L. Danielle Koch, P.E. Aerospace Engineer

NASA Glenn Research Center, Acoustics Branch L.Danielle.Koch@nasa.gov 216-433-5656

Summit 2017: Nature-Inspired Exploration for Aerospace Ohio Aerospace Institute Cleveland, Ohio October 5, 2017



#### **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





Have you heard the sounds of nature?



#### Inspiration

Map of the Quietest Places in the United States—Natural Conditions Source: National Park Service<sup>1,2</sup>

This model estimates the distribution of natural sounds in the U.S., excluding the noise of machines. 38 - 40 40 dBA 37 - 37 37 - 36 36 - 36

L50 SPL, dBA re 20µPa



#### Inspiration

Map of the Quietest Places in the United States—Existing Conditions Source: National Park Service<sup>1,2</sup>

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 39 - 40 ouder 32 - 33 30 - 31 27 - 29 <sup>21-26</sup>< 20 dBA<sup>5</sup>



**1960 2013** 

Since the 1960's, the number of commercial aircraft has tripled, as did other vehicles. Aircraft are a significant source of transportation noise.

National Transportation Noise Map: Road and Aviation Noise Near Cleveland, Ohio<sup>4</sup>





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.<sup>5</sup>



Inspiration



### 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.<sup>6,7</sup>





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



#### Inspiration



NASA is developing technology for quiet and efficient aircraft of the future.<sup>9</sup>



#### Inspiration



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



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

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.



#### Inspiration



Photo Credit: Jim Nemet, Cleveland Metroparks Zoo

Today's presentation is not about owls.



#### 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.<sup>11</sup>

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.



#### **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.



### **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.



### **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.



#### **Description of the experiment**



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.



#### **Description of the experiment**



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



#### **Description of the experiment**



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?



#### **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.



#### **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.

#### **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. The acrylic sample holder was chosen to be compatible with this acoustic rig and the X-ray CT scanner.

#### **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.



#### **Description of the prototypes**



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.



### **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.



#### **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 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.



## The path forward: research and outreach

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

- NASA GRC and LaRC Normal Incidence Tube
- Concept 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
- Product Other Ground Tests
  - **Other Flight Tests**



DGEN-380 engine in the NASA Glenn AeroAcoustic Propulsion Lab



Small

Large

### 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.



### 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!



### 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.



#### 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!



Acknowledgements

**NASA Glenn Research Center** 

Chris Miller, Acoustics Branch Pete Bonacuse, High Temperatures and Smart Alloys Branch Chris Johnston, Multiscale and Multiphysics Modeling Branch Maria Kuczmarski, Multiscale and Multiphysics Modeling Branch Karen Bartos, Technology Transfer Office Amy Hiltabidel, Technology Transfer Office

> NASA Langley Research Center Mike Jones, Structural Acoustics Branch

Funding provided by NASA's Aircraft Noise Reduction Advanced Air Transport Technology (AATT) Project **Hamilton Fernandez**, Sub-Project Manager





To explore licensing and partnerships with NASA Glenn for this or any of our other technologies, visit the NASA Glenn Tech Transfer website at:

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



#### Point of contact

Karen Bartos, IP Portfolio Manager/Technology Manager 216-433-6478 kbartos@nasa.gov *Discover available NASA technologies* Website: http://technology.grc.nasa.gov Twitter: @NASAGlennBiz



Bringing NASA Technology Down to Earth

https://technology.grc.nasa.gov

### References

- 1 U.S. National Park Service, "Natural Sounds Website," 2017, https://www.nps.gov/subjects/sound/soundmap.htm
- 2 Mennitt, D., Fristrup, K. M., Sherrill, K. and Nelson, L., "Mapping sound pressure levels on continental scales using a geospatial sound model," Proceedings of Internoise 2013, Institute of Noise Control Engineering, 2013, http://www.inceusa.org/publications
- 3 U.S. Department of Transportation, Bureau of Transportation Statistics, "Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances," 2017.

https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national\_transportation\_statistics/html/table\_01\_11.html

- 4 U.S. Department of Transportation, Bureau of Transportation Statistics, "National Transportation Noise Map," 2017. https://maps.bts.dot.gov/arcgis/apps/webappviewer/index.html?id=a303ff5924c9474790464cc0e9d5c9fb
- 5 U.S. Federal Aviation Administration,"Air Tour Management Plan," 2017. https://www.faa.gov/about/office\_org/headquarters\_offices/arc/programs/air\_tour\_management\_plan/
- 6 Envia, E., (eds Nelson, E. S. and Reddy, D. R.), Part 1. Environmental Impacts of Aviation Chapter 1, Noise Emissions from Commercial Aircraft in *Green Aviation: Aircraft Technology, Alternative Fuels and Public Policy,* CRC Press, To be published.
- 7 ICAO, "Onboard a Sustainable Future: ICAO's Environment Report 2016," 2016.
- 8 Huff, D. L., "NASA Glenn's Contributions to Aircraft Engine Noise Research," NASA TP-2013-217818, 2013.
- 9 Ashcraft, S. W., Padron, A. S., Pascioni, K. A., Stout, J., Gary W. and Huff, D. L., "Review of Propulsion Technologies for N+3 Subsonic Vehicle Concepts," NASA-TM-2011-217239, 2011.
- 10 Koch, L. D., "Predicting the Inflow Distortion Tone Noise of the NASA Glenn Advanced Noise Control Fan with a Combined Quadrupole-Dipole Model," NASA TM-2012-217673, AIAA-2012-2196, 2012.
- 11 Oldham, D. J., Egan, C. A. and Cookson, R. D., "Sustainable acoustic absorbers from the biomass," *Applied Acoustics*, Vol. 72, No. 6, 2011, pp. 350-363.
- 12 Koch, L. D. and Jones, M. G., "Measurement of the acoustic absorption of natural reeds and comparison to aircraft engine acoustic liner prototypes," NASA TM-2016-218851, 2016.
- 13 Koch, L. D. et al., "The Development of Acoustic Absorbers That Mimic Assemblies of Natural Reeds: Progress Report 1," NASA TM-2017-219438, 2017.

