Investigation of a Bio-Inspired Liner Concept

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Overview

- Inspiration
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Inspiration

The Advanced Noise Control Fan
Formerly in the NASA Glenn AeroAcoustic Propulsion Lab
Currently at the University of Notre Dame

Predicting the Inflow Distortion Tone Noise of the NASA Glenn Advanced Noise Control Fan with a Combined Quadrupole-Dipole Model

L. Danielle Koch

NASA-TM-2012-217679

I became curious about nature while conducting an experiment to validate a fan inlet distortion tone noise prediction code I had developed for aircraft engine noise reduction research.

Inspiration

Photo Credit: Jim Nemet, Cleveland Metroparks Zoo

Owls are often the inspiration and subject of research for engineers interested in quiet flight.

Investigation of a Bio-Inspired Liner Concept

Inspiration

Photo Credit: Jim Nemet, Cleveland Metroparks Zoo

Inspired by research I had heard at a number of conferences sponsored by the American Institute of Aeronautics and Astronautics (AIAA) and the Institute of Noise Control Engineering (INCE), I began to read about owls and the impact of transportation noise on the national parks.

Inspiration

Photo Credit: Jim Nemet, Cleveland Metroparks Zoo

Today's presentation is not about owls.

Description of the Prototypes

Common reed, *Phragmites australis*

Image Source: Ohio Department of Natural Resources: http://ohiodnr.gov/invasiveplants

Nature is inspiring! Researchers in the School of Architecture at the University of Liverpool, UK published an intriguing observation: 2 inch deep bundles of natural reeds were effective at absorbing sound in the 400-1000 Hz range. (Oldham, et al., Sustainable Acoustic Absorbers from the Biomass, Applied Acoustics, Vol 72 (6), 2011)

Introduction

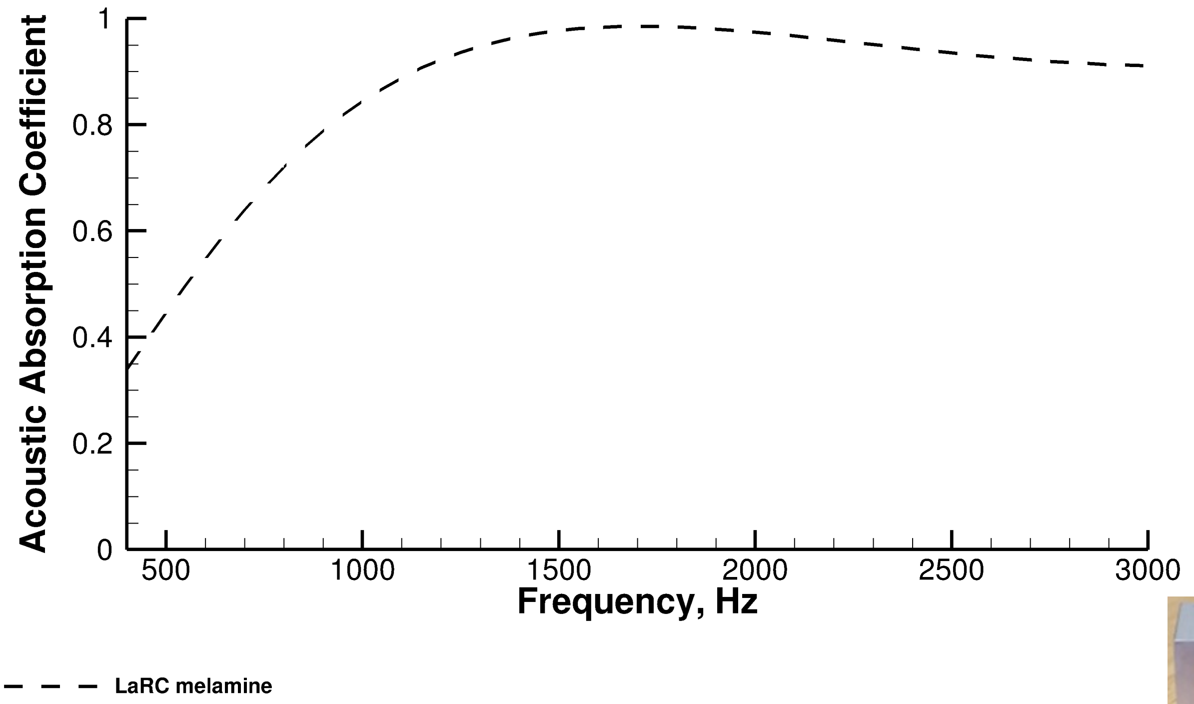
In general, it has been difficult to absorb sounds below 1000 Hz with commercially available materials that are thin and lightweight, particularly in applications with harsh environmental conditions.

Inspired by natural reeds, we have a designed, fabricated, and tested prototypes of broadband acoustic absorbers that are capable of providing good absorption performance between 0 and 3,000 Hz, and particularly below 1,000 Hz.

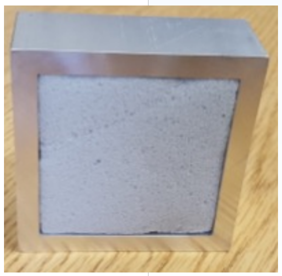
Prototypes were additively manufactured using the NASA Glenn Stratasys Fortus 400 Fused Deposition Modeler.

Exploratory proof-of-concept tests were performed in the NASA Glenn and NASA Langley Normal Incidence Tubes.

Summary of Proof-of-Concept Tests

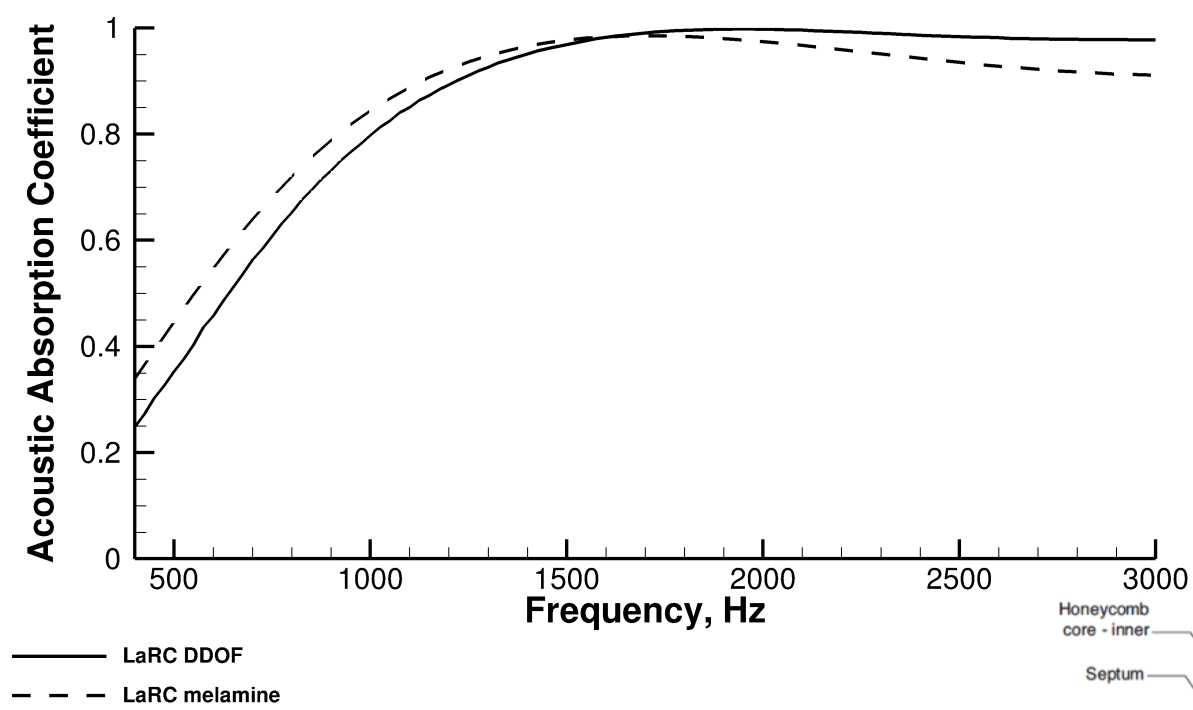


Melamine



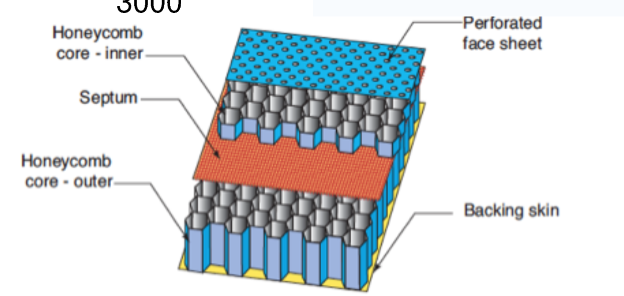
For example, melamine foam is a widely used acoustic absorber in industry today. Normal Incidence Tube measurements show the acoustic absorption coefficients for this 2 inch deep sample are lowest in the 400-1000 Hz range.

Summary of Proof-of-Concept Tests



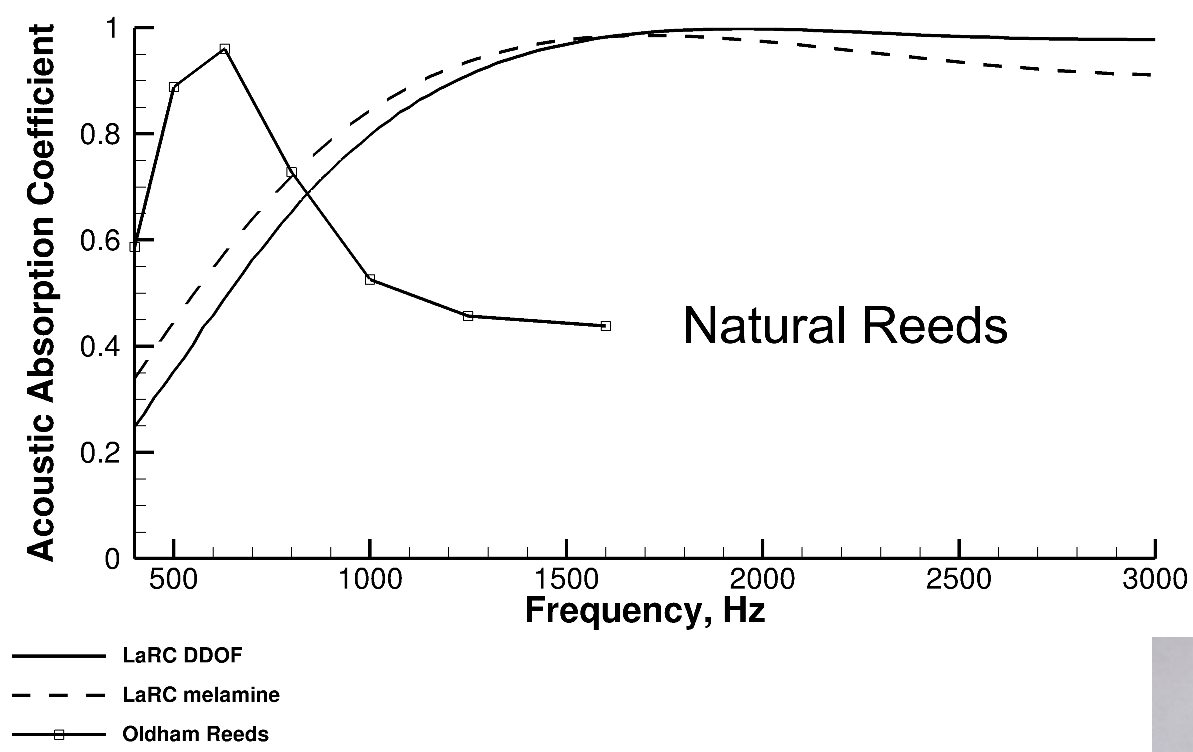
DDOF-POHC

Melamine



For example, Double Degree of Freedom (DDOF) Perforate-Over-Honeycomb structures are commonly used as aircraft engine acoustic liners today. The acoustic absorption coefficients for this DDOF liner are also lowest between 400-1000 Hz.

Summary of Proof-of-Concept Tests

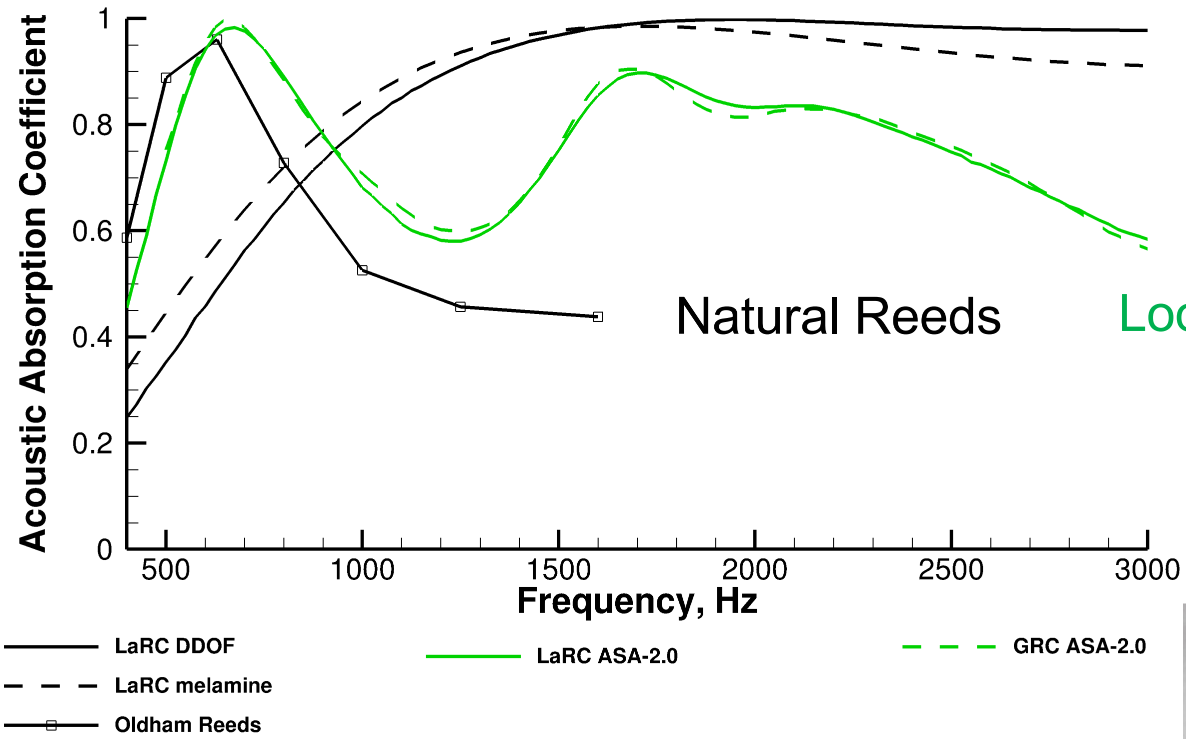


DDOF-POHC

Melamine

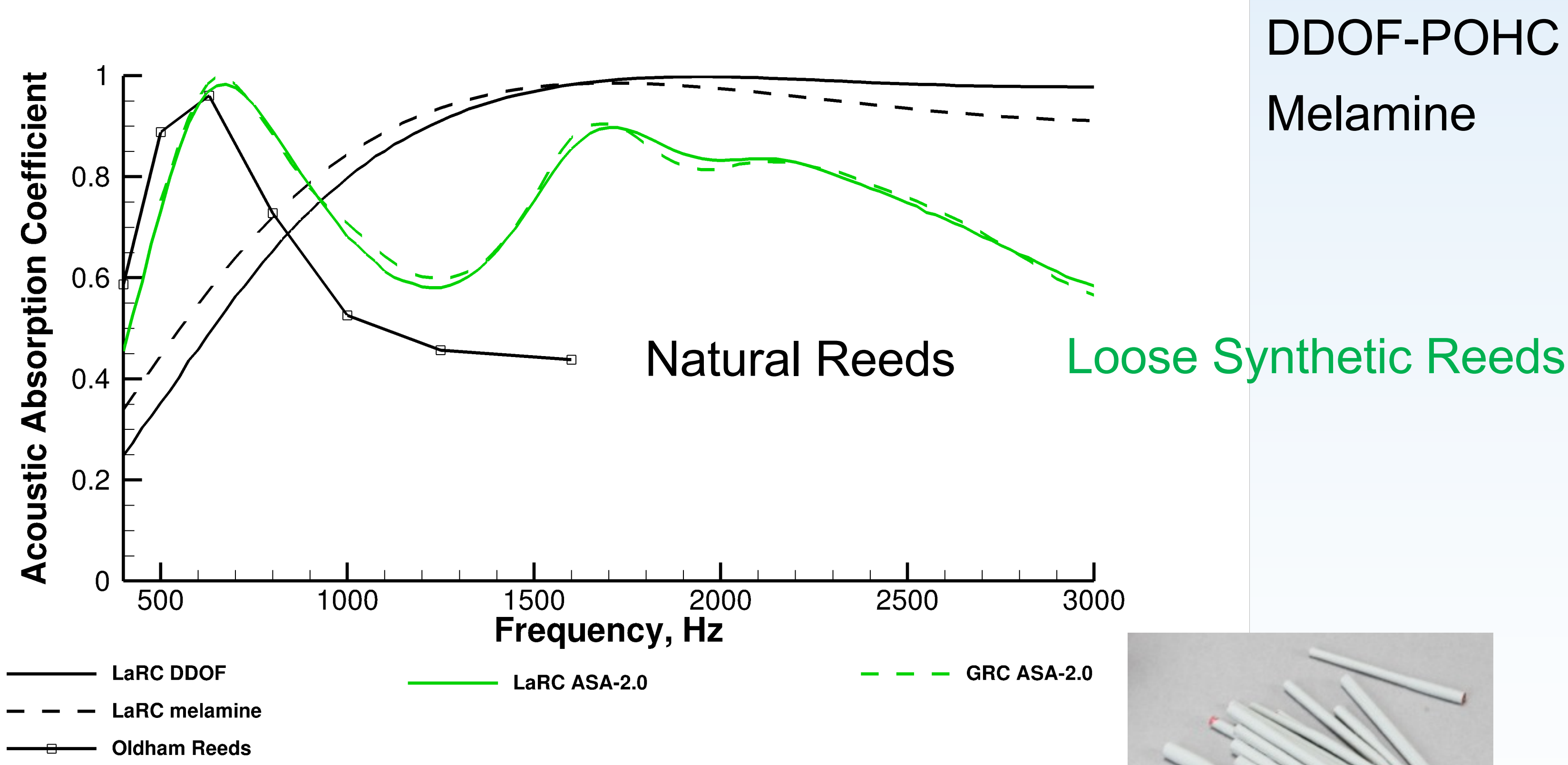
Natural reeds are often not suited for industrial use.
Could we manufacture structures that resemble bundles of natural reeds from other materials and still get high acoustic absorption at low frequencies?

Summary of Proof-of-Concept Tests



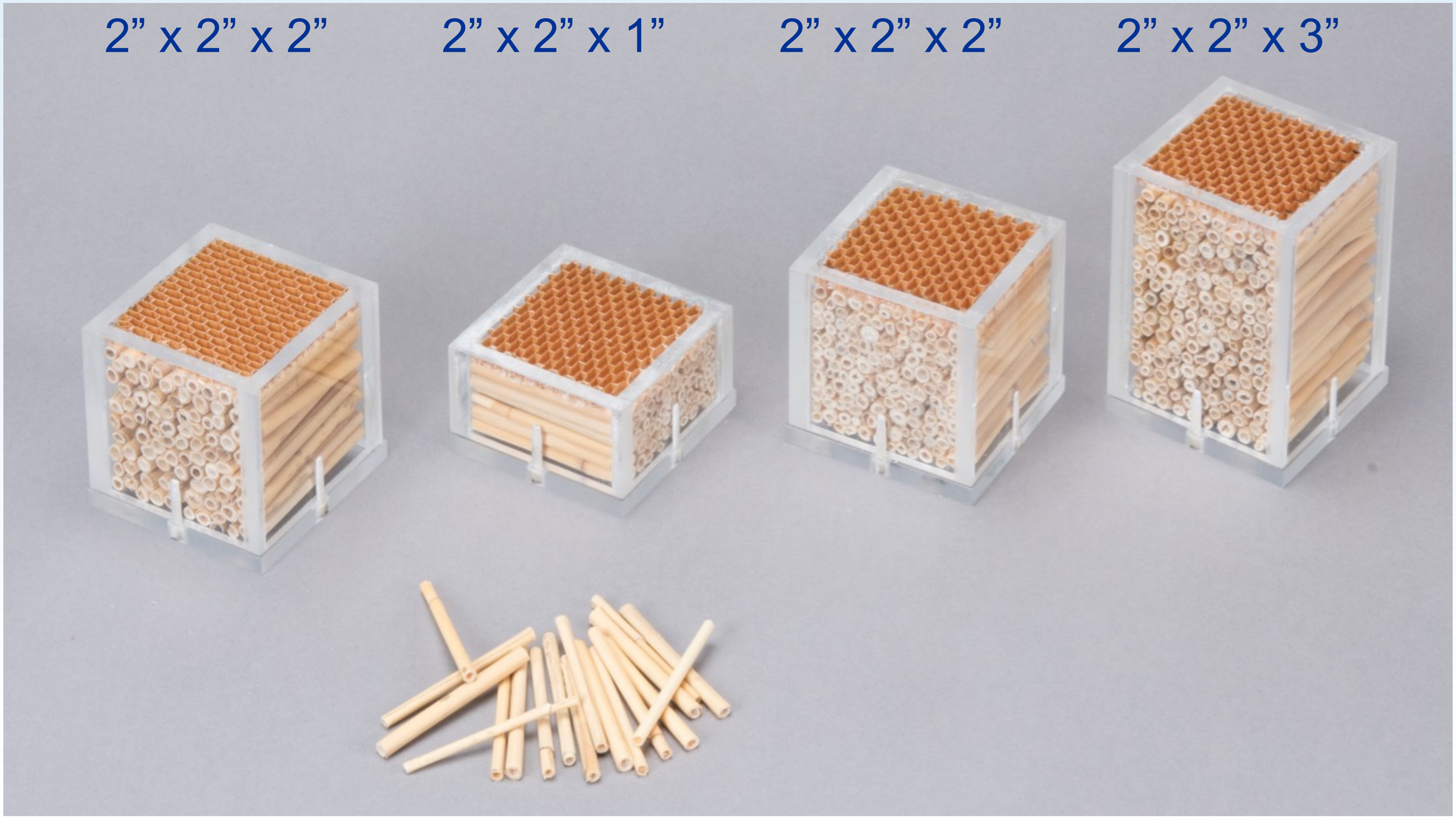
Yes! We did manufacture structures that resemble 2 inch deep bundles of natural reeds from a synthetic material that effectively absorbed sounds in the 0-3000 Hz frequency range, and especially below 1000 Hz.

Summary of Proof-of-Concept Tests



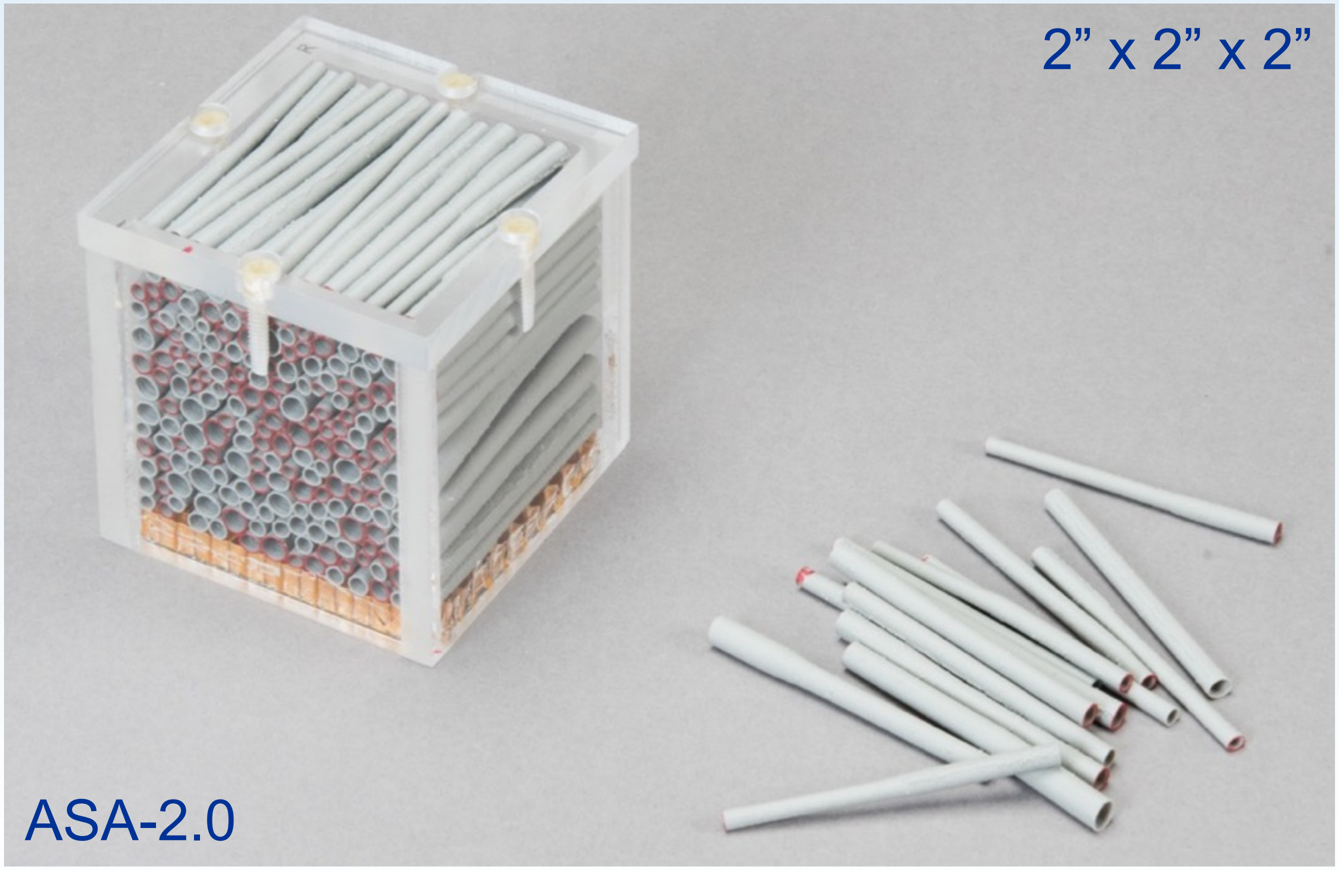
We believe these promising initial results warrant further investigation. There may be a number of aviation and industrial applications with challenging sets of constraints that could use broadband acoustic absorbers.

Description of the Prototypes



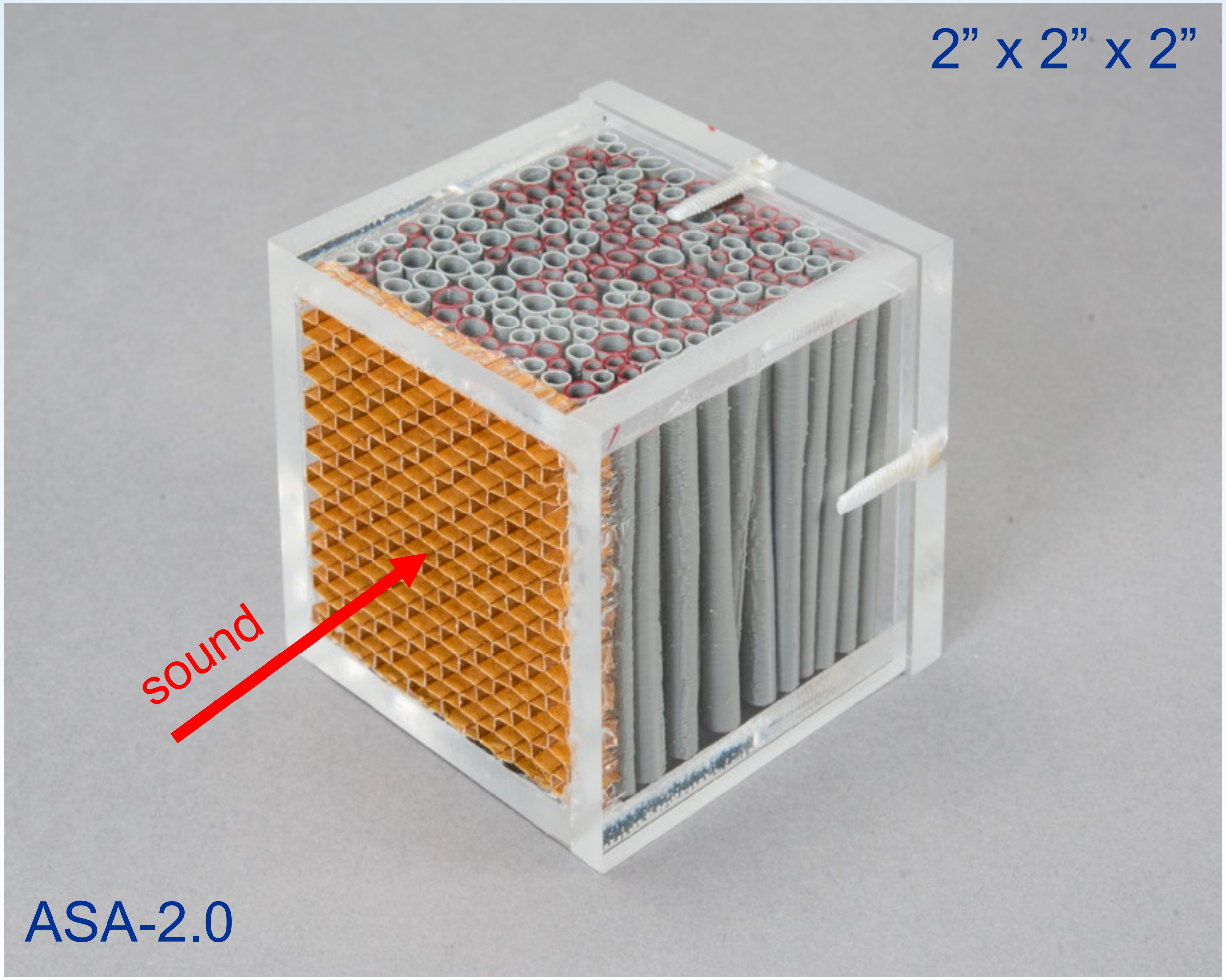
Four samples of natural reeds, *Phragmites australis*, were packed inside acrylic sample holders. Sound entered the sample through Nomex honeycomb. The acrylic back plate was held in place with glass reinforced nylon screws.

Description of the Prototypes



One sample consisted of loose synthetic reeds packed in an acrylic sample holder. The synthetic reeds were designed using X-ray Computed Tomography images of some natural reeds. The synthetic reeds were additively manufactured from ASA thermoplastic on the NASA Glenn Stratasys Fortus 400 Fused Deposition Modeler.

Description of the Prototypes



Sound enters the sample through the Nomex honeycomb, and passes through the spaces formed between the synthetic reeds.

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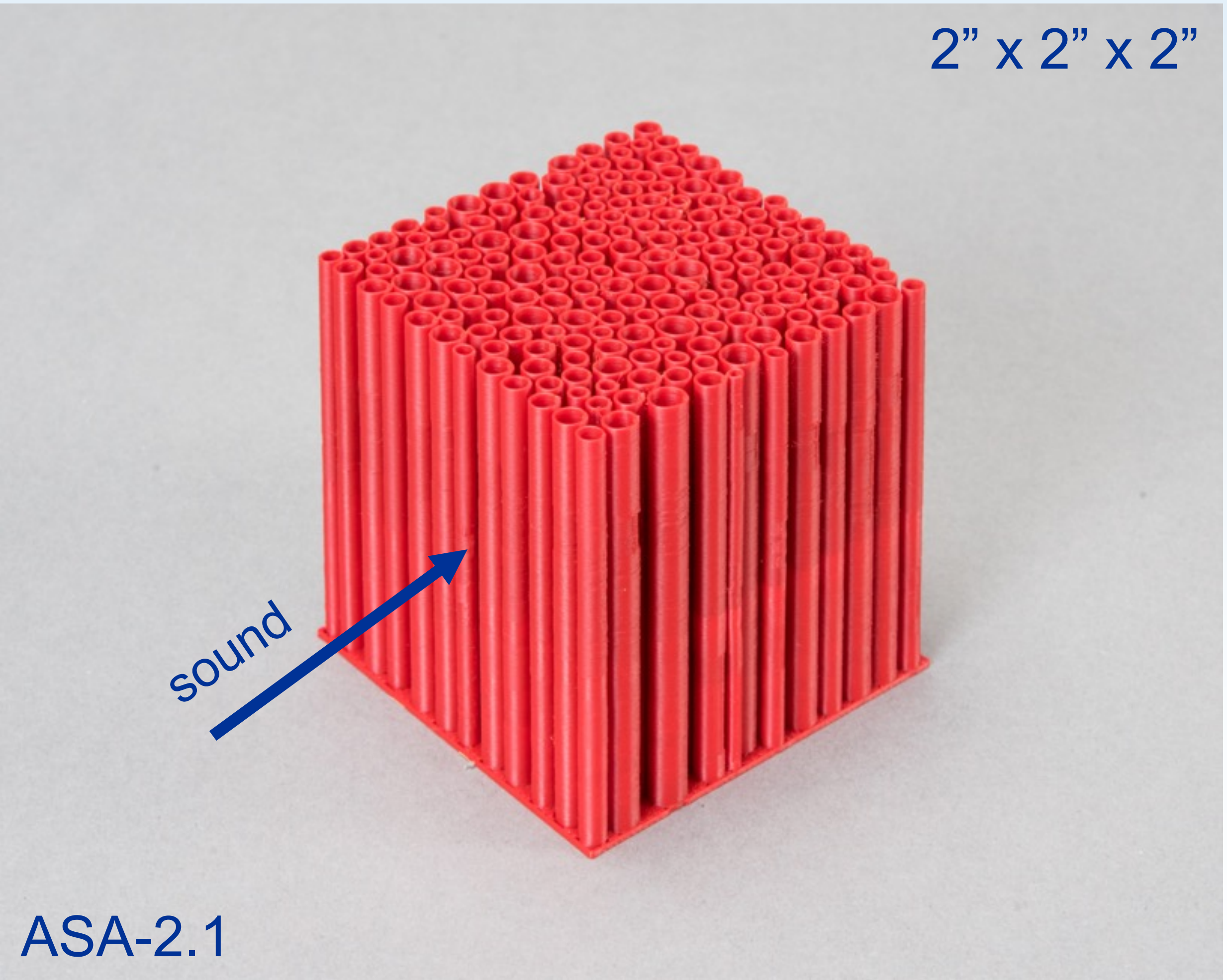

Several other prototypes were built that did not need a sample holder to hold its shape. These were also designed using X-ray Computed Tomography images and Fused Deposition Modeling.

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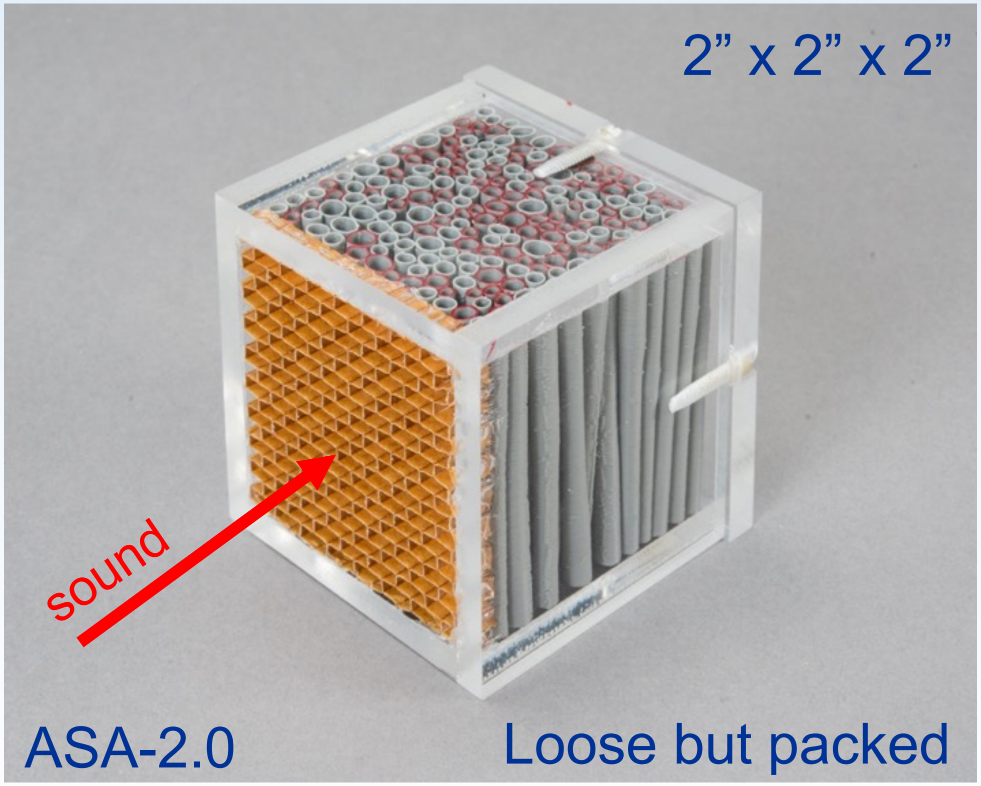
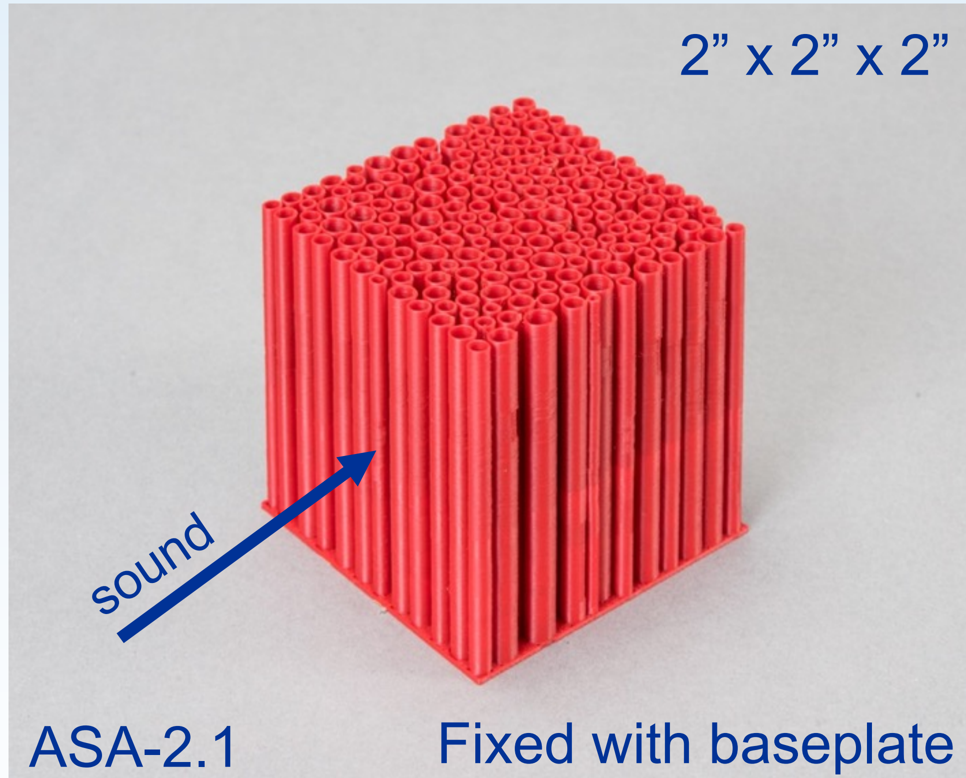
Description of the Prototypes



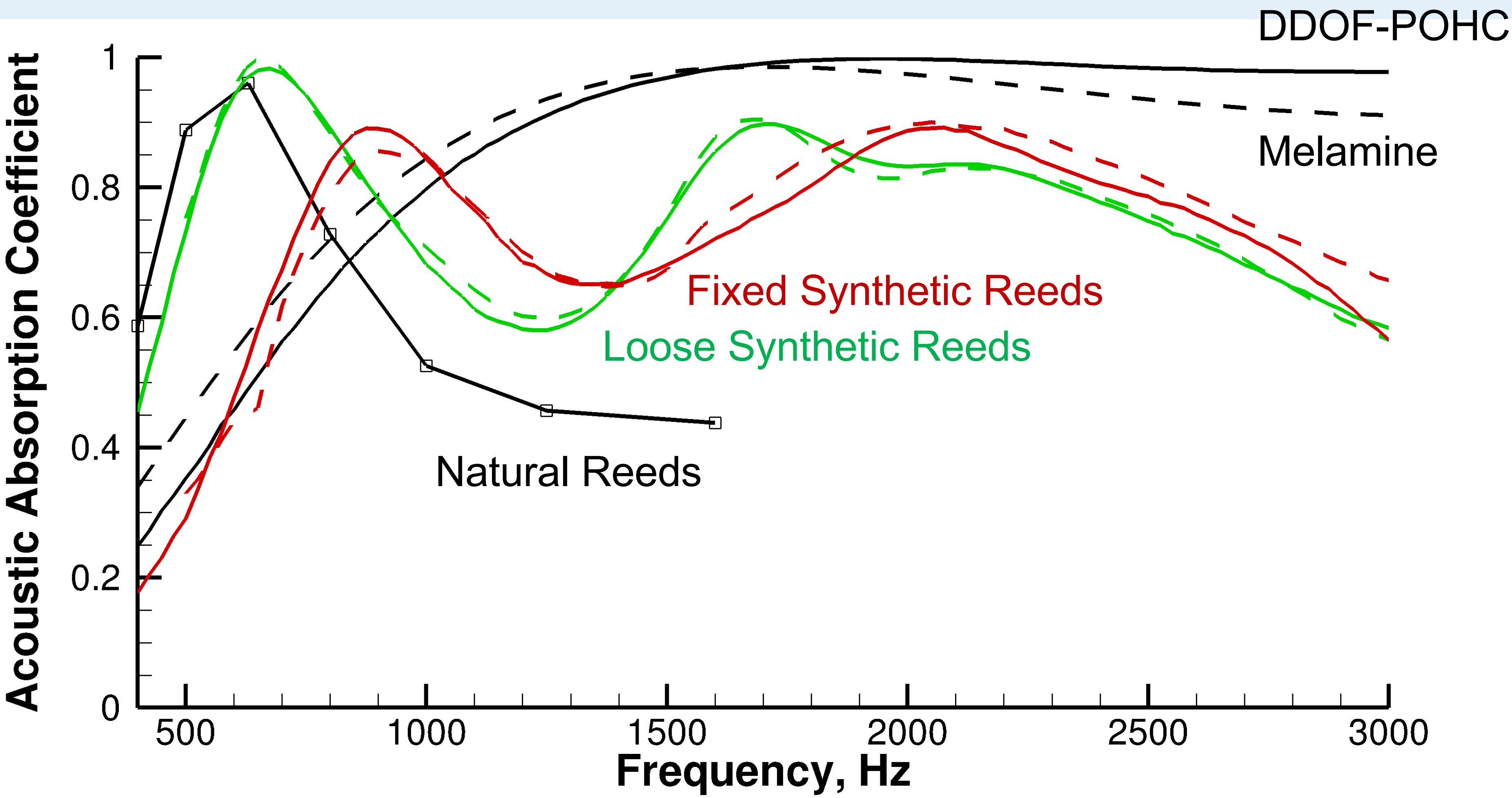


- Loose tubes are packed together.
- Needs retainer to hold shape.
- Fully 3D--Cross-section shape and size varies along length of each.

- Tubes are held in place with a base.
- Does not need retainer to hold shape.
- 2D: Cross-section shape, size, and position of each tube varies in the x-y plane only; lengthwise uniform.

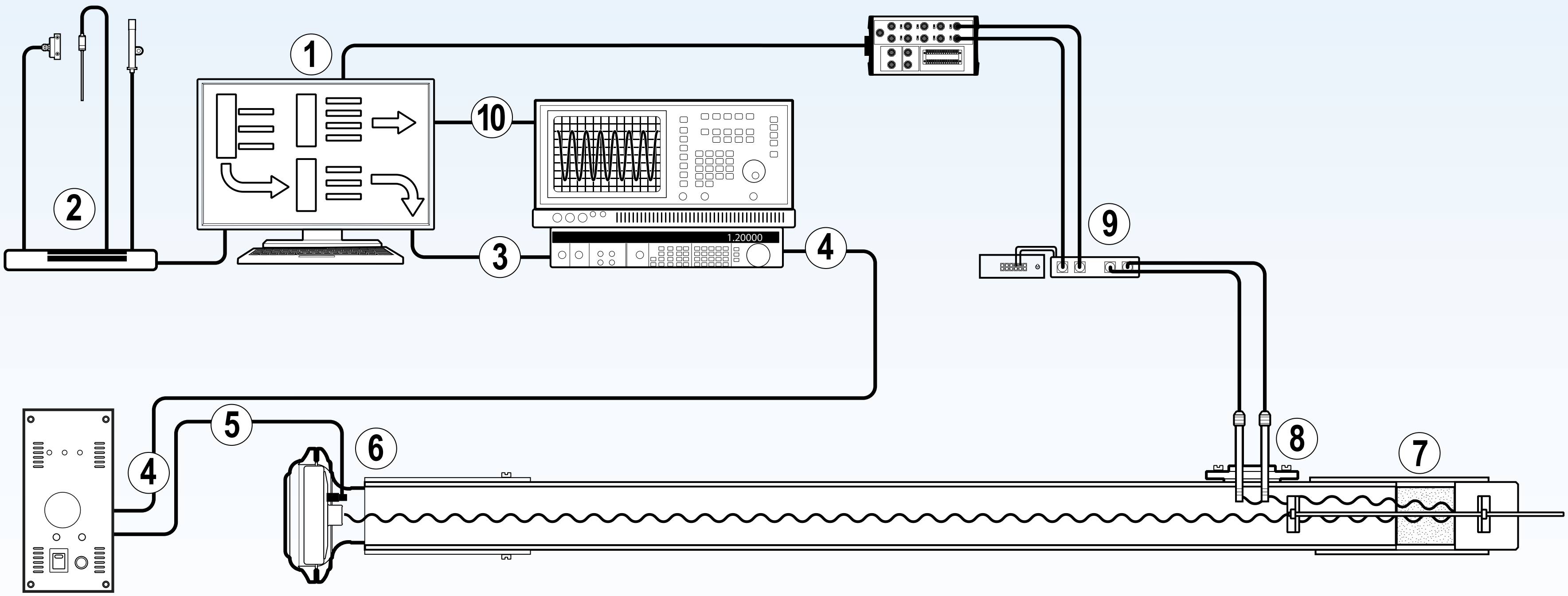
Investigation of a Bio-Inspired Liner Concept

Description of the Prototypes



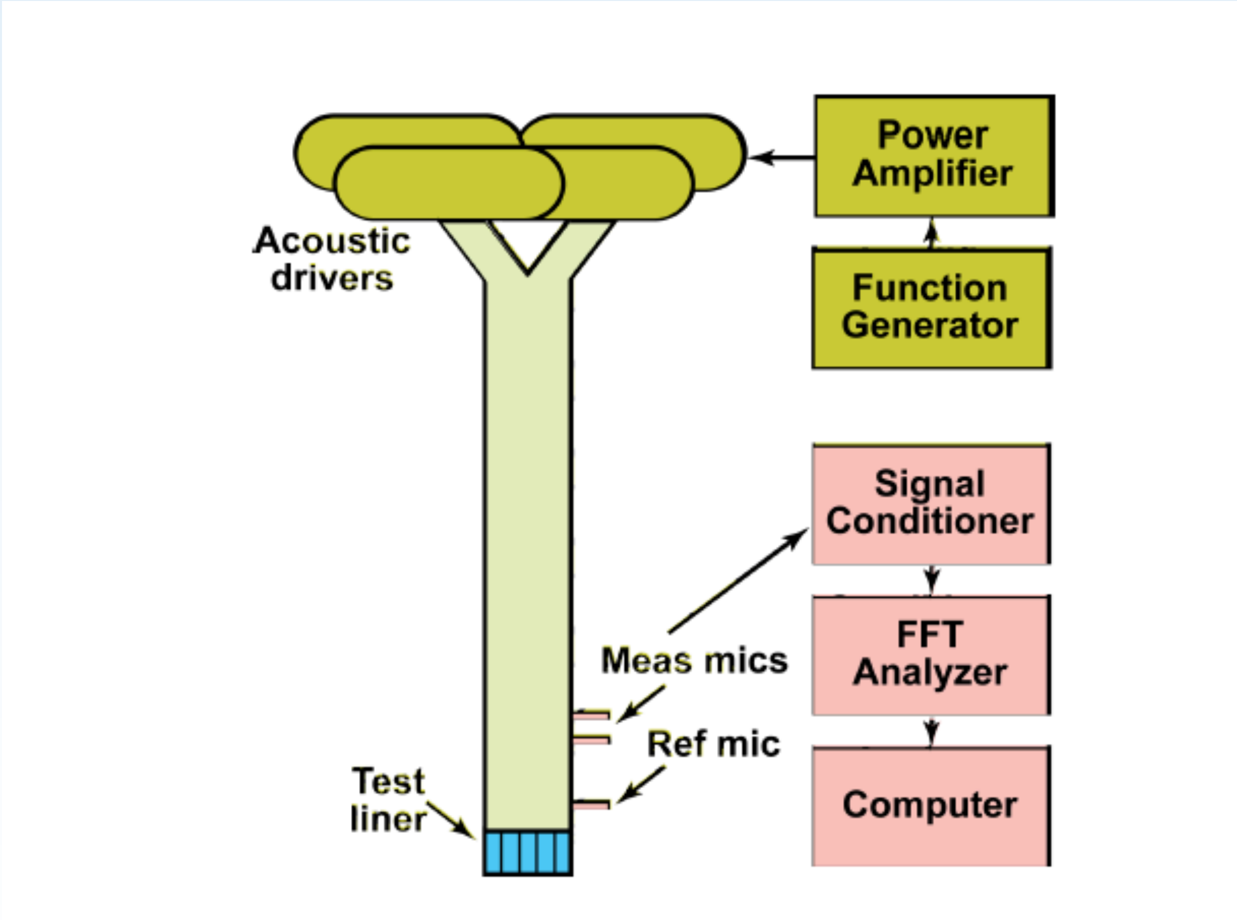
The fixed sample is useful since it is one geometry that we could consider for more controlled tests as we try to develop physics-based models to predict acoustics.

Description of the Experiment



To measure how much sound was absorbed, the samples were tested in the horizontal NASA Glenn Normal Incidence Tube. The acrylic sample holder was chosen to be compatible with this acoustic rig and the X-ray CT scanner.

Description of the Experiment



Acoustic absorption was also measured in the vertical NASA Langley Normal Incidence Tube.

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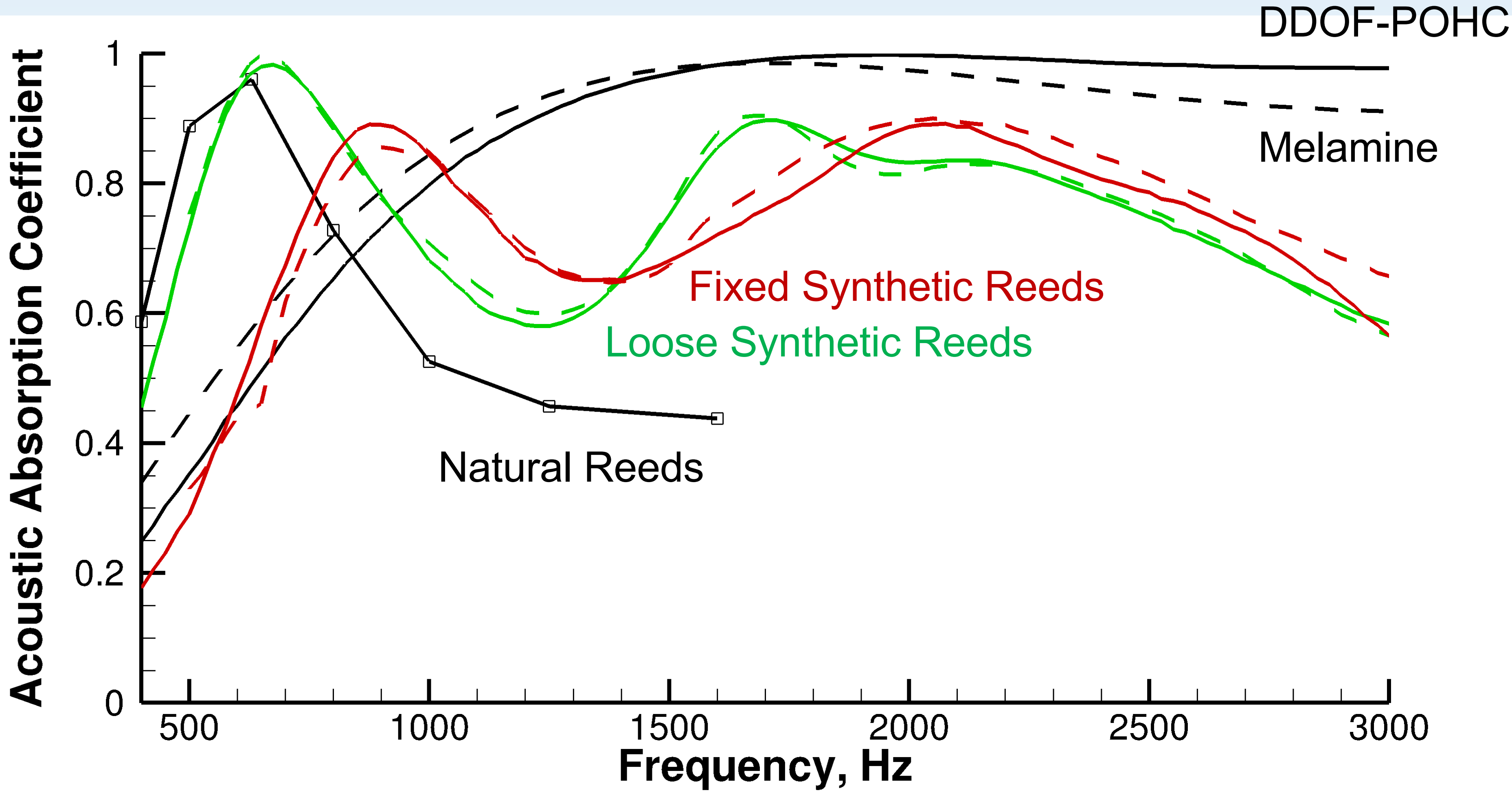
Description of the Experiment



This observation might have some practical use in controlling low frequency noise in aviation and industrial applications where there may be constraints on treatment thickness, weight, temperature, and exposure to liquids.

References

For more information, please refer to these NASA reports:

NASA TM-2016-218851, "Measurement of the acoustic absorption of natural reeds and comparison to aircraft engine acoustic liner prototypes,"
Koch and Jones

NASA TM-2017-219438, "The development of acoustic absorbers that mimic assemblies of natural reeds: Progress Report 1,"
Koch, Bonacuse, Kuczmarski, Johnston, Miller, Jones

Patent Pending

Conclusion

Four samples of natural reeds, *Phragmites australis*, were tested in the NASA Langley and Glenn Normal Incidence Impedance Tubes in order to experimentally determine the acoustic absorption coefficients as a function of frequency from 400 to 3000 Hz.

Six samples that mimicked the geometry of the assemblies of natural reeds were also designed and additively manufactured from ASA thermoplastic and tested.

Results indicate that structures can be manufactured of synthetic materials that mimic the geometry and the low frequency acoustic absorption of natural reeds.

This accomplishment demonstrates that a new class of structures can now be considered for a wide range of industrial products that need thin, lightweight, broadband acoustic absorption effective at frequencies below 1000 Hz.

Aircraft engine acoustic liners and aircraft cabin acoustic liners, in particular, are two aviation applications that might benefit from further development of this concept.

Conclusion

A variety of rigs are available to us for future aviation-related proof-of-concept tests:

NASA GRC and LaRC Normal Incidence Tube

NASA LaRC Grazing Flow Incidence Tube

NASA LaRC Curved Duct Rig

NASA/Notre Dame Advanced Noise Control Fan

NASA GRC DGEN-380 Aeropropulsion Research Turbofan Engine

NASA GRC 9 x 15 Low Speed Wind Tunnel Tests

Other Ground Tests

Other Flight Tests

Your feedback is important to us!

Conclusion

The current work has been exploratory, and a wide range of research questions are now being asked and answered:

How might we predict the acoustic absorption of these structures?
Which variables are important: porosity, tortuosity, mass, stiffness…?
How might we manufacture prototypes to test our hypotheses?
How might we adapt the prototypes to an installation?
How might we improve the prototypes?
How might we continue to learn from nature?
How might we use these observations for the benefit of all?

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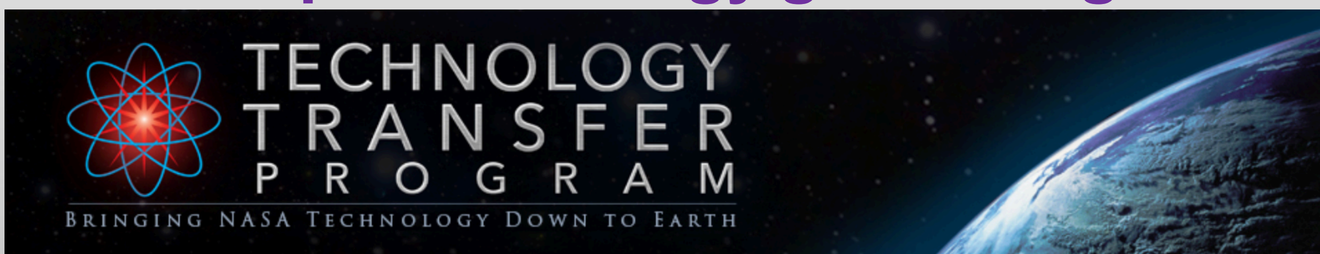

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