

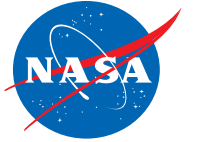
# NASA's Quiet Electric ENgines (QUEEN): Summary of the Acoustic Tests of the QUEEN V1

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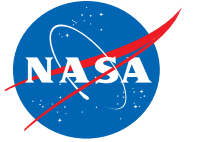
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**Purpose: To summarize a test of the QUEEN V1, an electric ducted fan system featuring prototype inlet duct acoustic liners, that was performed at the NASA Glenn Research Center's Acoustical Testing Laboratory in 2024.**

- Research Questions
- Description of the full-size SUSAN, NASA's SUBsonic Single Aft ENgine Aircraft Concept
- Description of the scale model SUSAN 25% Flight Research Vehicle (FRV)
- Description of the QUEEN V1, an electric ducted fan system intended for the wings of SUSAN 25% FRV
- Description of the inlet duct acoustic liners for the QUEEN V1
- Description of GRC Acoustical Testing Laboratory (ATL) for the QUEEN V1 test
- Test objectives
- Acoustic results
- Conclusion
- Acknowledgements
- Questions



## Research Questions

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How might we develop a commercial air transportation system accessible to a growing population that is safer, cleaner, and quieter than the one we have today?

How might we take off safely and quietly in hybrid/electric aircraft on hot or cold windy days, keeping the motor and controller from overheating, preventing ice from forming on propulsion system components, and meeting takeoff and landing noise regulations?

Many experiments ranging from small bench-tests to full size flight tests are needed, as we develop the components for more sustainable aircraft propulsion systems.

# SUSAN: NASA's SUBsonic Single Aft ENgine Aircraft Concept

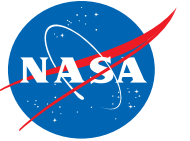


- SUSAN is one hybrid-electric aircraft concept intended to guide our imagination as we study distributed electric propulsion for large single-aisle aircraft (~180 passengers).
- One tail-mounted turbine engine is proposed to provide thrust and generate electricity onboard.
- Sixteen wing-mounted motor-driven fans are also proposed to propel the plane.



**NASA's SUSAN, the Subsonic Single Aft Engine Concept Aircraft with eight Quiet Electric Engines (QUEENs) mounted on each wing.**

# SUSAN 25% FRV: SUBsonic Single Aft ENgine 25% Flight Research Vehicle



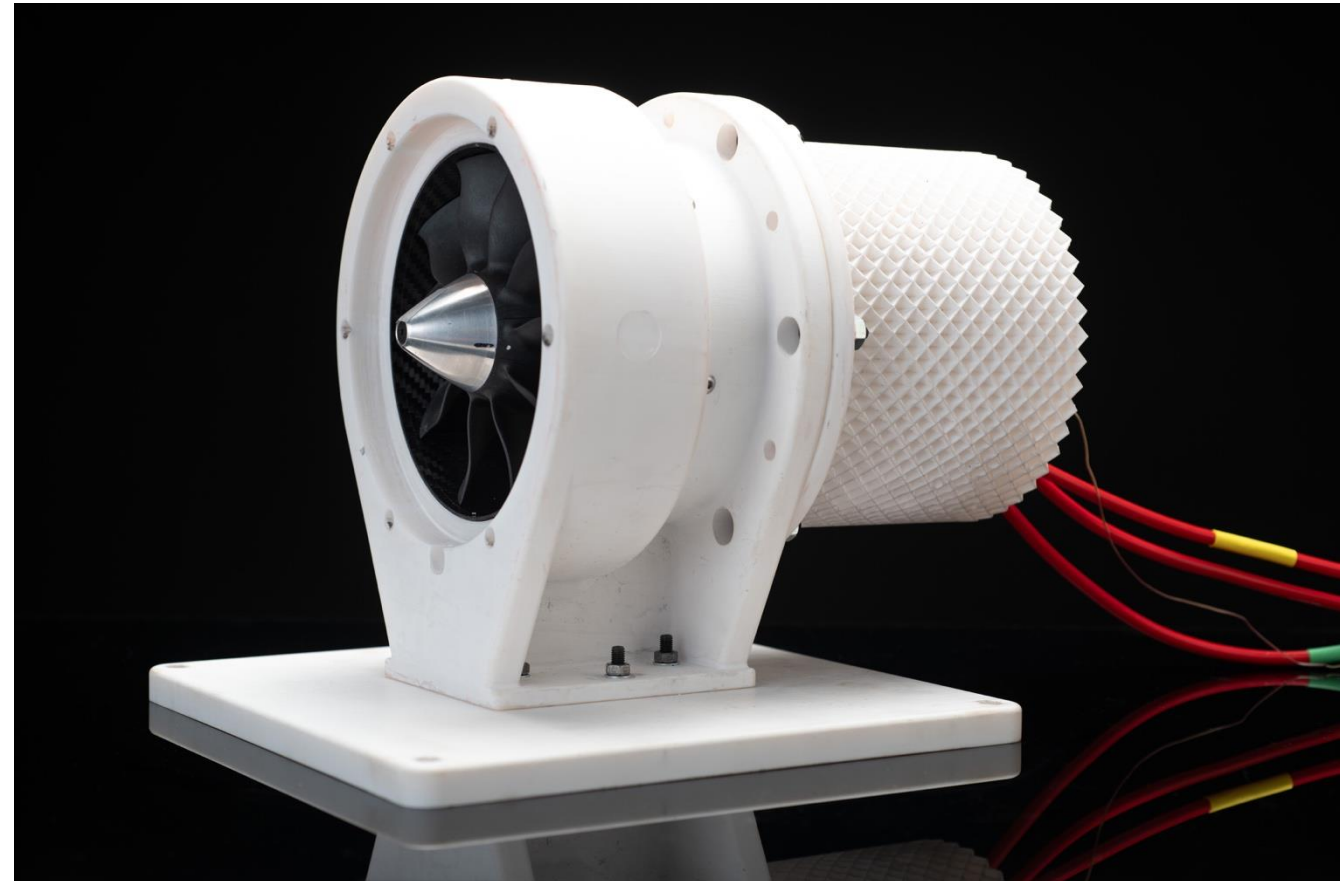
- A manufacturing prototype of the SUSAN 25% Flight Research Vehicle (SUSAN 25% FRV) was on display at NASA GRC August 2024.
- This model featured a new structure to mount the engine in the tail section.
- The QUEEN team is testing prototypes of the wing mounted engines for the SUSAN 25% FRV.
- The QUEEN propulsors are not shown on the wings of the SUSAN 25% FRV in the photo on the right.



**SUSAN 25% FRV was on display at NASA GRC in 2024.**

## Description of the QUEEN V1

- The QUEEN V1 features a Commercial-Off-the-Shelf (COTS) fan, motor and Electronic Speed Controller (ESC).
- The COTS fan was mounted in a 3D printed housing attached to a base.
- 3D printed parts were manufactured with a glass-filled photopolymer resin using stereolithography at NASA GRC.



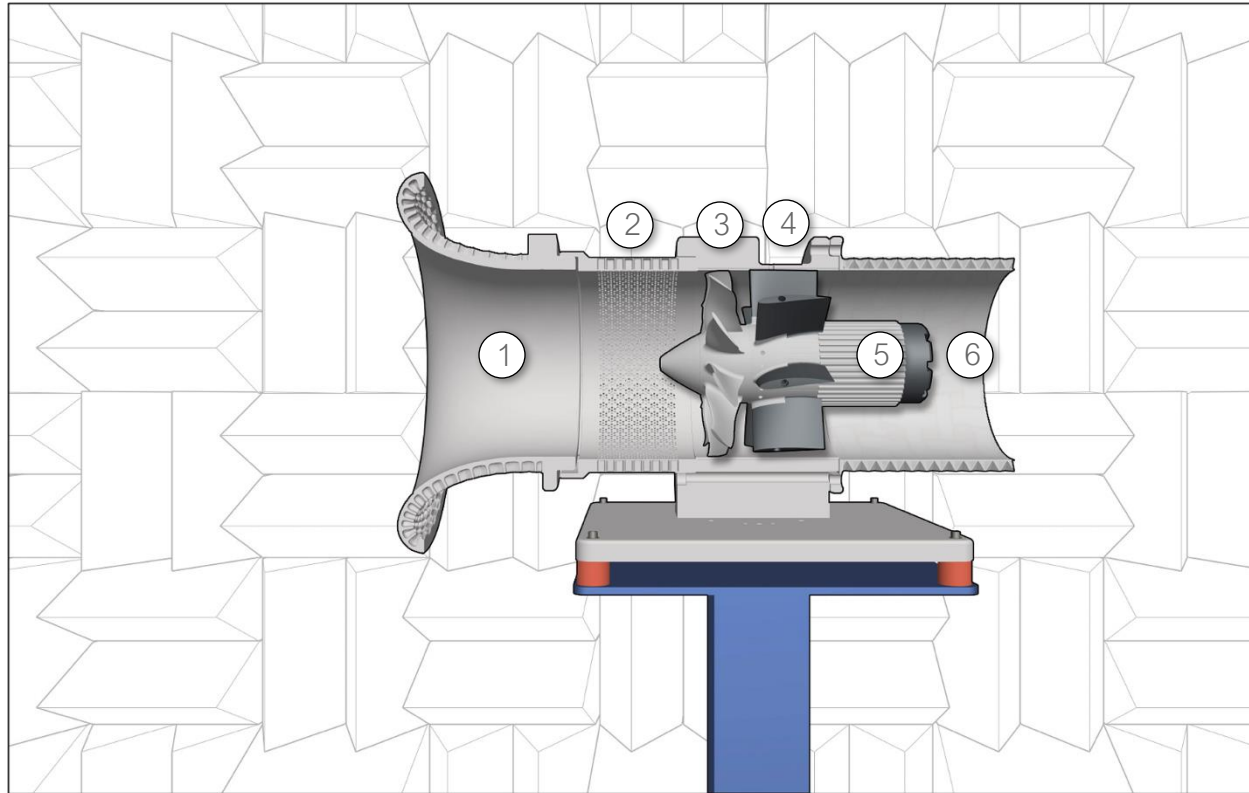
**Photograph of the QUEEN V1 without the inlet section installed.**

## Description of the QUEEN V1

Other 3D printed parts of the QUEEN V1 ducted fan system included:

1. bellmouth
2. inlet duct acoustic liner section
3. aft duct section

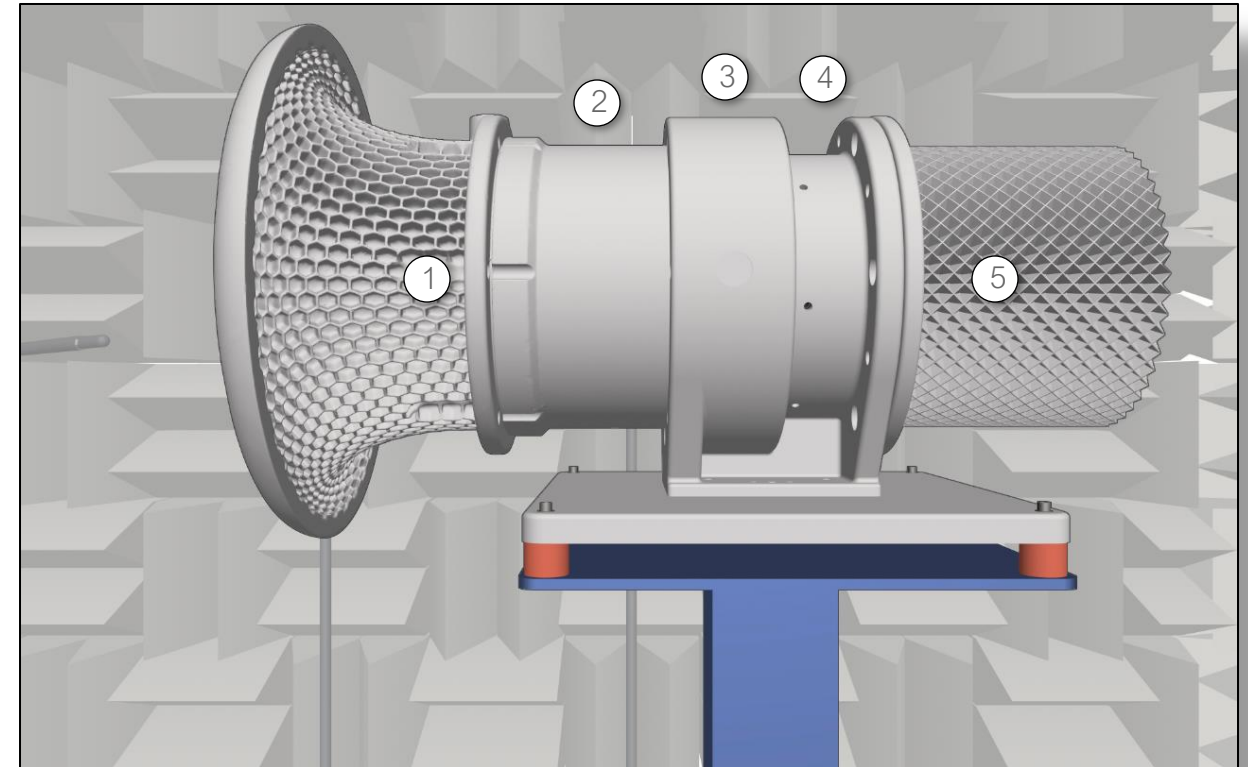
The QUEEN V1 inlet section for this test was significantly longer than the short carbon fiber lip provided with the COTS fan.



**Illustration of the QUEEN V1:**  
**1. Bellmouth 2. Duct Acoustic Liner Section**  
**3. Rotor Section 4. Stator Section 5. Motor 6. Aft Duct.**

# Description of the QUEEN V1

<b>Rotor tip diameter</b>	13.0 cm (5.11 in)
<b>Duct inner diameter</b>	13.3 cm (5.23 in)
<b>Number of rotor blades</b>	10
<b>Number of outlet guide vanes</b>	7
<b>Maximum motor rotational speed</b>	45,000 rpm
<b>Tip clearance</b>	1.5 mm (0.060 in)
<b>Maximum rotor speed during the test in ATL</b>	25,400 rpm
<b>Maximum tested power during the test in ATL</b>	6.33 kW



**Illustration of the QUEEN V1:**  
**1. Bellmouth 2. Duct Acoustic Liner Section**  
**3. Rotor Section 4. Stator Section 5. Aft Duct.**

## Description of Inlet Duct Acoustic Liners for the QUEEN V1

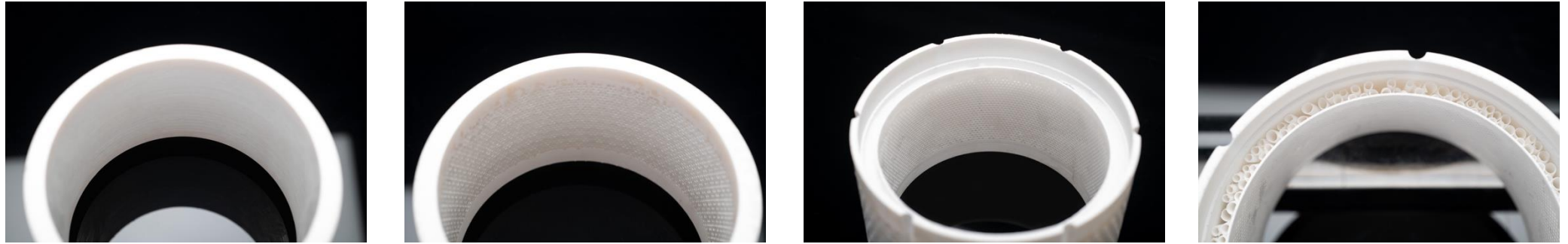
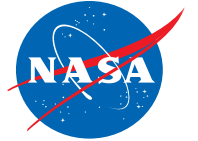
Four inlet duct acoustic liner prototypes were designed, fabricated, and tested:

1. Hardwall liner
2. Perforate Over Honeycomb liner
3. Perforate Over Bulk Absorber liner
4. Perforate over NASA's bio-inspired Broadband Acoustic Absorber liner.



**The QUEEN V1 inlet duct liner prototypes.**

# Description of Inlet Duct Acoustic Liners for the QUEEN V1



	<b>Hardwall Inlet</b>	<b>Perforate Over Honeycomb Inlet Duct Acoustic Liner</b>	<b>Perforate Over Bulk Absorber Inlet Duct Acoustic Liner</b>	<b>Perforate over NASA's patented bio-inspired Broadband Acoustic Absorber</b>
<b>Pros</b>	<ul style="list-style-type: none"> <li>Simple design</li> <li>Low-drag</li> <li>Can be used to reduce noise from ducted fan systems</li> </ul>	<ul style="list-style-type: none"> <li>State-of-the art acoustic liners for turbofan engines for over 50 years.</li> </ul>	<ul style="list-style-type: none"> <li>Lightweight fibrous materials behind a perforate can absorb sound over a wide range of frequencies</li> </ul>	<ul style="list-style-type: none"> <li>Data show that structures that resemble bundles of natural reeds absorb sound well from 400-3000 Hz, and better than Perforate over Honeycomb and Melamine for similar thickness &lt; 1000 Hz.</li> </ul>
<b>Cons</b>	<ul style="list-style-type: none"> <li>Becomes less effective at reducing noise as axial length is shortened</li> </ul>	<ul style="list-style-type: none"> <li>Drag penalty incurred by flow over the perforated duct surface</li> <li>Thin layers are less effective for absorbing sound below 1000 Hz</li> </ul>	<ul style="list-style-type: none"> <li>Fibrous materials absorb liquids therefore not suitable for aircraft engine liners that are exposed to the weather.</li> <li>Thin layers are less effective for absorbing sound below 1000 Hz.</li> </ul>	<ul style="list-style-type: none"> <li>Research and development is needed to mature this new technology.</li> </ul>

# Description of Inlet Duct Acoustic Liners for the QUEEN V1

## Hardwall Liner Specifications:

Liner Axial Length	6.60 cm (2.60 in)
Duct Inner Diameter	13.3 cm (5.23 in)
Liner Radial Thickness	0.965 cm (0.380 in)

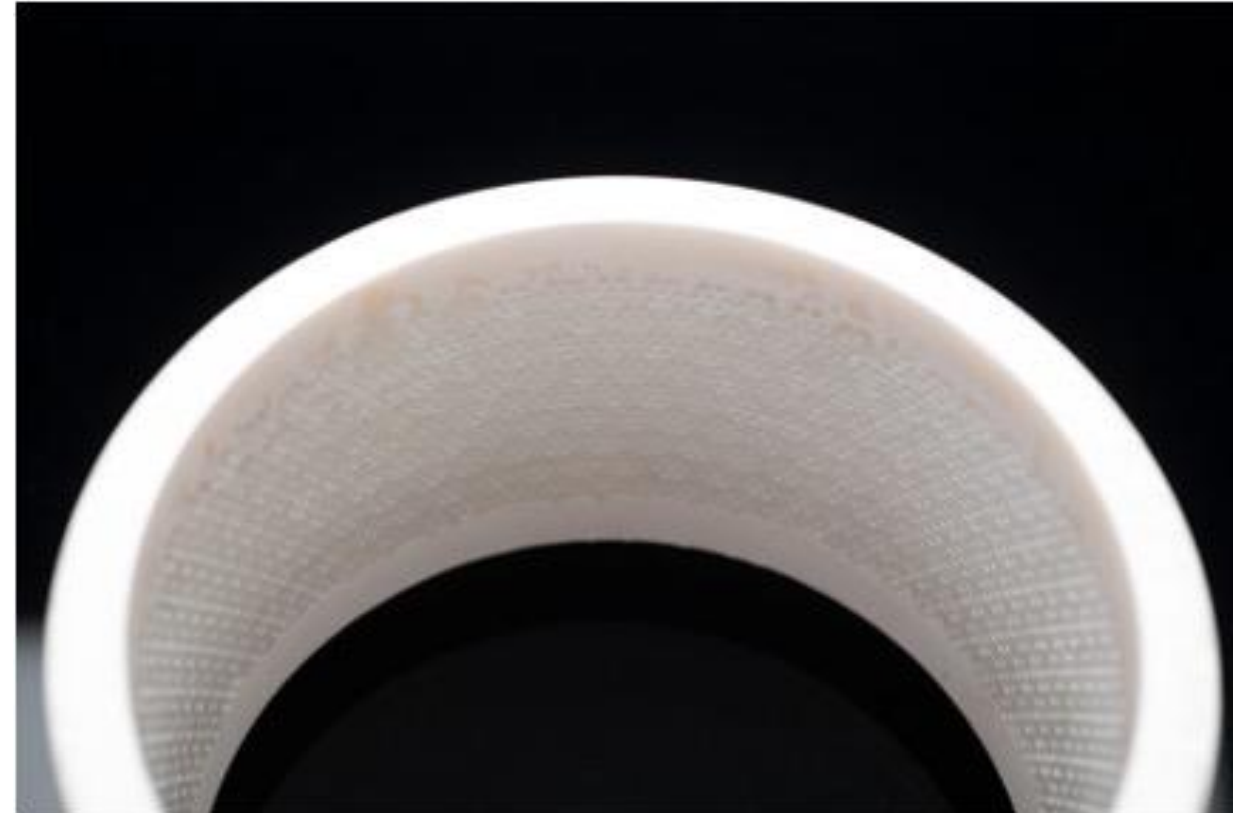


**Hardwall Liner**

# Description of Inlet Duct Acoustic Liners for the QUEEN V1

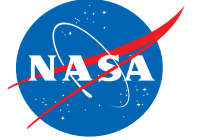
## Perforate Over Honeycomb Liner Specifications:

Liner Axial Length	6.60 cm (2.60 in)
Design Frequency Range	4000 Hz to 10 kHz
Honeycomb hexagonal cell flat-to-flat distance	0.635 cm (0.25 in)
Honeycomb Cell Depth	0.76 cm (0.30 in)
Face Sheet Perforate Hole Diameter	1.52 mm (0.06 in)
Face Sheet Thickness	1.02 mm (0.04 in)
Face Sheet Percent Open Area	16%



**Perforate Over Honeycomb Liner**

# Description of Inlet Duct Acoustic Liners for the QUEEN V1



## Bulk Absorber Liner Specifications:

Liner Axial Length	6.60 cm (2.60 in)
Duct Inner Diameter	13.3 cm (5.23 in)
Liner Thickness	0.76 cm (0.30 in)
Bulk Absorber Material	PrimaLoft One
Face Sheet Perforate Hole Diameter	1.52 mm (0.06 in)
Face Sheet Thickness	1.02 mm (0.04 in)
Face Sheet Percent Open Area	16%



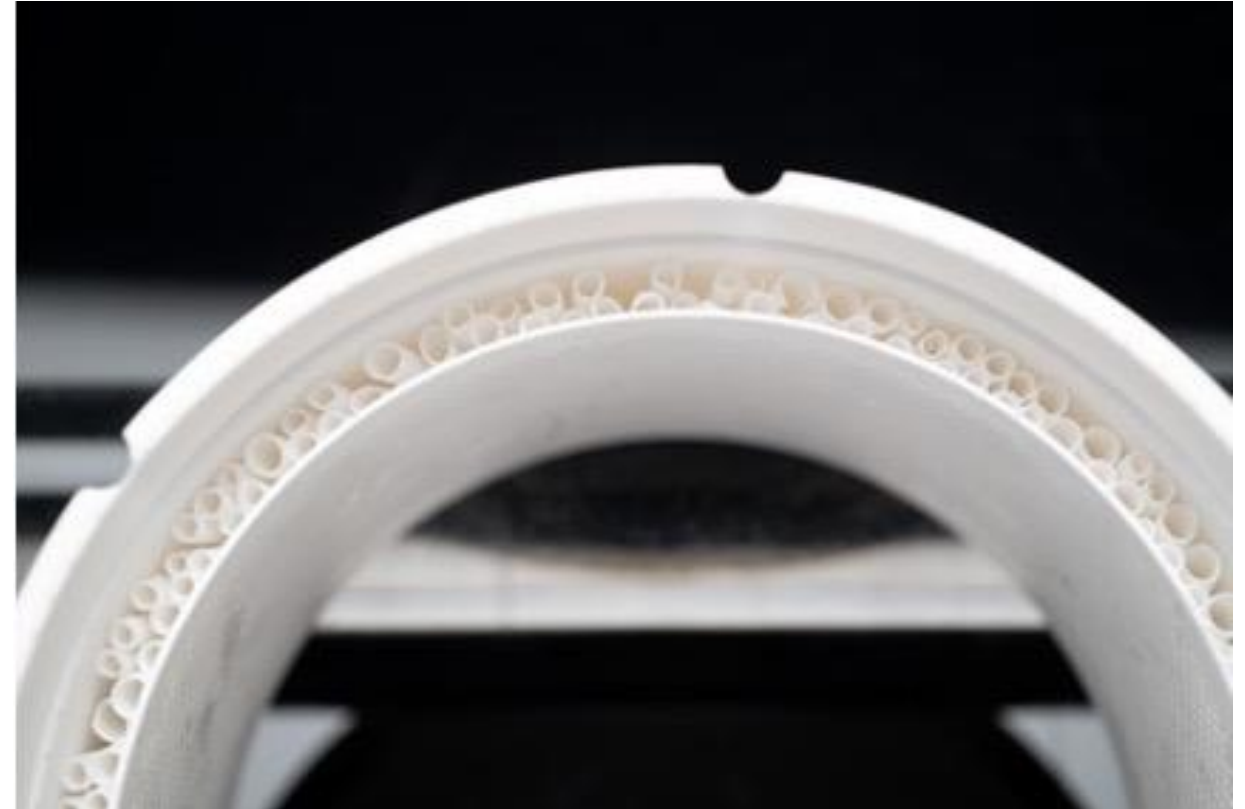
**Bulk Absorber Liner includes a layer of fibrous PrimaLoft One behind the perforated face sheet.**

# Description of Inlet Duct Acoustic Liners for the QUEEN V1

## Bio-inspired Broadband Acoustic Absorber Liner Specifications:

Liner Axial Length	6.60 cm (2.60 in)
Duct Inner Diameter	13.3 cm (5.23 in)
Bioliner Prototype Design	ASA-2.0
Liner Thickness	0.76 cm (0.30 in)
Face sheet Perforate Hole Diameter	1.52 mm (0.06 in)
Face Sheet thickness	1.02 mm (0.04 in)
Face Sheet Percent Open Area	16%

Reference: Koch, Jones, Bonacuse, Miller, Johnston, Kuczmarski, **“An introduction to NASA’s broadband acoustic absorbers that resemble natural reeds,”** *International Journal of Aeroacoustics*, Vol. 20, No. 5-7, pp. 662-679. 2021.



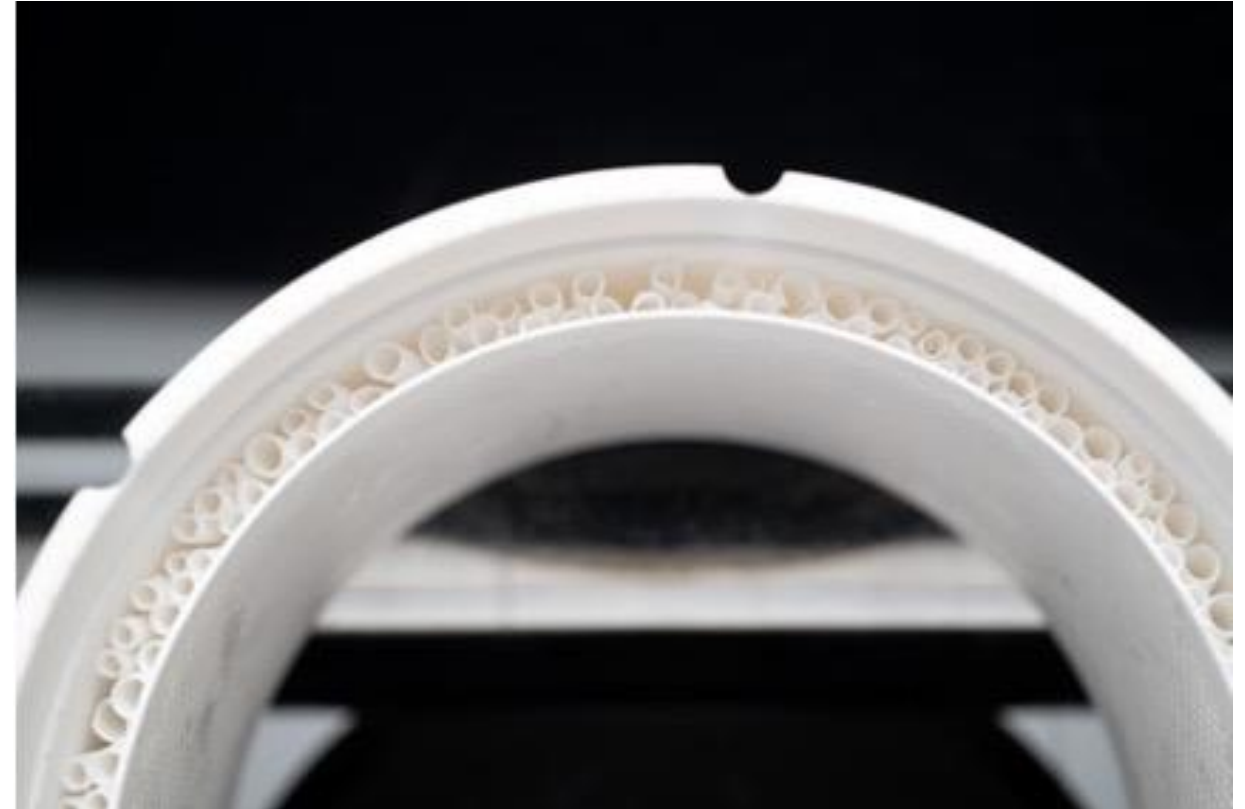
**First annular ‘bioliner’ prototype installed in a fan system.**

# Description of Inlet Duct Acoustic Liners for the QUEEN V1

## Bio-inspired Broadband Acoustic Absorber Liner Specifications:

Liner Axial Length	6.60 cm (2.60 in)
Duct Inner Diameter	13.3 cm (5.23 in)
Bioliner Prototype Design	ASA-2.0
Liner Thickness	0.76 cm (0.30 in)
Face sheet Perforate Hole Diameter	1.52 mm (0.06 in)
Face Sheet thickness	1.02 mm (0.04 in)
Face Sheet Percent Open Area	16%

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**First annular 'bioliner' prototype installed in a fan system.**

# Description of the Acoustical Testing Laboratory for the QUEEN V1 test

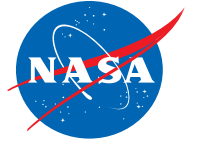


- The experiment was performed in the NASA GRC Acoustical Testing Laboratory (ATL).
- The QUEEN V1 was mounted on a pedestal near the center of the chamber.
- The ATL was configured as a fully anechoic chamber, though the chamber bay doors were open to reduce air recirculation.
- In this photo, chamber internal bay doors are open inward and external bay doors are closed.

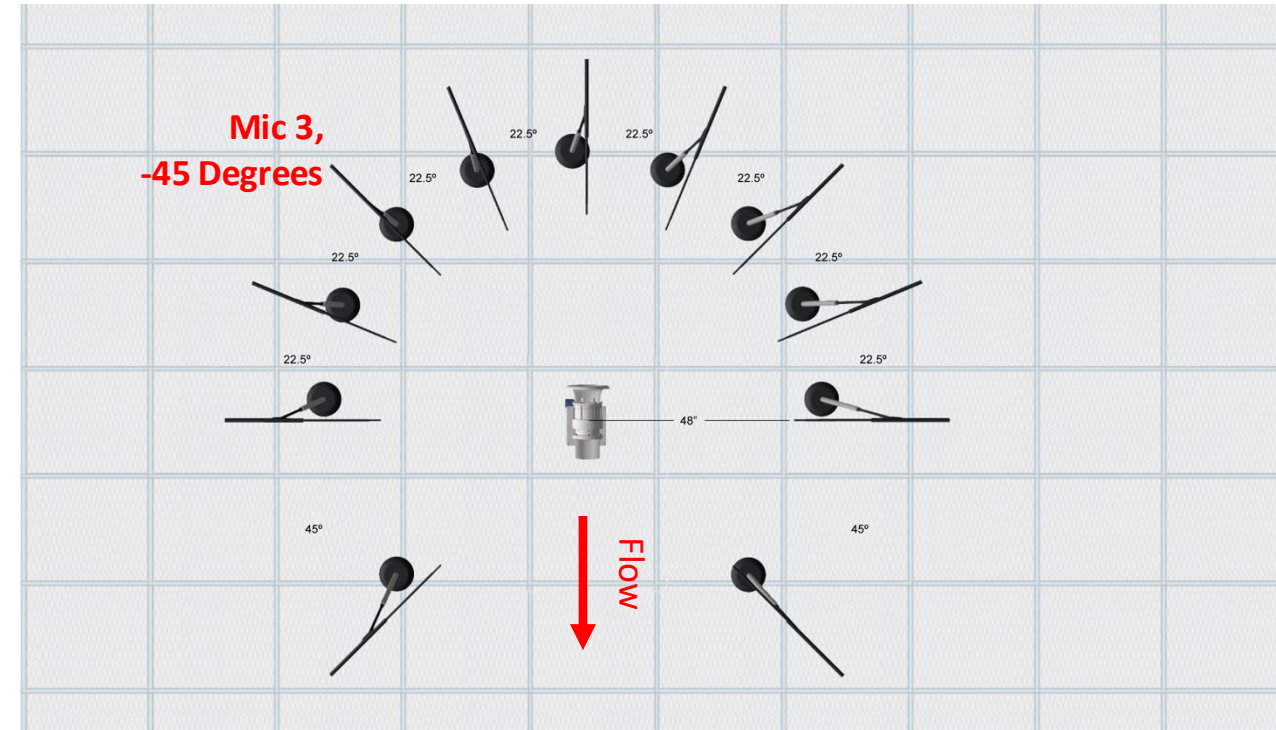


**Photograph of the QUEEN V1 test set-up in the NASA GRC Acoustical Testing Laboratory, forward looking aft.**

# Description of the Acoustical Testing Laboratory for the QUEEN V1 test



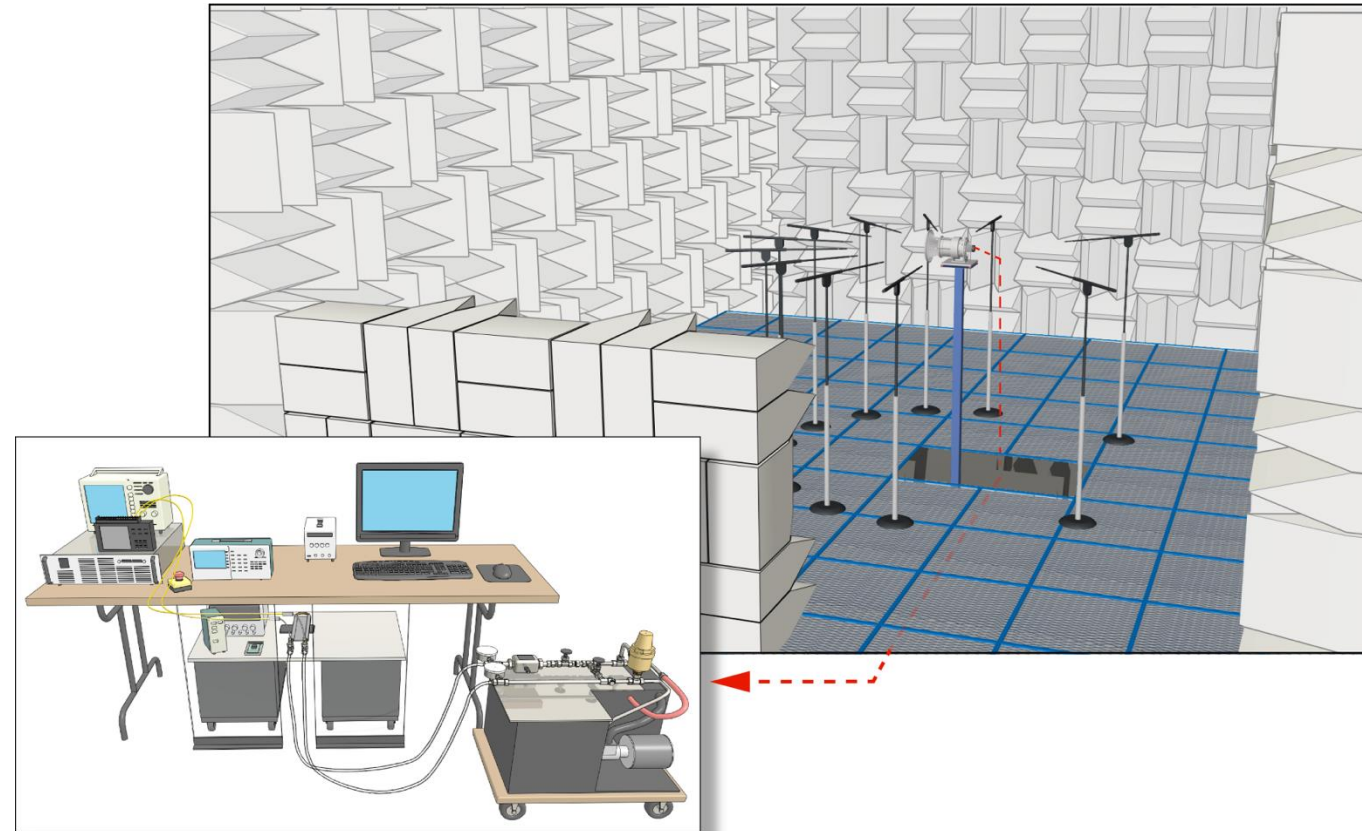
- Eleven microphones were placed on a 4 ft radius referenced to a datum at the fan rotor leading edge centerline location.
- Nine microphones were used to measure inlet radiated noise and to characterize performance of the four inlet-duct acoustic liners. These were equally spaced  $22.5^\circ$  apart,  $\pm 90^\circ$  from the datum.
- Two microphones were used to measure the aft radiated noise. These were equally spaced  $\pm 45^\circ$  from the datum.



**An array of microphones were equally spaced around the fan inlet to characterize the inlet radiated noise.**

# Test Objectives

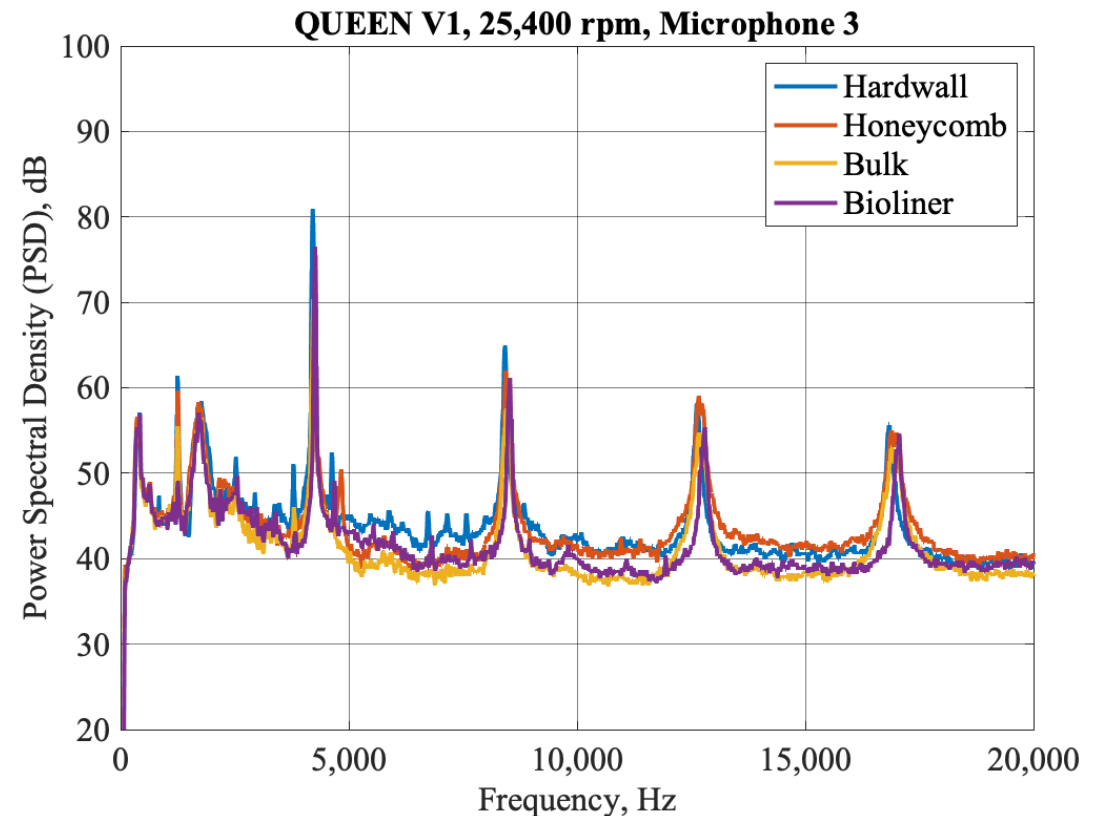
1. The first objective was to measure inlet radiated noise of the QUEEN V1 with the four inlet-duct acoustic liners at different speeds.
2. The second objective was to characterize the thermal performance of the Electronic Speed Controller on a cold plate at different rotor speeds.
3. This paper and presentation will focus on the acoustic results.



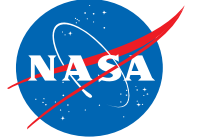
**Illustration of the QUEEN V1 test set-up in the ATL anechoic chamber (upper right) and control room (lower left).**

## Hardwall vs. all other liners

- Fan blade passing tones were evident in the acoustic data.
- Differences between the different liner prototypes were measured.
- Acoustics results at the maximum tested rotor speed of 25,400 rpm are presented.

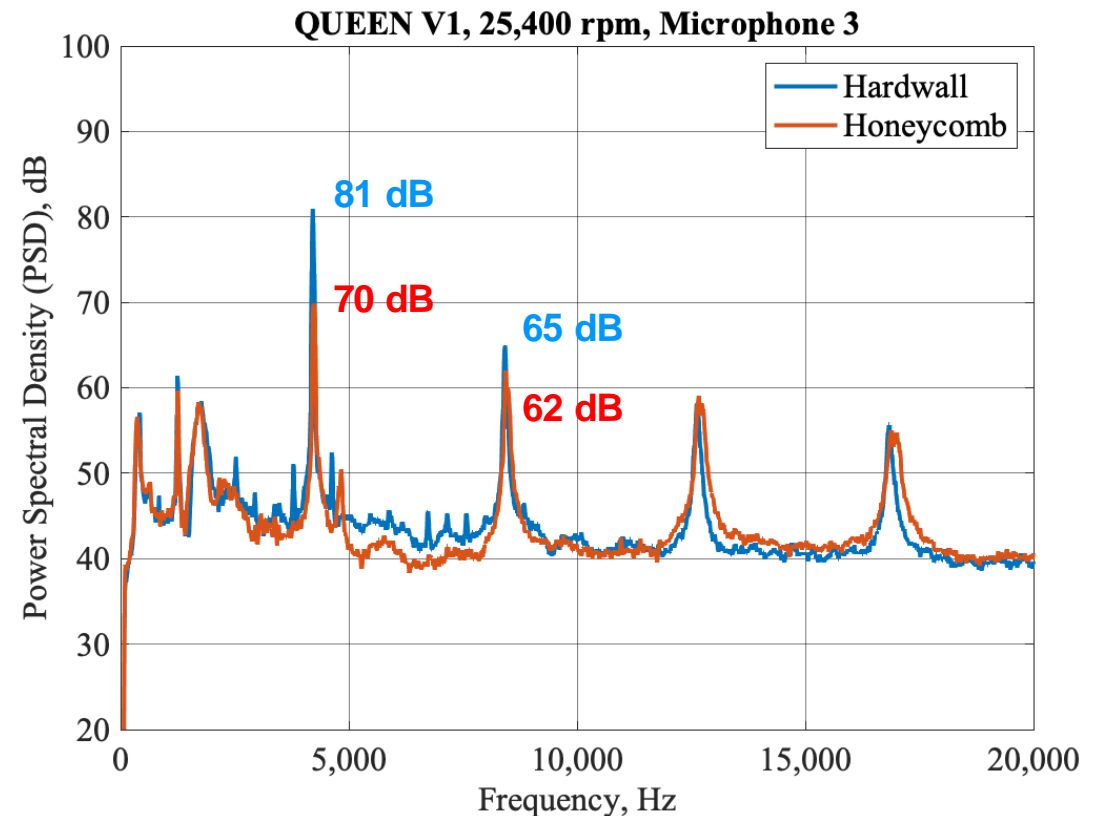


Spectra from Microphone 3 (- 45°) in the inlet array for each of the four inlet duct acoustic liners.



## Hardwall vs. Honeycomb Liner

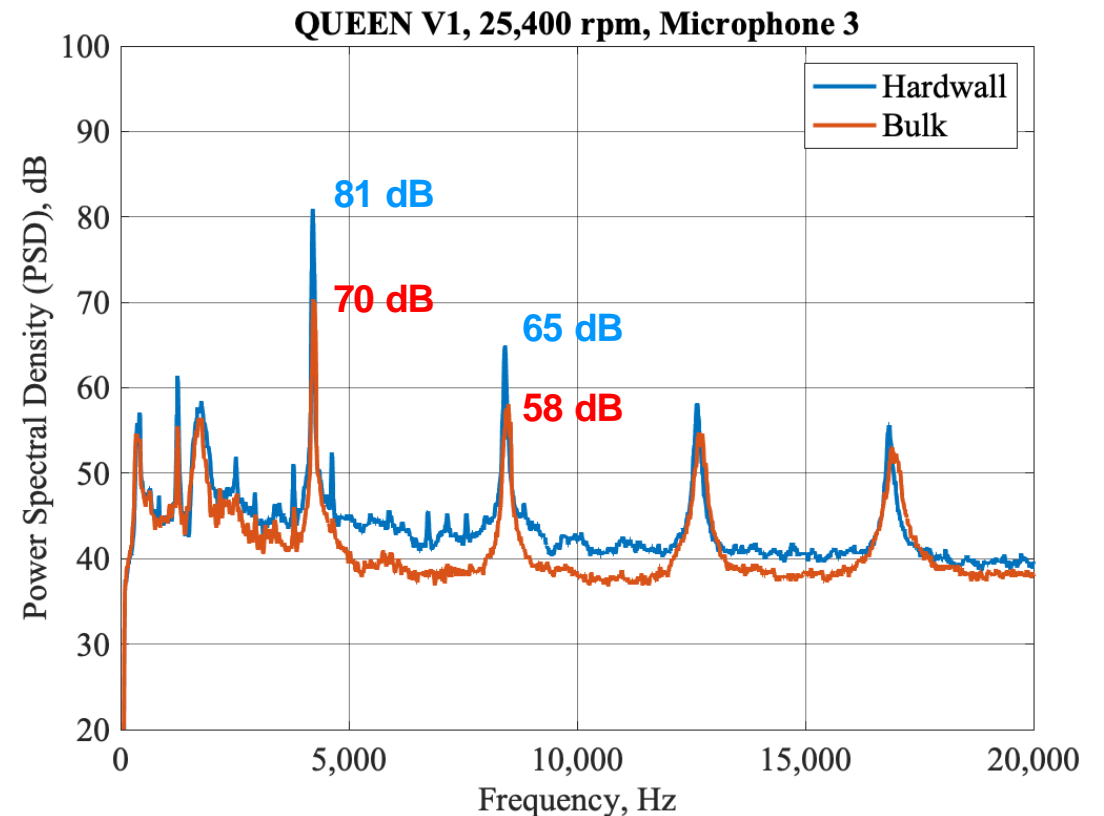
- The Perforate Over Honeycomb liner reduced the tone and broadband noise of the QUEEN V1.
- Measured tone noise reductions with the Honeycomb liner for the first two harmonics of the Blade Passing Frequency were:
  - 1BPF: 11 dB reduction
  - 2BPF: 3 dB reduction



Spectra from Microphone 3 (- 45°) in the inlet array for each of the Hardwall Liner and the Honeycomb Liner.

## Hardwall vs. Bulk Liner

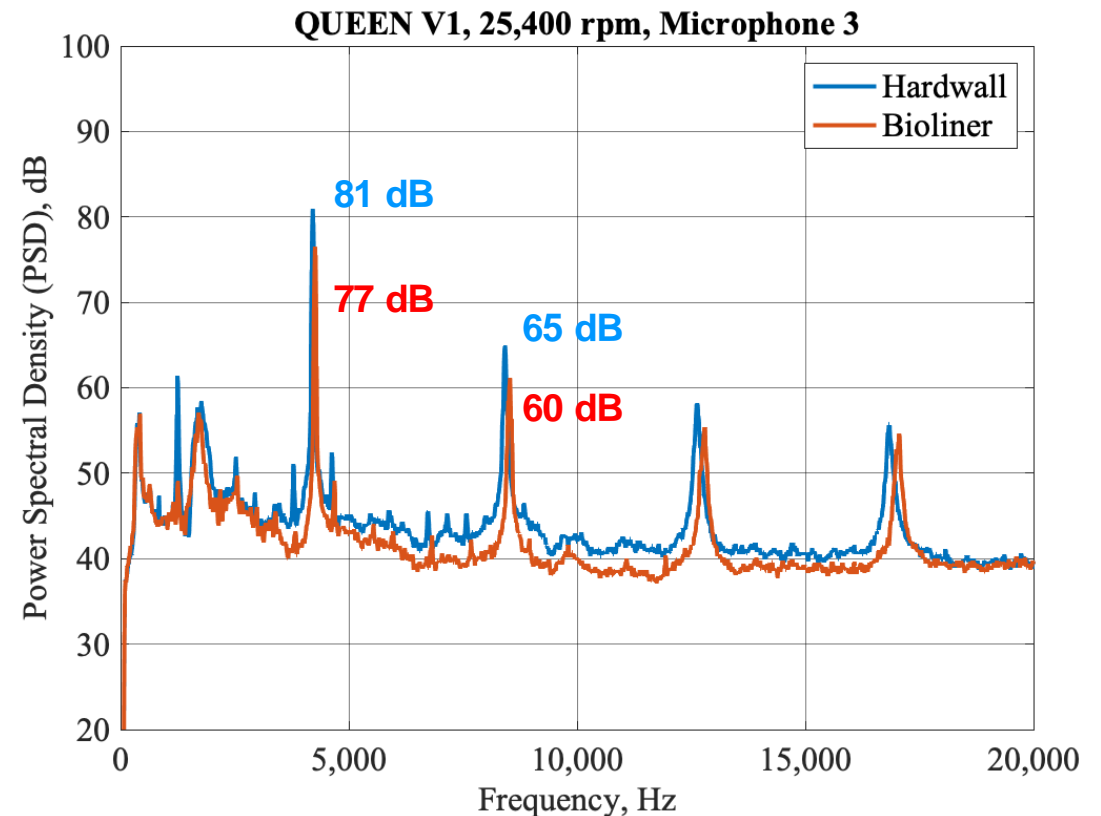
- The Bulk liner reduced the tone and broadband noise of the QUEEN V1.
- Measured tone noise reductions with the Bulk liner for the first two harmonics of the Blade Passing Frequency were:
  - 1BPF: 11 dB reduction
  - 2BPF: 7 dB reduction



Spectra from Microphone 3 ( $-45^{\circ}$ ) in the inlet array for each of the Hardwall Liner and the Bulk Liner.

## Hardwall vs. 'Bioliner'

- The bio-inspired Broadband Acoustic Absorber liner ('Bioliner') reduced the tone and broadband noise of the QUEEN V1.
- Measured tone noise reductions with the Bioliner liner for the first two harmonics of the Blade Passing Frequency were:
  - 1BPF: 4 dB reduction
  - 2BPF: 5 dB reduction
- This is the first proof-of-concept data for an annular version of NASA's bio-inspired broadband acoustic absorber concept in a fan system.

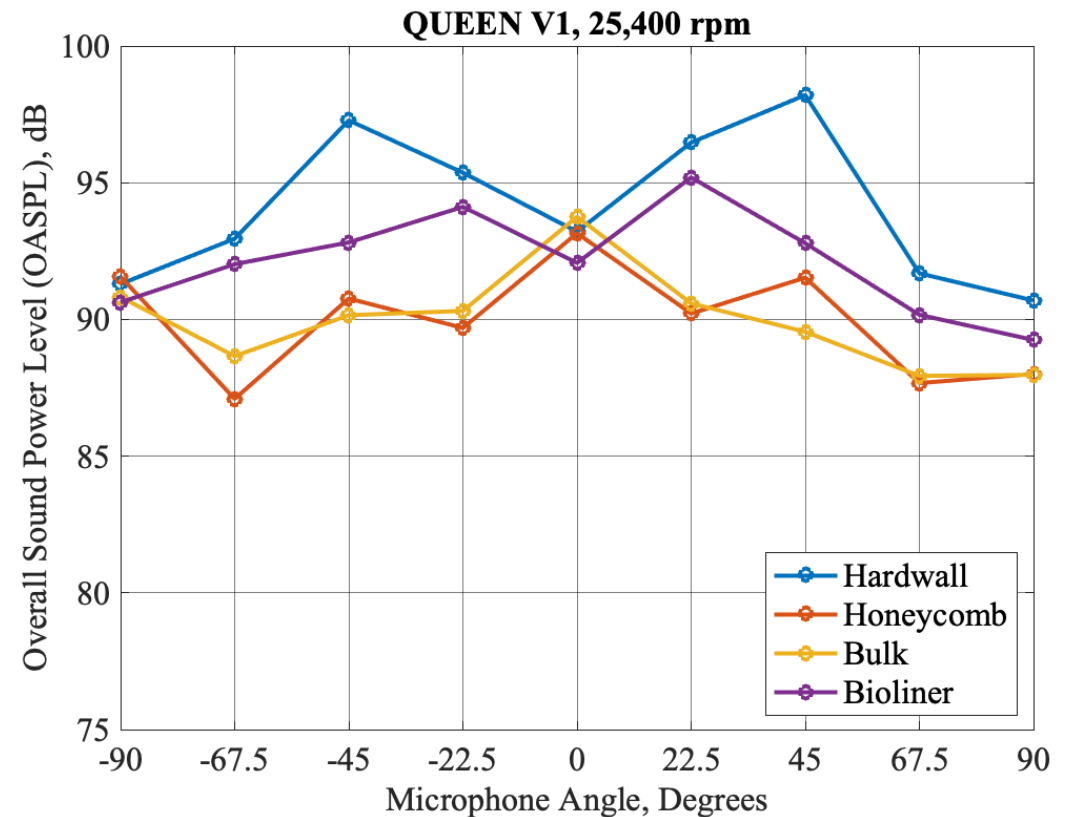
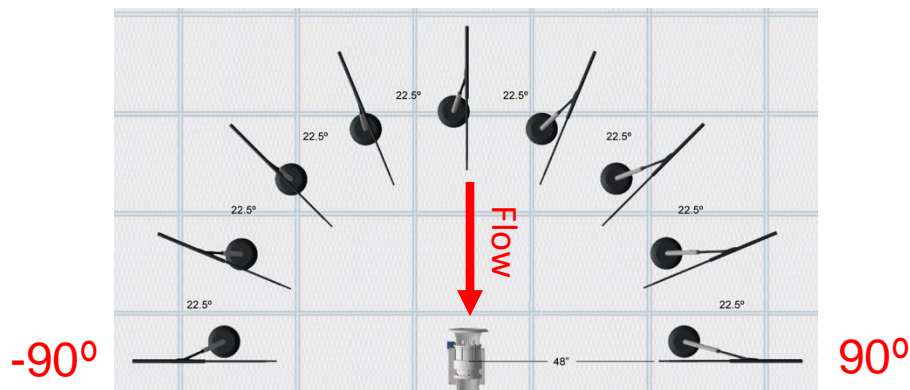


Spectra from Microphone 3 ( $-45^{\circ}$ ) in the inlet array for each of the Hardwall Liner and the Bioliner.

# Acoustic results

## Directivity for all liners

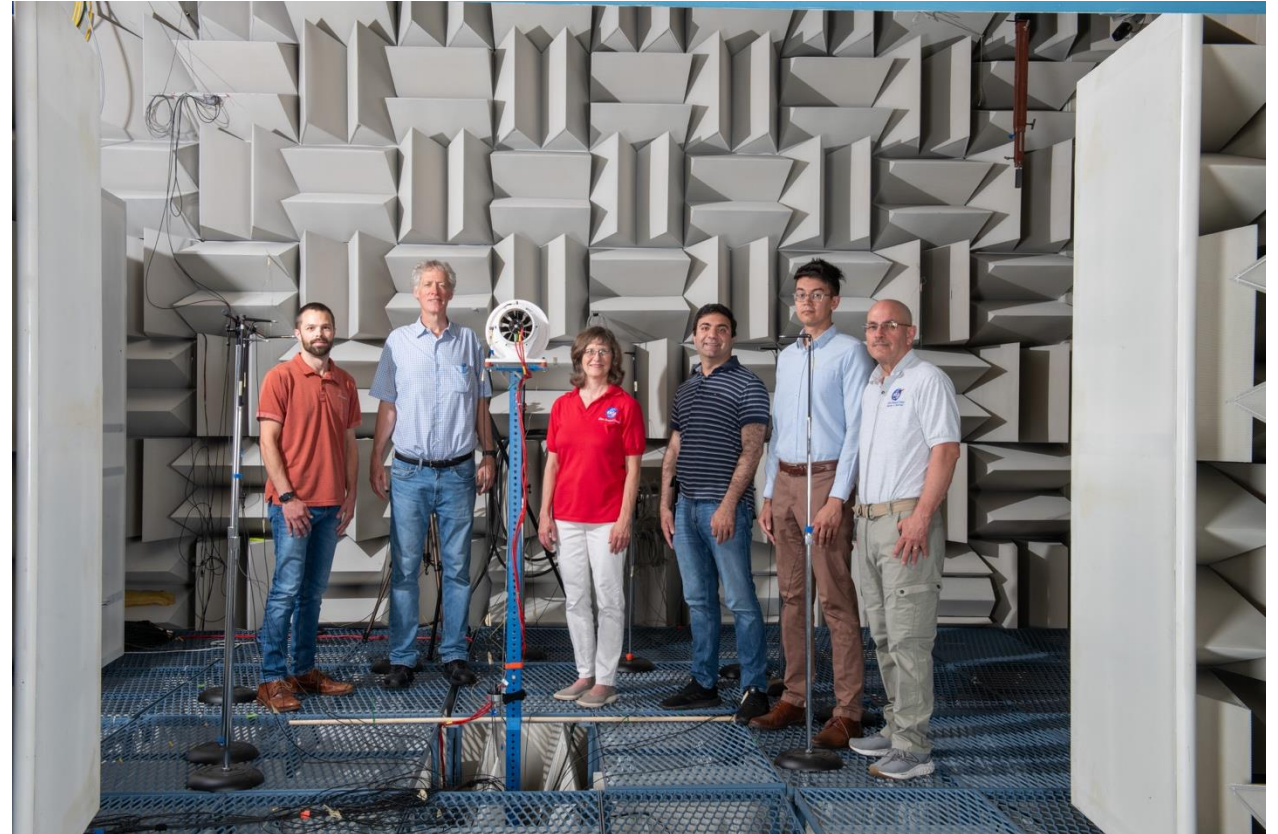
- The directivity of the sound propagating from the inlet of the QUEEN V1 for all the four liners showed that all the liners reduced noise compared to the hardwall condition.
- The Overall Sound Power Level was plotted as a function of the microphone angle for the nine microphones external to the bellmouth.



Directivity from all the microphones in the inlet array for each of the four inlet duct acoustic liners.

## Conclusion

- The QUEEN V1 electric ducted fan was designed, built, instrumented, and tested at NASA GRC Acoustical Testing Laboratory in spring 2024.
- The QUEEN V1 features a single Commercial-Off-the-Shelf fan with outlet guide vanes.
- Four inlet duct acoustic liners were tested.
- Results of the acoustic test indicate that all three liners reduced tone and broadband noise produced by the fan compared to the hardwall liner.
- Results of the thermal test of the Electronic Speed Controller are given in a separate paper and presentation.



**Some members of the QUEEN V1 Test Team in the NASA GRC Acoustical Testing Laboratory, May 2024.**



# Acknowledgements

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## **NASA Glenn QUEEN Team**

**Danielle Koch**, Acoustics Branch

**Jacob Gold**, Acoustics Branch

**Dan Sutliff**, Acoustics Branch

**Alexander Svetgoff**, Acoustics Branch

**David Stephens**, Acoustics Branch

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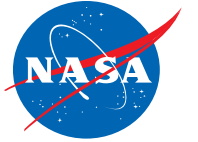
**Jeff Chin**, CAS GRC Center Integration Lead

**Ralph Jansen**, Principal Investigator SUSAN

**Brad French**, Co-PI SUSAN

# Summary of the Acoustic Tests of the QUEEN V1

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**Thank you!**

**Questions?**