

# Spacecraft Cabin Ventilation Fan Research at NASA

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Danielle Koch, David Stephens, Jonathan Goodman, Arman Mirhashemi,  
Rebecca Buehrle, Daniel Sutliff, Christopher Allen  
National Aeronautics and Space Administration

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[L.Danielle.Koch@nasa.gov](mailto:L.Danielle.Koch@nasa.gov).

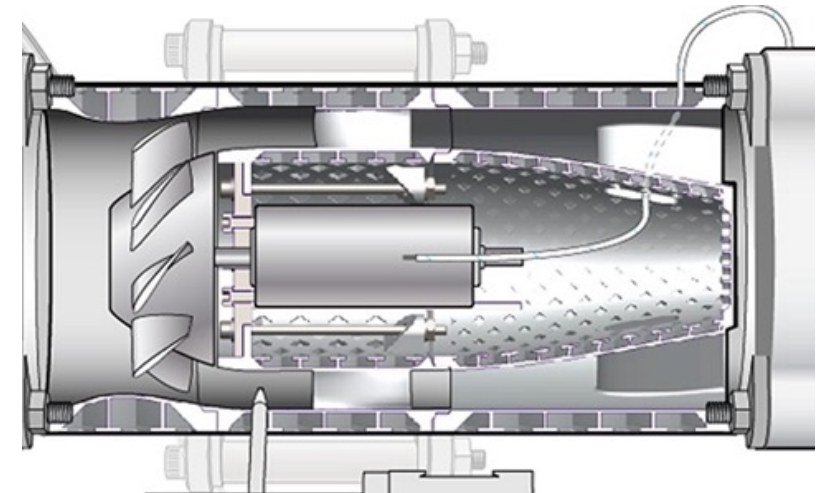
# Spacecraft Cabin Ventilation Fan Research at NASA

## Outline



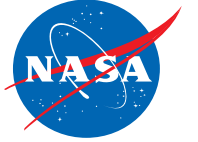
## Outline

- Introduction
- Aerodynamic Design and Analysis
- Acoustic Design and Analysis
- Mechanical and Electrical Design and Manufacture
- Test Facility and Fan Test Rig
- Aerodynamic Measurements
- Acoustic Measurements
- Recommendations
- Conclusions
- Acknowledgements



# Spacecraft Cabin Ventilation Fan Research at NASA

## Introduction



## Introduction

- Noise continues to be a concern for future long duration human space exploration missions.
- Ventilation fans have been dominant sources of noise on the Apollo Command Module, the Space Shuttle, and the International Space Station (ISS).
- Mufflers, liners, and enclosures add weight and volume.



# Spacecraft Cabin Ventilation Fan Research at NASA

## Aerodynamic Design and Analysis



### Aerodynamic Design and Analysis

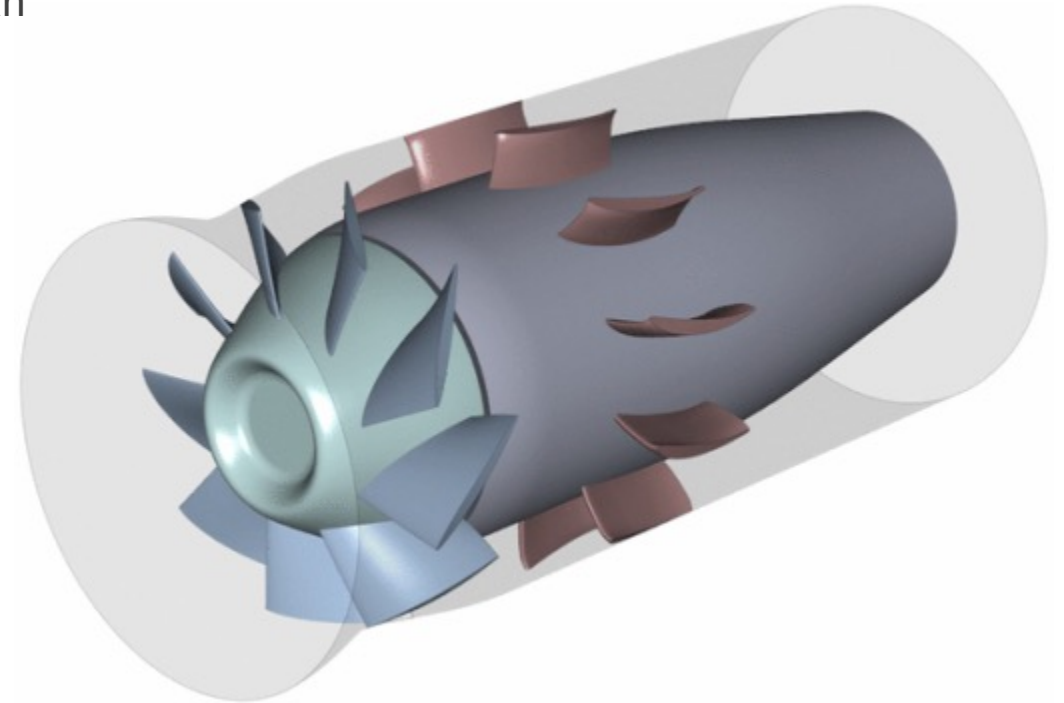
For research and development purposes, NASA chose to study an axial fan representative of an ISS Intermodule Ventilation Fan.

#### Using these Design Point Conditions;

|                          |                          |
|--------------------------|--------------------------|
| Flow rate:               | 150.3 cfm                |
| Total pressure rise:     | 3.64 in H <sub>2</sub> O |
| Inlet total pressure:    | 14.7 psia                |
| Inlet total temperature: | 70° F                    |

#### A fan was designed with the following features:

|                                    |            |
|------------------------------------|------------|
| Rotor tip diameter (leading edge): | 3.14 in    |
| Rotor hub diameter (leading edge): | 1.60 in    |
| Number of rotor blades:            | 9          |
| Number of stator vanes:            | 11         |
| Rotational speed:                  | 12,000 rpm |
| Tip clearance:                     | 0.009 in   |
| Overall axial length               | 9.0 in     |



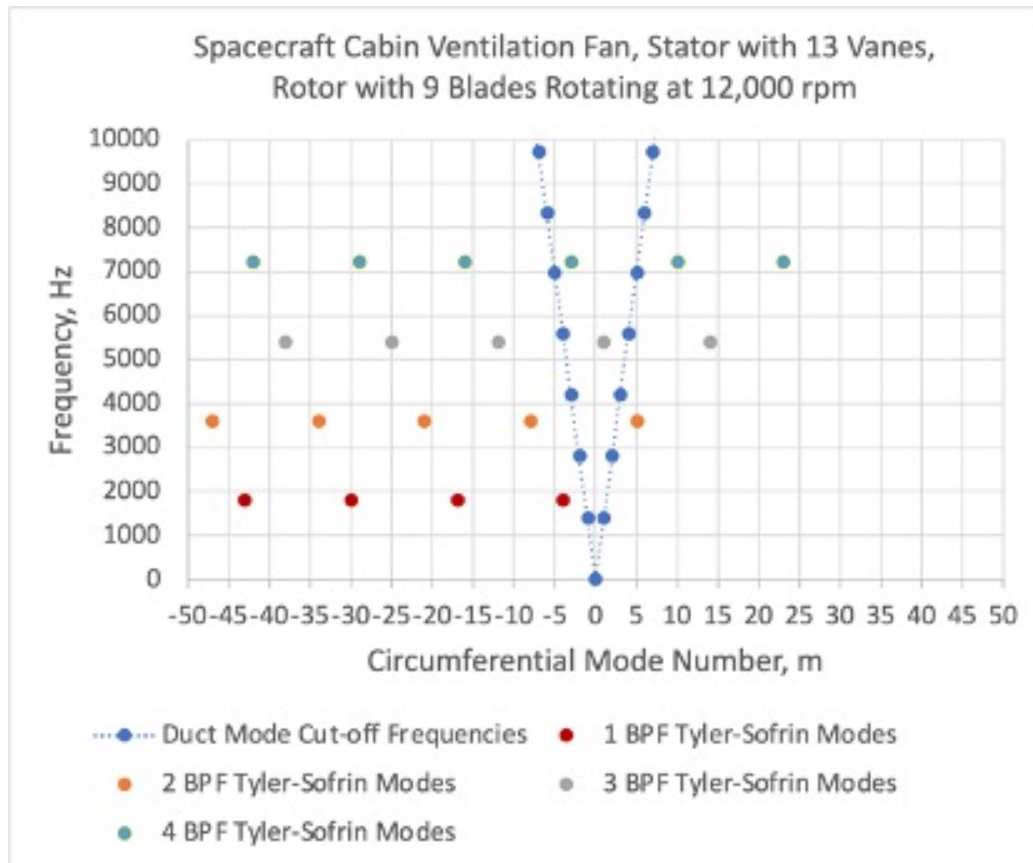
The aerodynamic design of a spacecraft cabin vent fan by Daniel Tweedt, using a low-noise blade-vane count specified by Danielle Koch.

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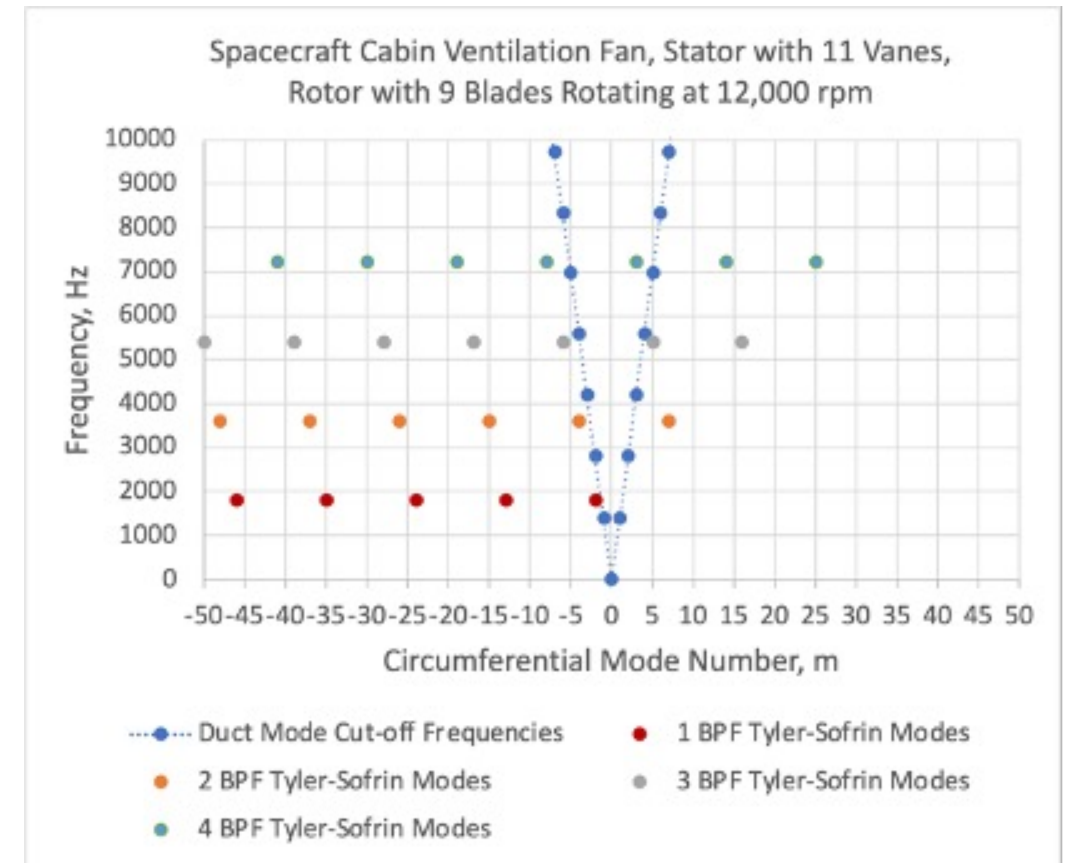
## Acoustic Design and Analysis



A low-noise blade-vane count was chosen to minimize tone noise caused by rotor-stator interaction.



Preliminary design with of the spacecraft cabin vent fan with 9 rotor blades and 13 stator vanes. BPF 3 and 4 are cut-on.



Final design with of the spacecraft cabin vent fan with 9 rotor blades and 11 stator vanes. BPF 4 is cut-on.

# Spacecraft Cabin Ventilation Fan Research at NASA

## Mechanical and Electrical Design and Manufacture

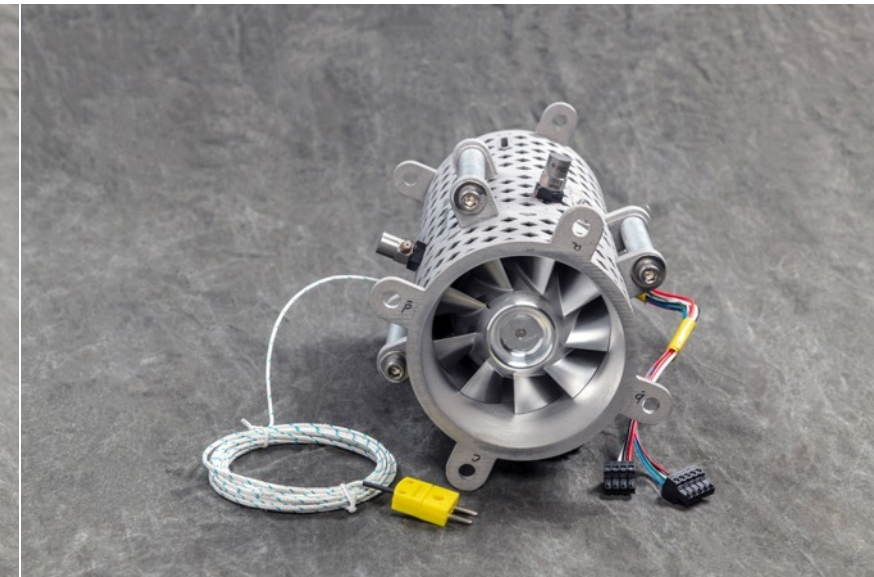
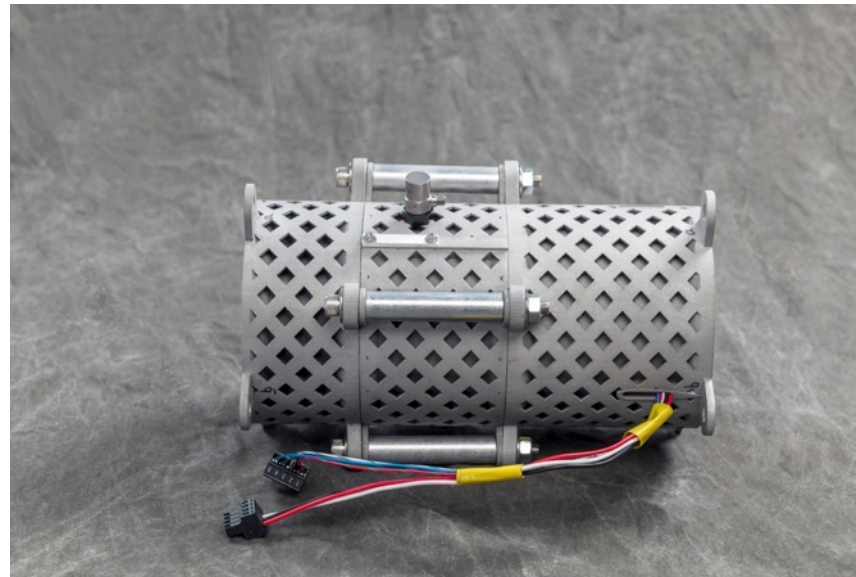


## Mechanical and Electrical Design and Manufacture

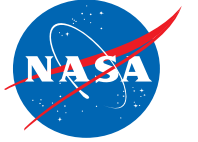
- In 2021, a metal version of the NASA Quiet Space fan was manufactured.
- It featured a stiffening ribbing structure that resembled T-beams to greatly increase stiffness as compared to conventional ribs while reducing weight.

The stationary parts of the fan were additively manufactured with direct metal laser sintering (DMLS) using a 3D Systems Laserform printer and an aluminum alloy powder (AlSi12). Two units were built—one for NASA GRC and one for NASA JSC.

The rotor was machined of T6061 aluminum. Portions of the duct were hand-polished. Trifecta Engineering, Inc. of Kettering, Ohio was contracted to manufacture and assemble the fan.

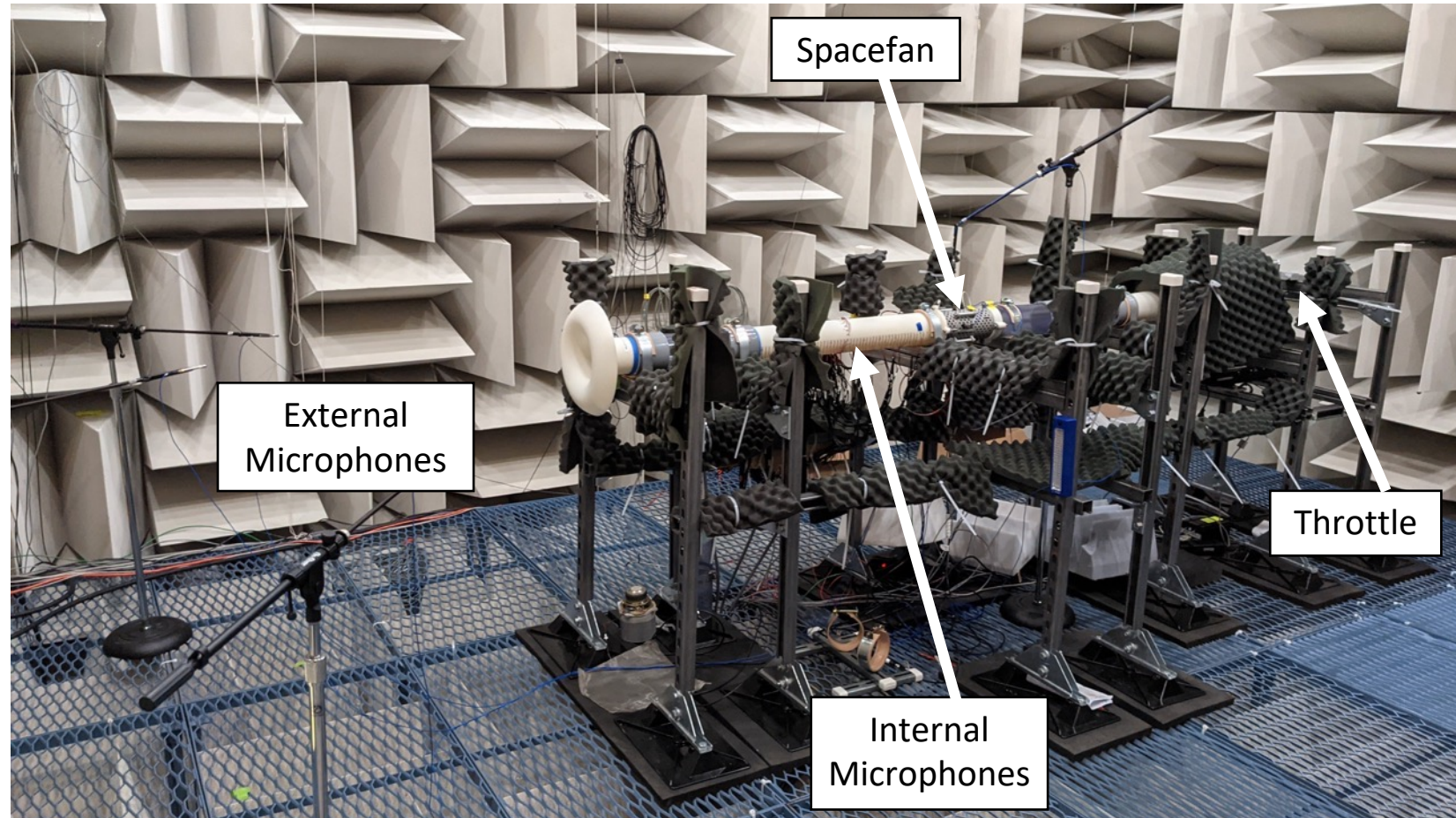


# Spacecraft Cabin Ventilation Fan Research at NASA Test Facility and Fan Test Rig



## Test Facility and Fan Test Rig

- The experiment was performed in the NASA GRC Acoustical Testing Laboratory. It was configured as a fully anechoic chamber for this test.
- The chamber internal dimensions are 7 m x 5.2 m x 5.2 m.
- The fan was mounted to a duct rig supported on a modular Unistrut frame.
- The rig design incorporated many features of the ASHRAE 68 and ISO 5136 fan testing standards.



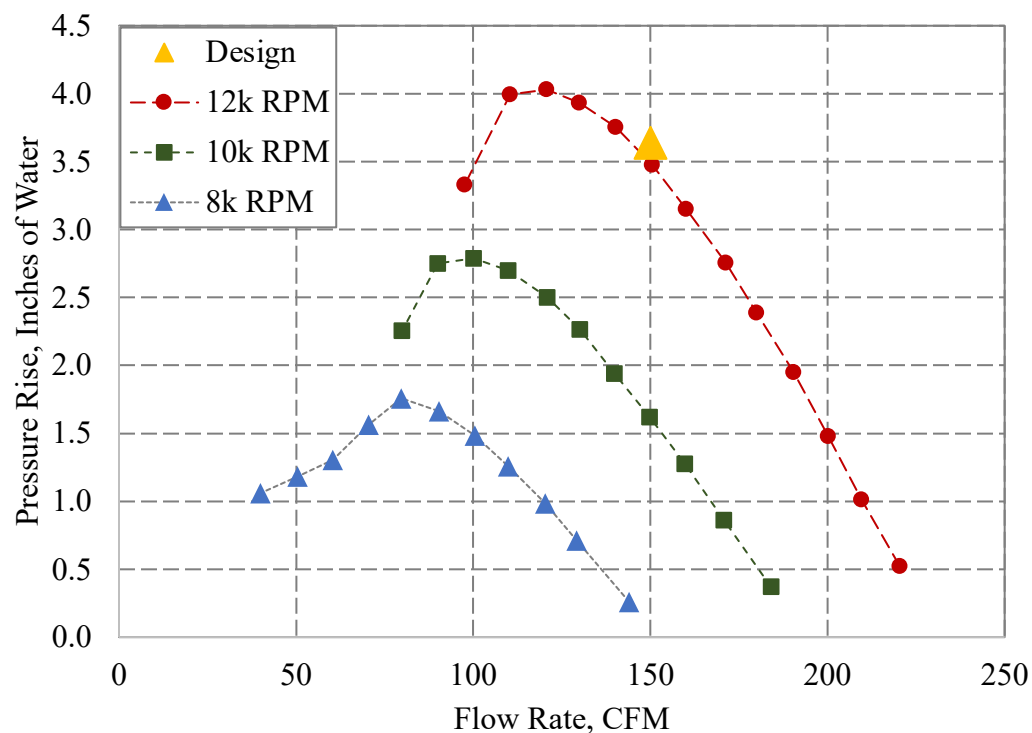
# Spacecraft Cabin Ventilation Fan Research at NASA

## Aerodynamic Measurements

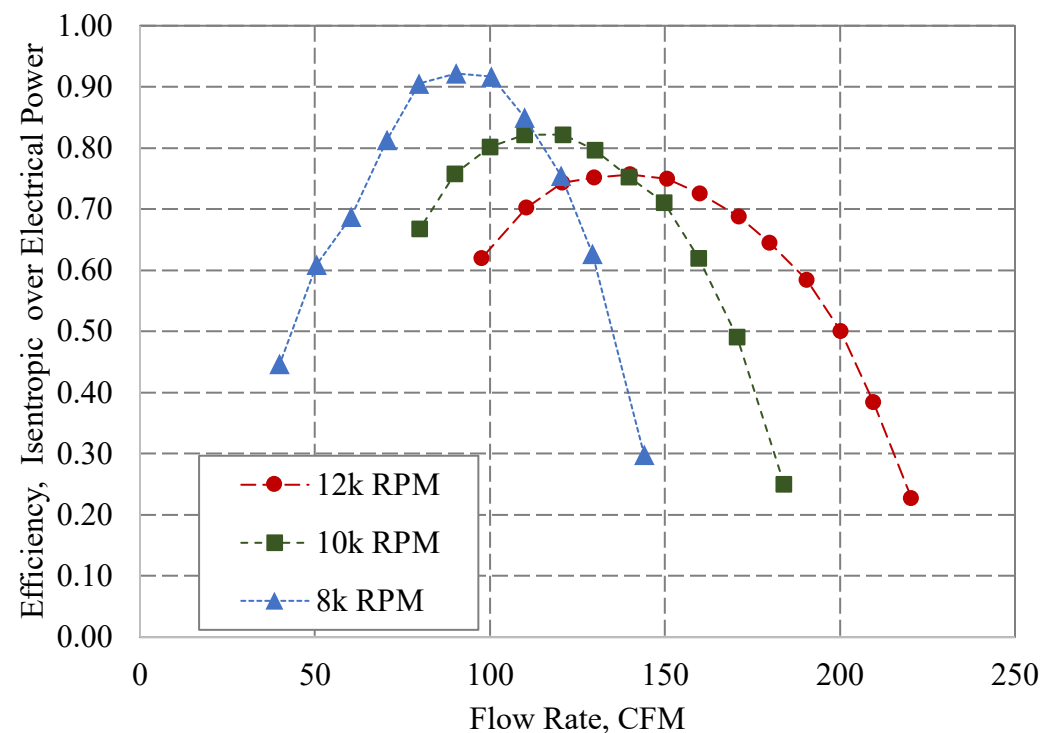


Results indicated that predicted and measured fan performance were in good agreement.

**Pressure Rise**

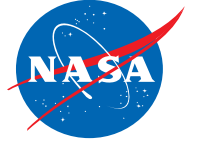


**Efficiency, including motor and controller losses**

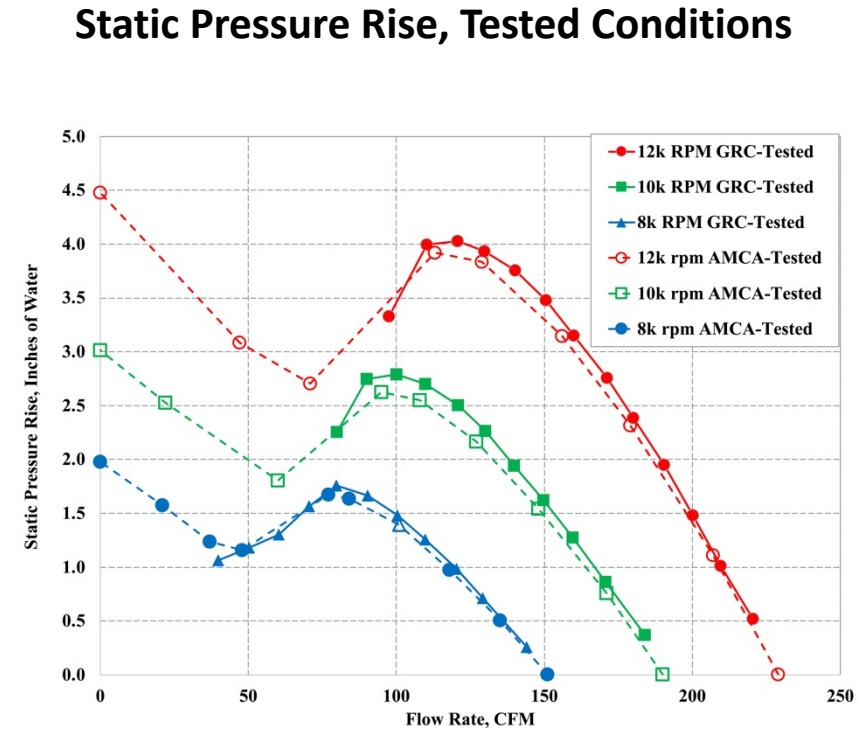
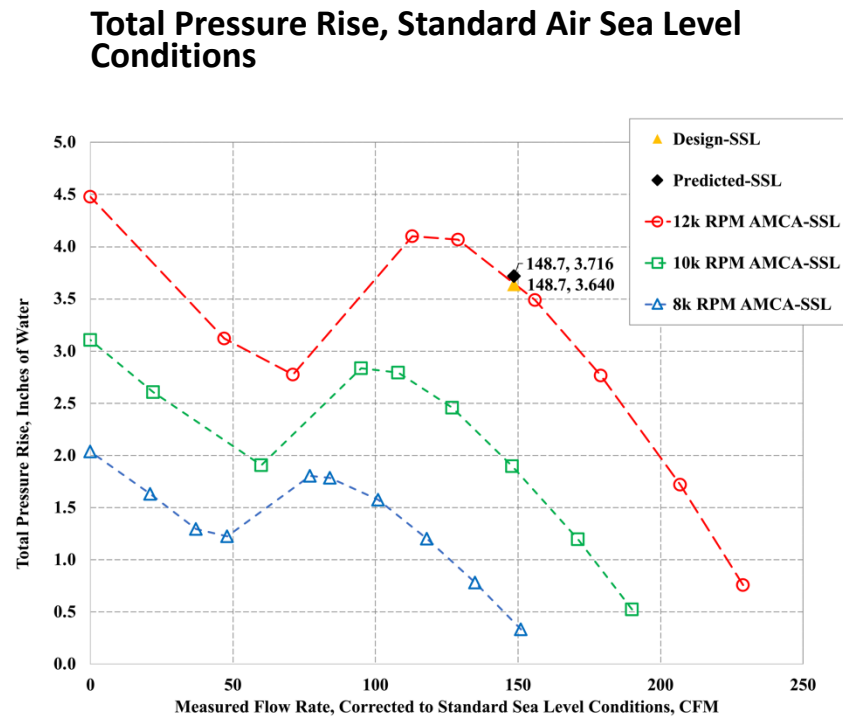


# Spacecraft Cabin Ventilation Fan Research at NASA

## Aerodynamic Measurements

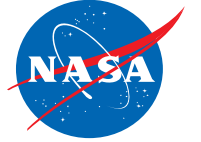


Results indicated that measured fan performance at NASA GRC and AMCA were in good agreement.

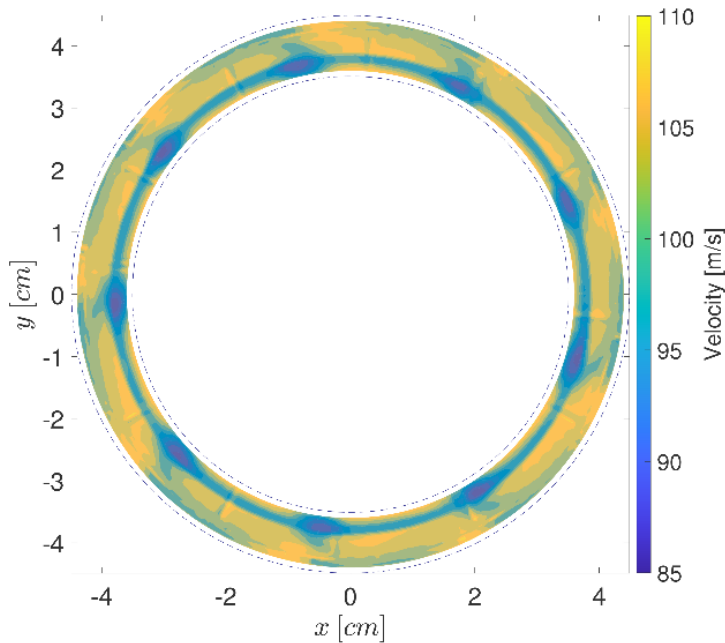


# Spacecraft Cabin Ventilation Fan Research at NASA

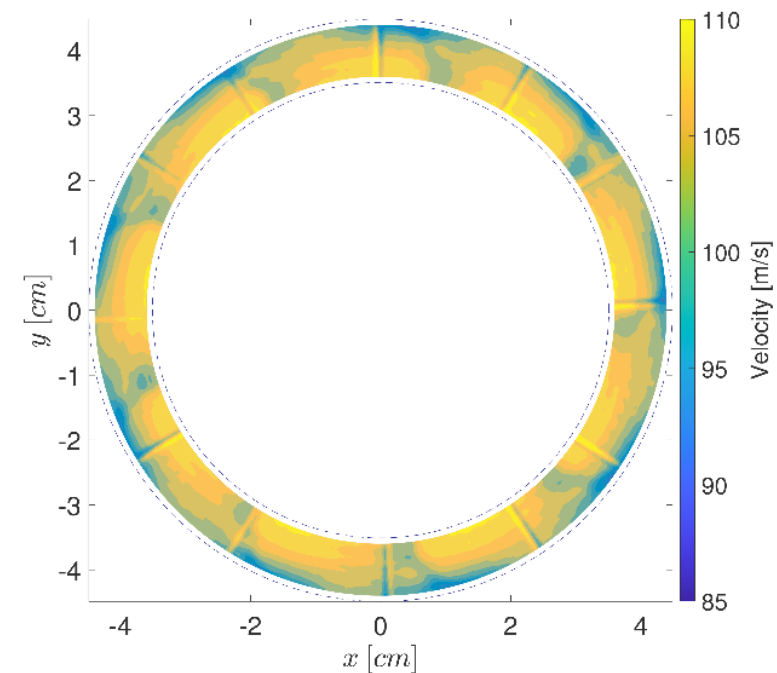
## Aerodynamic Measurements



Hot wire probe measurements were recorded from tests at NASA GRC to characterize the rotor wakes.



**Velocity for the fan at design point conditions close to the trailing edge.**



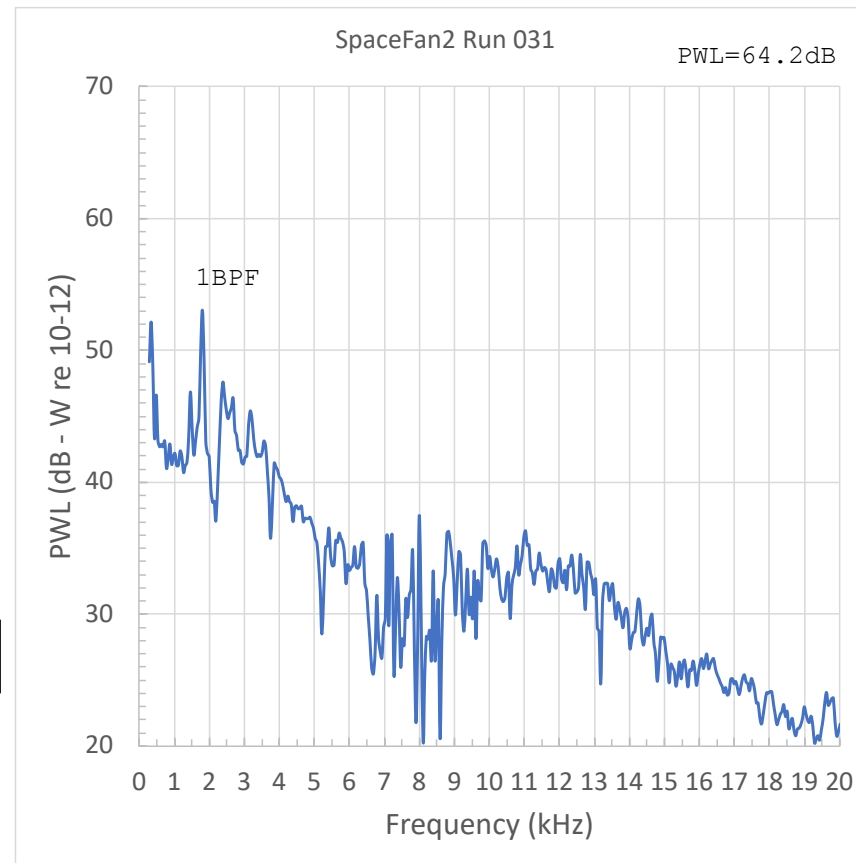
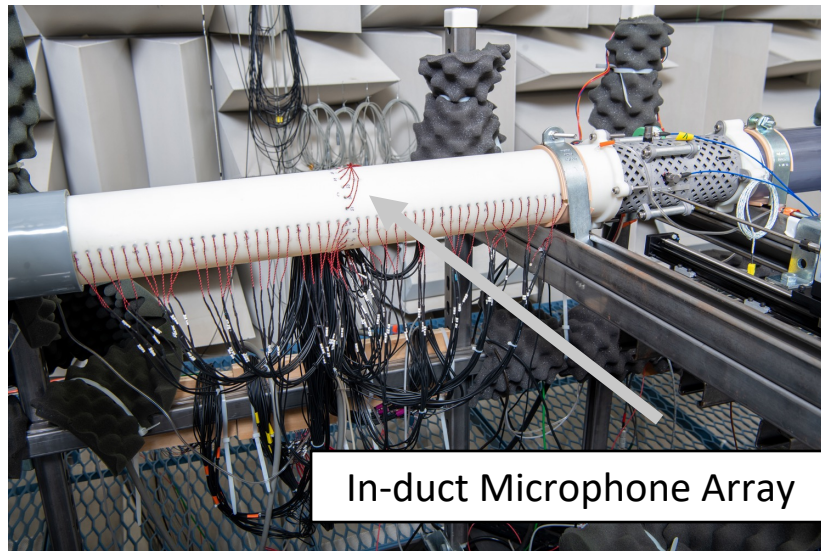
**Velocity for the fan at design point conditions close to stator leading edge**

# Spacecraft Cabin Ventilation Fan Research at NASA

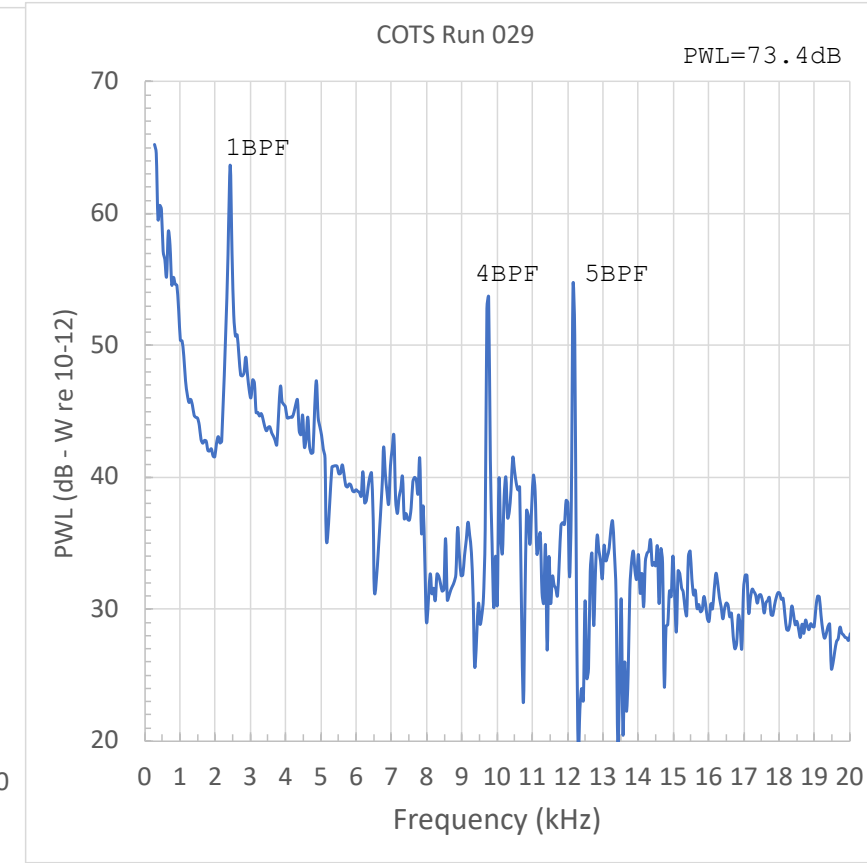
## Acoustic Measurements



Noise produced by the fan was measured with the 72-channel in-duct microphone array.



**NASA QSF**



**A Commercial-Off-the-Shelf  
(COTS)Fan**

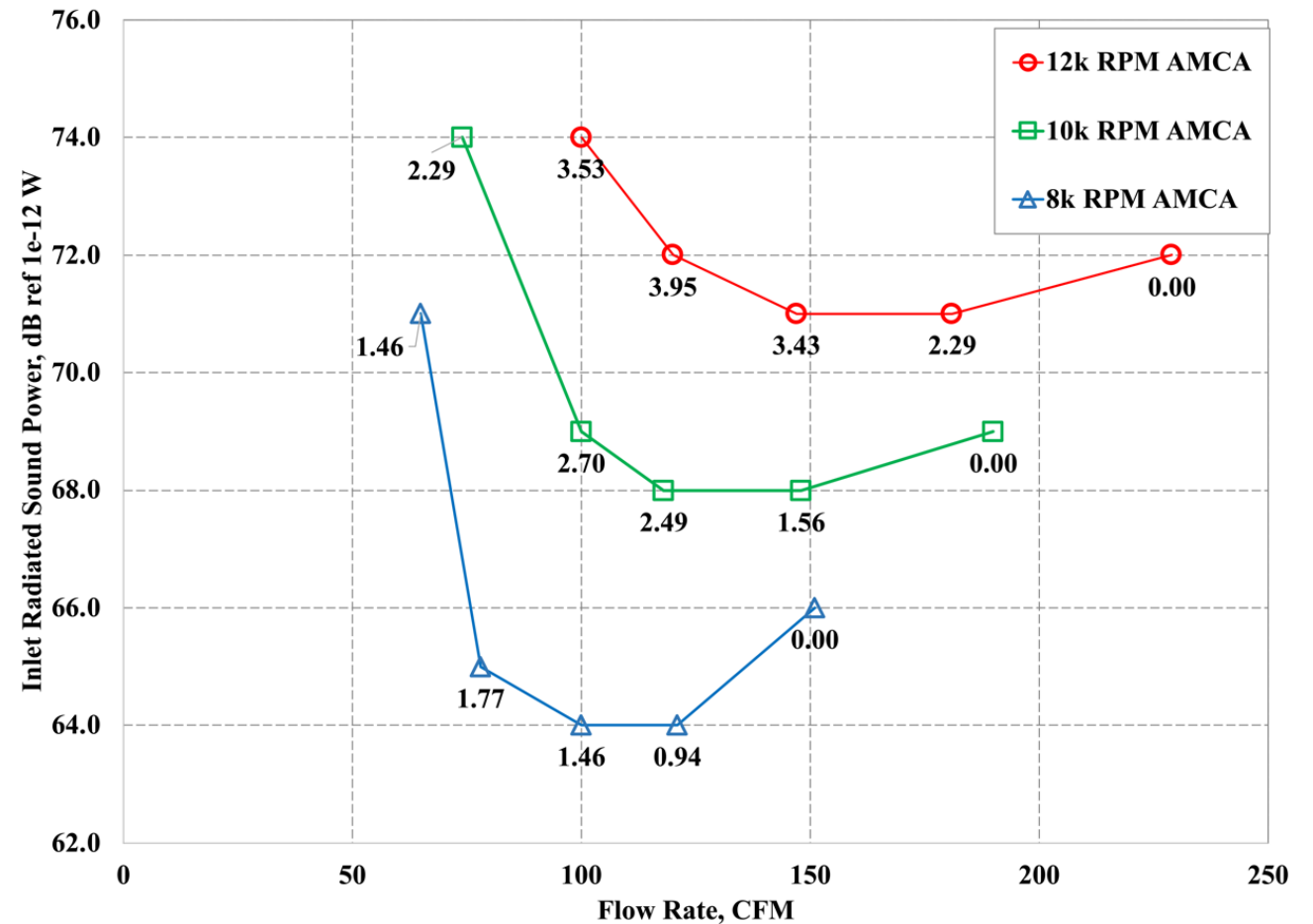
# Spacecraft Cabin Ventilation Fan Research at NASA

## Acoustic Measurements



### Acoustic Measurements

- The metal spacecraft cabin ventilation fan prototype was also tested by Air Movement and Control Association, Inc (AMCA International).
- Measurements of noise was made at three speeds (8000, 10,000, and 12,000 rpm) in accordance with AMCA Standard 300-14, Reverberant Room Method for Sound Testing of Fans.



**Inlet radiated sound power level measured by AMCA,  
per AMCA 310-14 standard.**

## Recommendations

- Investigation of fan performance for distorted inflow
- Exploration and development of post-processing techniques for improving the surface finish of additively manufactured parts is also recommended.
- Improved acoustic duct liners and mufflers are also needed.

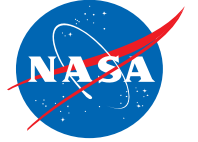


## Conclusions

- NASA has made geometry for a metal prototype of a spacecraft cabin ventilation system fan publicly available via the NASA Technical Reports Server.
- The NASA Quiet Space Fan was designed, fabricated, and then tested at the NASA GRC Acoustical Testing Laboratory using a duct rig inspired by several fan testing standards.
- Standardized tests were also performed by AMCA.
- The fan was throttled through its operating range, and results indicated that the measured aerodynamic and acoustic performance was in good agreement with predictions.



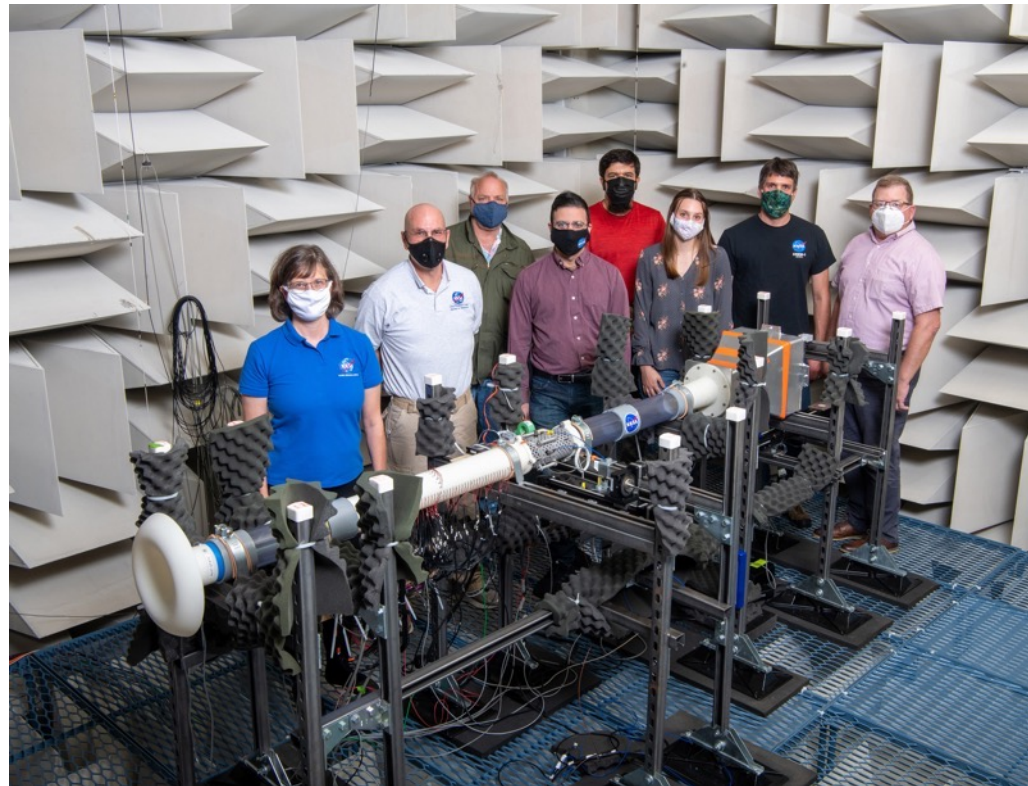
# Spacecraft Cabin Ventilation Fan Research at NASA Acknowledgements



## NASA Glenn Research Center

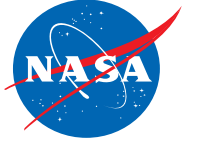
- Jan Sobon
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  - Bruce Grone
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  - Terry Condrich
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**Thank you!**  
**Questions?**