# NASA's Bio-Inspired Acoustic Absorber Concept

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Glenn Research Center at Lewis Field

# NASA's Bio-Inspired Acoustic Absorber Concept

## Overview

NASA is learning from nature to develop new technology to reduce noise pollution.

- Inspiration

- Concept overview

- Description of the experiments

- Description of the prototypes

- The path forward: research and outreach

- Summary

- Acknowledgements

- Contact information

- References

# NASA's Bio-Inspired Acoustic Absorber Concept



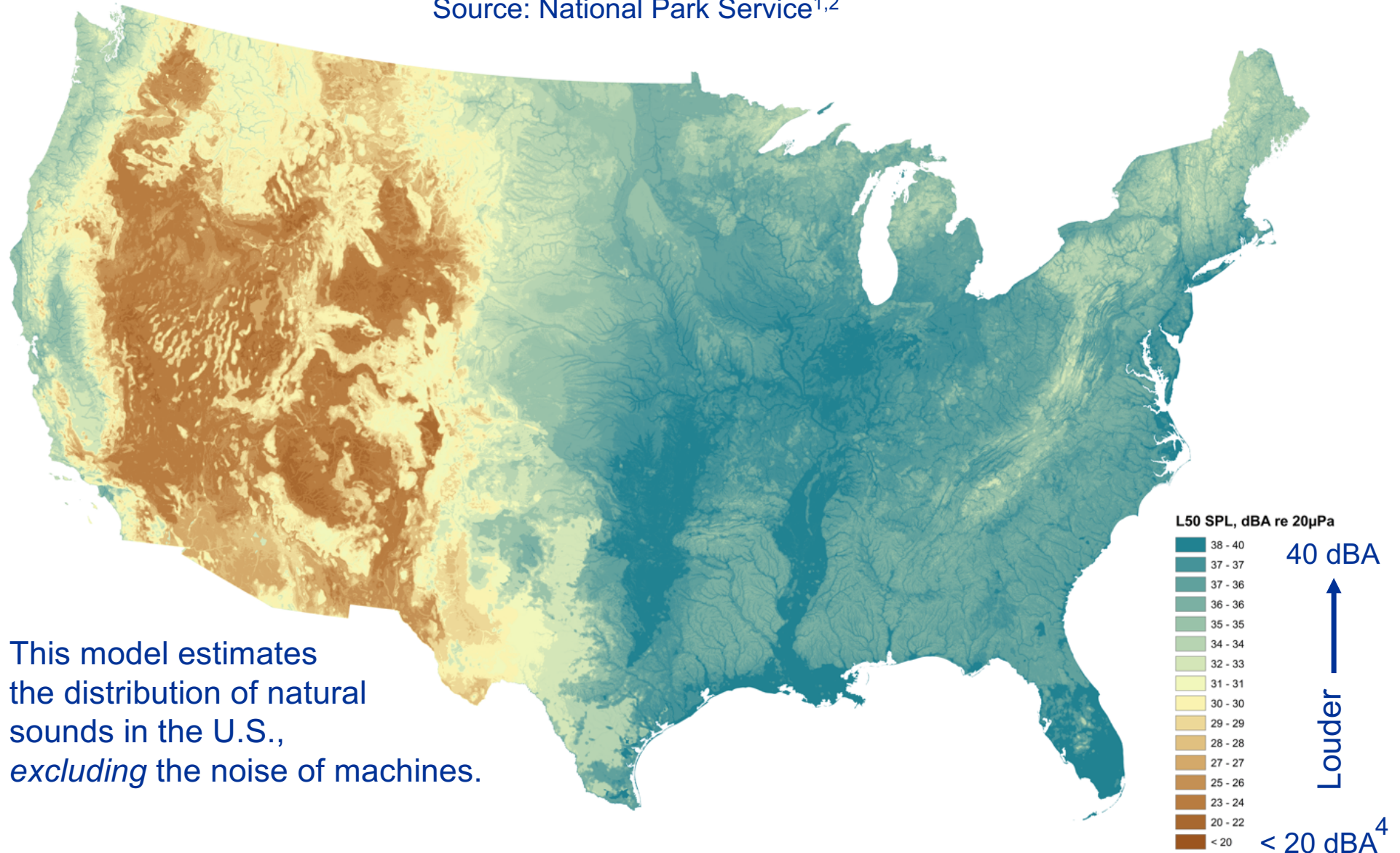Kalmiopsis Wilderness, Siskiyou National Forest, Oregon

## Have you heard the sounds of nature?

# NASA's Bio-Inspired Acoustic Absorber Concept

## Inspiration

### Map of the Quietest Places in the United States—Natural Conditions
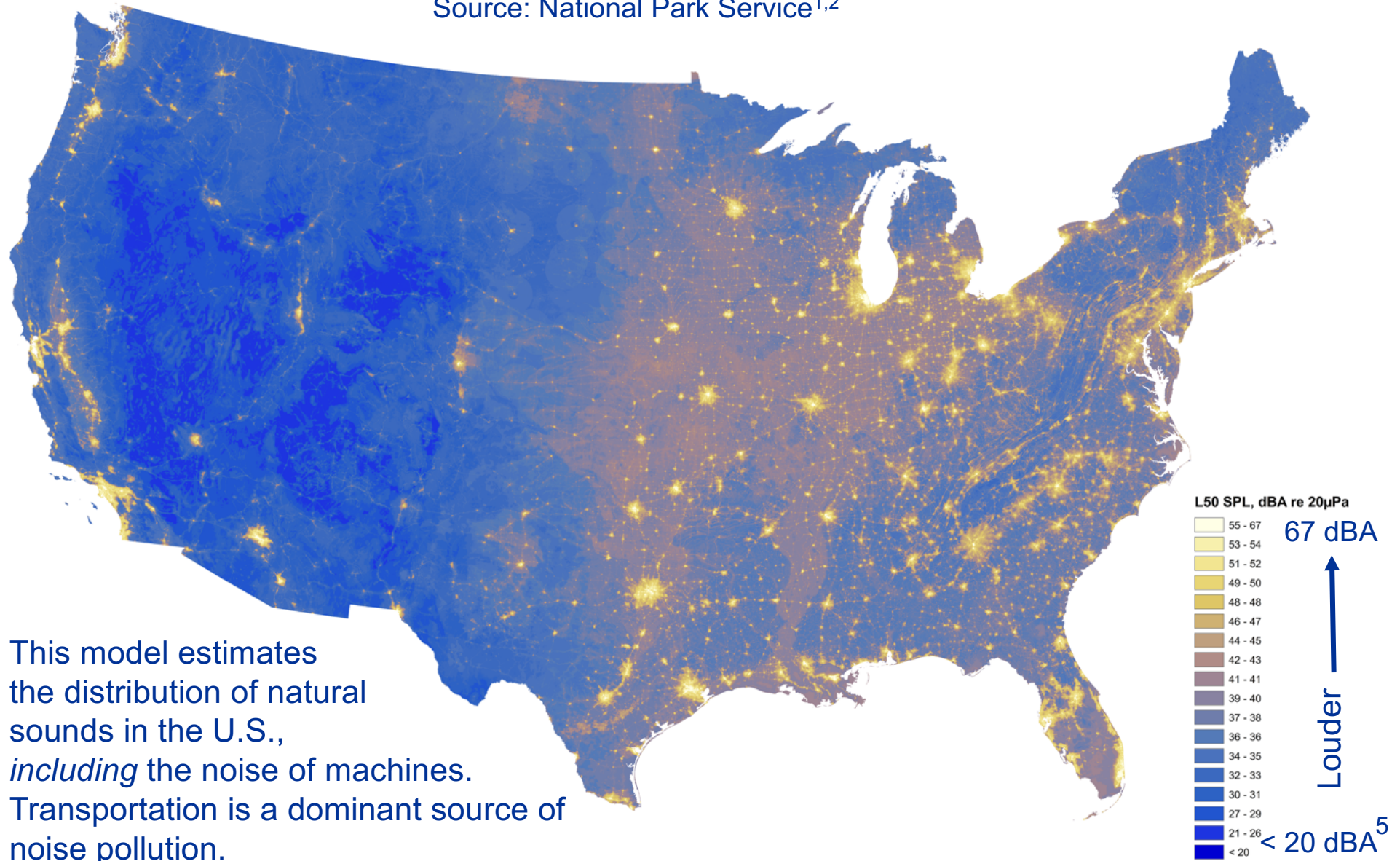Source: National Park Service[1,2]



This model estimates the distribution of natural sounds in the U.S., *excluding* the noise of machines.

L50 SPL, dBA re 20µPa

| | |
|---|---|
| 38 - 40 | |
| 37 - 37 | 40 dBA |
| 37 - 36 | |
| 36 - 36 | |
| 35 - 35 | |
| 34 - 34 | |
| 32 - 33 | |
| 31 - 31 | |
| 30 - 30 | Louder |
| 29 - 29 | |
| 28 - 28 | |
| 27 - 27 | |
| 25 - 26 | |
| 23 - 24 | |
| 20 - 22 | |
| < 20 | < 20 dBA[4] |

# NASA's Bio-Inspired Acoustic Absorber Concept

## Inspiration

### Map of the Quietest Places in the United States—Existing Conditions
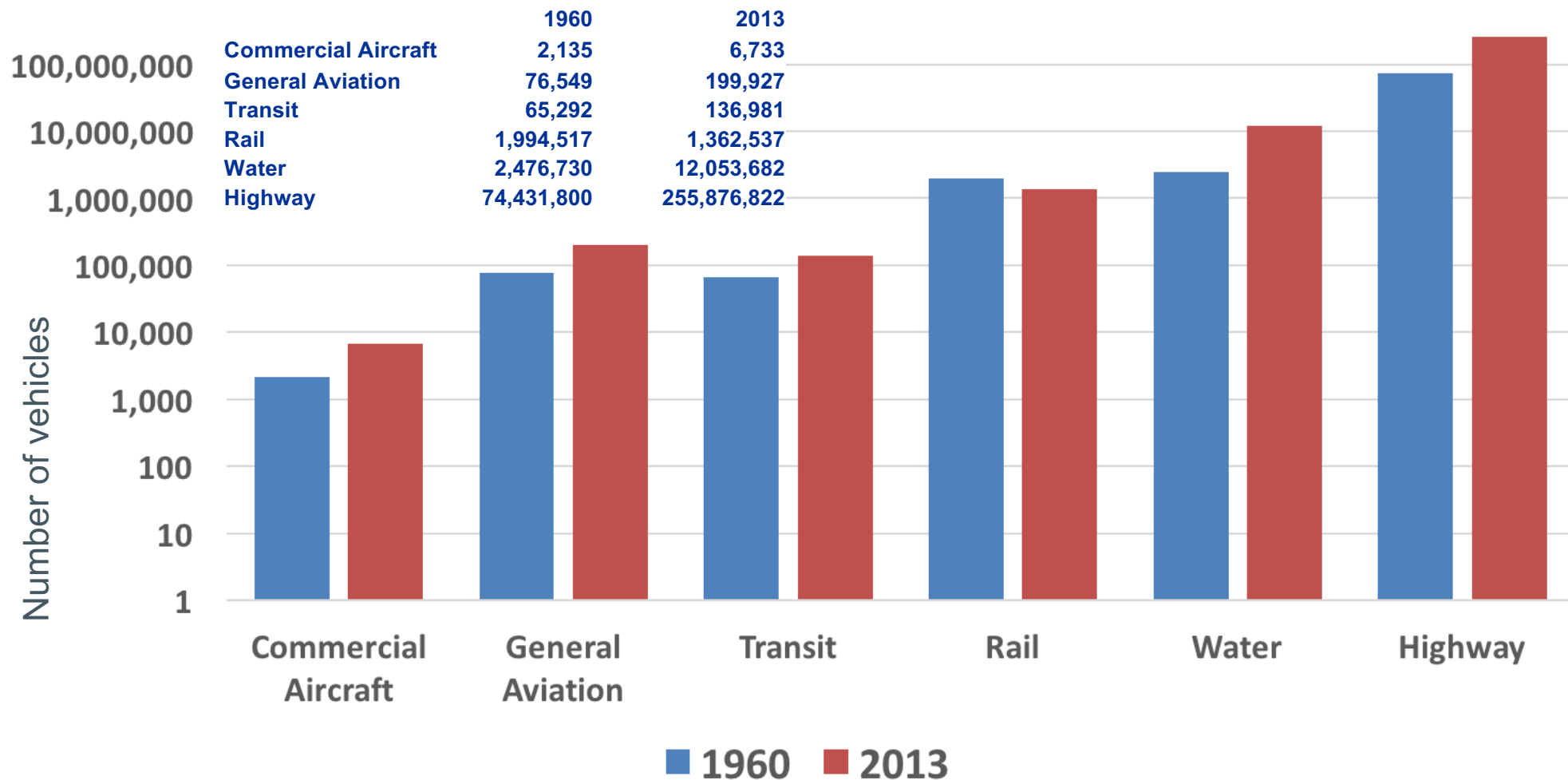Source: National Park Service[1,2]



This model estimates the distribution of natural sounds in the U.S., *including* the noise of machines. Transportation is a dominant source of noise pollution.

L50 SPL, dBA re 20µPa

| | |
|---|---|
| 55 - 67 | 67 dBA |
| 53 - 54 | |
| 51 - 52 | |
| 49 - 50 | |
| 48 - 48 | |
| 46 - 47 | |
| 44 - 45 | |
| 42 - 43 | |
| 41 - 41 | Louder |
| 39 - 40 | |
| 37 - 38 | |
| 36 - 36 | |
| 34 - 35 | |
| 32 - 33 | |
| 30 - 31 | |
| 27 - 29 | |
| 21 - 26 | < 20 dBA[5] |
| < 20 | |

# NASA's Bio-Inspired Acoustic Absorber Concept

**Inspiration**

## Number of Vehicles in the United States, 1960-2013
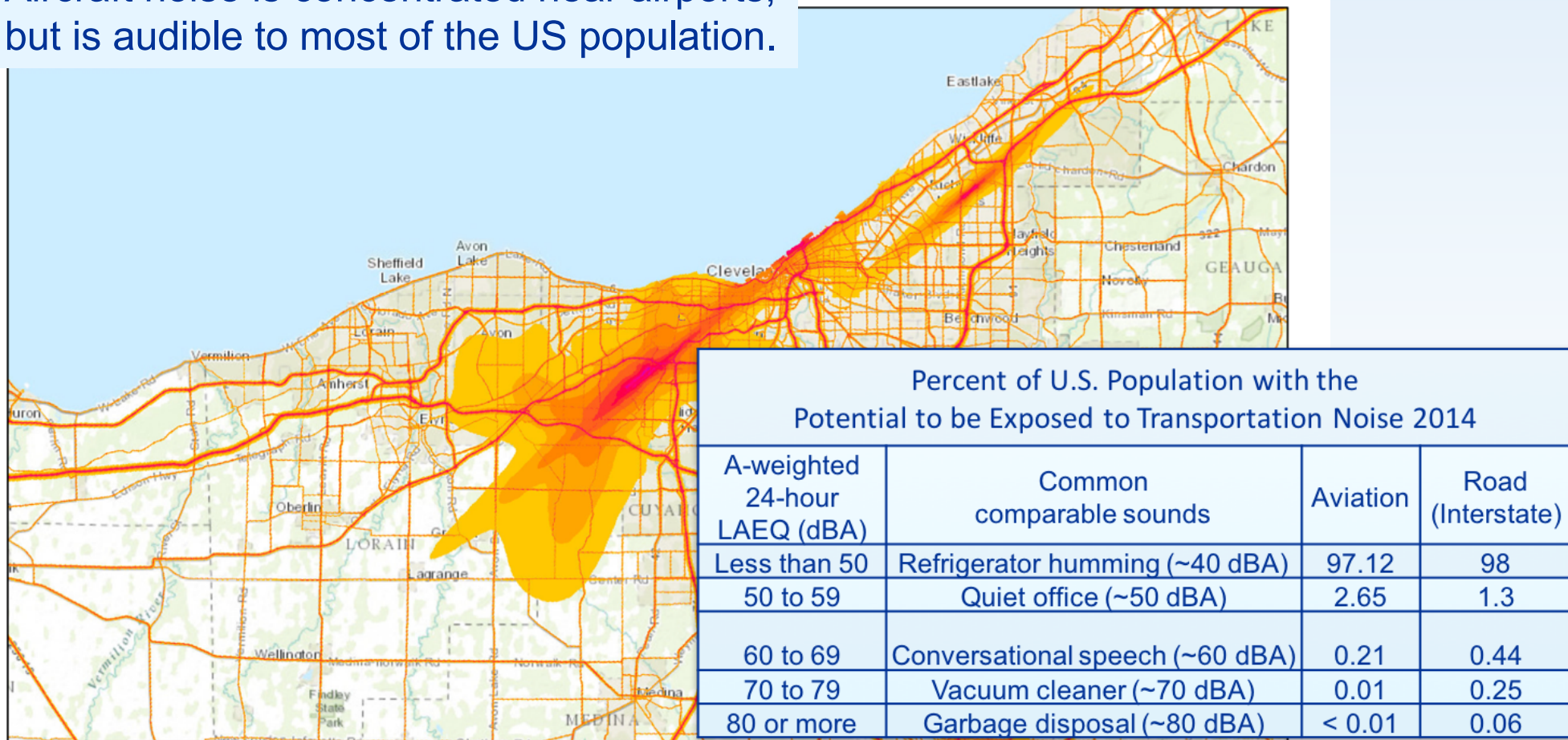### Source: Bureau of Transportation Statistics[3]

|                     | 1960       | 2013        |
|---------------------|-----------|-------------|
| Commercial Aircraft | 2,135     | 6,733       |
| General Aviation    | 76,549    | 199,927     |
| Transit             | 65,292    | 136,981     |
| Rail                | 1,994,517 | 1,362,537   |
| Water               | 2,476,730 | 12,053,682  |
| Highway             | 74,431,800| 255,876,822 |

Since the 1960's, the number of commercial aircraft has tripled, as did other vehicles. Aircraft are a significant source of transportation noise.
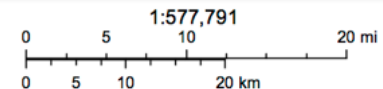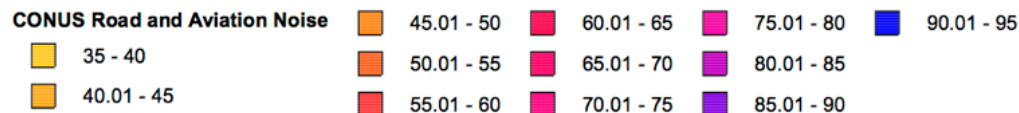
# NASA's Bio-Inspired Acoustic Absorber Concept

## National Transportation Noise Map: Road and Aviation Noise Near Cleveland, Ohio[4]

Aircraft noise is concentrated near airports, but is audible to most of the US population.



### Percent of U.S. Population with the Potential to be Exposed to Transportation Noise 2014

| A-weighted 24-hour LAEQ (dBA) | Common comparable sounds | Aviation | Road (Interstate) |
|---|---|---|---|
| Less than 50 | Refrigerator humming (~40 dBA) | 97.12 | 98 |
| 50 to 59 | Quiet office (~50 dBA) | 2.65 | 1.3 |
| 60 to 69 | Conversational speech (~60 dBA) | 0.21 | 0.44 |
| 70 to 79 | Vacuum cleaner (~70 dBA) | 0.01 | 0.25 |
| 80 or more | Garbage disposal (~80 dBA) | < 0.01 | 0.06 |

August 30, 2017

**CONUS Road and Aviation Noise**

| | |
|---|---|
| 35 - 40 | |
| 40.01 - 45 | |
| 45.01 - 50 | |
| 50.01 - 55 | |
| 55.01 - 60 | |
| 60.01 - 65 | |
| 65.01 - 70 | |
| 70.01 - 75 | |
| 75.01 - 80 | |
| 80.01 - 85 | |
| 85.01 - 90 | |
| 90.01 - 95 | |

1:577,791

0   5   10   20 mi
0   5   10   20 km

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Web AppBuilder for ArcGIS
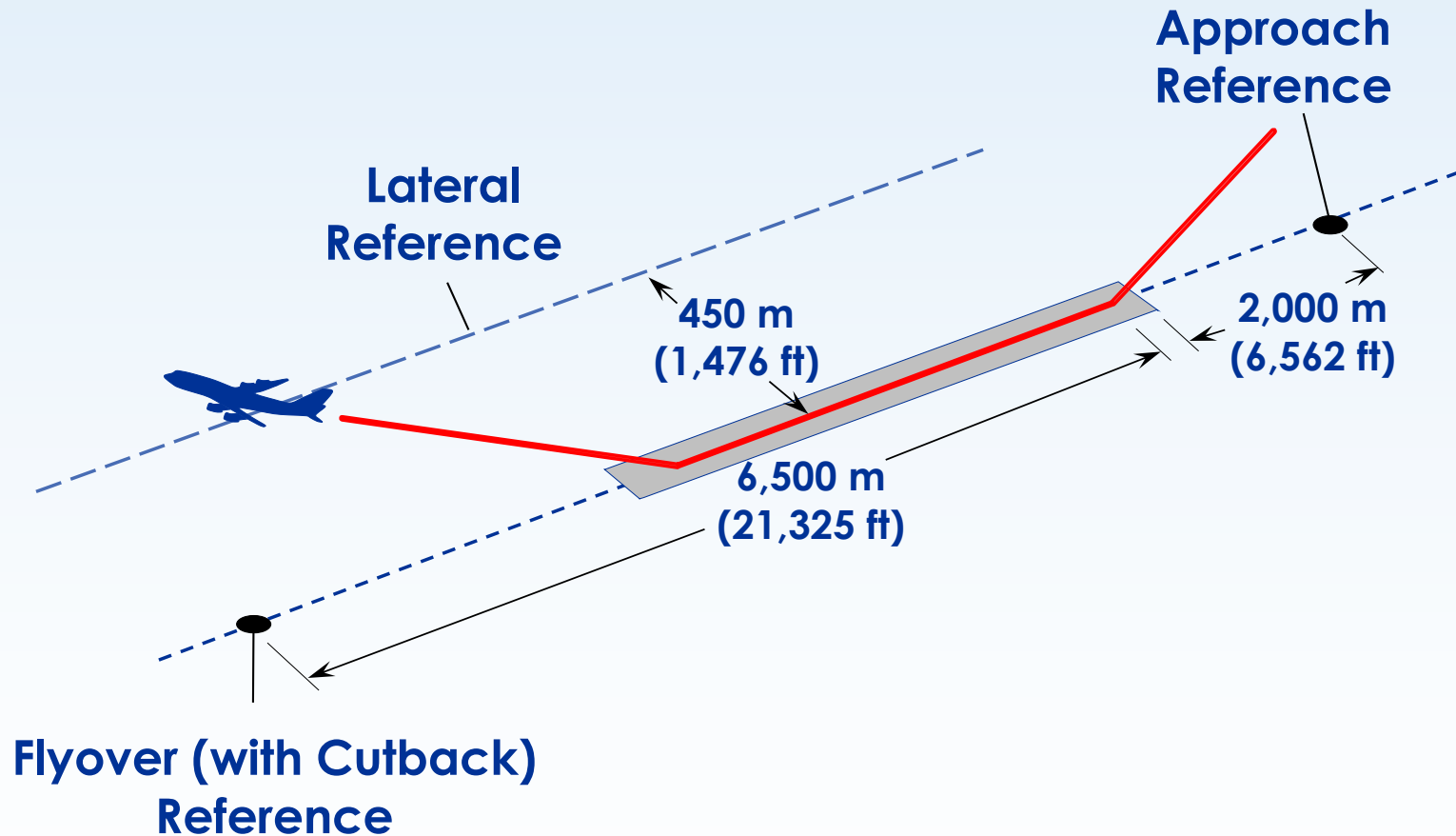Bureau of Transportation Statistics, VOLPE | Esri, HERE, Garmin, USGS, NGA, EPA, USDA, NPS |

# NASA's Bio-Inspired Acoustic Absorber Concept



Glen Canyon National Park, Image Credit: NPS

The National Park Service is working with the Federal Aviation Administration to establish Air Tour Management Plans or voluntary agreements with air tour providers that protect the natural soundscapes in popular national parks.[5]

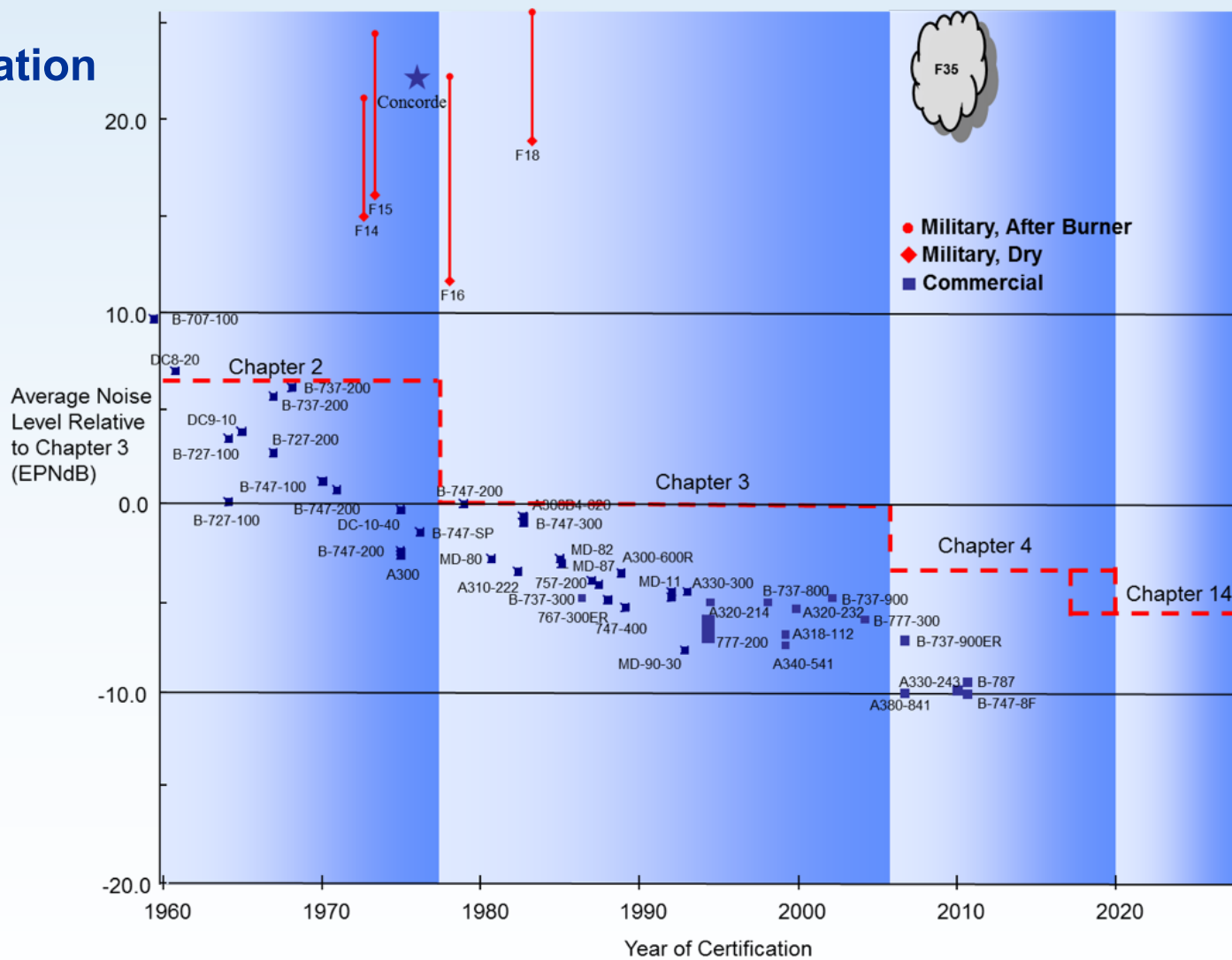# NASA's Bio-Inspired Acoustic Absorber Concept

**Inspiration**

**Approach Reference**

**Lateral Reference**

450 m
(1,476 ft)

2,000 m
(6,562 ft)

6,500 m
(21,325 ft)

**Flyover (with Cutback) Reference**

The International Civil Aviation Organization and the Federal Aviation Administration establish aircraft noise regulations. Commercial aircraft must fly a prescribed trajectory over a set of microphones to measure takeoff and landing noise. In order to be certified to operate, noise measurements must be below current regulations.[6,7]

# NASA's Bio-Inspired Acoustic Absorber Concept



Aircraft noise limits have decreased over time, which has driven innovation. Individual aircraft are significantly quieter than they were in the 1960's.[8]

# NASA's Bio-Inspired Acoustic Absorber Concept
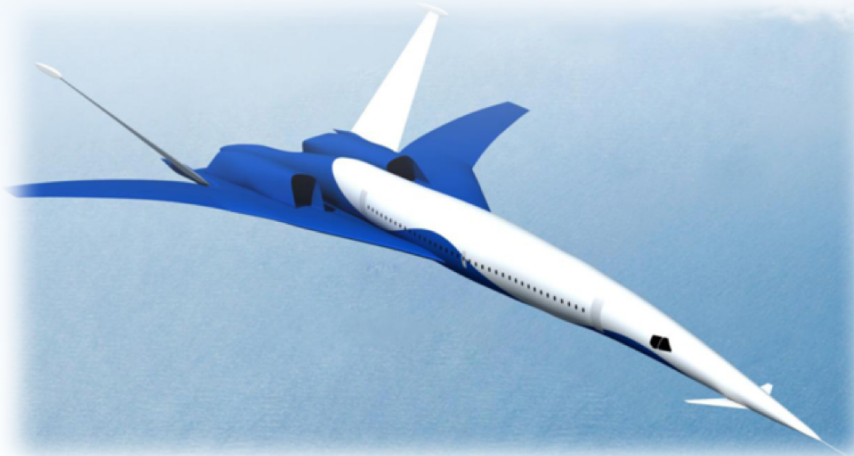
## Inspiration



NASA is developing technology for quiet and efficient aircraft of the future.[9]
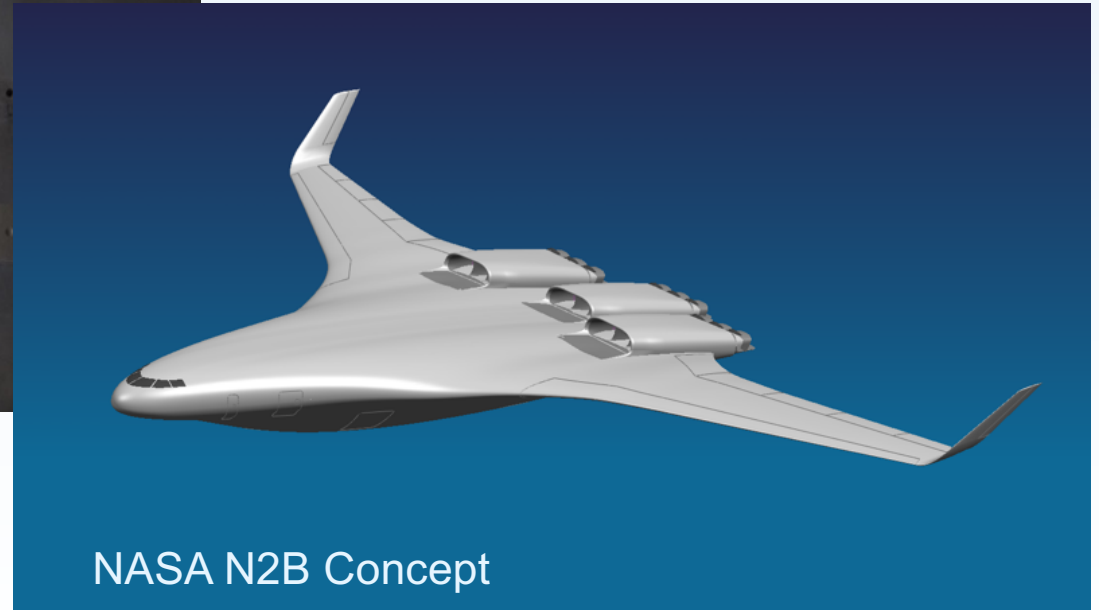
# NASA's Bio-Inspired Acoustic Absorber Concept
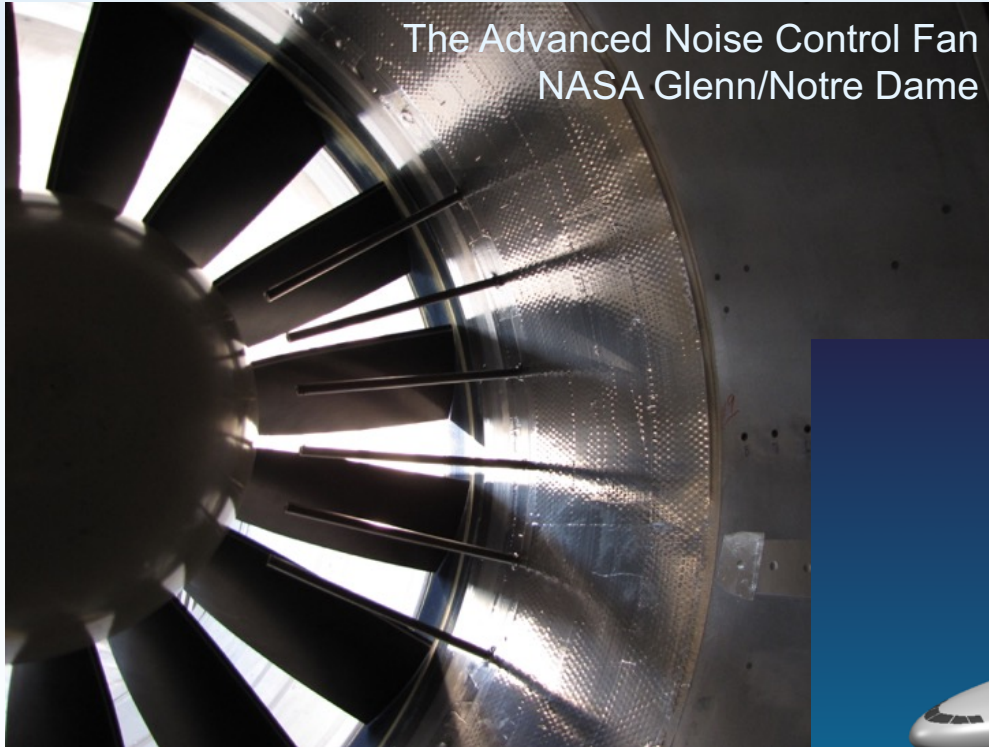
## Inspiration



The Advanced Noise Control Fan
NASA Glenn/Notre Dame

Predicting the Inflow Distortion Tone Noise of the NASA Glenn Advanced Noise Control Fan with a Combined Quadrupole-Dipole Model[10]
L. Danielle Koch
NASA-TM-2012-217673



NASA N2B Concept

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.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Inspiration

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



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.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Inspiration



Photo Credit: Jim Nemet, Cleveland Metroparks Zoo

Today's presentation is not about owls.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Inspiration



**Common reed, *Phragmites australis***
Image Source: Ohio Department of Natural Resources
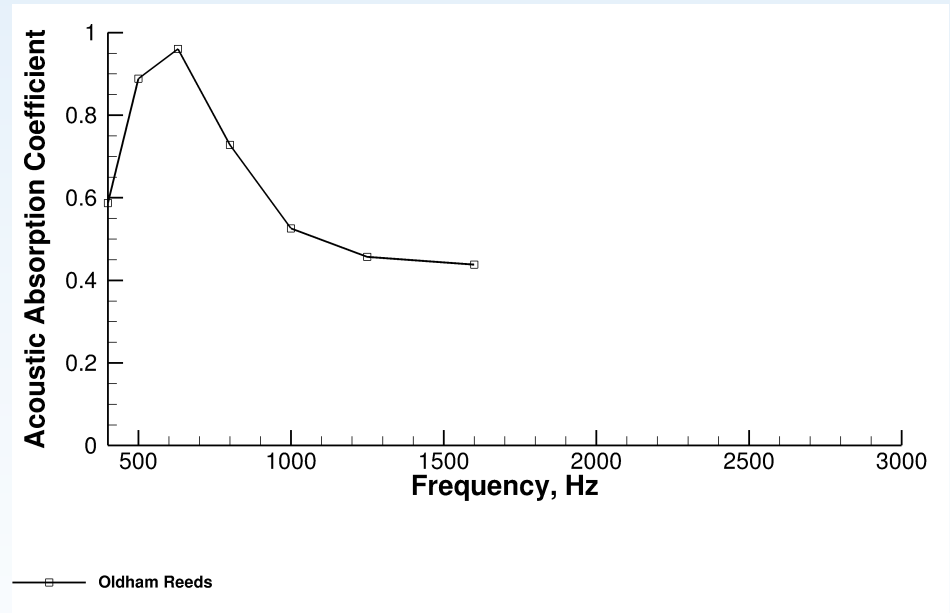


**Data replotted from**
Oldham, et al., Sustainable Acoustic Absorbers from the Biomass, Applied Acoustics, Vol 72 (6), 2011.[11]

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.

# NASA's Bio-Inspired Acoustic Absorber Concept

**Concept overview**

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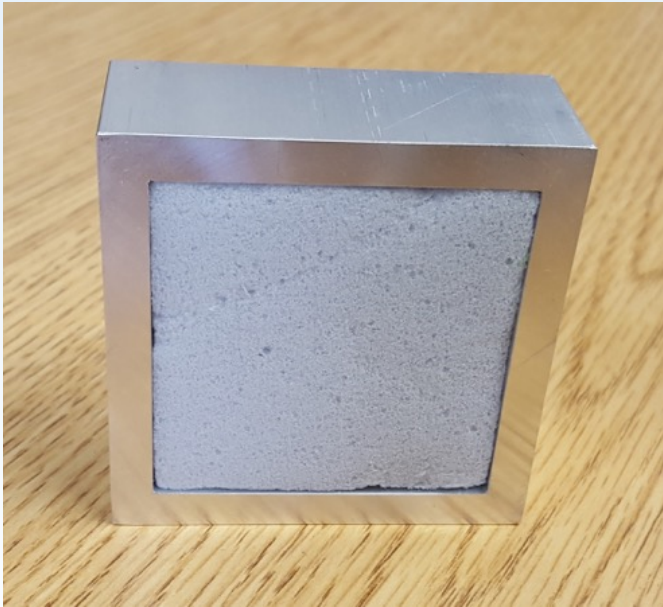
Prototypes were additively manufactured using the NASA Glenn Stratasys Fortus 400 Fused Deposition Modeler.

Exploratory proof-of-concept tests were performed in the NASA Glenn and NASA Langley Normal Incidence Tubes.
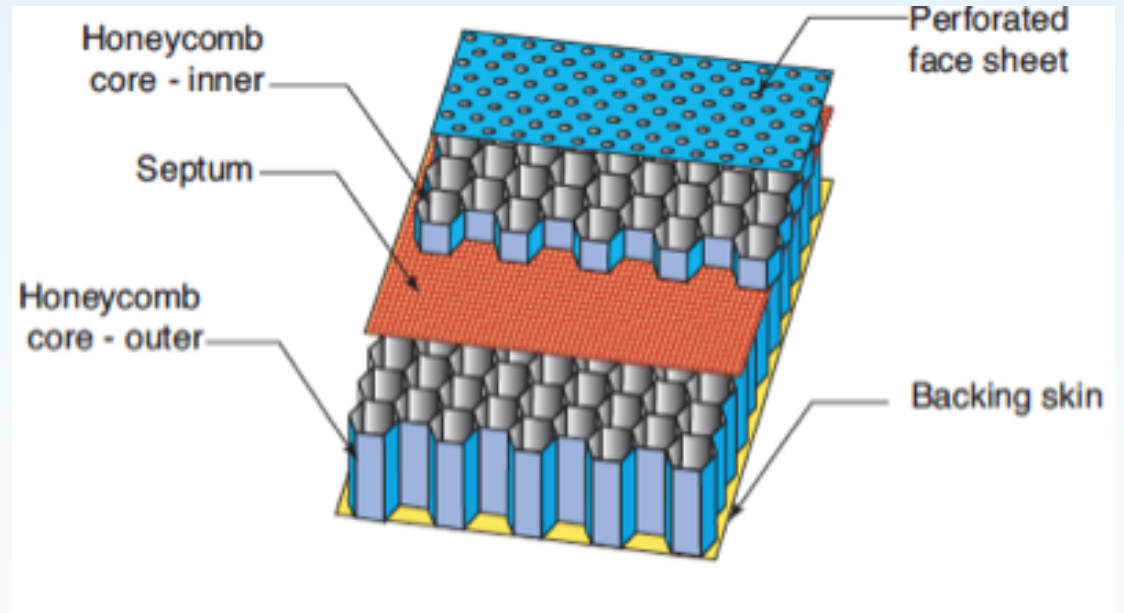
# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the experiment

### Melamine Foam



Commercial acoustic absorber

### Double Degree of Freedom Perforate-Over-Honeycomb (DDOF-POHC)
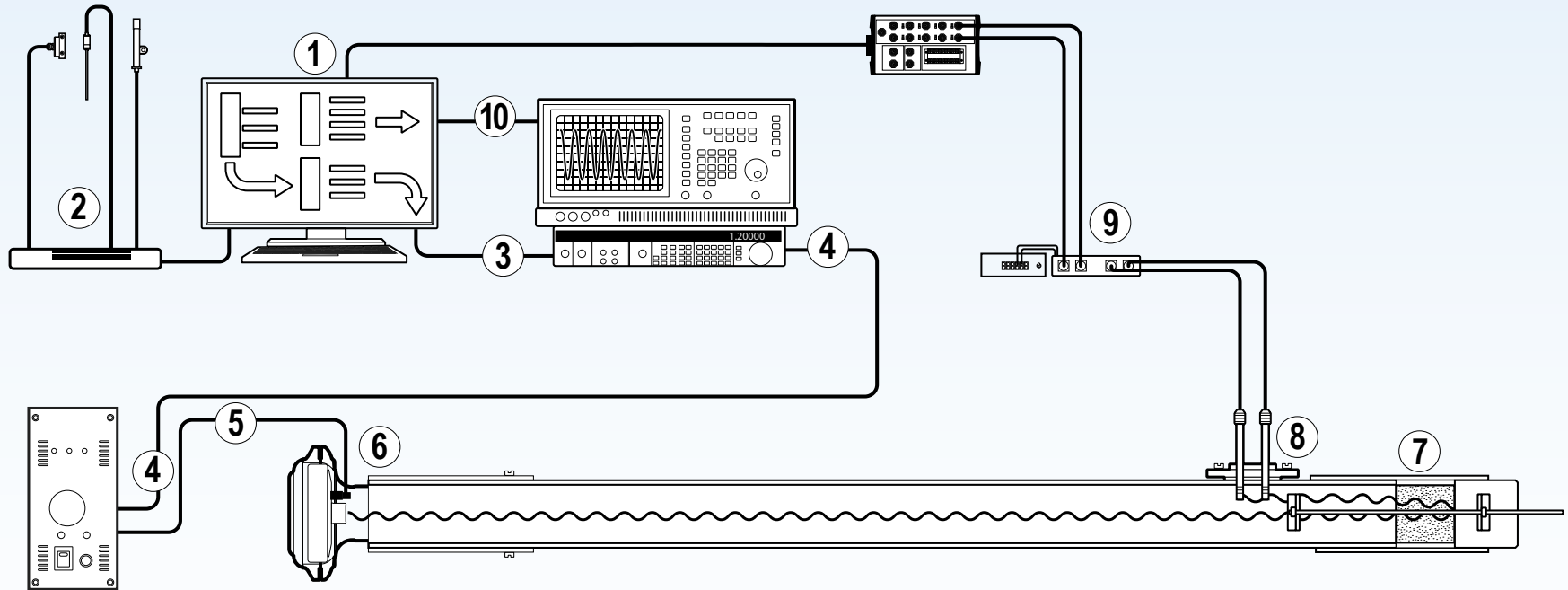


Aircraft Engine Acoustic Liner

Today for example, melamine foam is a widely used acoustic absorber in industry. Double Degree of Freedom Perforate-Over-Honeycomb (DDOF-POHC) structures are commonly used as aircraft engine acoustic liners.
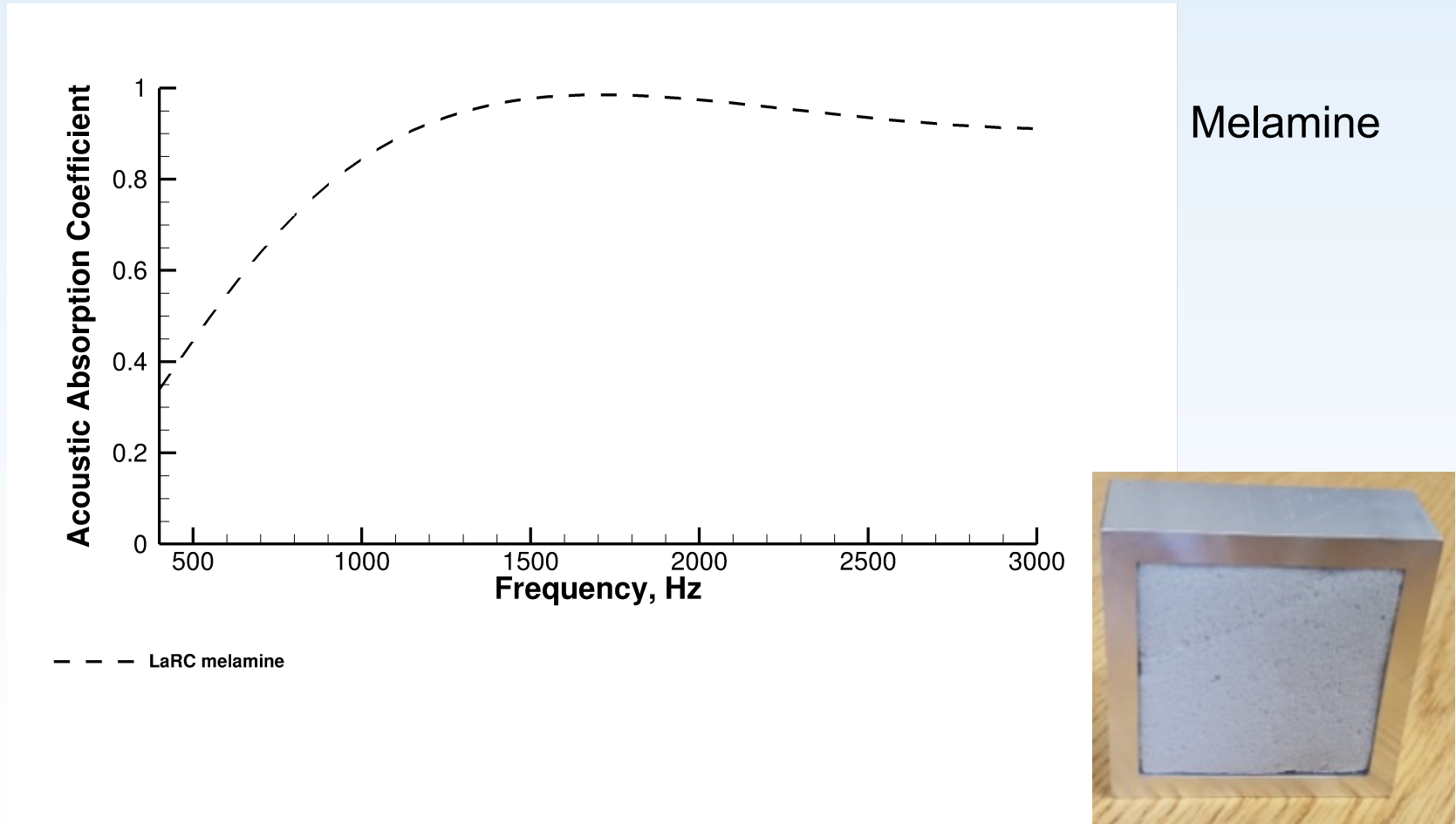
# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the experiment



To measure how much sound was absorbed, the samples were tested in the horizontal NASA Glenn and NASA Langley Normal Incidence Tubes.
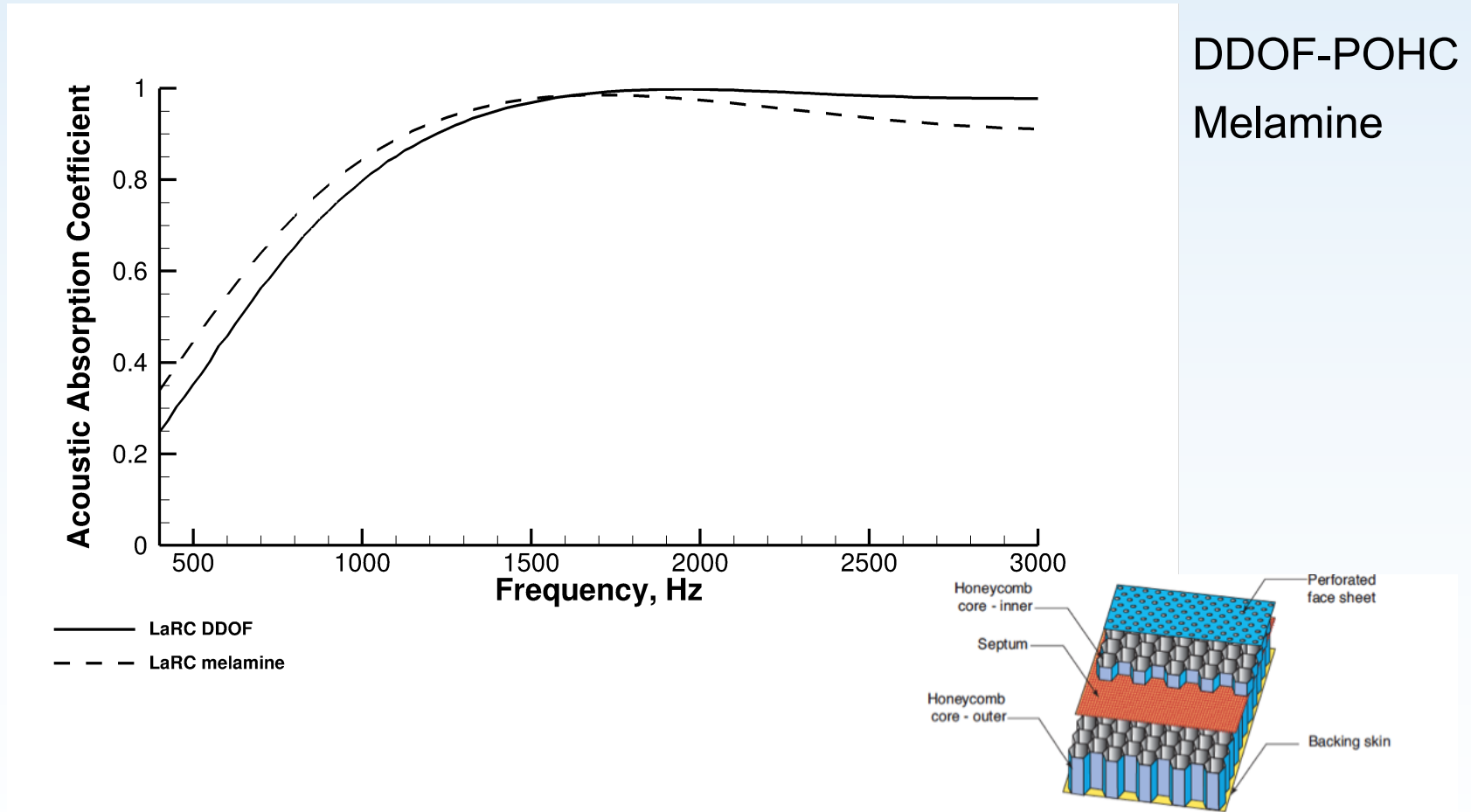
# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the experiment



Melamine

Normal Incidence Tube measurements show the acoustic absorption coefficients for this 2 inch deep sample of melamine are lowest in the 400-1000 Hz range.

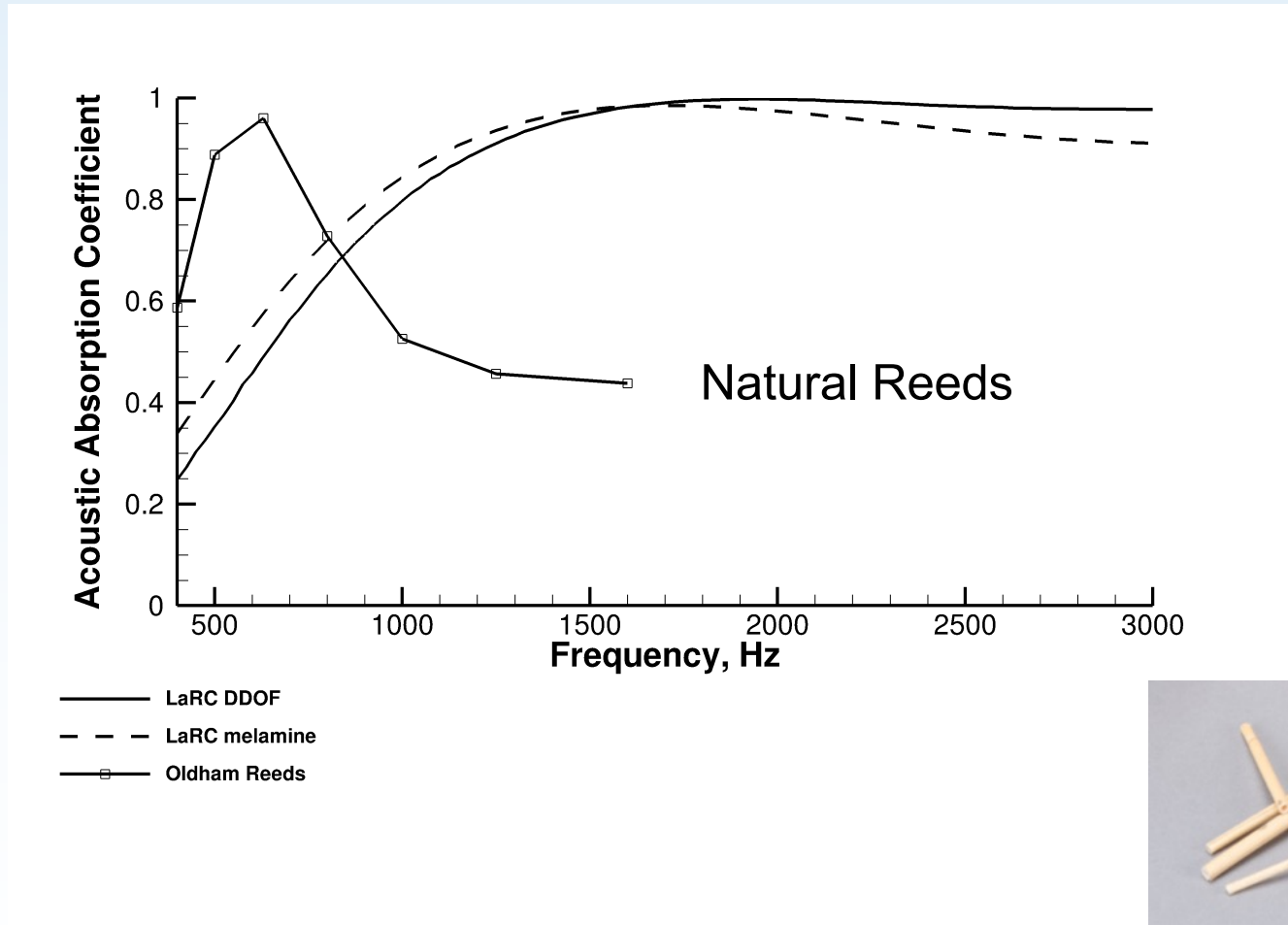# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the experiment



DDOF-POHC

Melamine

The acoustic absorption coefficients for this Double Degree of Freedom Perforate over honeycomb liner are also lowest between 400-1000 Hz.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the experiment
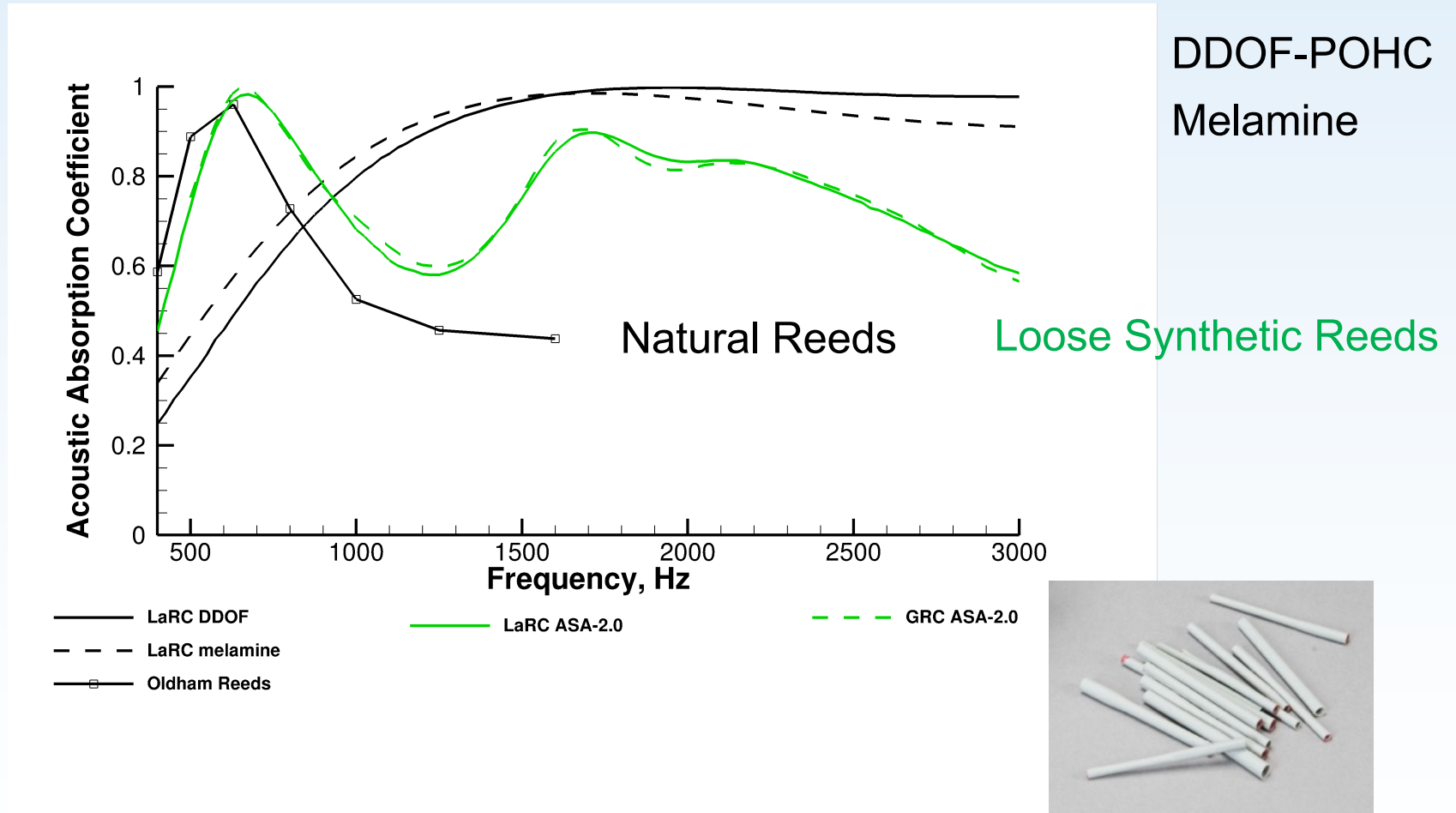


DDOF-POHC

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?

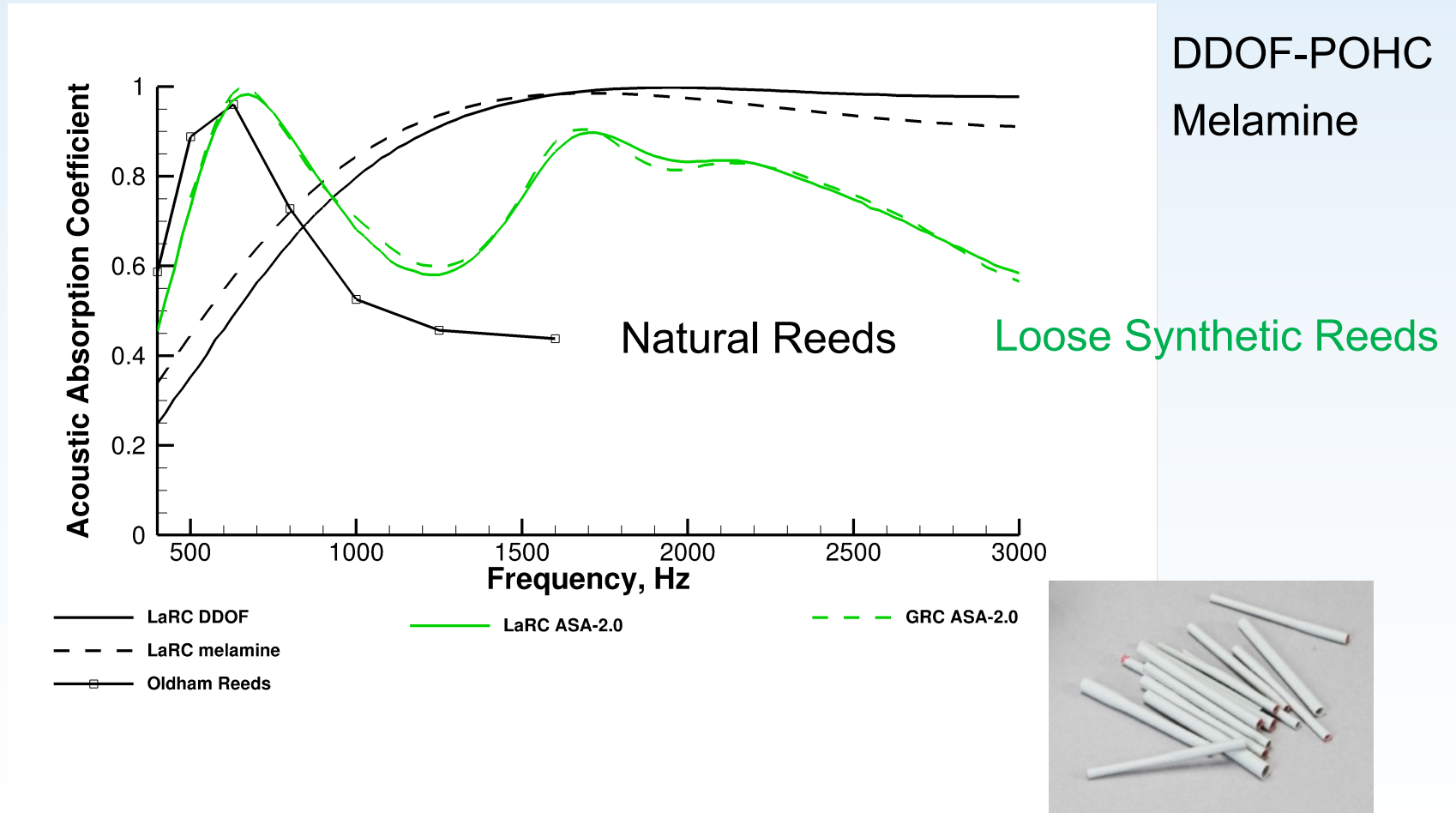# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the experiment



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.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the experiment



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.
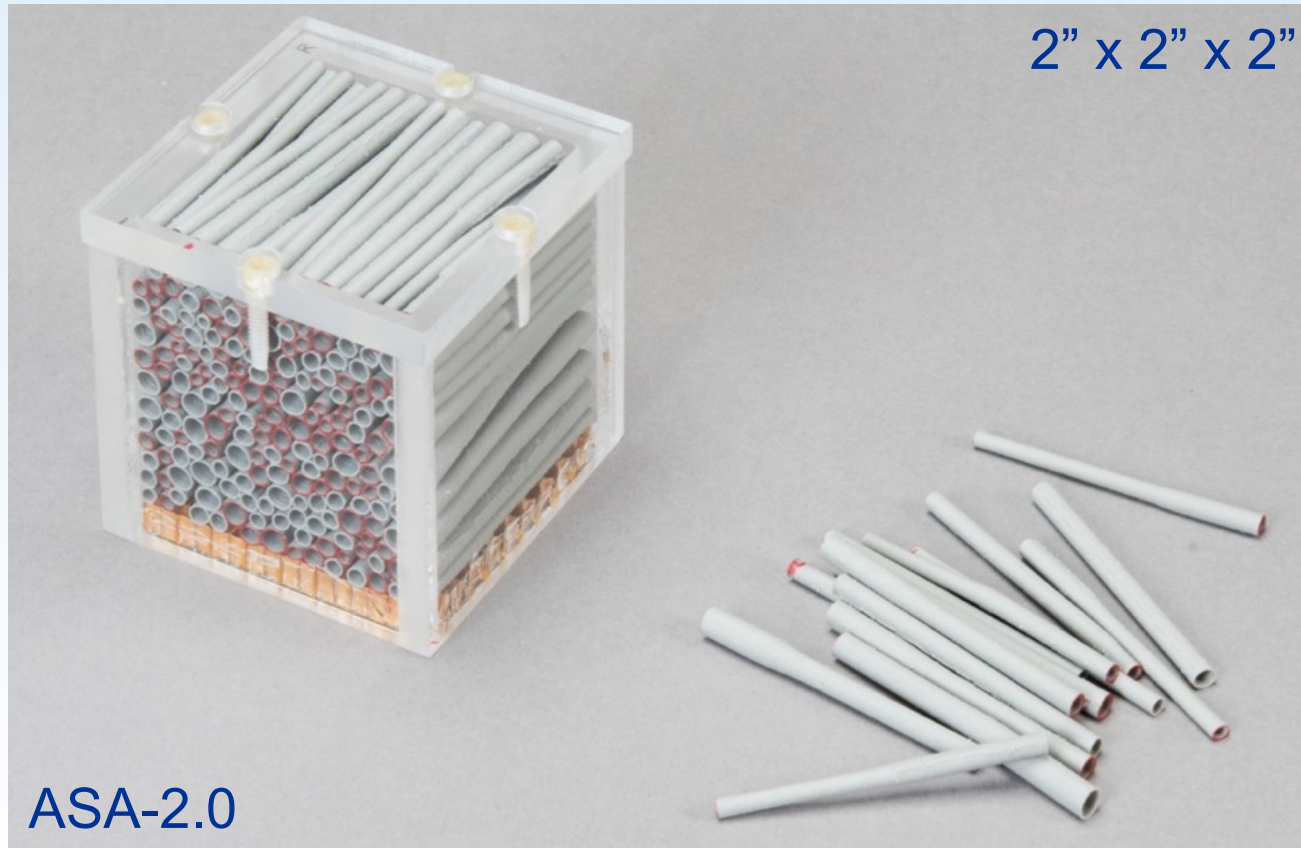
# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the prototypes



2" x 2" x 2"    2" x 2" x 1"    2" x 2" x 2"    2" x 2" x 3"

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. The acrylic sample holder was chosen to be compatible with this acoustic rig and the X-ray CT scanner.
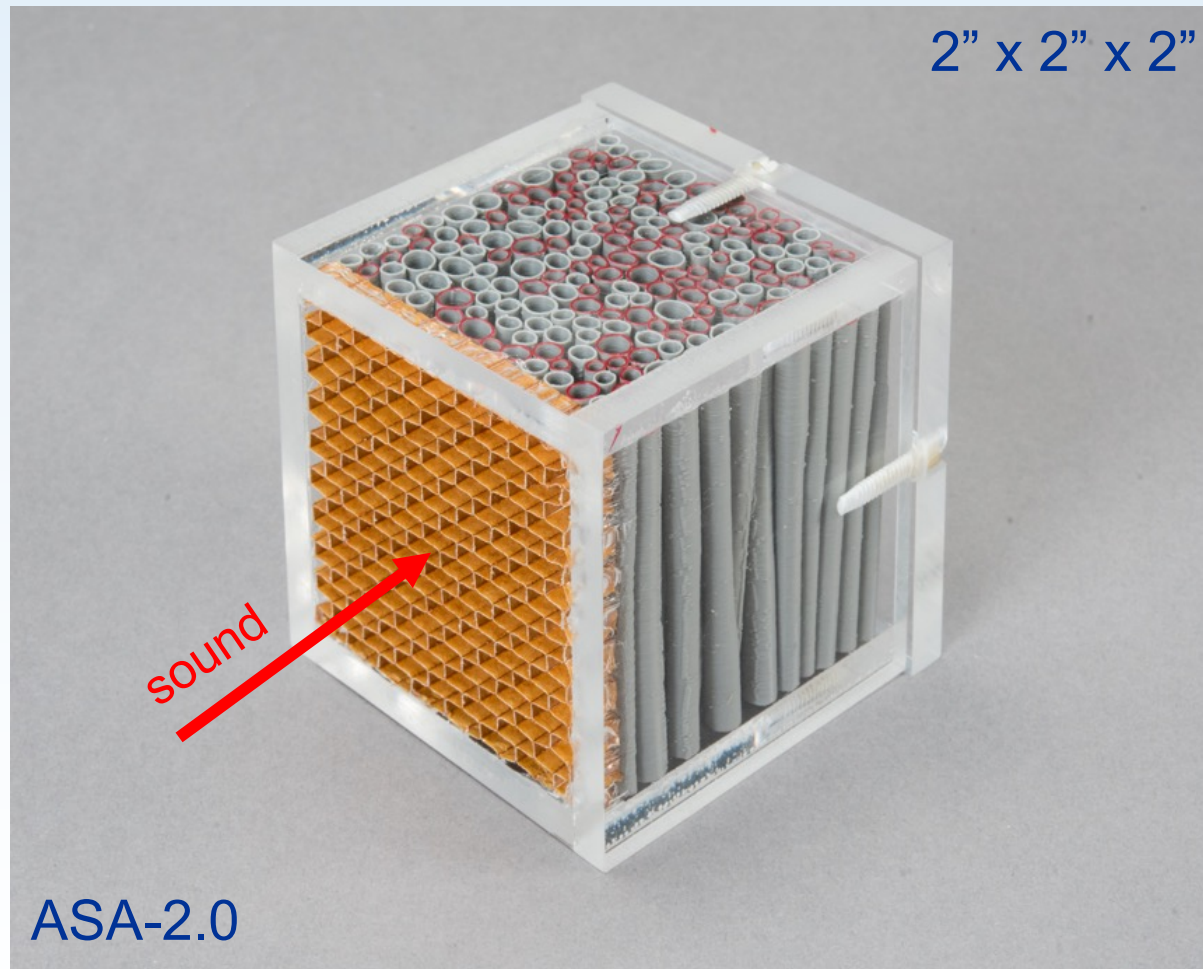
# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the prototypes



2" x 2" x 2"

ASA-2.0

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.
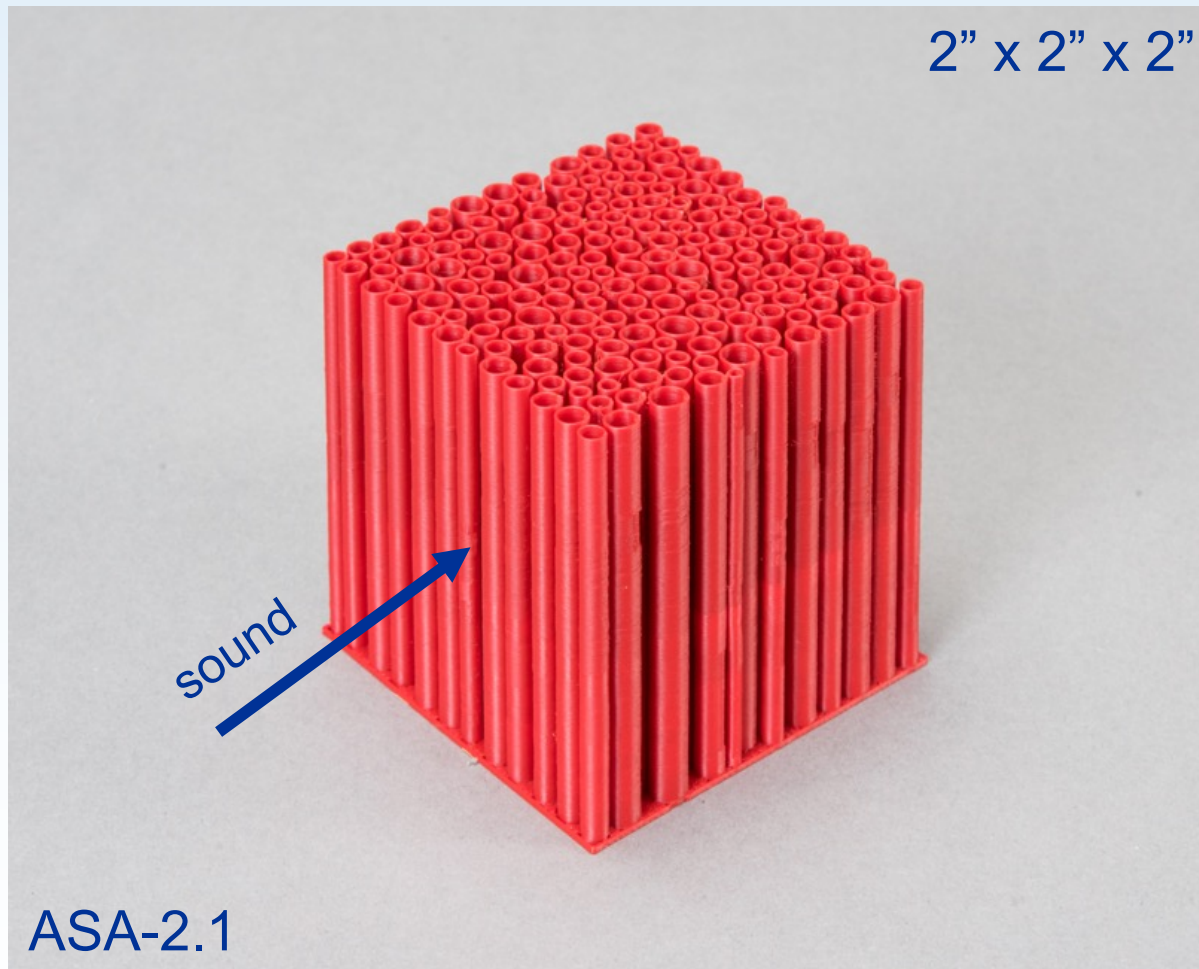
# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the prototypes



2" x 2" x 2"

sound

ASA-2.0

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

# NASA's Bio-Inspired Acoustic Absorber Concept

**Description of the prototypes**



2" x 2" x 2"

sound

ASA-2.1

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.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the prototypes



ASA-2.0 — Loose but packed — 2" x 2" x 2" — sound



ASA-2.1 — Fixed with baseplate — 2" x 2" x 2" — sound
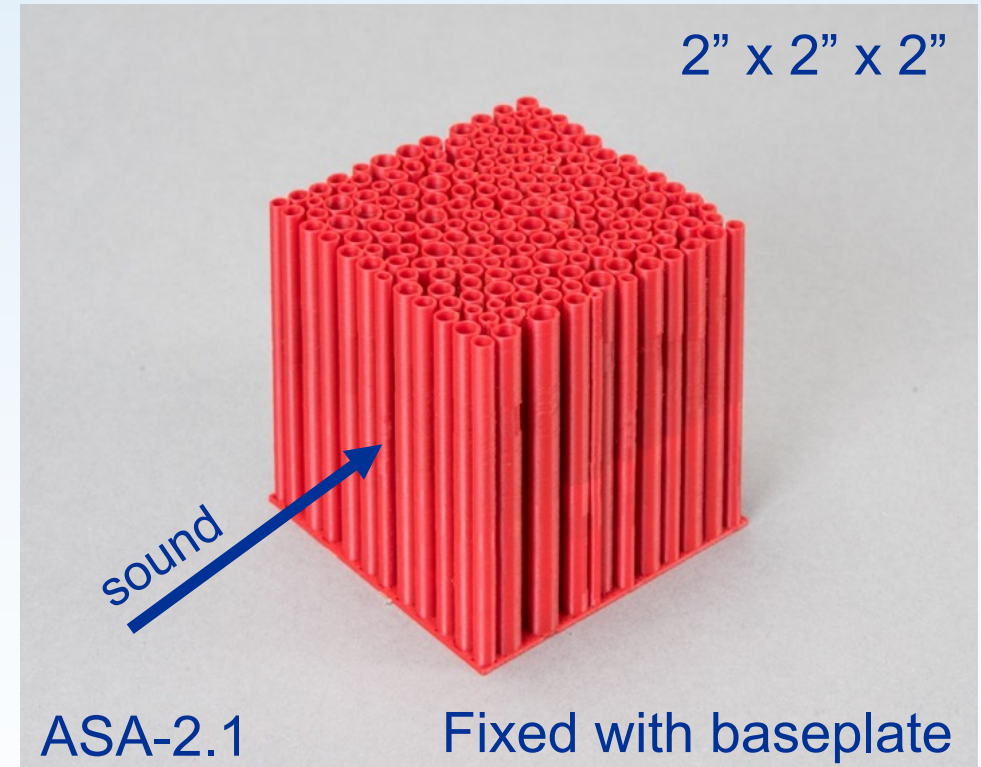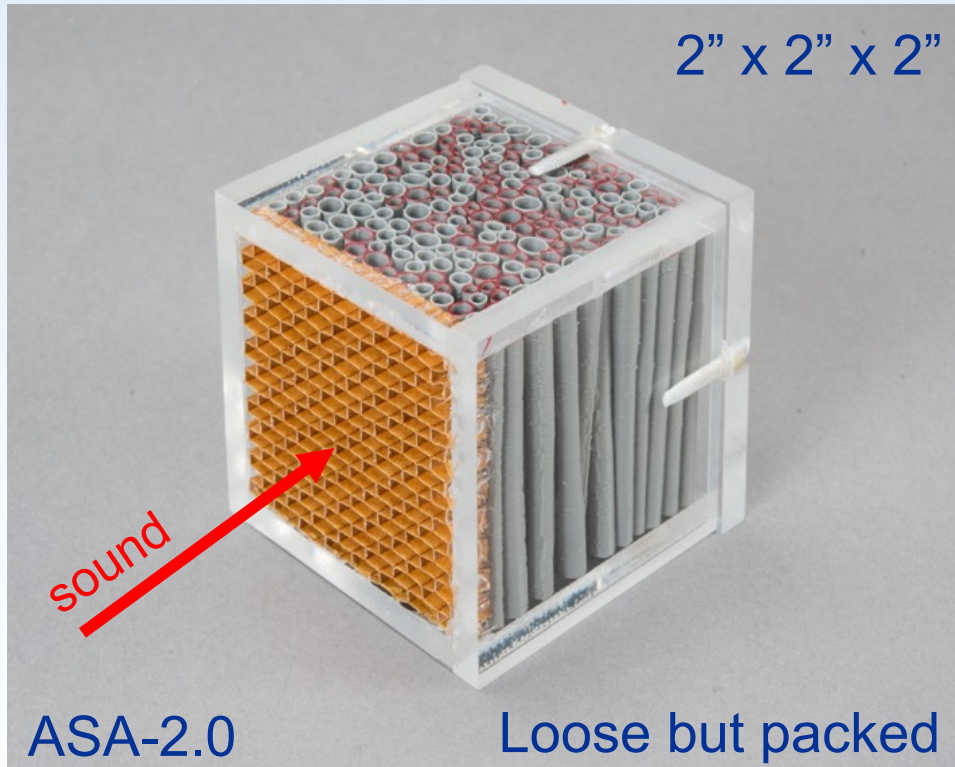
- Loose tubes are packed together.
- Needs retainer to hold shape.
- Fully 3D--Cross-section shape and size varies along length of each.

- 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.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the prototypes
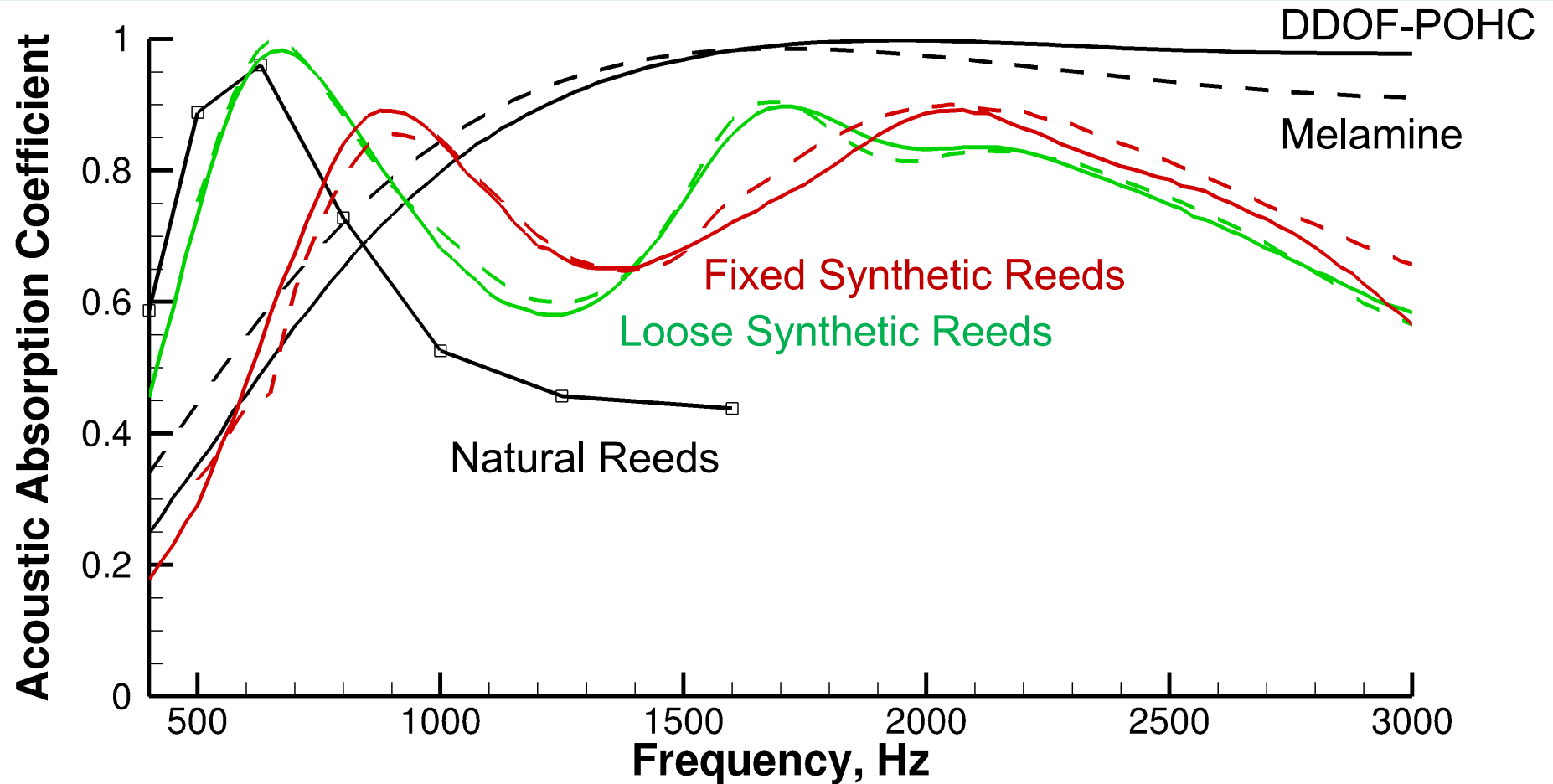


The fixed sample is useful since it is one geometry that we could consider for more controlled tests as we try to develop physics-based models to predict acoustics.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Description of the prototypes
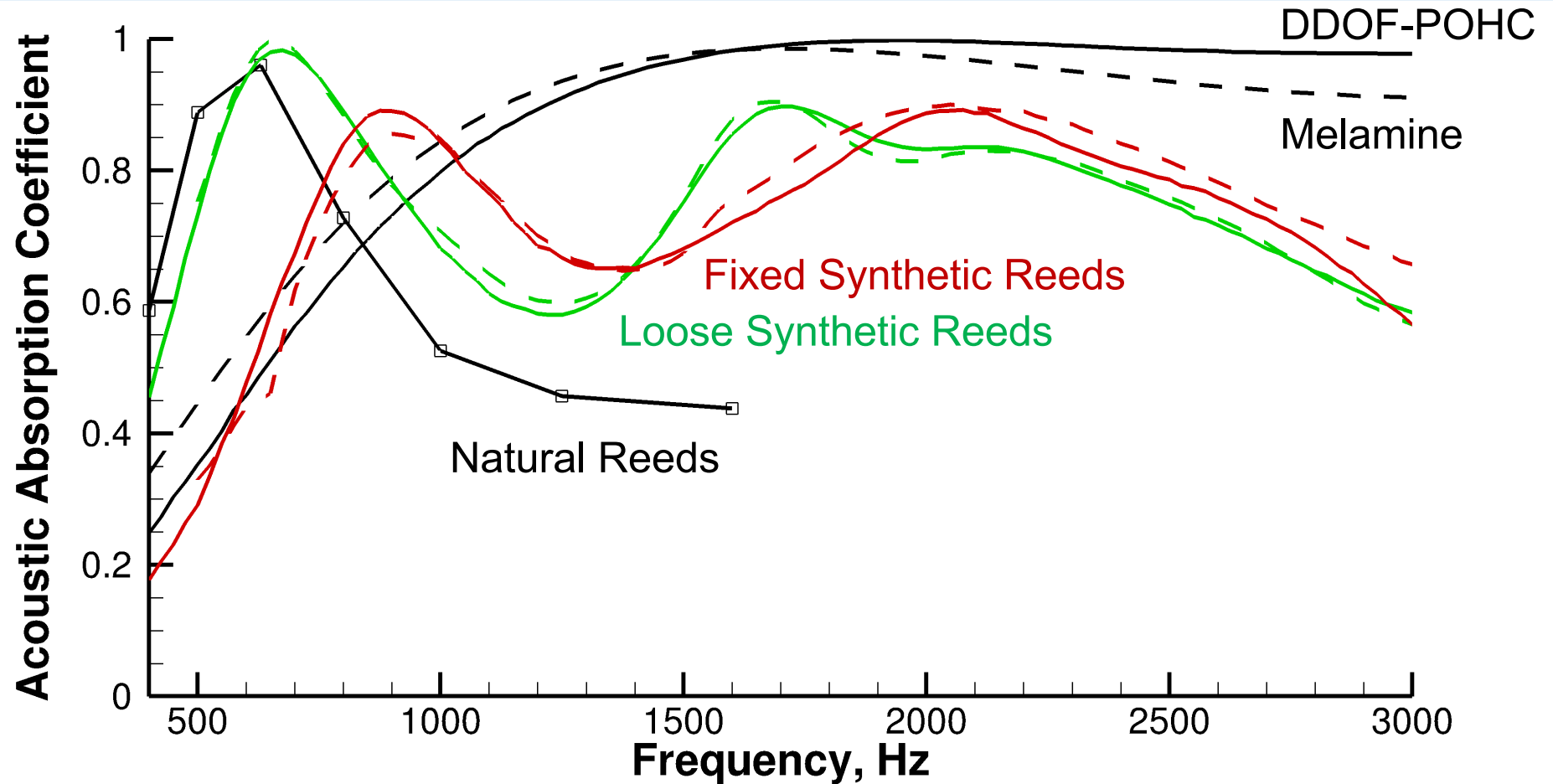


This observation might have some practical use in controlling low frequency noise in aviation and industrial applications where there may be constraints on treatment thickness, weight, temperature, and exposure to liquids.

# NASA's Bio-Inspired Acoustic Absorber Concept
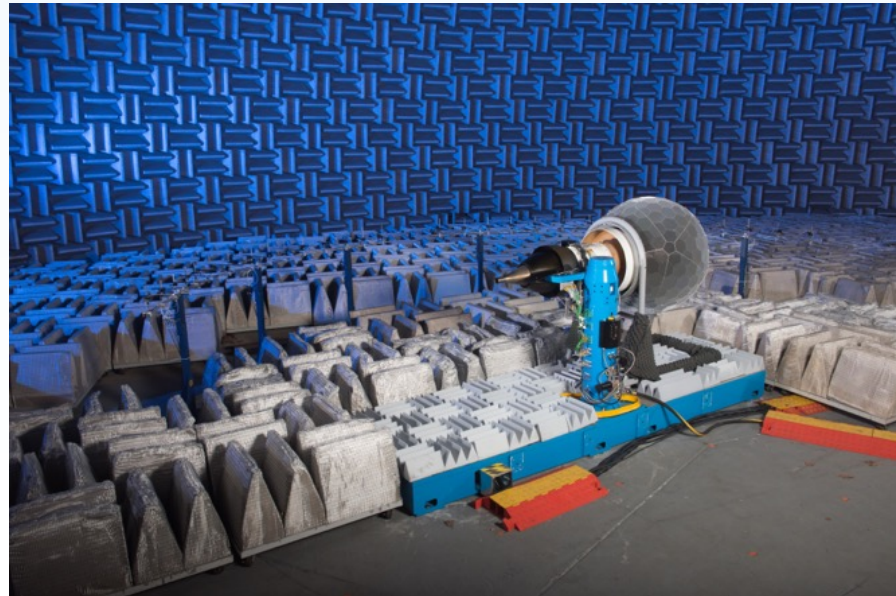
**The path forward: research and outreach**

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

Large ----------Product----------Small
Concept

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



DGEN-380 engine in the
NASA Glenn AeroAcoustic Propulsion Lab

# NASA's Bio-Inspired Acoustic Absorber Concept

**The path forward: research and outreach**

This patent-pending technology might be of wide practical use, for example:

**Aviation**

**Automotive**

**Architectural**

**Space exploration**

**Other?**

Prototype ----?---- Product
Small ----?---- Large
Few ----?---- Many

These structures can control noise over a broad frequency range,
particularly below 1000 Hz,
in applications that have tight constraints on weight and thickness,
and may be exposed to high temperatures or liquids.

# NASA's Bio-Inspired Acoustic Absorber Concept

**The path forward: research and outreach**

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

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?

**Your feedback is important to us!**

# NASA's Bio-Inspired Acoustic Absorber Concept

## The path forward: research and outreach

We interact with
students in a variety of ways:

tutoring

career shadowing

STEM competitions

internships

capstone projects

school presentations

distance learning broadcasts

content for media requests



Interview at the NASA Glenn AeroAcoustic Propulsion Laboratory for an educational video.

# NASA's Bio-Inspired Acoustic Absorber Concept

## Summary

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.

**Your feedback is important to us!**

**NASA's Bio-Inspired Acoustic Absorber Concept**

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**Amy Hiltabidel**, Technology Transfer Office

**NASA Langley Research Center**

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Advanced Air Transport Technology (AATT) Project

**Hamilton Fernandez,** Sub-Project Manager

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**http://technology.grc.nasa.gov**



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Twitter:  @NASAGlennBiz

# NASA's Bio-Inspired Acoustic Absorber Concept

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