Acoustic Scattering Predictions for Complex Sources and Aircraft Configurations

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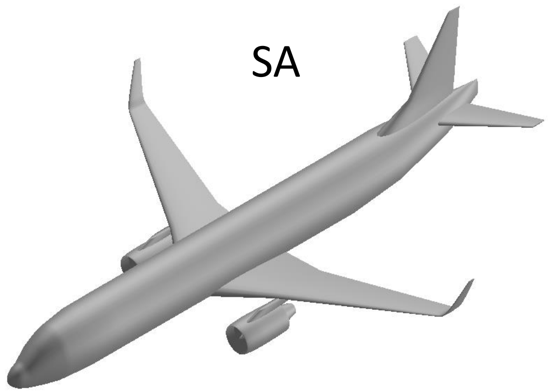
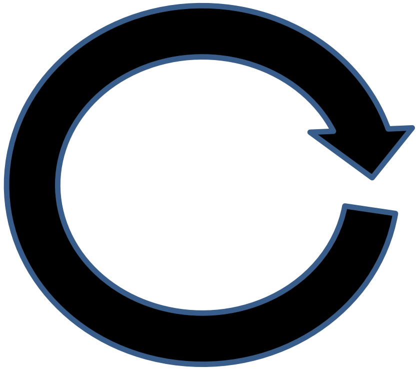
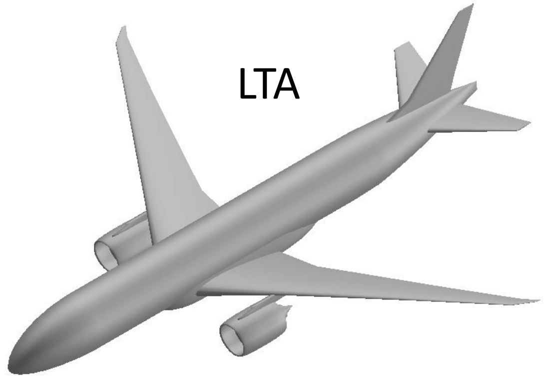
Outline

- Background
- MIT D8.5 scattering/shielding
  - FSC Suppression Tables
  - Next Steps
- Incident Source Directivity Effects
  - F31A31 9x15 test predictions
  - Initial TD-Fast predictions
  - Additional geometric complexity
- Concluding Remarks

Background



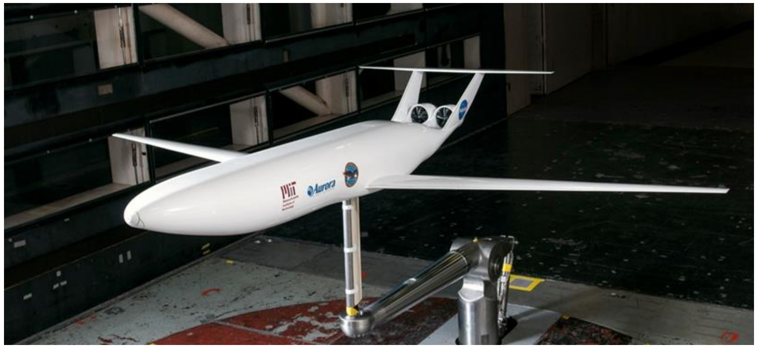


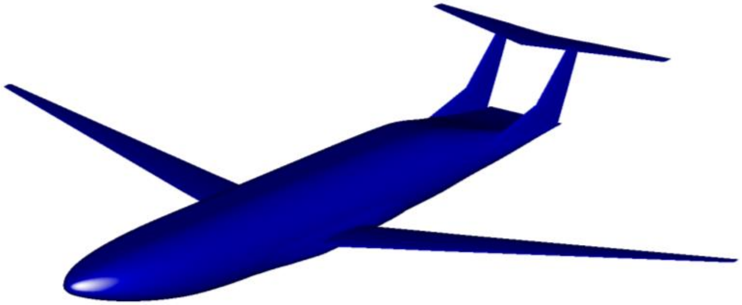


Incorporate higher-fidelity acoustic scattering/shielding predictions into system noise assessment of integrated configurations

MIT D8.5 System Noise Assessment

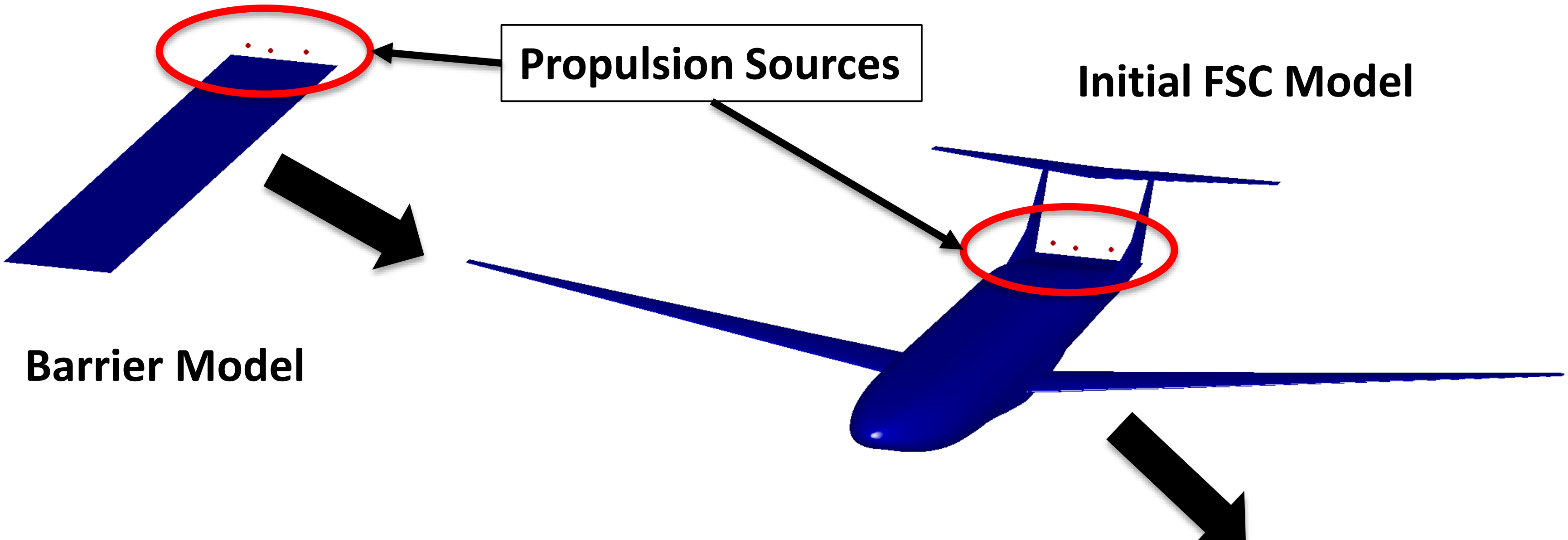
- Shielding can constitute a large portion of Stage 4 margin
- Work from initial D8.5 (tri-jet) assessment by Berton
  - ANOPP/WING module initially employed
  - Create ANOPP suppression table using FSC
  - Quantify effect on system noise benefit





MIT D8.5 System Noise Assessment

Modeling Progression



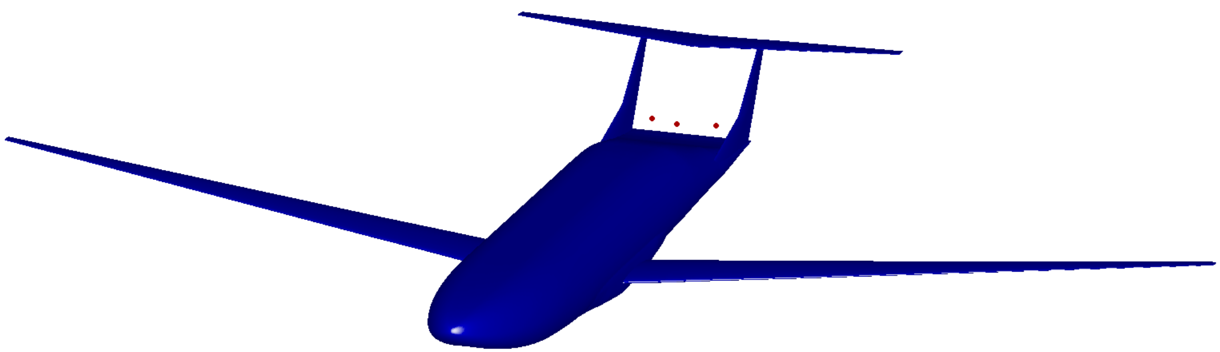
FSC Modeling:

- Incorporates geometric effects
- Propulsion sources considered separate point sources

MIT D8.5 System Noise Assessment

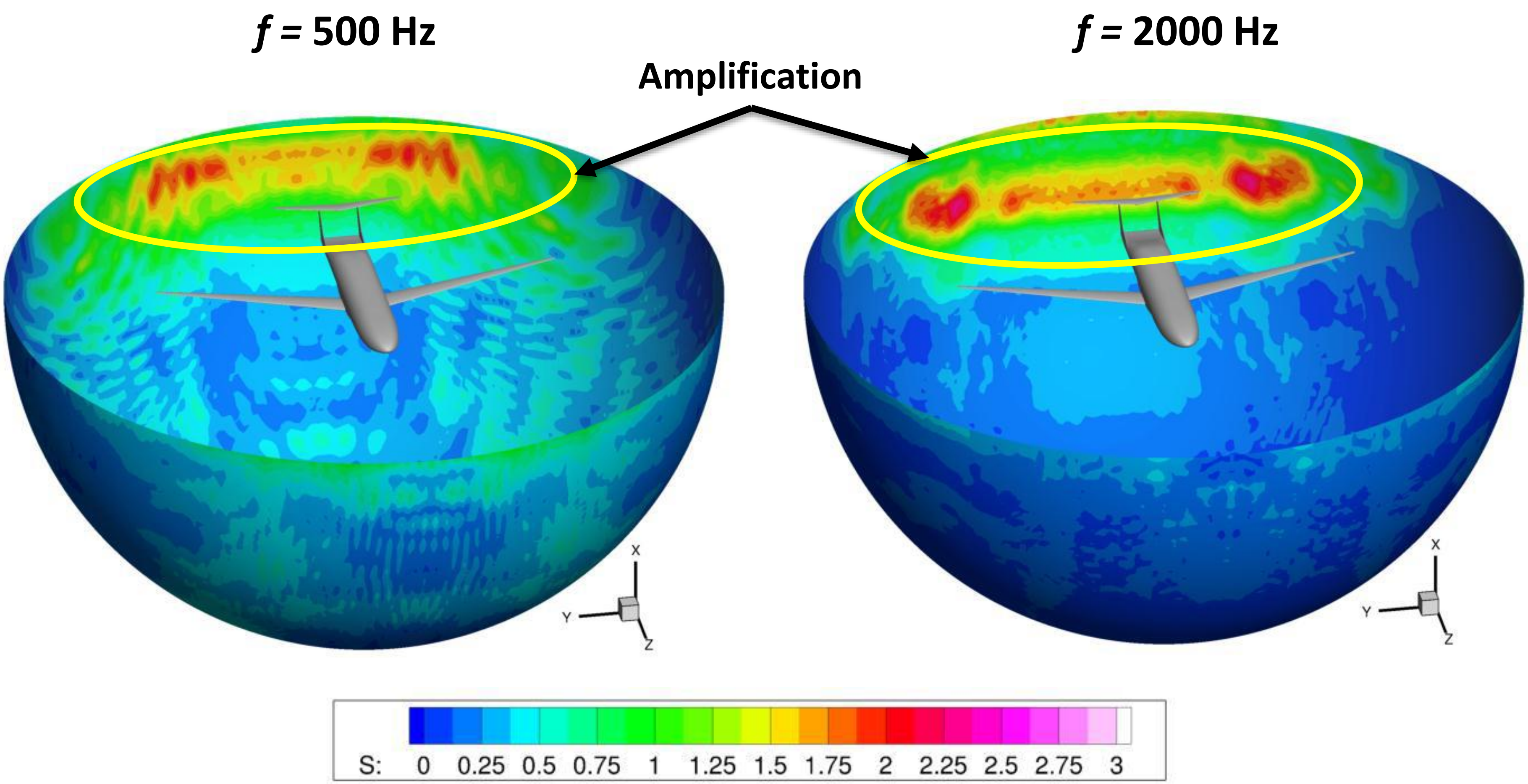
Suppression Table Generation using FSC

- Suppression Factor, $S = 10^{\frac{\Delta dB}{10}}$
  - $\Delta dB = SPL_{\text{shielded}} - SPL_{\text{unshielded}}$
  - $S < 1$ indicates suppression
  - $S > 1$ indicates amplification
- Predictions combined for each 1/3-octave band



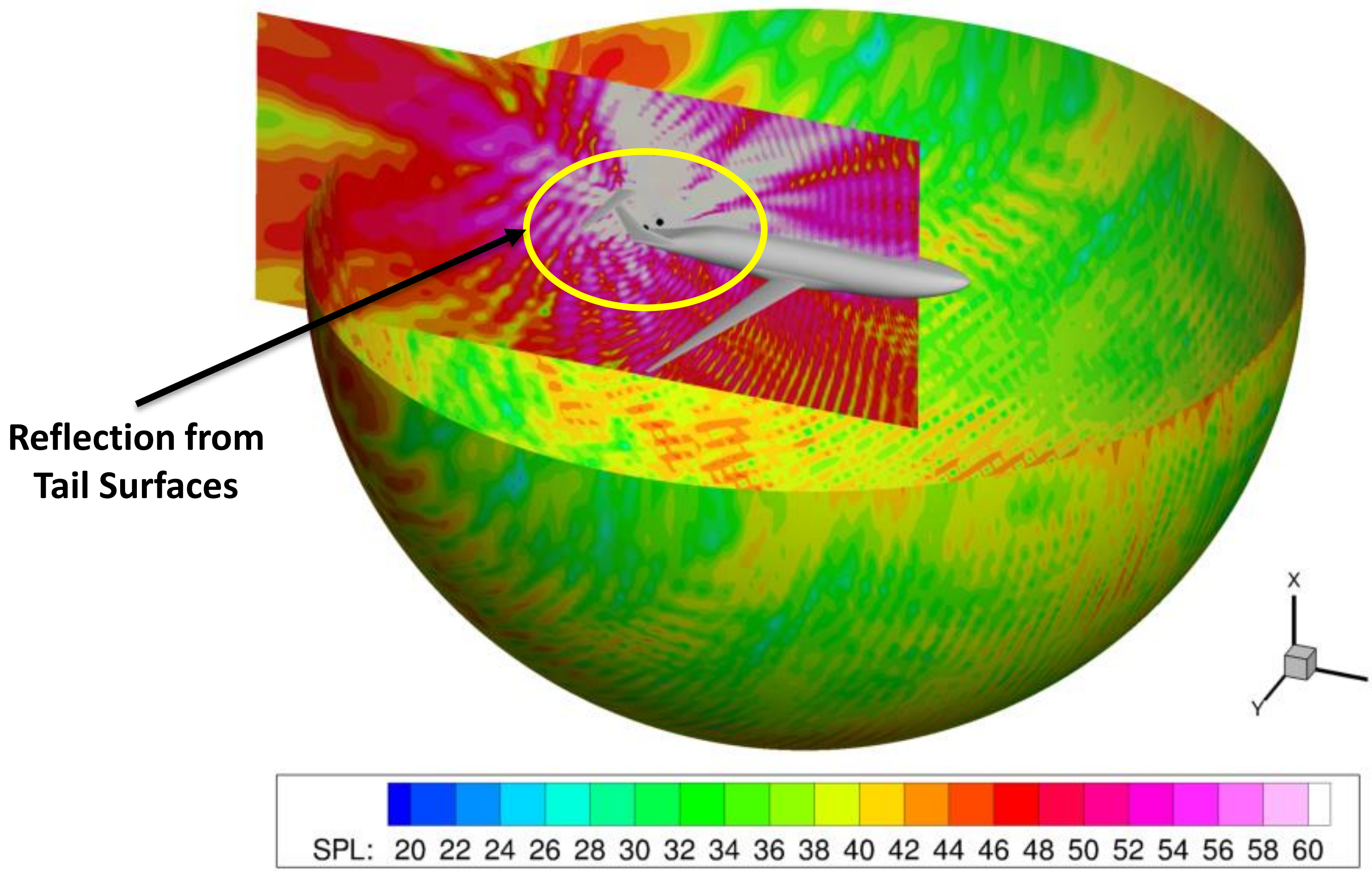
MIT D8.5 System Noise Assessment

FSC Suppression Tables



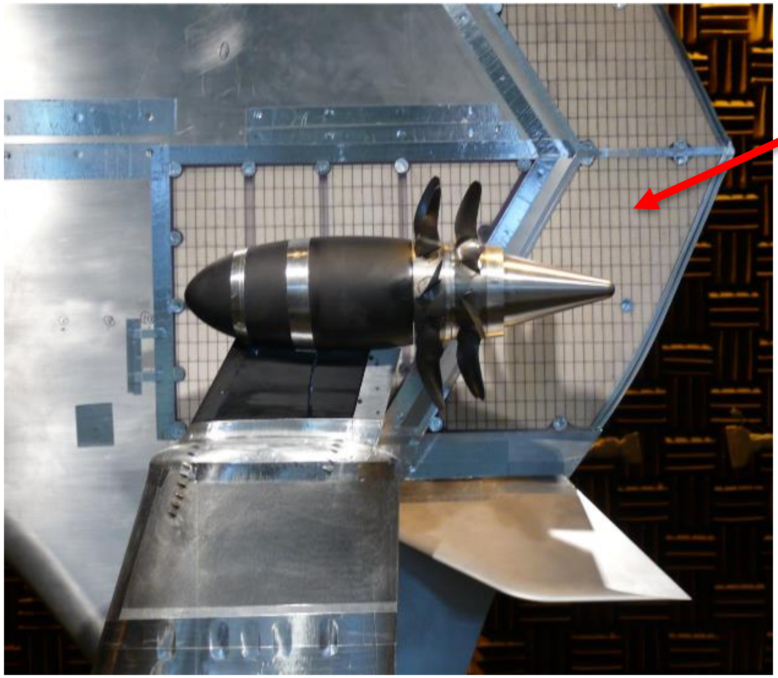
MIT D8.5 System Noise Assessment

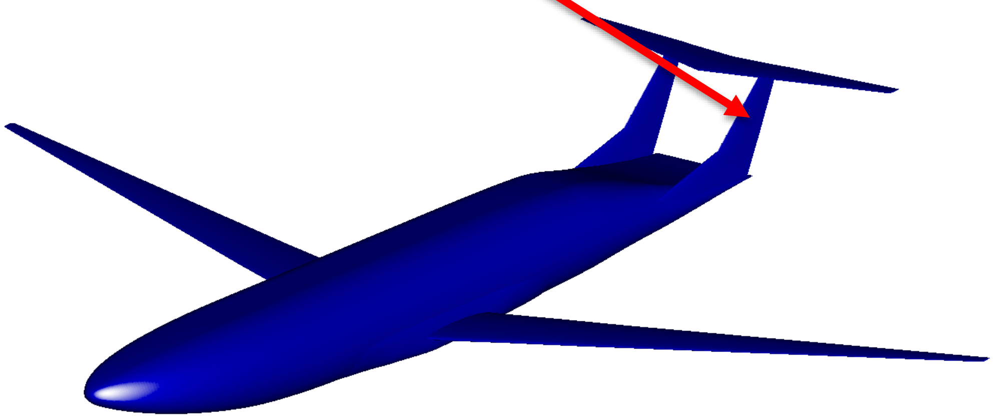
Total Acoustic Field: *f* =500 Hz, M = 0.23



D8.5 Assessment: Next Steps

- System noise assessment using FSC suppression tables
  - Improved estimate of shielding effectiveness
- Couple with work on adaptive low-drag liners
  - Assess system benefit with updated suppression tables (accounting for liners)
  - Adaptation on impedance and/or drag metrics
  - Optimize liner location based on source and liner characteristics





Incident Source Directivity Effects

- Consider incident acoustic field from various propulsion sources
  - 14x22 HWB test: Broadband Engine Simulator (BENS)
  - Podded engine configuration: Turbofan source
  - Open Rotor: F31A31 Historical Baseline

Van Zante *et. al.*: ISABE-2011-1310, Stephens and Envia: AIAA Paper 2011-2940, Envia: CMFF `12

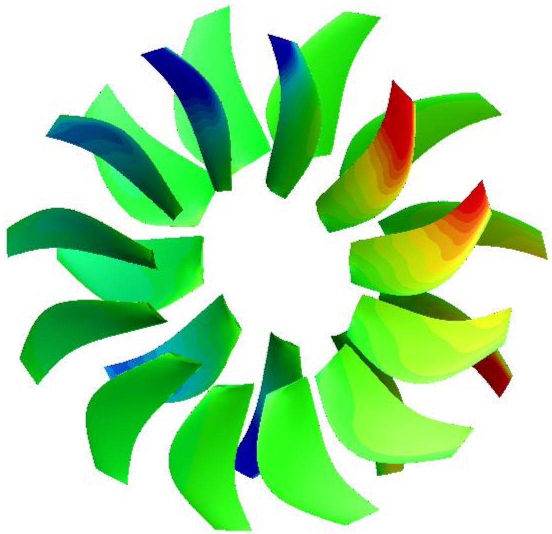
F31A31 9x15 Test

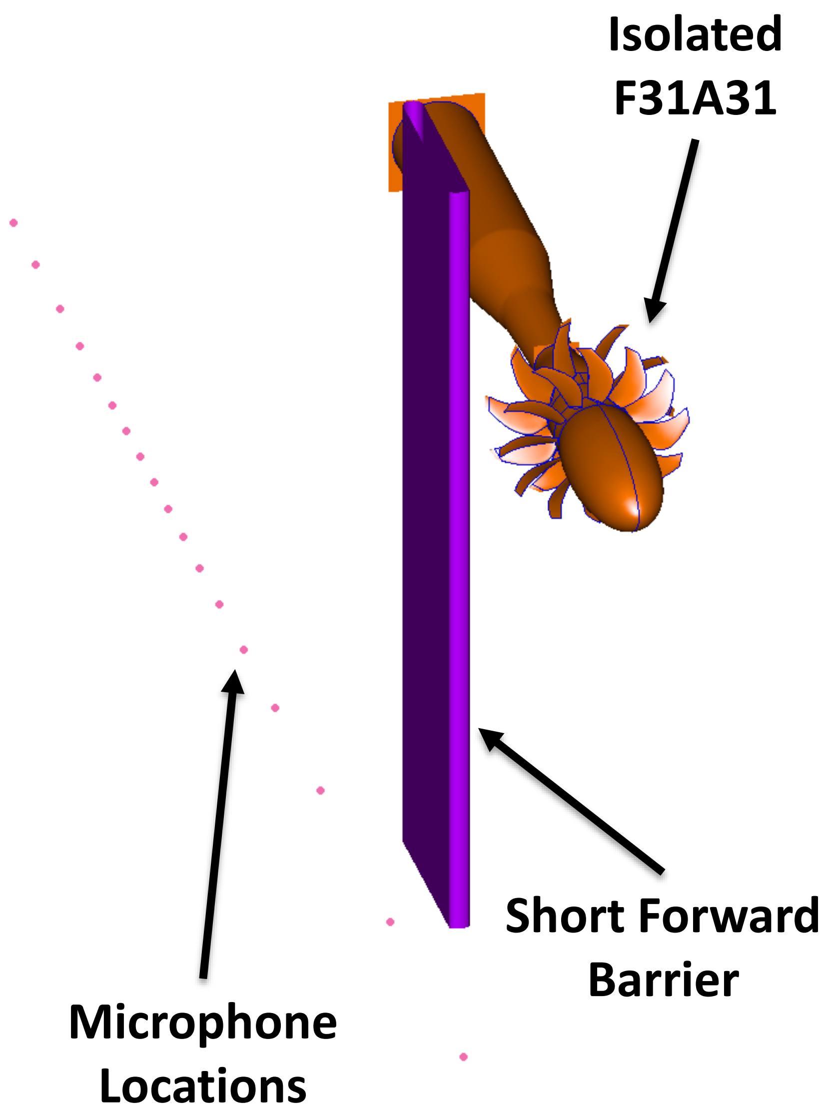
Blade Loading

- OVERFLOW, FUN3D
- RPM: 6436
- Time Resolution: 1-degree

Acoustics

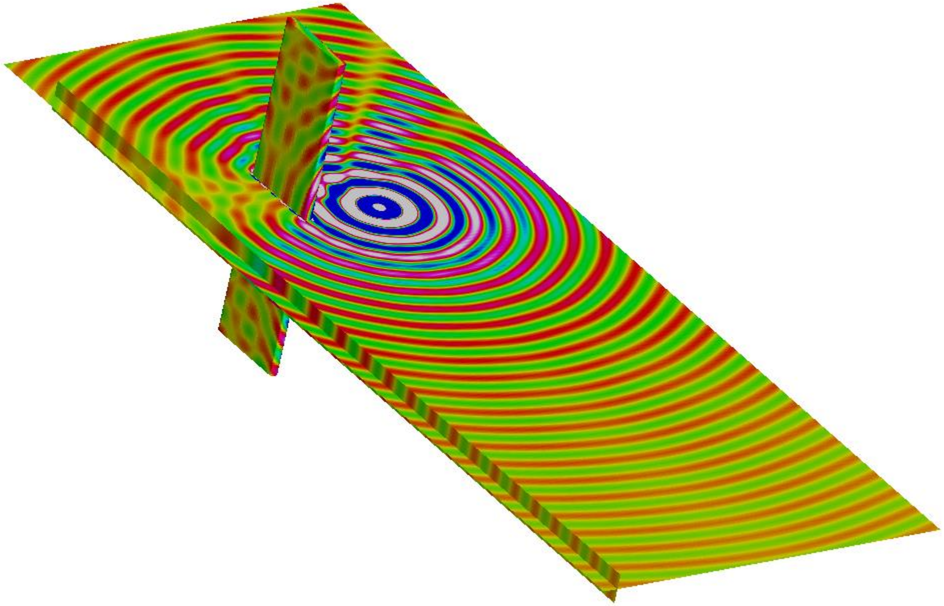
- ASSPIN, PSU-WOPWOP, F1A

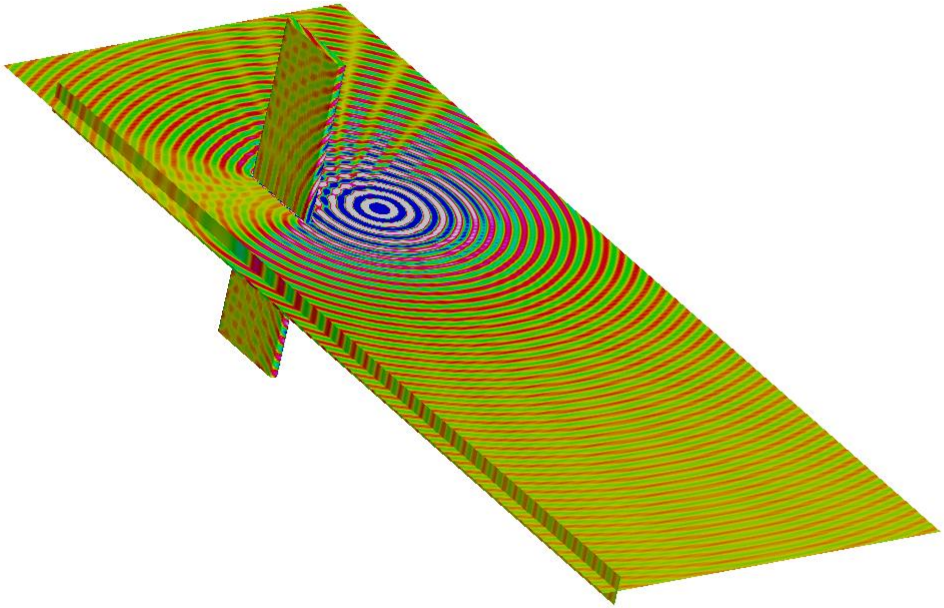




TD-Fast (Initial Set-Up): Short Barrier, Point Source

f = 800 Hz



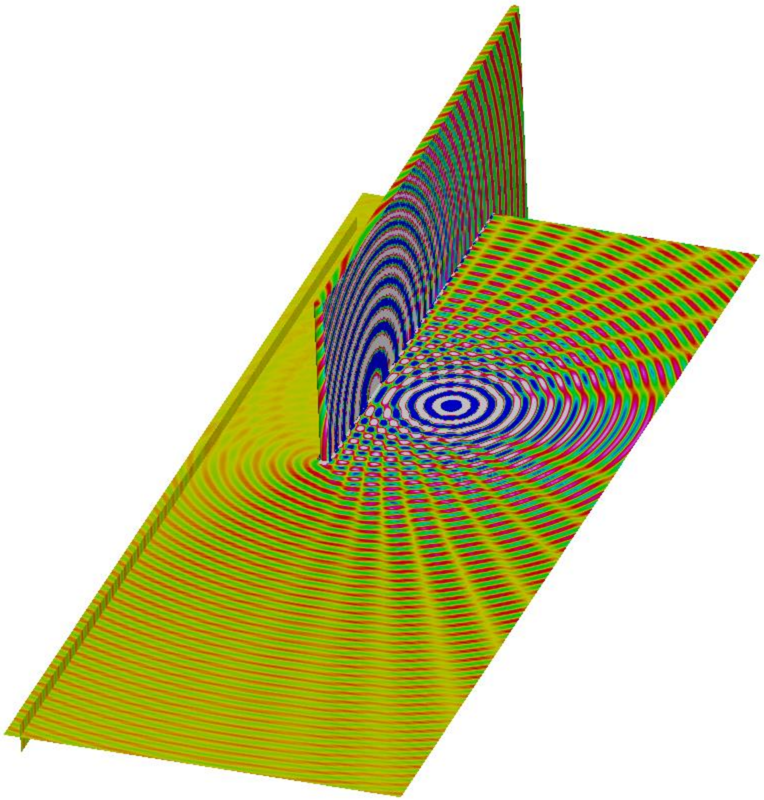


f = 1600 Hz

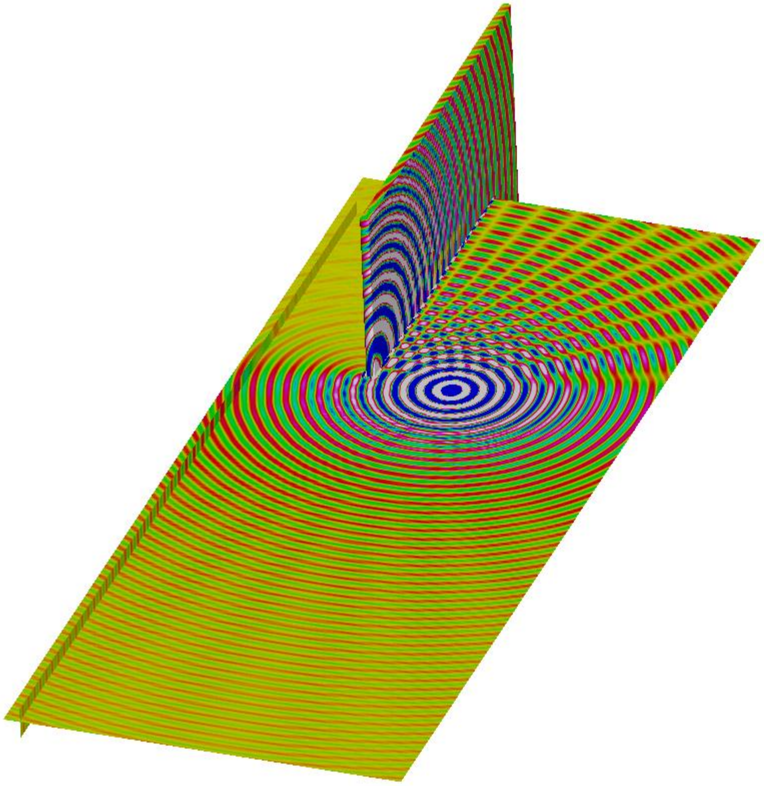
F31A31 9x15 Test

TD-Fast (initial Set-Up): Long Barrier, Point Source
(*f* = 1600 Hz)

Forward Position

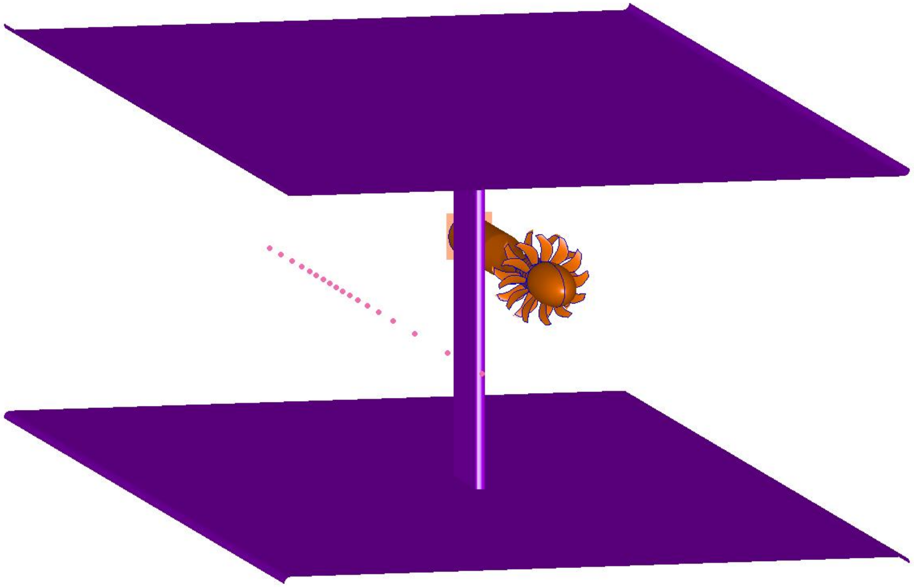


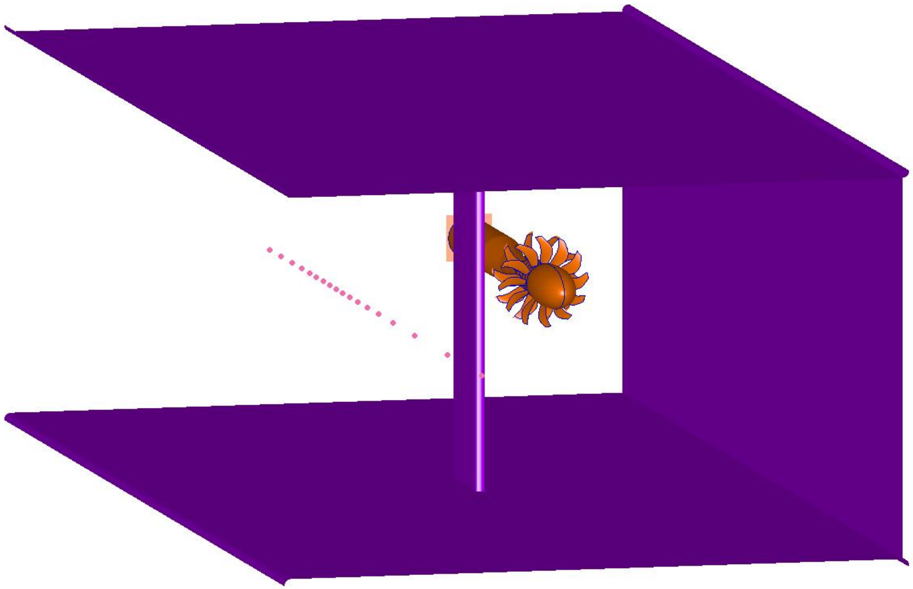
Aft Position



F31A31 9x15 Test

Additional Complexity

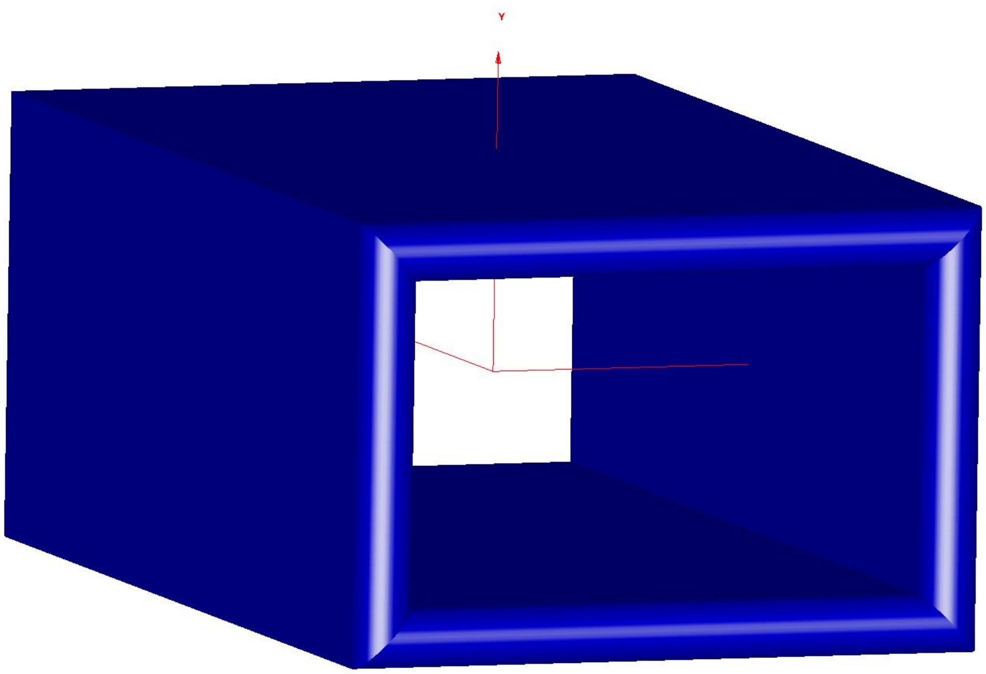


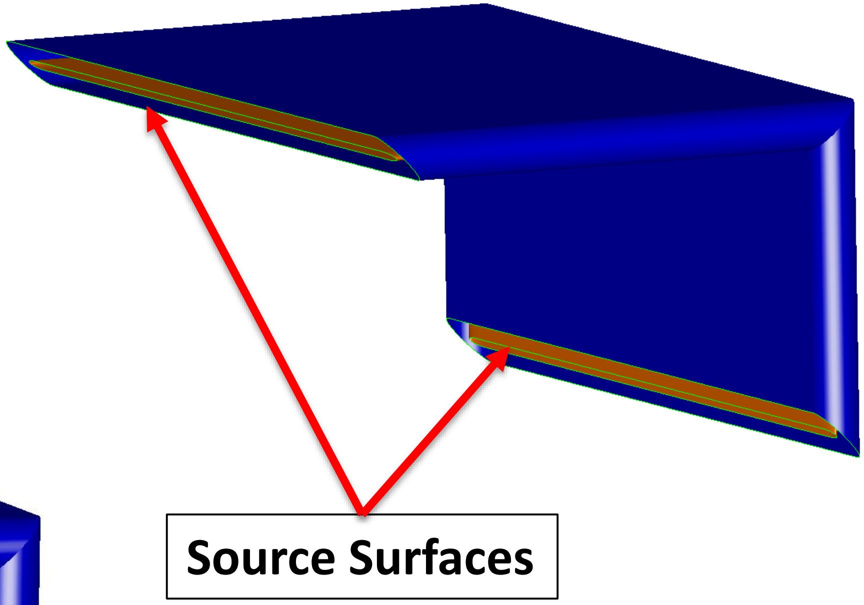


F31A31 9x15 Test

Full Test Section

- Incorporate full tunnel geometry in scattering predictions





Concluding Remarks

- Apply higher-fidelity scattering methods to quantify effects on system noise assessments
- Investigate benefits of properly placed low-drag external liners on system noise
  - Broadband attenuation capabilities increase possible liner locations
- Incorporate tunnel geometry in scattering predictions

Incorporate higher-fidelity acoustic scattering/shielding predictions into system noise assessment of integrated configurations

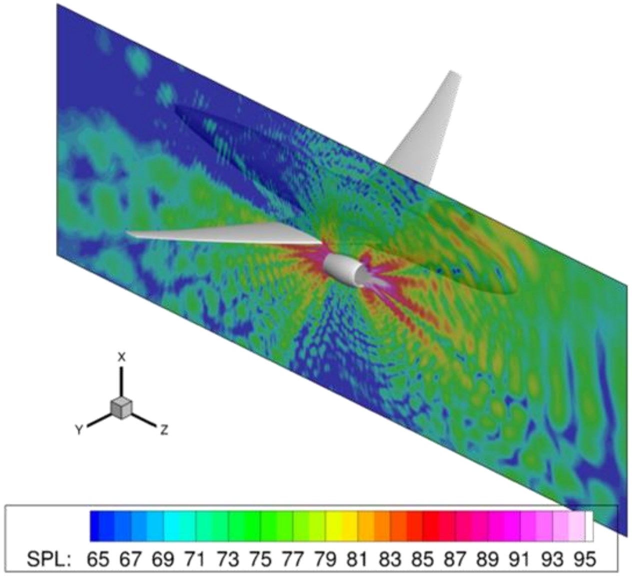
Acknowledgements

- Jeff Berton (NASA): ANOPP (AATT)
- Doug Boyd (NASA): Overflow (RVLT)
- Casey Burley (NASA): ANOPP (AATT)
- Fang Hu (ODU): TD-Fast (TTT NRA)
- Bill Jones: FUN3D (AATT)
- Len Lopes (NASA): ANOPP2 (RVLT, TTT)
- Ana Tinetti (AS&M): FSC (AATT)
- Nik Zawodny (NASA): Overflow (AATT)

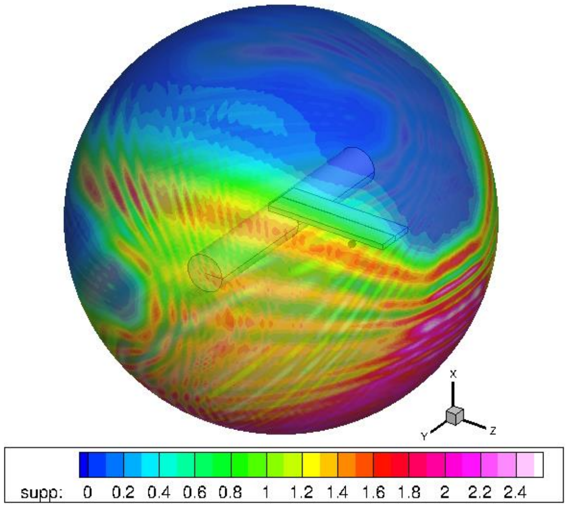
Backup Slides

Background

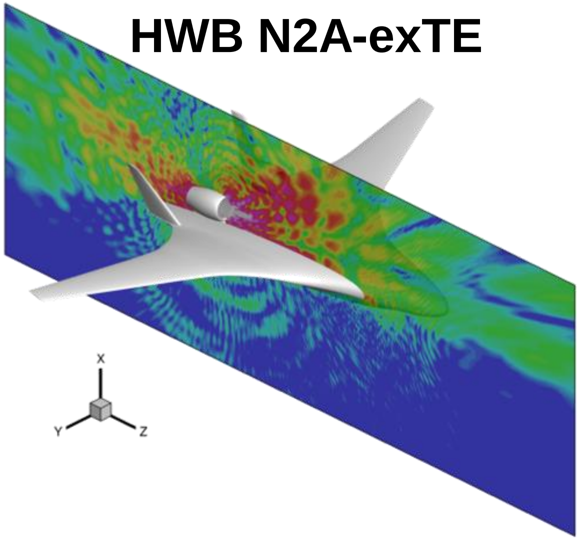
Conventional Tube and Wing



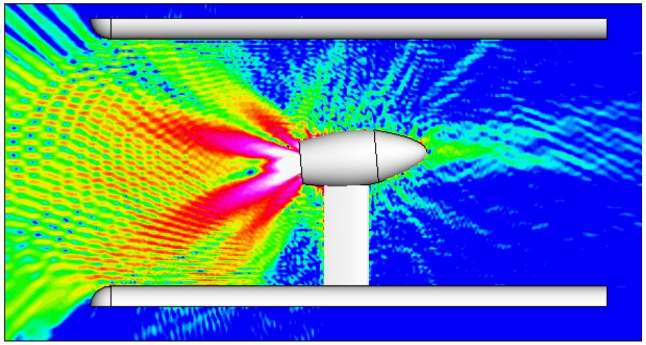
Suppression Table Creation



HWB N2A-exTE



Installation Effects



Scattering/Shielding Methods

ANOPP: WING module

- Zorumski, W., “Aircraft Noise Prediction Program Theoretical Manual,” NASA TM-83199, 1982.

DIM3 (based on MIT diffraction integral method) (ERA: PI: Spakovszky, POC: Burley)

- Colas, D., “A Diffraction Integral Based Turbomachinery Noise Shielding Method,” PhD dissertation, Massachusetts Institute of Technology, 2011.

Fast Scattering Code (FSC) (SFW NRA (ended 2012): PI: Dunn, POC: Nark)

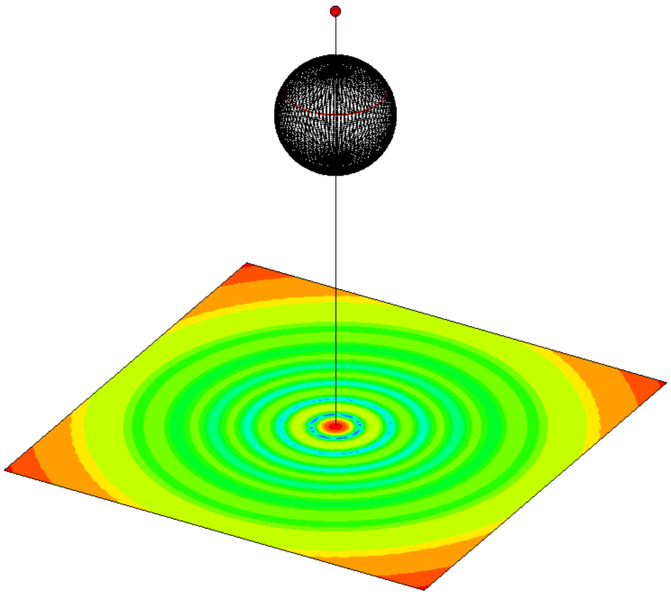
- Dunn, M., and Tinetti, A. F., “Aeroacoustic Scattering Via the Equivalent Source Method,” AIAA 2004-2937.
- Tinetti, A., and Dunn, M., “The Fast Scattering Code (FSC): Validation Studies and Program Guidelines,” NASA CR-2011-217158.

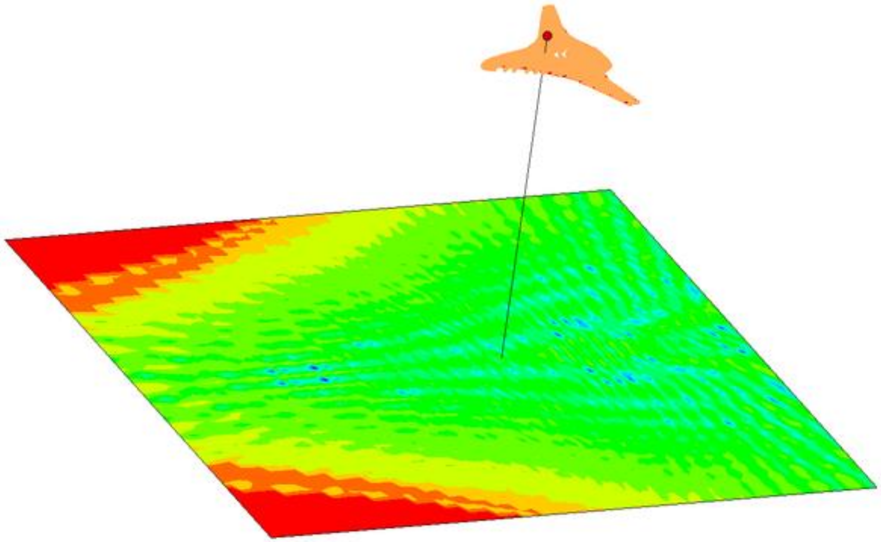
Time Domain Fast Acoustic Scattering Toolkit (TD-FAST) (AS NRA: PI: Fang Hu, POC: Nark)

- Hu, F., “An efficient Solution of Time Domain Boundary Integral Equations for Acoustic Scattering and its Acceleration by Graphics Processing Units,” AIAA paper 2013-2018.
- Hu, F., “Further Development of a Time Domain Boundary Integral Equation Method for Aeroacoustic Scattering Solutions,” AIAA paper 2014-3194.

Diffraction Integral Method (DIM3)

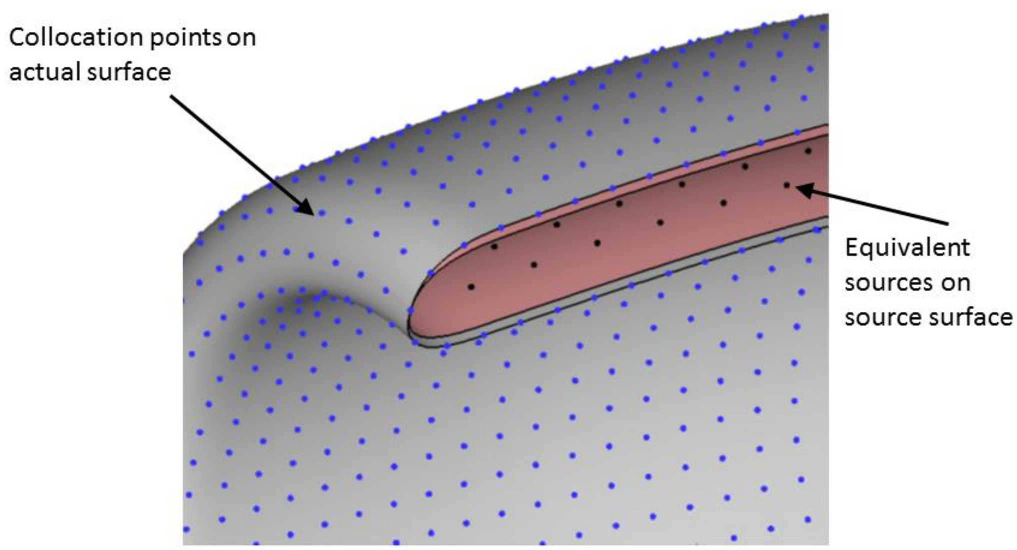
- Based on Kirchoff diffraction theory expressing diffracted field as superposition of waves emitted through an aperture
- Determine outline of shielding object based on source location and numerically solve the contour integral
  - Babinet's Principle with wedge potential for edge modeling
  - Beam tracing for reflections
  - Allowance for directional sources

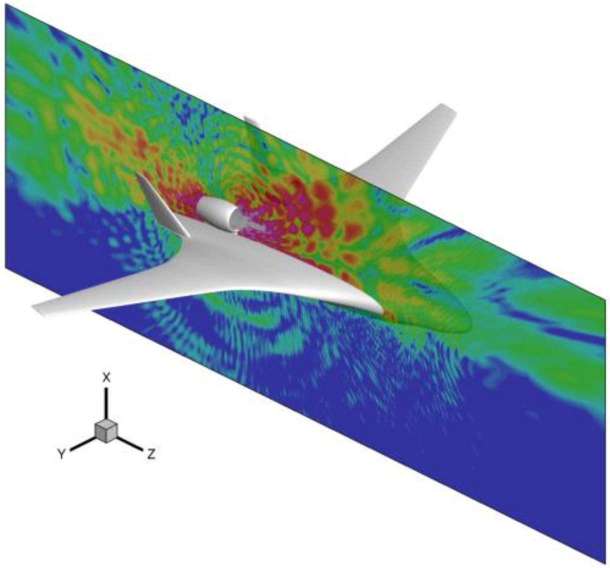




Fast Scattering Code (FSC)

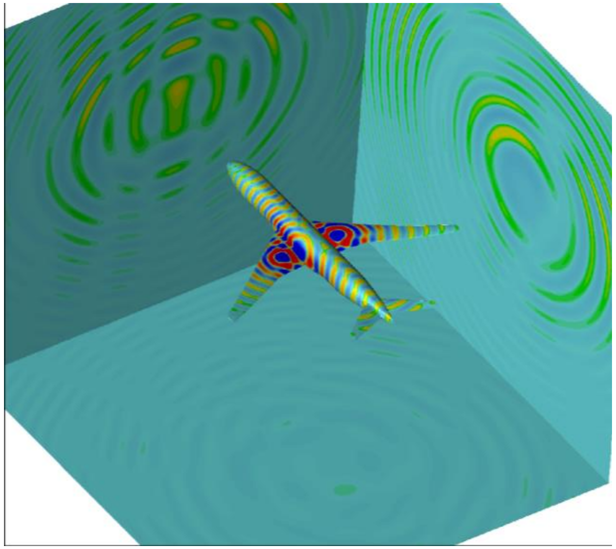
- Frequency domain solve of a 3-D Helmholtz boundary value problem via the equivalent source method (ESM)
- Scattered acoustic pressure field expanded into a series of point sources (Ns) distributed on a fictitious surface placed inside the actual scattering surface
- Scattering surface is discretized into collocation points (Nc) to produce a dense, over-determined system of linear equations of size Nc x Ns.
- Source strengths are adjusted to satisfy surface boundary condition using least squares methods

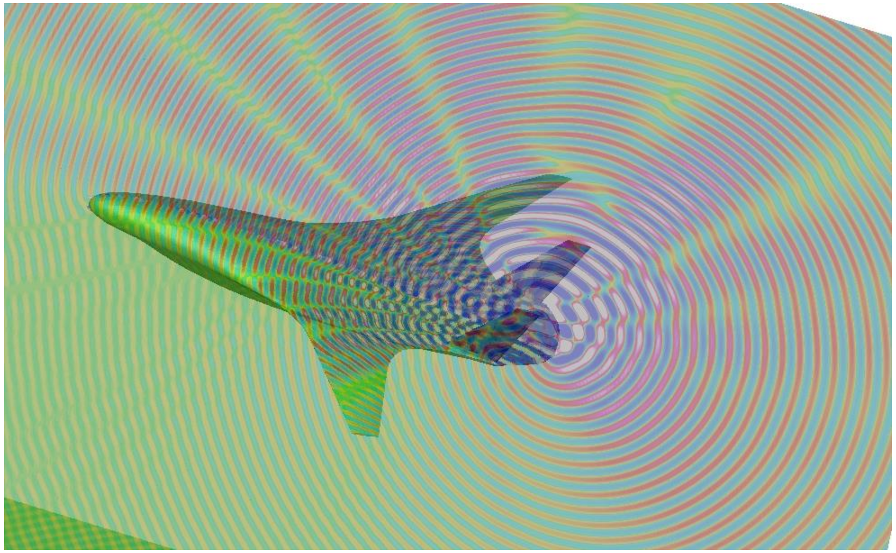




Time Domain BEM (TD-FAST)

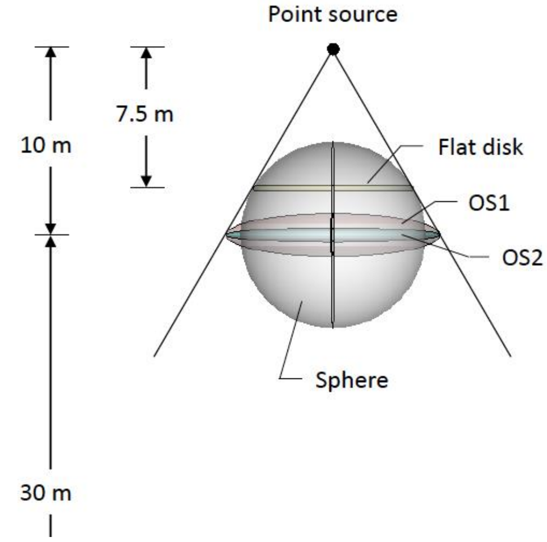
- Time domain boundary integral equation (TDBIE) reformulated for the convective wave equation
- Numerical instability in time marching stages addressed via Burton-Miller type formulation
- Computational cost of direct solution addressed via
  - High-order basis functions
  - Multi-level Fast Methods
- Utilize multi-core CPU and GPU architectures

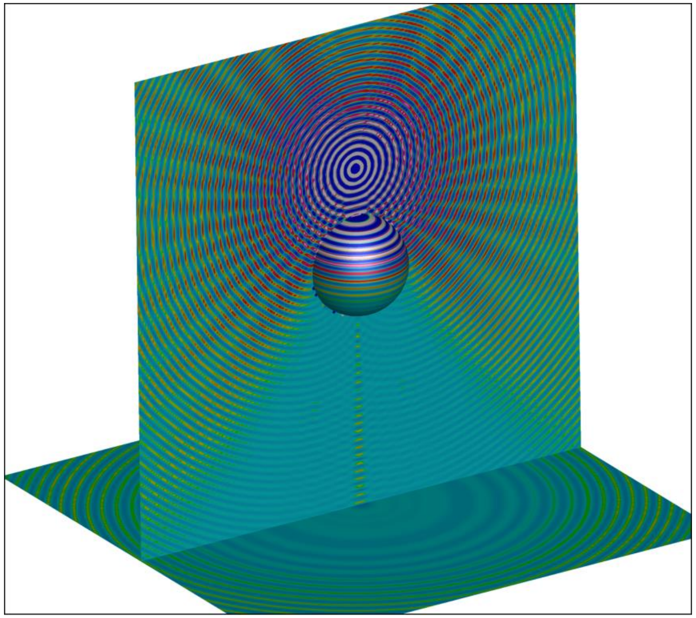




Validation Studies

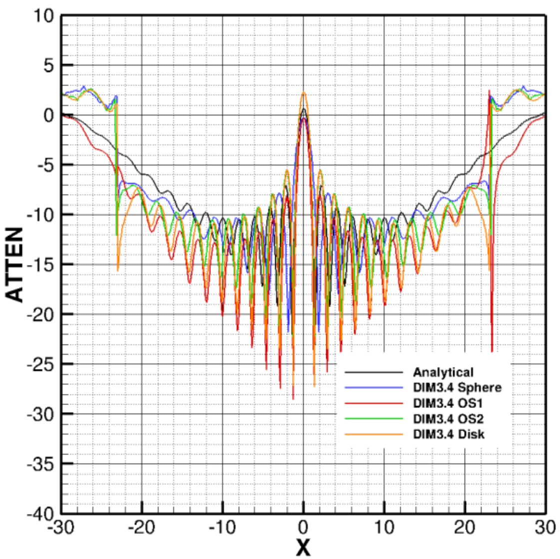
- **Source projects geometrically similar shadow zone**
- **Spheroids (centered at origin)**
  - Sphere: $r = a = b = 5.0$ m
  - OS1: $a = 5.77$ m, $b = 1.147$ m
  - OS2: $a = 5.77$ m, $b = 0.38$ m
- **Sound Source**
  - Monopole of unit strength
  - Frequencies: $1 < ka < 400$
- **Observer fields**
  - Bisecting plane, plane at z = -30 m
  - Line at z = -30 m
  - Ring, $r = 7.5$ m, centered at origin





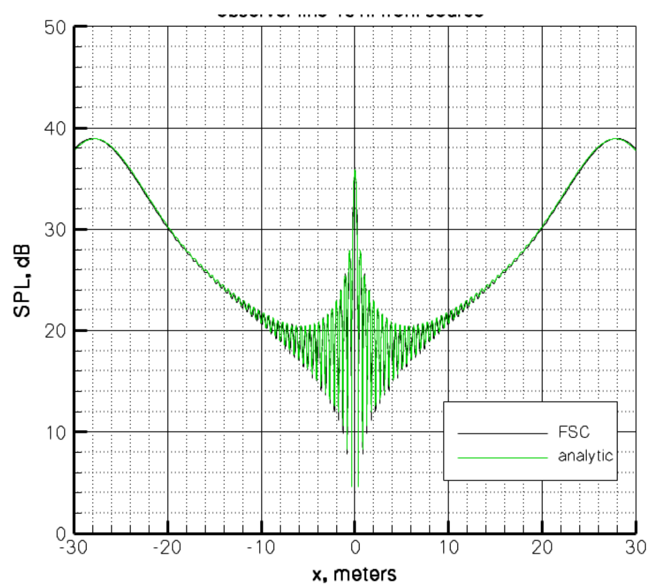
Sphere/Spheroid Predictions

DIM



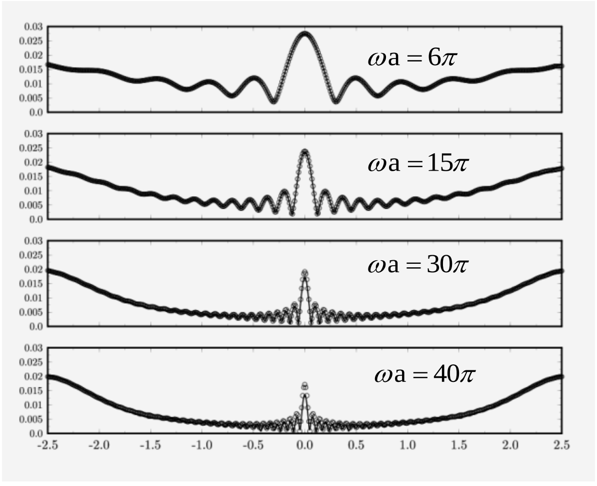
Pope, Burley

FSC



Tinetti (NRA: NNL09AA17C)

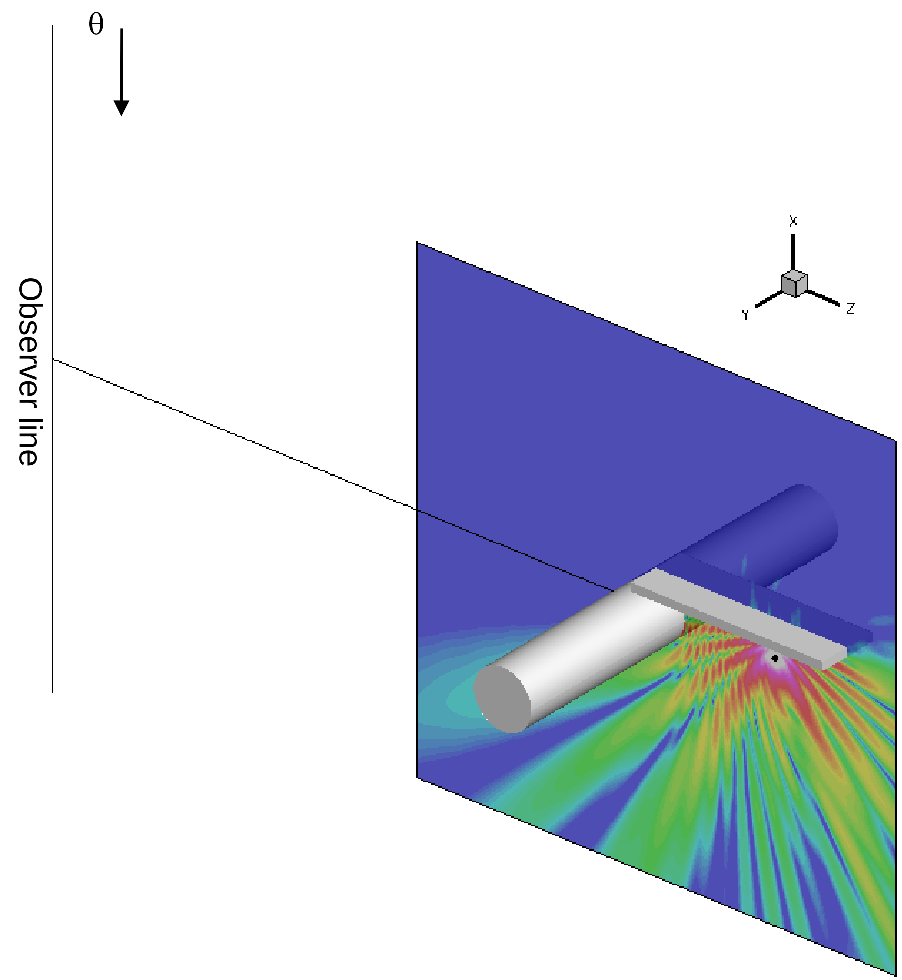
TD-Fast



Hu (NRA: NNX11AI63A)

Validation Studies

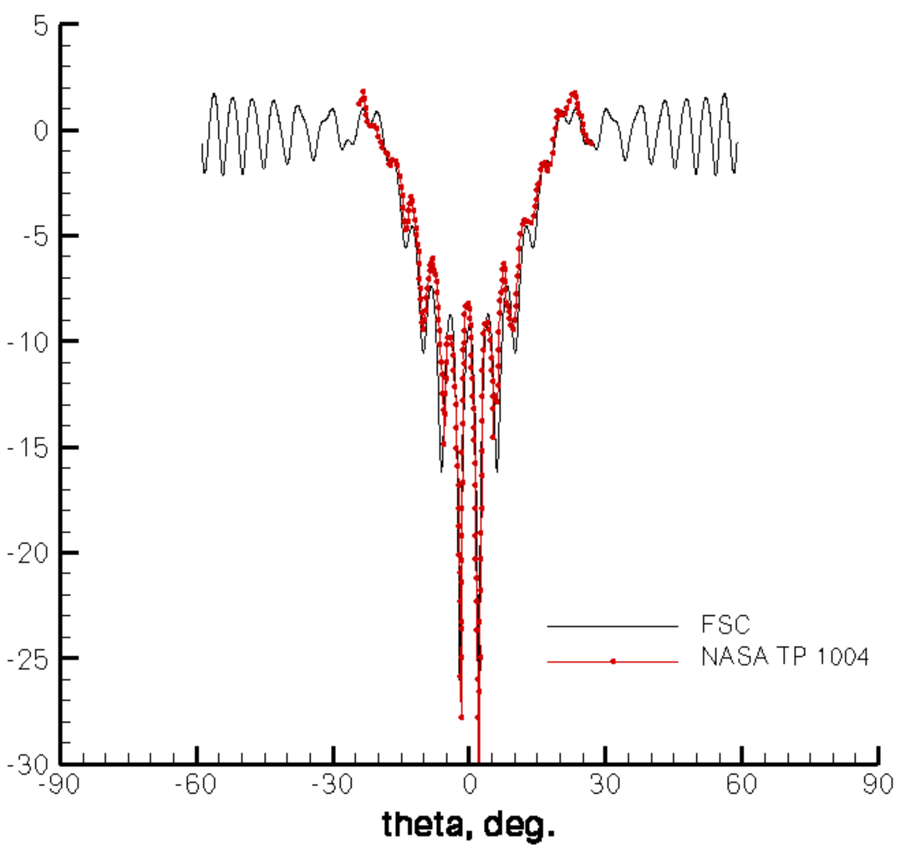
- **Configuration geometry/data from NASA TP 1004**
- **Cylinder (centered at origin)**
  - Diameter: d = 0.48 m
  - Length: L = 3.05 m
- **Flat plate**
  - Square edges
  - W= 0.5 m, L = 1.6 m, t = 0.07m
- **Sound Source**
  - Monopole of unit strength
  - Location: (0.0, 0.0, 0.9936) m
  - Excitation frequencies: 9 < kd < 69
- **Observer fields**
  - Bisecting plane
  - Line at z = -5.04 m
  - Sphere: r = 2.5 m, centered at origin



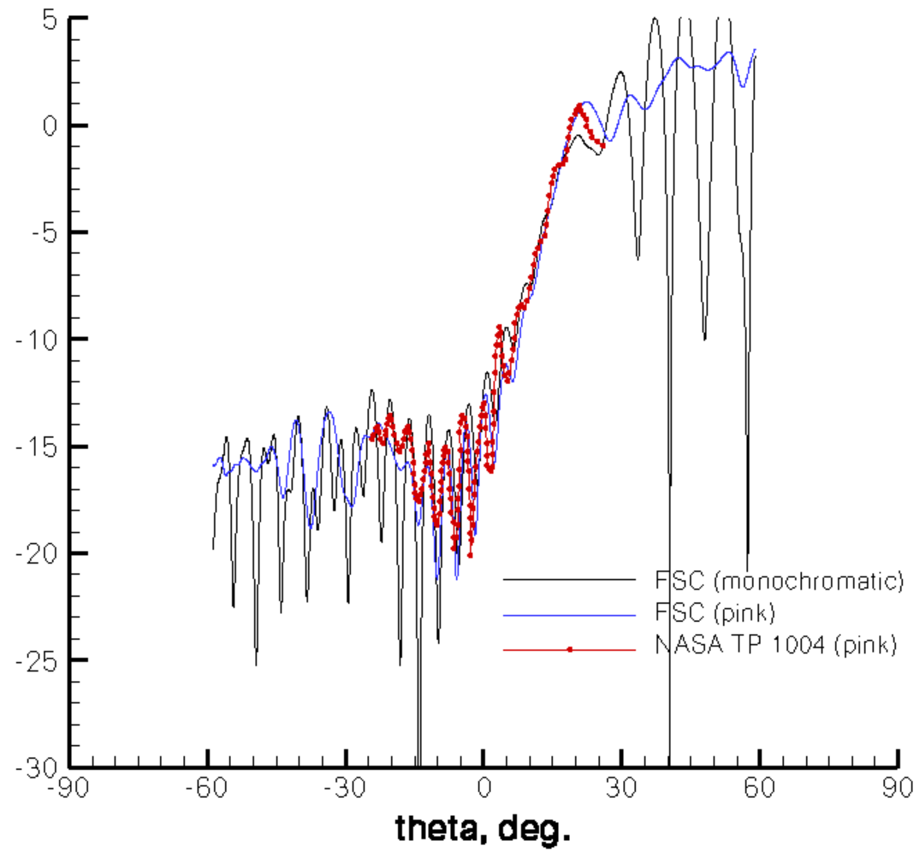
Validation Studies

Fast Scattering Code
(f = 8kHz)

Cylinder Alone



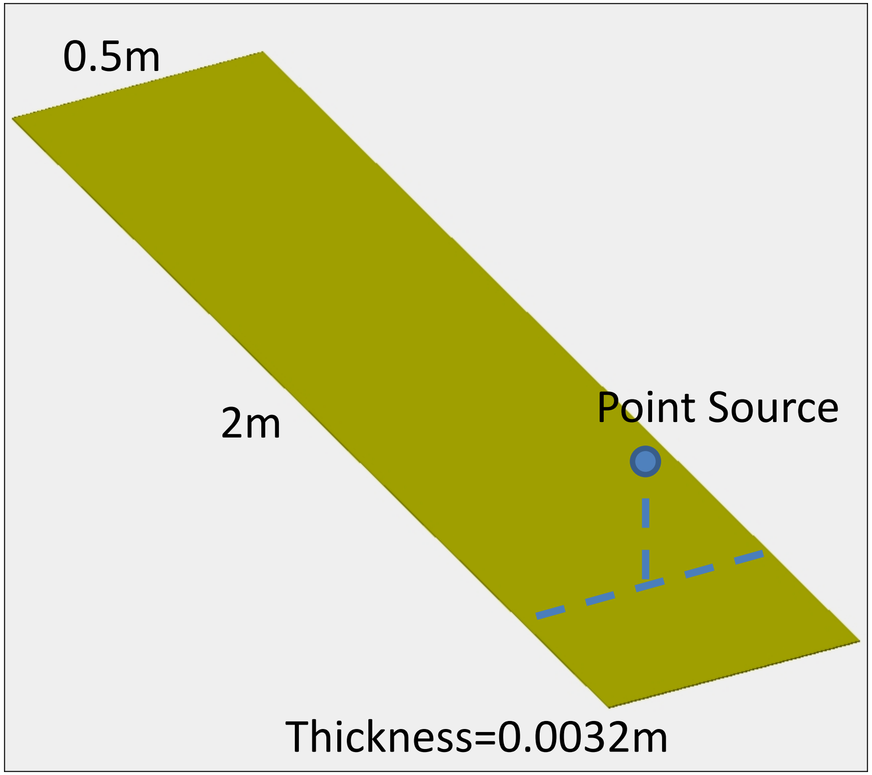
Cylinder – Plate

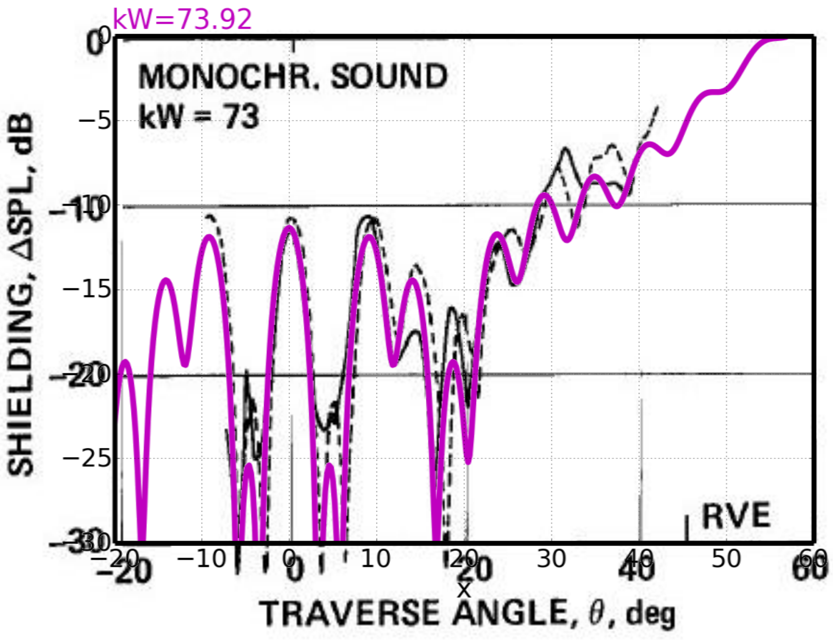


Tinetti (NRA: NNL09AA17C)

Time Domain BEM: TD-Fast

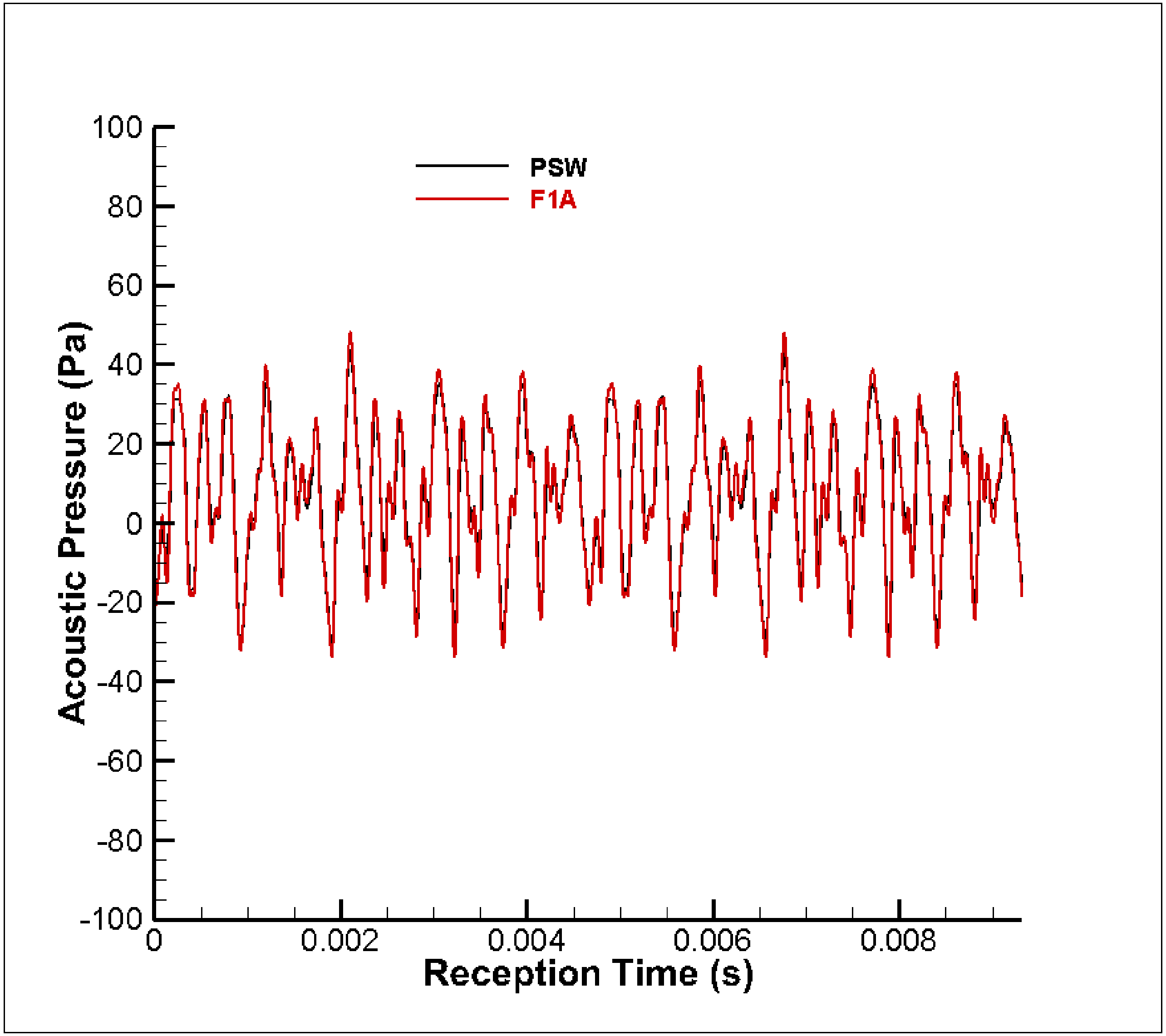
(Plate Alone: f = 8kHz)



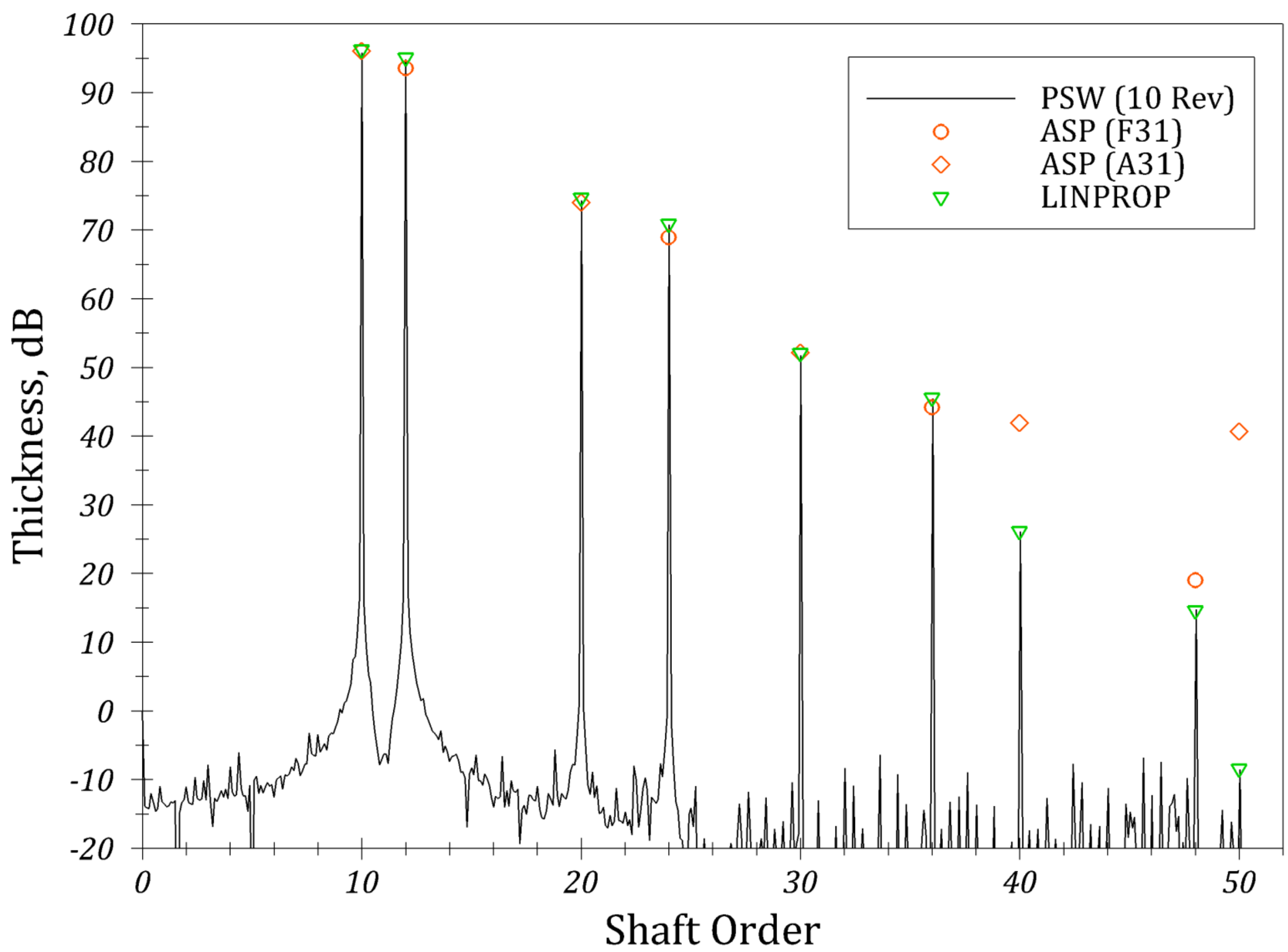


Hu (NRA: NNX11AI63A)

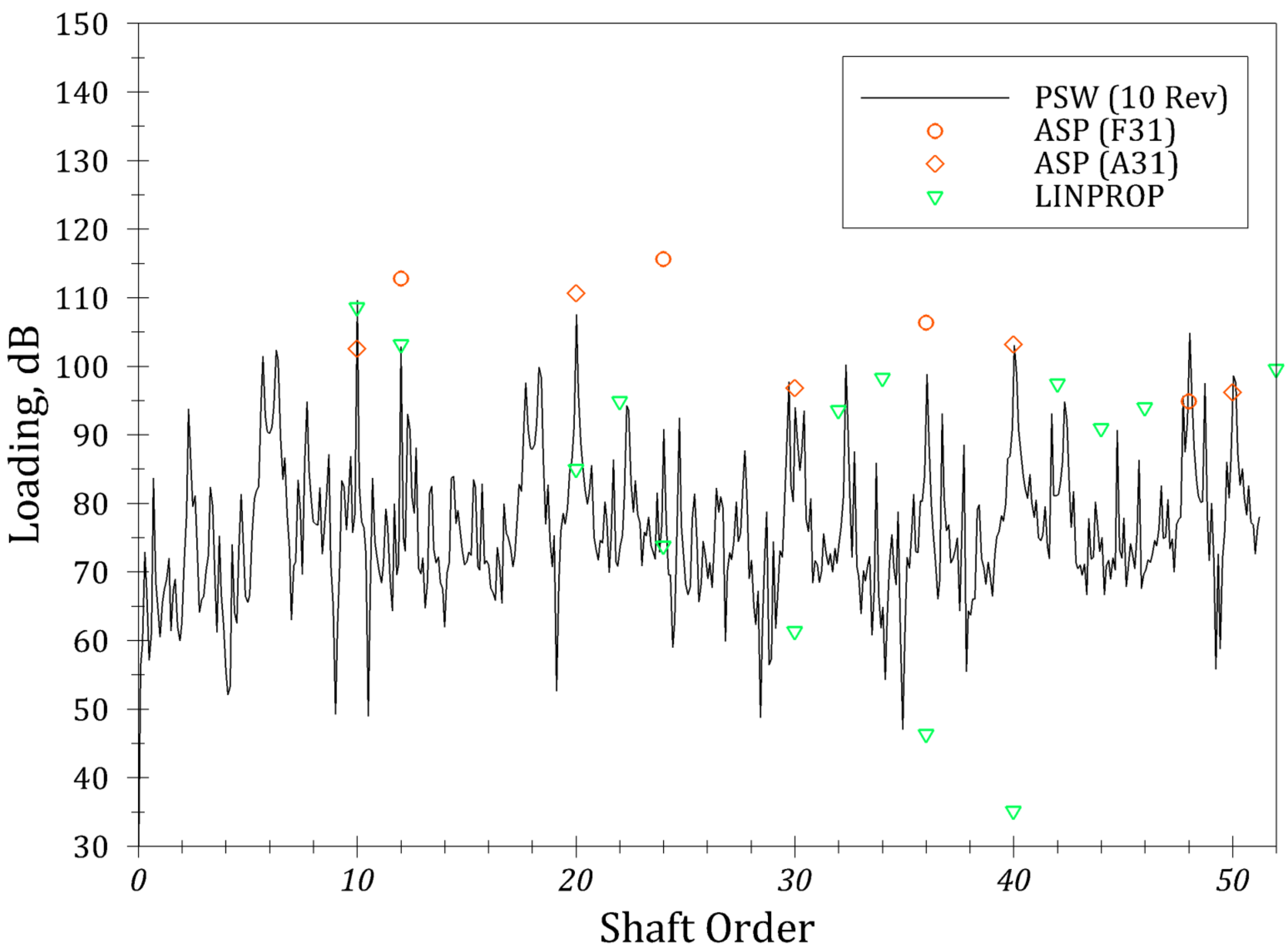
Isolated OR Noise Prediction



Isolated OR Noise Prediction



Isolated OR Noise Prediction



Isolated OR Noise Prediction