



Recent Progress in Liner Modeling ***(with a brief Liner Research Overview)***

Michael Jones
NASA Langley Research Center
michael.g.jones@nasa.gov
(757) 864-5272

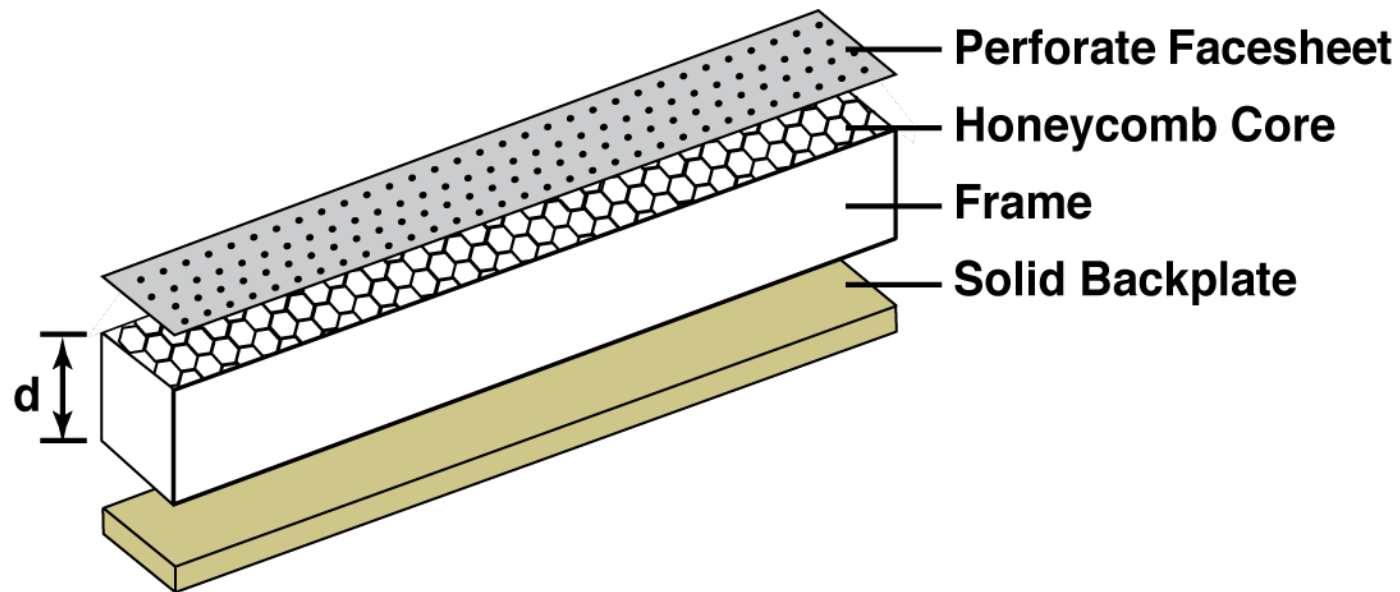


Impedance Prediction Model

Problem Statement

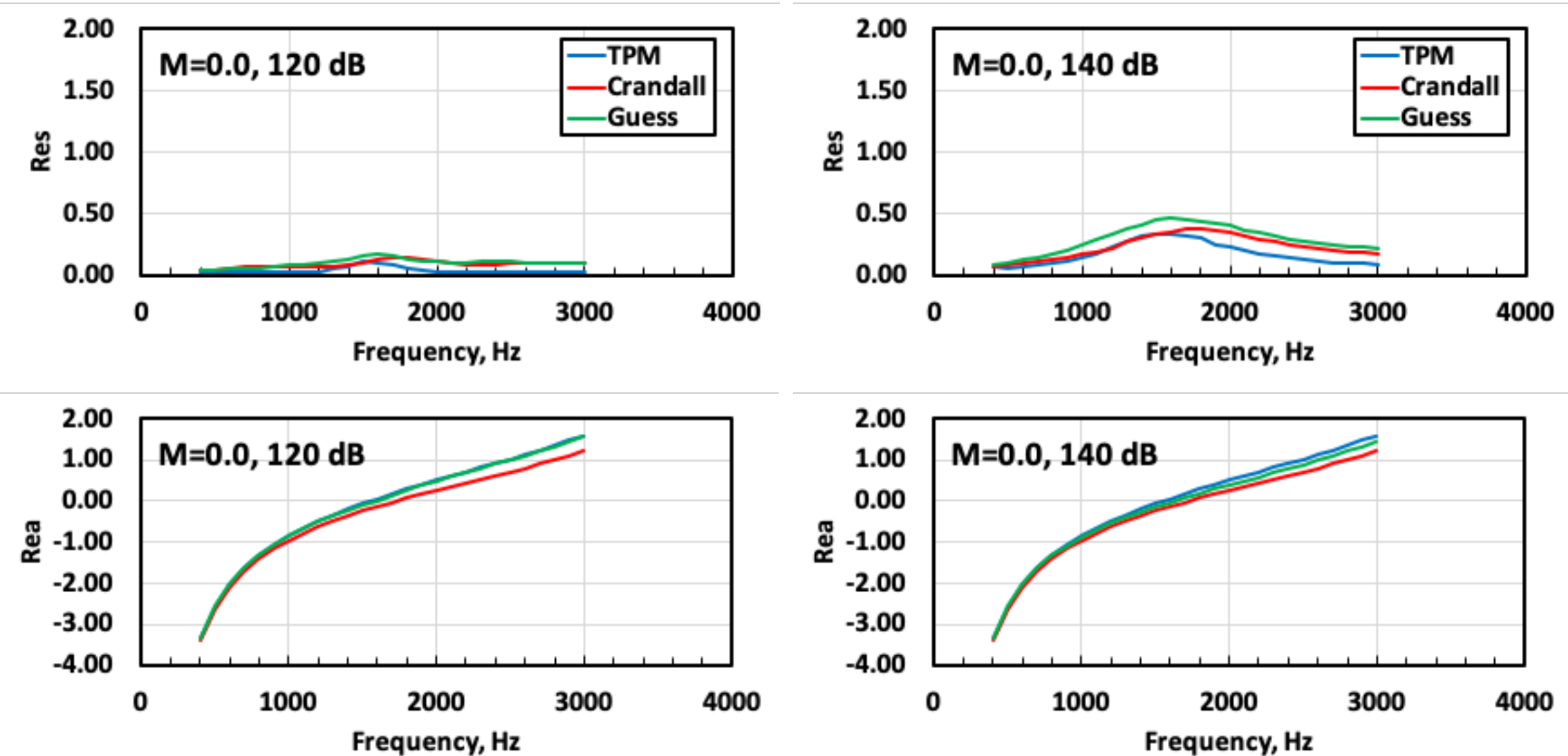


- Many impedance prediction models have been developed over the last century
- Most tend to work well for conditions used in their development, but don't necessarily account for novel liner configurations (e.g. variable-impedance liner concepts)

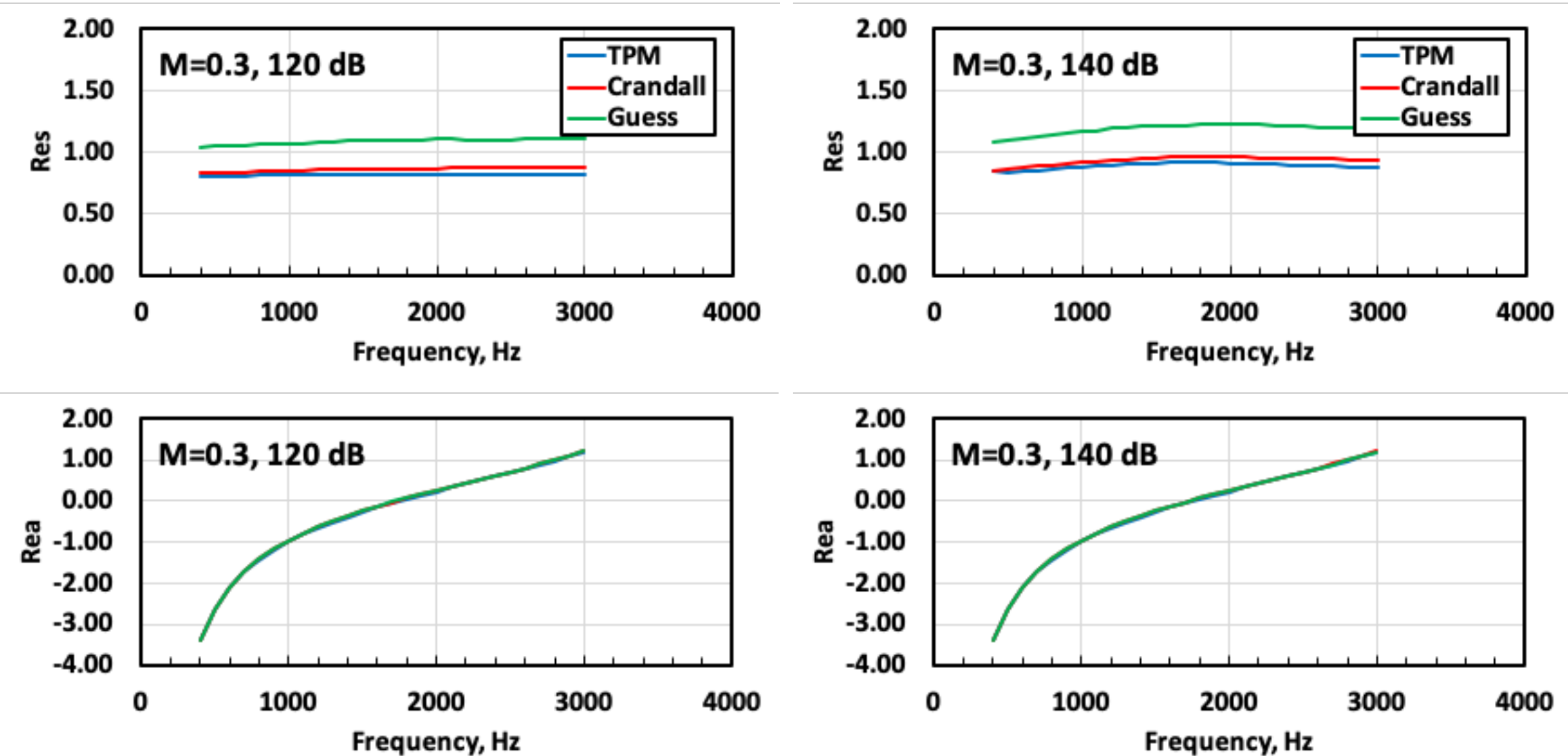


- Currently reviewing models by:
 - **Crandall:** Melling analysis of Crandall model; no mean flow effects
 - **Guess:** provides explicit expressions for linear contributions
 - Motsinger and Kraft: perforate-over-honeycomb-core [POHC] with mean flow, without and with Parrott correction; **Two-Parameter Model (TPM)**
 - Yu, Ruiz, Kwan: based on Crandall model, POHC with mean flow
 - Premo: derived from DC flow resistance model with grazing flow effects due to an effective acoustic velocity
 - Kabral, Boden, Elnady: based on Elnady single-hole, no-flow model; POHC with mean flow
 - Maa: circular orifice, mean flow as per Rice-Heidelberg
 - Parrott, Jones: modified version of TPM with 'optimized' discharge coefficient; no mean flow
 - Parrott: Symmetrical Split-Parameter
 - Jones: transmission-line model; ZKTL
- Most are variants of Crandall and Guess models, and use inputs that are available via NIT and GFIT
- Each model has been incorporated into a new modeling package

Sample Comparison: $t = 0.032''$, $d = 0.038''$, $h = 1.5''$, $\sigma = 0.089$



Sample Comparison: $t = 0.032''$, $d = 0.038''$, $h = 1.5''$, $\sigma = 0.089$



- Find or develop an impedance prediction model to (1) cover range of test conditions and (2) support evaluation of novel liner concepts
- Validate this model using data acquired in the Liner Technology Facility

Model should account for:

- Liner geometry (t, d, σ, h ; may be different for each chamber)
- Mean flow (Mach 0.0 to 0.5)
- Frequency (0.4 to 3.0 kHz)
- SPL (100 to 150 dB)
- Partition thickness (for 3D printed liners)
- Interaction between adjacent chambers
- Others???



1. Acquire NIT database
 - ~60 facesheets (controlled variation of t, d, σ)
3D printed (Accura 60) and aluminum
 - 5 cores (2 uniform, 3 variable-depth)
2. Predict each configuration using each model
 - Account for partition thickness; ignored for conventional honeycomb core
3. Down-select to 'best' models
4. Build a subset of these configurations and test using the GFIT
5. Apply selected models to predict each configuration
6. Develop a new model (may be semi-empirical fit of current models) that best fits the full set of data



Brief Overview of Liner Research

Liner Technology Facility Status



High Intensity Modal Impedance Tube (HIMIT): **Hardware upgrades complete; awaiting final control system validation**

- Mach 0.0, $\text{SPL} \leq 170 \text{ dB}$, $\text{Freq} \leq 6 \text{ kHz}$

Normal Incidence Tube (NIT): **Full testing has resumed!**

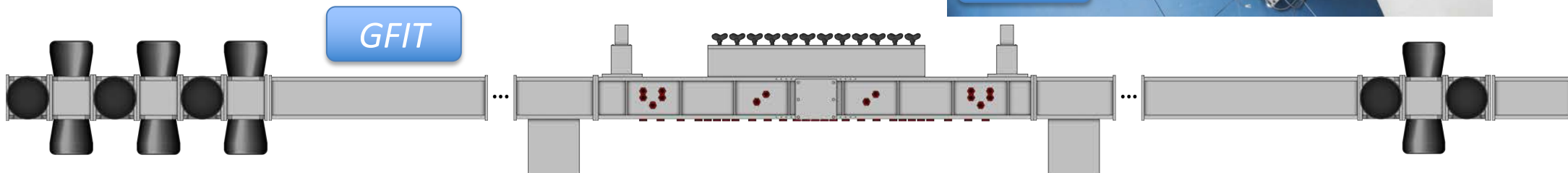
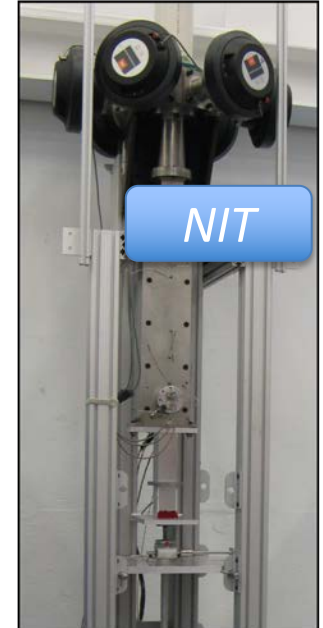
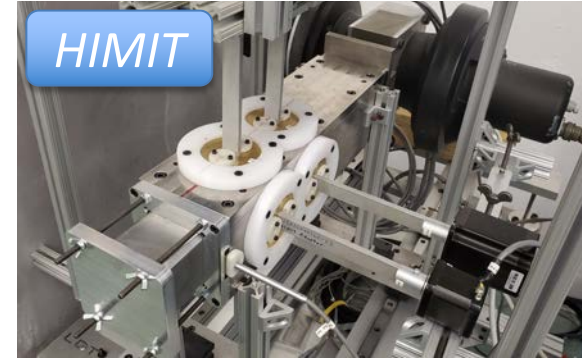
- Mach 0.0, $\text{SPL} \leq 155 \text{ dB}$, $\text{Freq} \leq 3 \text{ kHz}$

Grazing Flow Impedance Tube (GFIT): **Full testing has resumed!**

- Mach ≤ 0.6 , $\text{SPL} \leq 155 \text{ dB}$, $\text{Freq} \leq 3 \text{ kHz}$

Curved Duct Test Rig (CDTR): **Currently being brought back online**

- Mach ≤ 0.5 , $\text{SPL} \leq 135 \text{ dB}$, $\text{Freq} \leq 3 \text{ kHz}$



Novel Liners

- Variable facesheet
 - Completed NIT (no-flow) tests on initial uniform and variable facesheet designs (AIAA 2020-2616)
 - Completed Mach 0.0 GFIT tests (Mach 0.3 and 0.5 tests in progress)
 - Will use data to validate impedance prediction model, then implement optimizer into design process
- Slotted core (Hexcel)
 - Interesting differences between additively manufactured and conventional phenolic core
- Bio-inspired liner (NASA GRC/LaRC)
 - Mimics geometry of natural reeds
 - Combines low-frequency (single tone, < 1 kHz) and broadband (1 – 3 kHz) absorption
 - Geometry, data, reports, and printed samples available through the NASA Glenn Tech Transfer Office
- Active liner (NRA: Boeing/FSU)
- LEONAR liner (ONERA)
- Variable depth, bent chamber

Liner Drag

- Currently evaluating commercially available and custom shear stress sensors for use in GFIT & CDTR

Plans for new benchmark database



- Purpose
 - Detailed database for evaluation of liner models, propagation codes, impedance reduction methods
 - Provide thorough evaluation of measurement and analysis tools
- Liners
 - CSQ3 (calibration liner)
 - GE01, GE03 (two conventional liners)
 - Mesh over two core depths
- NIT
 - Source: Stepped and swept sine, broadband
 - SPL: 100 to 150 dB, 10 dB increments
 - Freq: 0.4 to 3.0 kHz
 - Analysis: Two-Microphone Method → Impedance
- GFIT
 - Upstream (aft mode) and downstream (inlet mode) sources
 - Source: Stepped and swept sine
 - SPL: 120, 140 dB
 - Freq: 0.4 to 3.0 kHz
 - Analysis: Prony, PyCHE (Hybrid) → Impedance
- CDTR
 - Subset of liners
 - Upstream (aft mode) source
 - Source: Stepped sine, multiple controlled modes
 - SPL: 120, 140 dB
 - Freq: 0.4 to 3.0 kHz
 - Analysis: Prony → Impedance



- International Agreement (ONERA) – Dr. Simon completed 1-yr sabbatical at NASA LaRC; collaboration on liner analysis and novel liner concepts (joint journal article) continues
- ODU (NIA) – Initial validation of broadband acoustic liner impedance boundary condition in time domain scattering predictions (TDFAST)
- NRA – Adaptive Liner (Boeing/FSU); scheduled to complete Dec 2020
- Vold LLC – Improvements to swept sine source for GFIT

Space Act Agreements

- Boeing/Purdue/ERAU – CDTR tests of acoustically treated heat exchangers
- FSU – Development of liner drag models
- GE Aviation – GFIT tests with novel liners
- General Atomics – GFIT tests of conventional liners
- Hexcel – Investigate liners with embedded high resistance caps
- Ikonics – Investigate liner facesheet manufacturing innovations
- WSU – Investigate metallic foams



NASA Technical Papers

- Jones, Watson, Nark, Howerton, Brown, “A Review of Acoustic Liner Experimental Characterization at NASA Langley,” NASA TP 2020-220583, April 2020 (DOI: 10.13140/RG.2.2.15613.10720)
- Roncen, Piot, Mery, Simon, Jones, Nark, “Wavenumber-Based Impedance Eduction with a Shear Grazing Flow,” AIAA Journal, April 2020 (DOI: 10.2514/1.J059100)

AIAA Aeroacoustics Conference (Virtual) June 2020

- Jones, Nark, Howerton, Watson, “Uniform and Multizone Liner Results for the International Forum for Aviation Research,” AIAA 2020-2533
- Howerton, Jones, Nark, “An Improved Impedance Eduction Process for the NASA Langley GFIT,” AIAA 2020-2534
- Brown, Jones, “Evaluation of Variable Facesheet Liner Configurations for Broadband Noise Reduction,” AIAA 2020-2616



Structural Acoustics Branch:

Dodge, Galles, Howerton, Jones, Nark

Aeroacoustics Branch:

Brown

Advanced Measurement and Data Systems Branch:

Scott

On-site contractor support:

Becker, Leath, Reid



Questions?



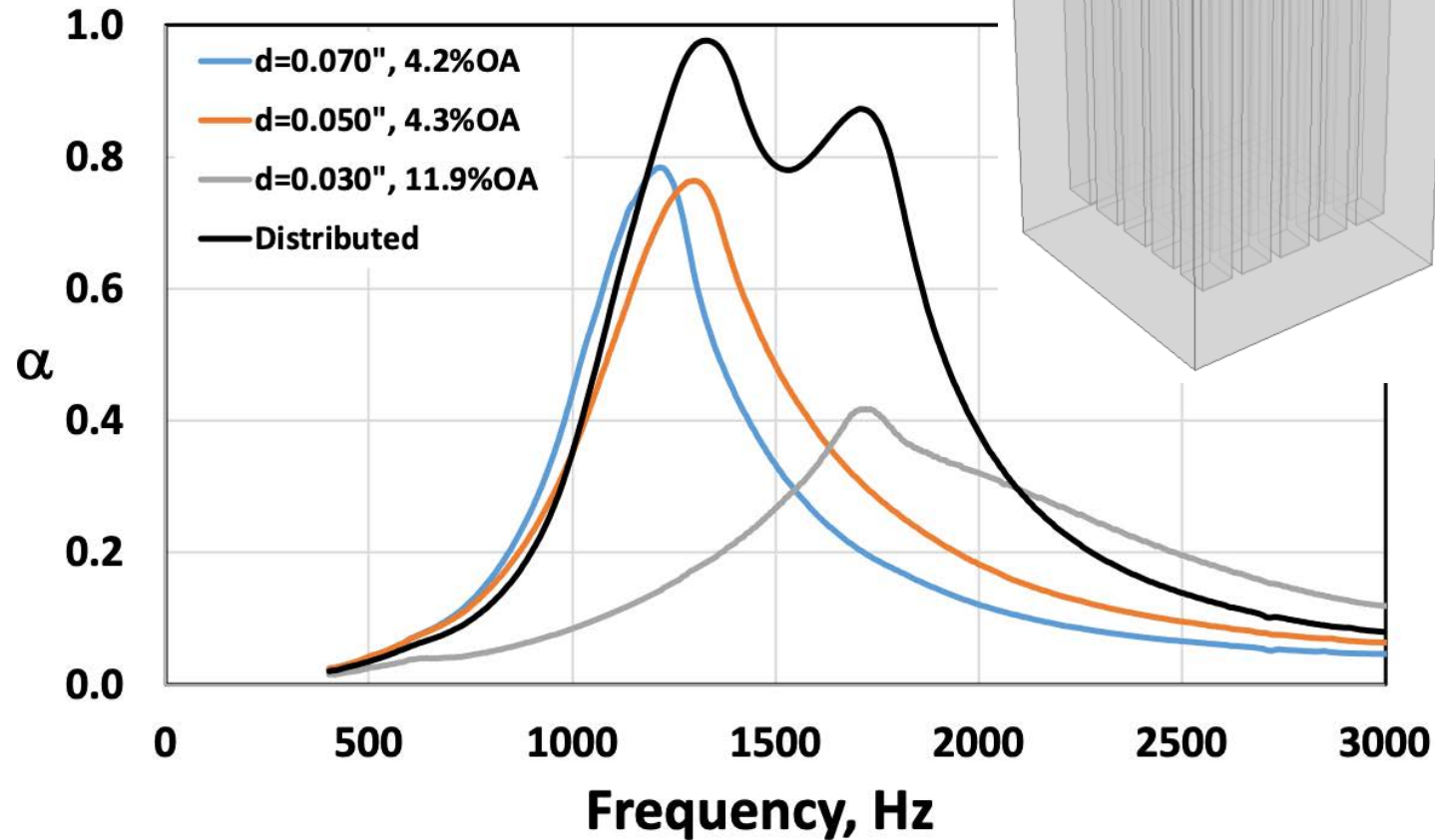


Back-Up Slides

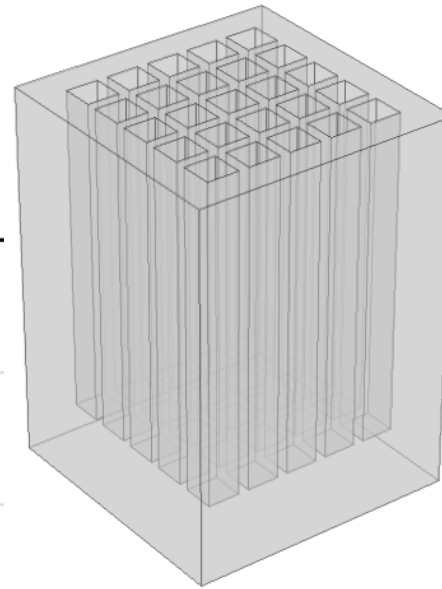
Novel Liner Concepts: Variable Facesheet



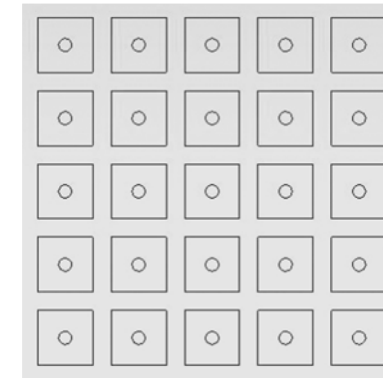
- Distributed (variable $\{d, \sigma\}$) facesheet for broadband noise reduction (Brown)
- NIT tests complete
- GFIT samples ready for testing



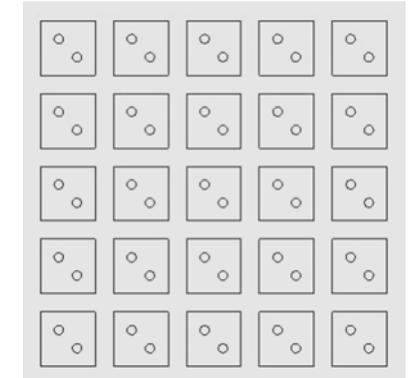
1.5" Core



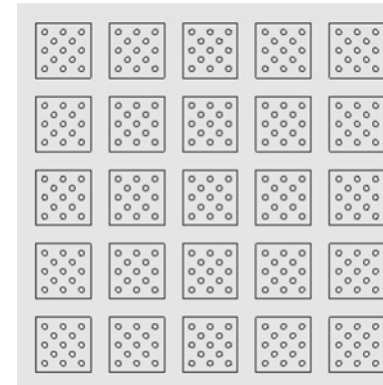
Facesheets



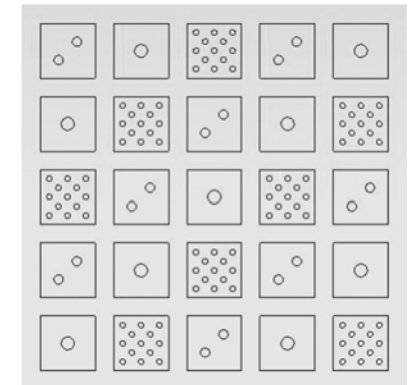
$d=0.070''$, 4.2% OA



$d=0.050''$, 4.3% OA



$d=0.030''$, 11.9% OA



Distributed

Bio-inspired Broadband Acoustic Absorber Update



- In general, it has been difficult to absorb sounds below 1000 Hz with commercially available structures that are thin and lightweight, particularly in applications where the structure is exposed to harsh environmental conditions, such as high temperatures, high-speed airflow, and sprays of liquid and solid debris.
- US Patent 10,460,714 for NASA's Broadband Acoustic Absorber indicates that structures that mimic the geometry of natural reeds absorb sound well in the 400 Hz to 3000 Hz frequency range and also offer an increase in sound absorption below 1000 Hz when compared to state-of-the-art structures of similar thickness, volume, and weight. This invention can be considered for a wide range of aviation, automotive, architectural, and spaceflight applications.
- NASA has recently demonstrated that rectangular and annular panels can be designed and fabricated, suitable for a variety of ground tests and modeling research necessary to mature this technology. See presentation from the April 2020 Acoustics Technical Working Group Meeting for more information. <https://ntrs.nasa.gov/citations/20205000140>
- The set of geometry, data, several reports, and printed samples are available through the NASA Glenn Tech Transfer Office.
- Entrepreneurs can submit proposals to the federal government's Small Business Innovation Research Program and the Small Business Technology Transfer Program: <https://www.sbir.gov>
- For more information, please contact L.Danielle.Koch@nasa.gov in or Jeanne.M.King@nasa.gov

Natural Reeds



Bio-inspired Liners
Loose Synthetic Fixed Synthetic



State-of-the-Art Acoustic Absorbers
Melamine DDOF-POHC

