

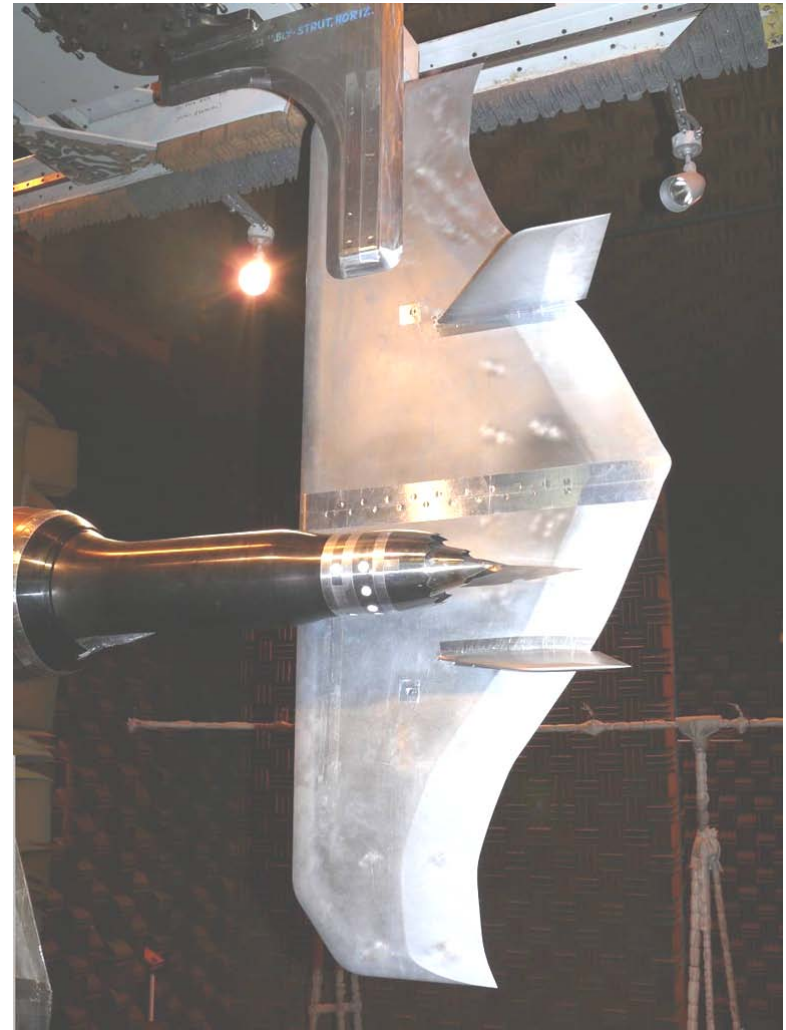
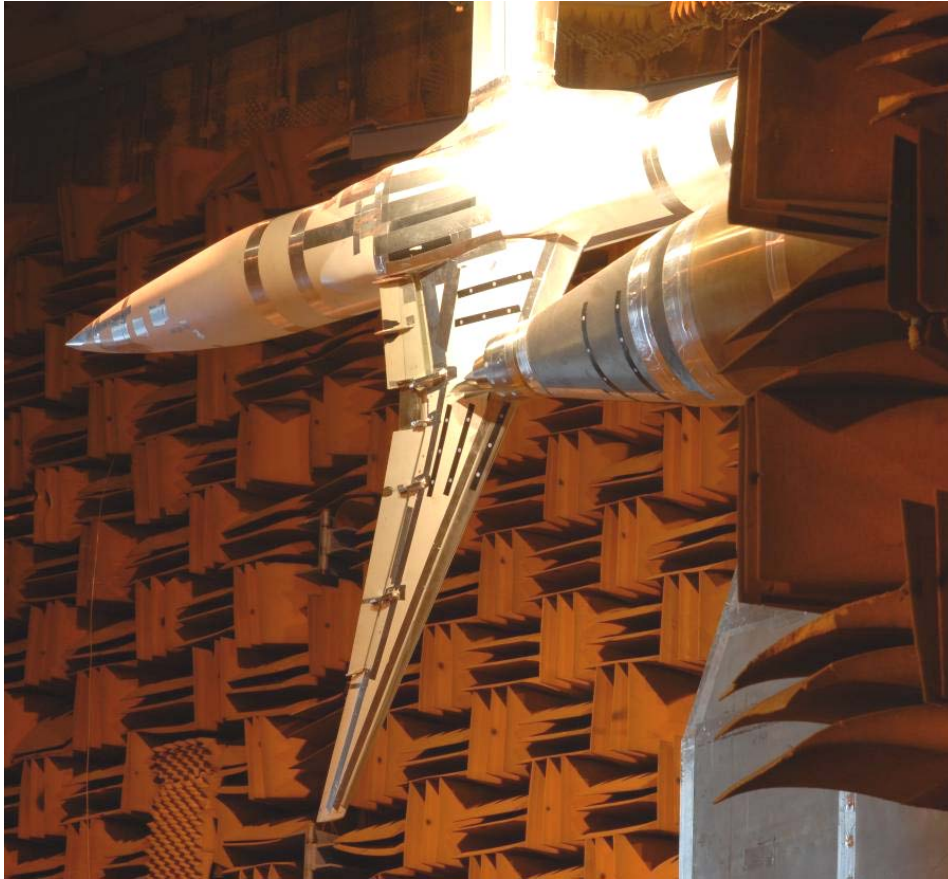
Experimental Studies of Open Rotor Installation Effects

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Russell H. Thomas, NASA**

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Acknowledgement to the Environmentally Responsible Aviation (ERA)
Project for funding this research, Dr. Fay Collier, Project Manager.

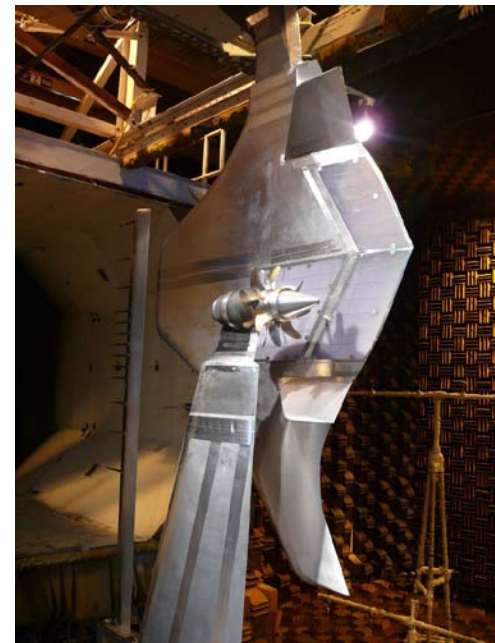
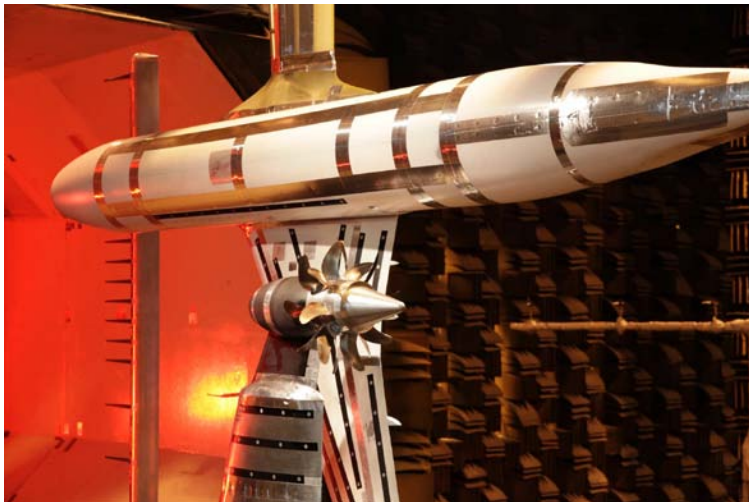
Look back at 2009



**Experimental studies of installation effects for turbo-fan engines (NASA/Boeing study)
AIAA-2010-3912: Propulsion airframe aeroacoustics effects for a hybrid wing body aircraft configuration**

Motivation

- ❑ Open rotor technology offers the promise of higher propulsive efficiency than advanced turbofans
- ❑ The challenges are numerous including high noise levels and the integration with the airframe
- ❑ Understanding open rotor propulsion airframe aeroacoustic (PAA) integration effects are a major driver in determining the potential aircraft benefits



Goals for current study

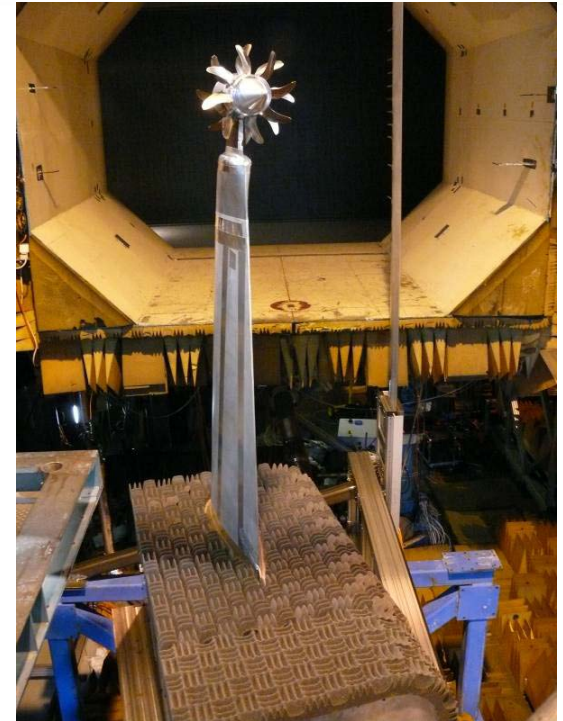
- ❑ Define open rotor noise for an isolated configuration as a reference
- ❑ Measure the PAA effects of an open rotor for two airframe configurations: conventional and unconventional (HWB)
- ❑ Develop and test technologies to exploit PAA effects of open rotors
- ❑ Acquire data for
 - ❑ Tool development and validation
 - ❑ System noise assessment

Requirements

Technical and hardware

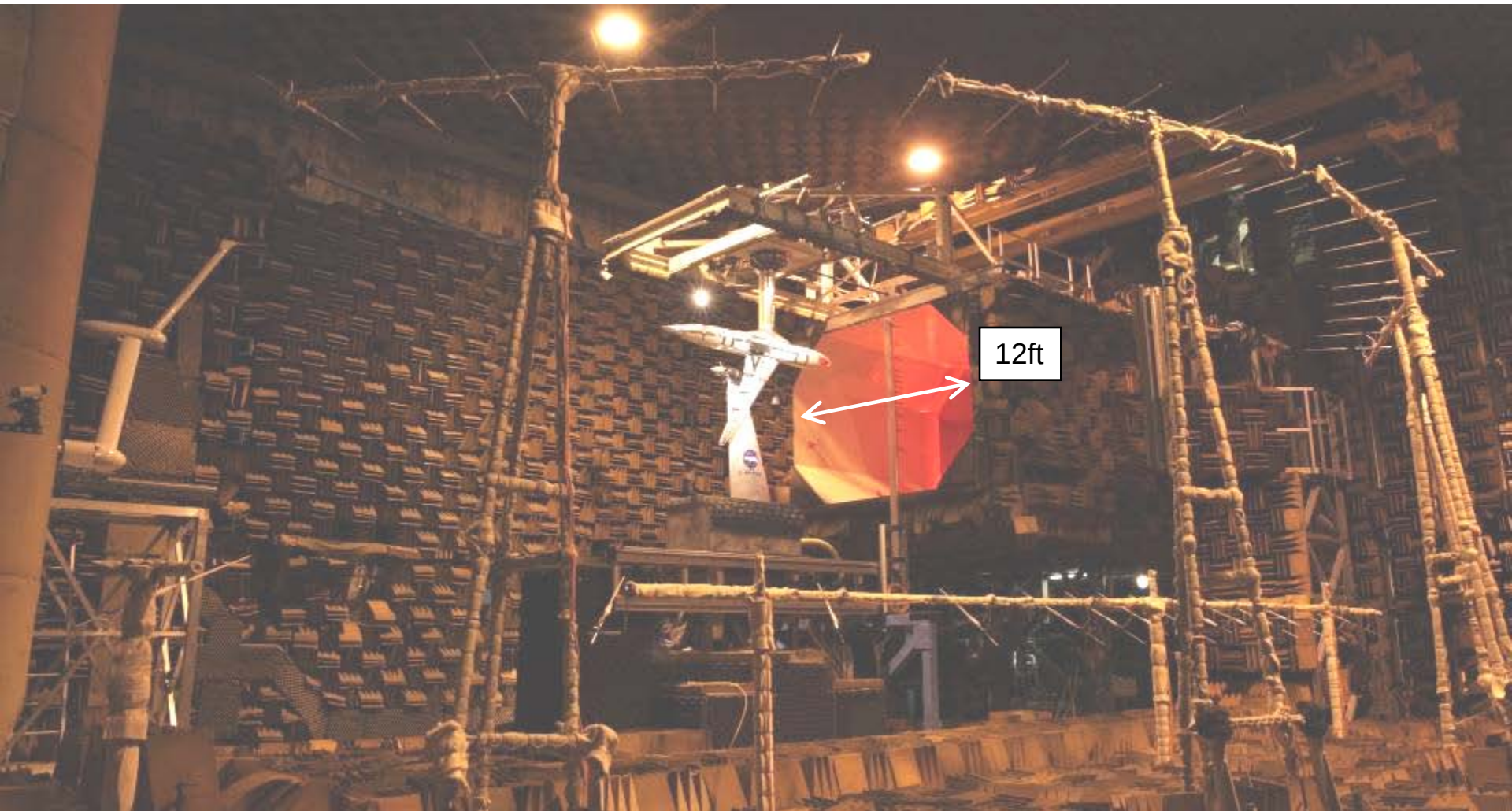
- ☐ Open rotor at an appropriate scale
 - ☐ Need flexibility
 - ☐ Need to match scale to airframes of interest
 - ☐ Availability
- ☐ Control system
- ☐ High pressure air system
- ☐ Rig support strut
- ☐ Overhead airframe traverse modifications
- ☐ New inflow microphone array
- ☐ New traverse track for QWSS flow survey system
- ☐ Airframes

Boeing 1602 Open Rotor Rig



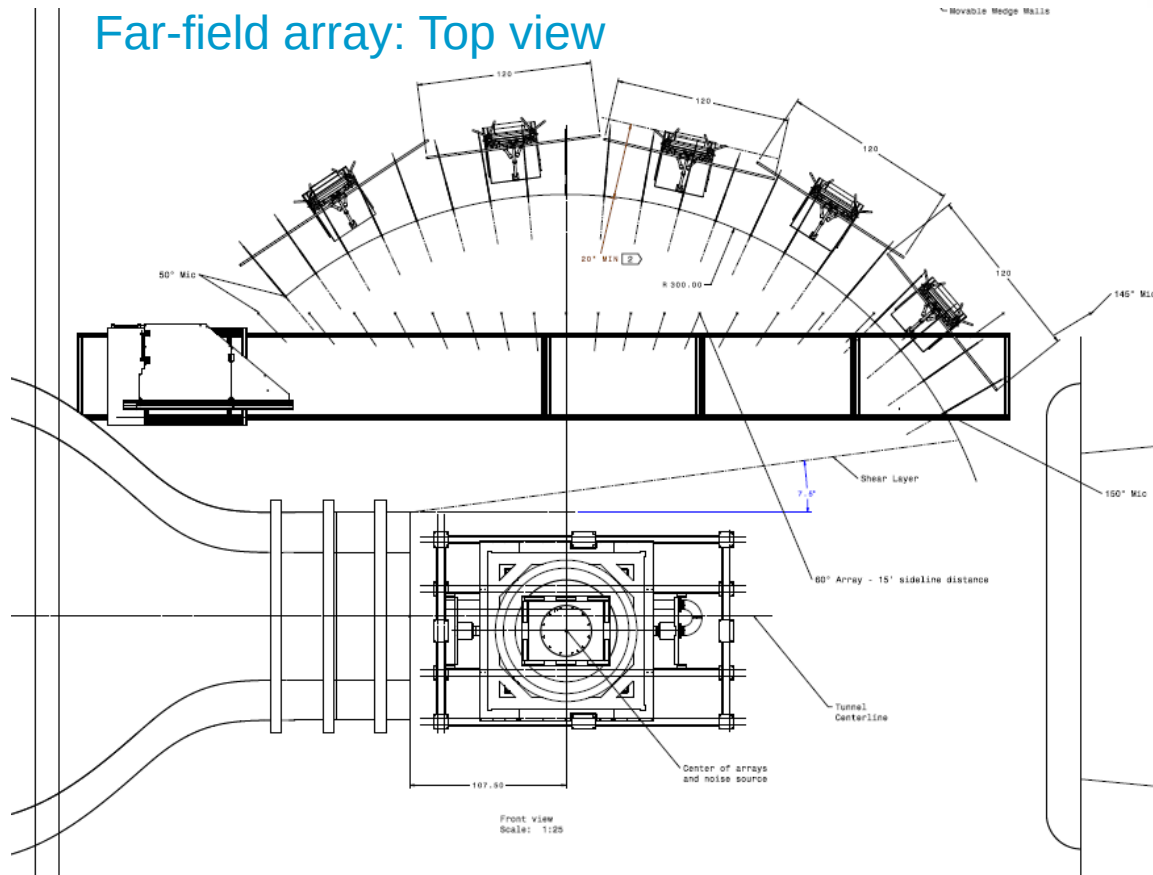
- ❑ Boeing 1602 rig
- ❑ 12 inch diameter F7A7 blades
- ❑ Pusher configuration

LSAF facility set-up



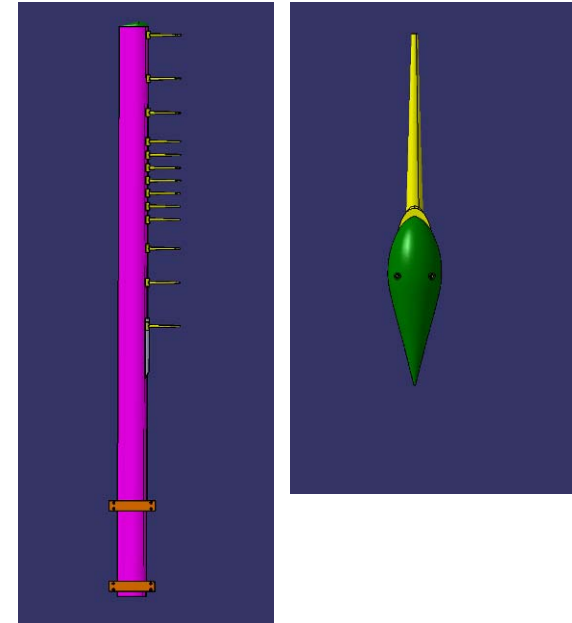
Microphone arrays

Far-field array: Top view



25 ft polar array at 90 deg azimuthal angles, 5 deg increments, 21 microphones
Sideline array at 60 deg, 14 microphones

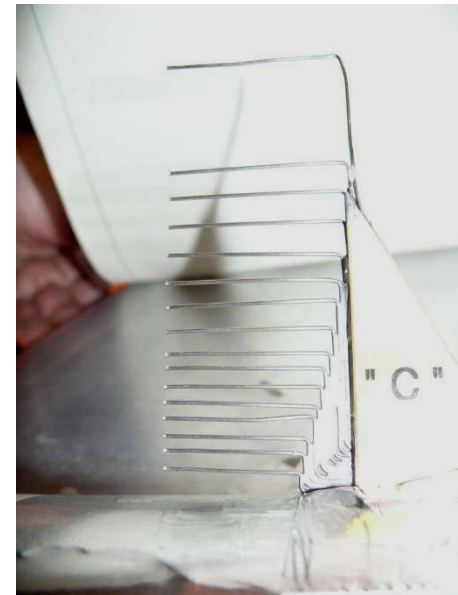
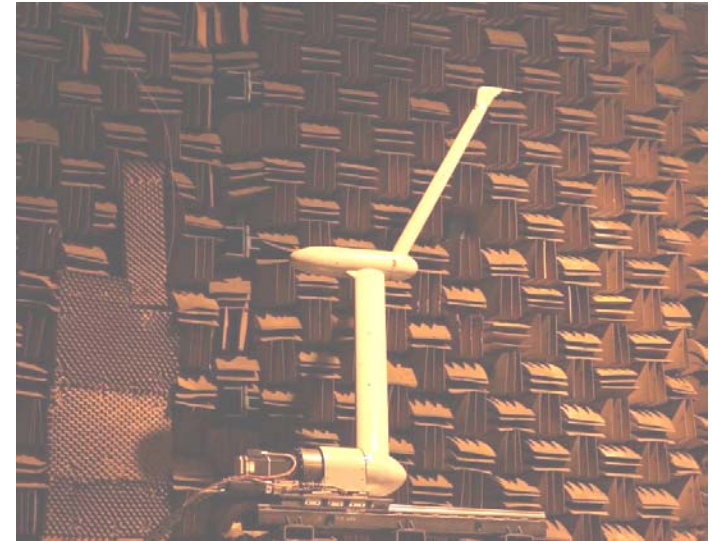
Inflow array



Inflow microphone traverse
13 microphones covering azimuthal angles from 45 to 135 degrees
36 inches from noise source
B&K $\frac{1}{4}$ inch microphones with B&K nose cones

Quantitative Wake Survey System

- ❑ Mk 17 is a two arm articulated traversing system
- ❑ 132 inch range (76 in from first arm and 56 in from second arm)
- ❑ 5 hole probe, $\frac{1}{4}$ inch diameter, closely coupled probe and transducers
- ❑ Uses interpolation to convert data from polar coordinates to a Cartesian system
- ❑ 5 inch/sec tangential speed of probe
- ❑ $\frac{1}{4}$ and $\frac{1}{8}^{\text{th}}$ inch data resolution



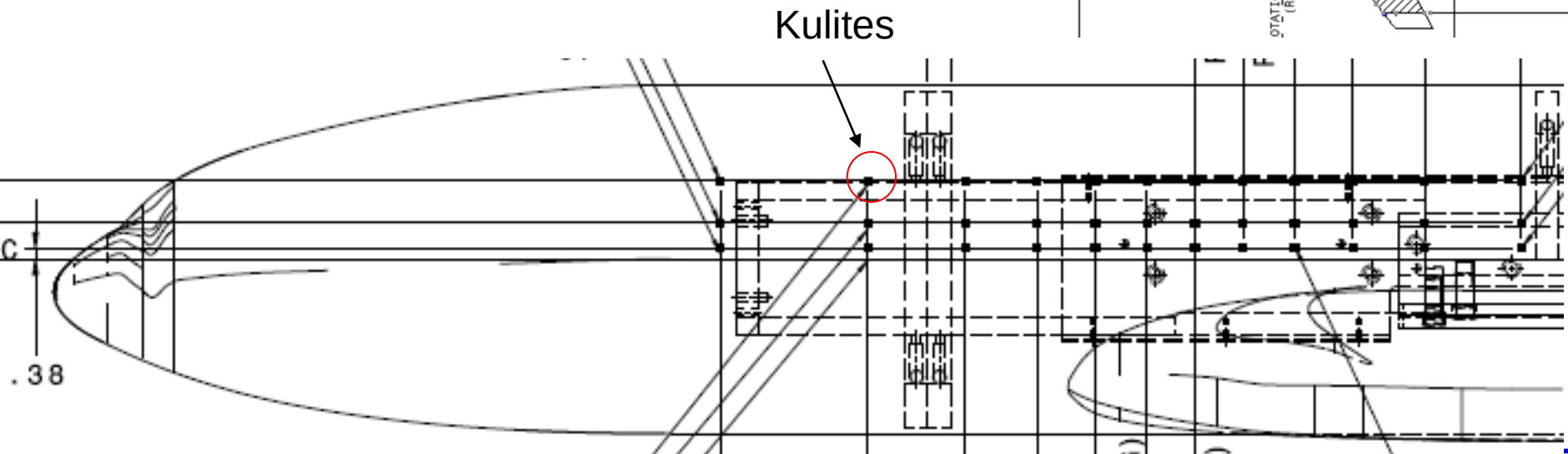
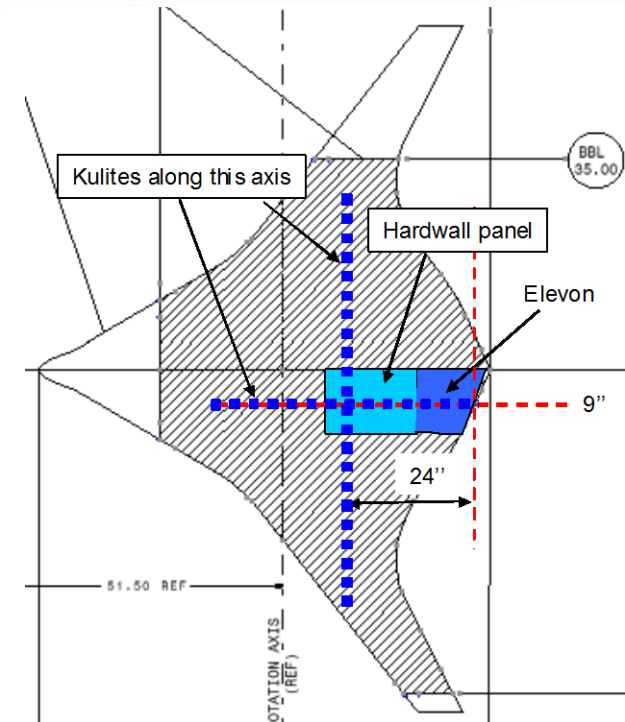
Phased array system

- ❑ Up to 416 microphones on a 9 by 11 foot panel
- ❑ Traverses the full length of the LSAF test section covering polar angles from 30 to 145 degrees
- ❑ 416 mics was used initially for diagnostic purposes
- ❑ Standard 208 mics used for majority of data sets
- ❑ Conventional beamforming was used for all of the phased array processing

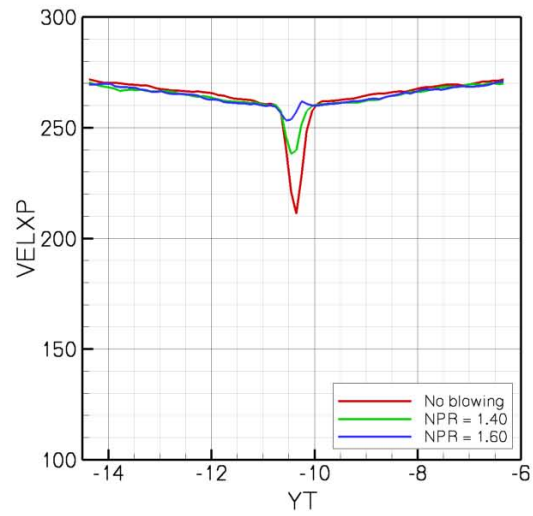
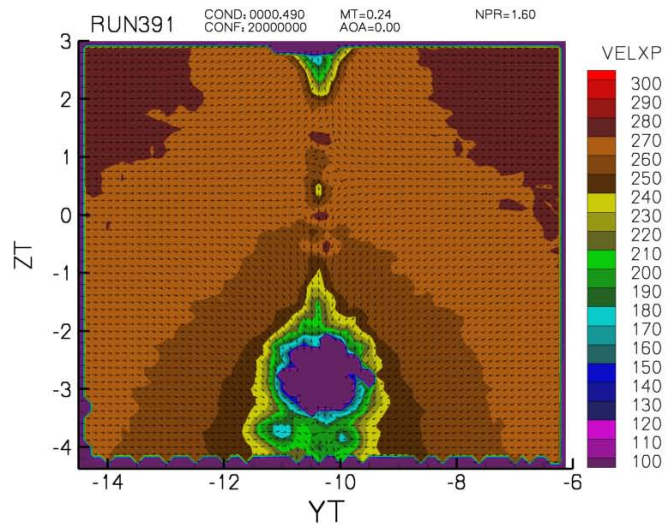
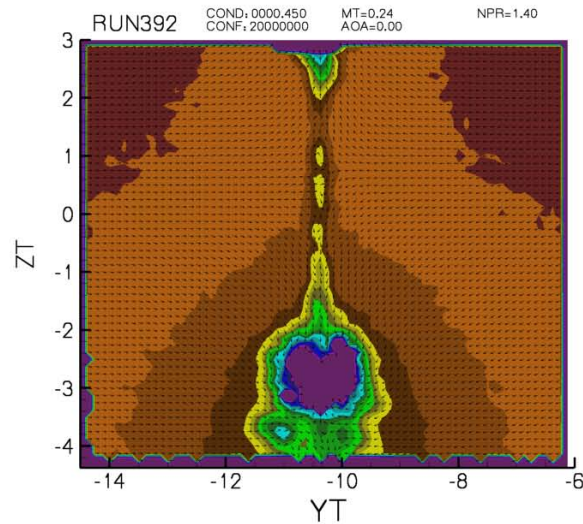
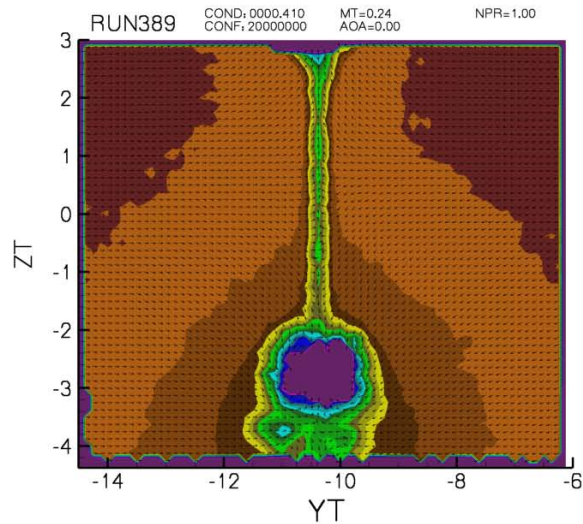


Airframe Surface Unsteady Pressure Arrays

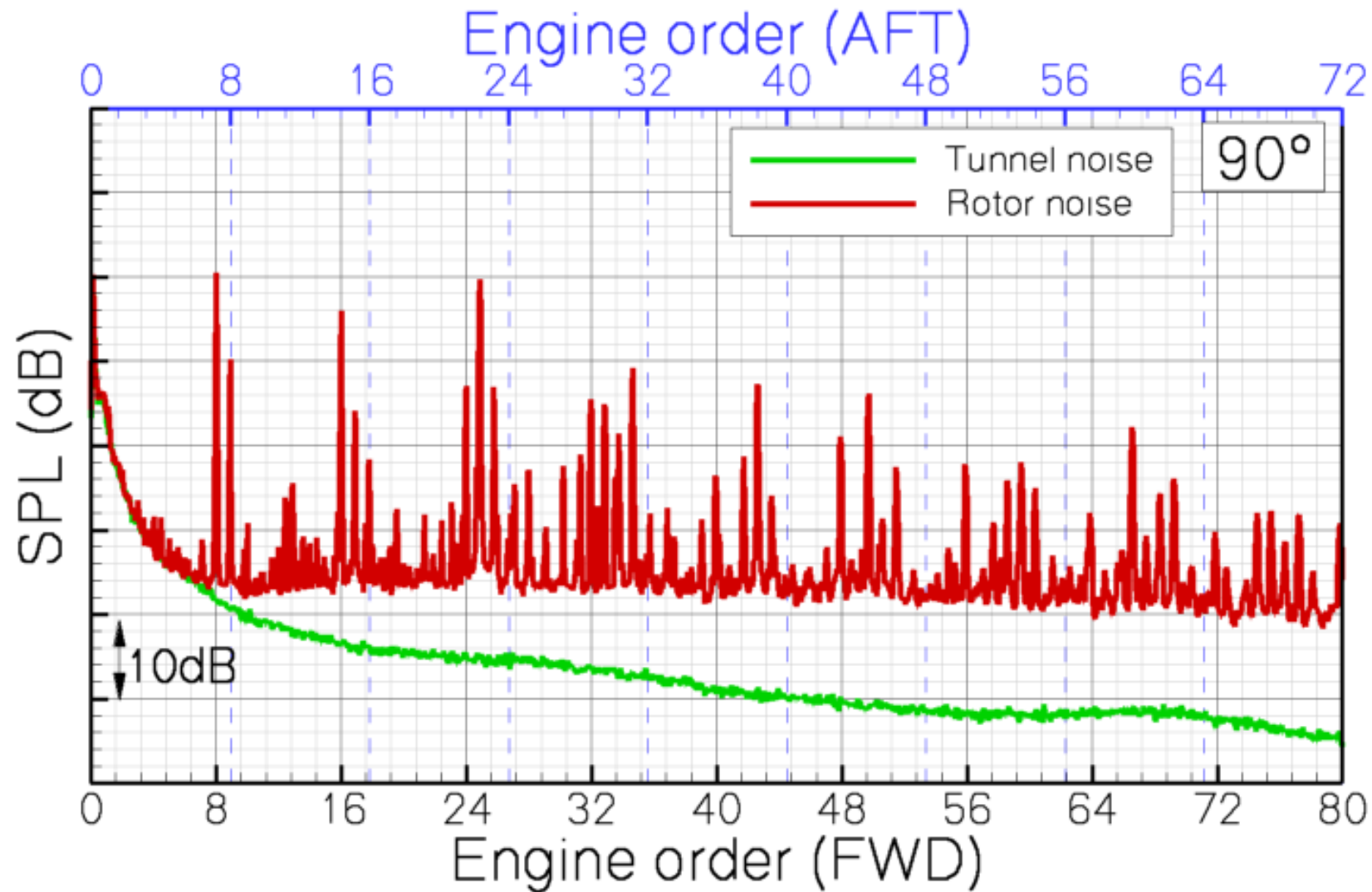
- ❑ Kulite transducers flush mounted on airframes for near field measurements
- ❑ 36 Transducers on the fuselage of the tube-and-wing forward of the main wing
- ❑ 34 Transducers in a cross pattern on the HWB planform body



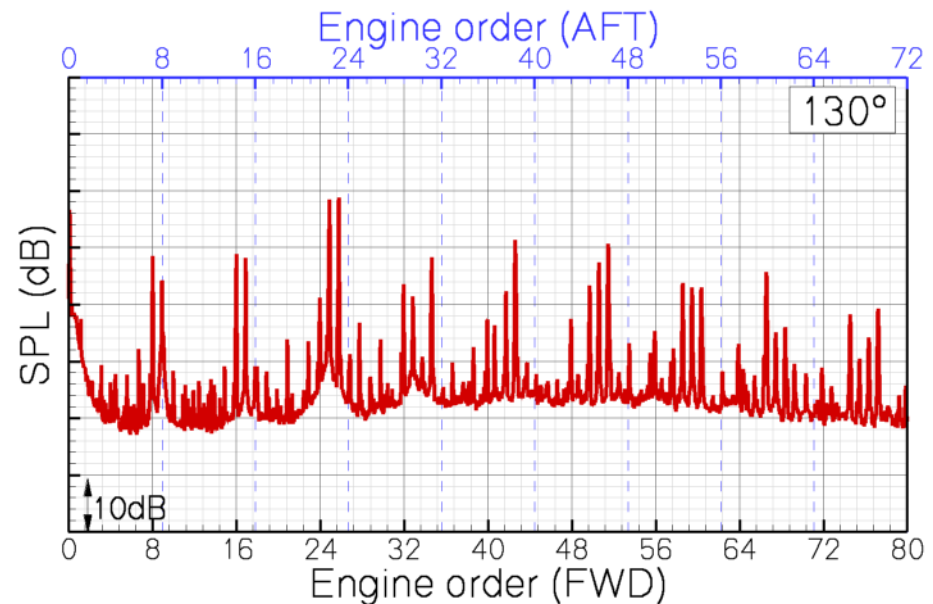
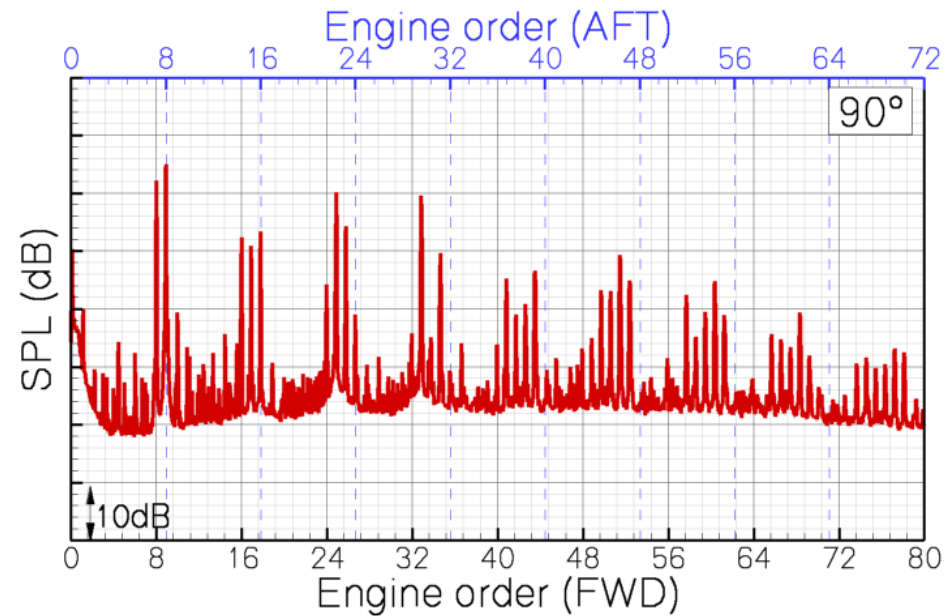
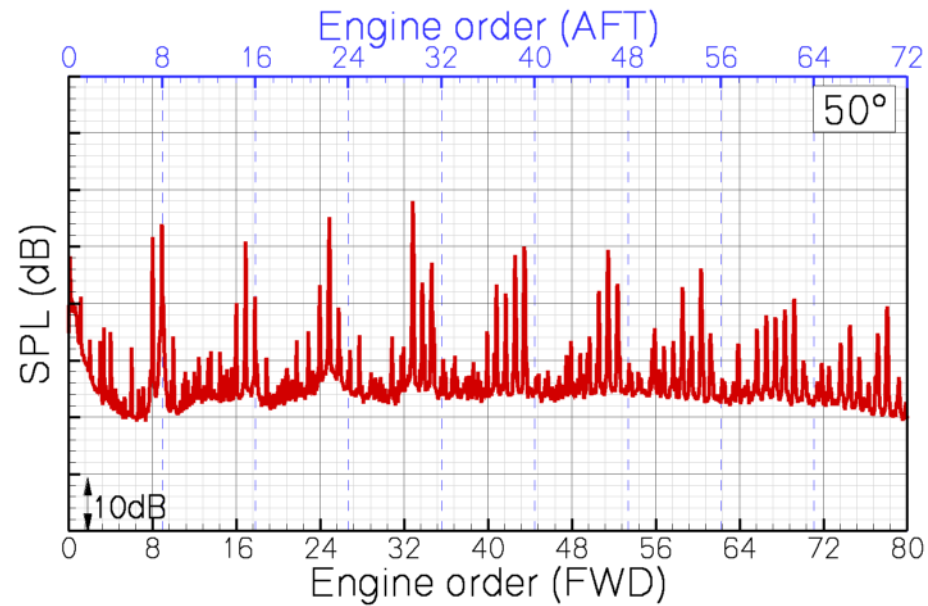
QWSS surveys of pylon wake / pylon blowing



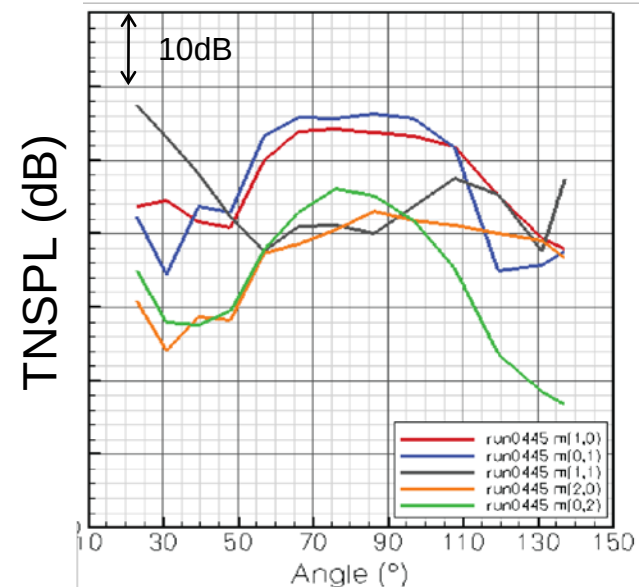
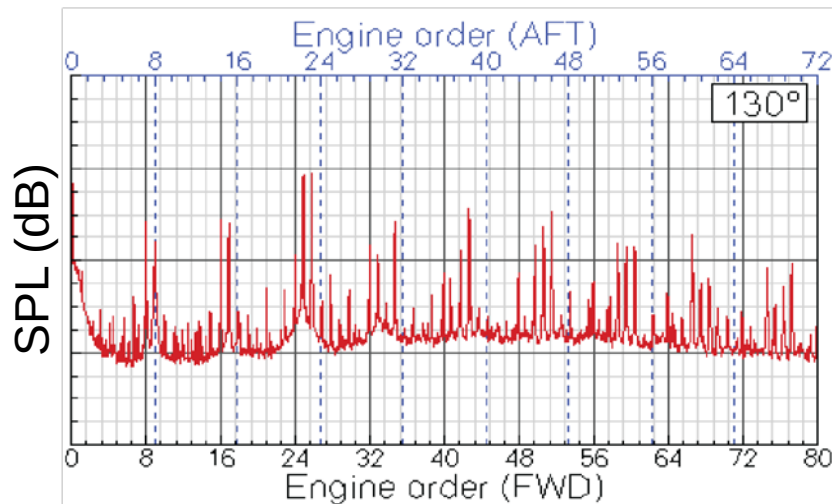
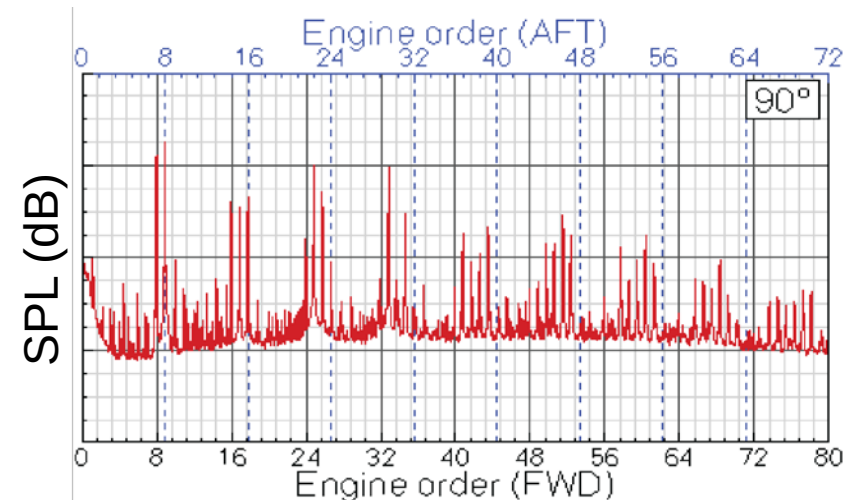
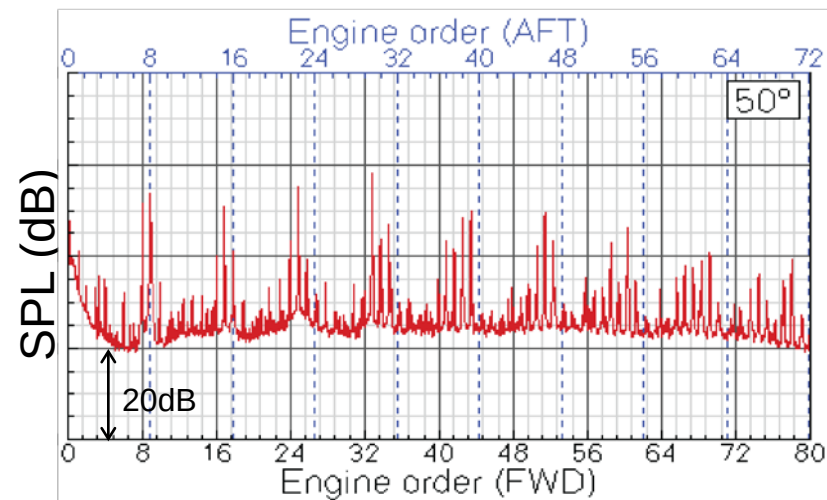
Rotor noise comparison to tunnel background



Open rotor spectral variation with polar angle

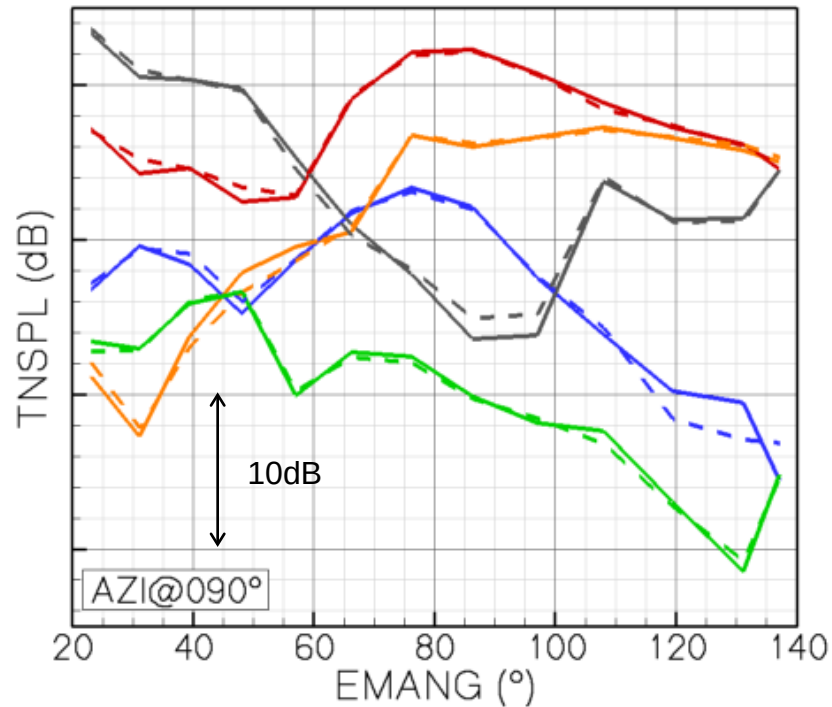


Isolated spectra at high power

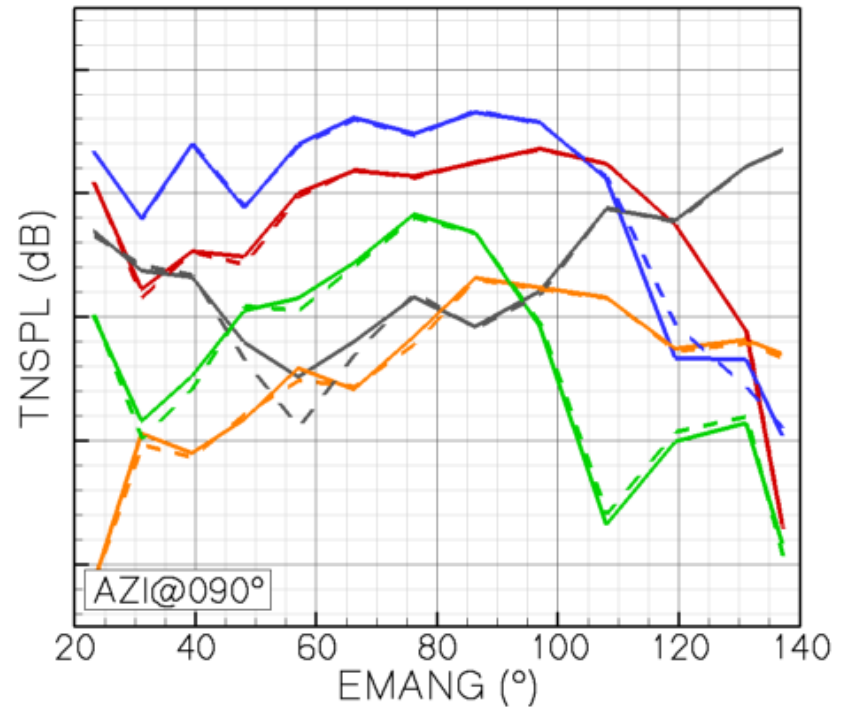


Repeatability at low and high power first five modes

Low power



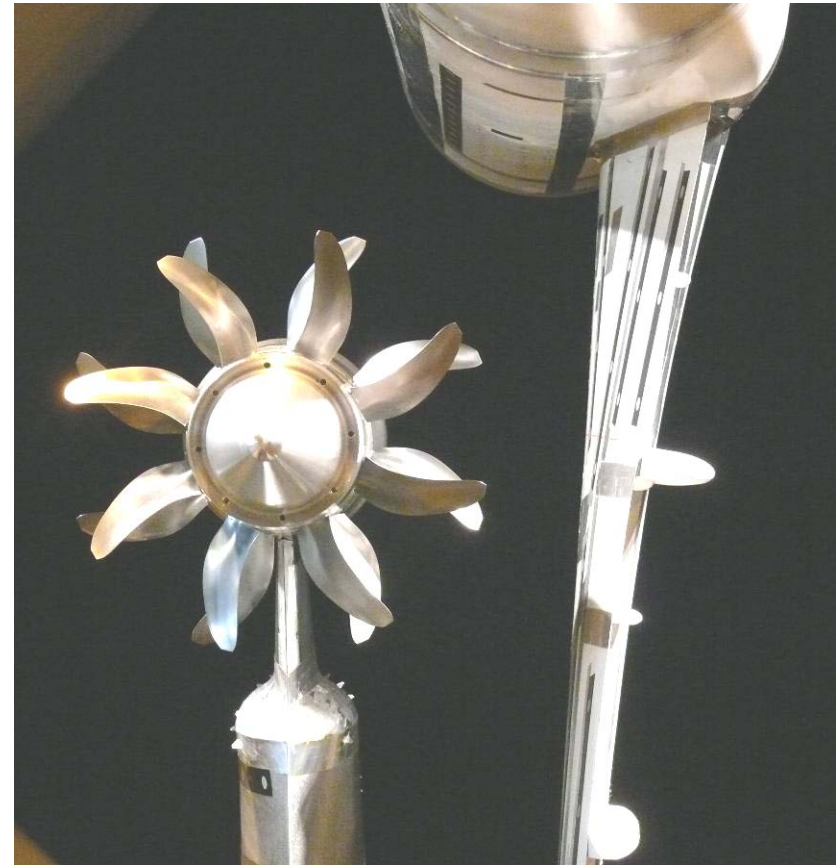
High power



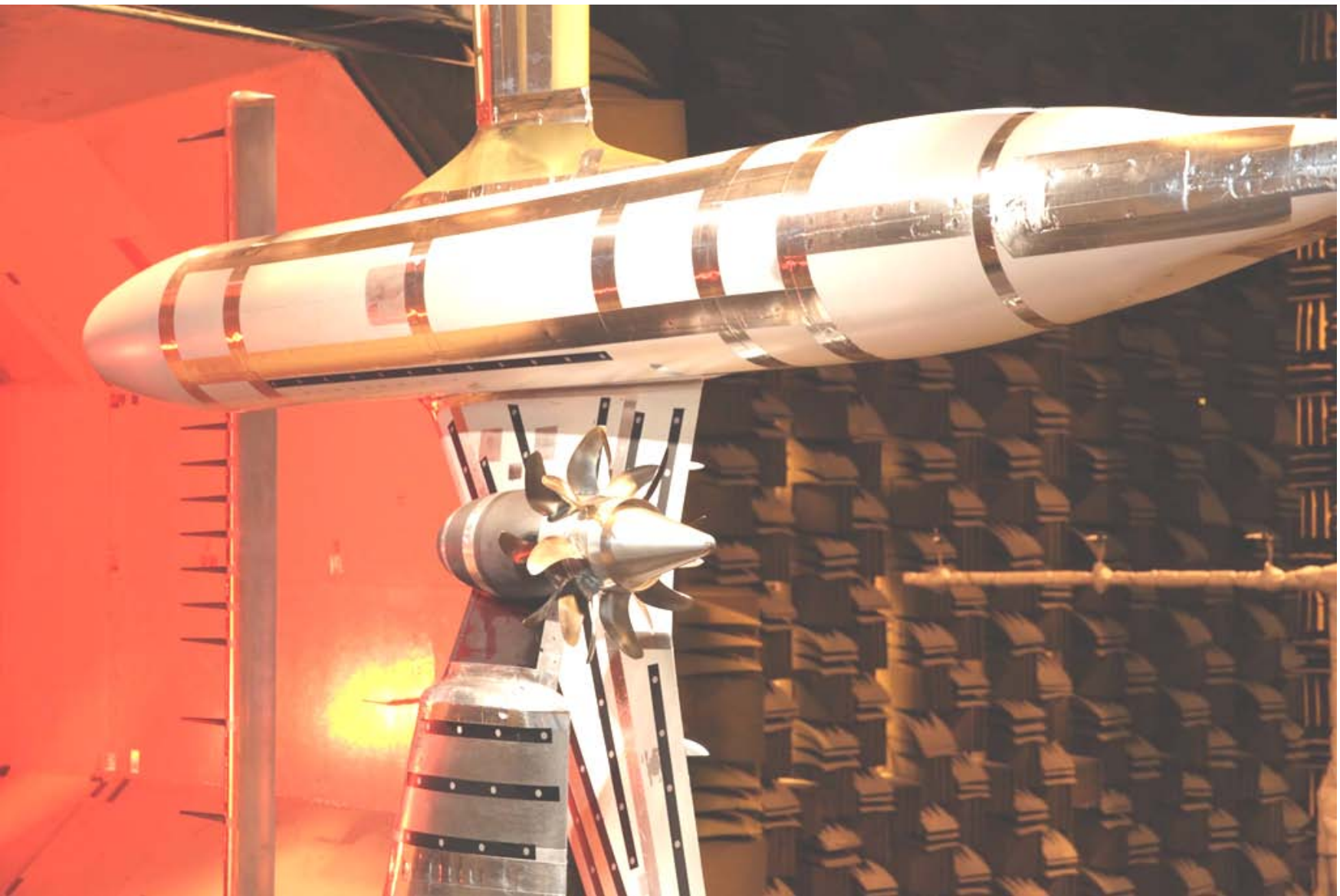
Tube and Wing Airframe

- ❑ 777 model chosen as technology platform representing an 8% scale single aisle sized full scale airframe
- ❑ U-tail and a T-tail variations
- ❑ Angle of attack of 0, 7, and 10 degrees
- ❑ Flaps 1 (cruise) and Flaps 30 (approach)
- ❑ Fuselage boundary layer thickness increased with roughness and effects measured

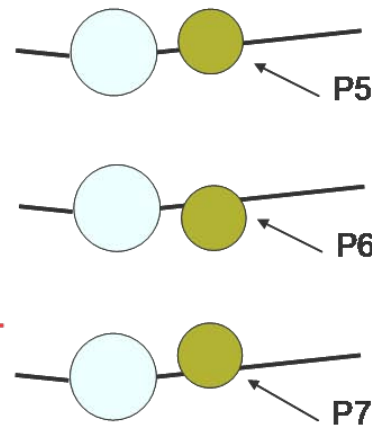
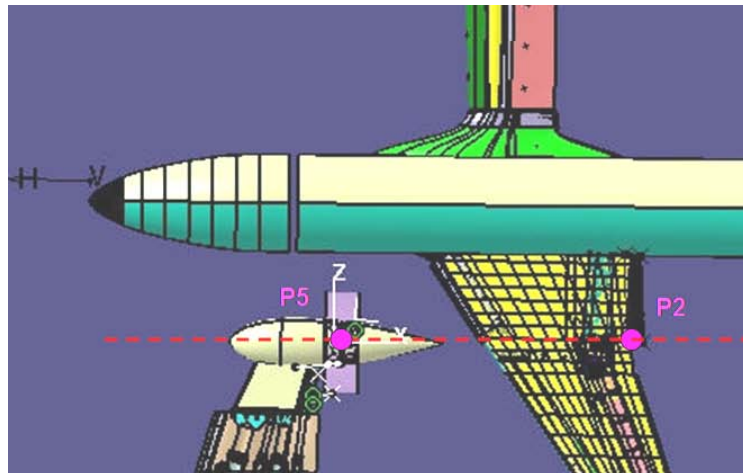
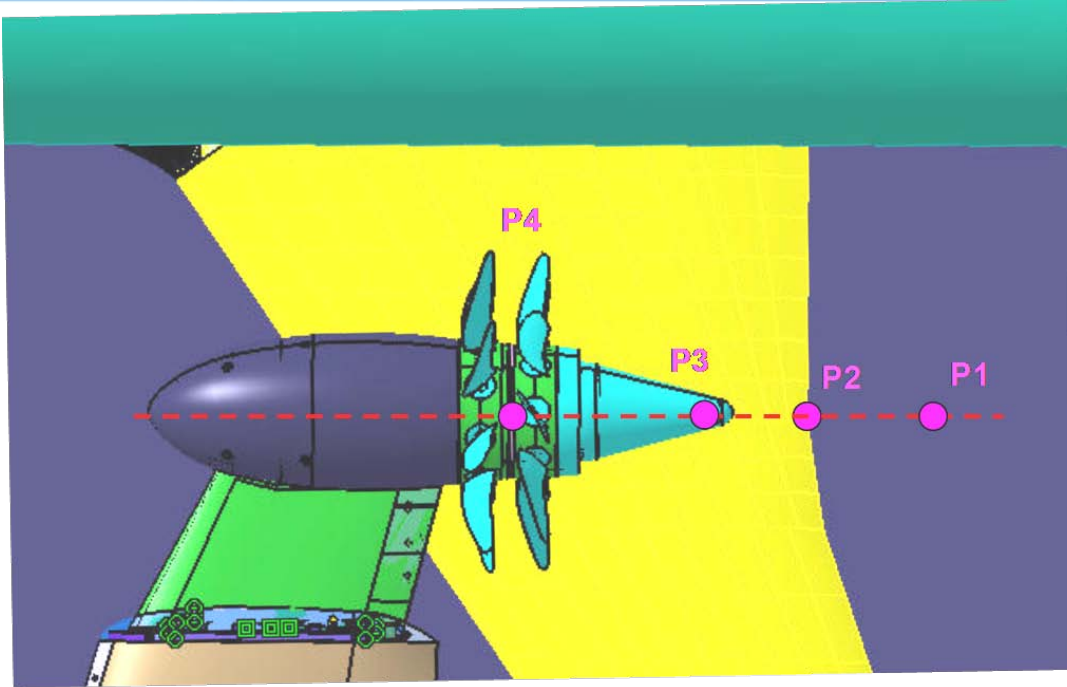
Wing configurations (I)



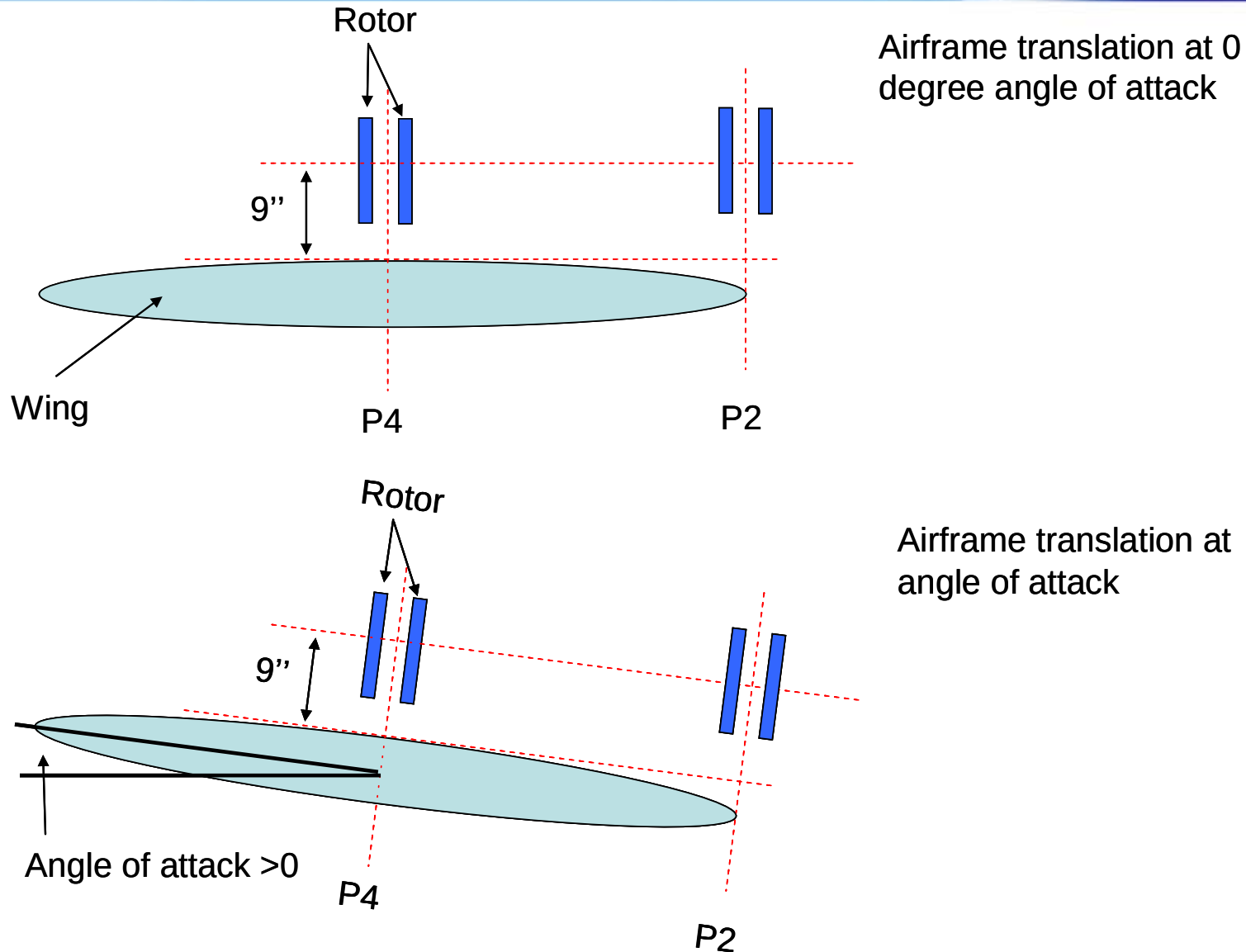
Wing configurations (II)



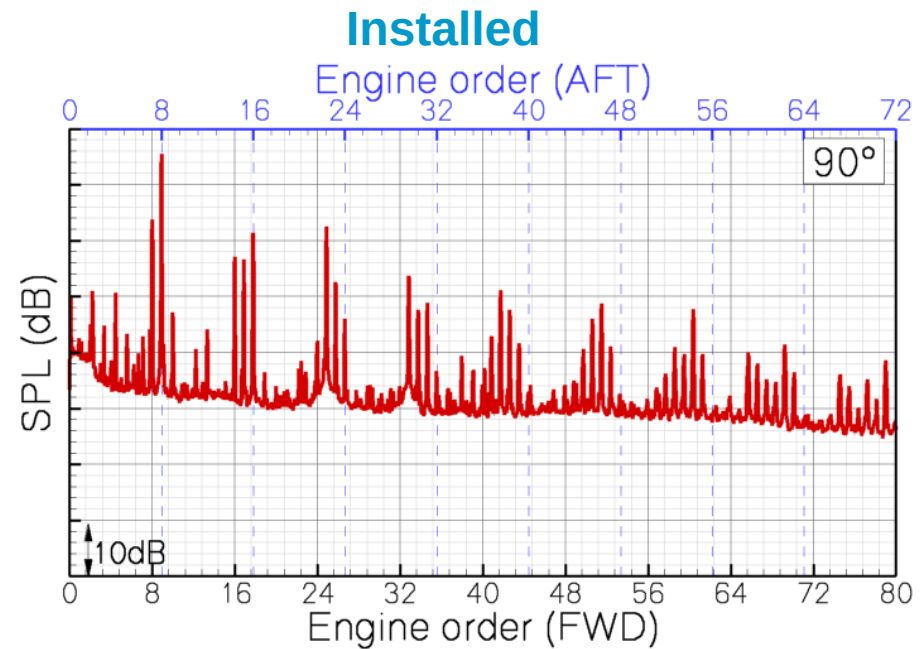
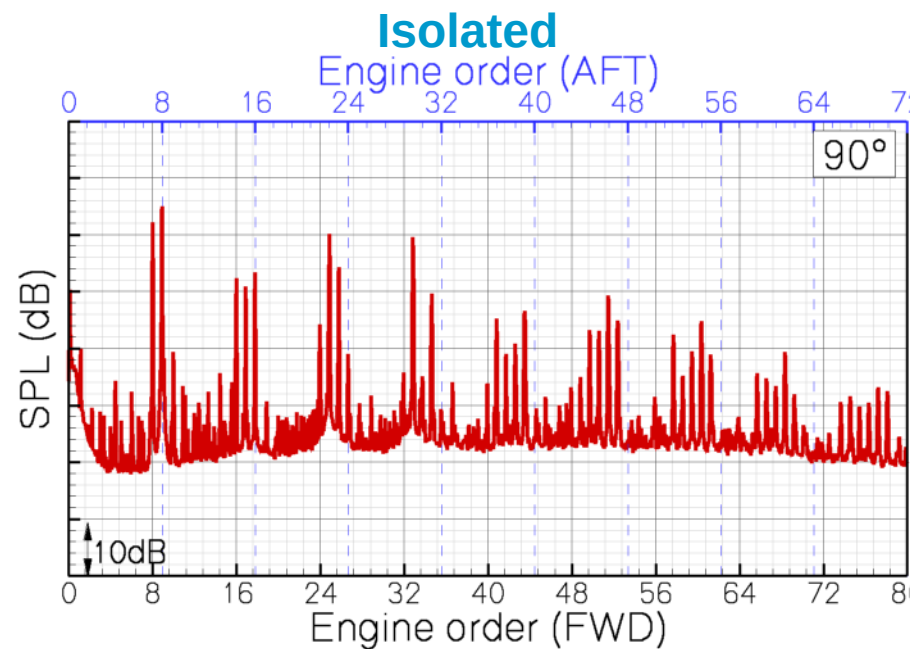
Rotor-wing positions



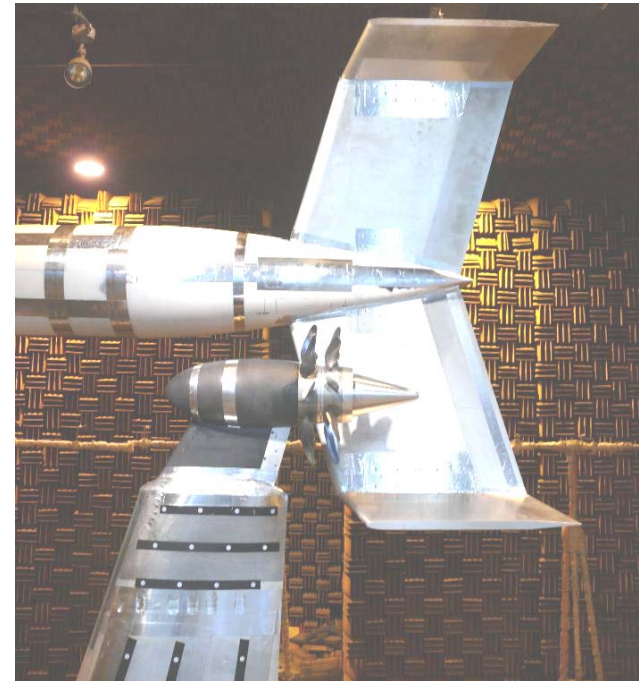
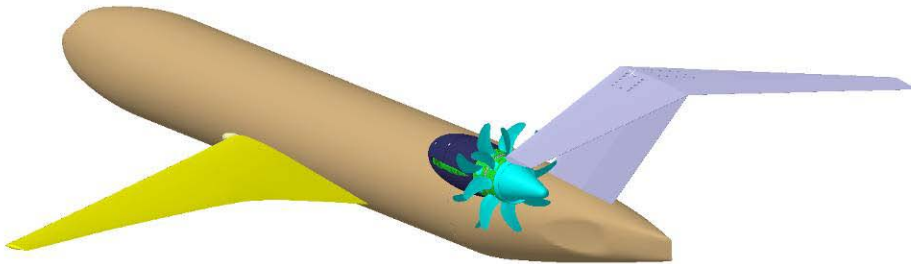
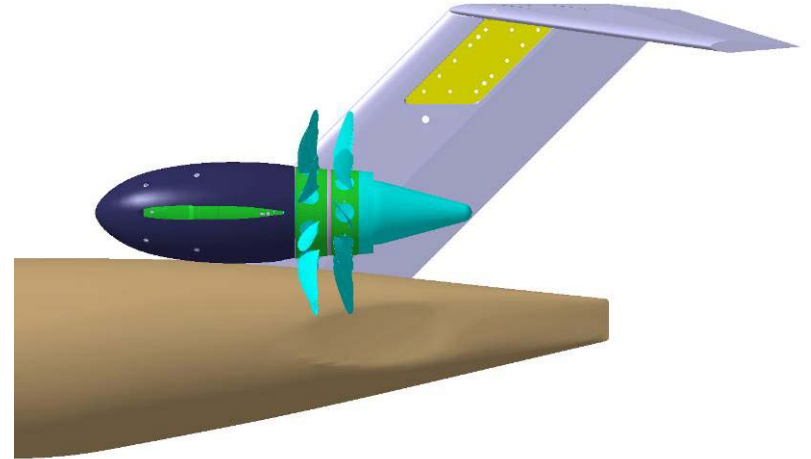
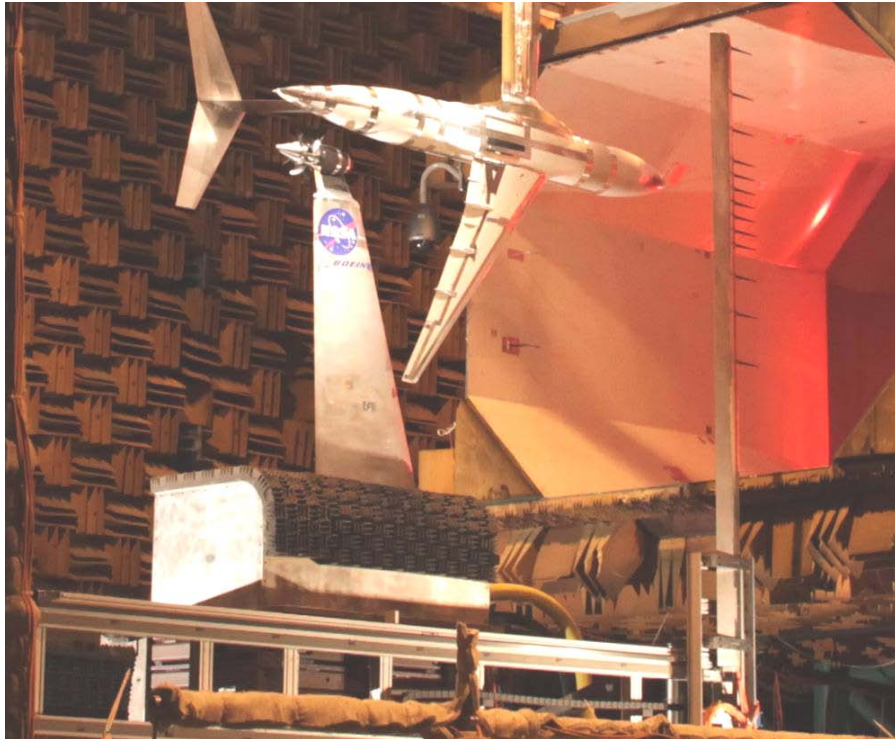
Rotor positions at different angles of attack



Installation effects forward of the wing

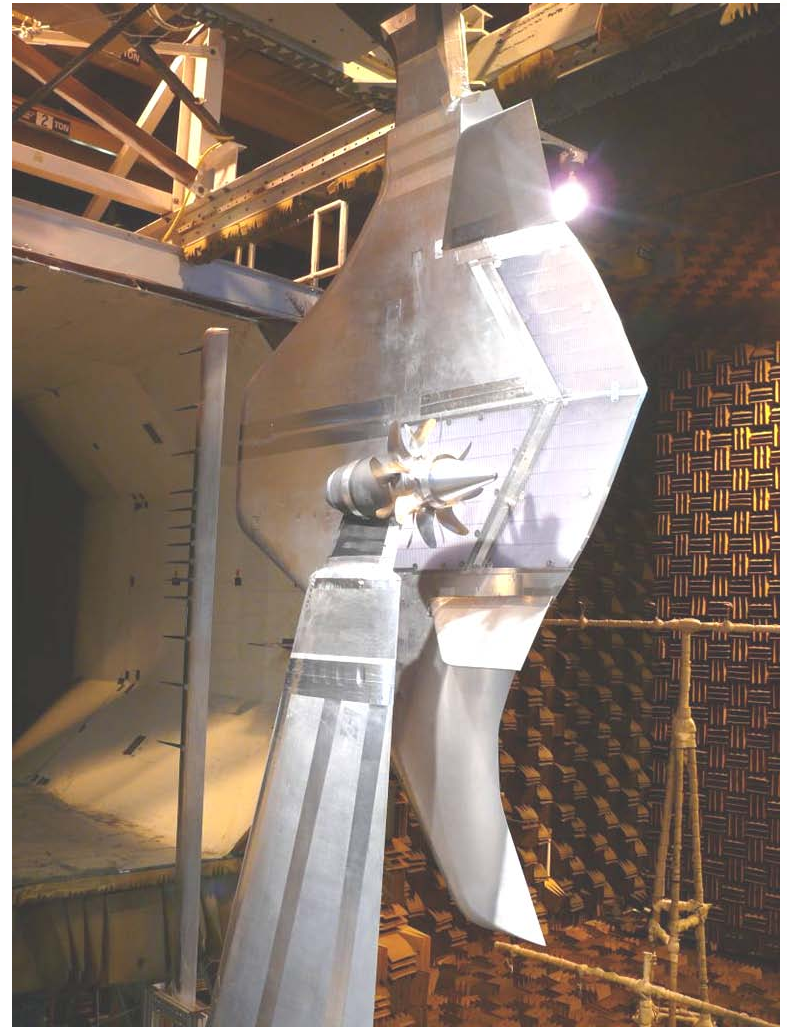


Airframe with T-tail and U-tail

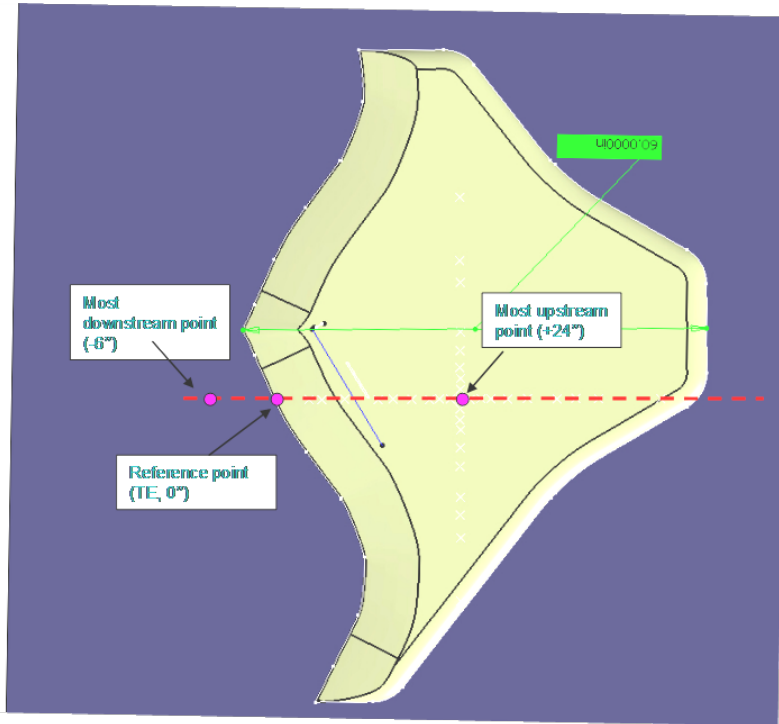


HWB Planform Airframe

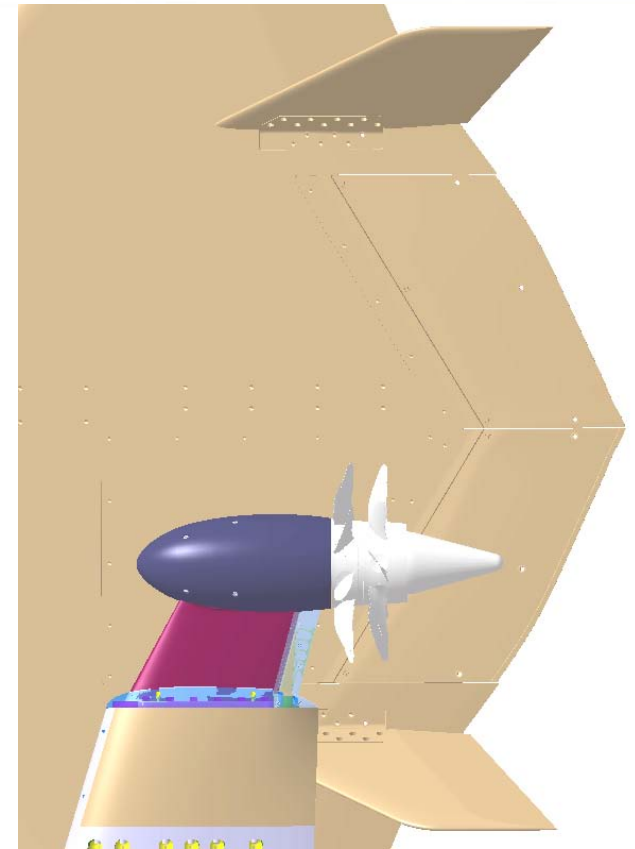
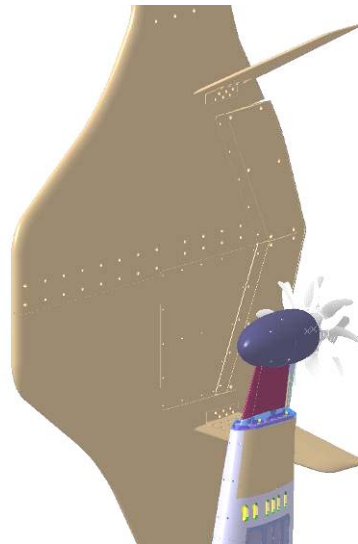
- ❑ Model made to 4% of full scale or 8% of a half-size demonstrator airframe
- ❑ Model derived from BWB 450
- ❑ Wing tips are clipped to fit model into tunnel
- ❑ NACA leading and trailing edges
- ❑ Pockets in the wing and elevons for instrumentation and lining
- ❑ Inboard verticals (two sizes and two cant angles)
- ❑ Elevons angles of 0, -5 (up) and +5 (down)
- ❑ Boundary layer thickness effect measured



HWB Rotor Positions

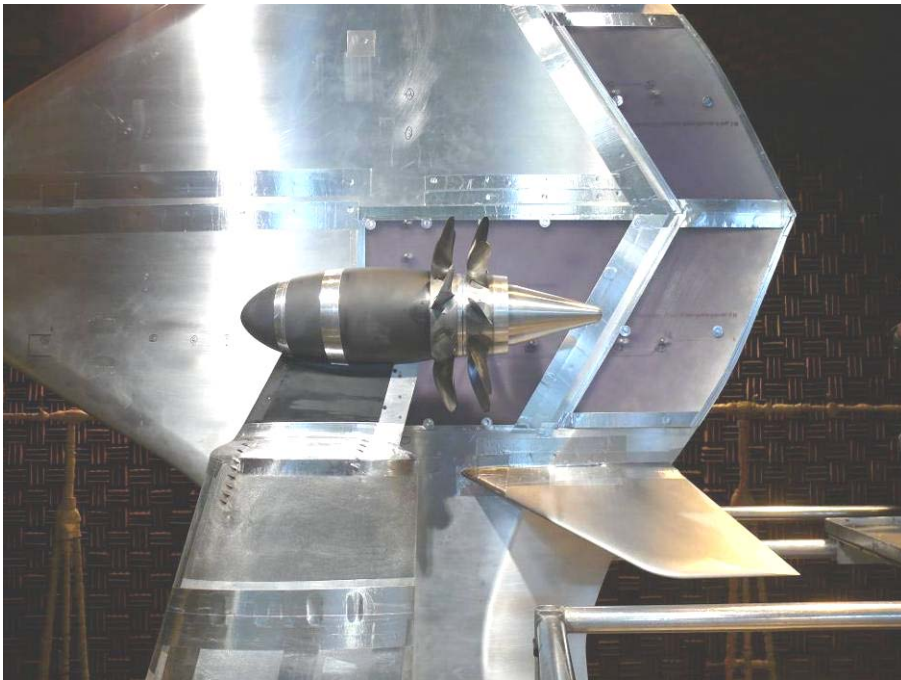


Name	Pos [in]	Vert. Pos [in]
B1	-6	3
B2	-3	3
B3	0	3
B4	3	3
B5	6	3
B6	9	3
B7	12	3
B8	15	3
B9	18	3
B10	21	3
B11	24	3

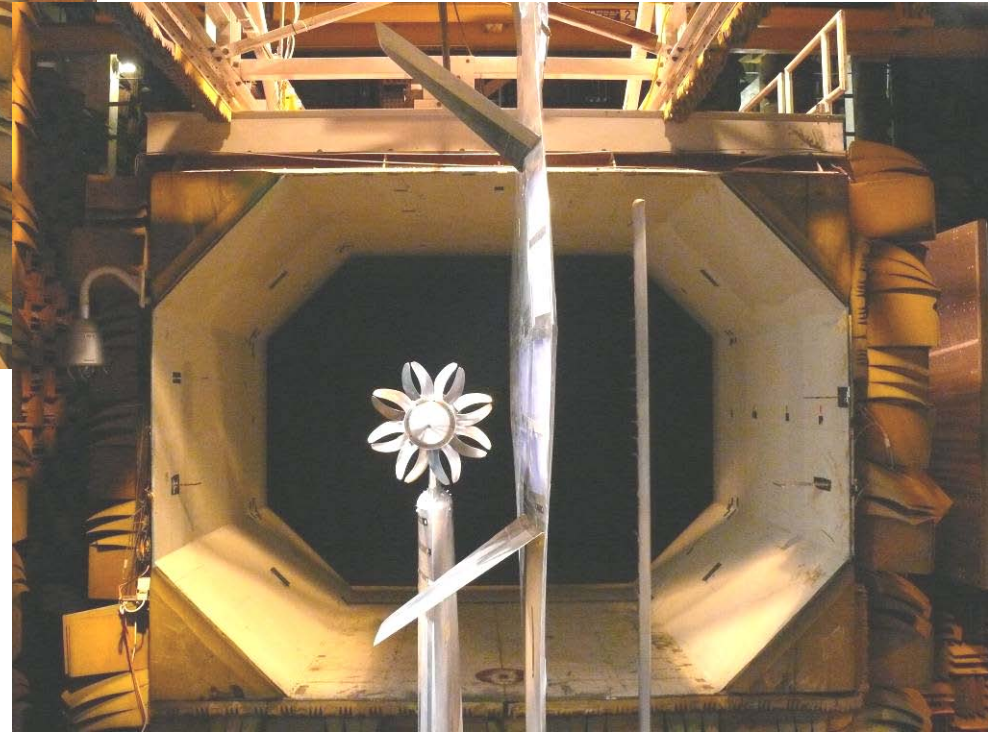
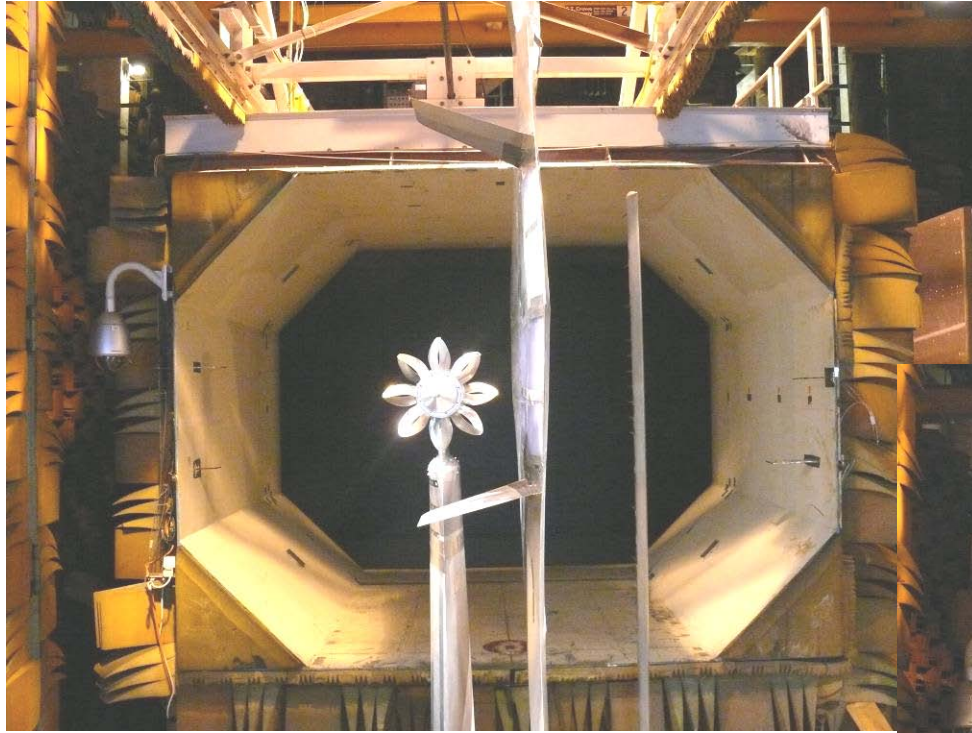


BWB lining technology

- ❑ Airframe acoustic liner designs supplied by NASA
 - ❑ Provisional Patent filed
- ❑ Three types of designs targeted for BPF and 2BPF frequency range
- ❑ Separate wing and elevon liners

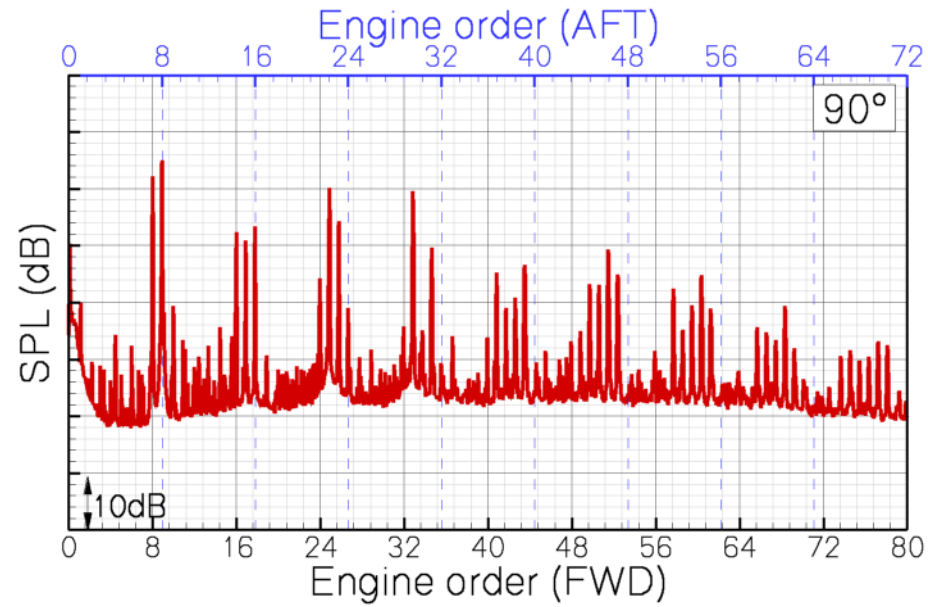


BWB Verticals

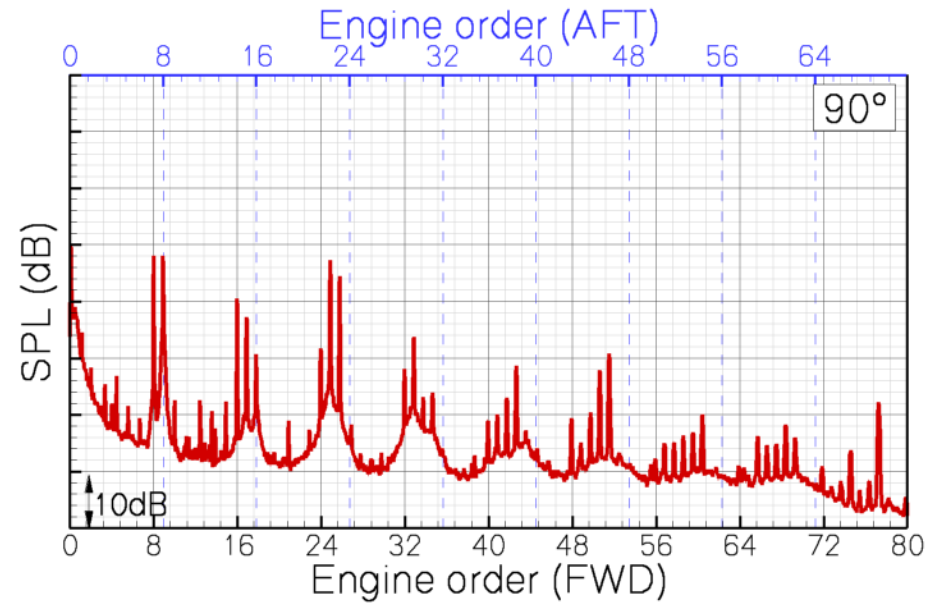


PAA effects for the BWB at 1D

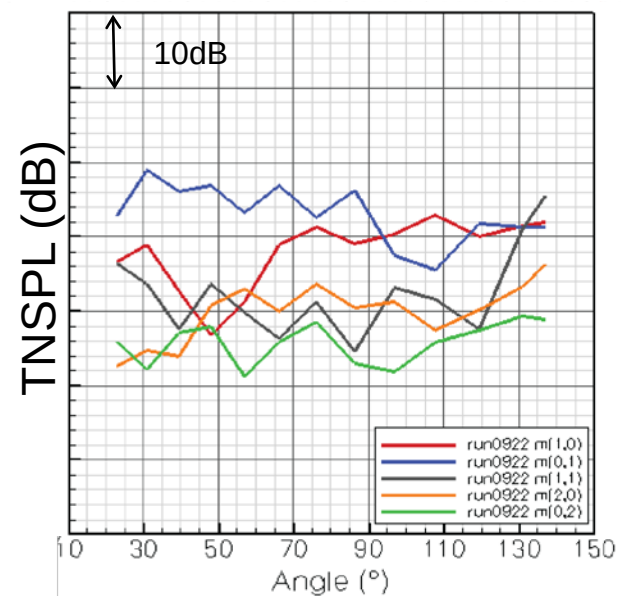
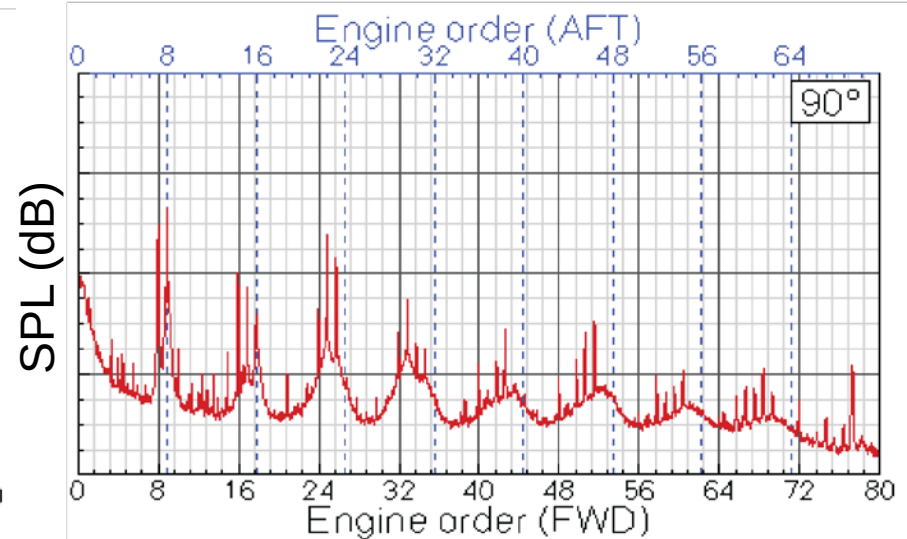
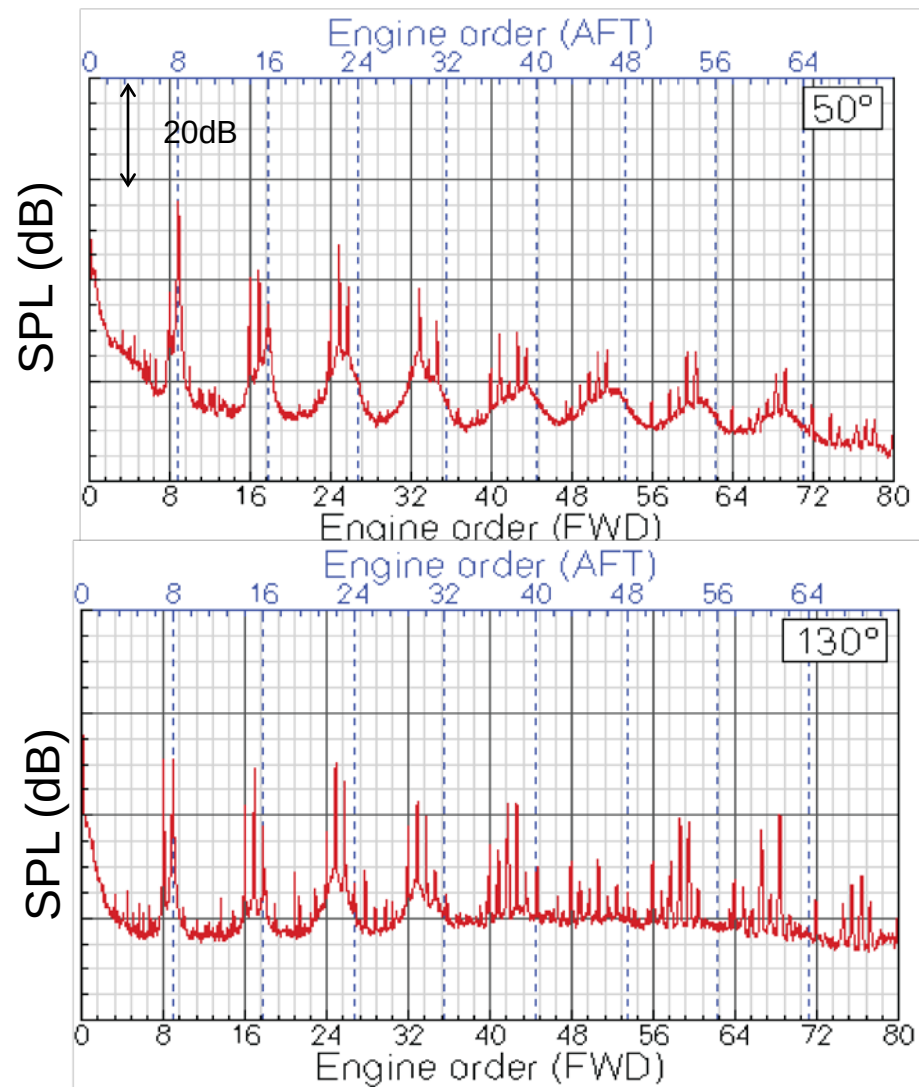
Isolated



Installed

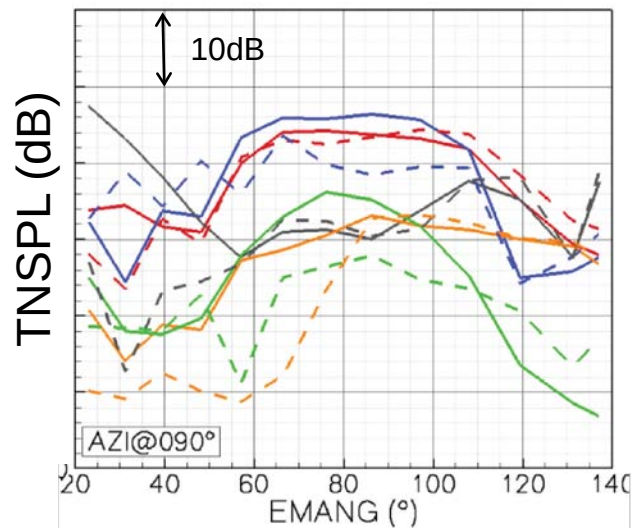


Open rotor shielding for the BWB at 1D

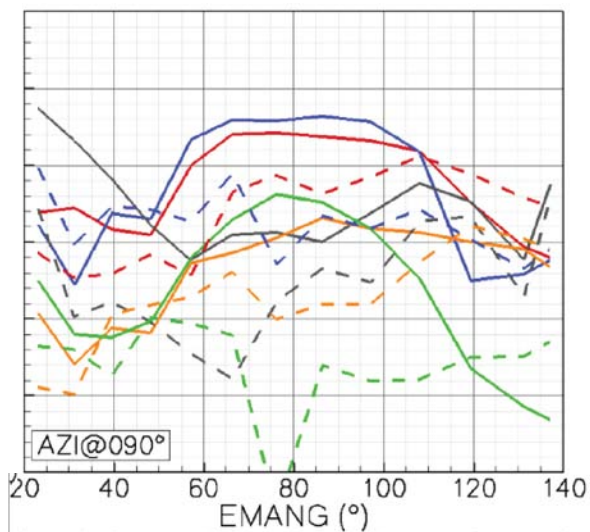


PAA effects – Peak modes

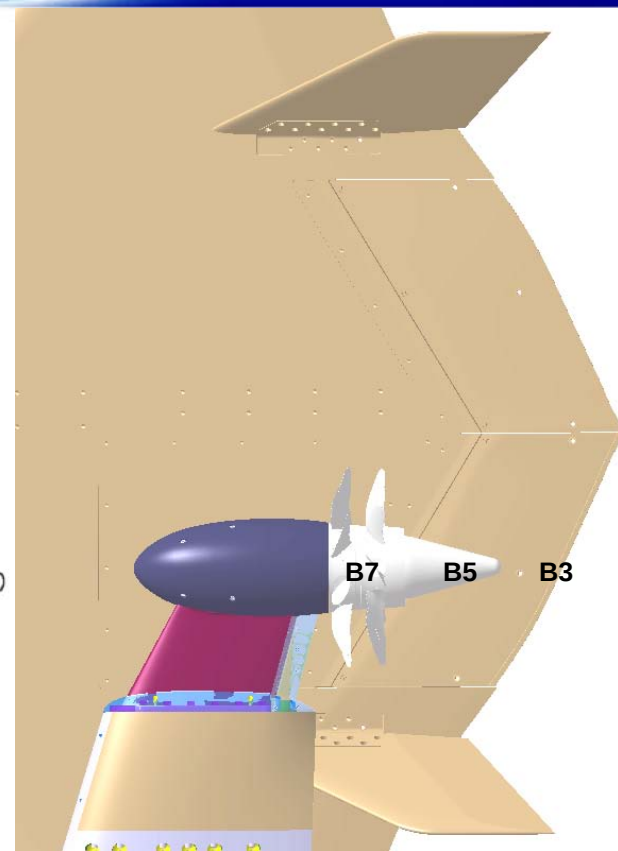
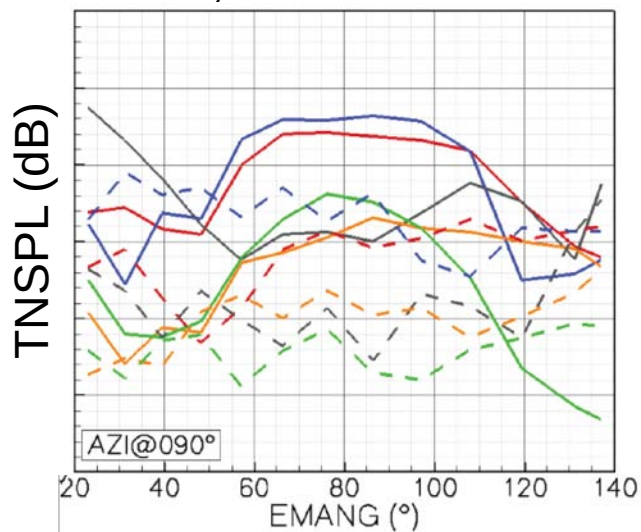
B3, Rotor at 0D



B5, Rotor at 0.5D

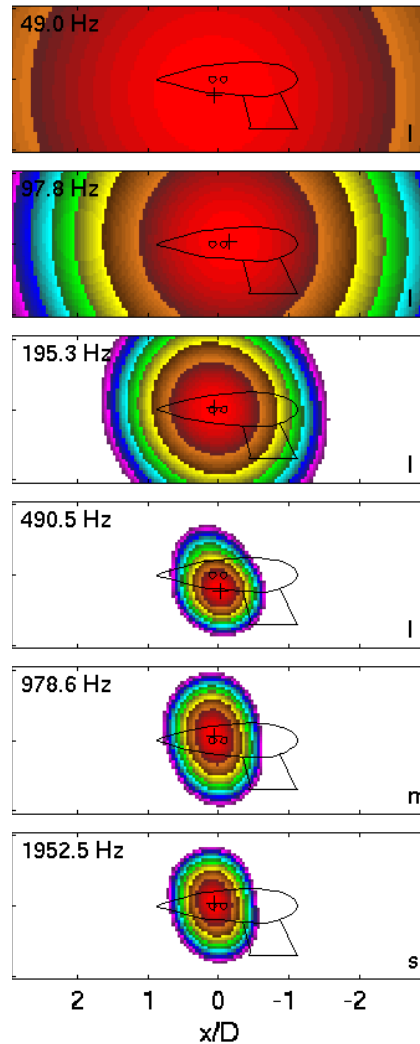


B7, Rotor at 1D

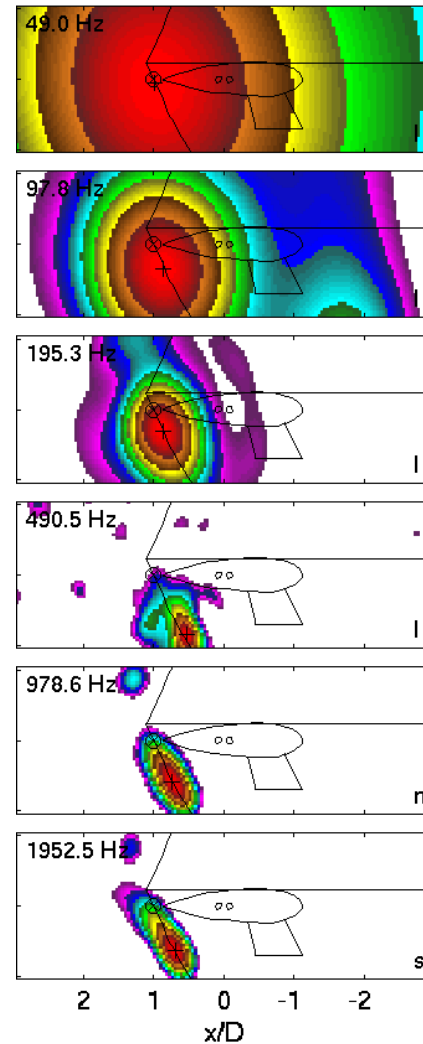


Phased array images for an isolated and installed configuration

Isolated set-up

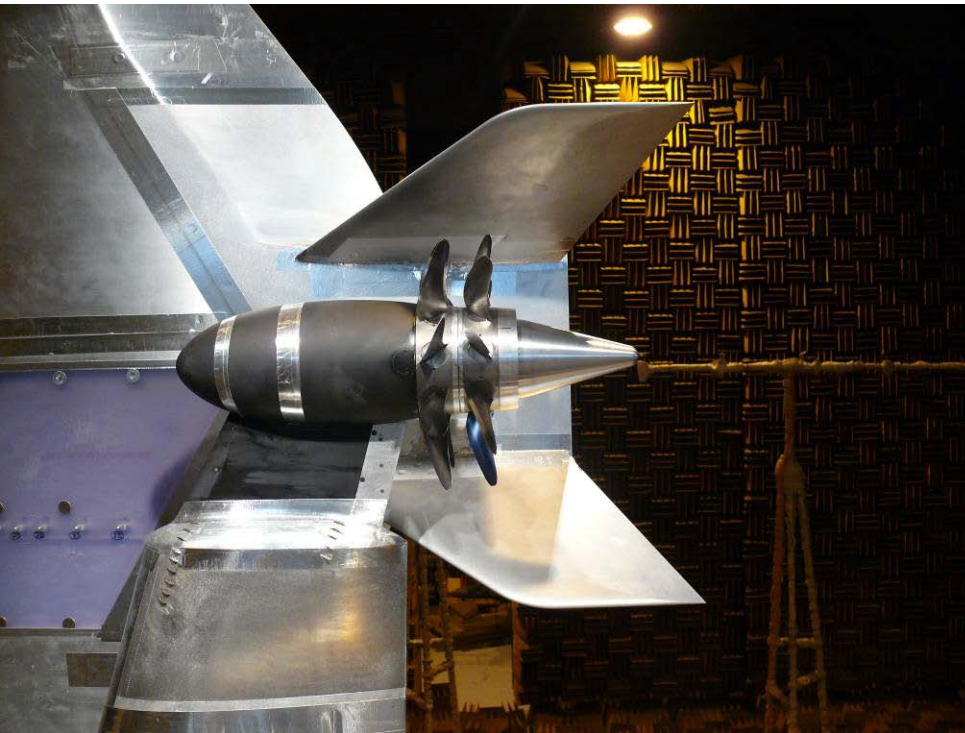


Installed set-up



Additional Configurations

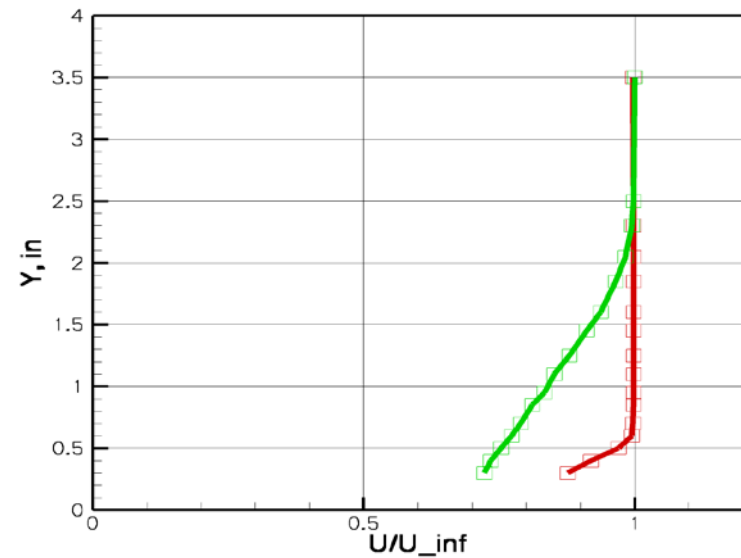
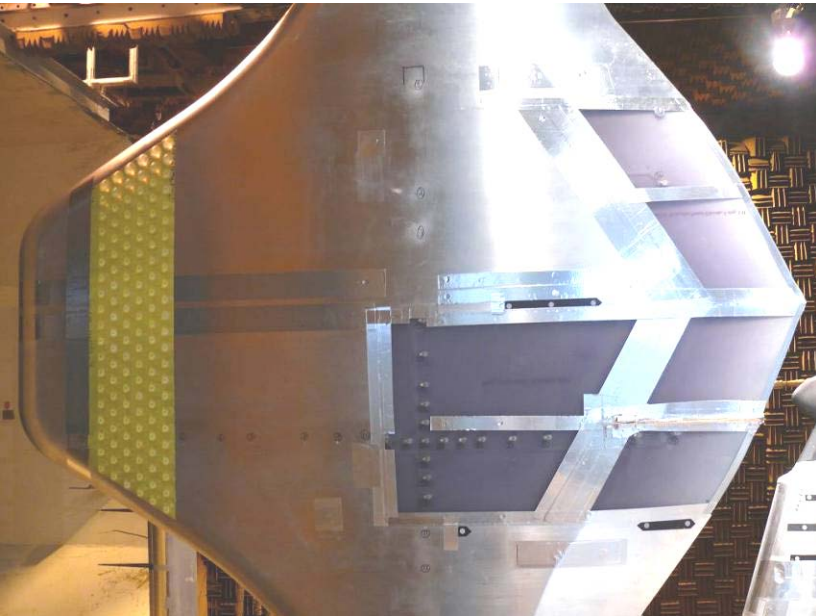
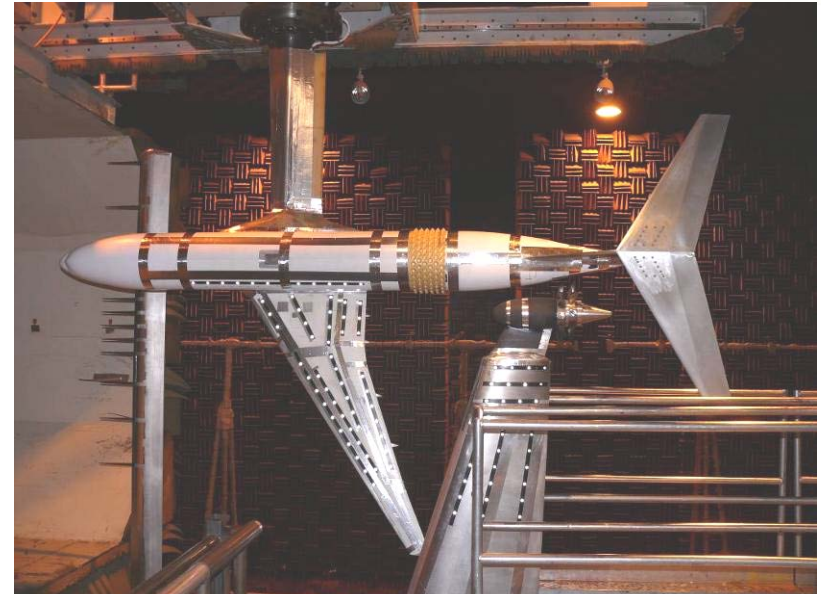
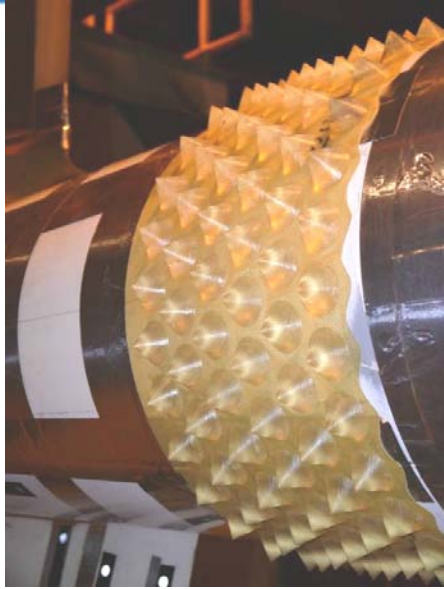
- ❑ V-tail extension for the HWB airframe
- ❑ Engine at the center line
- ❑ Closely configured verticals with open rotor



Broadband noise source testing / with and without nacelle



Boundary layer variations



Summary

- ❑ Large open rotor study, funded by NASA, conducted at Boeing's LSAF facility
- ❑ Three phase test: Rotor only, rotor installed with conventional and unconventional airframe
- ❑ Characterized open rotor acoustics in an isolated set-up to establish a reference
- ❑ Observed significant aeroacoustic installation effects due to inflow distortion (e.g. angle of attack) and scattering effects
- ❑ Unconventional airframes (HWP) offer potential for substantial shielding benefits
- ❑ Obtained data provides valuable guidance for both tool development as well as system level assessments