



Status of Liner Technology Research

Michael Jones (for Liner Team)

NASA Langley Research Center

michael.g.jones@nasa.gov

(757) 864-5272

Acoustics Technical Working Group Meeting

Cleveland, OH

October 20 – 21, 2015

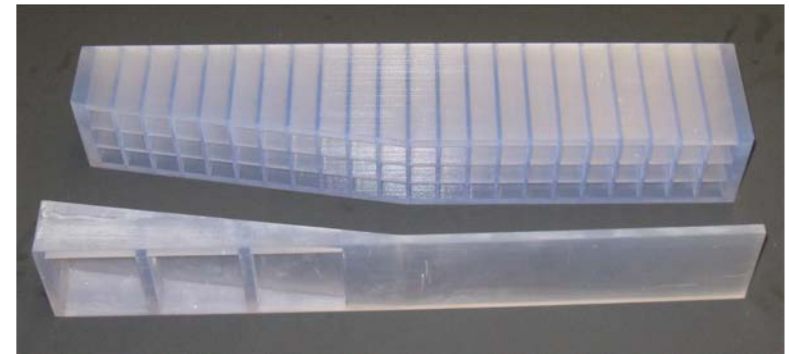
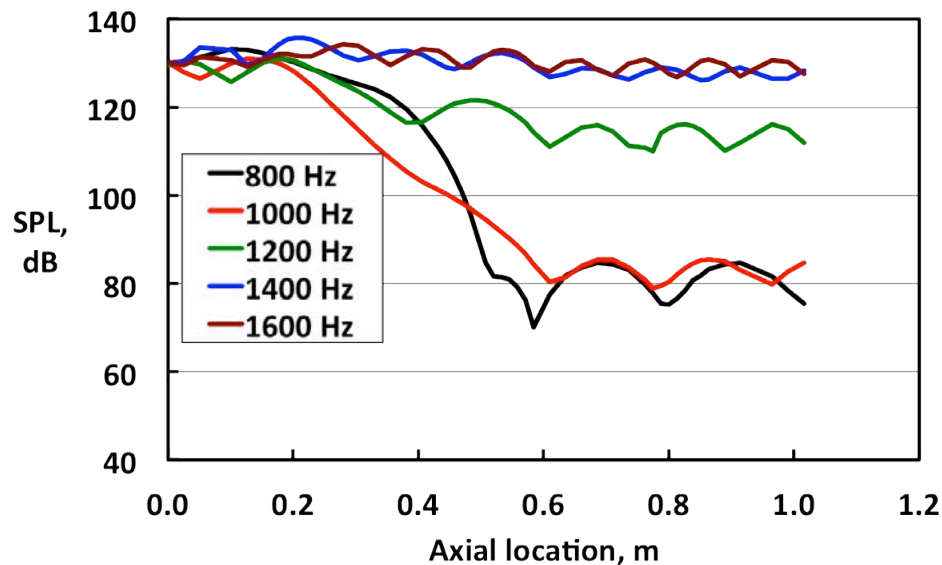
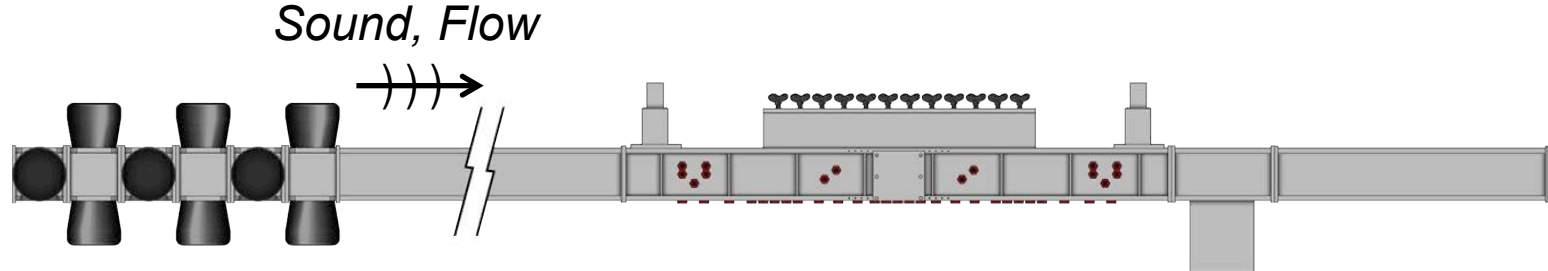


- Research Areas
 1. Liner Concepts
 2. Propagation Codes
 3. Liner Drag
 4. Liner Technology Facility Enhancements
- External Collaborations
- Research Team
- References



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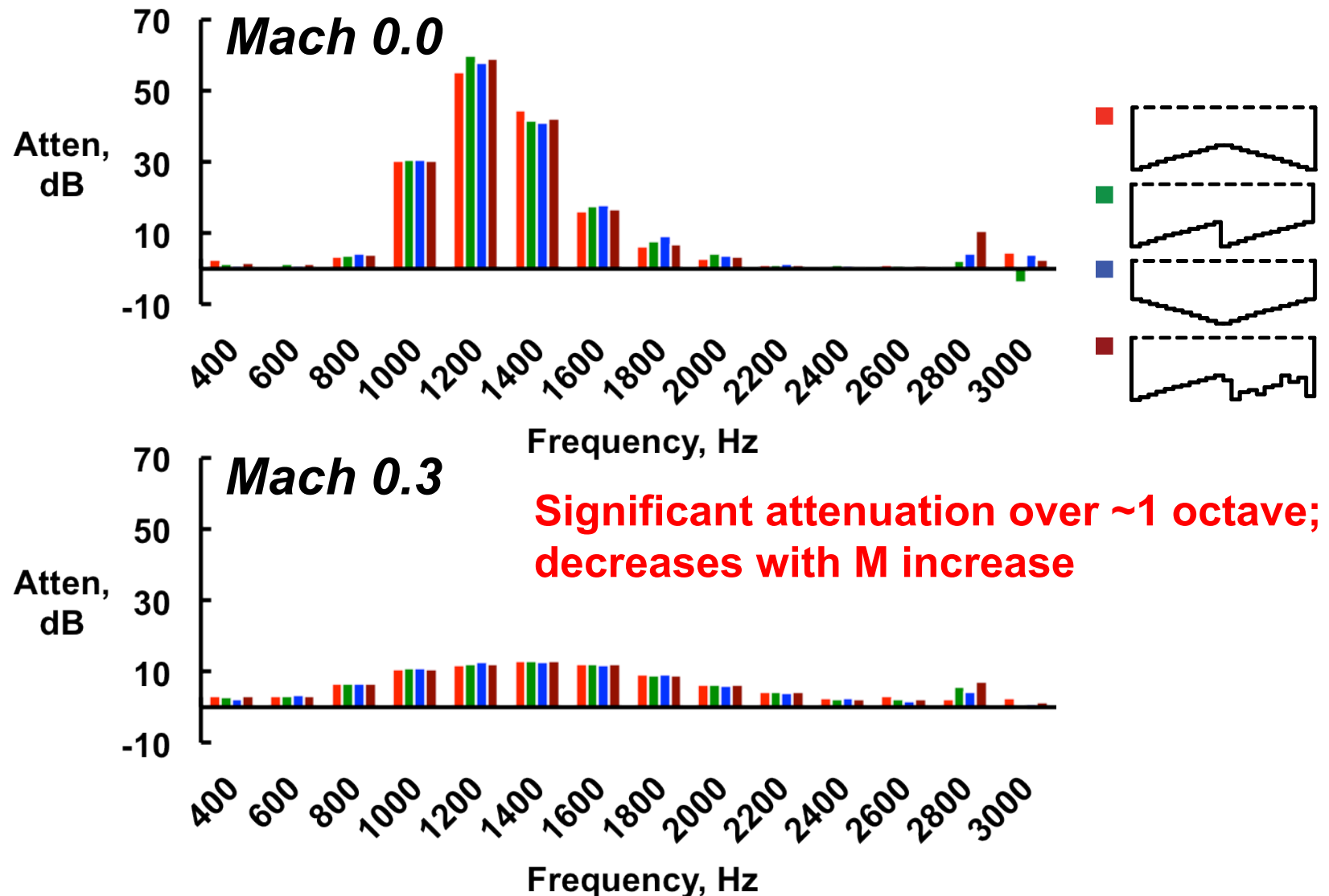
Variable Depth Liners



Partial variable depth liner

Variable-depth liners offer potential for significant broadband noise reduction

Variable Depth Liners – Geometric Effects

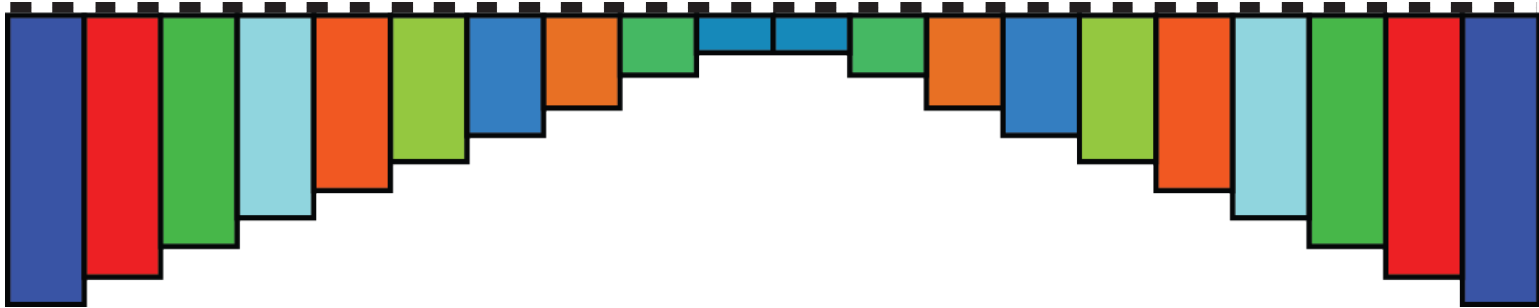


Relatively configuration independent - packaging opportunity?

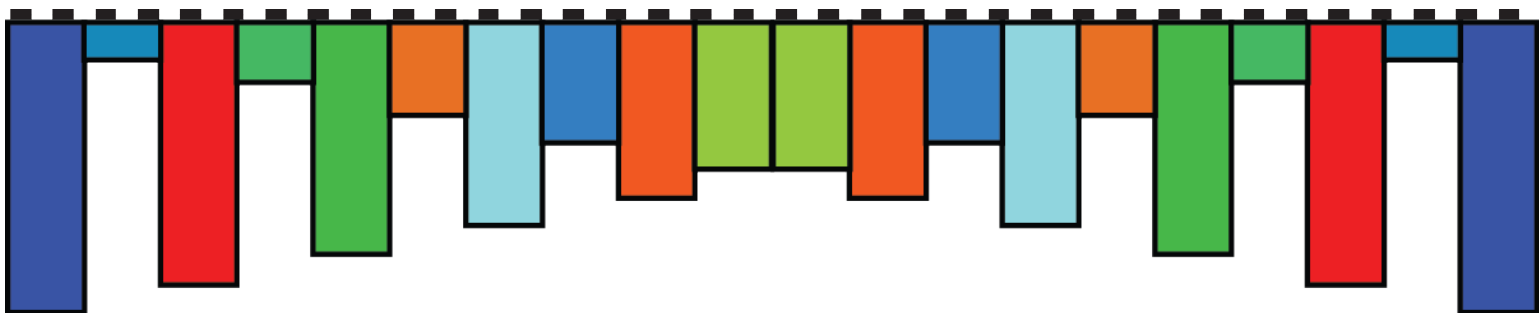
Repackaging Example



Original configuration



Rearrange order of chambers



Compressed design



Significant reduction in liner thickness!

MDOF Liner Test: Honeywell Fan Rig

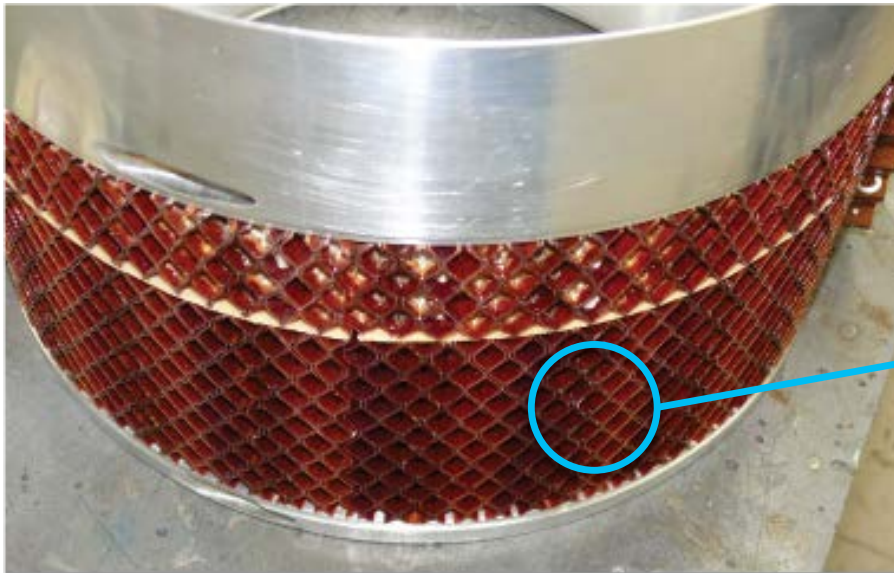
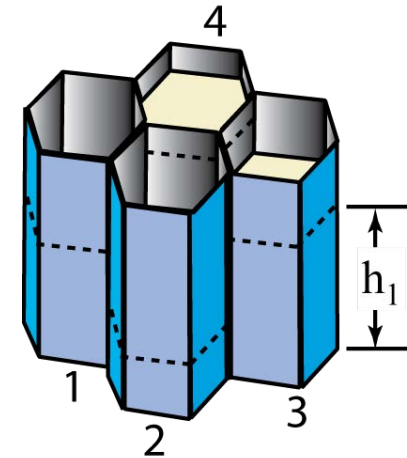


Photo of inner hub liner



Hexcel: Fabricate liner core

Honeywell: Add facesheet and back plate; provide fan rig

GRC: Conduct 9x15 test & process rotating rake and far-field data

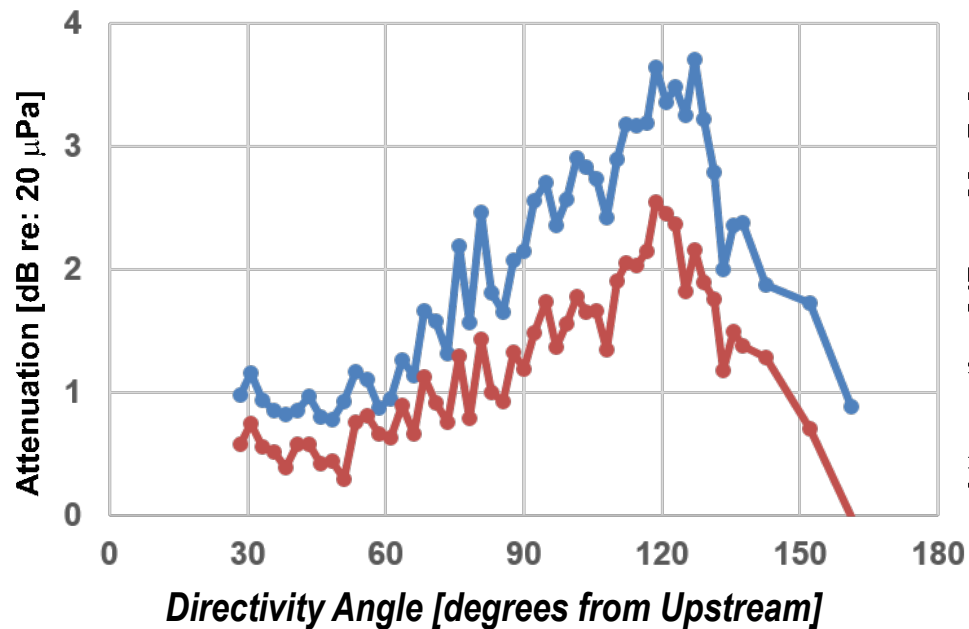
LaRC: Design liners; Use results to validate prediction codes

Initial Results: MDOF Liner Test

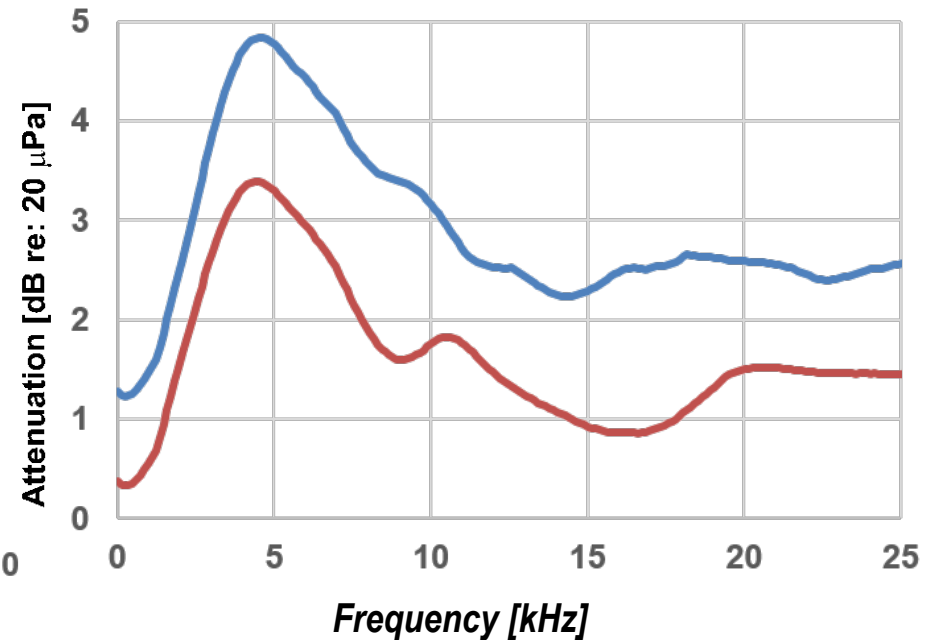


Measured Farfield Attenuations

*Sideline OASP at 80% RPM
(1kHz-25kHz)*



135 Degrees from Upstream



— NASA MDOF

— Honeywell SDOF

Other Liner Development/Evaluation



- SAA with Hexcel: MDOF Liners
- Variable-Depth Liners: Optimize for GFIT
- Over-the-Rotor Liners: Preparing to investigate multiple liner concepts for possible use in the OTR application
- Micro-Perforate Modeling
- Meta-Materials Concepts (Mitchell: rec'd M.S. in May)
- Biologically-Inspired Materials (Koch)



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Effects of Liner Length on ζ -Eduction



- Historical concern regarding use of CHE to educe ζ at low frequencies
- Possible cause: liner length re acoustic wavelength
- Investigate effects of liner length via application of aluminum tape

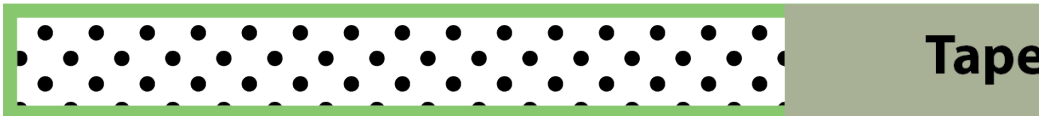
16"



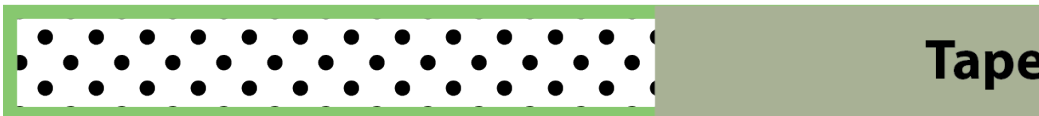
14"



12"



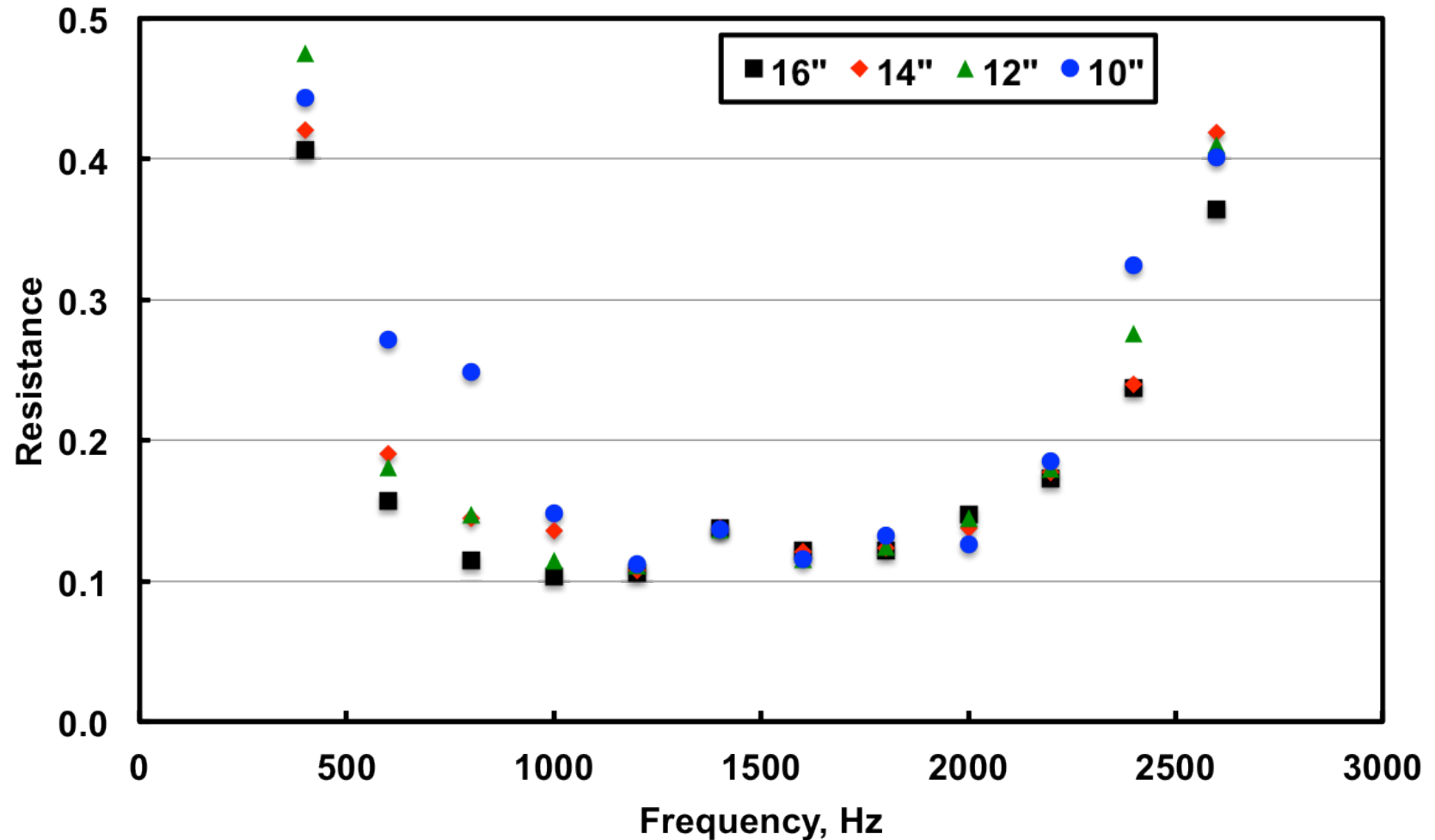
10"



Effects of Liner Length on ζ -Eduction



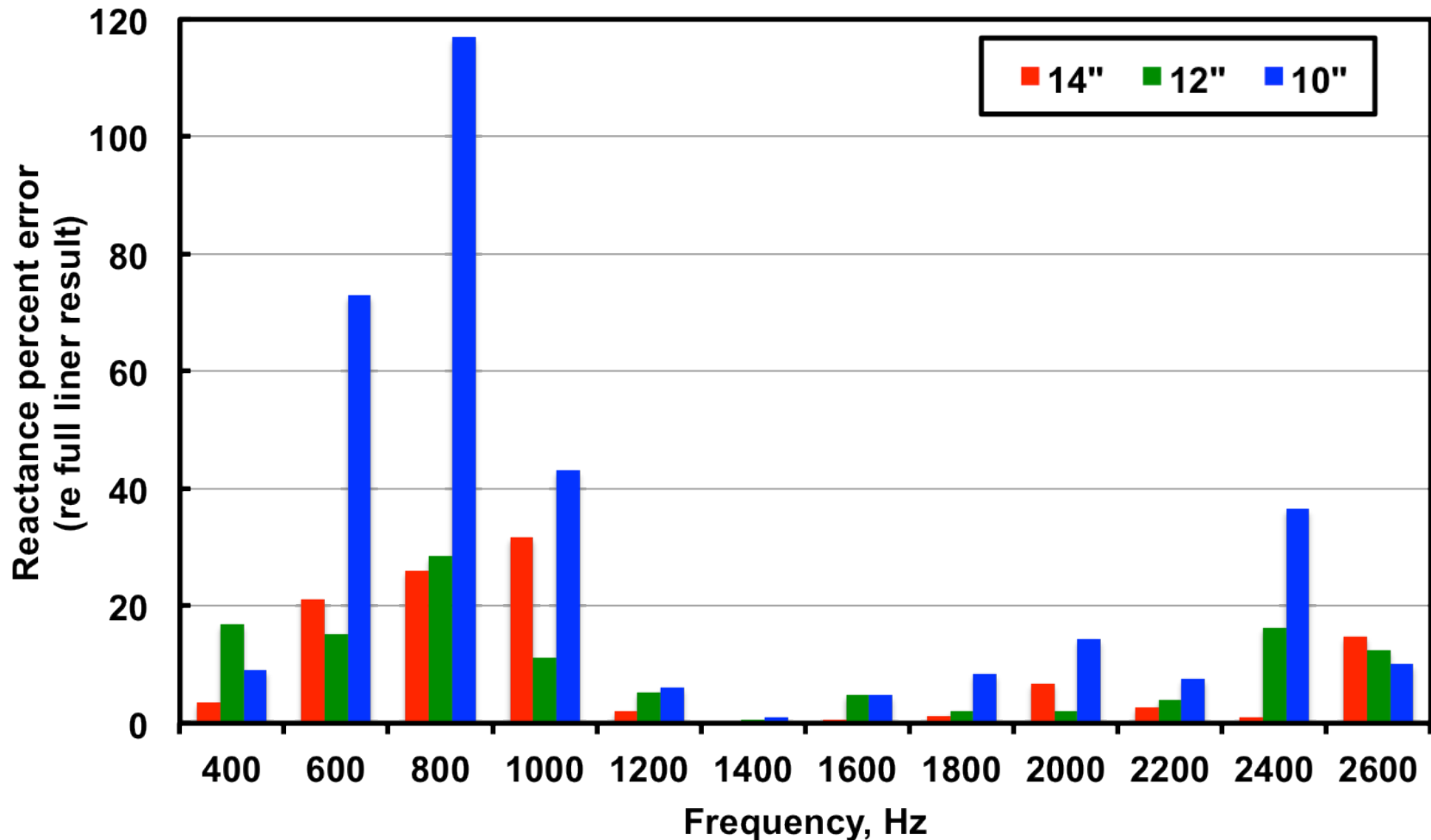
Mach 0.0 Results



Effects of Liner Length on ζ -Education



Mach 0.0 Results



Plan: Include flow effects, try different liners, use simulated data



CDL Enhancements

Developed software to solve parabolized, 3D, wide angle, one-way wave equation in orthogonal coordinates (parabolized version of 3D convective Helmholtz eqn). Capabilities include:

- 1) Pade' approximation to solve for **oblique angles up to 50 deg**
- 2) **Choice of** second-order (trapezoidal rule) or fourth-order (ESDIRK4) **marching accuracy**
- 3) Direct matrix inversion for linear systems (**efficiency improvement**)
- 4) Current: implement wide-angle, soft-wall (liner) boundary condition

Propagation Code Comparison

- CDL, CHE, LEE, COMSOL comparison with GFIT data

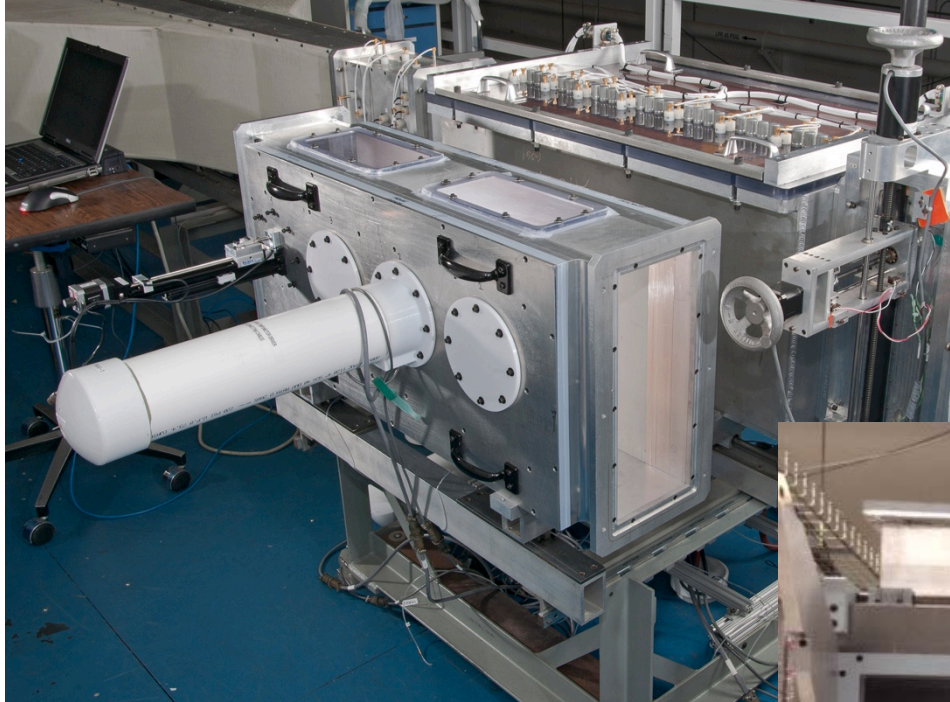
Extended-Reaction Propagation Code

- Developing improved CHE for use with extended-reaction liners
- Compare with COMSOL



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CDTR and Notre Dame Wind Tunnel

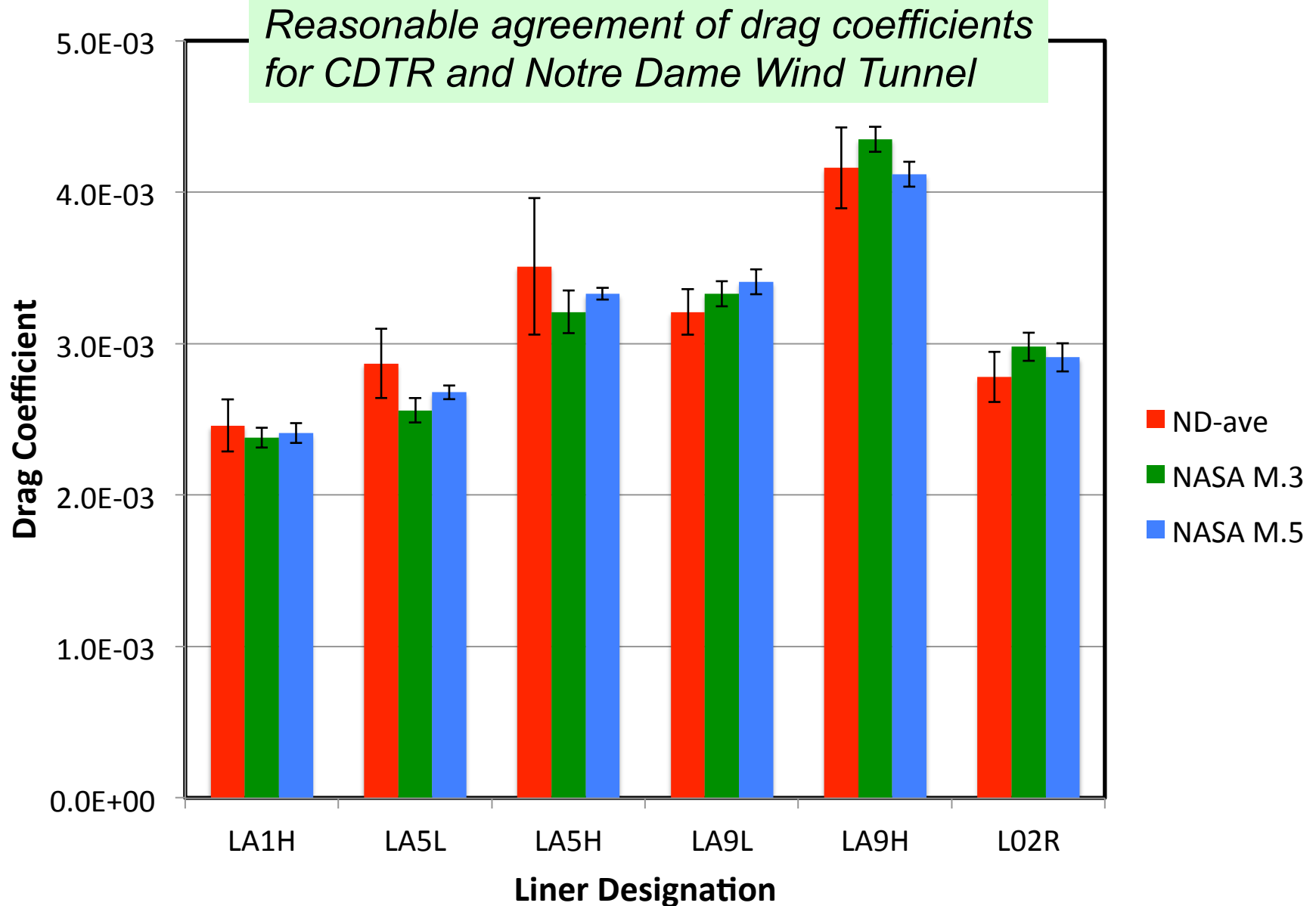


*Drag Test Duct for CDTR
- Momentum loss method -*

*Notre Dame Wind Tunnel
- Force balance -*



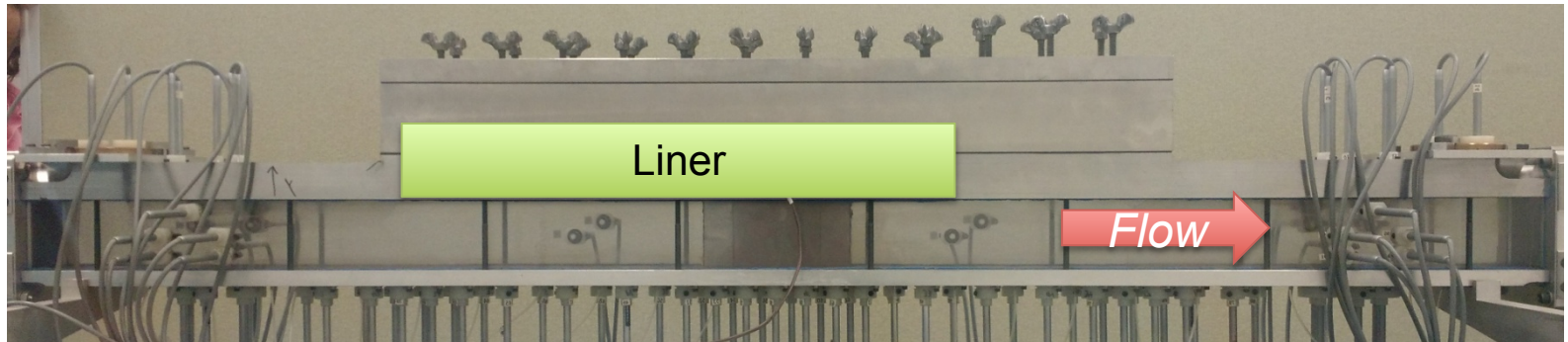
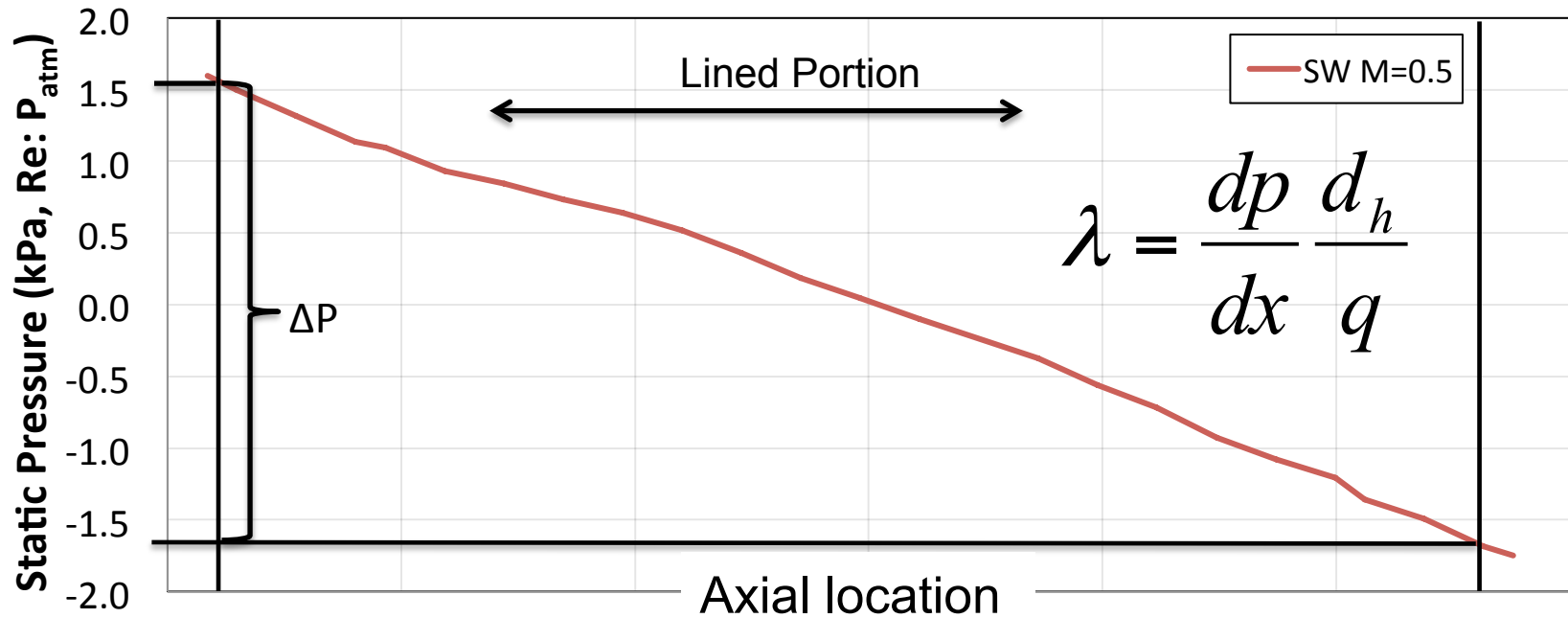
Drag Coefficient Comparison



Grazing Flow Impedance Tube: GFIT



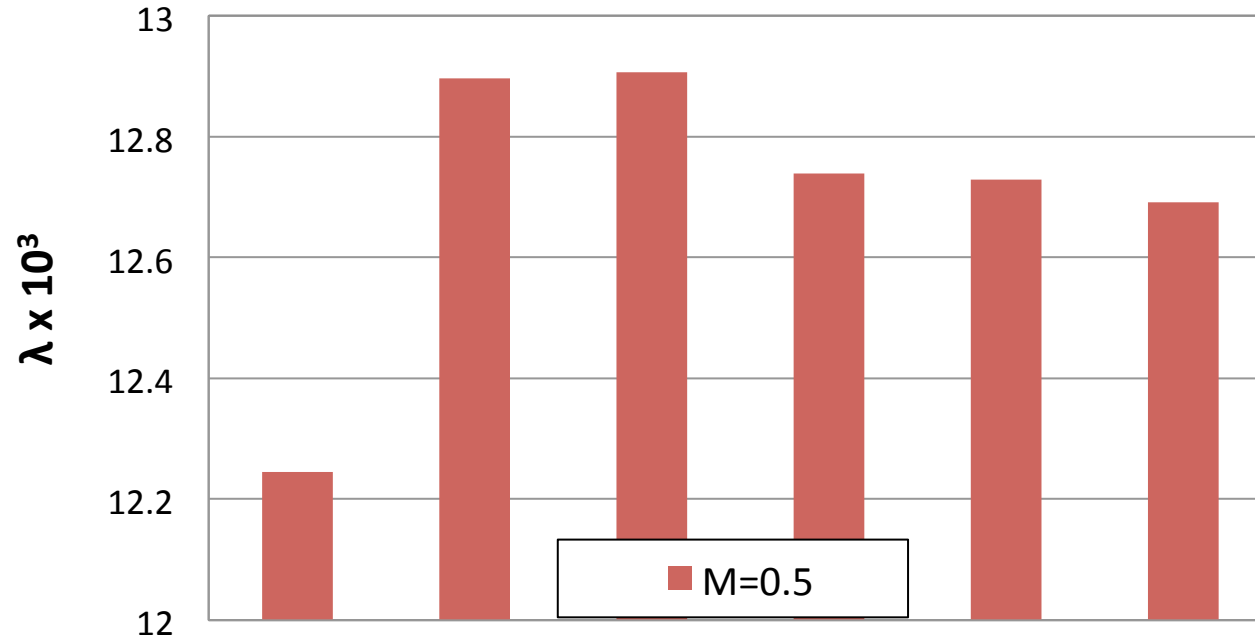
Goal: Develop method to rapidly evaluate relative drag of acoustic liners and apply it to create low-drag designs



Conventional Liner Results



Resistance Factor (λ)- All Liner Configurations, No Sound



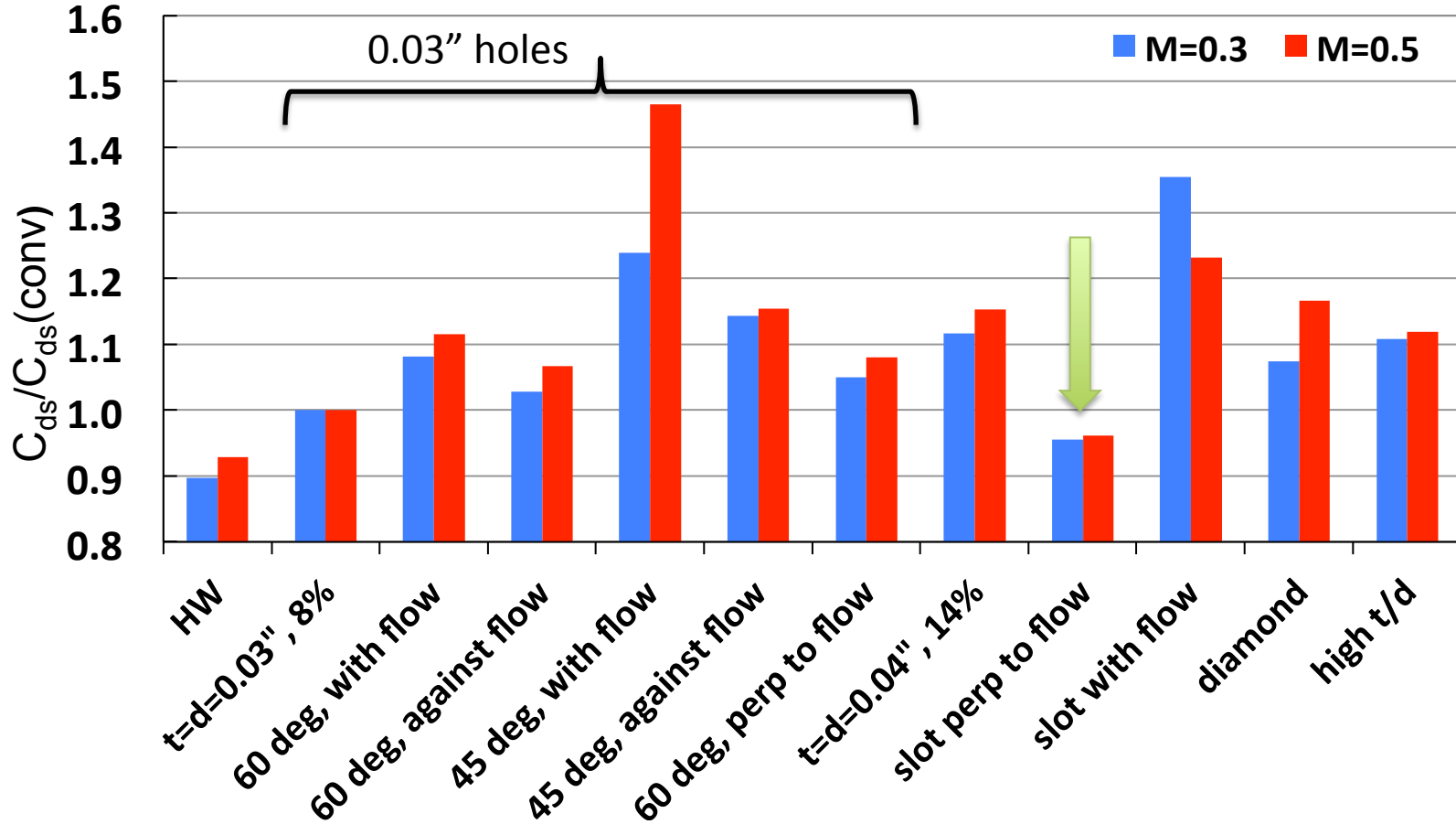
	SW	S1C1	S1C2	S2C1	S2C2	S3C1
d (mm)	N/A	1.0	1.0	0.7	0.7	0.5
h (mm)	N/A	38.1	76.2	38.1	76.2	38.1

Low Drag, Conventional Liner → Small Facesheet Hole Diameter

Preliminary Novel Liner Results



Novel Liner Concepts – Phase 1, No Sound



- Most configurations made drag worse re: conventional perforate
- Slots perpendicular to the flow showed improvement

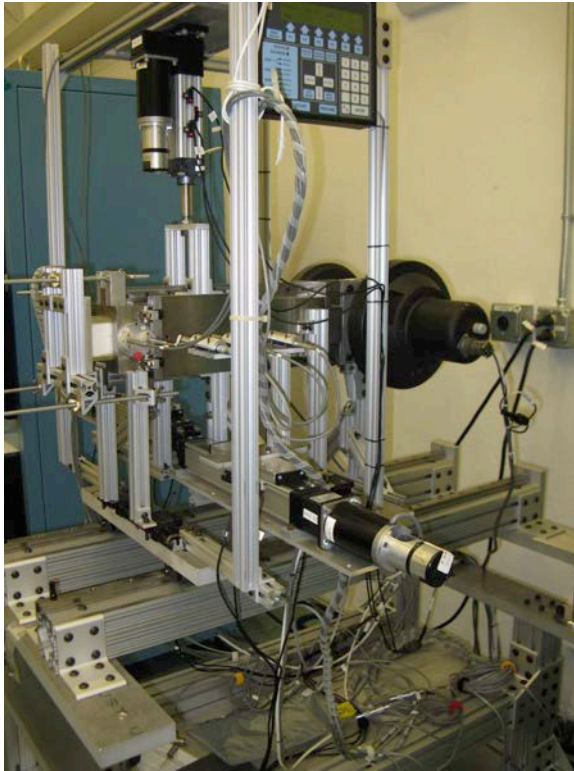


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CDTR Enhancement

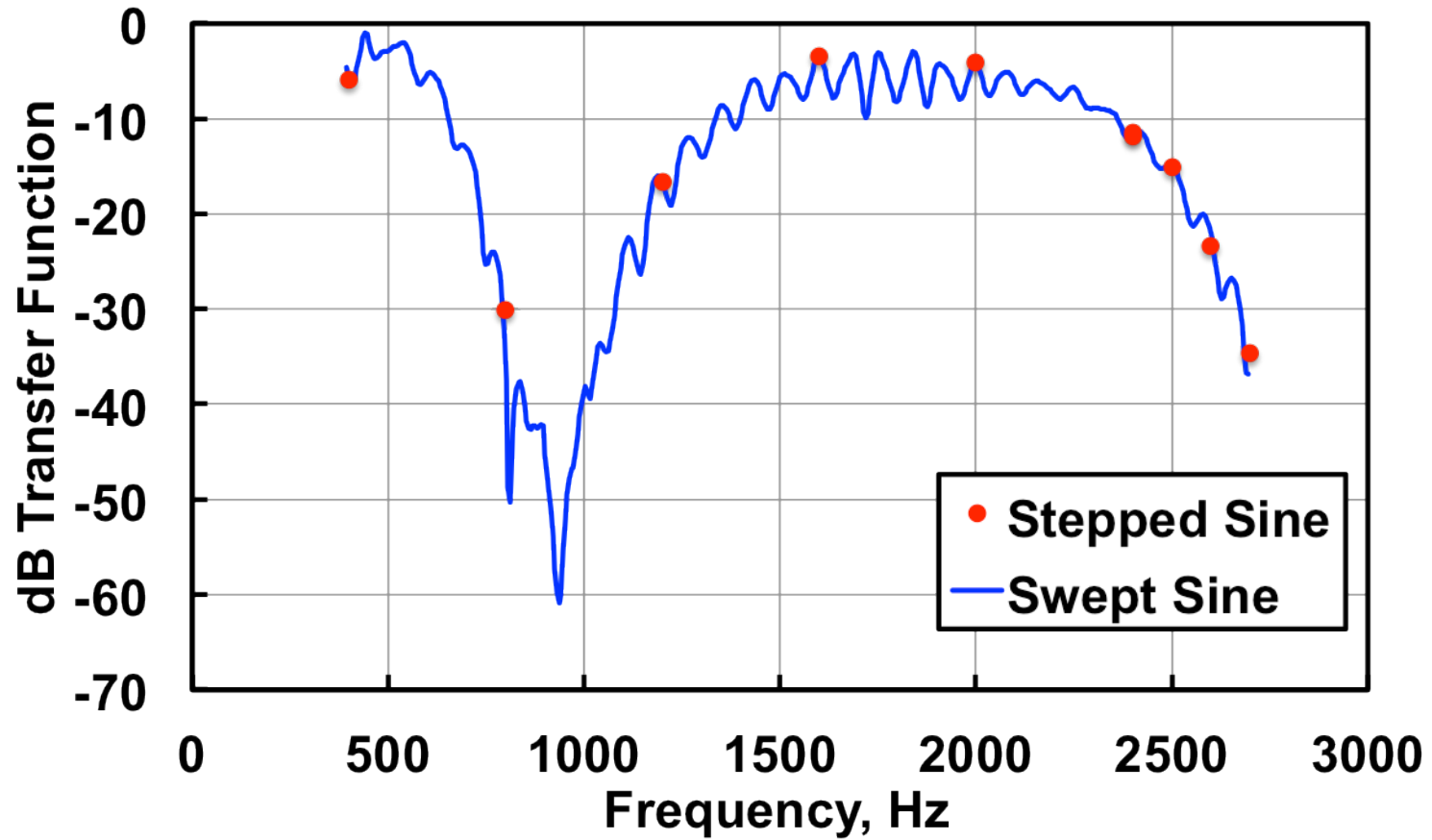


- Doubled number of drivers to increase frequency range and source levels
- Working on updated control algorithms for mode control



- Triple-probe data acquisition system online: allows investigation of higher-order mode effects (**Watson presentation**)
- High-intensity, high-frequency sound source (Hartmann generator) ready for evaluation
- Plan: Evaluate multiple over-the-rotor liner concepts; down-select for ANCF and 22" fan rig tests at GRC

GFIT Enhancement



Working with ATA-E to increase GFIT data acquisition rate and resolution
(Vold presentation)



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- Space Act Agreements:
 - Active: UTAS, Cornerstone Research Group
 - Completed: GEAE, Hexcel
 - Planned: Boeing, Hexcel
- NRA: University of Florida (shear stress sensors)
- Universities: Florida State (Tam), Notre Dame (Corke), Univ of Cincinnati (Syed, retired), Univ of Florida (Sheplak), Virginia Tech (Fuller)

Liner Team & Contributors



M. Jones (Liner Team Lead, liner modeling, ζ education, liner drag)
B. Howerton (LTF data acquisition, liner modeling, liner drag)
D. Nark (propagation code development, liner optimization)
N. Schiller (COMSOL)
M. Brown (LTF manager, liner drag)
H. Haskins (designer)
M. Carpenter (propagation code development)
W. Watson (propagation code development, ζ education)
C. Gerhold (NIA – liner drag)
M. Scott, E. Adcock (shear stress sensor development)
C. Harrison (technician)
L. Becker, B. Leath (contractor support)
C. Jasinski, J. June, K. Mitchell (students)

Journal Articles

1. Beck, Schiller, Jones: "Impedance Assessment of a Dual-Resonance Acoustic Liner," *Applied Acoustics Journal*, Vol. 93, pp. 15-22, June 2015.
2. Gerhold, Brown, Jones, Howerton: "Analysis of Liner Performance using the NASA Langley Research Center Curved Duct Test Rig," *Applied Acoustics Journal*, Vol. 102, pp. 19-32, Jan 2016

ASA Conference, May, 2015

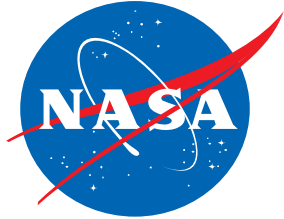
1. Brown, Jones, Howerton: "Acoustic Characterization of Micro-Perforate Porous Plates," presentation

AIAA Aeroacoustics Conference, June, 2015

1. Howerton, Jones: "Acoustic Liner Drag: A Parametric Study of Conventional Liners," AIAA 2015-2230
2. Jones, Watson, Nark, Howerton: "Evaluation of Variable-Depth Liner Configurations for Increased Broadband Noise Reduction," AIAA 2015-2697
3. Jones, Watson, June: "Optimization of Microphone Locations for Acoustic Liner Impedance Eduction," AIAA 2015-3271
4. Nark, Jones, Sutliff: "Modeling of Broadband Liners Applied to the Advanced Noise Control Fan," AIAA 2015-2693
5. Watson, Jones: "Impedance Eduction in 3D Sound Fields with Peripherally Varying Liners and Flow," AIAA 2015-2228
6. Mitchell, Fuller: "Design Optimization of Broadband Acoustic Liners Through Finite Element Efficacy Studies," AIAA 2015-2694

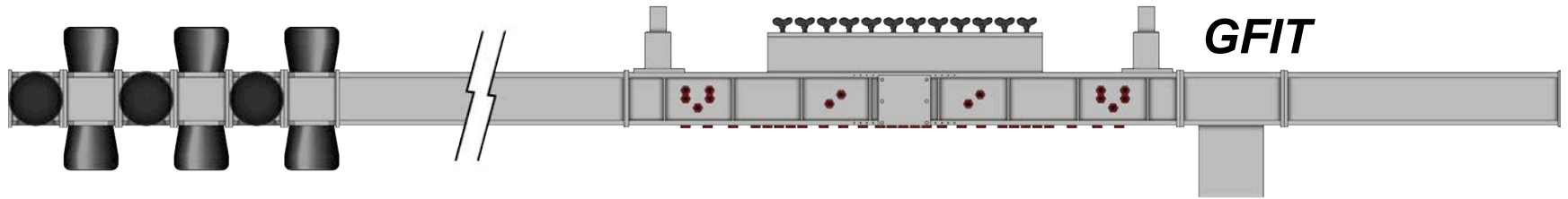
Miscellaneous

1. Jones: "NASA Langley Activities on Broadband Fan Noise Reduction via Novel Liner Technologies." Keynote presentation for CEAS/X-Noise Workshop on Broadband Noise of Rotors and Airframe, September, 2015
2. Grady, Haller, Poinsatte, Halbig, Schnulo, Singh, Weir, Wali, Vinup, Jones, Patterson, Santelle, Mehl: "A Fully Non-Metallic Gas Turbine Engine Enabled by Additive Manufacturing – Part I: System Analysis, Component Identification, Additive Manufacturing, and Testing of Polymer Composites," NASA TM-2015-218748, May 2015.



Backup Slides

Grazing Flow Impedance Tube (GFIT)



Mach #: 0.0 to 0.6

Frequency: 0.4 to 3.0 kHz

Source SPL: up to ~155 dB

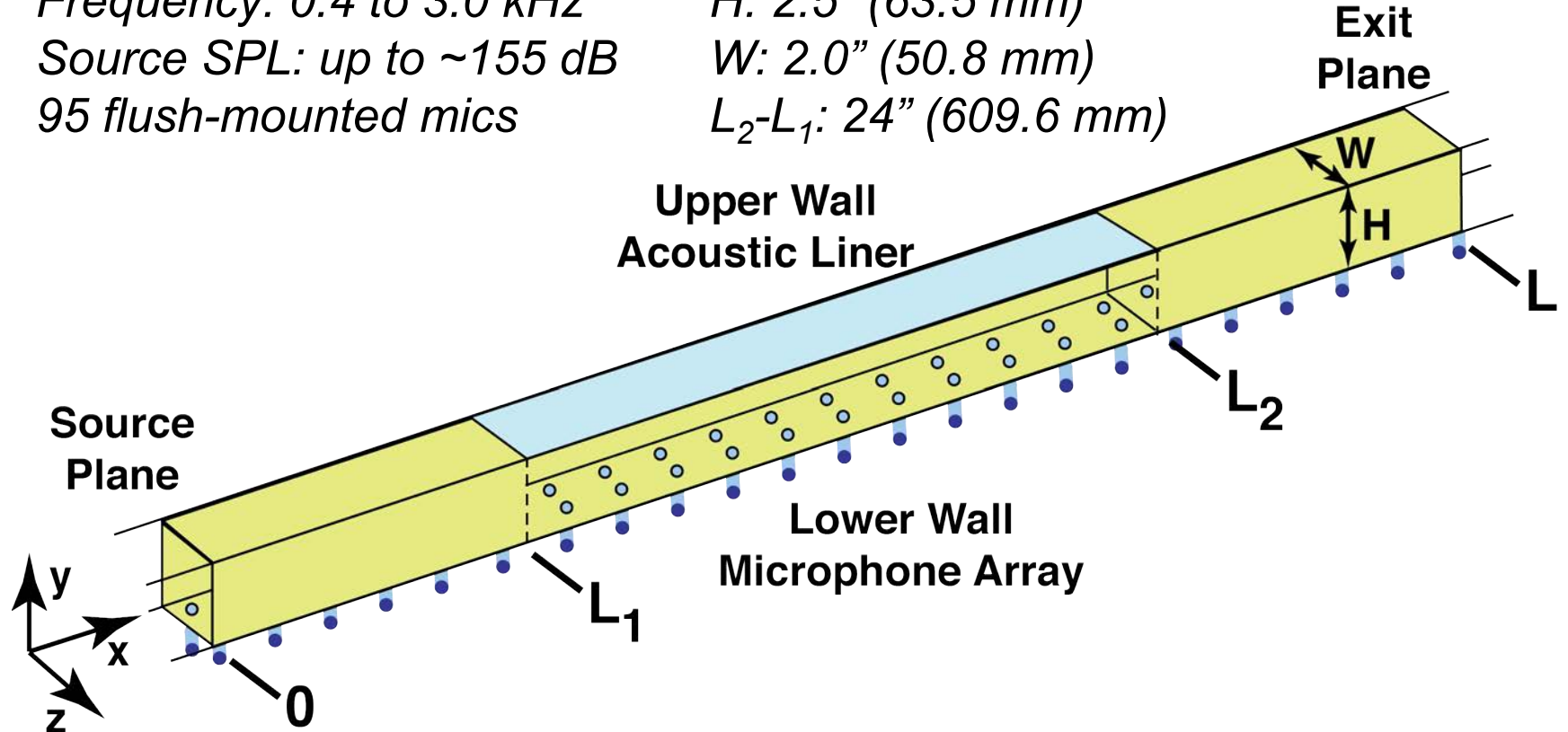
95 flush-mounted mics

Configuration: Inlet or Aft

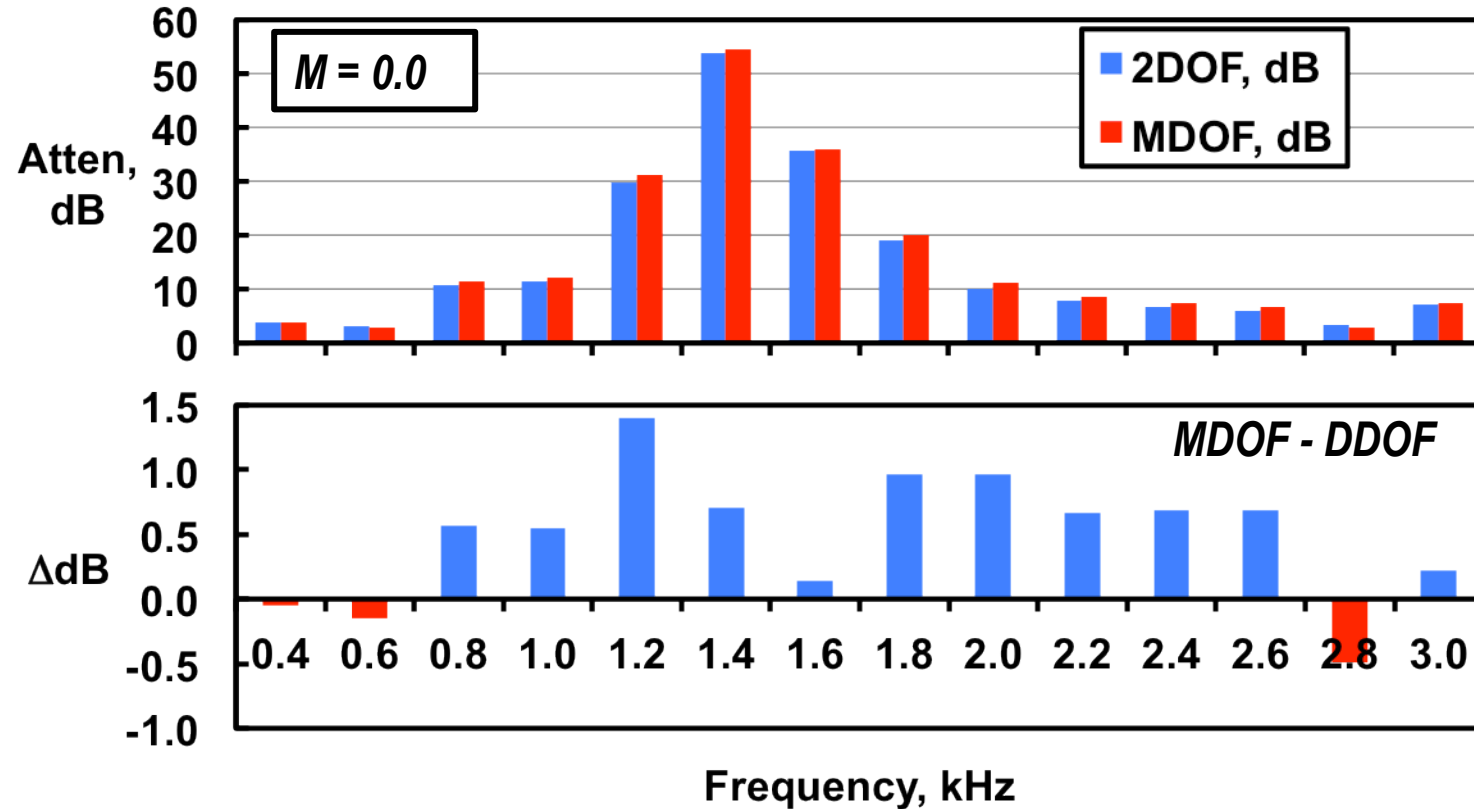
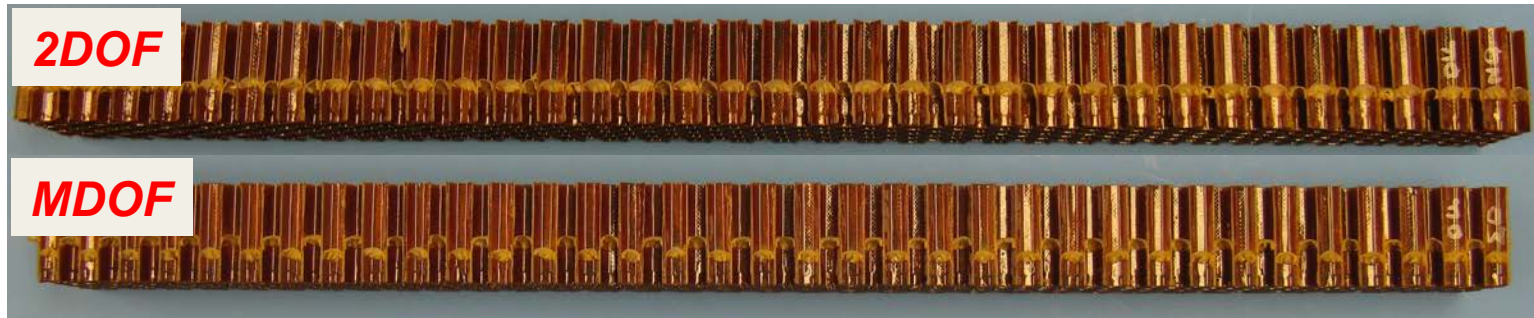
H: 2.5" (63.5 mm)

W: 2.0" (50.8 mm)

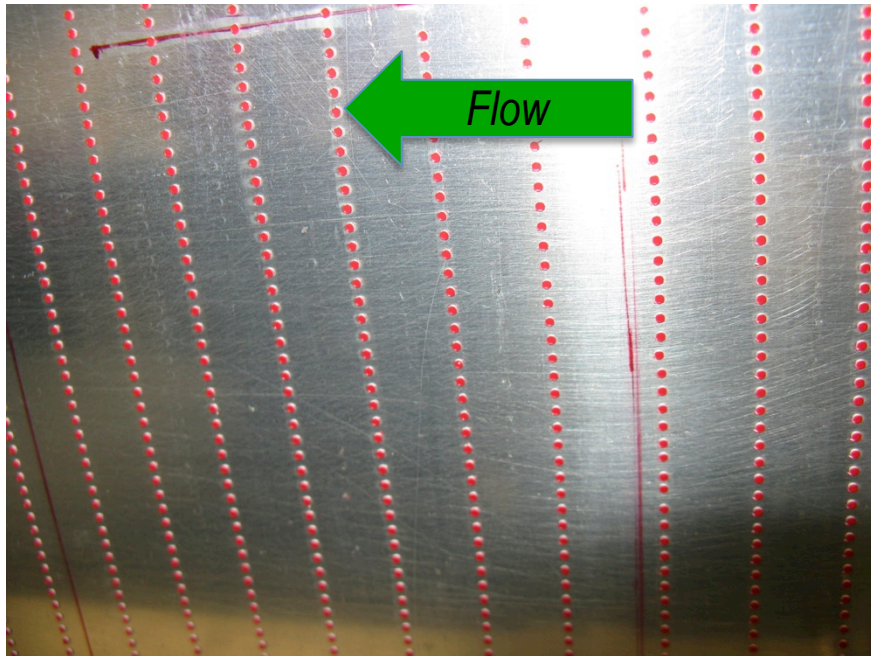
$L_2 - L_1$: 24" (609.6 mm)



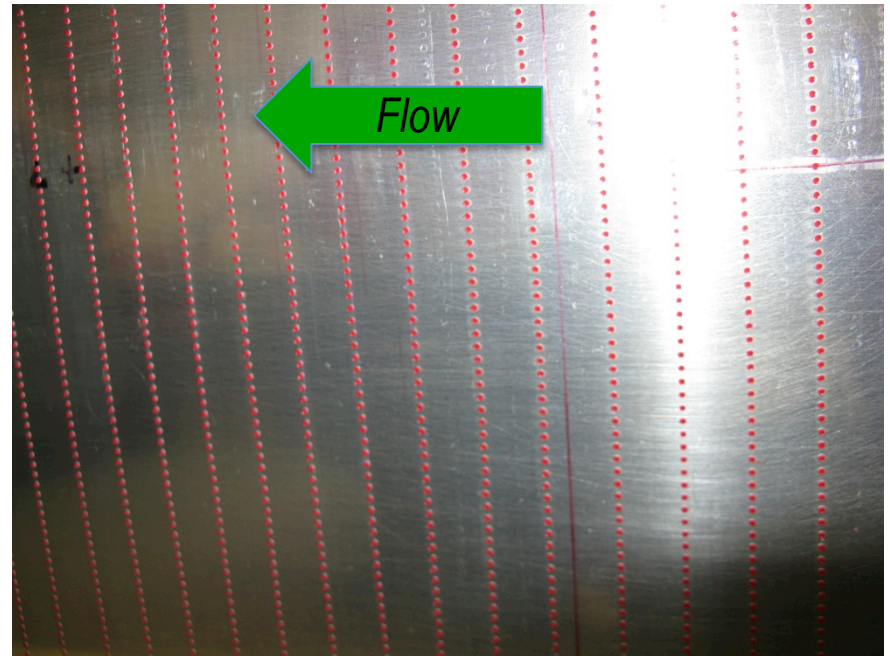
Mesh-Cap Liners: 2DOF vs MDOF



Calibrated Roughness Elements



- Element height – 0.005, 0.009 in
- Cross-stream spacing – 0.10 inch
- Streamwise spacing-0.50 inch
- Density – 20 dots/in²
- Designation: LA5L, LA9L



- Element height –0.005, 0.009 in
- Cross-stream spacing – 0.10 inch
- Streamwise spacing-0.25 inch
- Density – 40 dots/in²
- Designation: LA5H, LA9H

Roughness experiment results for both facilities agree with expectation