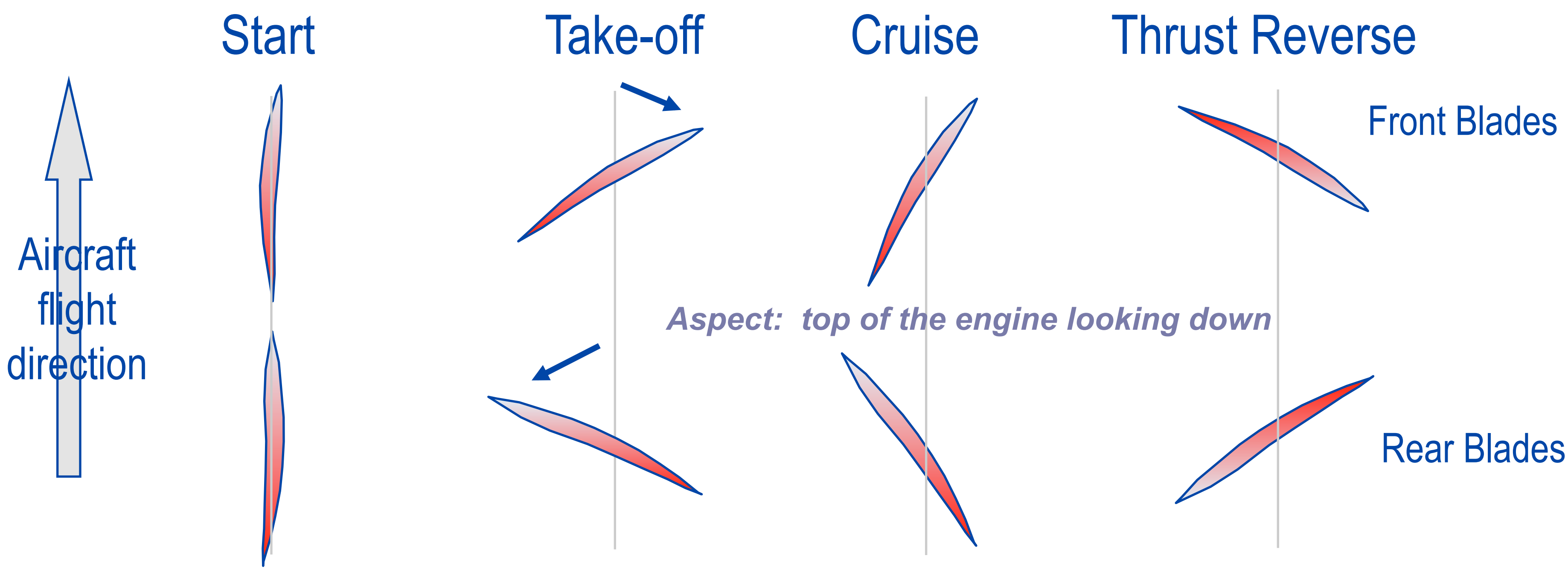
- A simple, durable, light-weight pitch change mechanism is required to accommodate the specific flow change from Takeoff to Cruise.

Migration of Fan Operating Points from Cruise to Take-off Shown on Fan Map



- Ducted fans at conventional fan pressure ratio migrate small amount on the map from cruise to take-off
- Open rotors see large changes in inlet relative flow angle requiring variable pitch mechanism to control angle of attack

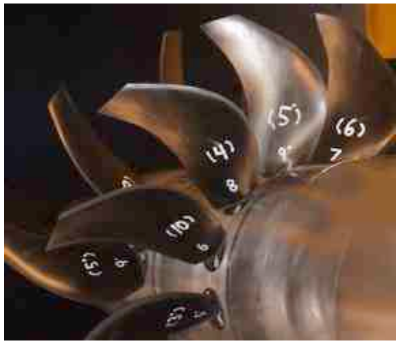
Pitch Actuation Range Required



- Pitch actuation system needed to keep blade angle of attack and lift coefficients at reasonable levels throughout the flight envelope
  - Also required for reverse thrust capability

Certification challenges

Are these propellers or fan blades or both?

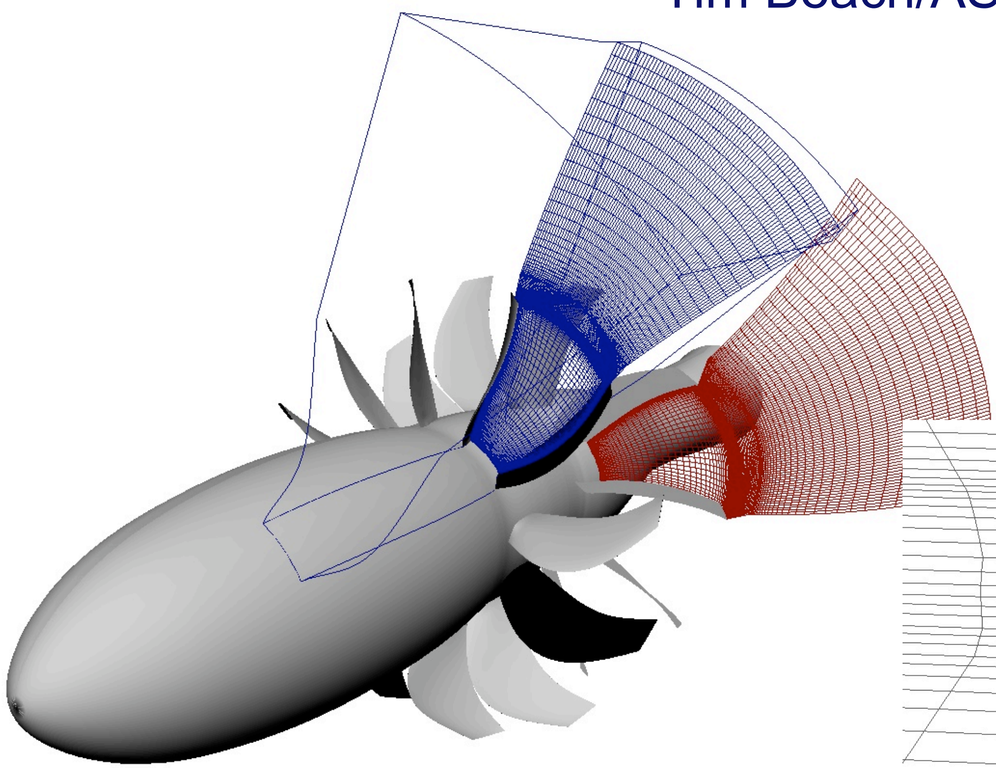


Certification requirements need high level of integration with airframers, engine manufacturers and agencies.

Currently engaging turboprop and turbofan agency experts to address unique requirements of an Open Rotor configuration.

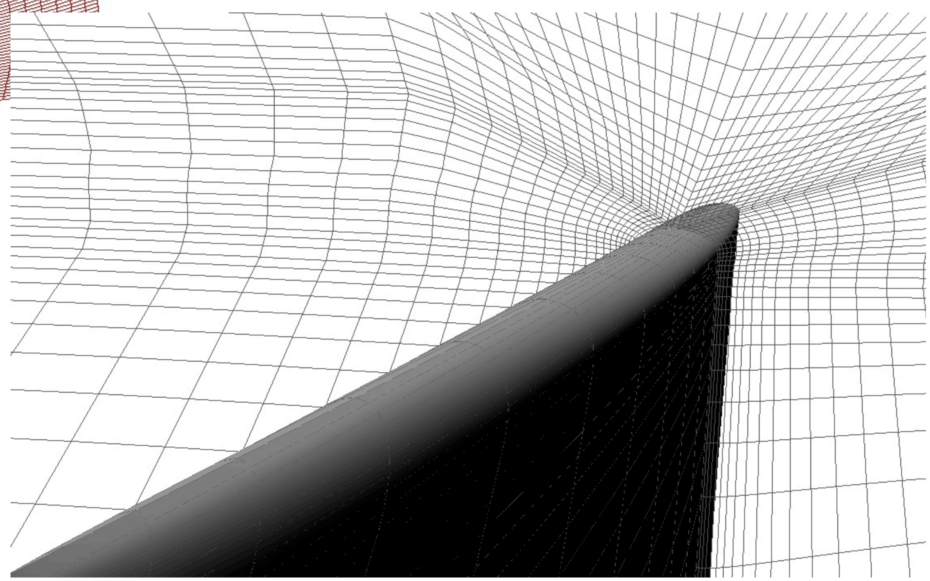
Reliability, performance, acoustics....all must be optimized for product success.

Open Rotor Meshing/Simulation status
Tim Beach/ASRC



Coarse meshes ready for ADPAC simulations to determine pitch angles.

Blade tip is rounded for single block mesh.



Much of the information from the diagnostics test is meant to improve modeling/simulation capabilities in support of design.

Open Rotor Propulsion Airframe Aeroacoustics (PAA) Experiment in Boeing Low Speed Aeroacoustics Facility (LSAF) (ERA)

Boeing PI: Michael.J.Czech@Boeing.com
NASA TM: Russell.H.Thomas@NASA.gov

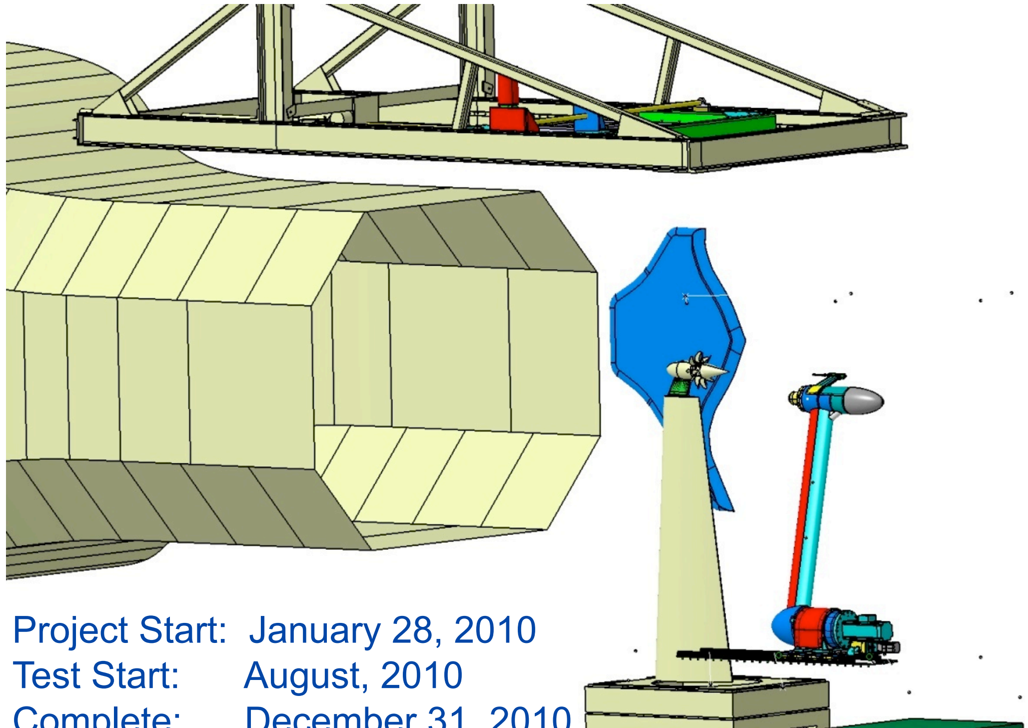
Objective: Study PAA effects of counter-rotating open rotor for both HWB and Tube-and-Wing aircraft types.

Open Rotor is the 8 X 8 1980s design.

Parameters/Effects:
- Axial and Height Spacing
- R1/R2 Speed Variation
- Angle-of-attack
- Elevon Interaction

Noise Reduction Approaches:
- Pylon Blowing
- Pylon and Surface Acoustic Linings

Instrumentation:
- Far Field Mic
- Near Field Mic Traverse
- Flow Field Survey
- Phased Array Traverse
- A/C Surface Unsteady Pressure

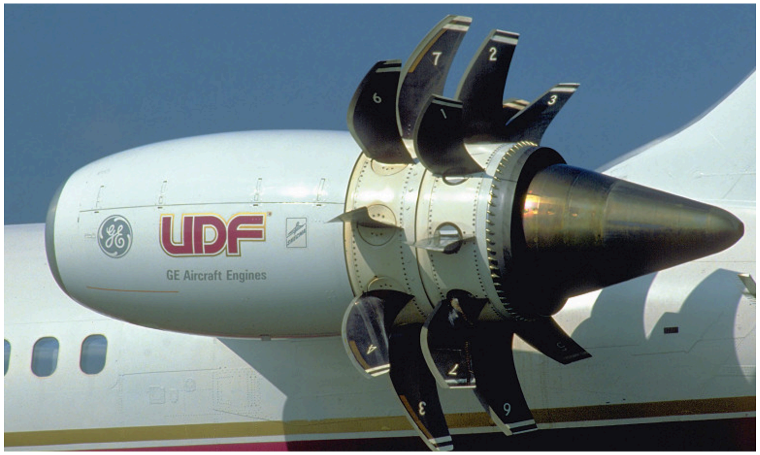


Project Start: January 28, 2010
Test Start: August, 2010
Complete: December 31, 2010

Current Status, In Progress:
- Rig Check-out
- LSAF Configuration
- Facility Modifications Design
- Concept Design

NASA system studies plan

- NASA SAD&O focus is on analytically modeling a counter-rotating, pusher architecture
  - Legacy GE36 UDF MD-81 demonstrator
  - Proposed CFM N+1 open rotor configuration
- Legacy GE and United Technologies analysis codes from Advanced Turboprop Project being resurrected
- Legacy codes will provide performance and acoustic analysis capability beyond the public-domain F7/A7 rotor data
- Potential to wrap these performance codes in NPSS element rather than use map socket static data
- Incorporation of performance and acoustic test data from collaborative GE/CFM/NASA open rotor test program



GE36 Unducted Fan MD-81 demonstrator at Farnborough, 1988

Proposed CFM open rotor configuration

An independent evaluation of ultra high bypass systems.

Summary

- NASA has acquired a substantial aerodynamic and acoustic dataset on a variety of blade geometries for an isolated configuration.
- 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.
- ERA Diagnostics will acquire a comprehensive, detailed data set which is not only useful for modeling these systems but also for understanding how future progress is possible.
- NASA simulation effort is beginning.
- NASA has substantial system analysis plans for ultra-high bypass systems.

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

ASME Turbo Expo 2010

THURSDAY, JUNE 17, 2010 **02:30 PM TO 05:30 PM**

COMM 1 Aircraft Engine

Point Contact(s): **Syed Khalid** *Rolls Royce*

Co-Chair/Contact(s): **Milt Davis** *Aerospace Testing Alliance, ATA*, **William Cousins** *Pratt & Whitney*

1-15 Ultra High Bypass Propulsion: Ducted Fans and Open Rotors *(Session)*

Session Organizer(s): **Christopher Hughes** *NASA Glenn Research Center*

Session Co-Chair(s): **Dale Van Zante** *NASA Glenn Research Center*

Session Description:

Highlight current research activities in Ultra High Bypass Ducted Fans and Open Rotor propulsion technologies, emphasizing improvements in fuel burn and emissions compared to conventional aircraft engine technology and other advanced propulsion technologies. The interest is in isolated and installed performance with viewpoints of both airframe and engine manufacturers are represented by panelists.

Papers

GT2010-23859 *(Panel)* Presentation Order: **1**

The NASA Environmentally Responsible Aviation Project

Authors: **Fayette Collier** *NASA*

GT2010-23841 *(Panel)* Presentation Order: **2**

Integration Challenges in Ultra High Bypass Propulsion Systems

Authors: **Cesare Hall** *Cambridge University*

GT2010-23861 *(Panel)* Presentation Order: **3**

Ultra High Bypass Propulsion System Integration - Challenges and Considerations

Authors: **Mark Anderson** *Boeing Research and Technology*

GT2010-23860 *(Panel)* Presentation Order: **4**

Open-Rotors: Benefits and Challenges

Authors: **Andy Breeze-Stringfellow** *General Electric - Global Research*

GT2010-23910 *(Panel)* Presentation Order: **5**

Pratt & Whitney Geared Turbofan Technology

Authors: **Jayant Sabnis** *Pratt & Whitney*

GT2010-23911 *(Panel)* Presentation Order: **6**

Ultra High Bypass Propulsion Technology at Rolls Royce

Authors: **Mark Taylor** *Rolls Royce*

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