Open Rotor - Analysis of Diagnostic Data

- NASA is researching open rotor propulsion as part of its technology research and development plan for addressing the subsonic transport aircraft noise, emission and fuel burn goals.

- The low-speed wind tunnel test for investigating the aerodynamic and acoustic performance of a benchmark blade set at the approach and takeoff conditions has recently concluded. A high-speed wind tunnel diagnostic test campaign has begun to investigate the performance of this benchmark open rotor blade set at the cruise condition.

- Databases from both speed regimes will comprise a comprehensive collection of benchmark open rotor data for use in assessing/validating aerodynamic and noise prediction tools (component & system level) as well as providing insights into the physics of open rotors to help guide the development of quieter open rotors.

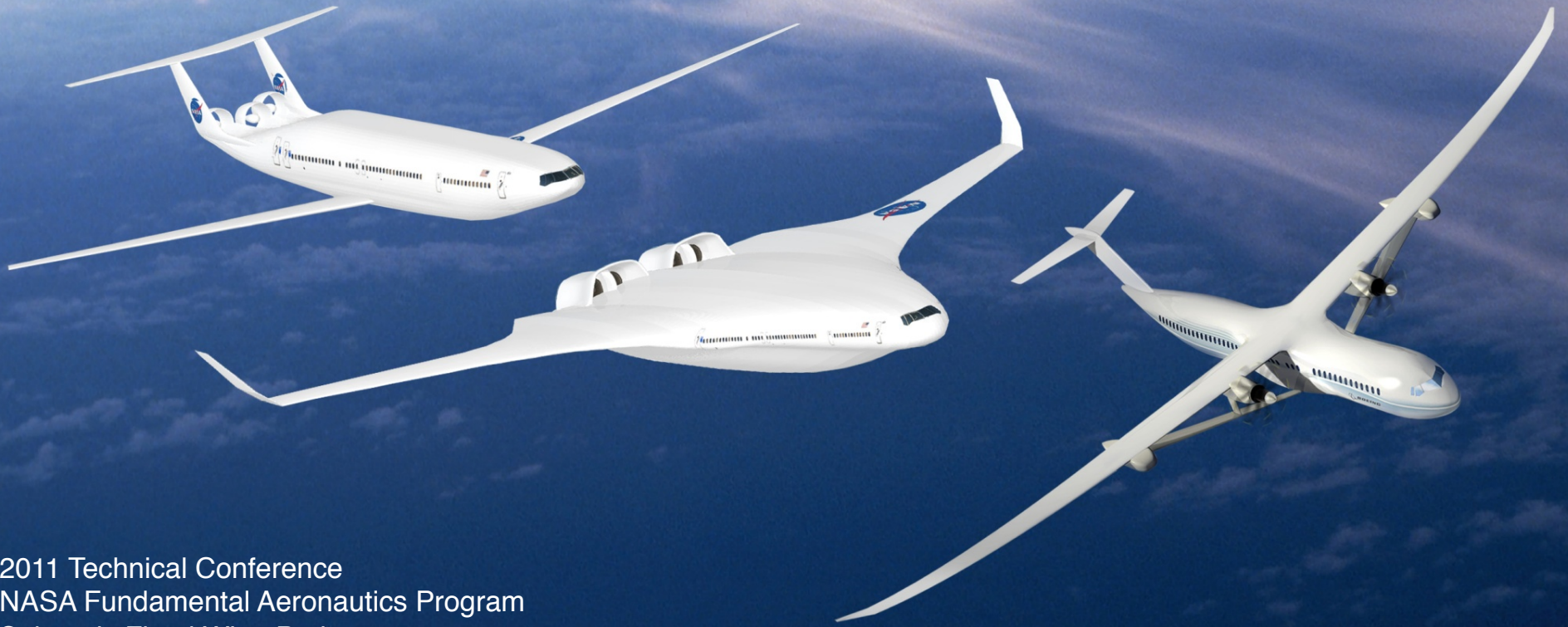
National Aeronautics and Space Administration

Open Rotor - Analysis of Diagnostic Data

Dr. Ed Envia

Research Aerospace Engineer
NASA Glenn Research Center

Acknowledgements:
The sponsorship of the NASA Environmentally Responsible Aviation Project (Dr. Fay Collier, Project Manager) in funding the open rotor diagnostic test campaign is gratefully acknowledged as is the collaboration of our partners at General Electric Aviation.



2011 Technical Conference
NASA Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Cleveland, OH, March 15 - 17, 2011

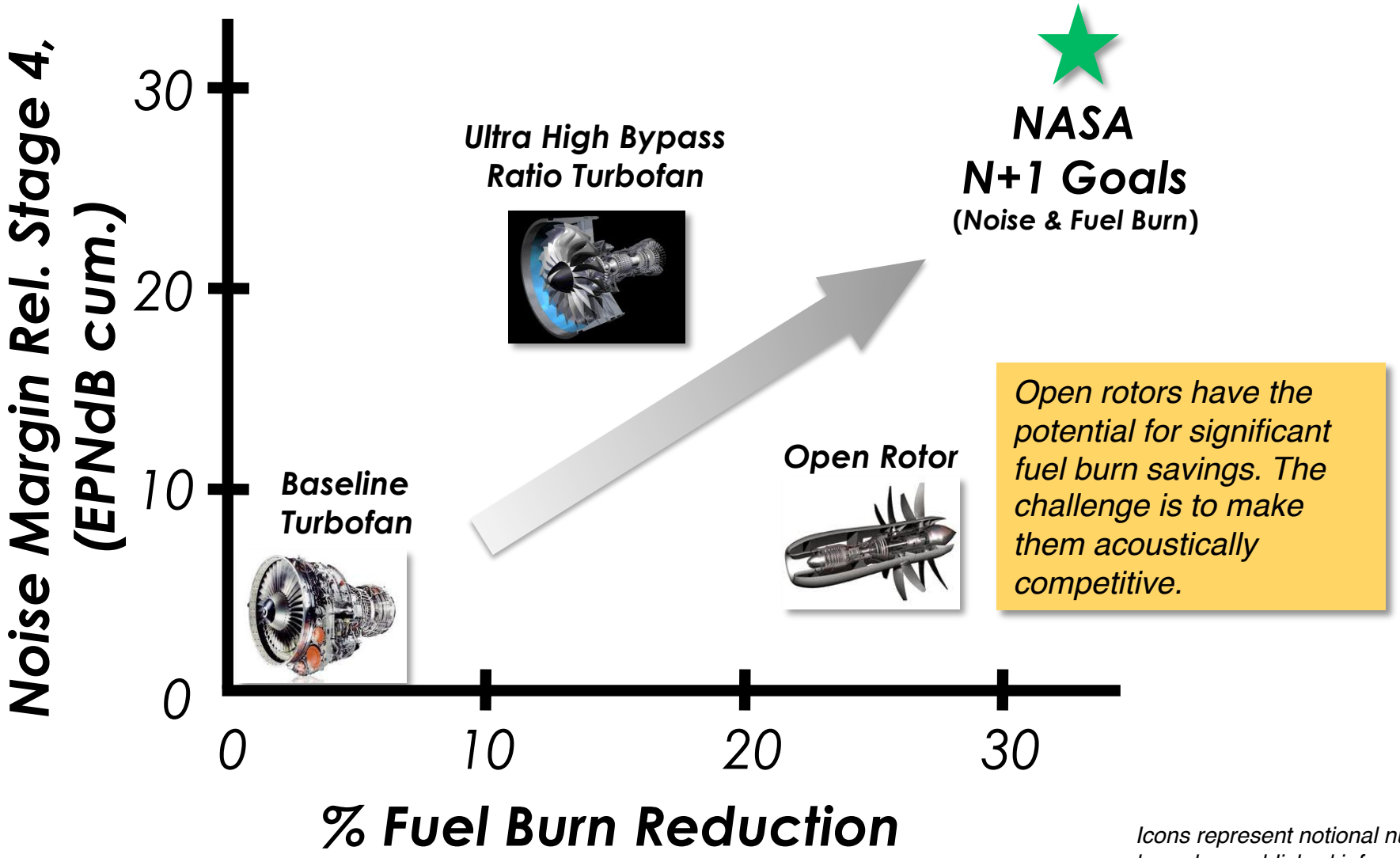
Background

- Open rotors offer significant fuel burn savings compared with the conventional turbofan engines. NASA is carrying out research to assess the merits of open rotor propulsion systems in meeting the Subsonic Transport Goals:

CORNERS OF THE TRADE SPACE	N+1 = 2015*** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020*** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025*** Technology Benefits
Noise (cum below Stage 4)	*-32 dB*	*-42 dB*	*-71 dB*
LTO NO_x Emissions (below CAEP 6)	*-60%*	*-75%*	*better than -75%*
Performance: Aircraft Fuel Burn	*-33%*	*-50%***	*better than -70%*
Performance: Field Length	*-33%*	*-50%*	*exploit metro-plex* concepts*

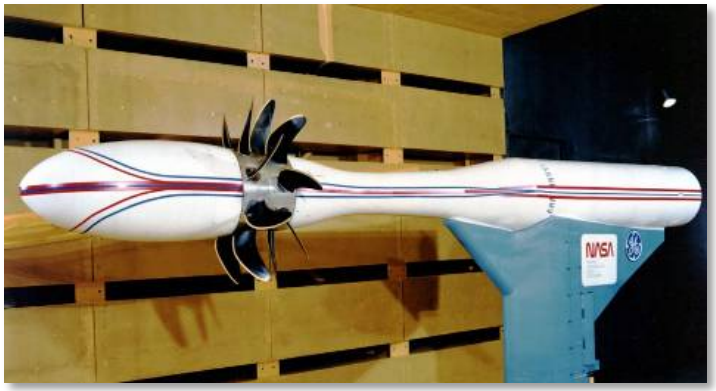
****Technology Readiness Level for key technologies = 4-6. ERA will undertake a time phased approach, TRL 6 by 2015 for "long-pole" technologies.*
*** Recently Updated. Additional gains may be possible through operational improvements.*
** Concepts that enable optimal use of runways at multiple airports within the metropolitan area.*

Propulsor Technology Roadmap



Icons represent notional numbers based on published information

Research Strategy



Unducted Fan (UDF) Model in NASA Wind Tunnel (1985)

GE UDF Engine on MD-80 Aircraft (1987)

PW/Allison 578-DX Engine on MD-80 Aircraft (1989)

- The feasibility of open rotor technology and its fuel burn advantage were demonstrated in the 1980's. So what is new?
- Improvements in 3D aerodynamic design tools has made possible the development of open rotor systems with decreased noise emissions while maintaining their fuel burn advantage.
- The NASA open rotor research strategy is a synergistic mix of *component testing & diagnostics*, *analysis & modeling*, and *system level testing & assessment*.

Component Testing & Diagnostics

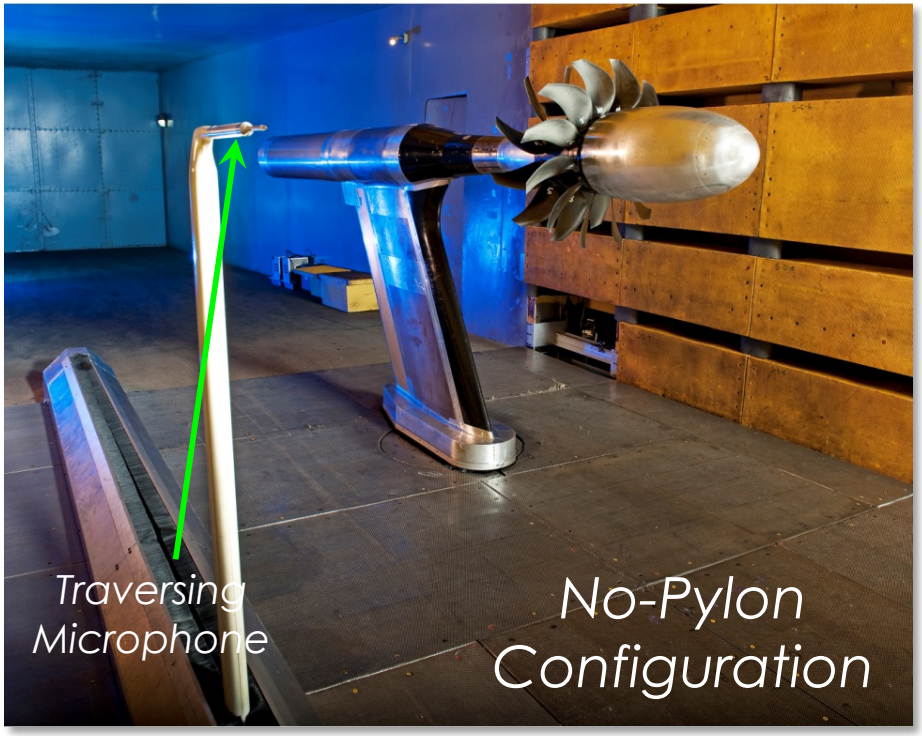
- NASA recently completed a series of low-speed wind tunnel experiments to characterize the aerodynamics and acoustic performance of a benchmark open rotor blade set called the GE HISTORICAL BASELINE. These include:
  - Sideline and phased array data
  - Optical flow diagnostic data
  - Basic shielding tests
- The diagnostic data is being analyzed and the results will be reported on in upcoming workshops, meetings, and conferences. Here is a sampling of the analyzed data.

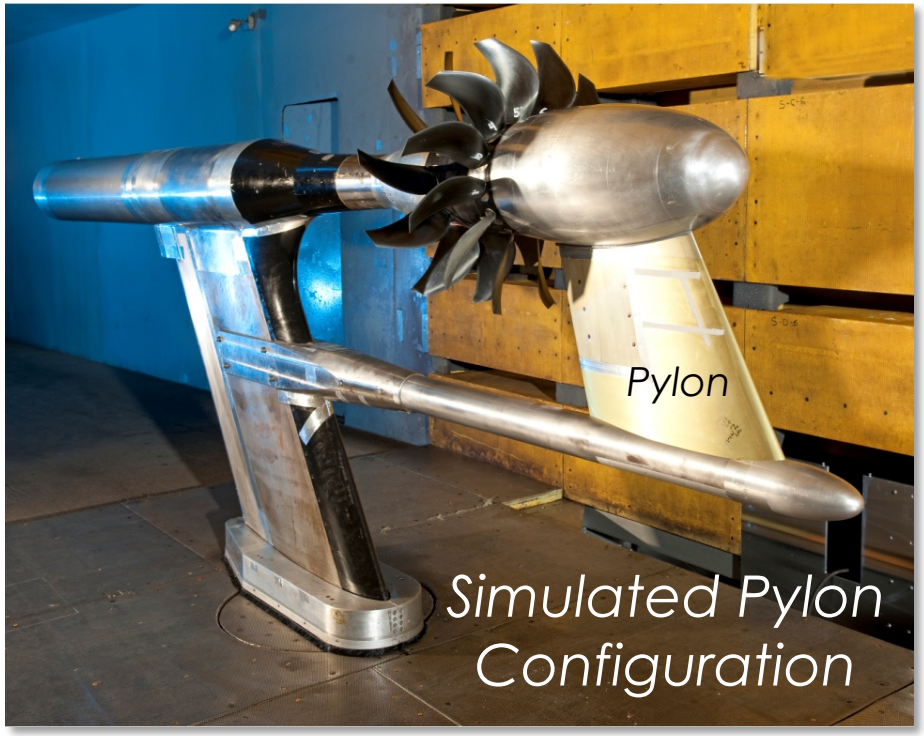
*Model Scale GE **HISTORICAL BASELINE** Blade Set Installed in NASA Low-Speed 9'x15' Acoustic Wind Tunnel*

Test Hardware & Test Facility

Test Rig: NASA Open Rotor Propulsion Rig (10,000 rpm & 750 SHP per Rotor)

Tested Configurations: Isolated and "Installed" with a Simulated Pylon



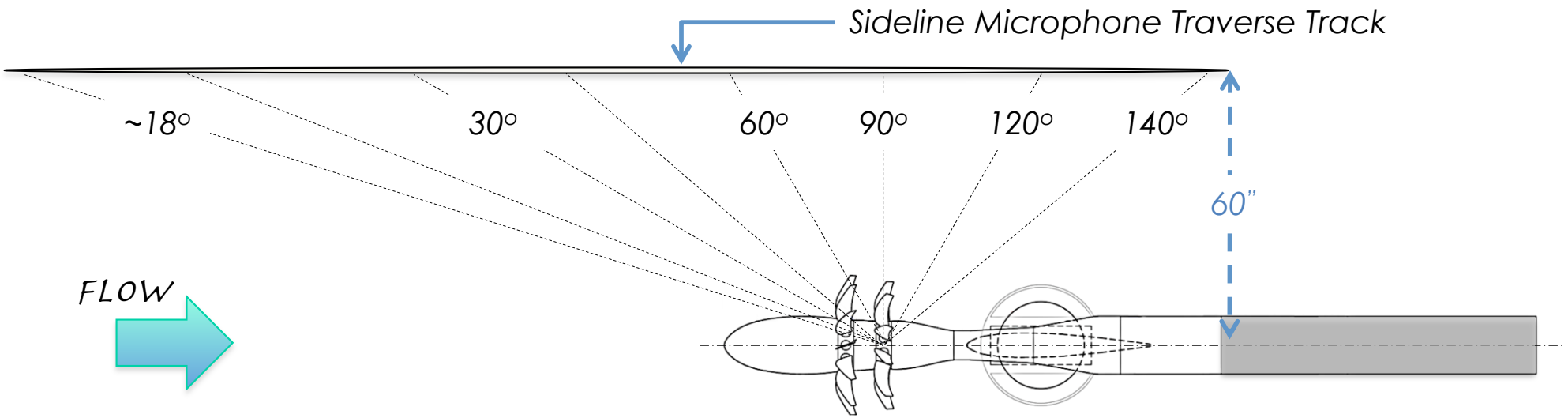


Open Rotor Rig Installed in NASA 9'x15' Acoustic Wind Tunnel

Lead Test Engineer/Coordinator
Dale Van Zante

Sideline Acoustic Measurements

- Sideline sound pressure level (SPL) at a minimum of 18 microphone locations was acquired in typical measurements. Tunnel Mach number was typically set at 0.2.



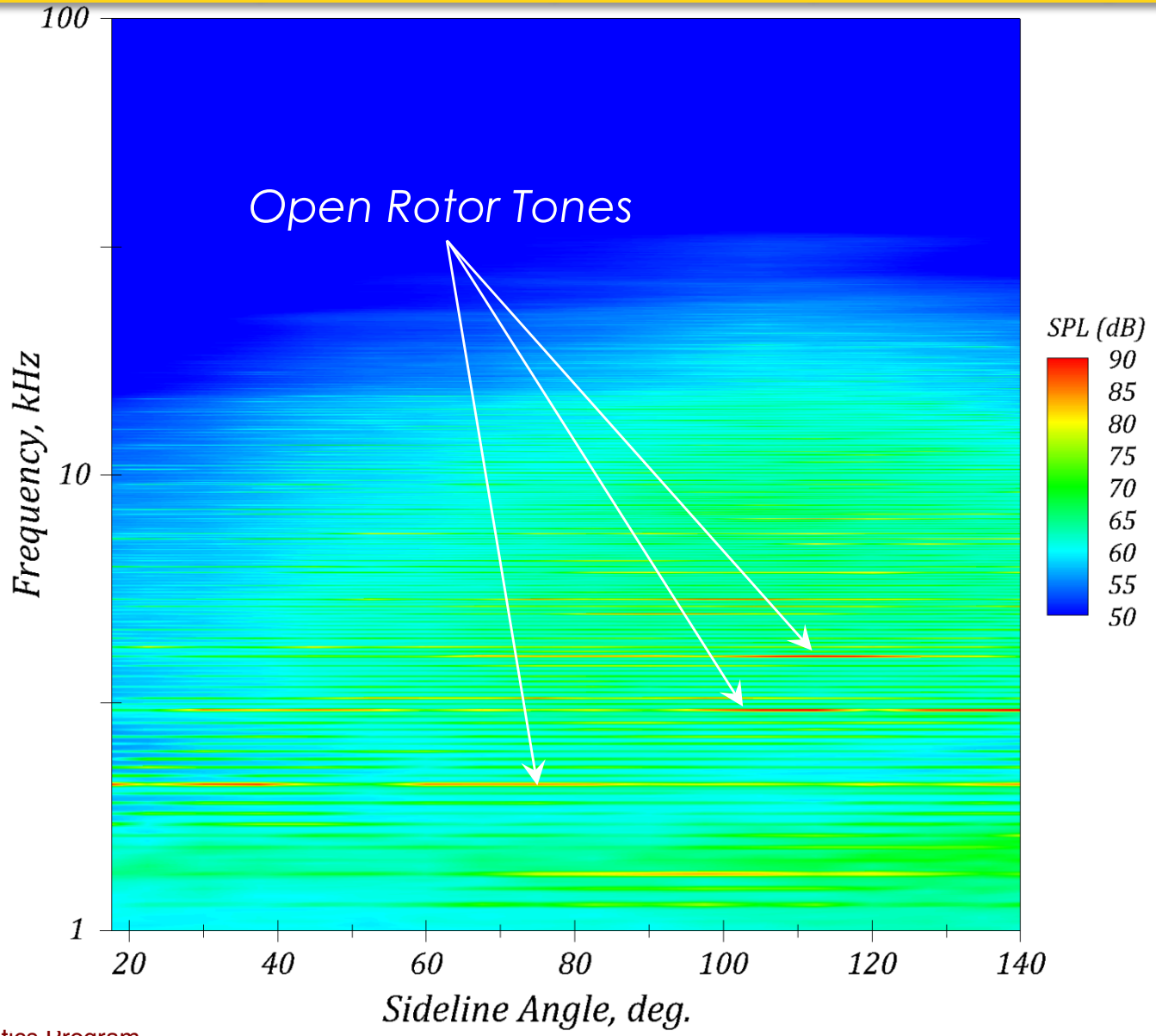
Angles measured from upstream direction.

Research Engineer
David Elliott

Sideline Acoustic Data

Example: Takeoff Power Condition – SPL Map for Isolated Open Rotor Configuration

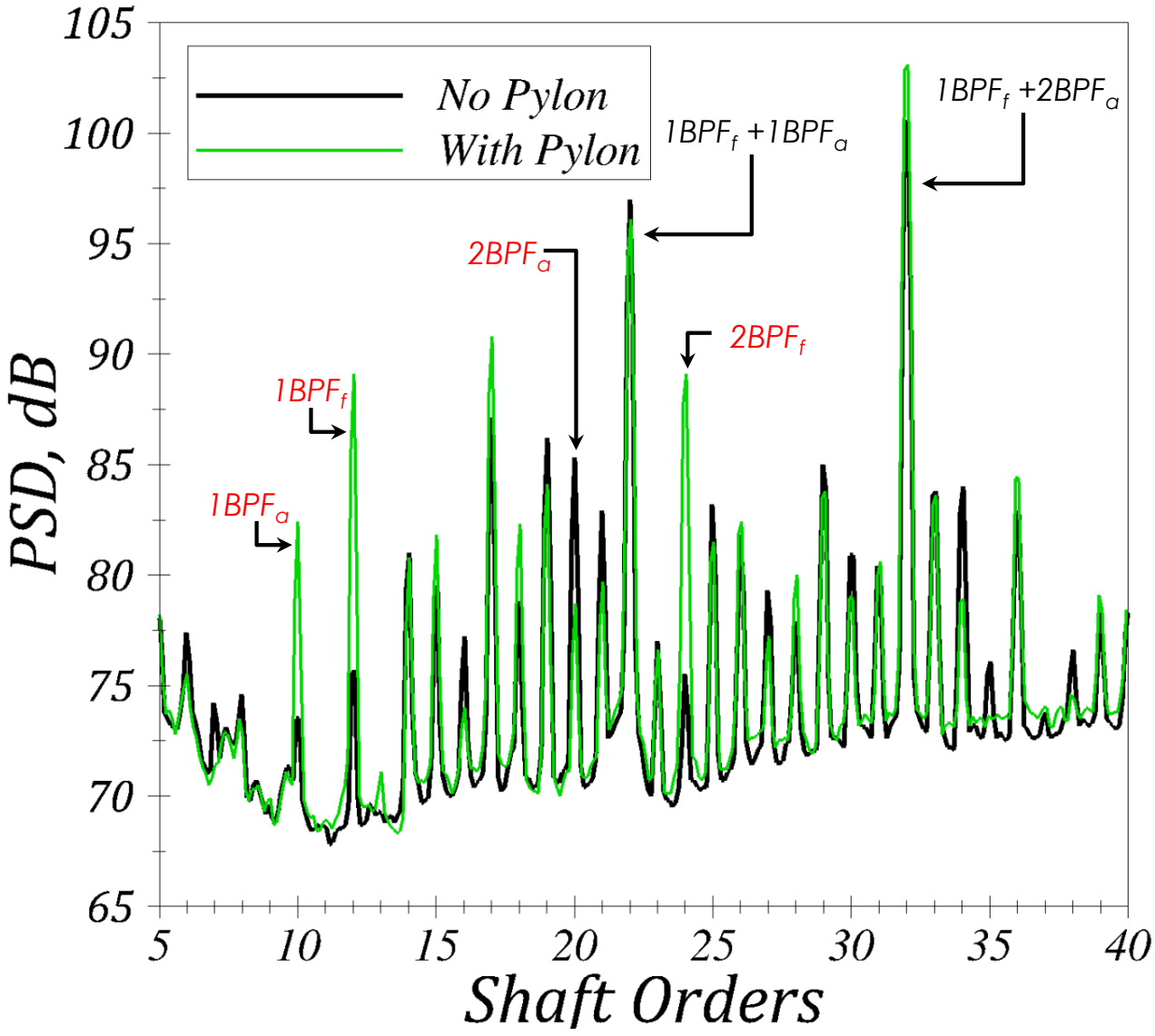
A prominent feature of open rotor noise spectrum is the presence of many rotor tones.



Sideline Acoustic Data

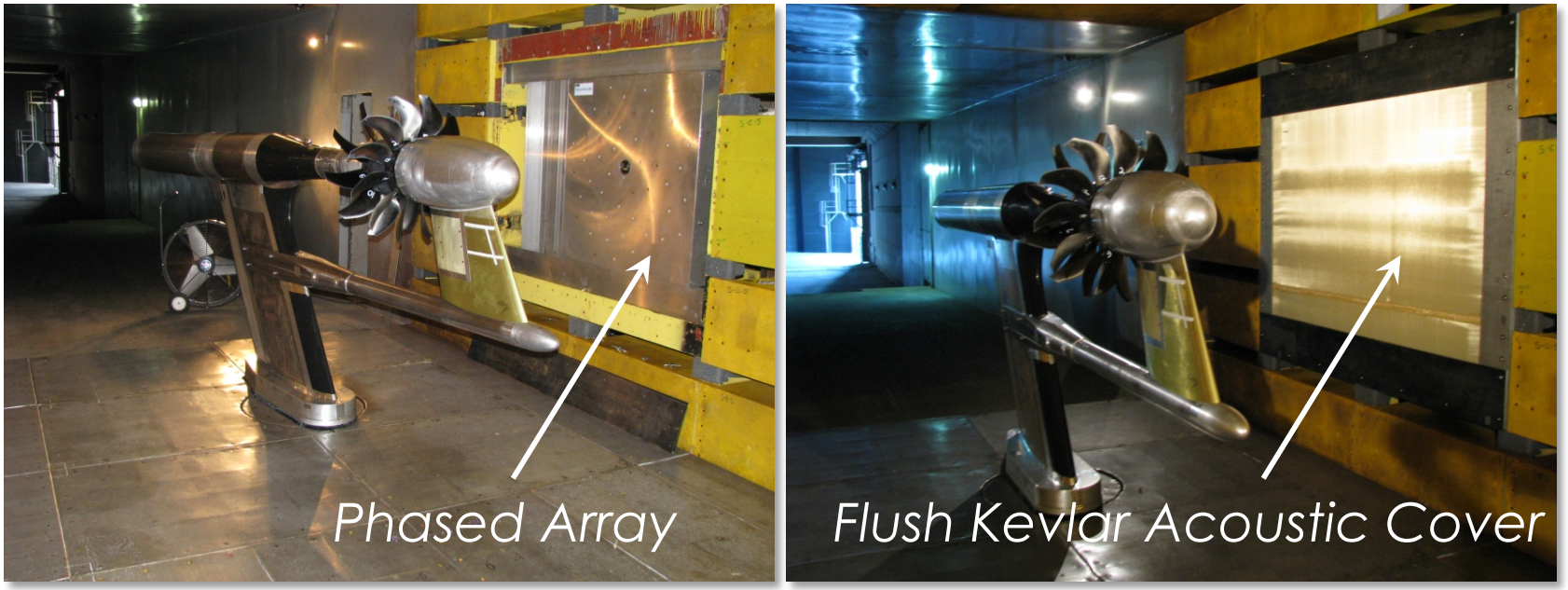
Example: Takeoff Power Condition – Effect of Pylon on Noise Level

Pylon wake typically affects individual rotor tone harmonics, but not the interaction tones.



Phased Array Diagnostic

- Phased array was used for source diagnostic/localization purposes. The array was embedded in the tunnel sidewall broadside to the open rotor drive rig.

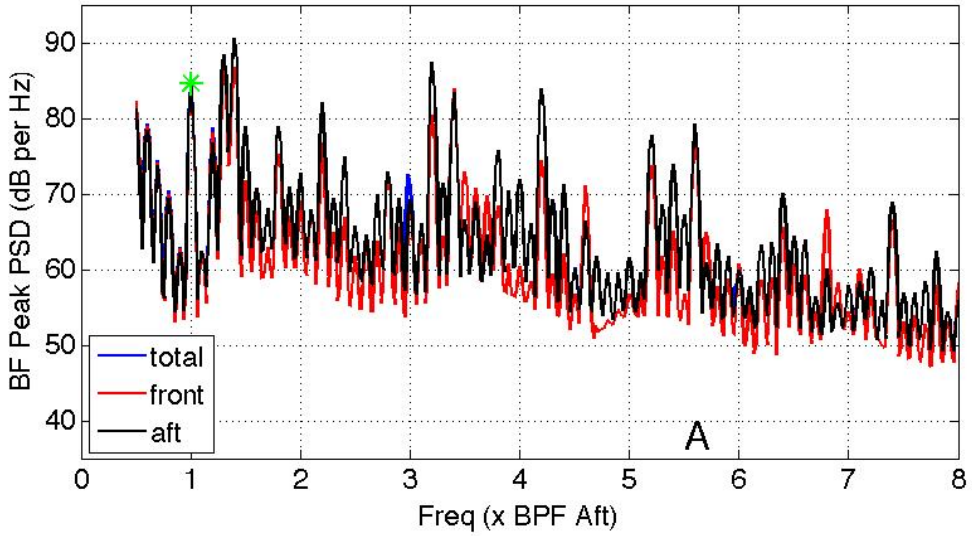


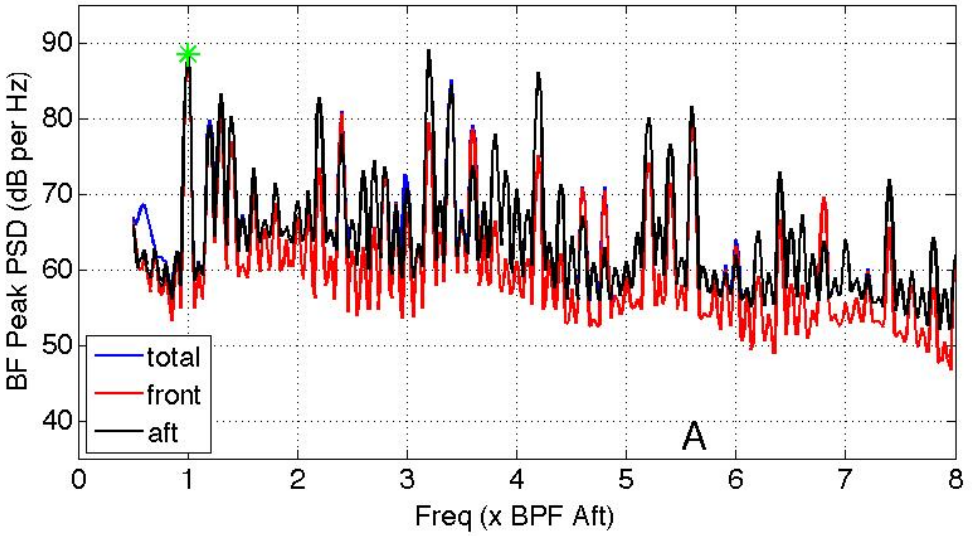
48-Microphone Phased Array System Deployed in NASA Acoustic Wind Tunnel

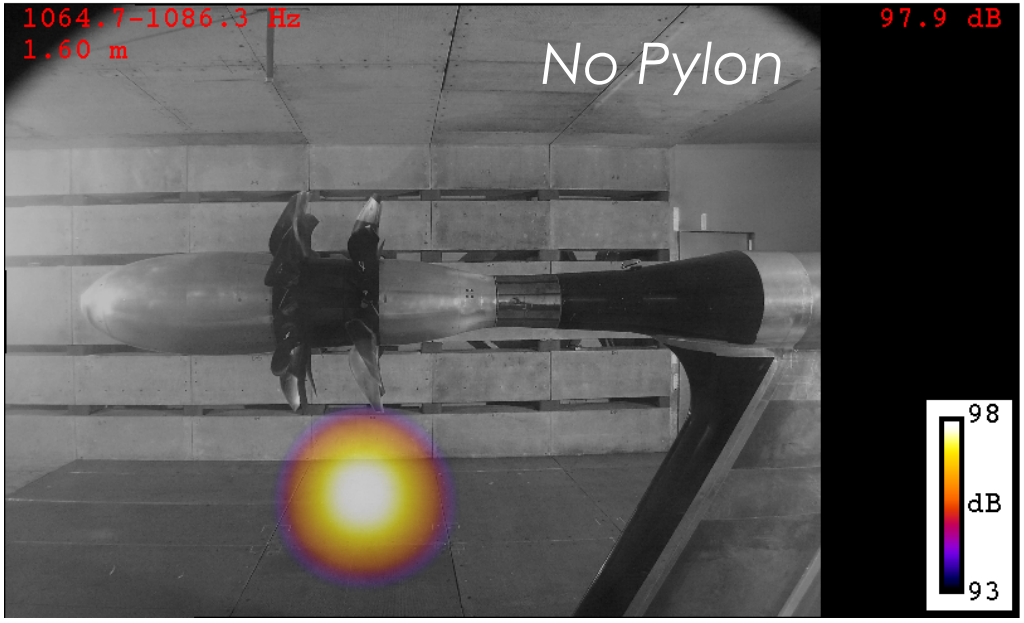
Research Engineer
Gary Podboy

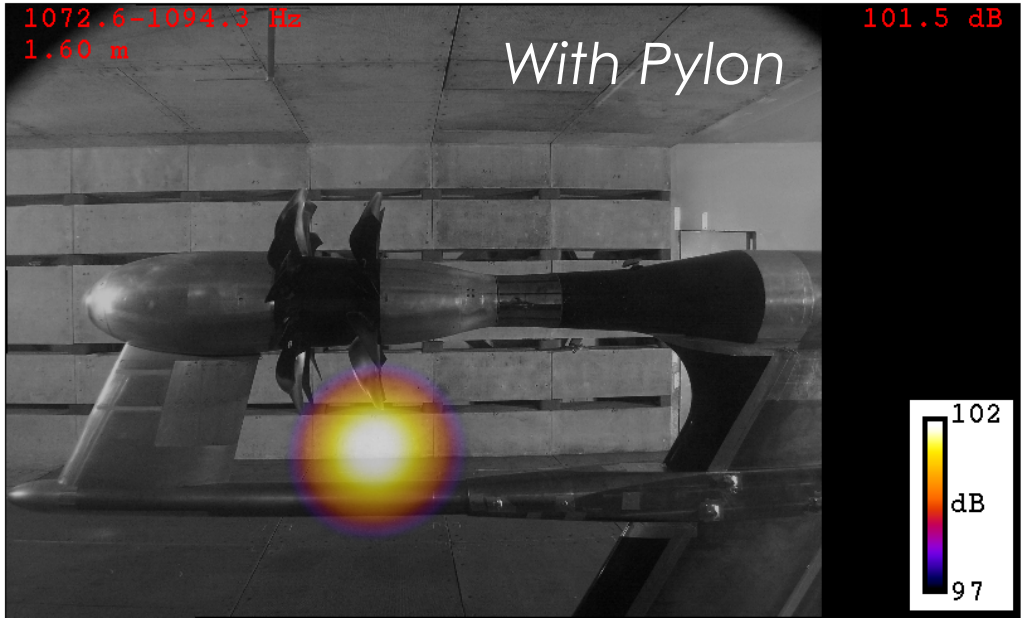
Phased Array Diagnostic

Example: Takeoff Power Condition – No Pylon (left) versus With Pylon (right)



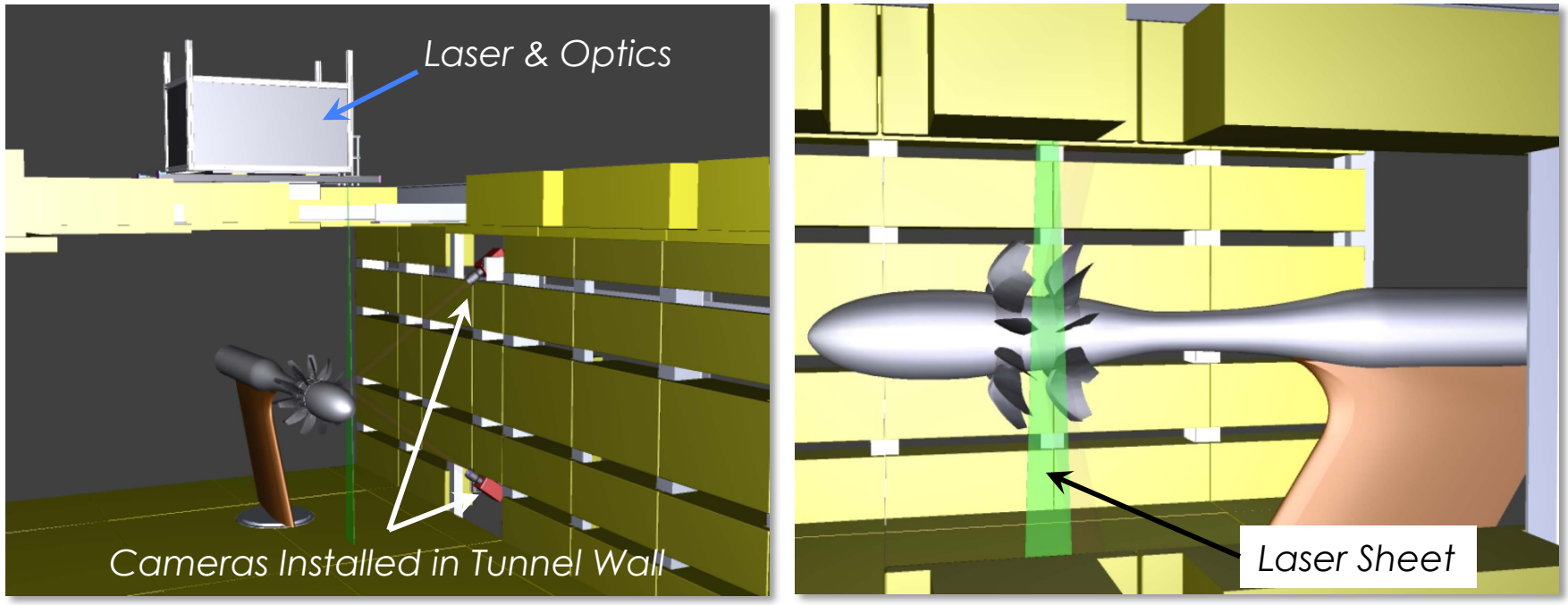






Optical Diag. : Particle Image Velocimetry (PIV)

- PIV was used to map the flowfield to track front blade row tip vortex and measure turbulence intensity between the blade rows. The results will be used for flow code validation.

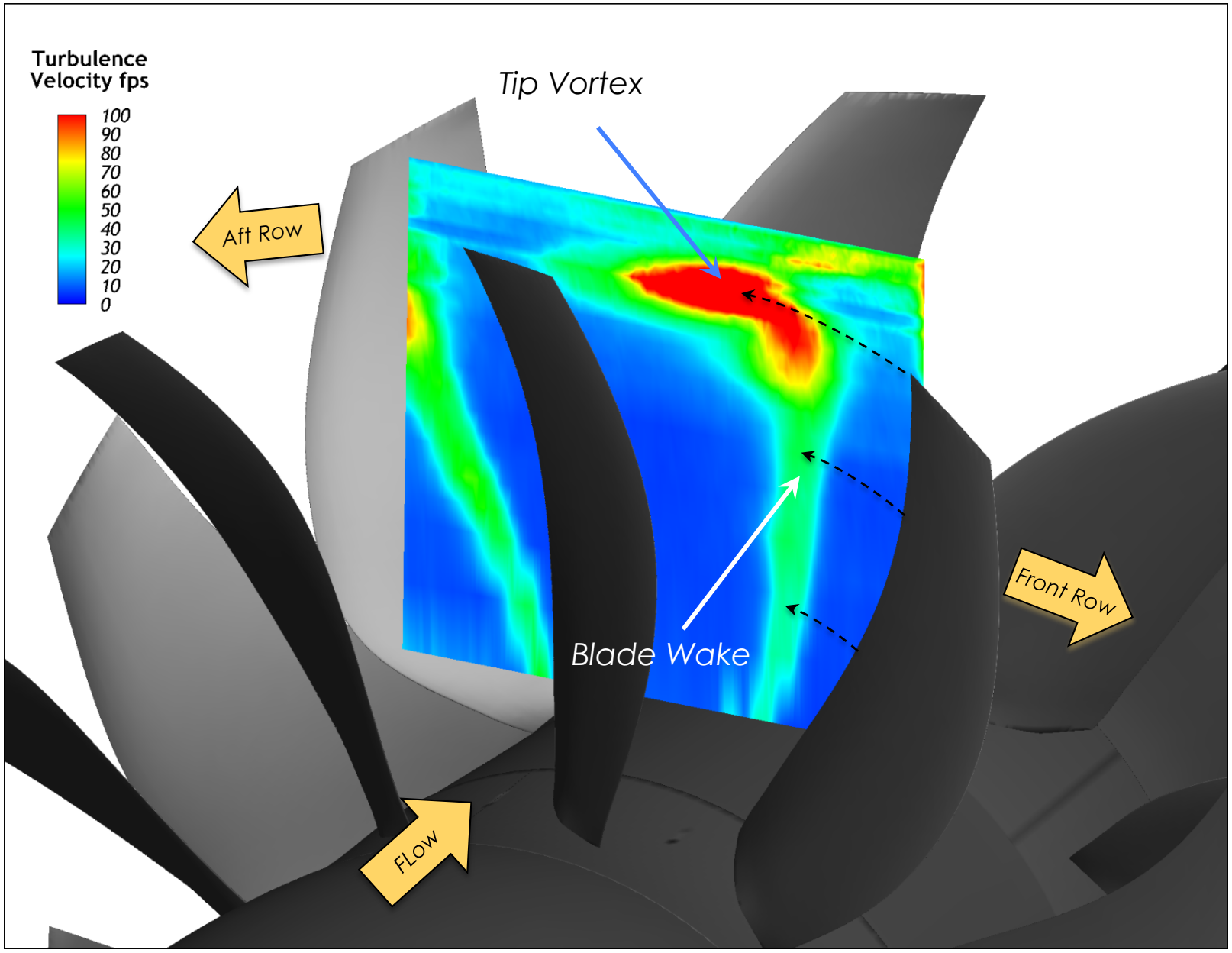


Sketch of A PIV System Deployed in NASA Acoustic Wind Tunnel

Research Engineers
Mark Wernet
Adam Wroblewski
Randy Locke

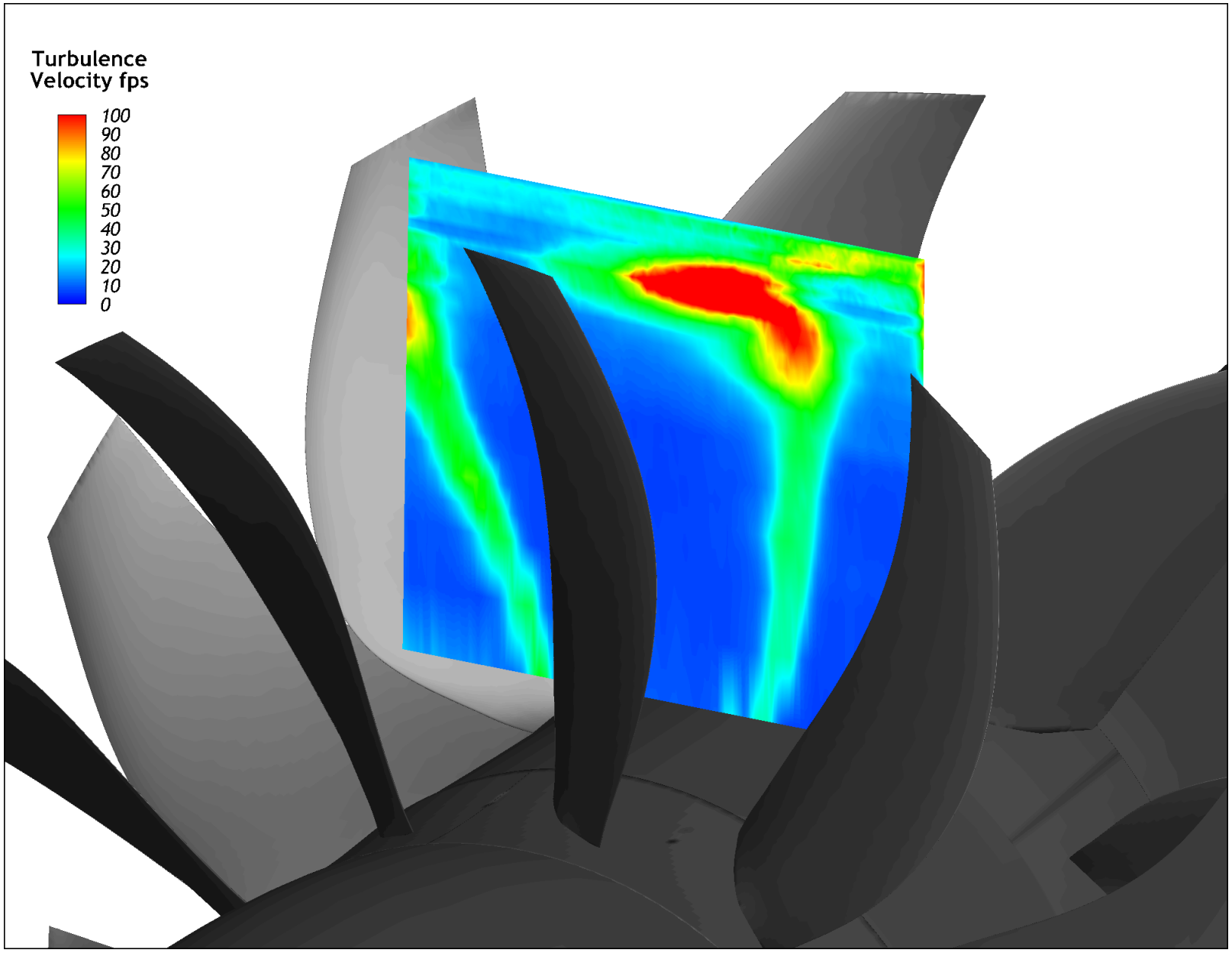
PIV Diagnostic

Example: Takeoff Power Condition; No Pylon – Blade Wake / Tip Vortex



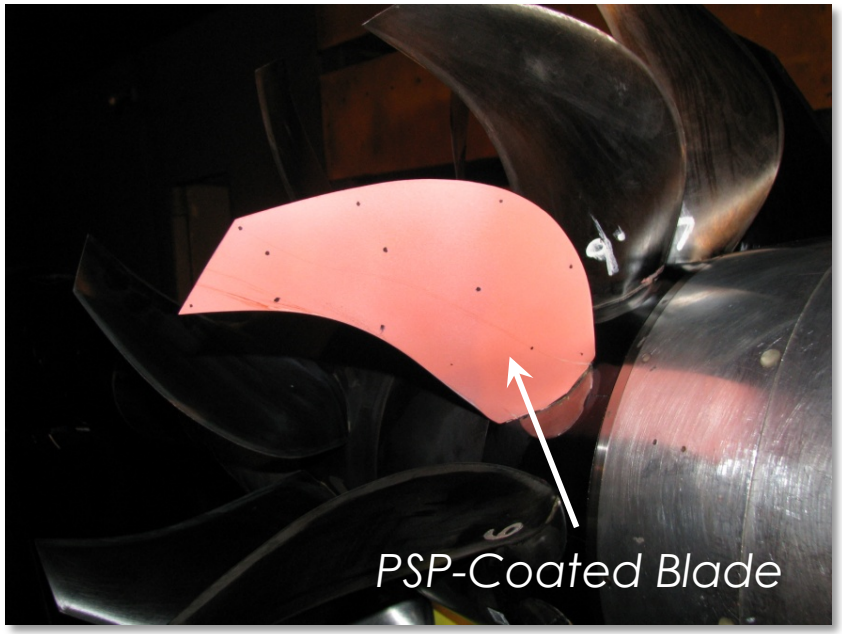
PIV Diagnostic

Example: Takeoff Power Condition; No Pylon – Blade Wake / Tip Vortex Trajectory

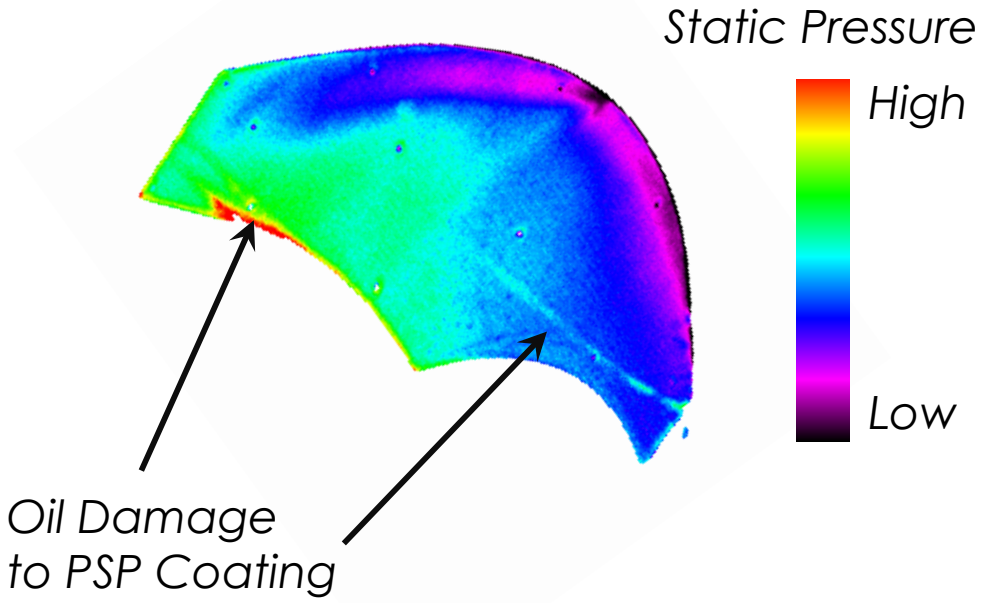


Optical Diag. Pressure Sensitive Paint (PSP)

- Unsteady PSP was used to acquire time variations of the static pressure distribution on the rotating blades. Data has not been analyzed in detail yet.



Surface pressure acquired with PSP lifetime acquisition technique synchronized to the rotor

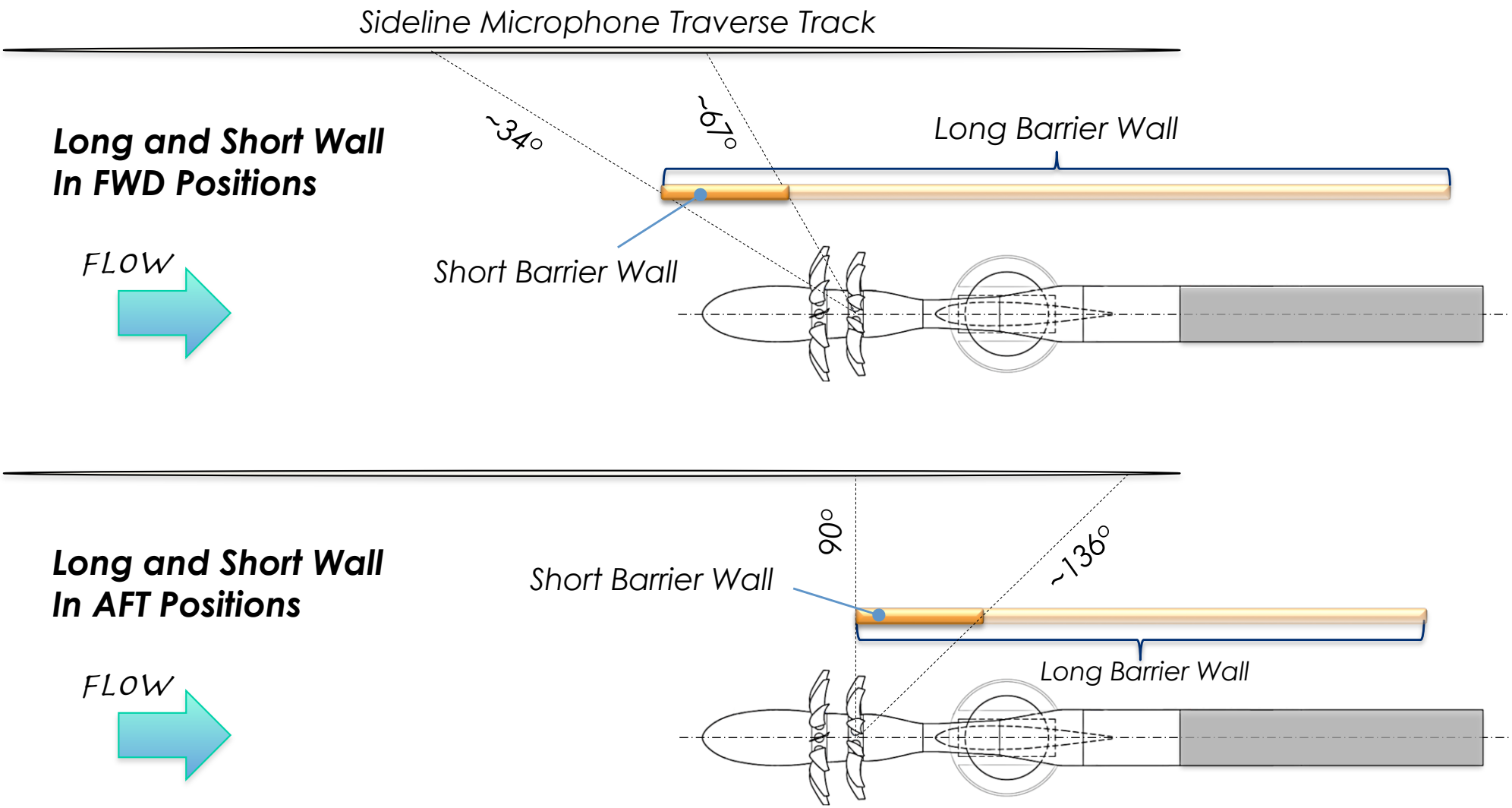


Snapshot in Time of Static Pressure Distribution on the Blade Suction Side

Research Engineer
Tim Bencic

Basic Shielding Experiment

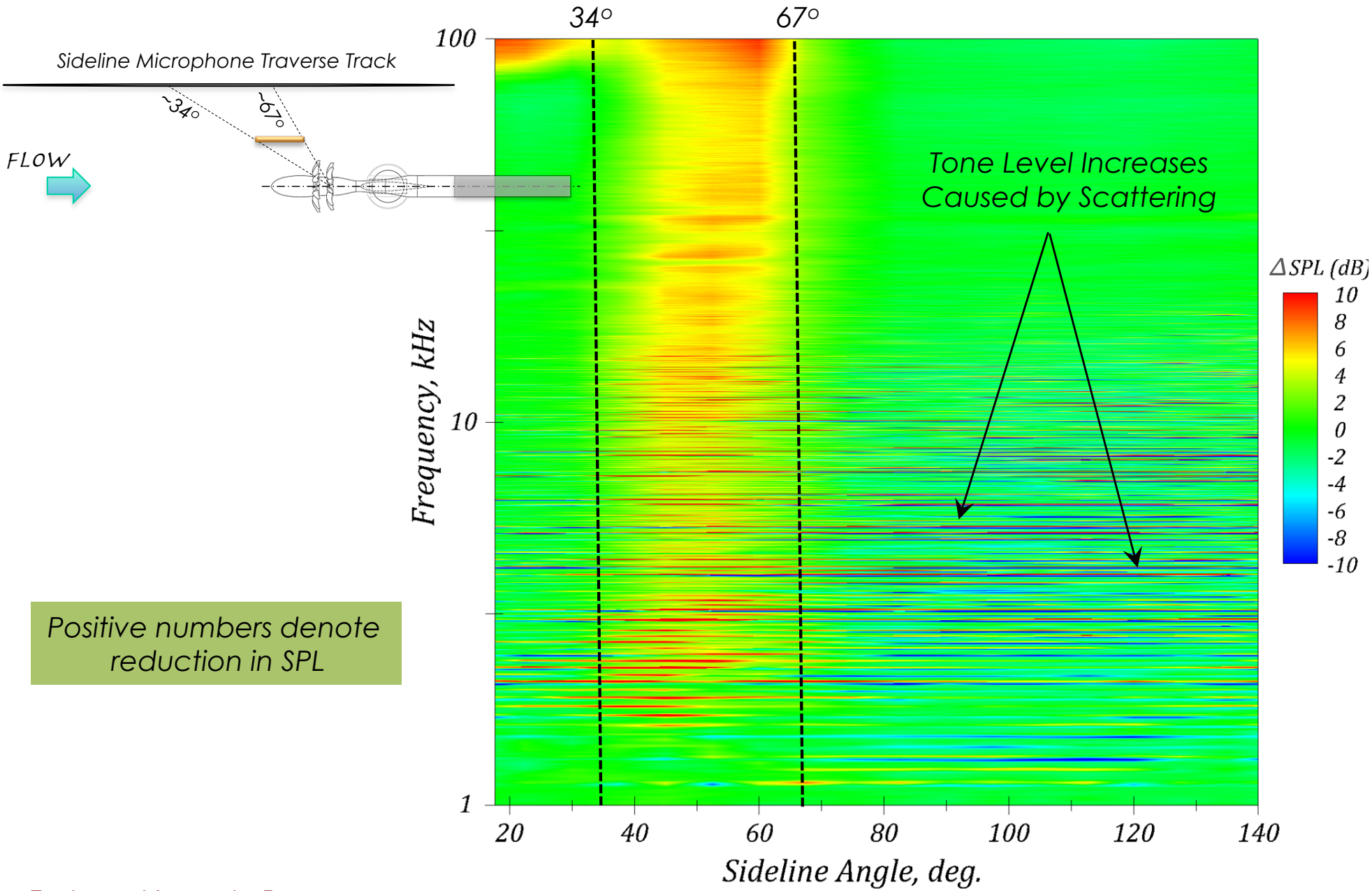
Layouts of Various Barrier Wall Configurations



Research Engineer
David Stephens

Basic Shielding Experiment

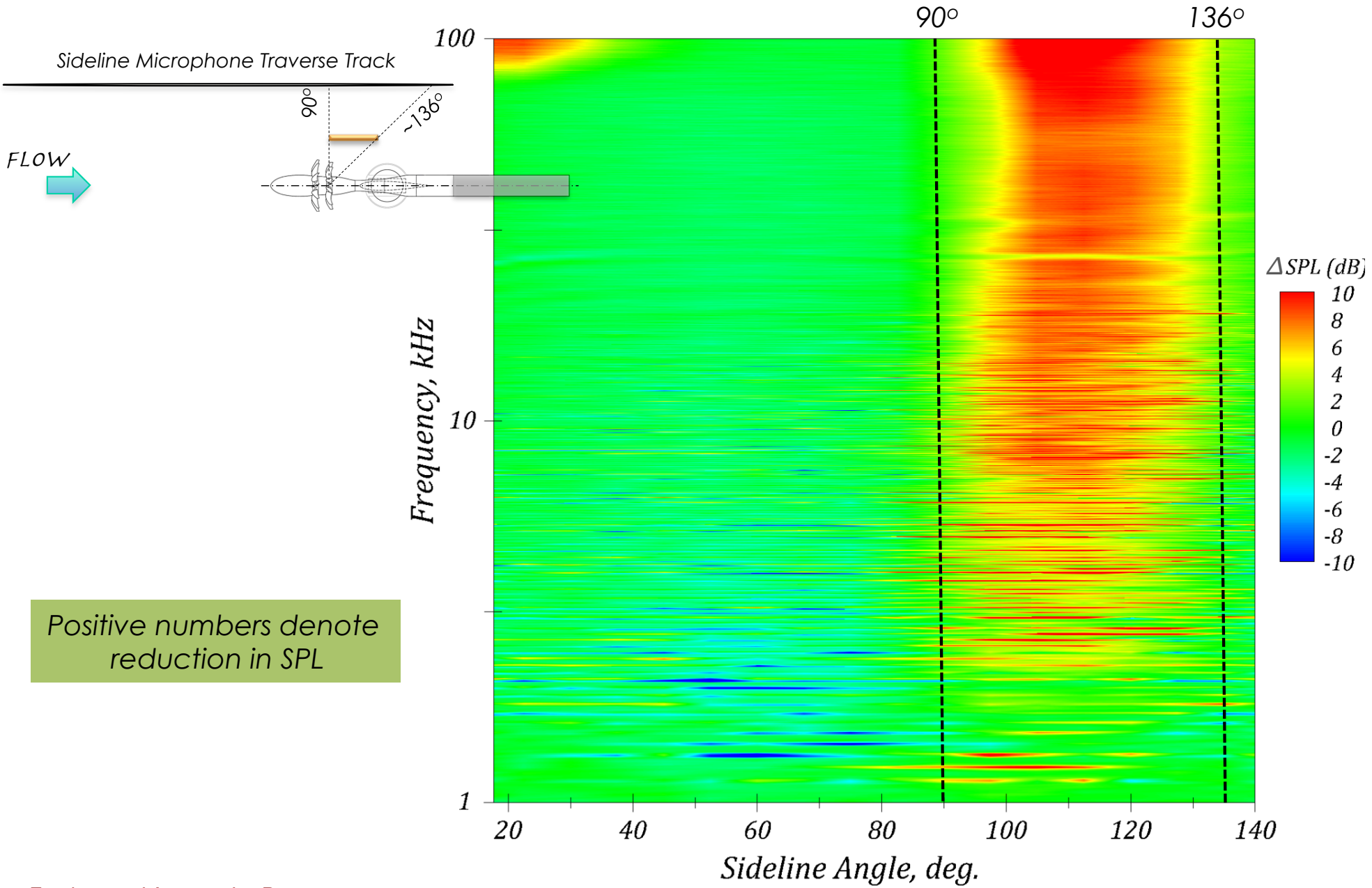
Example: Takeoff Power Condition; Insertion Loss for Short Barrier in FWD Position



Positive numbers denote reduction in SPL

Basic Shielding Experiment

Example: Takeoff Power Condition; Insertion Loss for Short Barrier in AFT Position



Positive numbers denote reduction in SPL

Current Status and Future Activities

- The low-speed wind tunnel diagnostic campaign is completed. Data from this test is being analyzed and will be reported on at various venues.

- A complementary high-speed wind tunnel diagnostics test is underway in the NASA 8' x 6' high speed wind tunnel. This activity is aimed at characterizing the aerodynamic and acoustic performance of the HISTORICAL BASELINE open rotor blade set at cruise.

Questions?