National Aeronautics and Space Administration

W-8 Inlet In-duct Array Evaluation

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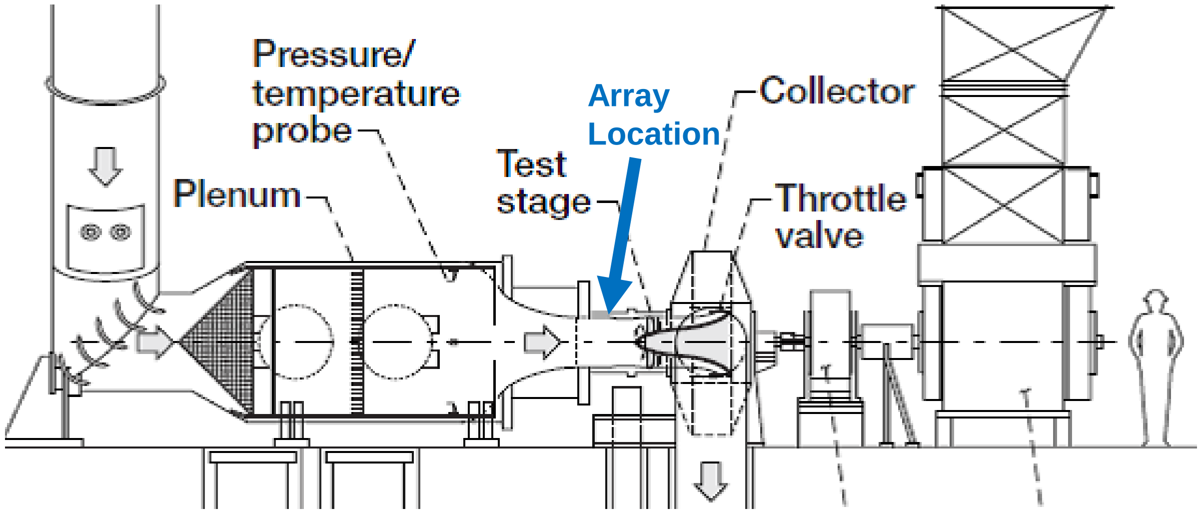
Acoustics Technical Working Group Meeting
NASA Langley Research Center
April 10-11, 2018

NASA Advanced Air Vehicles Program
Advanced Air Transport Technology Project
Aircraft Noise Reduction Subproject

Outline

- W-8 Inlet In-duct Array
- Source Diagnostic Test - Rotor Alone Nacelle Comparison
- W-8 Background Noise Identification
- Evaluation of a BPF Cut-on Mechanism
- Summary

W-8 Single Stage Axial Compressor Facility



- Internal flow propulsor facility
- Electric drive motor provides up to 7000 hp, 21,240 RPM
- Mass Flows up to 100 lb_m/sec
- 22” Rotor Alone or Stage Fan Models
- Dual Flow or Bypass only
- Atmospheric or Altitude Exhaust Capability

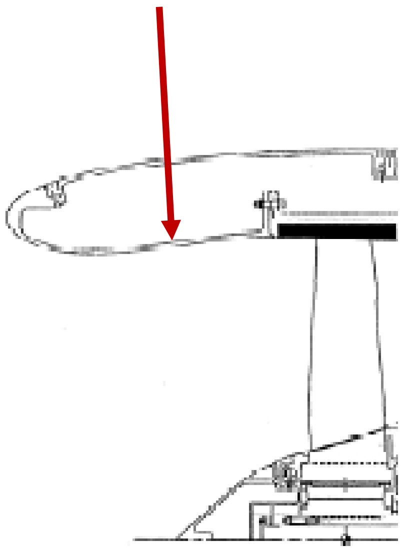
Source Diagnostic Test (SDT) – Rotor Alone Nacelle (RAN) Comparison

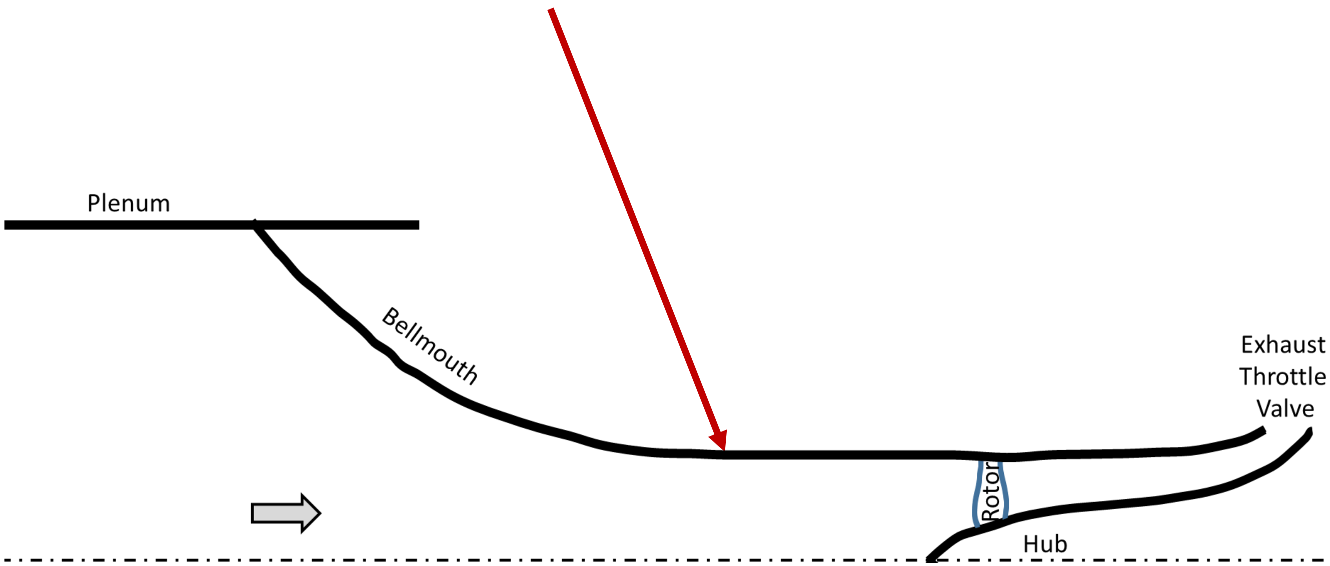
SDT – RAN [4,5]

- 9x15 Low Speed Wind Tunnel
- Flight Inlet
- 60 sensor inlet circumferential array
  - ½ circle, 3° spacing
  - m +/- 60

W-8 Rotor Alone: Hardwall Configuration

- W-8 Internal Flow Compressor
- Straight 22" diameter duct
- 43 sensor inlet circumferential array
  - ~½ circle, 4° spacing
  - m +/- 44

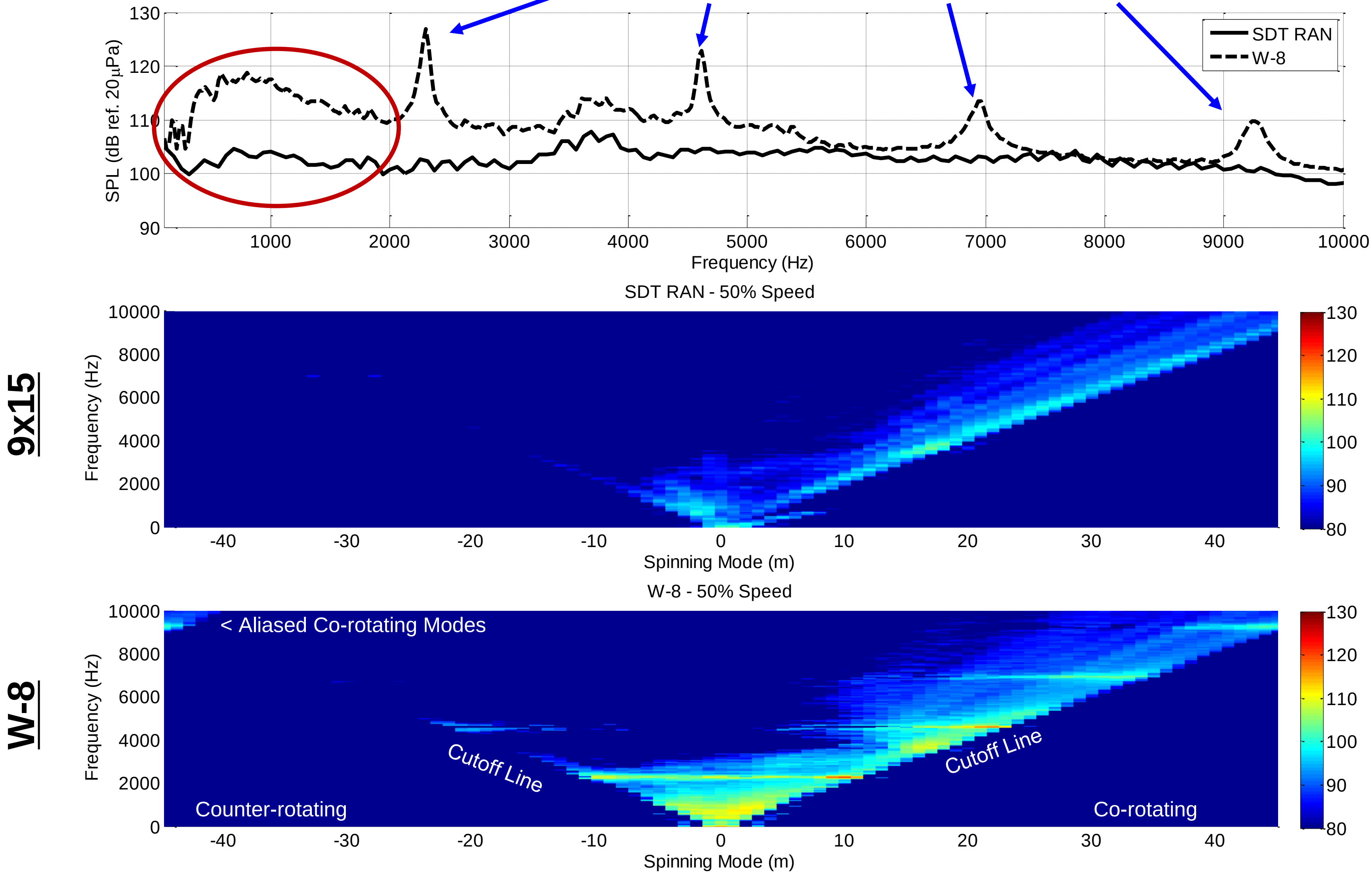




50% Speed Comparison – Atmospheric Exhaust

Low Frequency Broadband

BPF and harmonics are cut-on and broad

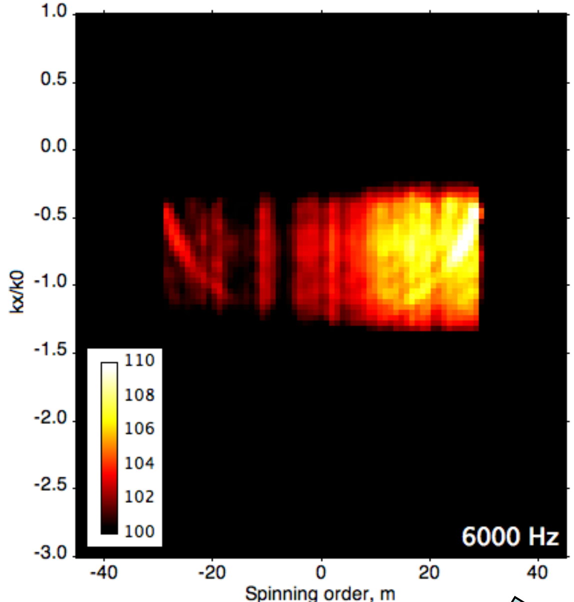


In-duct Array Data Processing to In-duct Mode Powers

Cross-Spectral Matrix

Quantitative Beamforming

Duct Wavenumber Space SPL

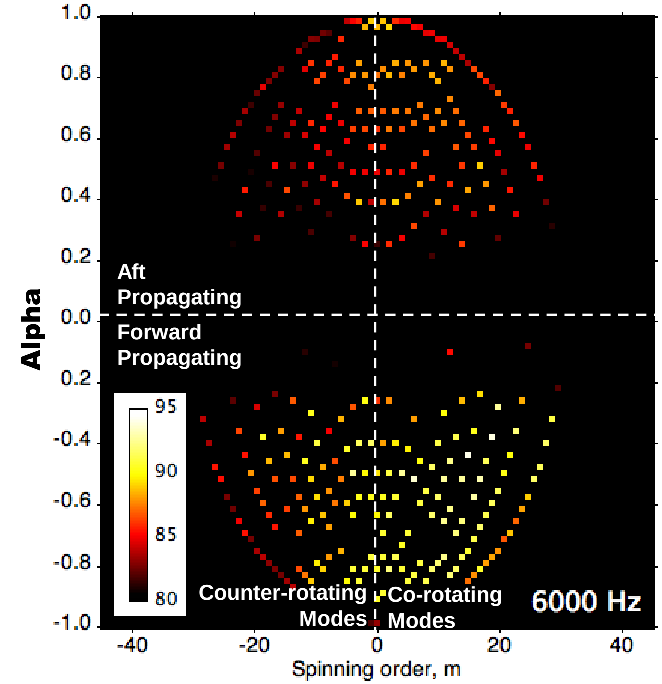


Mode Power Conversion

Cuton Condition

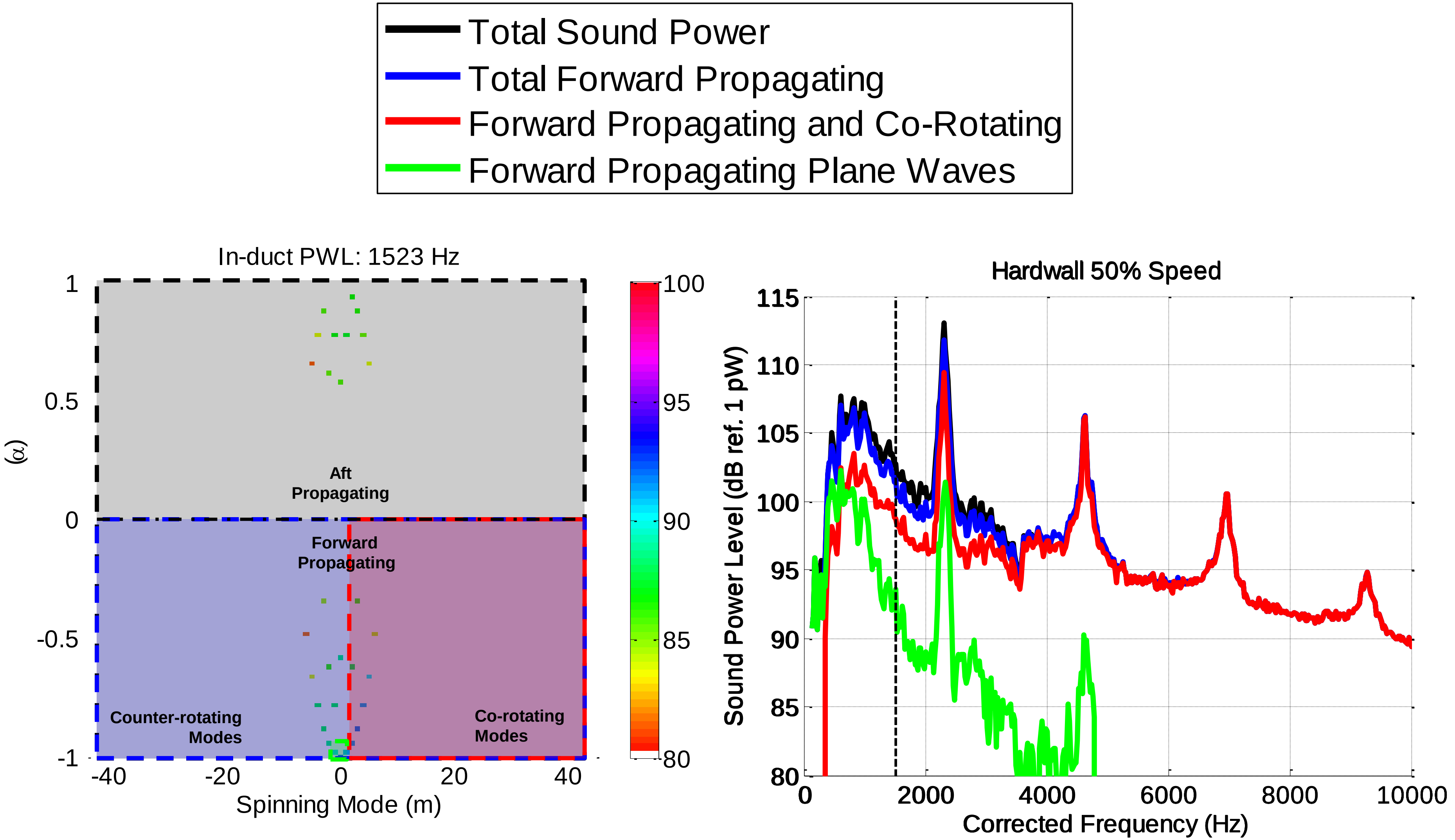
$$\alpha = \pm\sqrt{1 - (1 - M^2)\left(\frac{k_N}{k_0}\right)^2}$$

Mode Powers



*To be presented at 2018 AIAA Aviation:
Dougherty, R. P., and Bozak, R. F., "Two-dimensional Modal Beamforming in Wavenumber Space for Duct Acoustics."

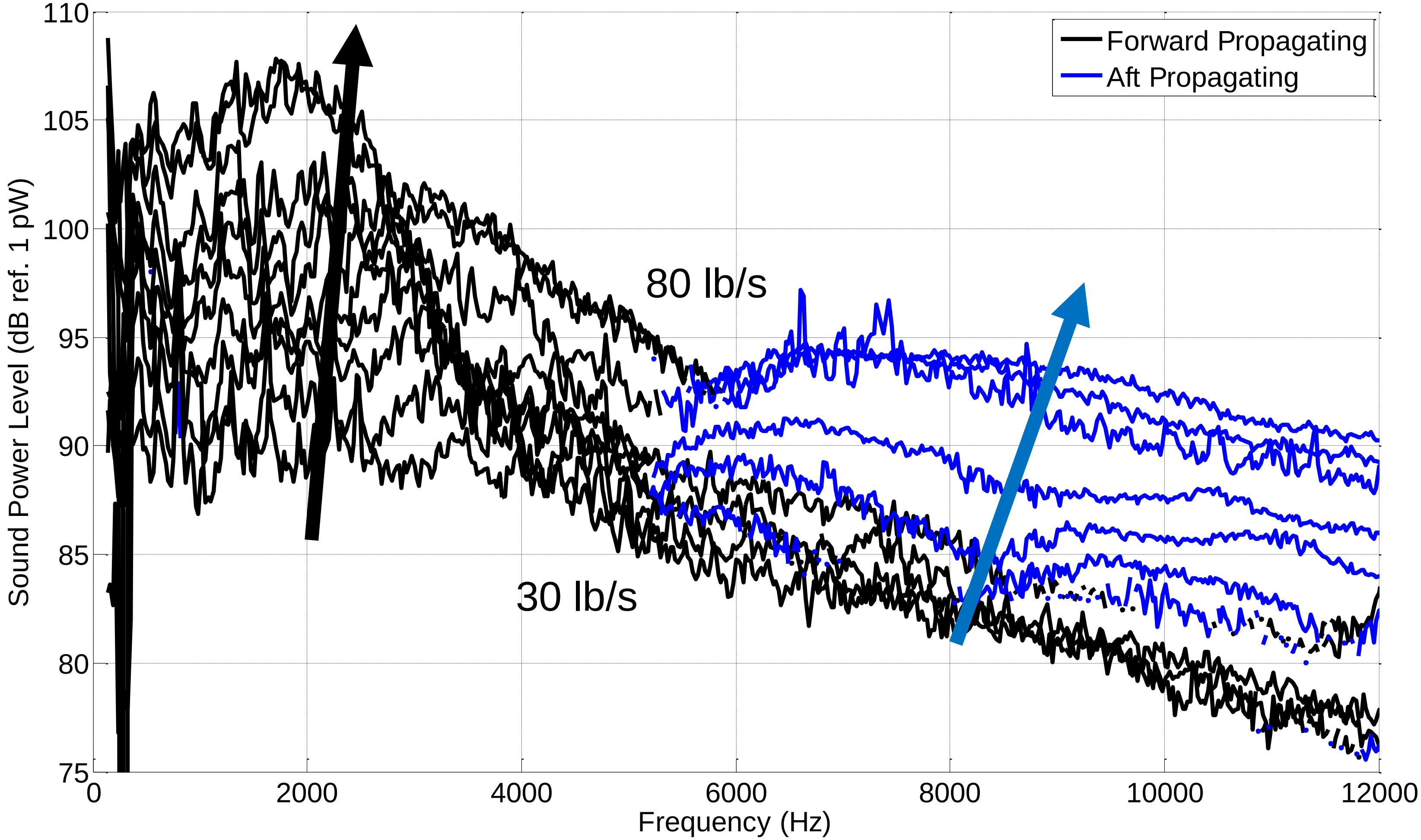
In-duct Modal Decomposition



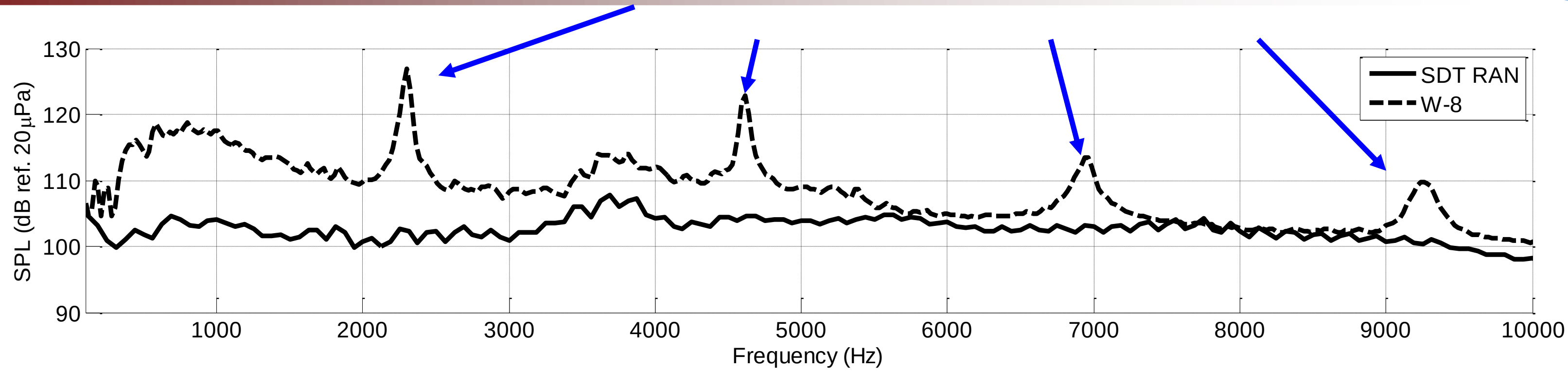
*Impact of treatments using this decomposition to be presented at 2018 AIAA Aviation: Bozak, R. F., and Dougherty, R. P., "Measurement of Noise Reduction from Acoustic Casing Treatments Over a Subscale High Bypass Turbofan Rotor."

Noise from Flow Through the Facility

Utilized ‘Altitude Exhaust’ to pull flow through the facility with a dummy hub installed (no fan blades).



Why is BPF Cut-on and Broad in W-8 Measurements?



Cut-on

1. BPF could be cut-on from an inlet static pressure distortion.
   – Circumferential Mach number variation is not significant: measured to be less than 0.01 (see backup slide).
   – BPF is not modulated about the shaft speed.

Broad

2. The BPF tone could broaden as the sound propagates through a boundary layer turbulence to the sensors.
   – The tone broadness does not appear to vary with boundary layer thickness (see backup slide).
3. The BPF frequency could be wandering, causing the appearance of a broad tone when averaged.
   – Does not appear to be the case (see backup slide).

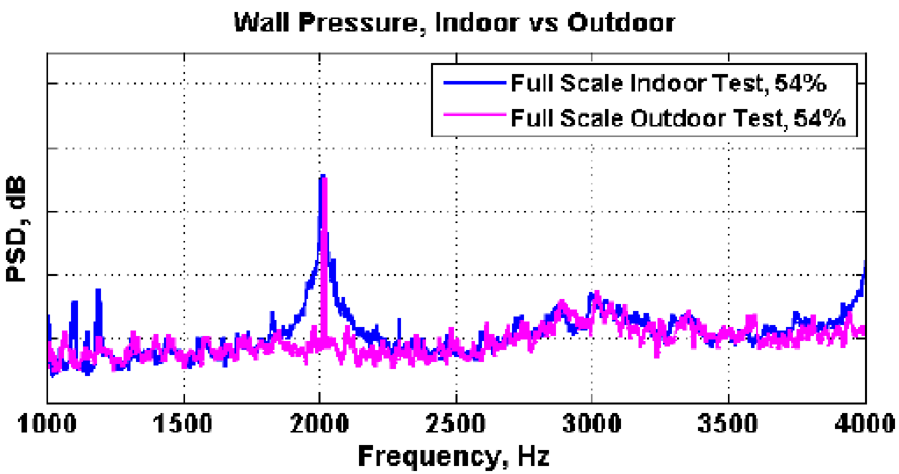
Both

4. Increased freestream or boundary layer turbulence from the W-8 inlet bellmouth could create turbulence-rotor interaction tones that are not present with the 9x15 flight inlet.

Turbulence-Rotor Interaction Noise

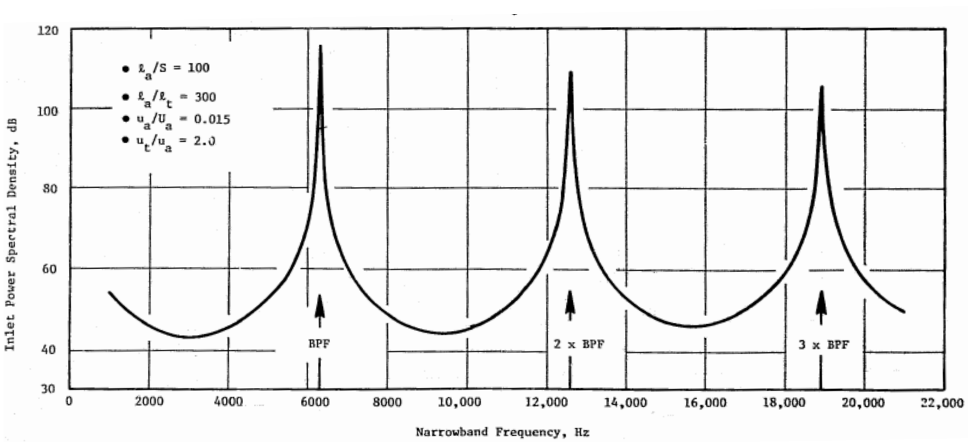
- Honeywell engine test data shows a ‘skirt’ around tones measured in an indoor test facility, while outdoor test data did not exhibit this skirt.
- An analytical model provided by Gliebe and Kerschen shows that the broadness turbulence rotor interaction BPF tones is driven by inlet turbulence length scales (larger length scales create broader tones).

<u>Honeywell Engine Test Data</u>



Marotta, T., Schuster, B., ‘*A Comparison of Fan Inlet Dynamic Wall Pressure Transducers from Rig and Engine Tests*,’ AIAA 2012-2271, AIAA Aeroacoustics Conference, Colorado Springs, CO, June 2012.

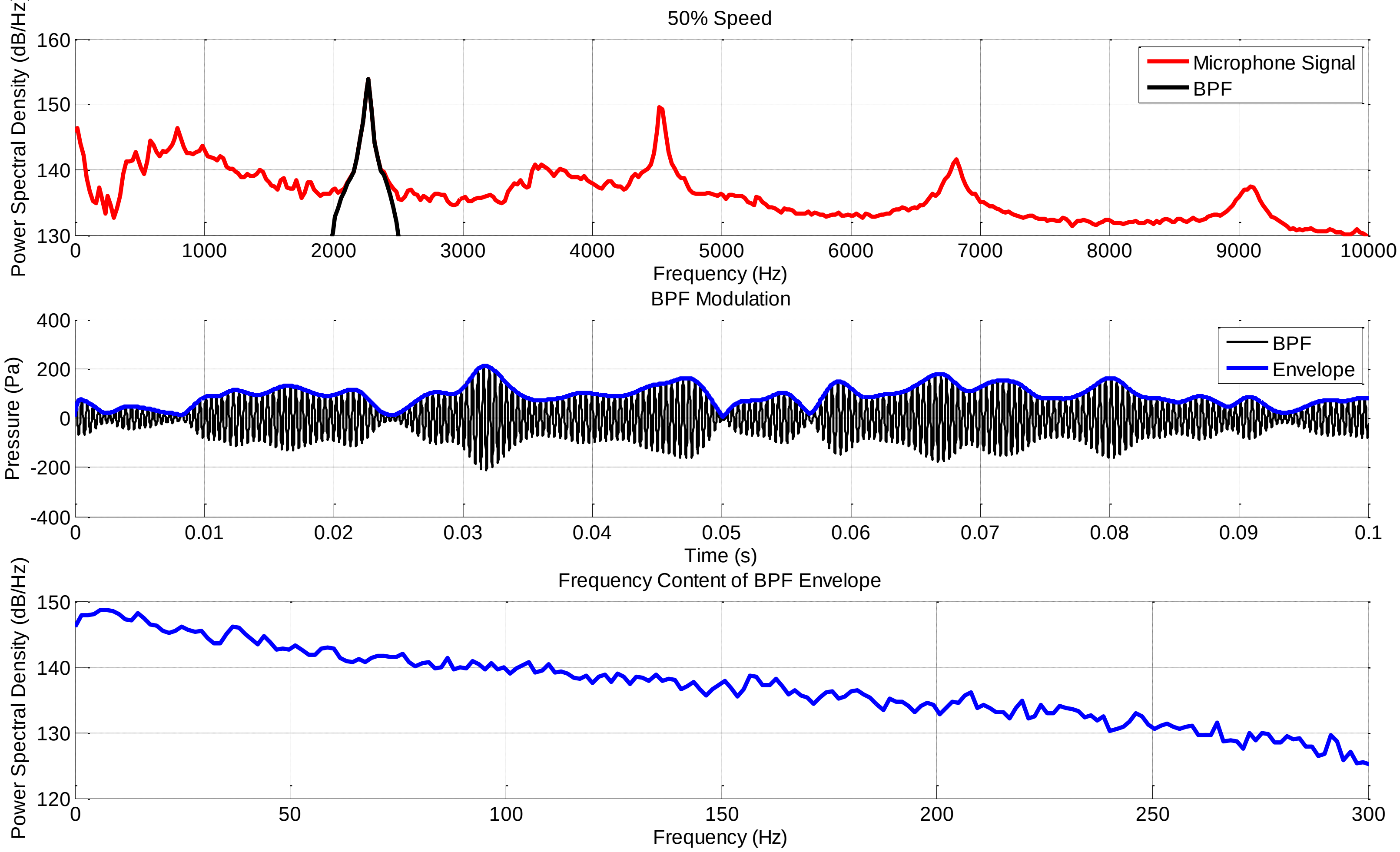
<u>Analytical Model for Turbulence-Rotor Noise</u>



Gliebe, P. R., and Kerschen, E. J., ‘*Analytical Study of the Effects of Wind Tunnel Turbulence on Turbofan Rotor Noise*’, NASA CR-152359, 1979.

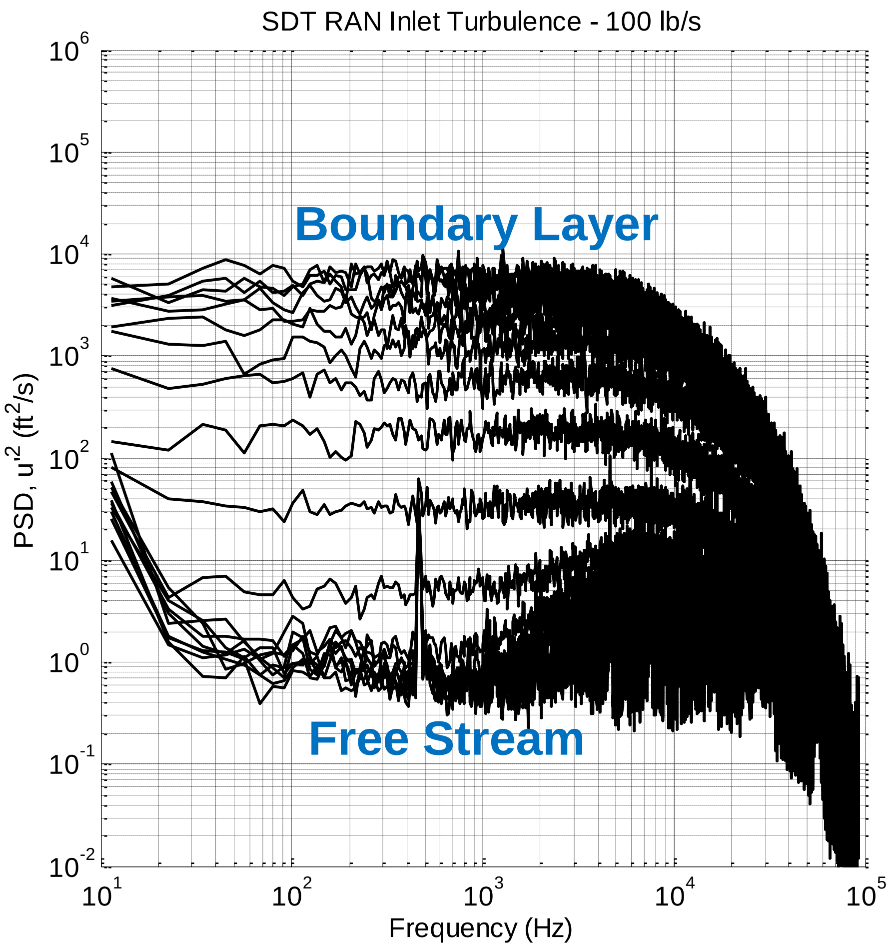
BPF Tone Envelope Investigation

Envelope = sqrt(lowpass(signal^2))

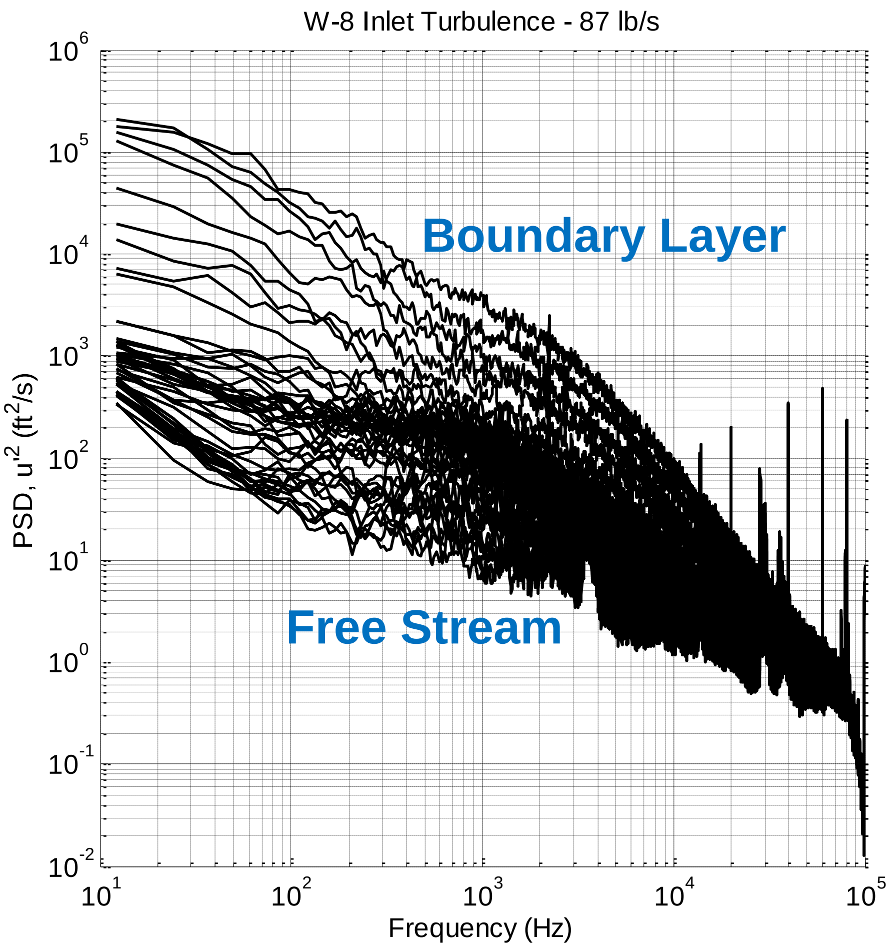


Inlet Turbulence Spectral Comparison

Flight Inlet – 9x15 LSWT



Inlet Bellmouth – W-8



Summary

- In-duct noise levels were compared between the W-8 internal flow facility and the 9x15 LSWT with the R4 fan in a rotor alone configuration.
- Rotor alone measurements were found to be a few dB louder than Source Diagnostic Test (SDT) Rotor Alone Nacelle in-duct measurements with a few exceptions:
  - When running W-8 in the atmospheric exhaust configuration, up to 10dB of additional broadband noise from 100-2,000 Hz. This is believed to be due to flow over rods in the exhaust.
  - In W-8, BPF tones are cut-on and broad.
    - The broadness of the tones appear to be a product of inlet boundary layer turbulence differences between the flight inlet in the 9x15 and inlet bellmouth in W-8.
    - The same characteristics are seen in Honeywell data[5] and in a Gliebe analytical model[7].

Recommendations:

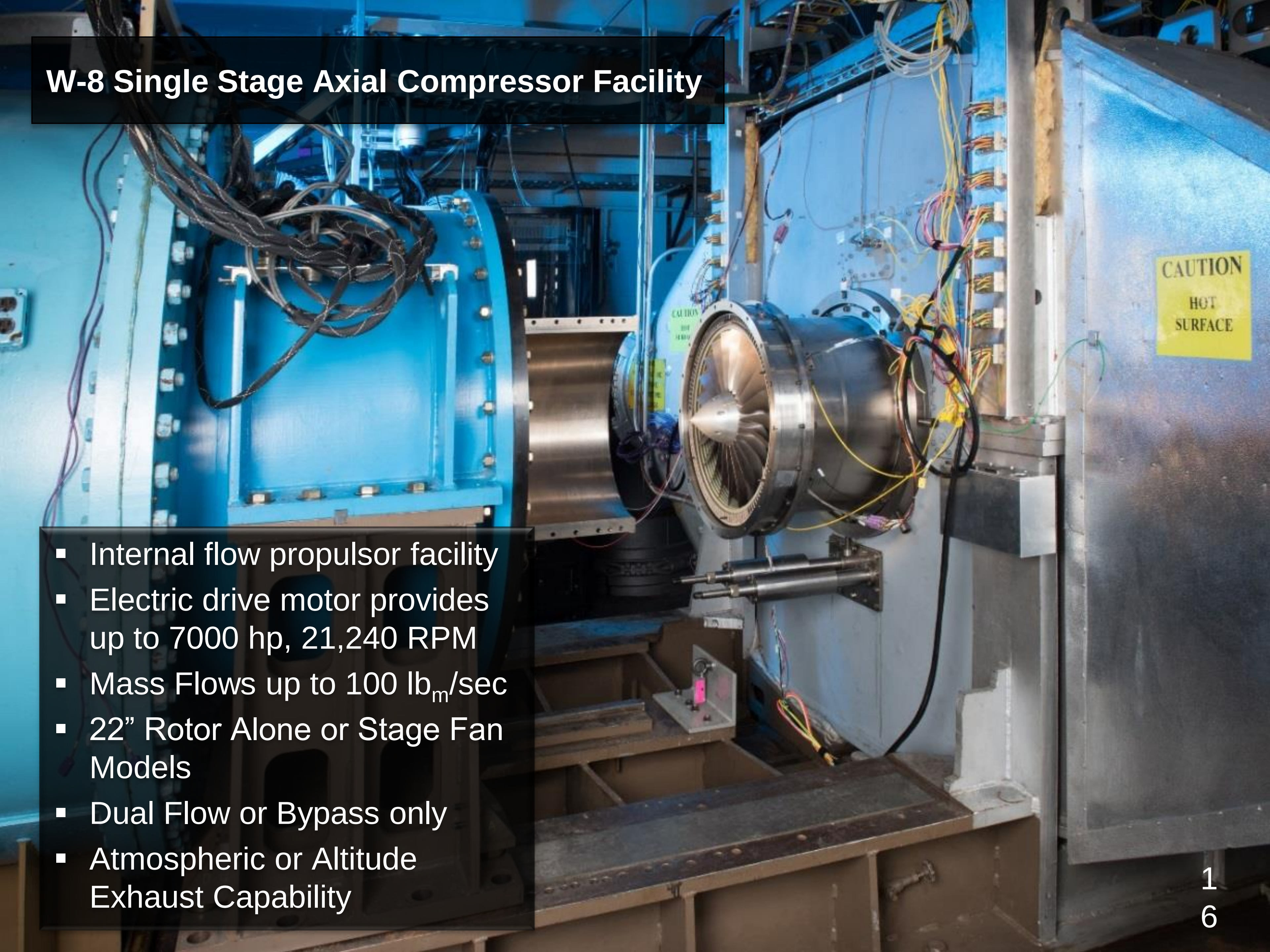
- Reduce W-8 background noise by modifying rods in the W-8 exhaust collector
- Further investigate facility inlet turbulence differences

References

1. Hughes, Christopher E., Jeracki, Robert J., and Miller, Christopher J., “Fan Noise Source Diagnostic Test – Rotor Alone Aerodynamic Performance Results,” AIAA 2002-2426 or NASA TM 2005-211681.
2. Van Zante, Dale E., Podboy, Gary G., Miller, Christopher J., Thorp, Scott A., “Testing and Performance Verification of a High Bypass Ratio Turbofan Rotor in an Internal Flow Component Test Facility,” GT2007-27246.
3. Premo and Joppa, ‘Fan Noise Source Diagnostic Test – Wall Measured Circumferential Array Mode Results,’ AIAA 2002-2429.
4. Heidelberg, L., ‘Fan Noise Source Diagnostic Test – Tone Modal Structure Results,’ AIAA 2002-2428 and NASA/TM-2002-211594.
5. Marotta, T., Schuster, B., ‘*A Comparison of Fan Inlet Dynamic Wall Pressure Transducers from Rig and Engine Tests*,’ AIAA 2012-2271, AIAA Aeroacoustics Conference, Colorado Springs, CO, June 2012.
6. Smith, E. B., Moore, M. T., and Gliebe, P. R., ‘Distortion – Rotor Interaction Noise Produced by a Drooped Inlet.’ AIAA-80-1050.
7. Gliebe, P. R., and Kerschen, E. J., ‘Analytical Study of the Effects of Wind Tunnel Turbulence on Turbofan Rotor Noise’, NASA CR-152359.
8. Bozak, R., “Inlet Acoustic Data from a High Bypass Ratio Turbofan Rotor in an Internal Flow Component Test Facility” NASA/TM-2017-219489.
9. Dougherty, R. P., and Bozak, R. F., “Two-dimensional Modal Beamforming in Wavenumber Space for Duct Acoustics,” To be presented at for 2018 AIAA Aviation Forum.
10. Bozak, R., F., and Dougherty, R. P., “Measurement of Noise Reduction from Acoustic Casing Treatments Installed Over a Subscale High Bypass Ratio Turbofan Rotor,” To be presented at 2018 AIAA Aviation Forum.

BACKUP SLIDES

W-8 Single Stage Axial Compressor Facility



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- Electric drive motor provides up to 7000 hp, 21,240 RPM
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W-8 Single Stage Axial Compressor Facility Schematic

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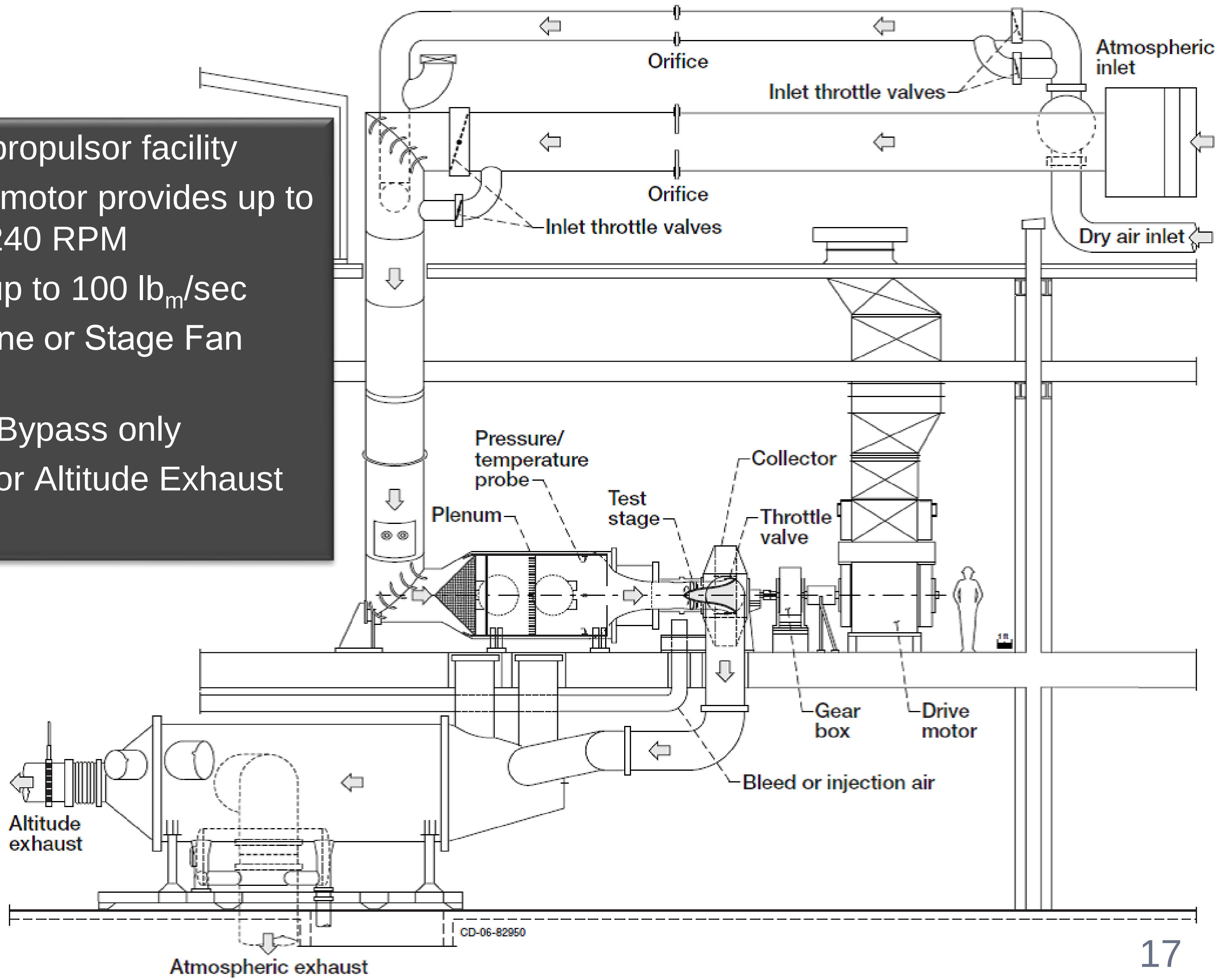
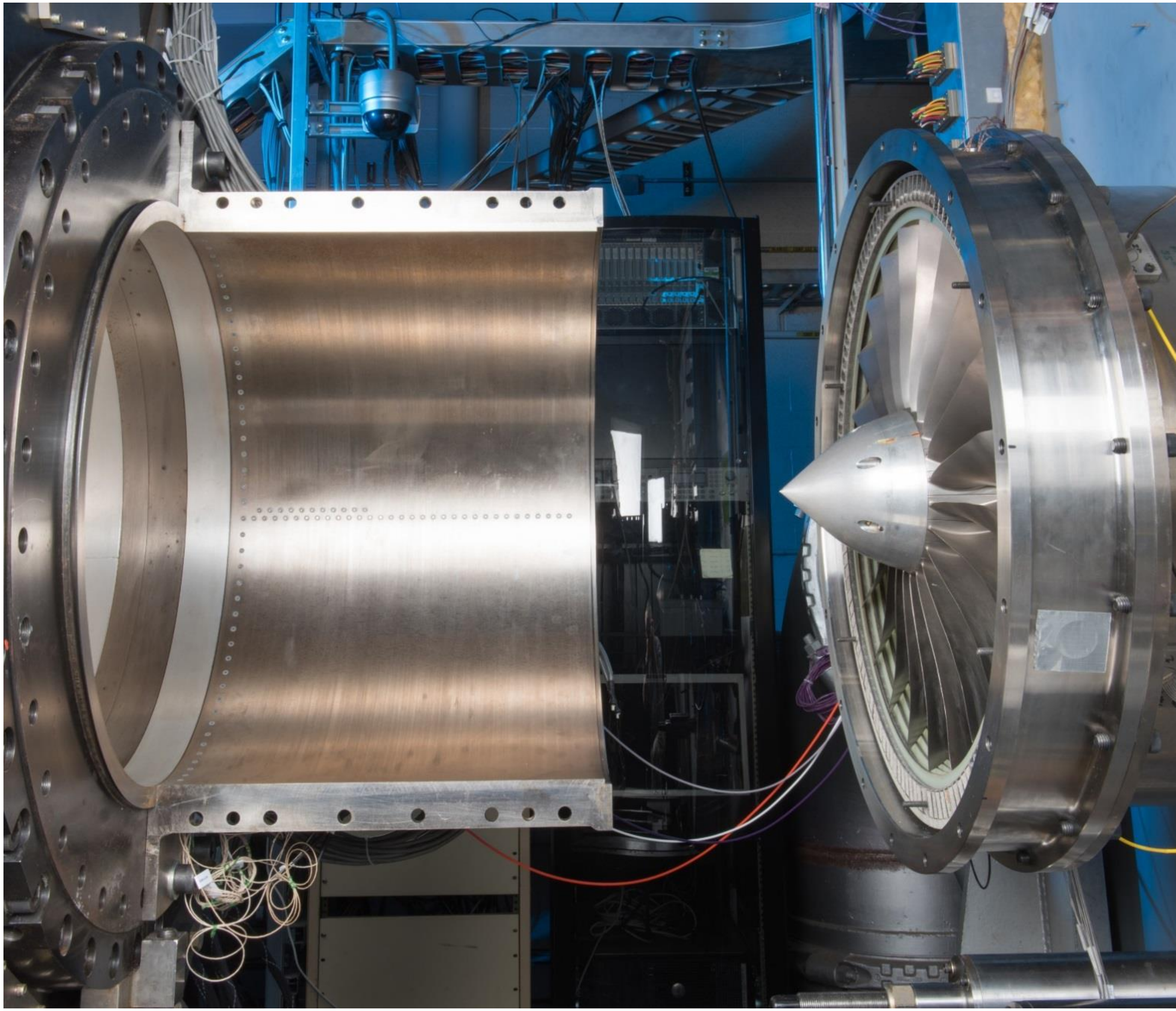


Inlet In-duct Array Instrumentation

- 22-inch constant area inlet duct
- 85 sensors
  - Kulite® 25PSIA
  - Installed into nylon inserts
- T-Array
  - ½ Circle, 4° Spacing
  - Long Axial
  - Staggered Short Axial



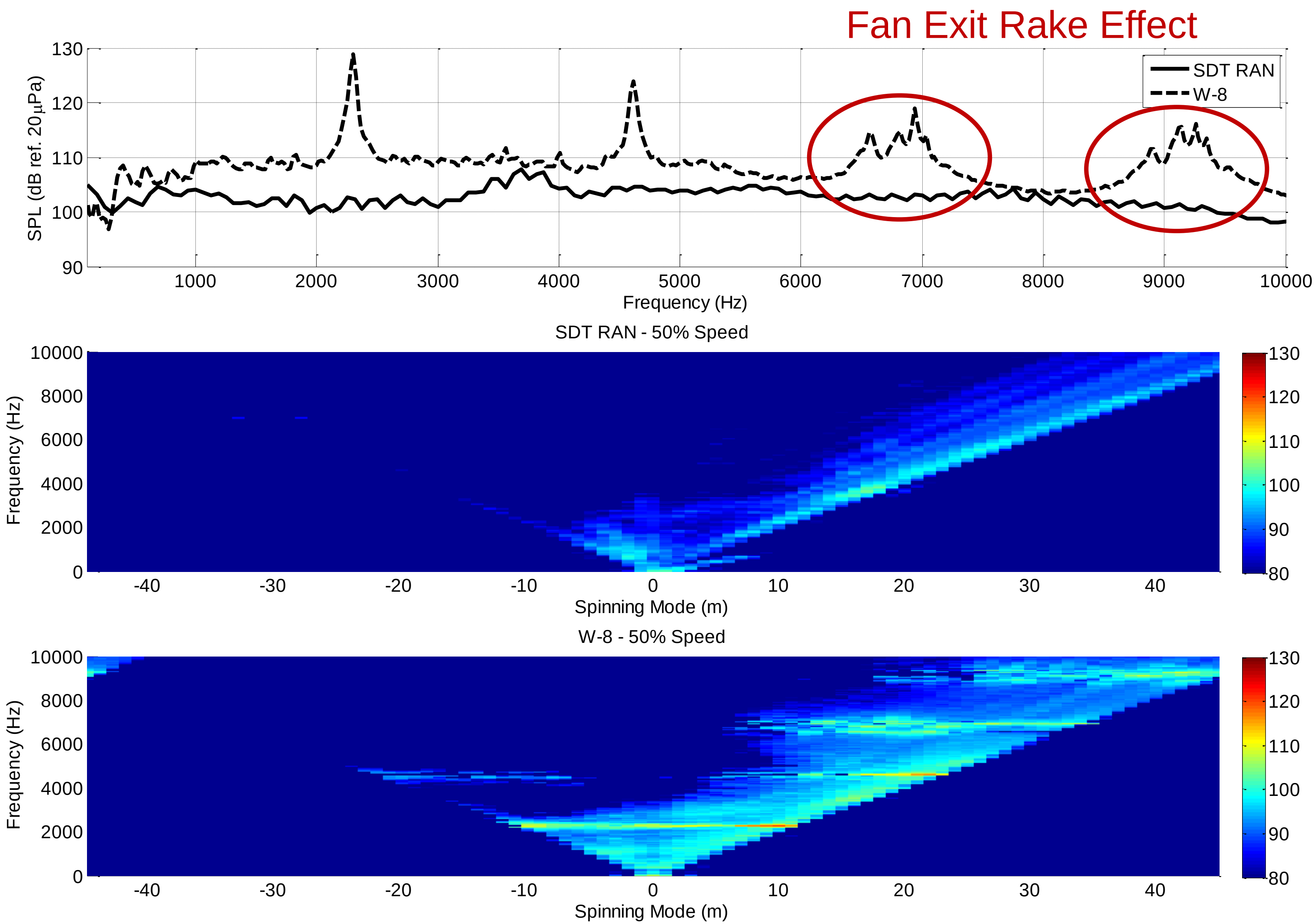
SDT/R4 Hardware

- The Source Diagnostic Test hardware was tested in a rotor alone configuration in the 9x15 wind tunnel[1] and the W-8 Single Stage Axial Compressor Facility[2] in the early 2000's

Parameter	Value
No. of Fan Blades	22
Fan Tip Diameter	22 in. (0.56m)
Hub/tip Ratio	0.30
Corrected Tip Speed	1215 ft/s (370 m/s)
Fan Design Speed, corrected rpm	12,657
Fan Design Pressure Ratio	1.50

[1]Hughes, Christopher E., Jeracki, Robert J., and Miller, Christopher J., "Fan Noise Source Diagnostic Test – Rotor Alone Aerodynamic Performance Results," AIAA 2002-2426 or NASA TM 2005-211681.
[2]Van Zante, Dale E., Podboy, Gary G., Miller, Christopher J., Thorp, Scott A., "Testing and Performance Verification of a High Bypass Ratio Turbofan Rotor in an Internal Flow Component Test Facility," GT2007-27246.

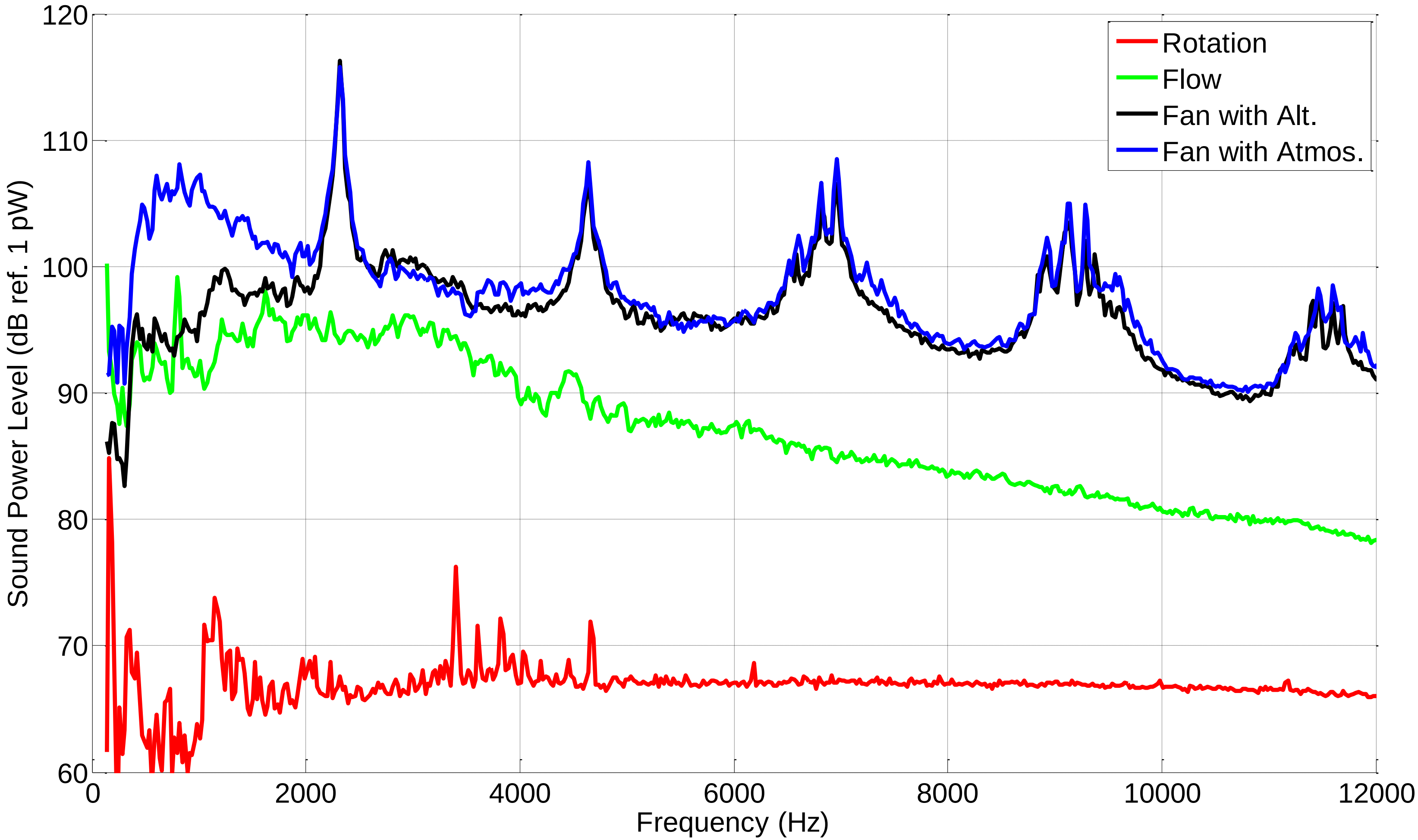
50% Speed Comparison – Altitude (Choked) Exhaust



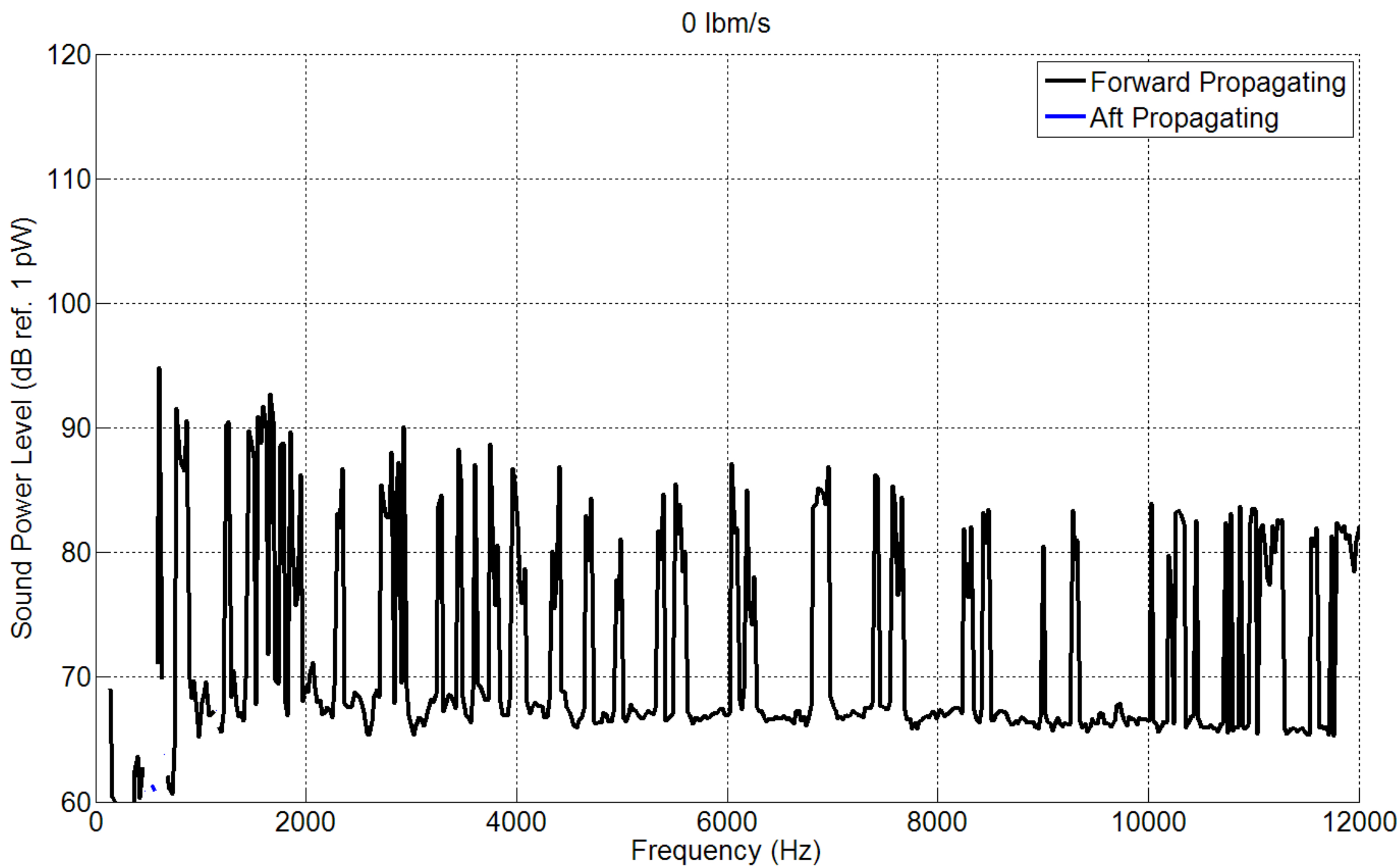
W-8 Noise Comparison at 50% Speed

With no fan installed (only a dummy hub):

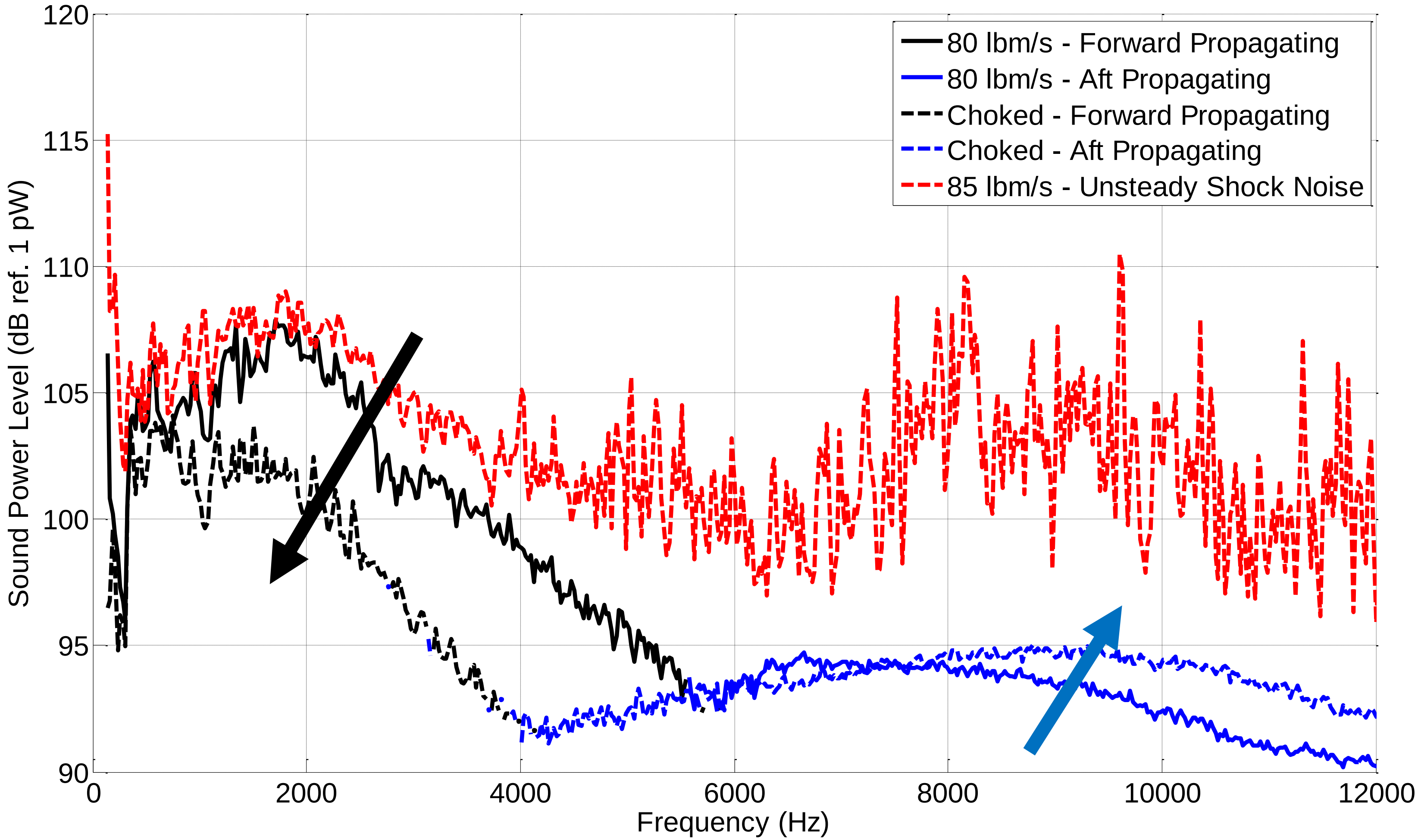
- Rotated a dummy hub up to expected fan speeds.
- Utilized ‘Altitude Exhaust’ to pull flow through the facility up to choke at 87 lbm/s.



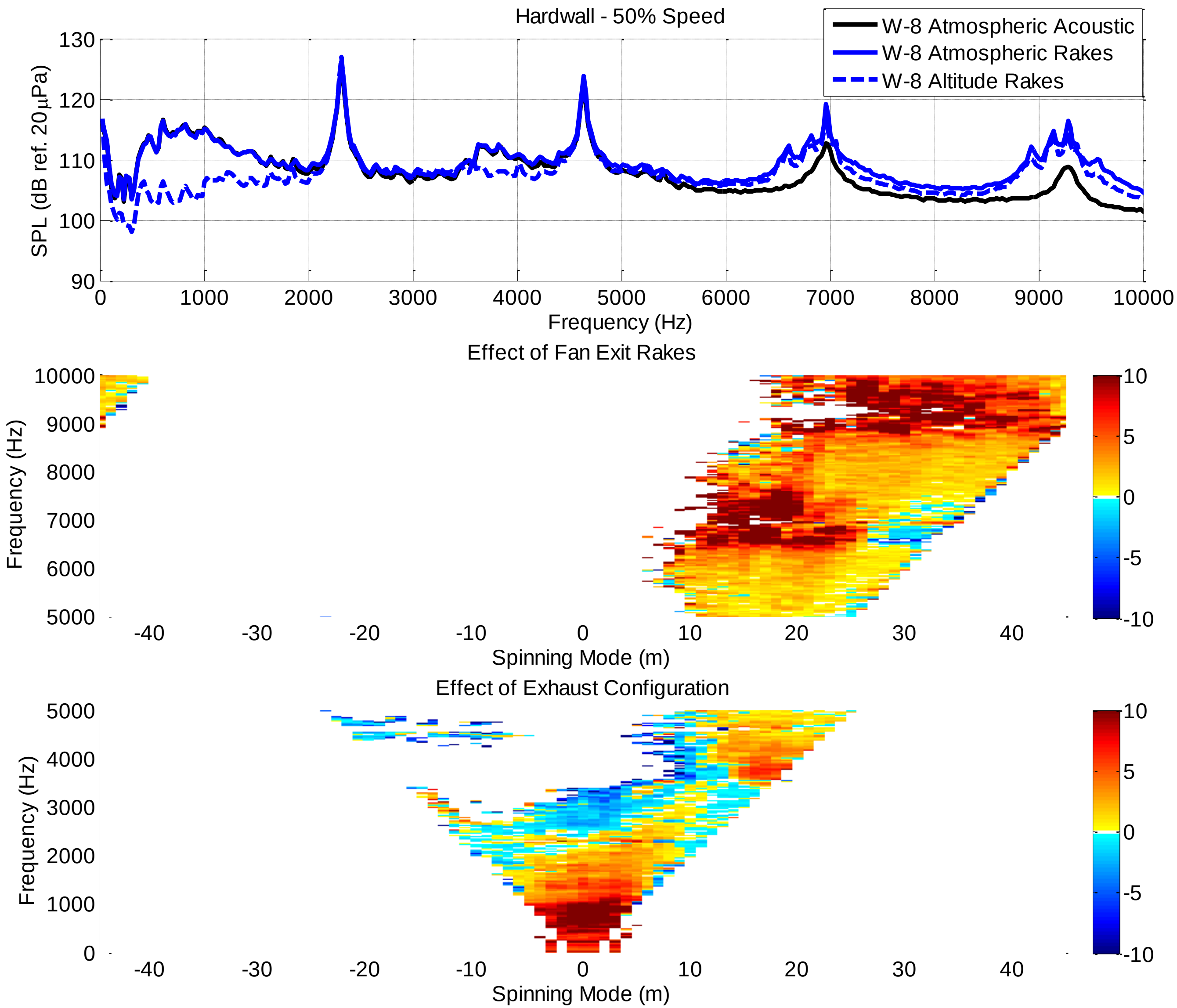
Flow Noise


0 lbm/s
Forward Propagating
Aft Propagating
Sound Power Level (dB ref. 1 pW)
Frequency (Hz)
120
110
100
90
80
70
60
0
2000
4000
6000
8000
10000
12000

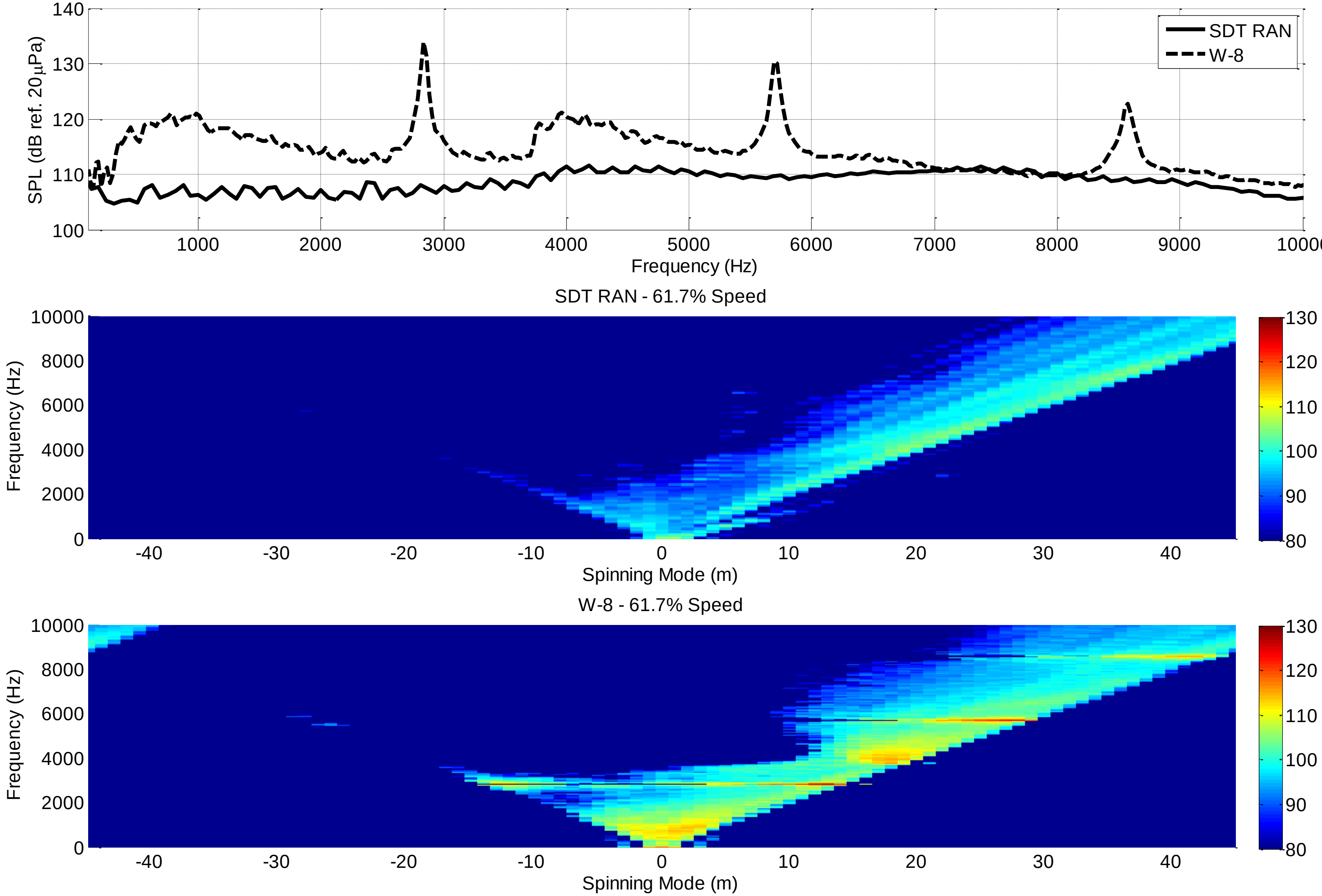
Effect of Choking the Exhaust Nozzle on Flow Noise



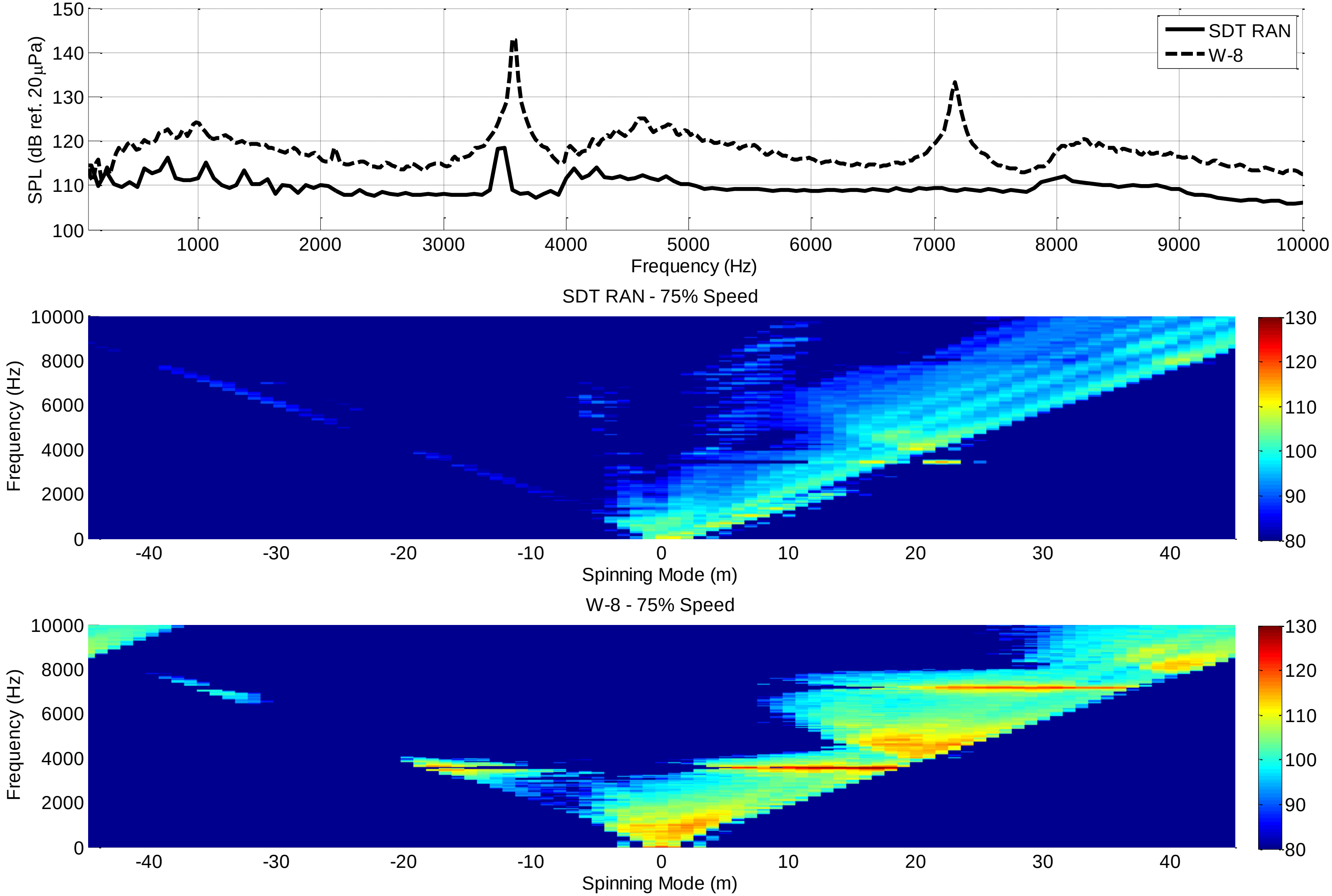
W-8 Background Effects



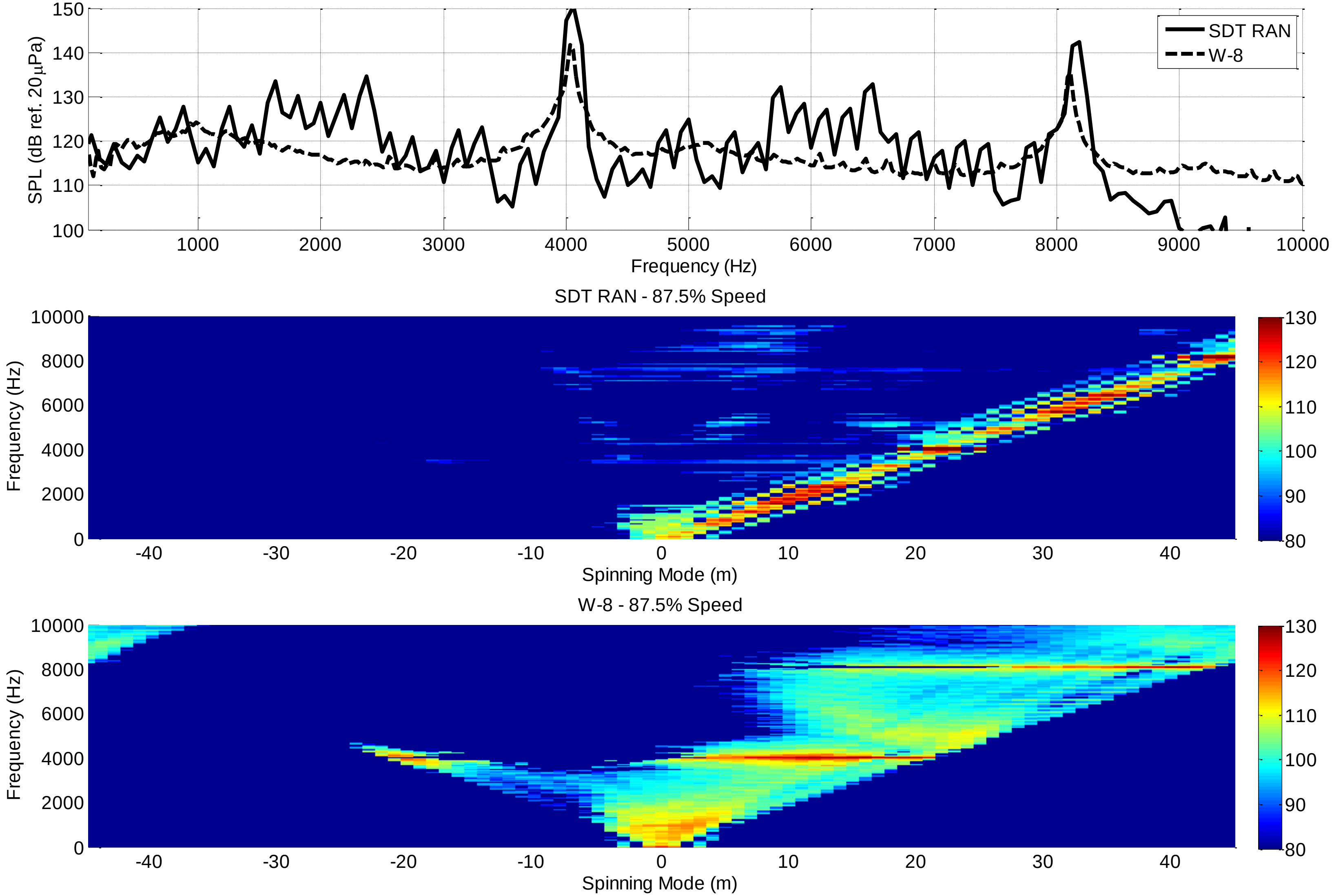
Background Subtracted SDT RAN Comparison – 61.7% Speed



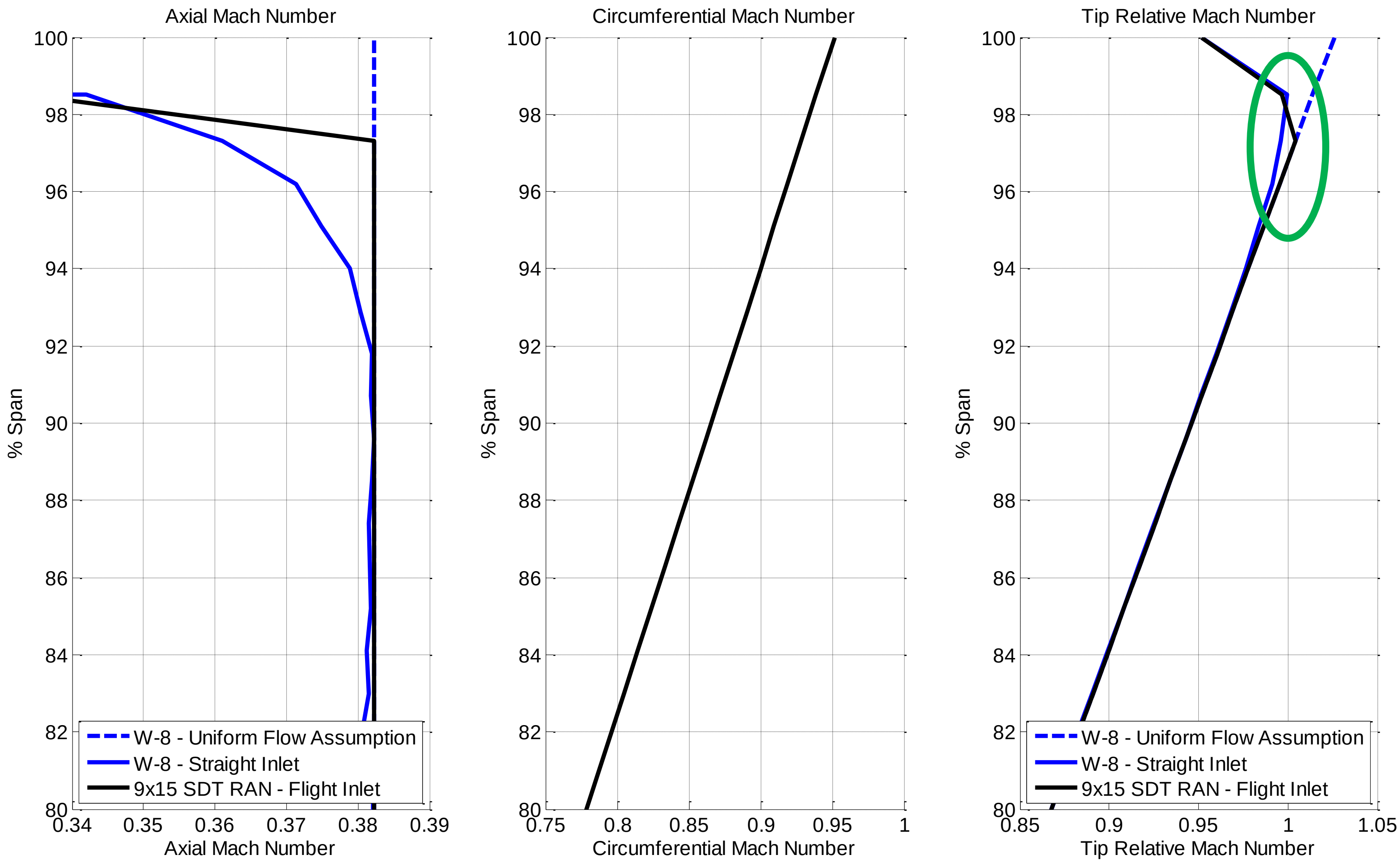
Background Subtracted SDT RAN Comparison – 75%, 77.5% Speed



Background Subtracted SDT RAN Comparison – 87.5% Speed

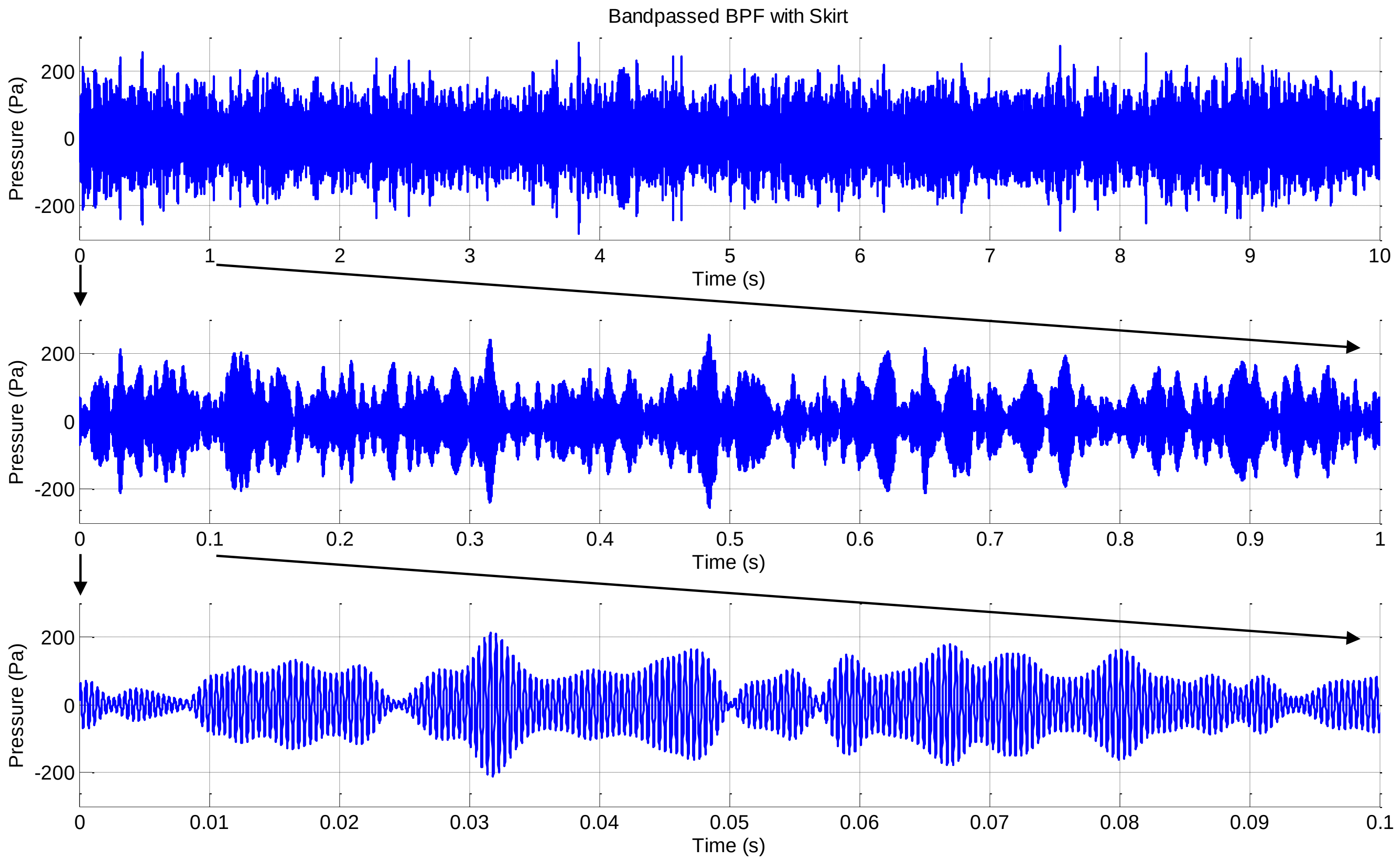


MPT/Buzzsaw Noise Difference



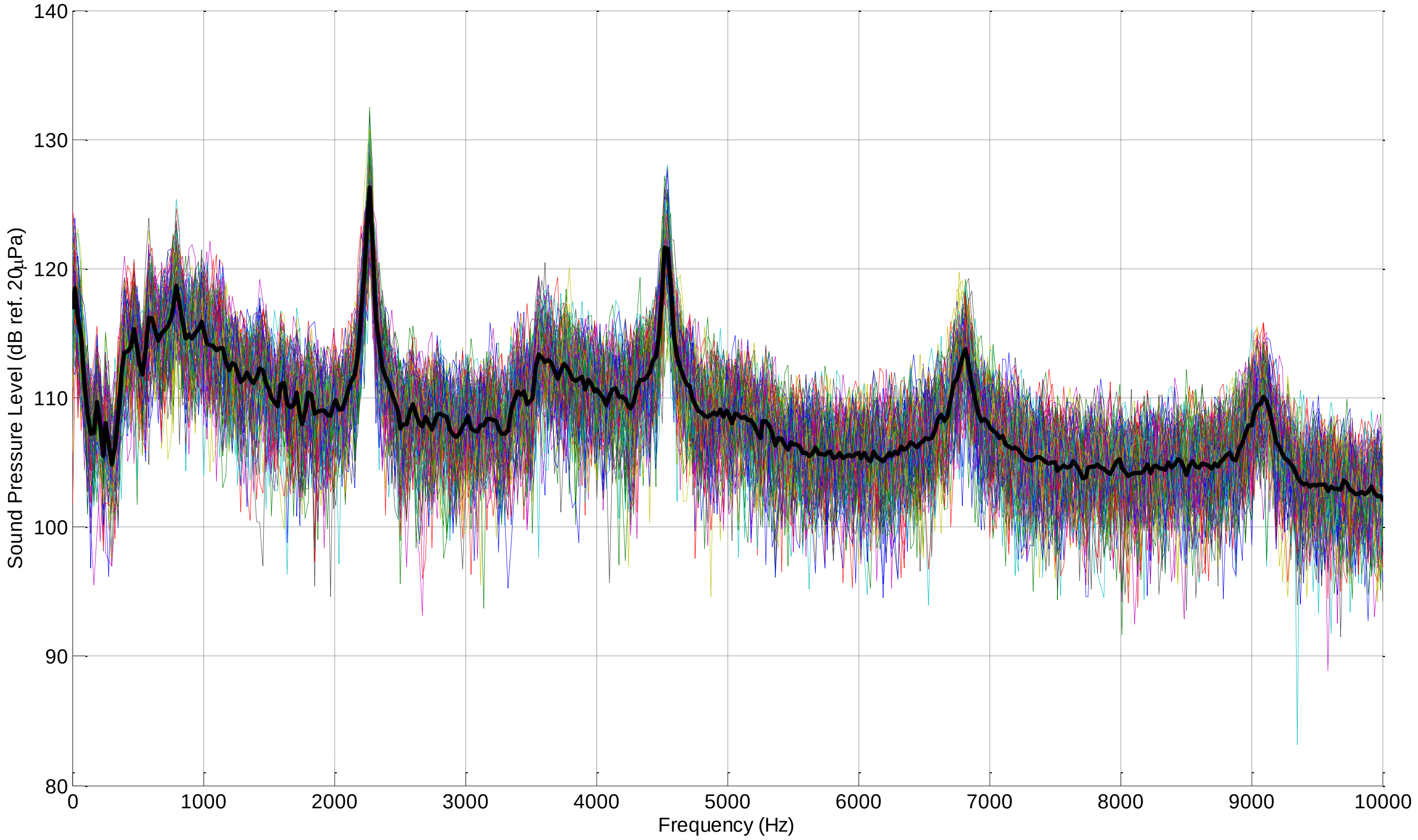
Fan tip goes sonic sooner with a cleaner boundary layer (SDT RAN data).

Measured BPF Timeseries - Zoom



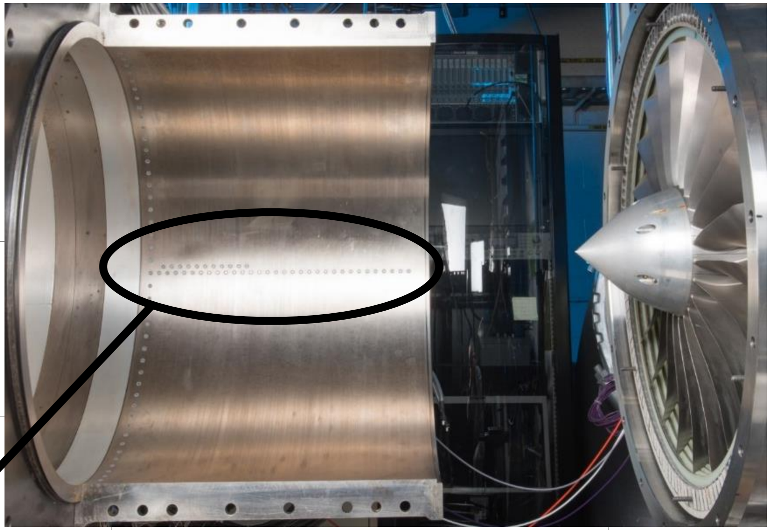
Is BPF Broad because the tone is wandering? … no

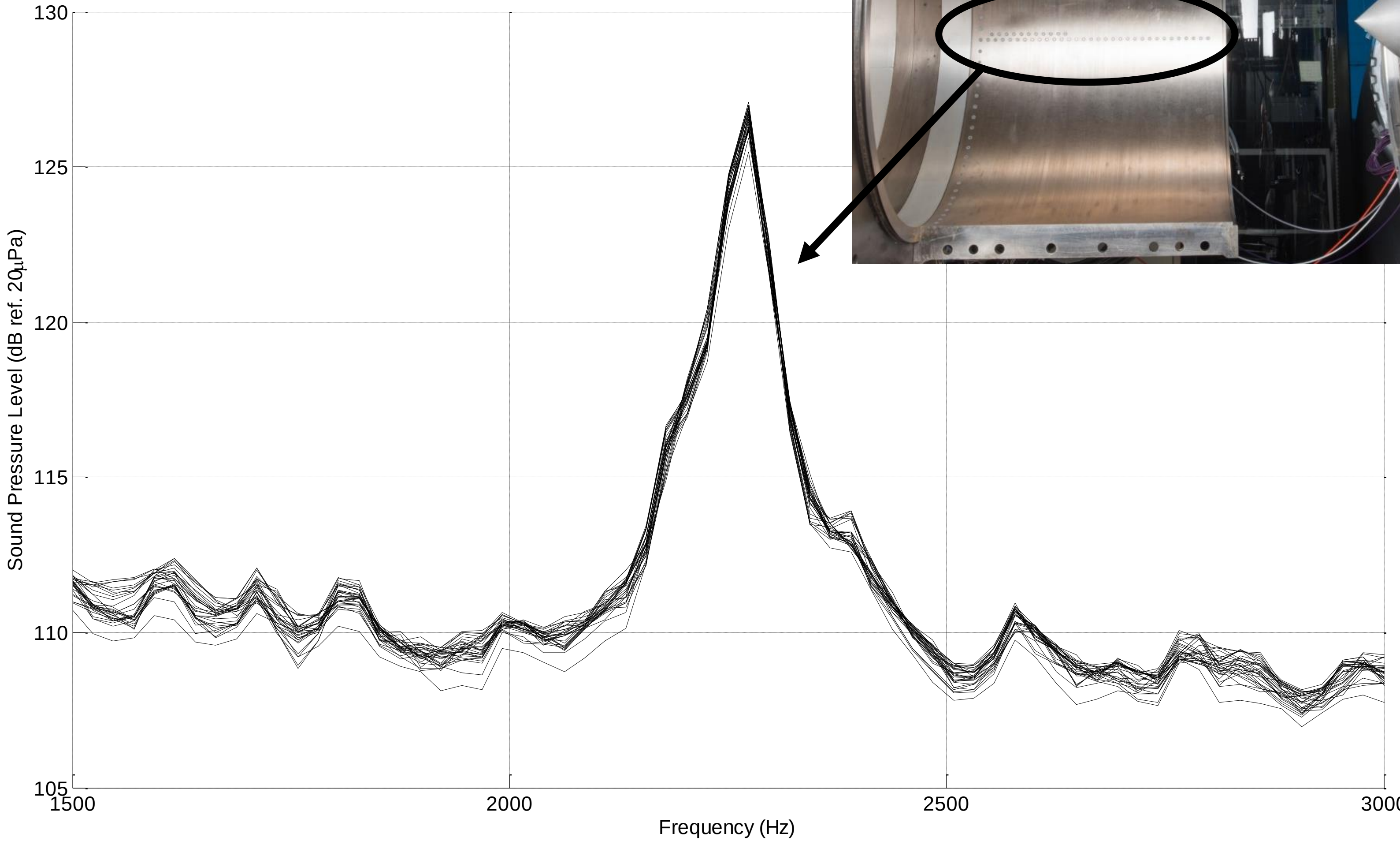
- 10 second sample broken into 100 - 0.1 second samples. Average of all in black.



SPL Variation Over Axial Array - 50% Speed

If the tone were broadened when propagating through the boundary layer turbulence, we'd expect to see variation over the axial array as the boundary layer grows.

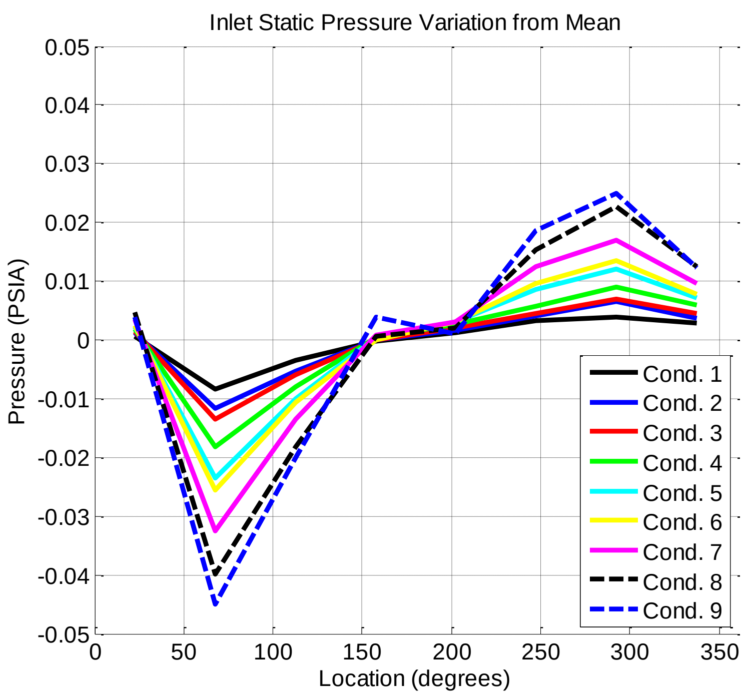


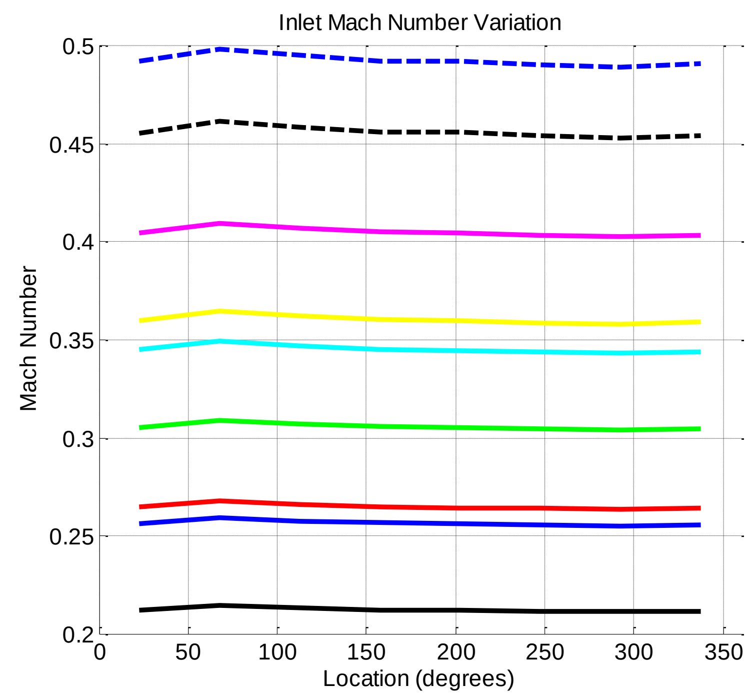


Is there an inlet static pressure distortion?

- Ring of 8 static pressures upstream of the fan.
- For each pressure, a Mach number is calculated:

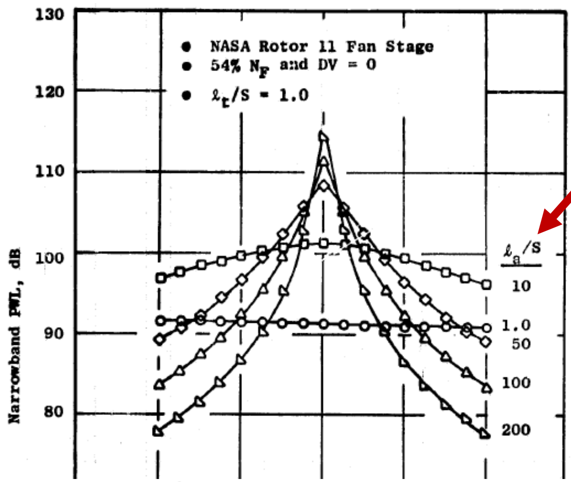
$$M = \sqrt{\frac{2}{\gamma - 1} \cdot \left(\frac{p}{p_t}^{\frac{1-\gamma}{\gamma}} - 1 \right)}$$





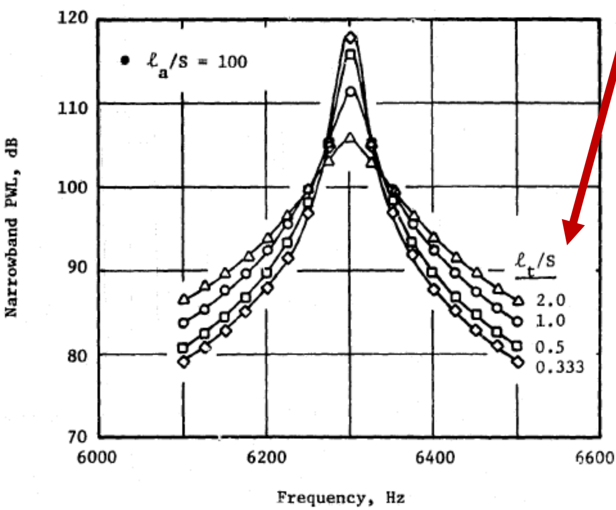
*Smith, E. B., Moore, M. T., and Gliebe, P. R., 'Distortion – Rotor Interaction Noise Produced by a Drooped Inlet.' AIAA-80-1050.

Analytical Model of Turbulence-Rotor Interaction Given by Gliebe and Kerschen (1979 NASA CR-152359)



Variation with Axial Turbulence Length-Scale

Variation with Tangential Turbulence Length-Scale



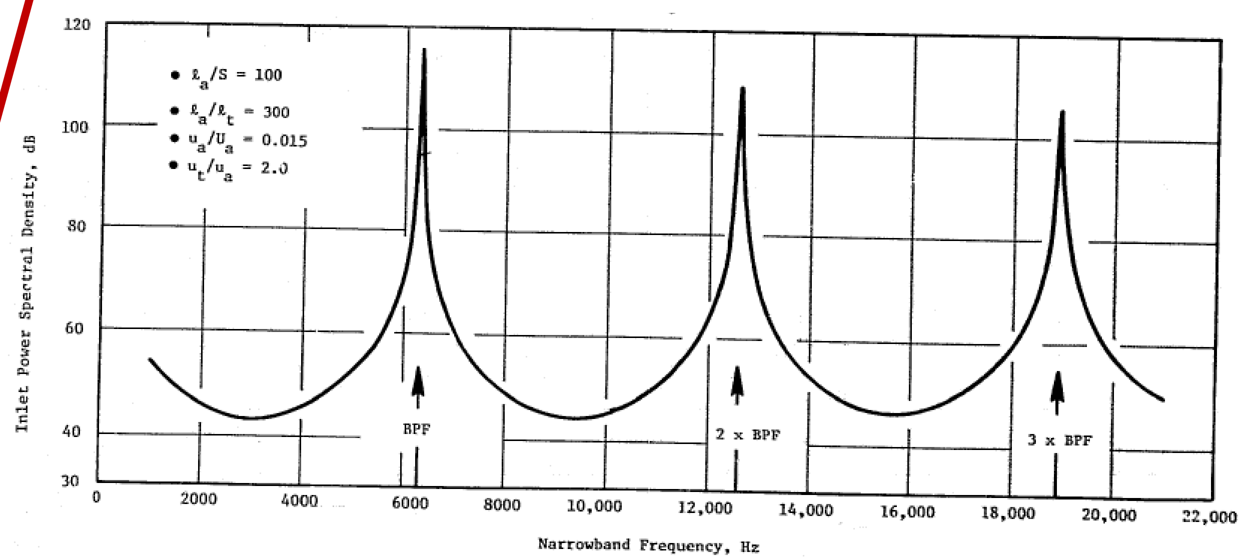
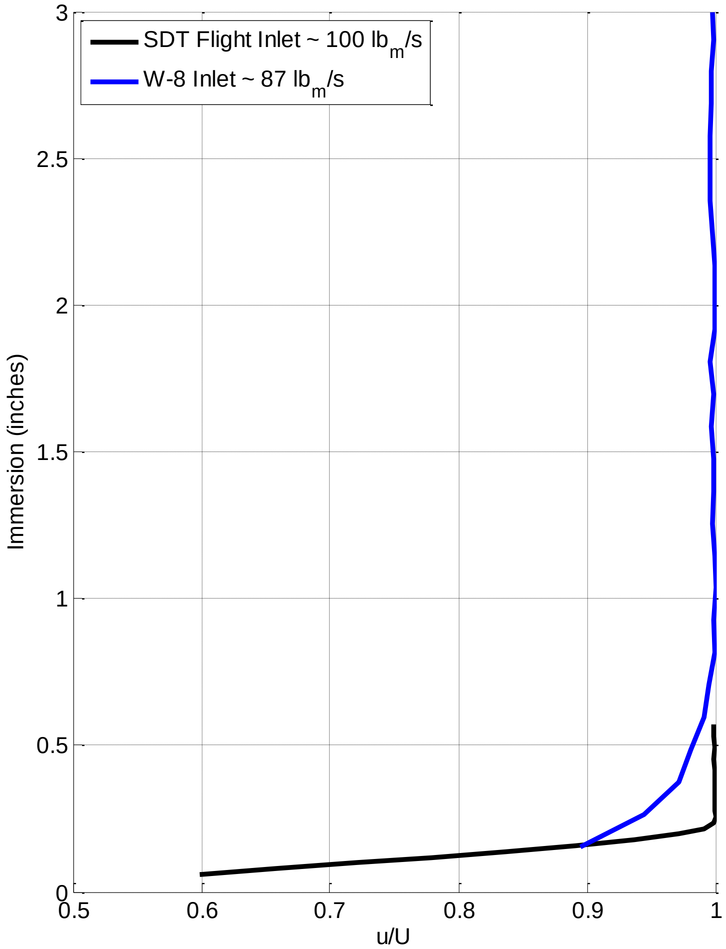
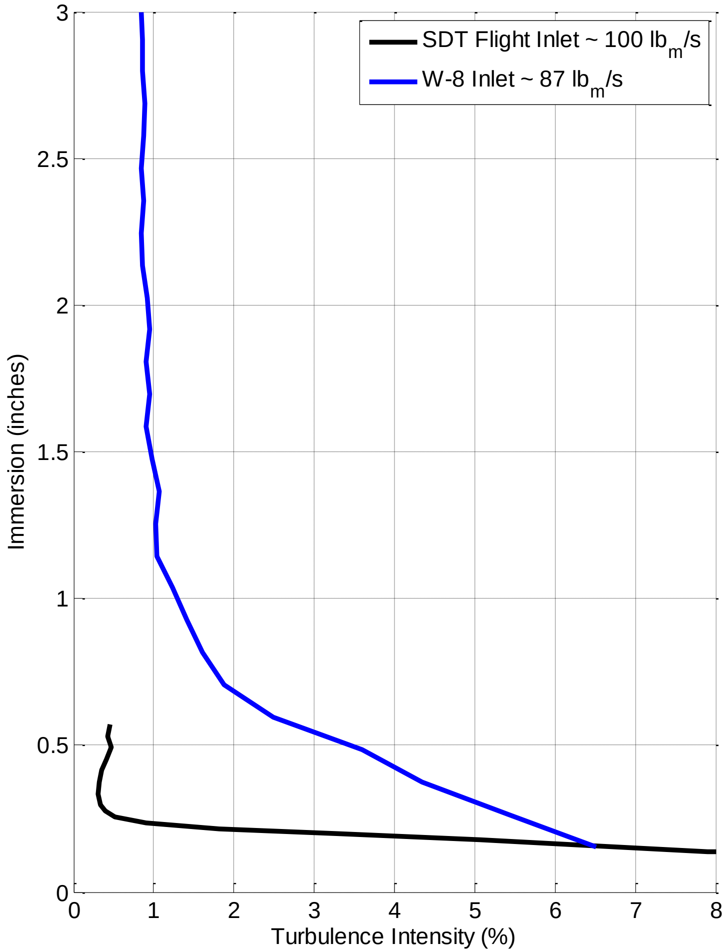


Figure 9. Prediction of Inlet Arc Power Spectral Density (1 Hz Narrowband PWL) Rotor/Turbulence Noise.

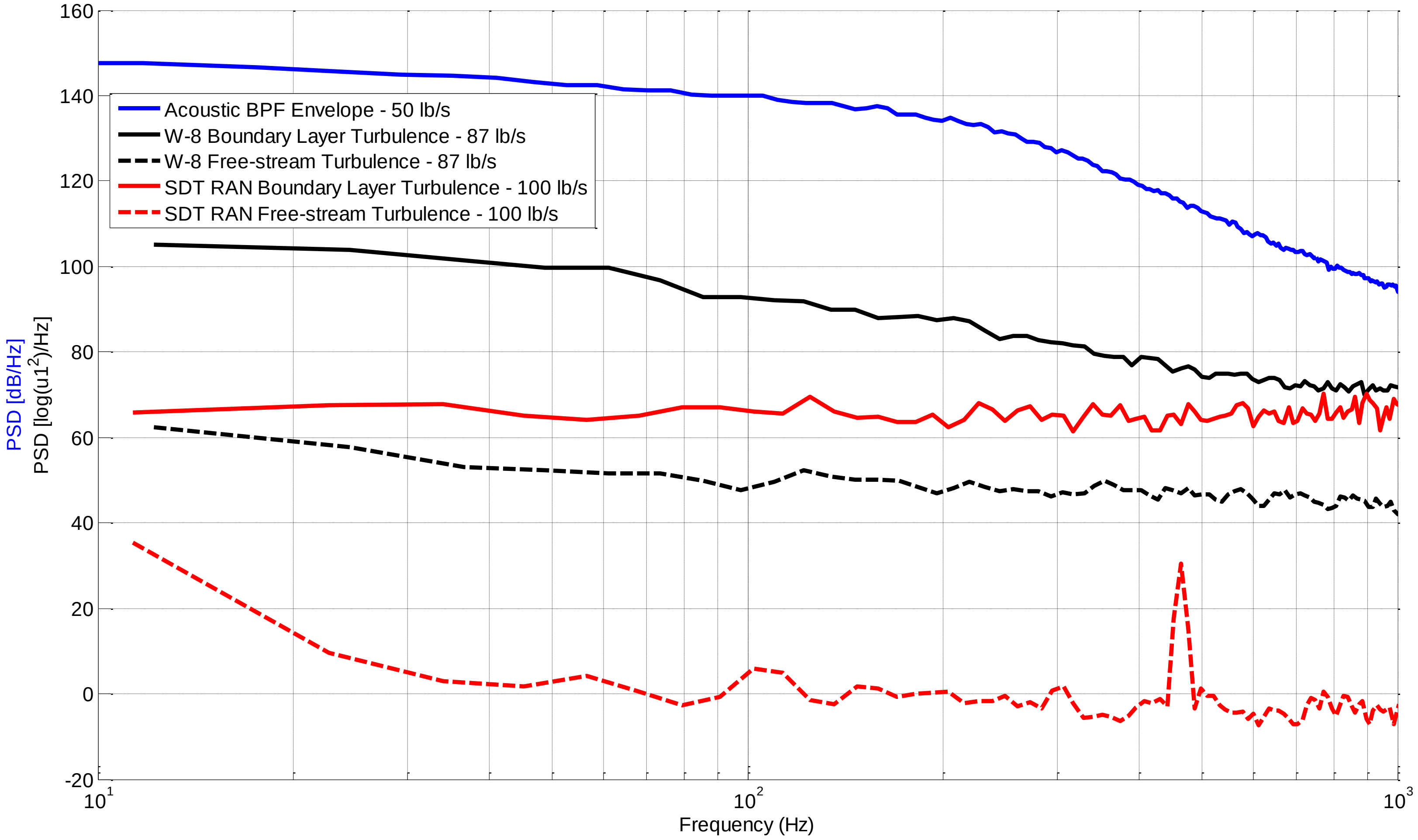
*Gliebe, P. R., and Kerschen, E. J., '*Analytical Study of the Effects of Wind Tunnel Turbulence on Turbofan Rotor Noise*', NASA CR-152359.

Inlet Turbulence Comparison



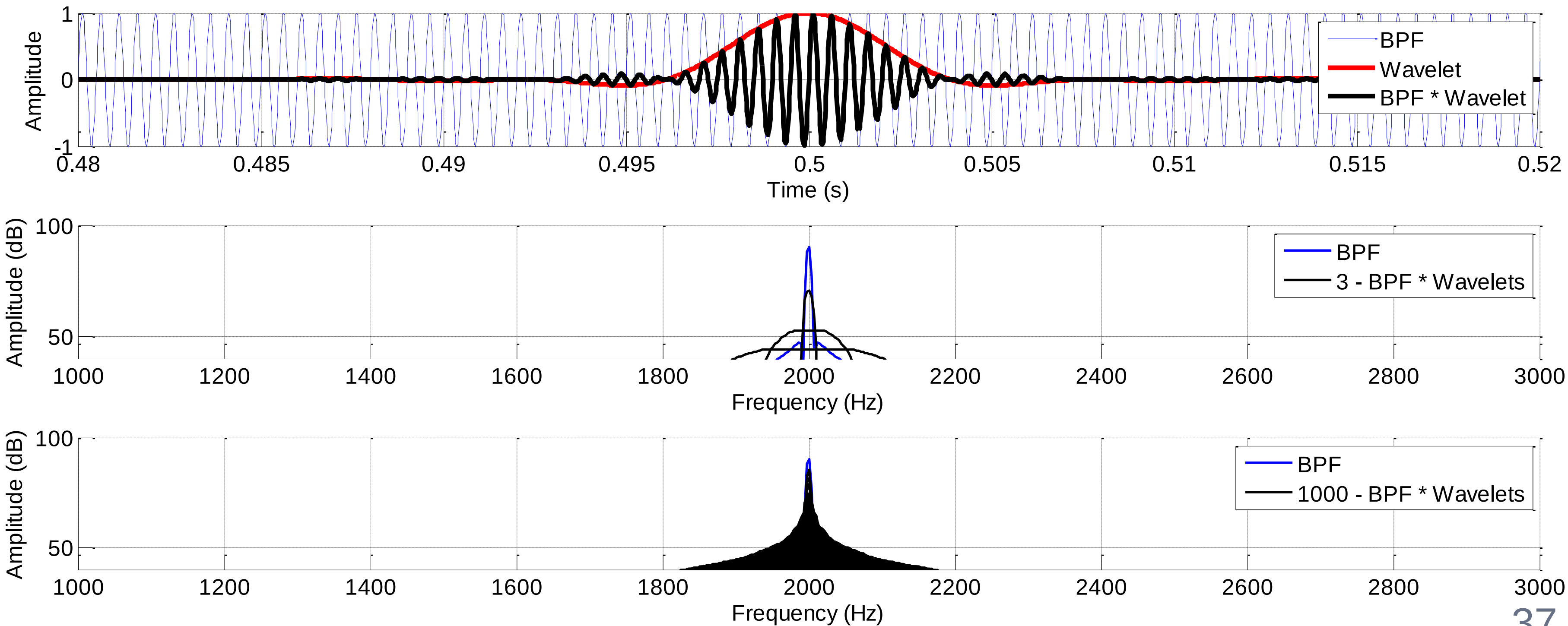


Comparison with Inlet Turbulence Measurements (Hotfilm)

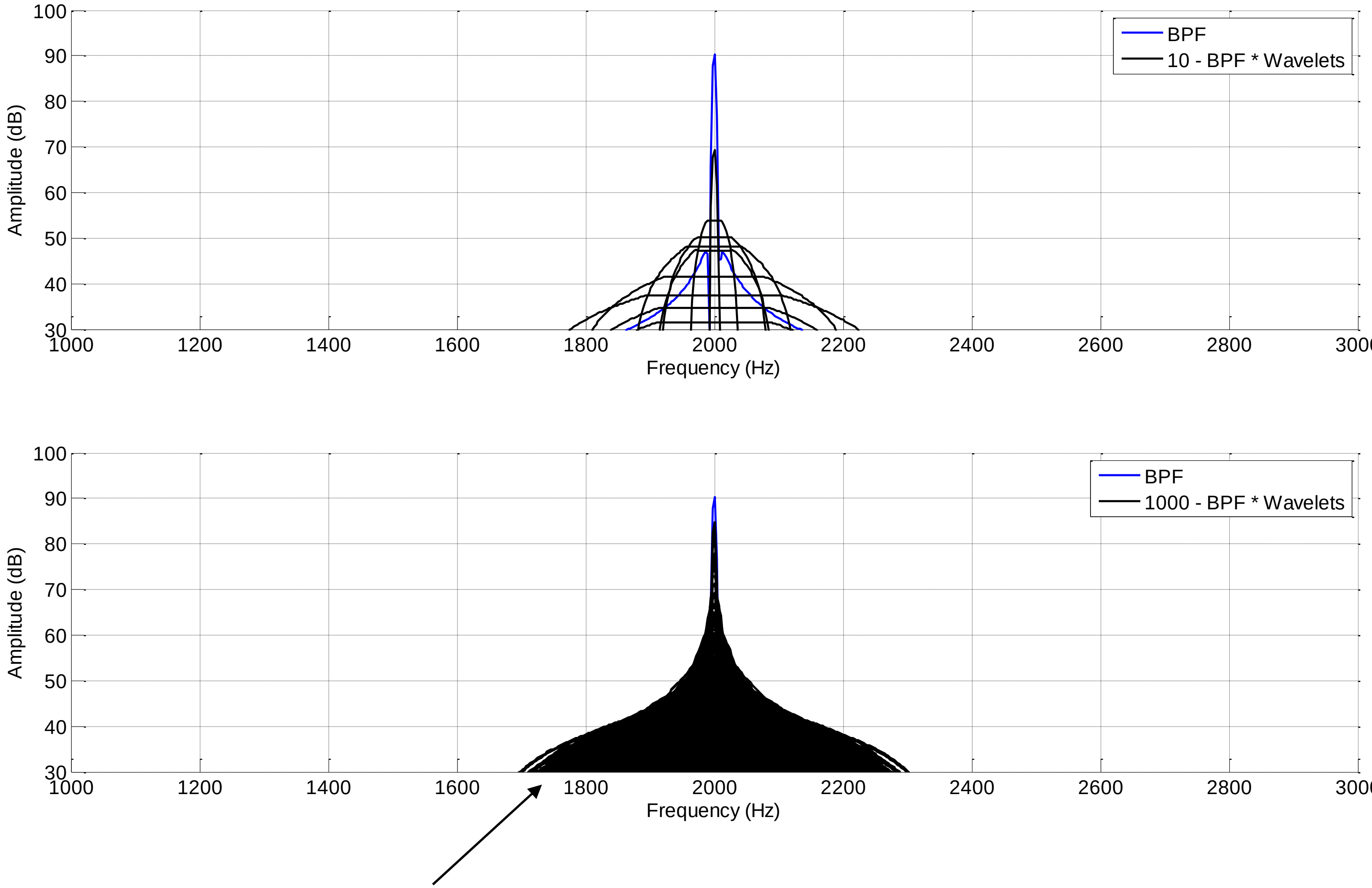


Recreation of Turbulence-Rotor Interaction Tone Broadening

- Each boundary layer source is modelled as a Shannon wavelet (sinc), as shown below.
- The noise from boundary layer impingement with the fan blades is modulated at the BPF.
- Many of these sources are present at any given time, and have are give a random distribution of amplitudes, length-scales, and phases.



Recreation of the spectra analytically



1000 Wavelets with a uniform random distribution of widths, phases, and amplitudes.

Recreation of the BPF Modulation Analytically