Modification of a Broadband Engine Noise Simulator for Enhanced Aft Fan Noise Representation

Kelly M. Shelts, Ian A. Clark, and Yueping Guo

Flight Vehicle Acoustics Branch

NASA Langley Research Center

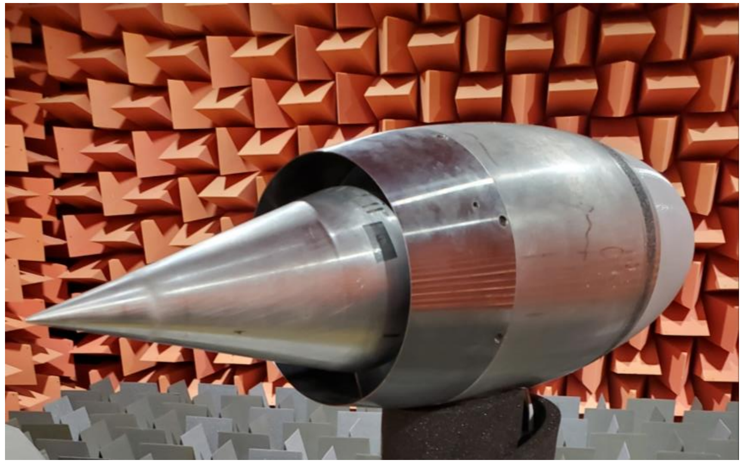
~~AIAA AVIATION 2025~~

NASA Acoustics Technical Working Group Fall 2025

Introduction

- Interaction between engine sources and an airframe (PAA effects) are significant contributors to noise certification levels, especially for unconventional aircraft configurations [1-3]
- Existing methods to model PAA effects include:
  - Empirical models
  - Computational aeroacoustics
  - Experimental tests (wind tunnel, flight, static)
  - Numerical scattering models (TDFAST [4], PAASc [5])
- Static experiments are highly valuable for low TRL concepts and model validation
- This work develops and demonstrates a modified broadband noise simulator to provide representative aft fan noise for future scattering studies

NASA Aeronautics Concept Vehicles

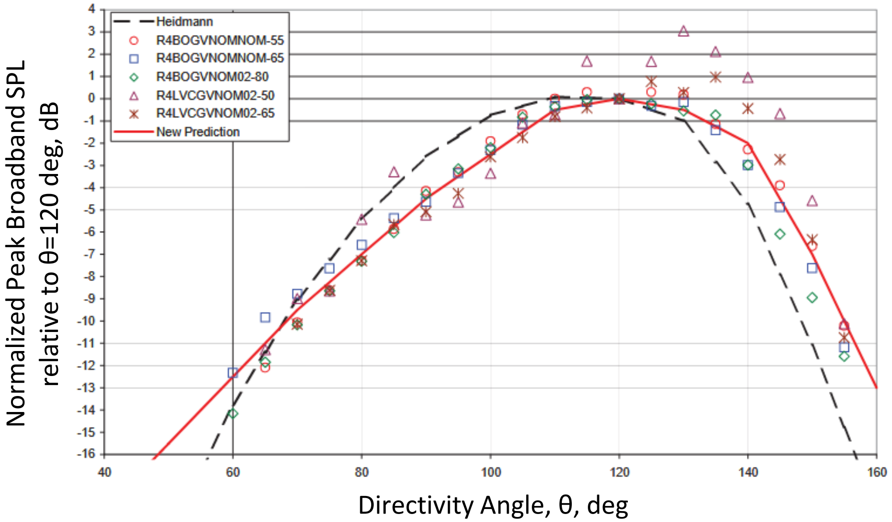


Broadband Noise Simulator (BNS)

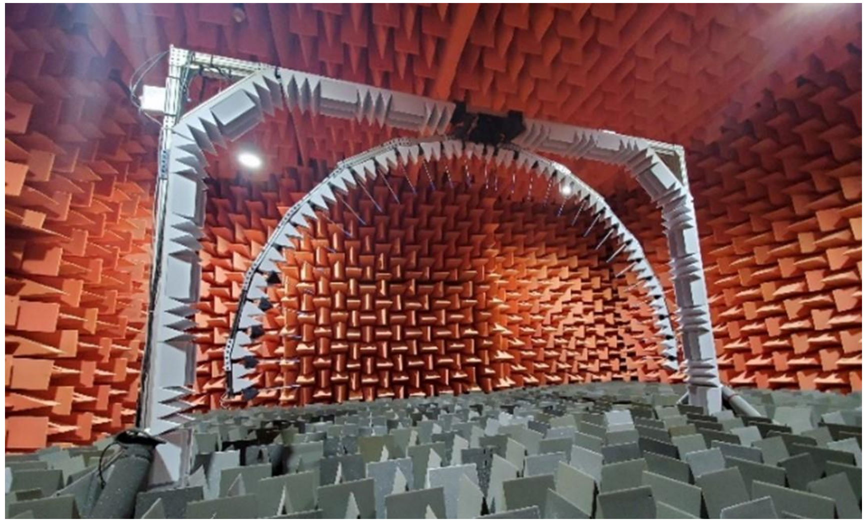
[1] June, et al., AIAA 2022-3049
[2] Clark, et al., AIAA 2018-3124
[3] Thomas et al., AIAA 2016-0863
[4] Nark and Hu, AIAA 2021-2201
[5] Guo and Thomas, “Airframe Scattering of Engine Fan Noise,” to appear in International Journal of Aeroacoustics

Goals

- Develop a noise simulator that represents aft-radiated broadband fan noise from high-bypass ratio turbofans
  - Representative directivity: peak noise approximately 120° from inlet axis (Krejsa & Stone model)
  - High noise levels from 8–50 kHz appropriate for 8–12% scale airframes
- Characterize acoustic behavior using the High Resolution Traversing Microphone Array (HiRTMA)
- Validate against published models and assess trade-offs in configurations
- Provide capability for future static PAA scattering experiments



Broadband Directivity Correlation from Krejsa and Stone Model [1]

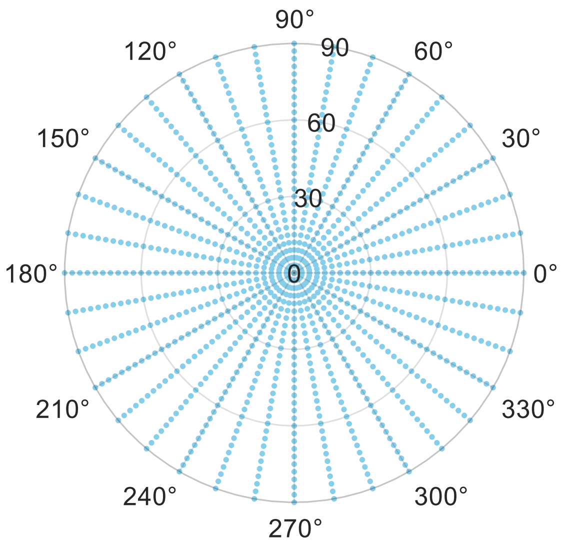


High Resolution Traversing Microphone Array (HiRTMA)

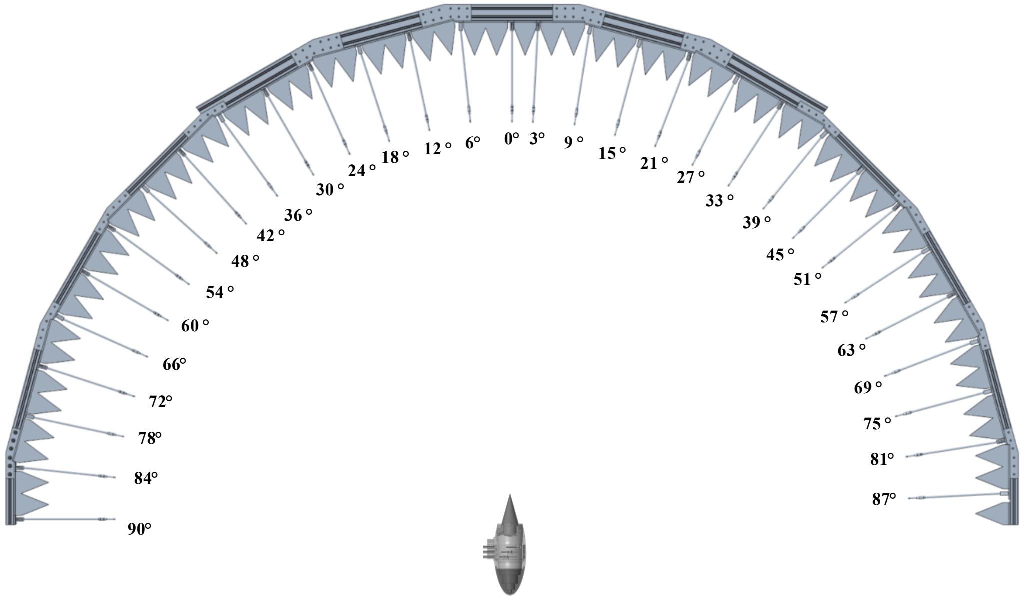
[1] Krejsa and Stone, AIAA 2014-2624

Instrumentation and Measurement

- High Resolution Traversing Microphone Array [1]
  - 31 microphones spaced on arc
  - Arc rotated with precision rotation stage
  - Microphone offset enabling 3° polar resolution with full +- 180° rotation of array
- Instrumentation
  - B&K 4954B microphones
  - Frequency response range from 16 Hz to 80 kHz
- Data Acquisition Procedure
  - Arc moved to desired position with ramp up/ramp down motion profile
  - Motor controller disabled
  - Data acquired for 10 sec at 204,800 samples/second



HiRTMA measurement locations projected on flat plane

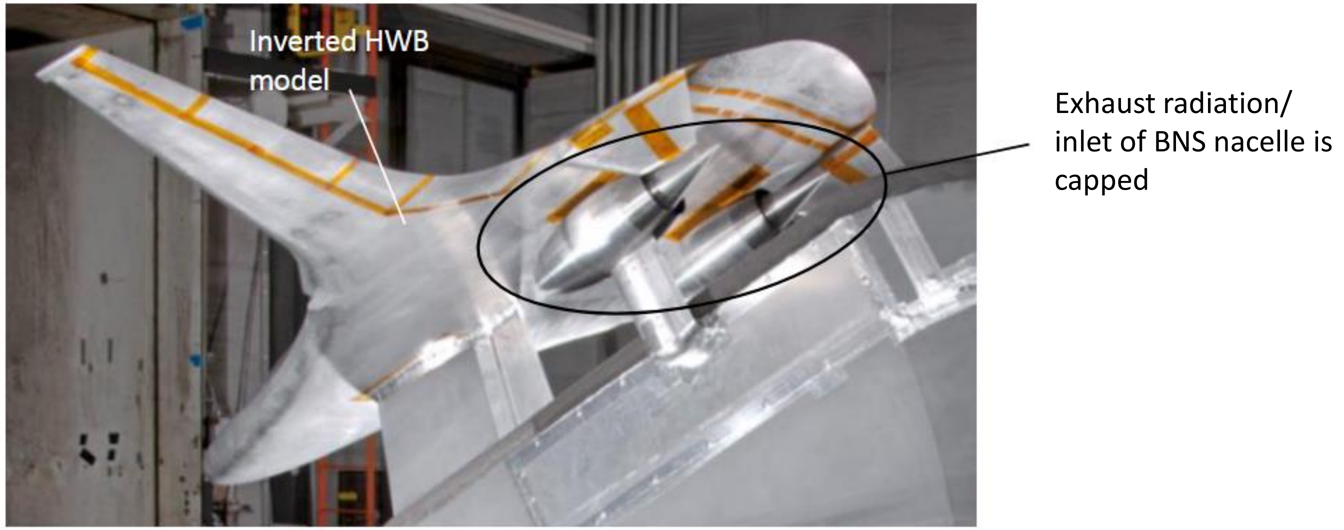


HiRTMA Arc with microphone angles

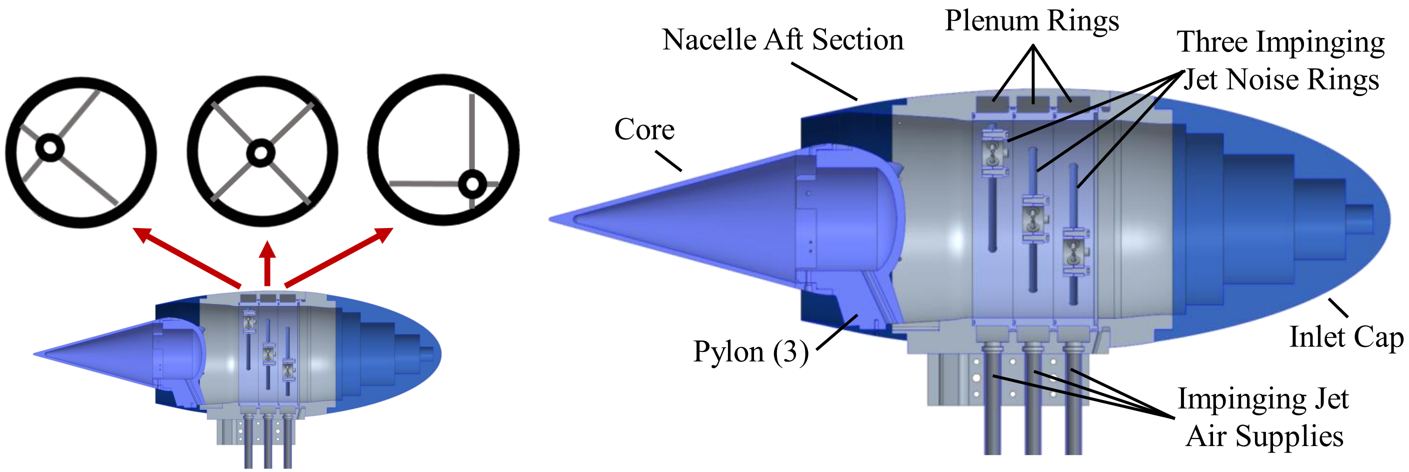
[1] Shelts, et al., NASA TM 20250008157

Broadband Noise Simulator (BNS)

- Hardware system used in previous wind tunnel experiments to study effects of engine placement on acoustic shielding [1]
- Pressurized air fed to impinging jet devices to create broadband noise
- Generates appropriate noise levels and spectral content, but directivity is not representative of aft fan broadband noise



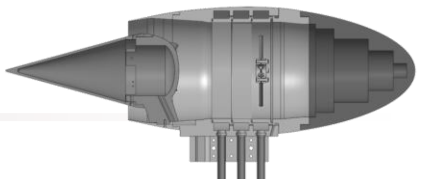
BNS nacelles installed with Hybrid Wing Body airframe in NASA Langley 14 x 22 Wind Tunnel [1]



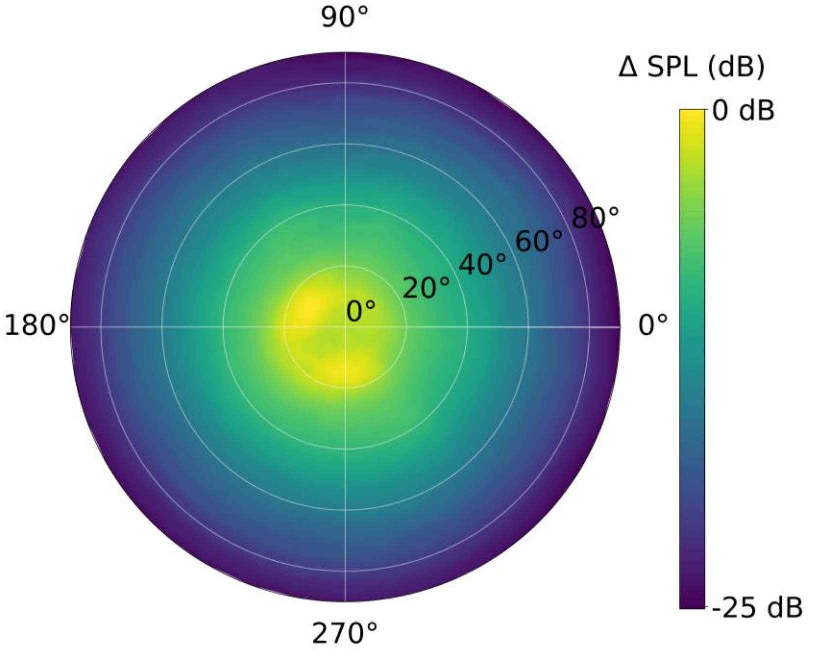
BNS Components

[1] Hutcheson, et al., AIAA 2014-2624

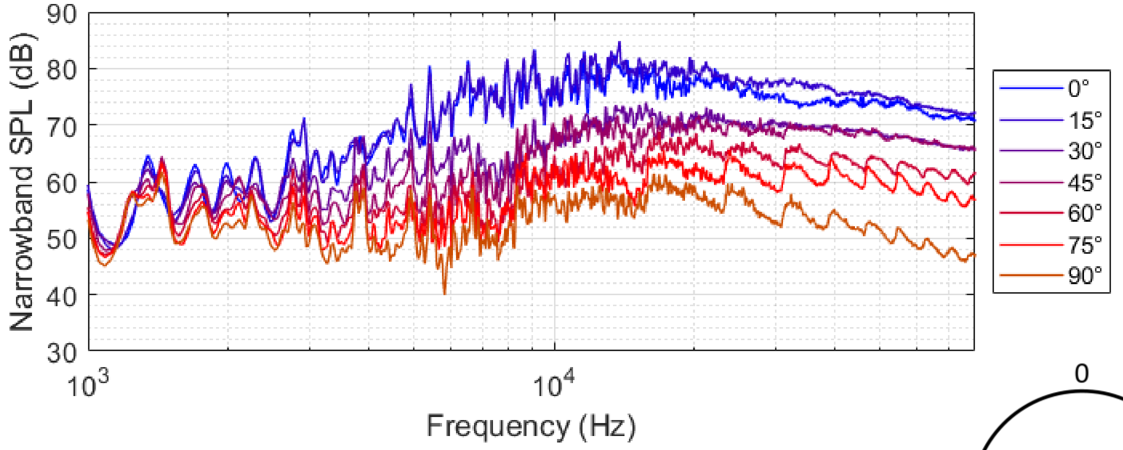
Original BNS



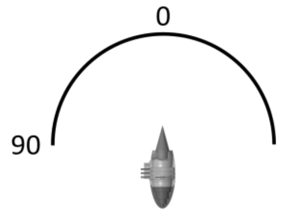
- Centered noise ring in upstream position
- Highest noise level in line with exhaust axis
- Significant decrease in sound levels past 30° polar angle
- Axial asymmetry in the center of measurement field due to individual noise ring characteristics

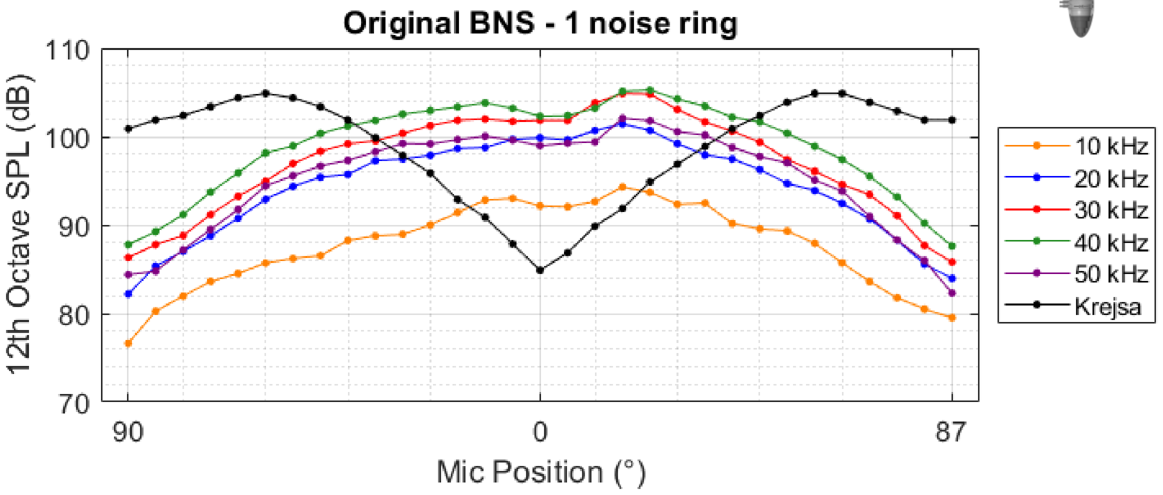


30 kHz one-twelfth-octave band SPL contours, normalized to the contour peak level



Narrowband far-field acoustic spectra



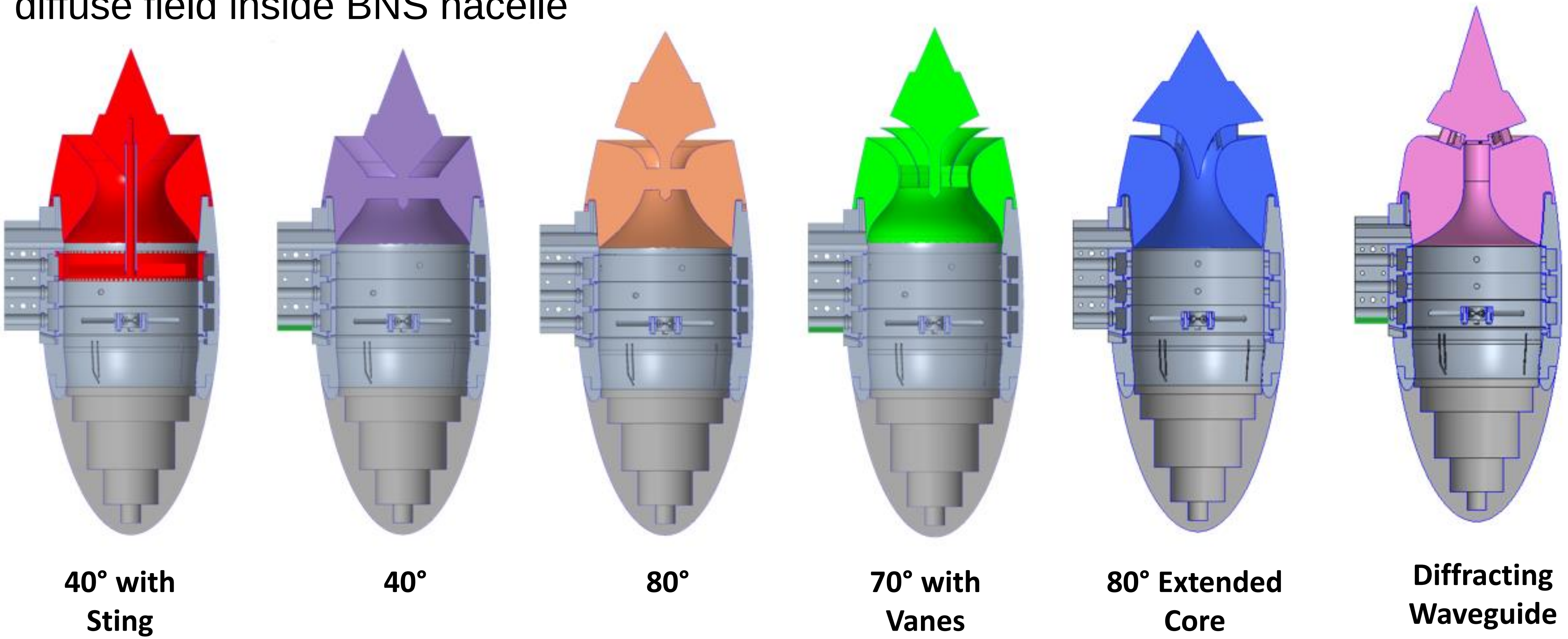


Far-field directivity

* Note that Krejsa values shown are normalized to peak sound level of measured data

Waveguides

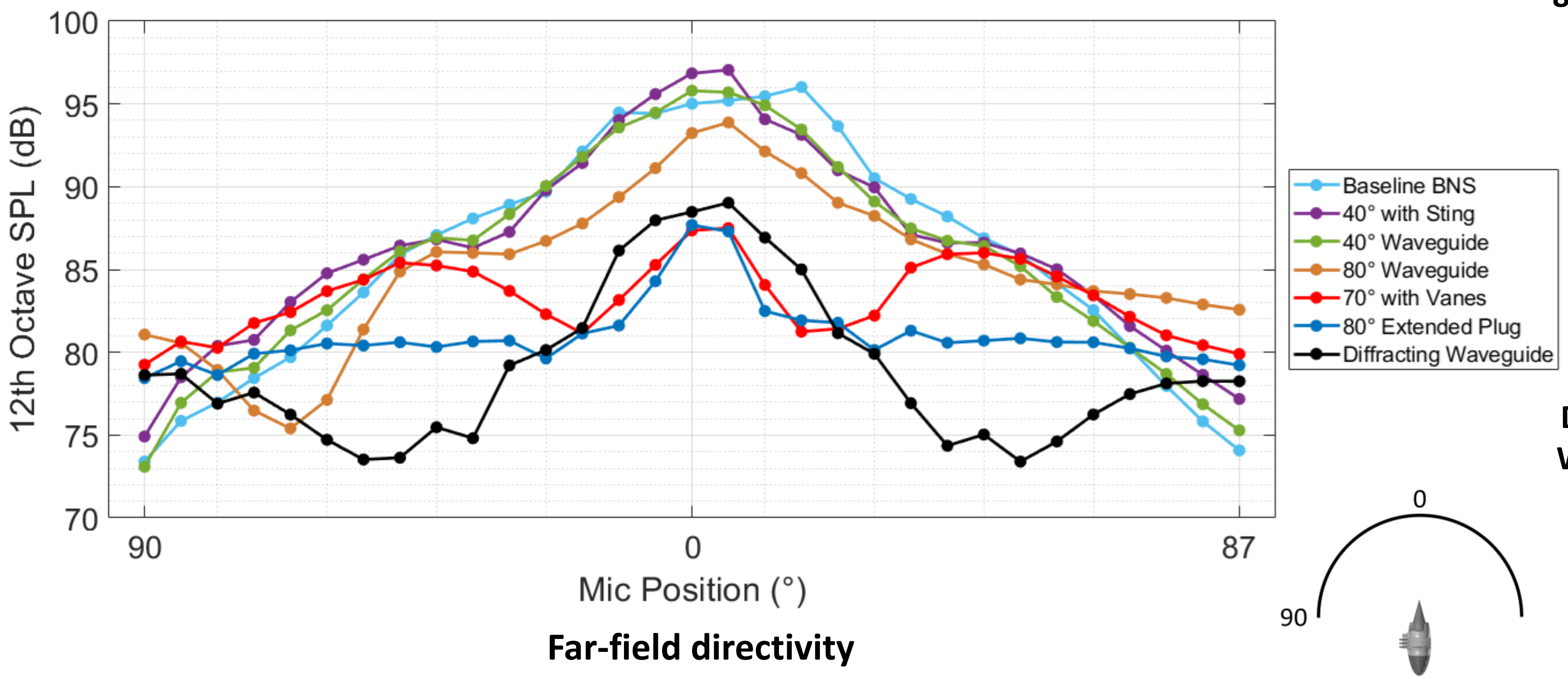
- First attempt at changing directivity while maintaining geometric realism
- Utilize converging-diverging channel around new plug to guide sound waves toward peak radiation direction
- Assuming that impinging jets are acting as omnidirectional point sources [1-3] creating diffuse field inside BNS nacelle



[1] Czech et al., Int. J. Aeroacoustics, 2012, [2] Gerhold et al., J. Sound & Vibration, 2006, [3] Clark and Gerhold, AIAA, 1999

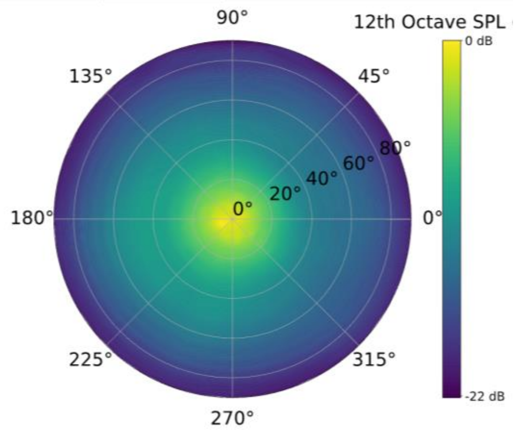
Waveguide Results

- All waveguide configurations maintained peak noise in line with exhaust axis
- Waveguides reduced radiated sound levels
- Vane locations observable for waveguides with support plug vanes closer to channel exit
- Unexpected results prompted investigation into impinging jet behavior

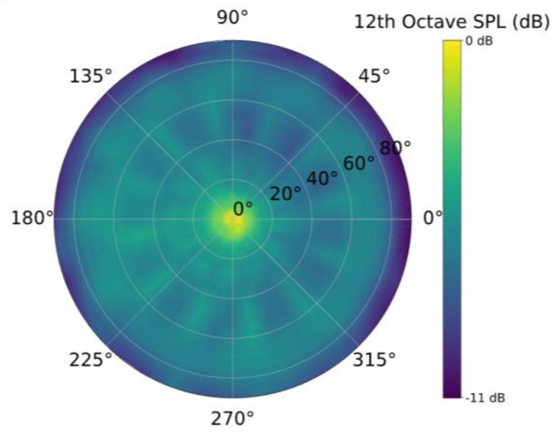


Far-field directivity

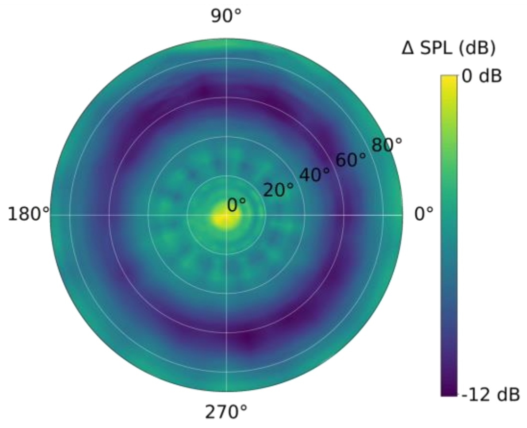
40° with Sting



80° Extended Plug



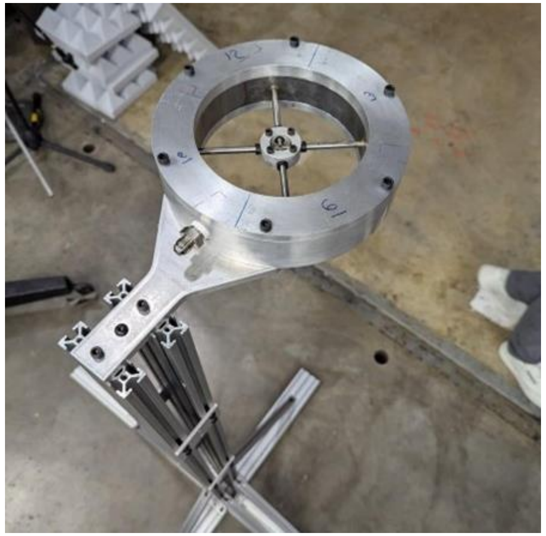
Diffracting Waveguide



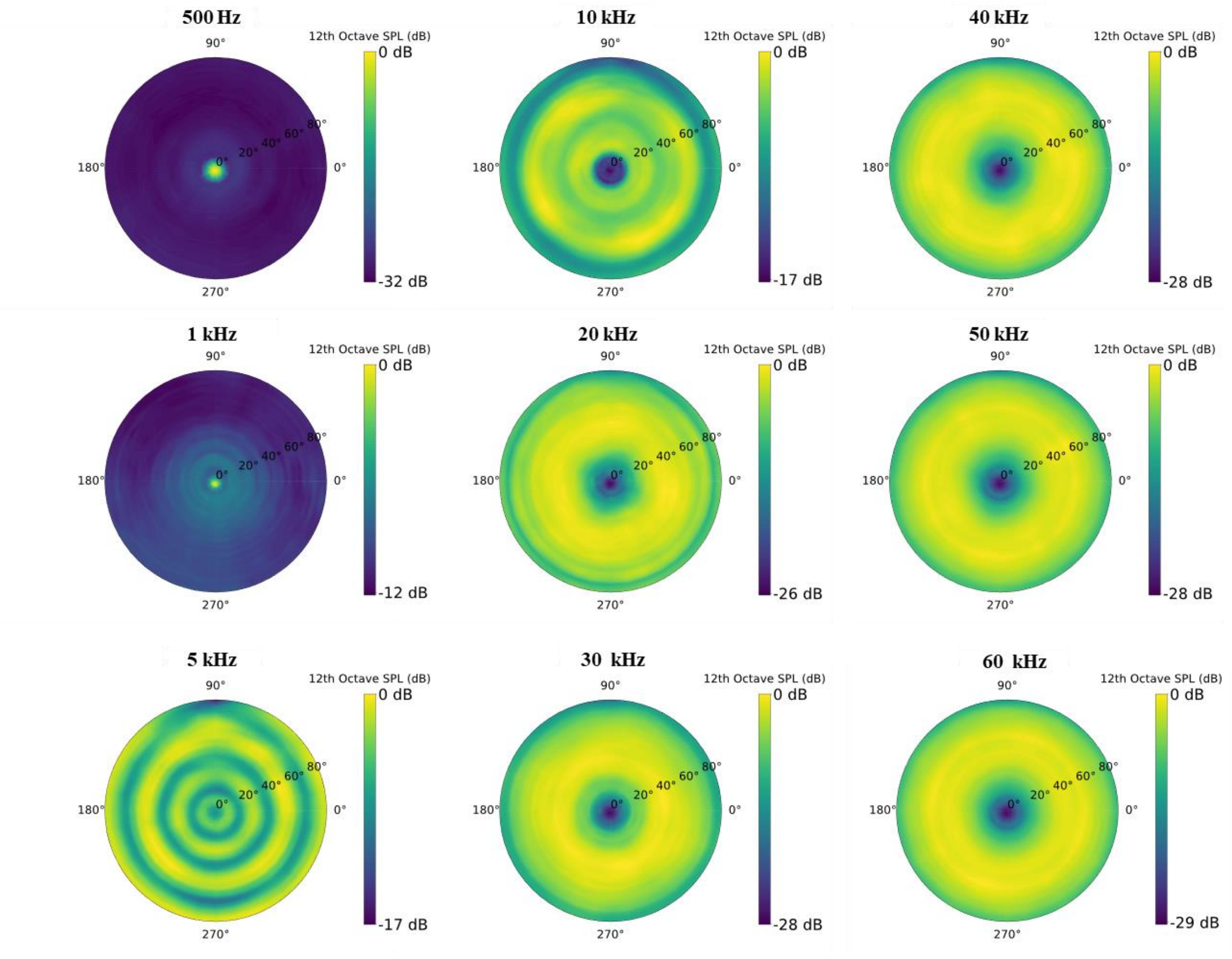
30 kHz

Impinging Jet Investigation

- Below 1 kHz, peak levels directly above jets
- Strong interference pattern at 5 kHz, where the wavelength approximately equals distance between jets and ring surface
- High frequencies (>20 kHz) show peak levels around 40° polar angle



Noise ring on stand



Normalized one-twelfth-octave SPL contours

Proposed Physical Explanation

Impinging Jet Physics

- Four jets impinge creating perpendicular air stream
- Jet stream carries low frequency hydrodynamic pressure fluctuations – localized excitation at 0°
- High frequency noise generated at impingement zone by turbulence and shock cell interactions [1]
- Air stream refracts acoustic waves away from centerline

Waveguide Ring Source

- Diffuse sound field forms inside BNS nacelle
- Sound propagates as plane waves through annular duct
- Exit plane acts as coherent 'ring source'
- All parts of ring have direct line-of-sight to 0°
- Ring source effect dominates radiation regardless of waveguide geometry

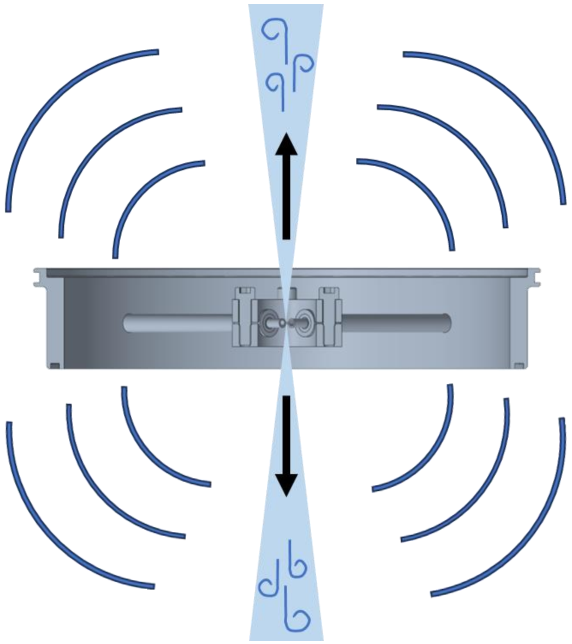


Illustration of impinging jet characteristics

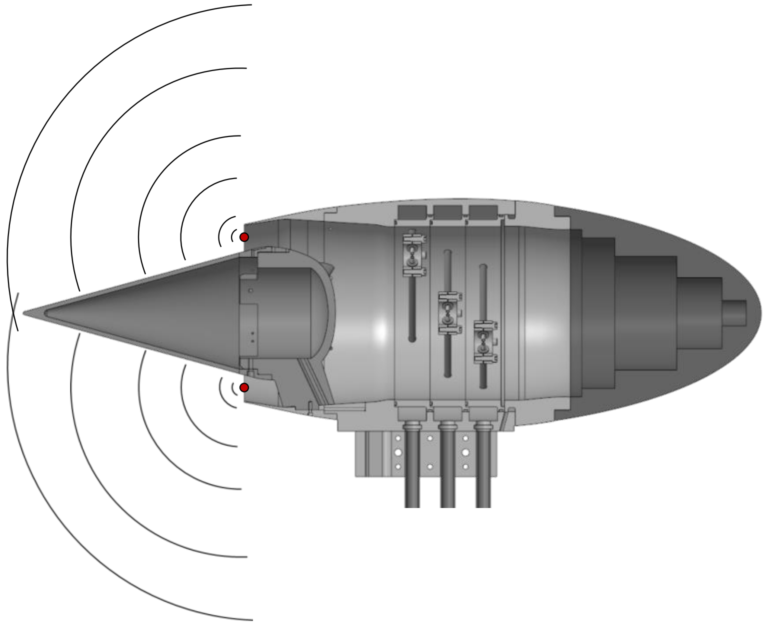


Illustration of acoustic radiation due to ring source

[1] Brehm, et al., AIAA 2015-2211

Optimized Configurations

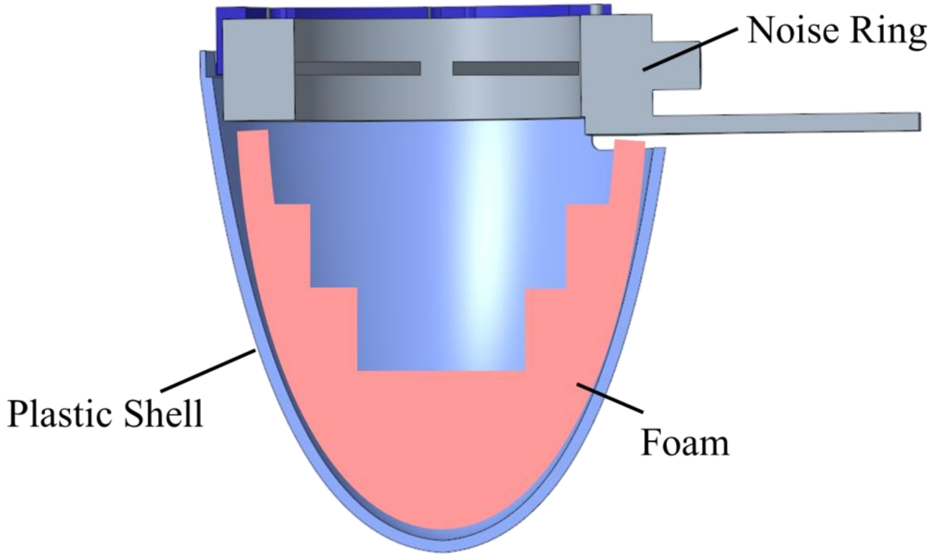
Shifted strategy from <u>modifying</u> directivity of diffuse field to <u>preserving</u> natural directivity of impinging jet source

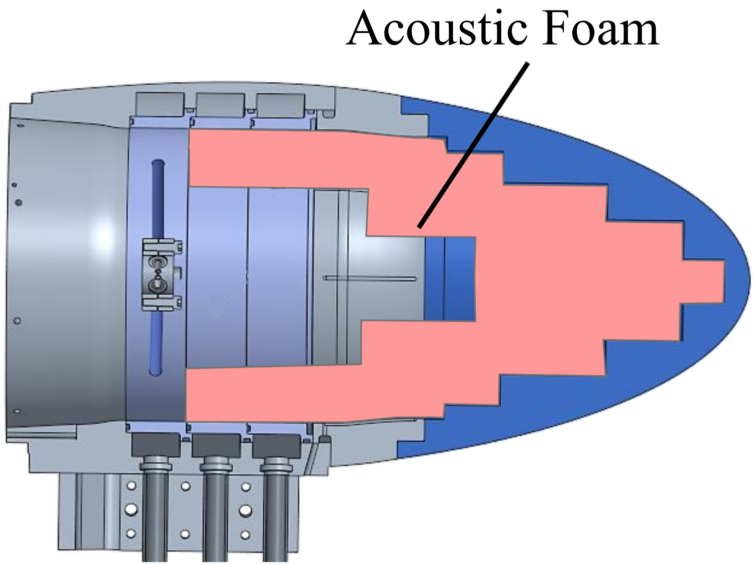
Acoustically treated inlet cover

- Shell blocks upstream radiation
- Acoustic treatment prevents internal reflections

Optimized BNS

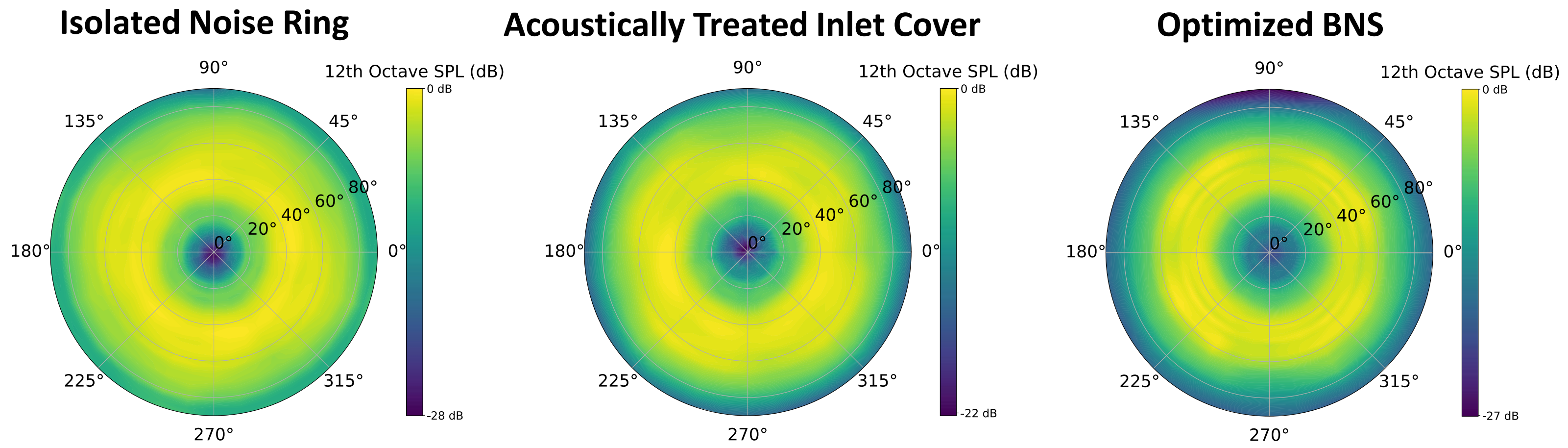
- Source moved downstream near nacelle exit
- Acoustic treatment prevents internal reflections



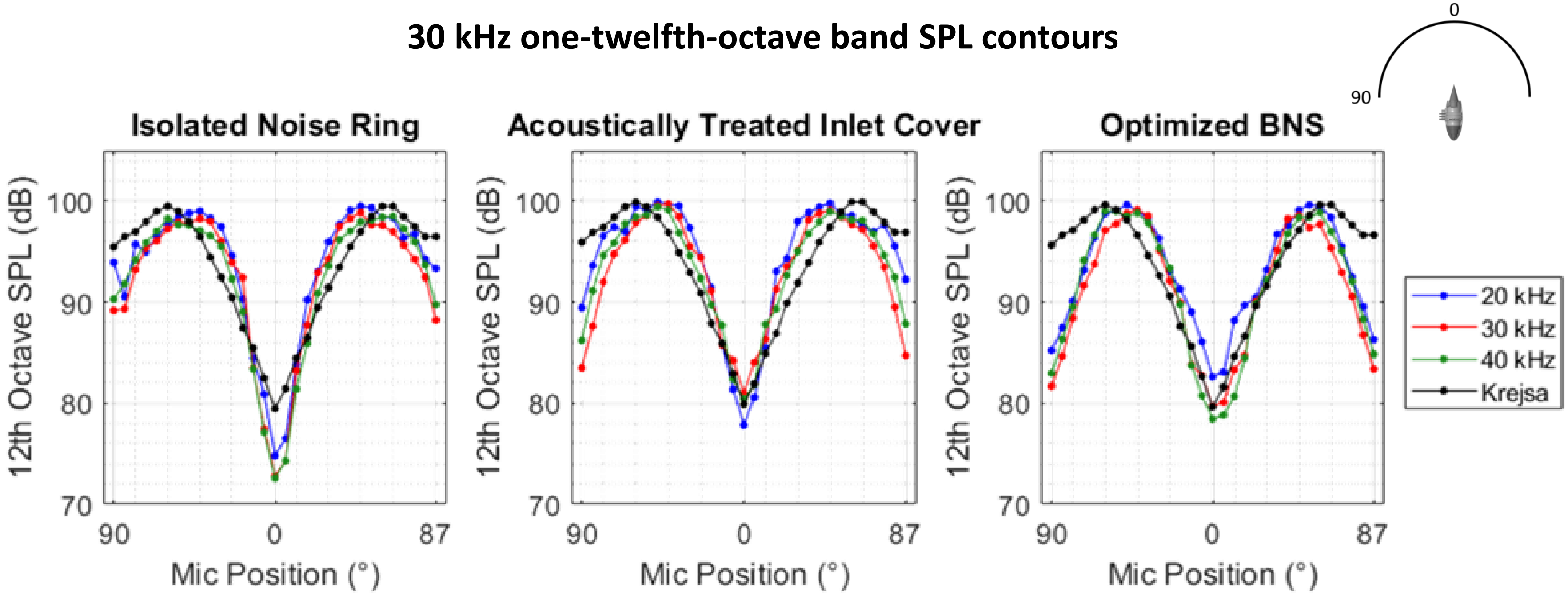


Optimized Configuration Results

- Acoustically Treated Inlet Cover
  - Preserves directivity of isolated noise ring from 0° to 80° polar angle
  - Peak sound level between 40° and 50°
  - Decreases in SPL at high polar angles due to additional shielding from cover structure
- Optimized BNS
  - Preserves directivity of isolated noise ring from 0° to 50° polar angle
  - Peak sound level between 40° and 50°
  - Decreases in SPL at high polar angles due to additional shielding from BNS nacelle



30 kHz one-twelfth-octave band SPL contours

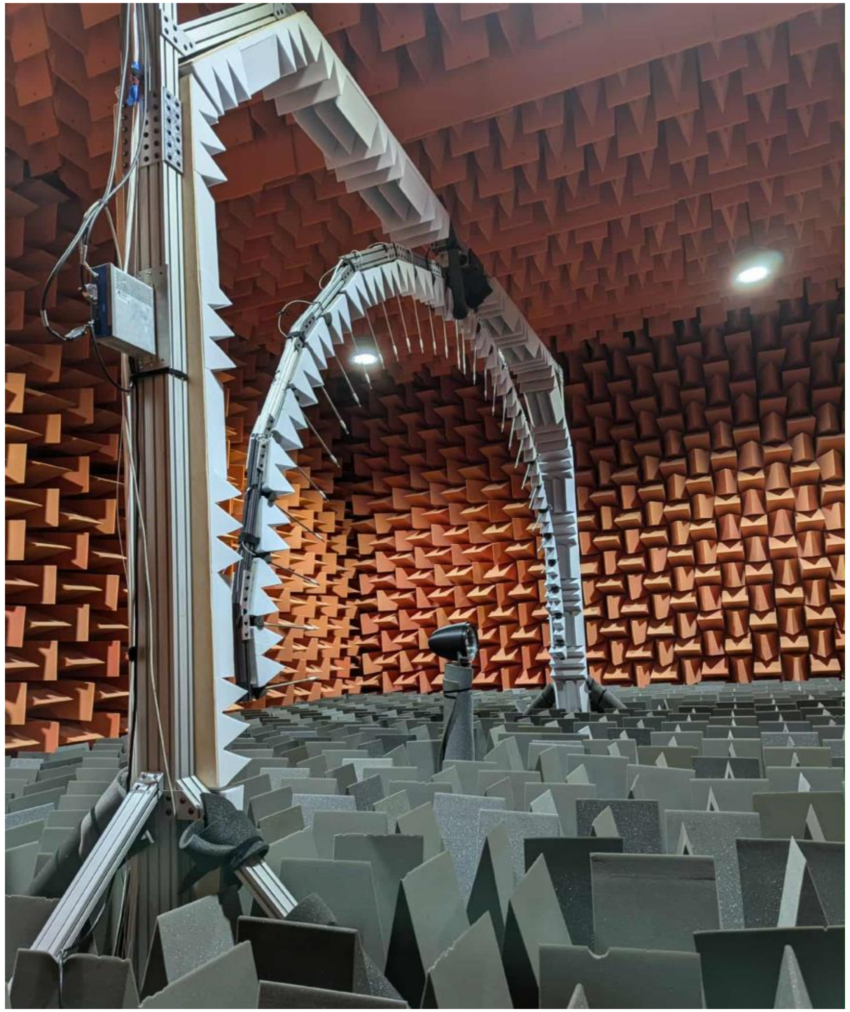


Far-field directivity

Concluding Remarks

- Waveguide approach limited by ring source effect
- Impinging jet source has more complicated and frequency-dependent radiation pattern than previous studies suggest
- Achieved desired simulator characteristics with two viable configurations
    - Both Acoustically Lined Inlet Cover and Optimized BNS configurations achieve peak sound directivity between 40° and 50°, similar to directivity of Krejsa-Stone aft fan noise predictions
    - Trade-off of sharper SPL rolloff at sideline
- Source is ready for integration into future propulsion-airframe scattering studies

- **Paper: AIAA 2025-3882**



Acoustically Lined Inlet Cover Configuration with HiRTMA

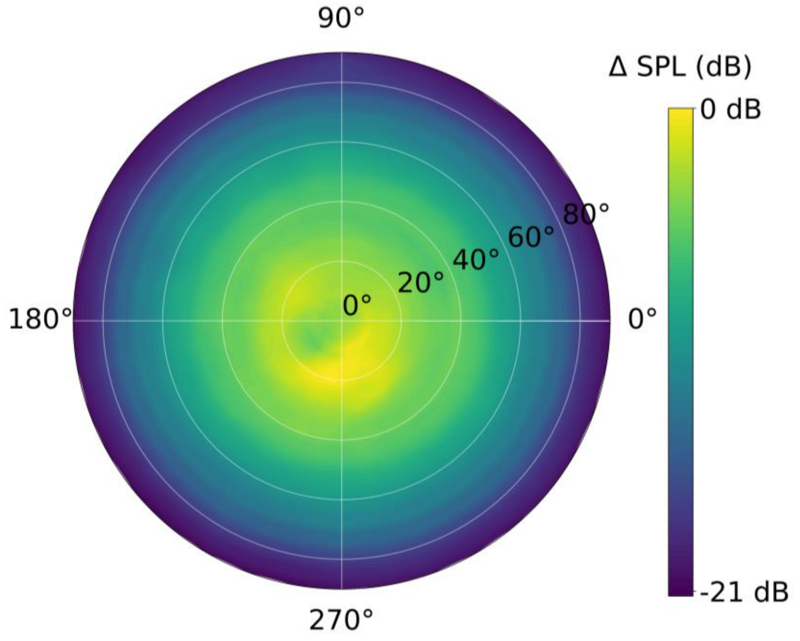
Acknowledgments

- This work was supported by the NASA Advanced Air Transport Technology (AATT) Project of the NASA Advanced Air Vehicles Program (AAVP).
- Additional thanks to:
  - Phillip London for his support on this experiment as a summer intern in 2024
  - Jason June, Eric Nesbitt, and Russell Thomas for valuable technical discussions
  - Jaye Moen for his facility and hardware support

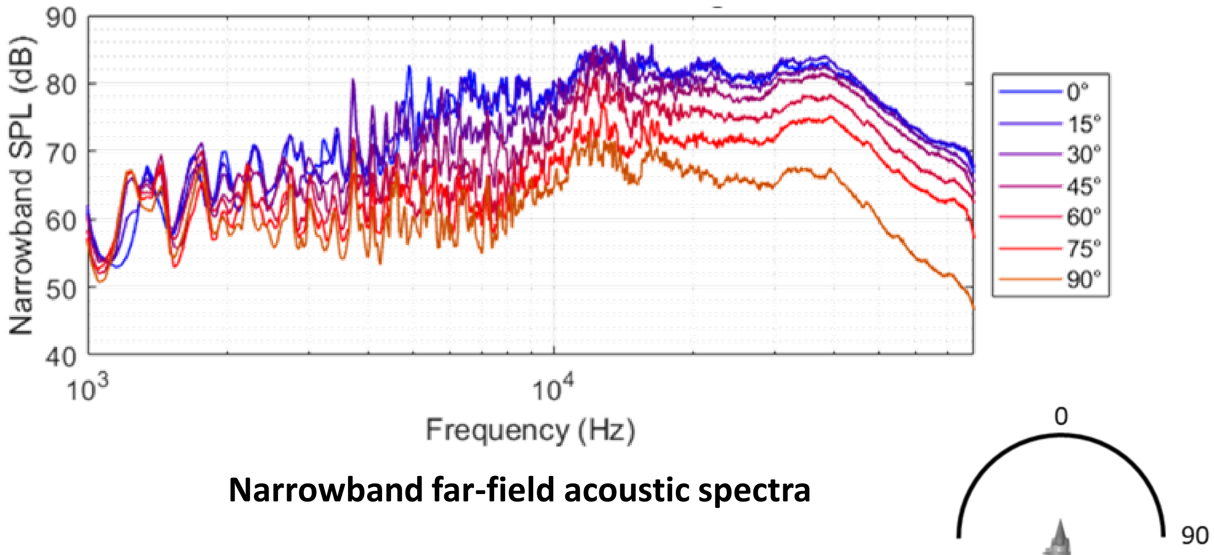
Extra Slides

Original BNS – 3 noise rings

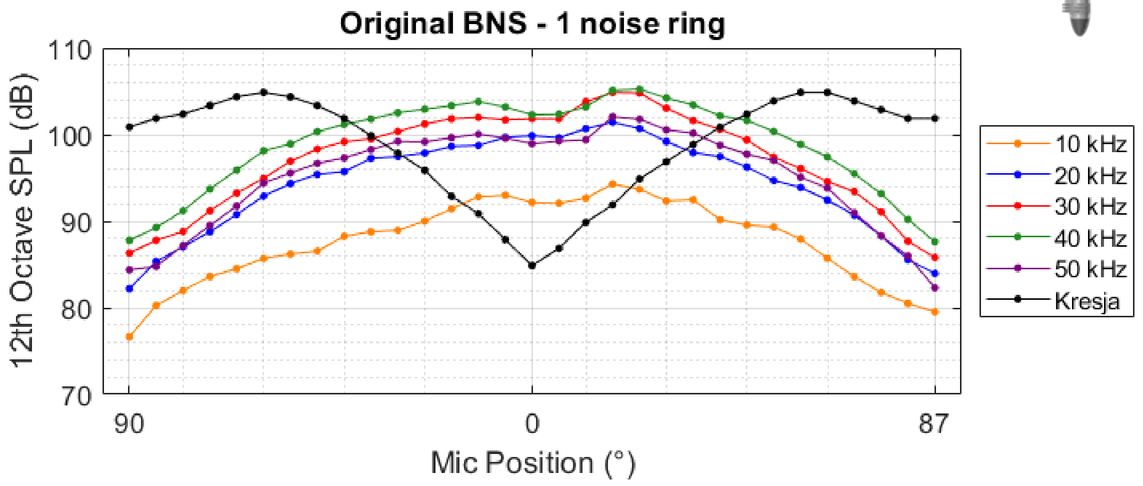
- Three noise rings
- Highest noise level in line with exhaust axis
- Significant decreases past 30° polar angle
- Axial asymmetry in the center of measurement field due to individual noise ring characteristics



30 kHz one-twelfth-octave band SPL contours, normalized to the contour peak level



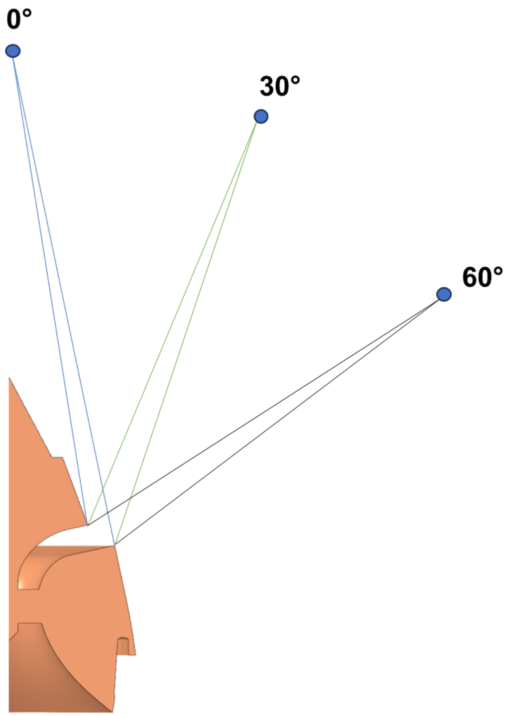
Narrowband far-field acoustic spectra

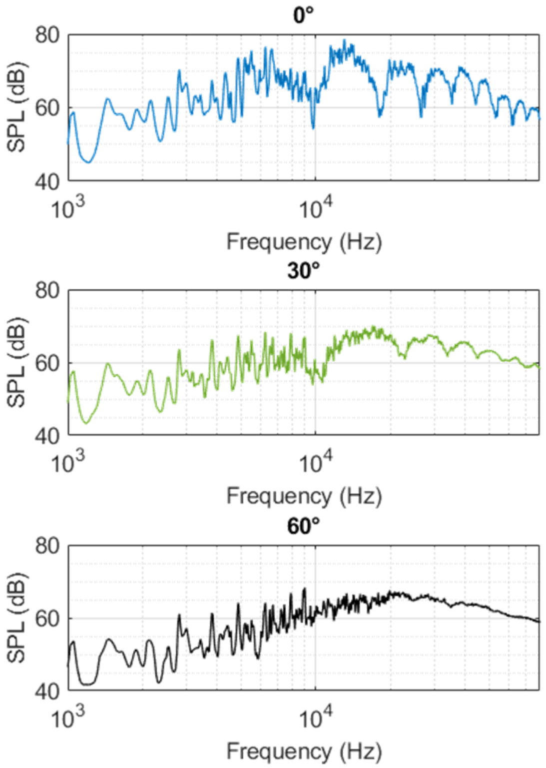


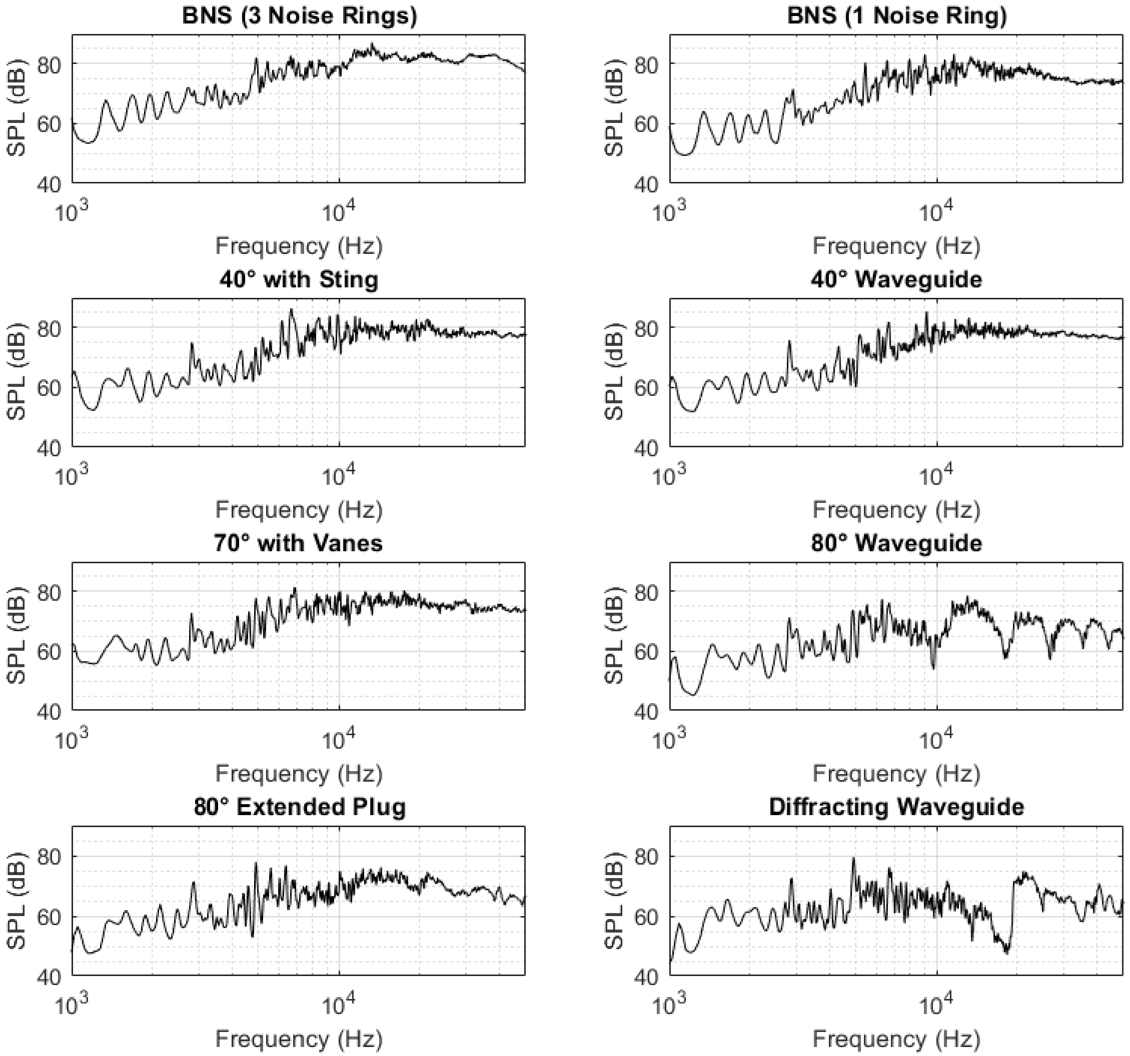
Narrowband far-field acoustic spectra

Waveguide Results

- Noise level reduced for all waveguide configurations compared to baseline
- More material in channel, lower noise level
- Interference pattern observable for some configurations due to diffraction of duct edges

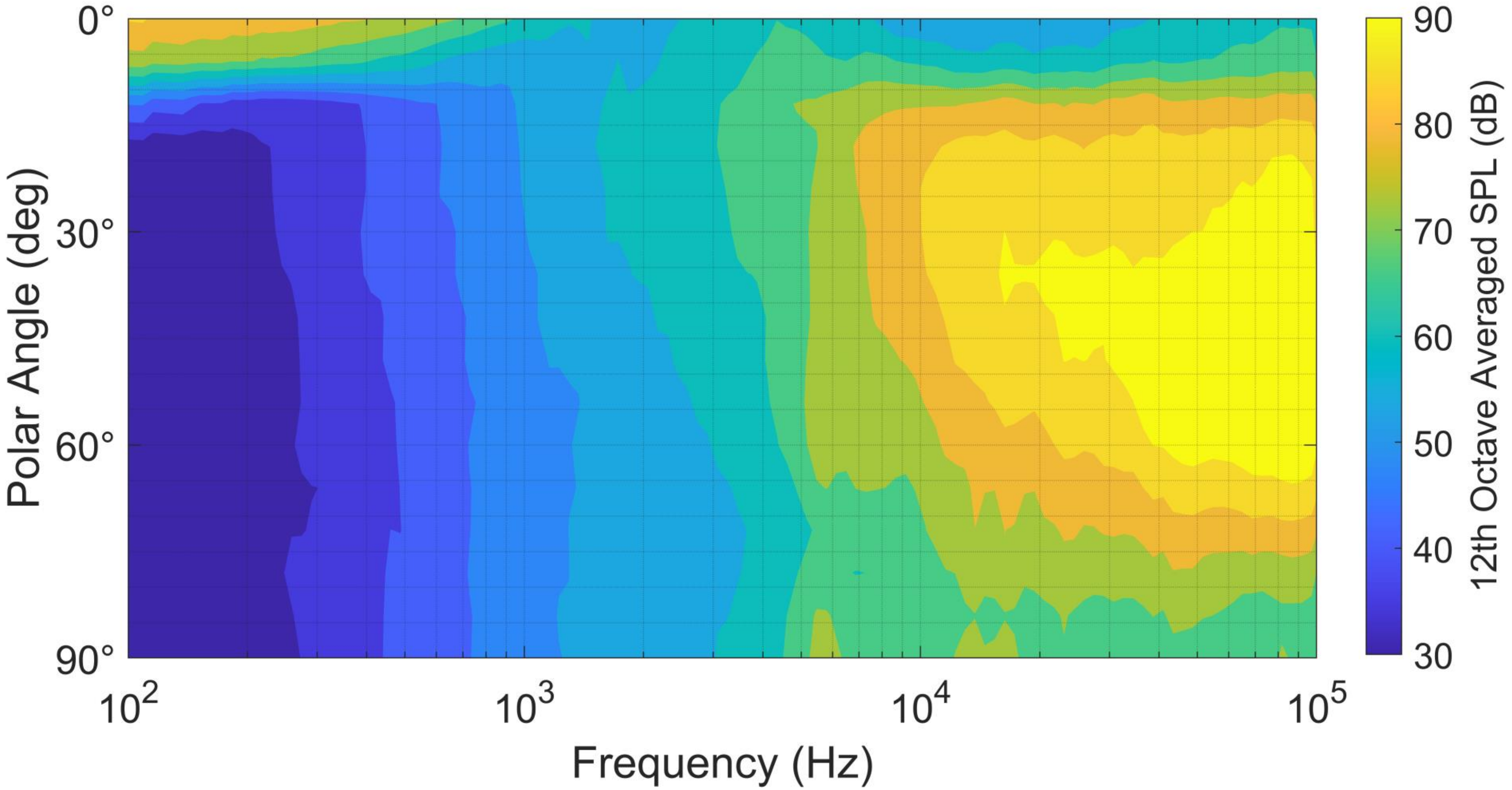




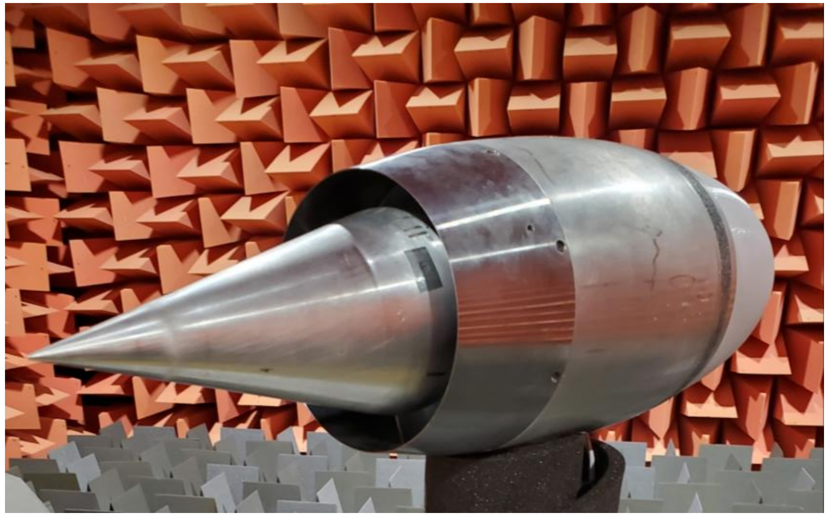


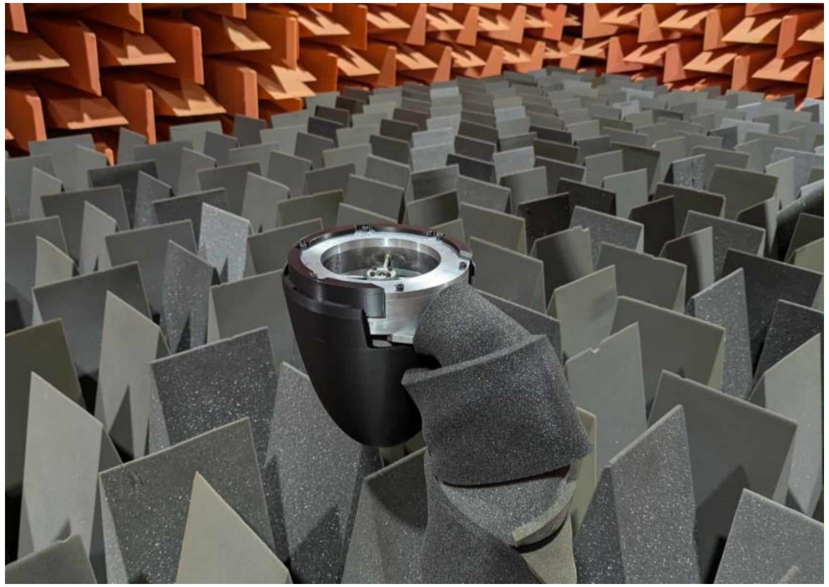
30 kHz one-twelfth-octave band SPL contours, normalized to the contour peak level

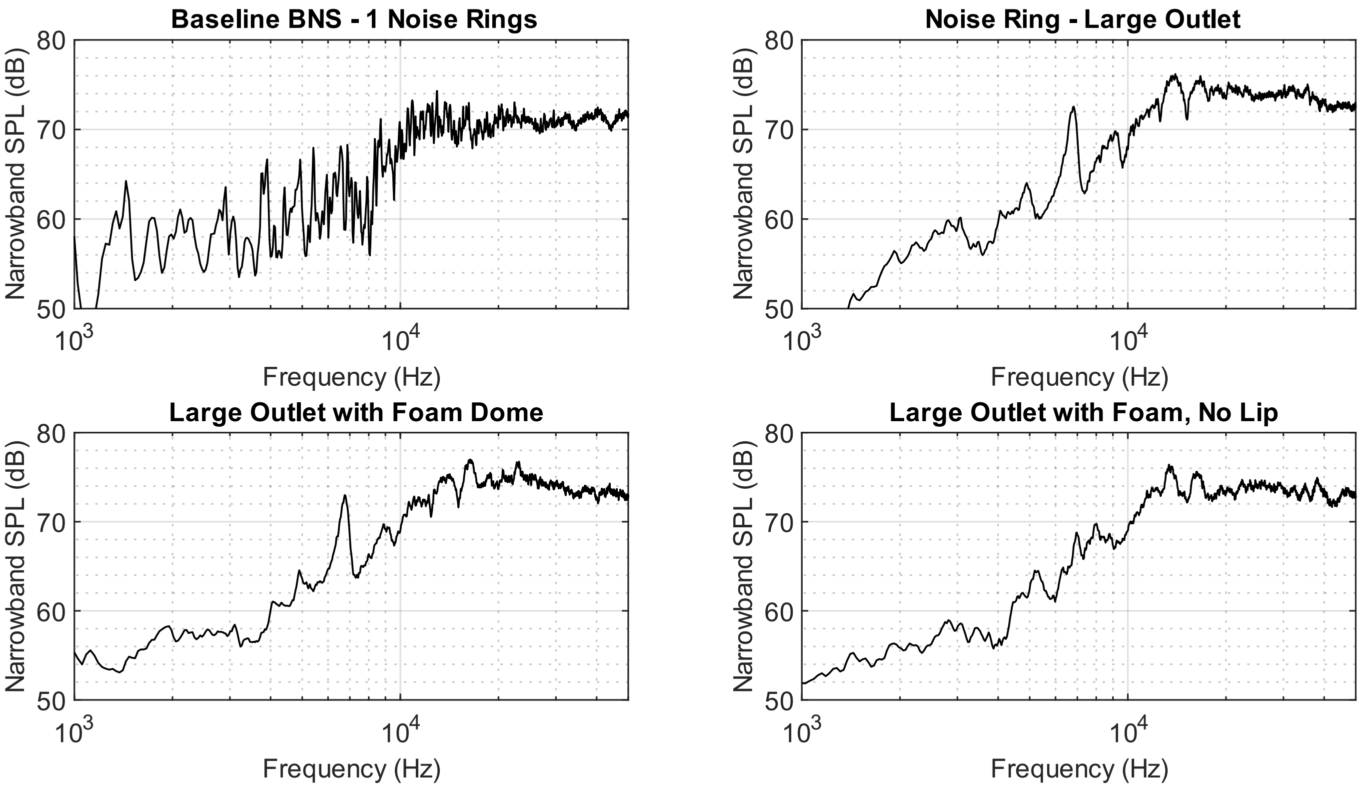
Impinging Jet Spectogram



Spectra






Baseline BNS - 1 Noise Rings
Noise Ring - Large Outlet
Large Outlet with Foam Dome
Large Outlet with Foam, No Lip
Narrowband SPL (dB)
50
60
70
80
Frequency (Hz)
10^3
10^4