Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results

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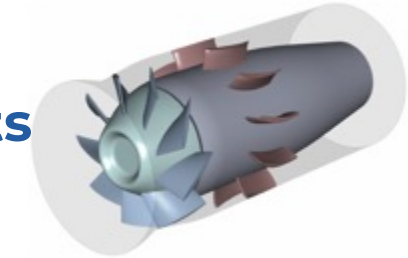
Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results
Outline

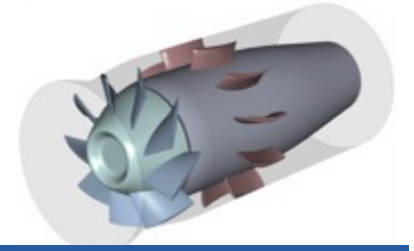


Outline

- Visual abstract
- Motivation
- Highlights of 2021 test
- Rotor assembly modifications
- Results of 2023 vibration test
- Recommendations
- Conclusion
- Acknowledgements
- Questions

Photo of Valley of Fire State Park, Nevada by Jannes Glas on Unsplash

Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Result
Visual abstract

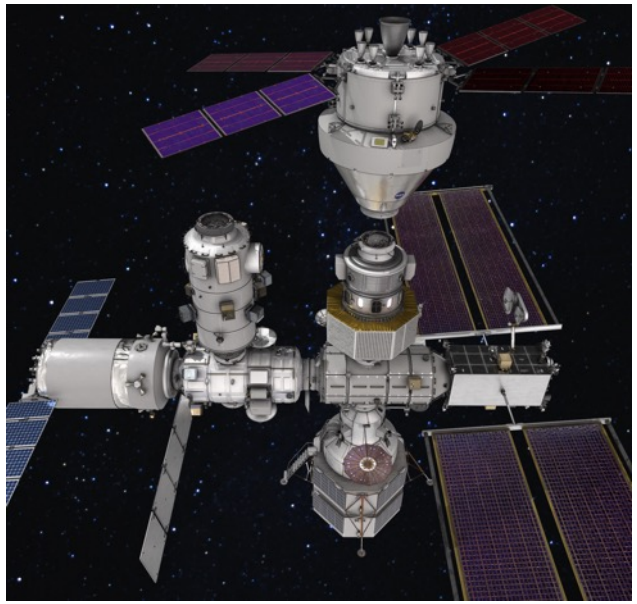


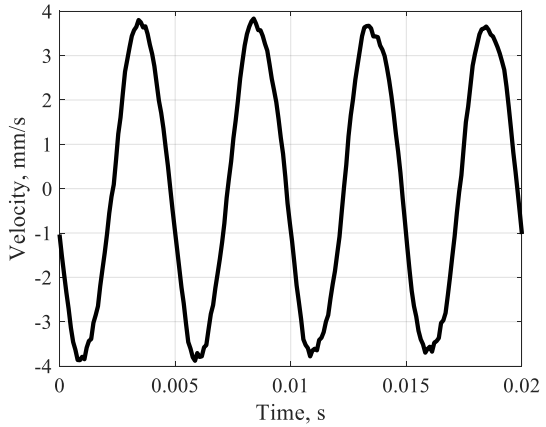
NASA is motivated to develop quiet, efficient fans needed for long duration space missions, like Gateway.

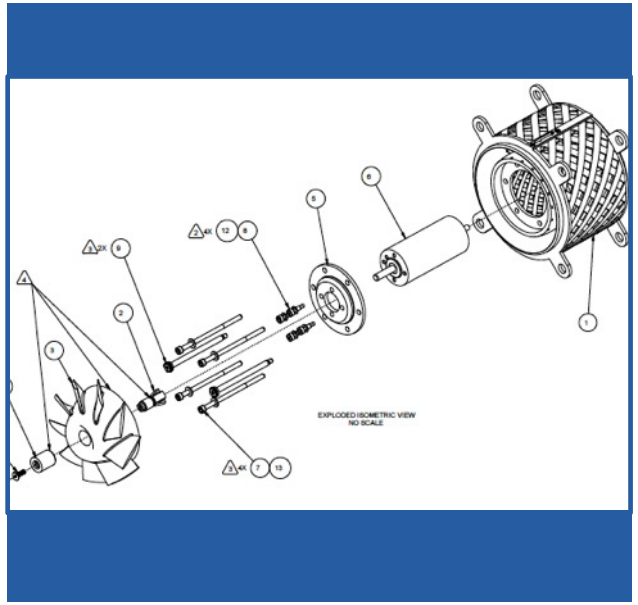
Vibrations were greater than desired when the metal spacecraft cabin vent fan was tested in 2021.

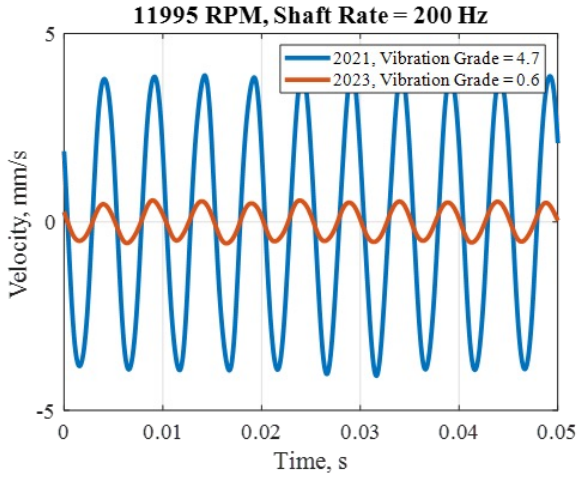
So, we redesigned the rotor in 2022.

Vibrations were significantly reduced when we tested the redesigned fan in 2023.



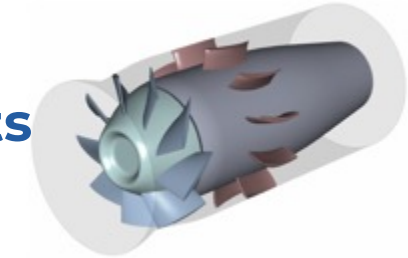






This spacecraft cabin vent fan prototype is intended for aeroacoustic research and ground tests, to further our knowledge of small fan performance for the benefit of all.

Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results
Motivation



Motivation

- Astronauts need quiet, efficient, and durable fans for life support systems in spacecraft, particularly for long duration exploration missions.
- The Gateway Outpost is shown here on the right, orbiting the moon.
- The Orion capsule is shown approaching the Gateway from the left.

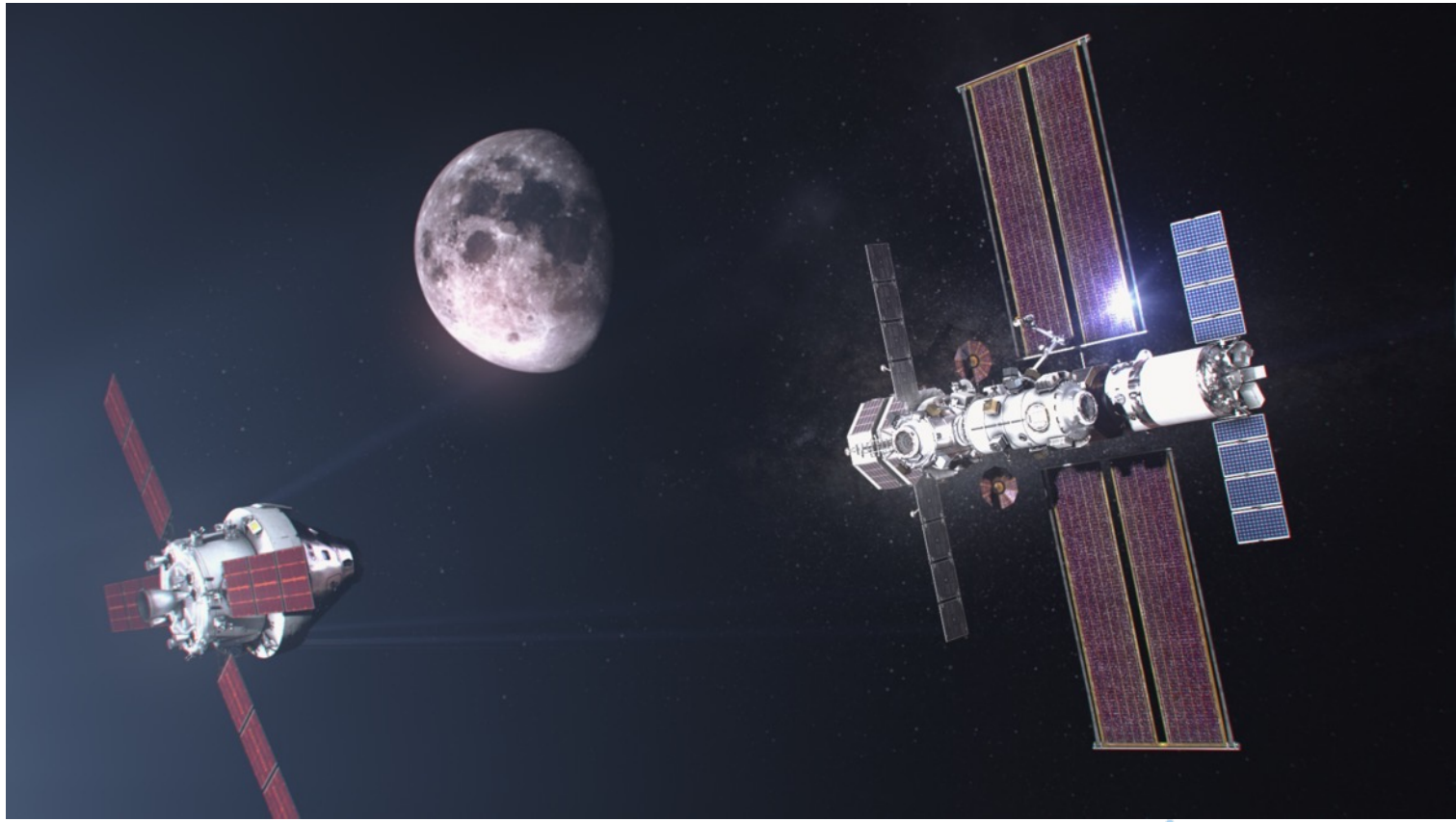
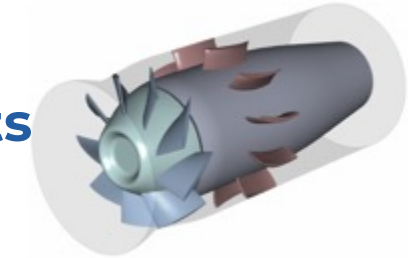


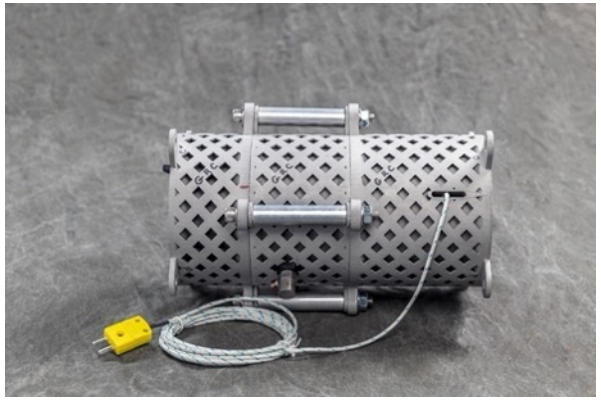
Image credit: NASA

Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results Highlights of 2021 test

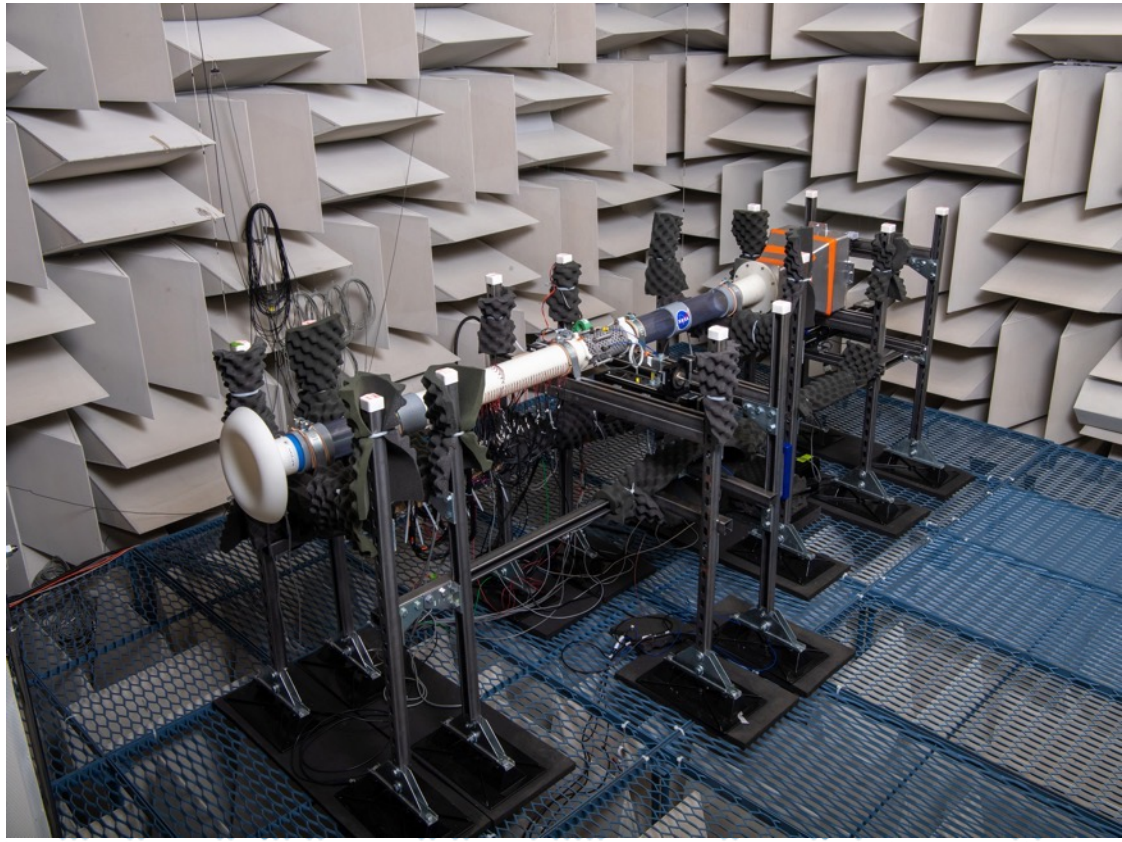


Highlights of 2021 test

- In 2021 NASA designed a metal spacecraft cabin ventilation fan prototype suitable for aerodynamic, acoustic, and mechanical ground tests.
- The fan was manufactured by Trifecta Engineering of Kettering, Ohio.



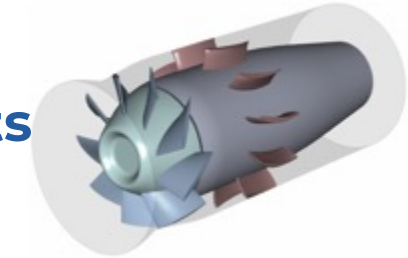
The metal spacecraft cabin vent fan.



The Acoustical Testing Laboratory at the NASA Glenn Research Center.

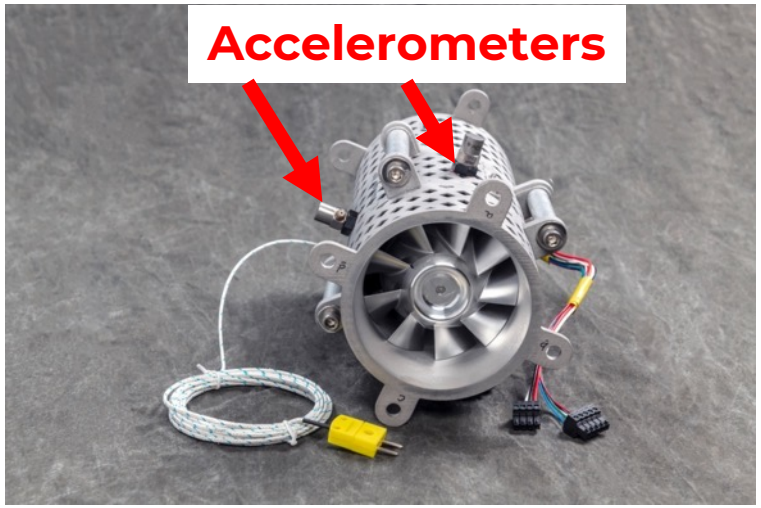
Photo credit: NASA

Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results Highlights of 2021 test



Vibration instrumentation

- Two piezoelectric accelerometers were attached to the fan housing and used to monitor vibrations.



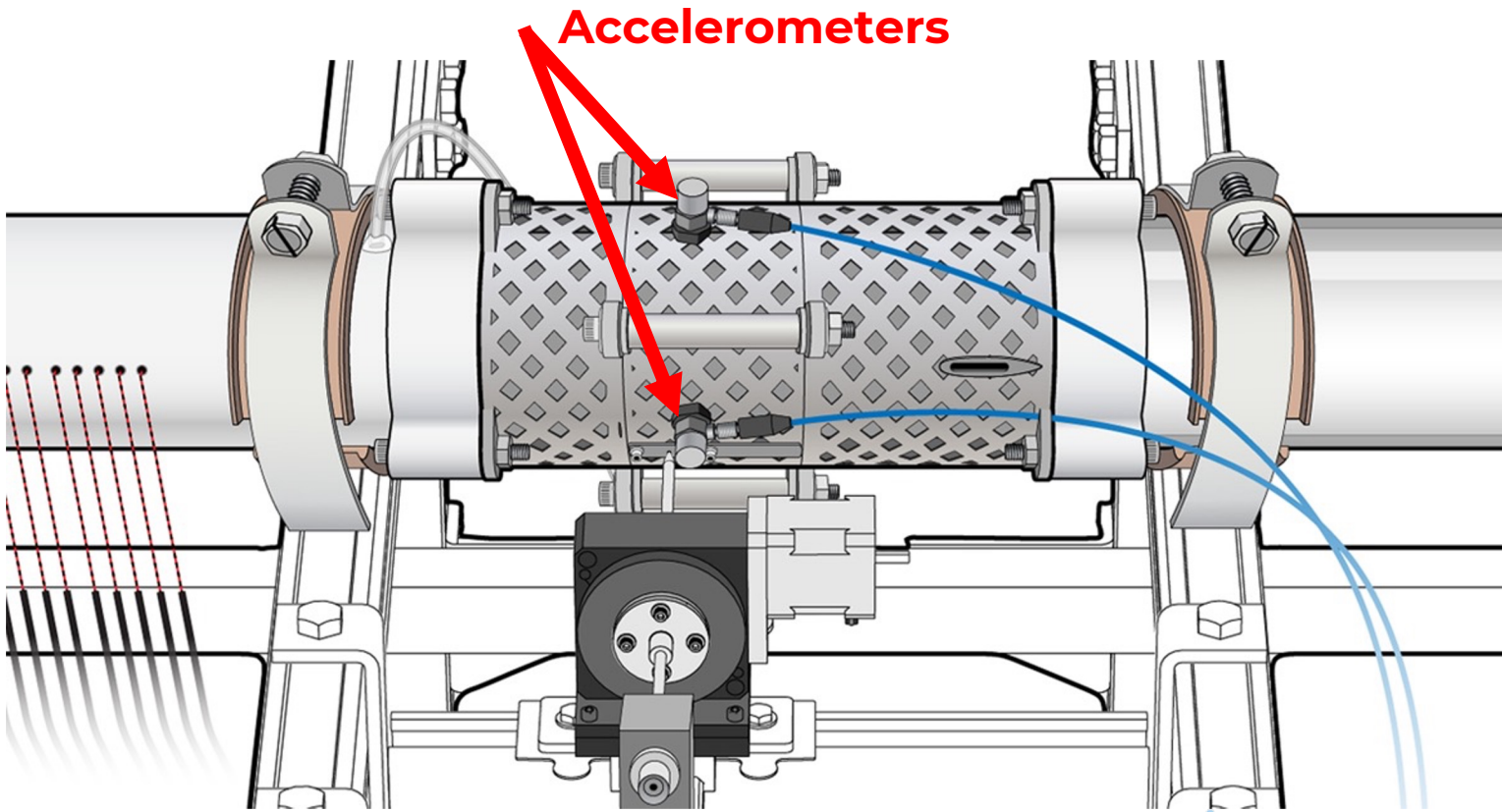
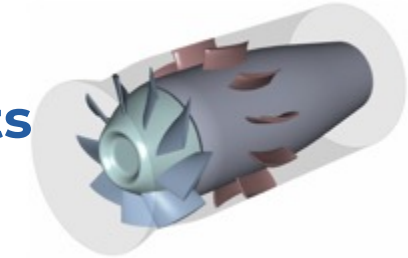


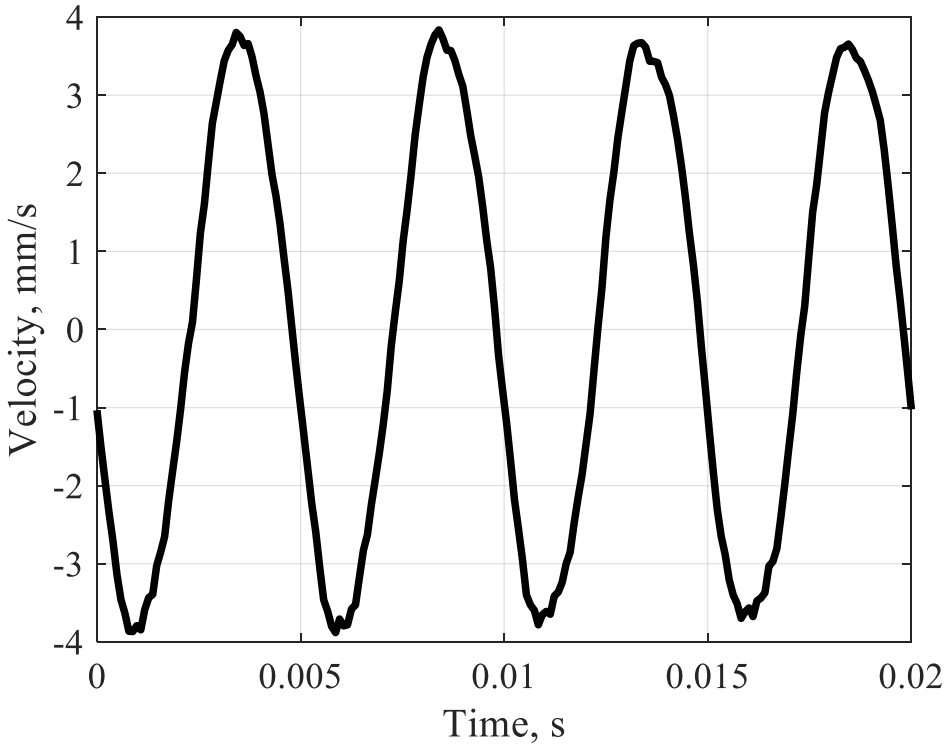
Photo credit: NASA

Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results Highlights of 2021 test



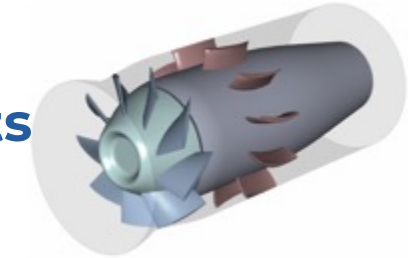
Vibration measurements

- The fan was throttled to design point conditions at 12,000 rpm.
- Acceleration was monitored in real time using LabVIEW software as a time-trace and as a scrolling root mean square (RMS) level.
- The peak velocity measured was just under 4 mm/s, suggesting an effective vibration grade of G 4.
- The 2021 tests revealed that while aerodynamic and acoustic measurements indicated that the fan was operating as intended, vibrations were greater than desired.



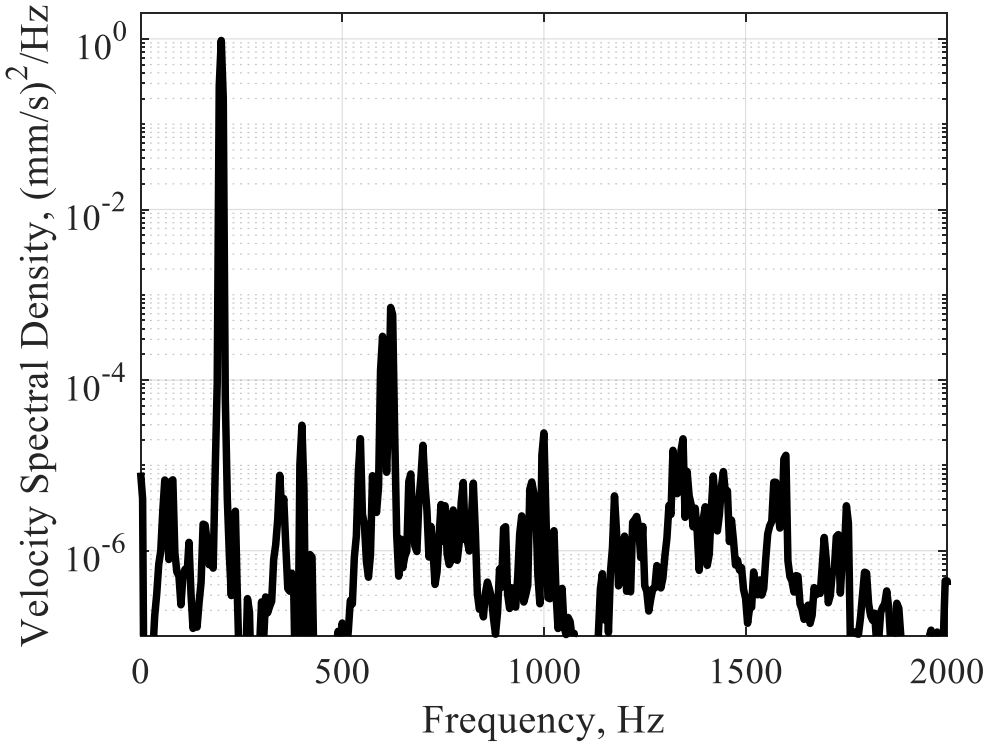
Vibration of the spacecraft cabin ventilation fan in 2021 at design point, velocity time trace.

Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results
Vibration measurements



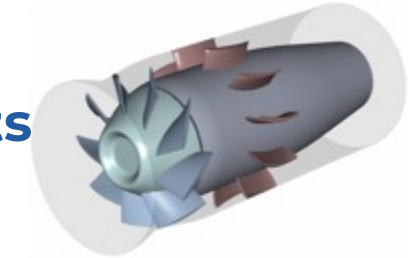
Vibration measurements

- Efforts were then taken to diagnose the causes of the vibration.
- The fan was subsequently removed from the duct rig and operated at design point conditions without backpressure to collect additional vibration data.
- This vibration was essentially insensitive to the back pressure on the fan, suggesting aerodynamic forcing was not causing the vibration.
- The time trace is dominated by a single periodic signal at the shaft frequency, suggesting a once-per-revolution imbalance.



Vibration of the spacecraft cabin ventilation fan in 2021 at design point, frequency content of velocity signal.

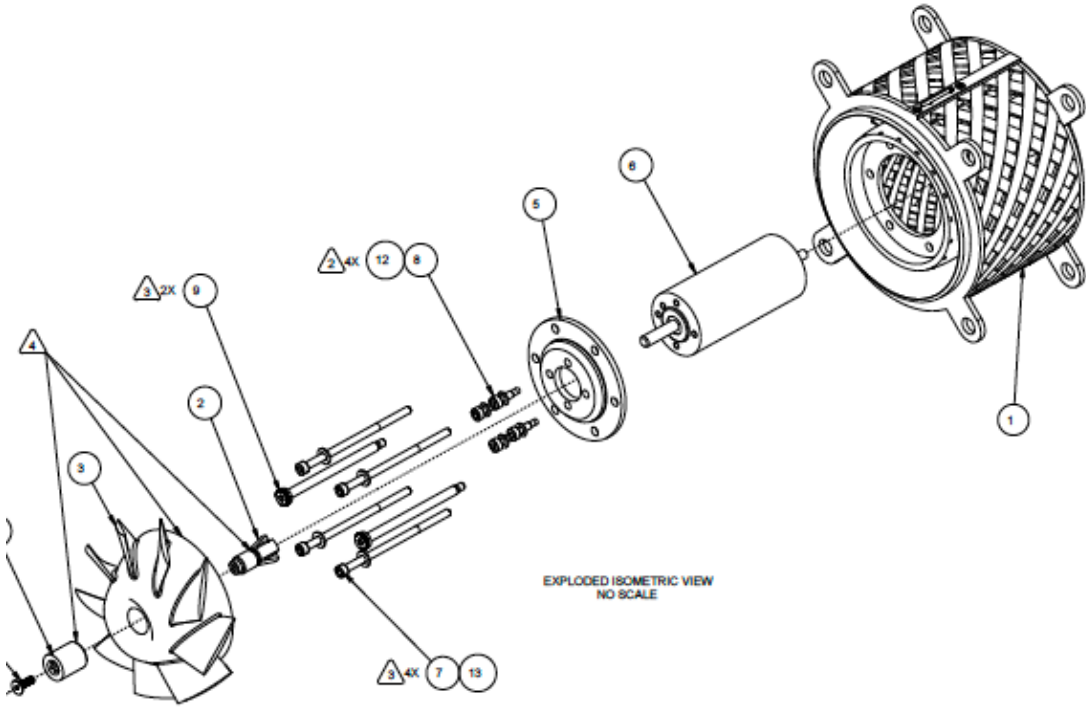
Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results
Rotor assembly modifications



Rotor assembly modifications

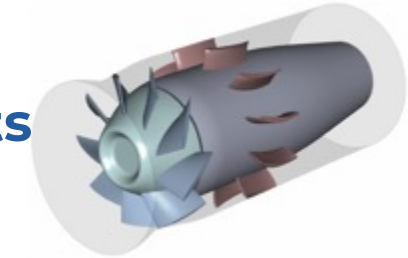
To try to reduce those vibrations, the redesigned rotor assembly included these features:

- a new lighter rotor with a tighter balance tolerance
- a new collet to attach the rotor to the motor shaft more securely and repeatably
- and a new bracket to center and hold the motor in the fan centerbody more precisely

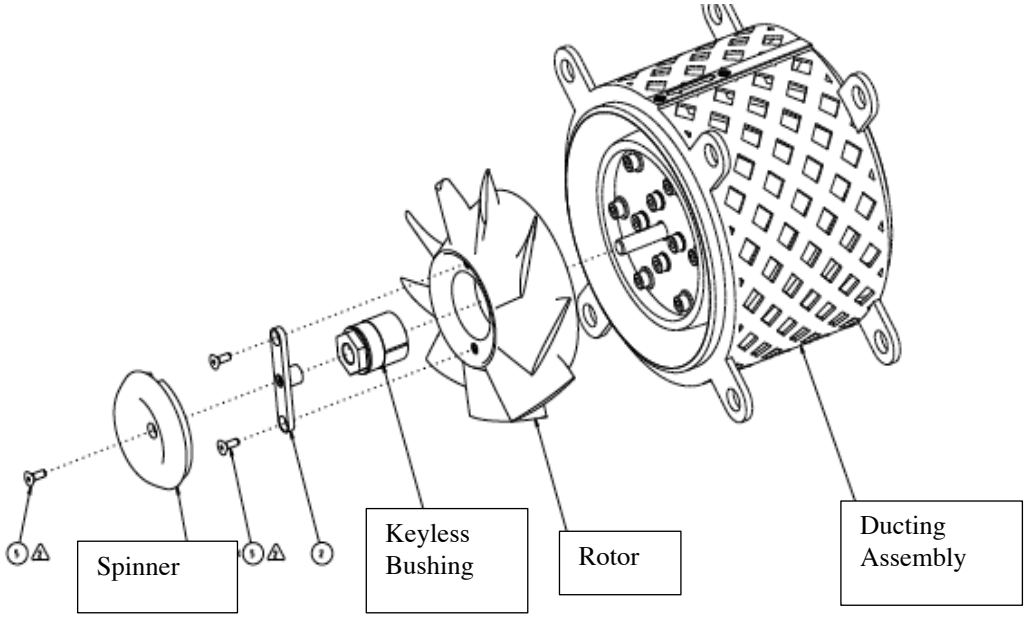


Fan Rotor Design Tested in 2023

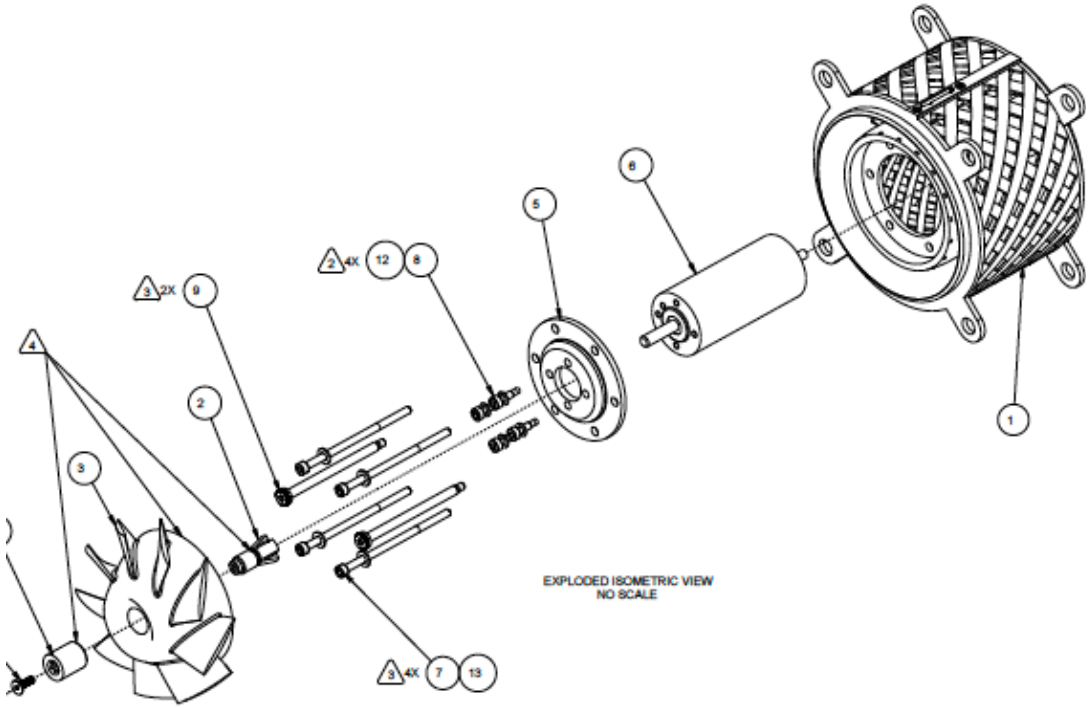
Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results
Rotor assembly modifications



Rotor assembly modifications



Fan Rotor Design Tested in 2021



Fan Rotor Design Tested in 2023

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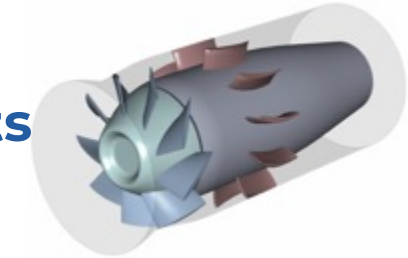
Rotor assembly modifications



Balance

- The balance grade of a rotor, *G*, is described by ISO-21940-11, is a function of:

  shaft angular velocity Ω is in radians/second
  the eccentricity e is in units of millimeters.

- The rotor tested in 2021 was balanced by The Balance Company, Vandalia, OH. The residual unbalance tolerance for the fan tested in 2021 was specified to be 0.762 g-mm (0.03 g-in), corresponding to G 5.

- The rotor tested in 2023 was balanced at NASA GRC. The residual unbalance tolerance for the fan tested in 2023 was specified to be 0.090 g-mm (0.004 g-in), corresponding to G 1.

- The new rotor was manufactured by Xometry, Inc and balanced a NASA GRC.

$$G = e \times \Omega,$$

$$e = \frac{U}{m_{rotor}} = r\frac{m_{unbalance}}{m_{rotor}},$$

$$\Omega = \frac{12000}{60} \times 2\pi = 1257\ rad/s.$$

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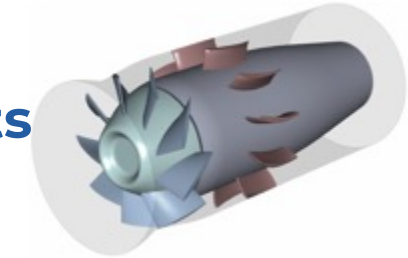
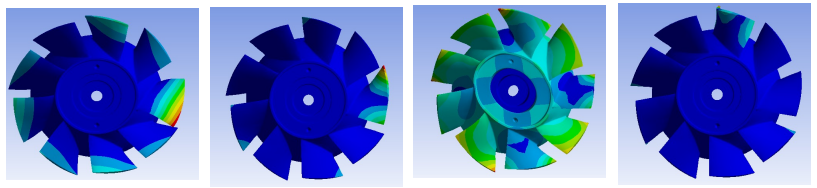
Rotor assembly modifications

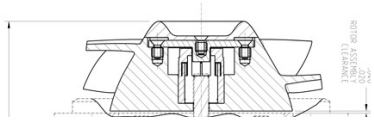


Modal analyses

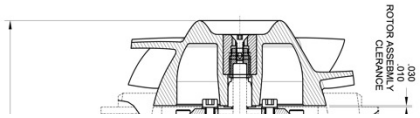
- Modal analyses were conducted with Ansys Mechanical and the frequencies of the vibration modes were identified.
- This confirmed that we would not be exciting natural frequencies of the structure at operating speeds.
- Fan was tested from 0 to 13,000 rpm

Modal Analysis of Fan Design Tested in 2021

Blade first-bending mode	Blade second-bending mode	Dipole mode	Blade third-bending mode
			
7429 Hz	14005 Hz	17430 Hz	24753 Hz

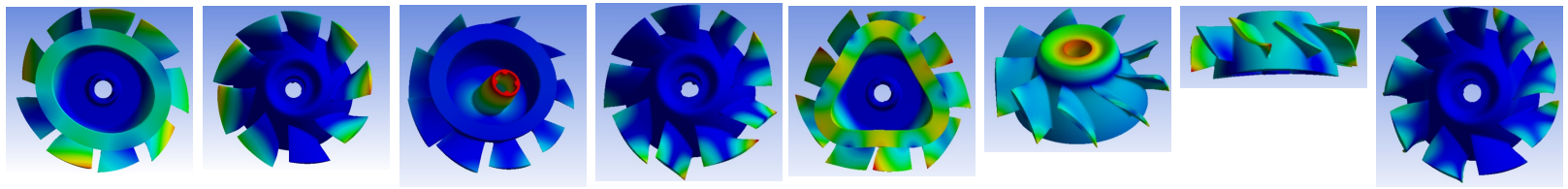


2021 rotor



2023 rotor

Modal Analysis of Fan Design Tested in 2023

Dipole mode	Blade first-bending mode	Axis first-bending mode	Blade second-bending mode	Tripole mode	Hub axial elongation mode	Hub first-bending mode	Blade third-bending mode
							
5699 Hz	7035Hz	10478 Hz	13526 Hz	15483 Hz	16760 Hz	21912 Hz	22946 Hz

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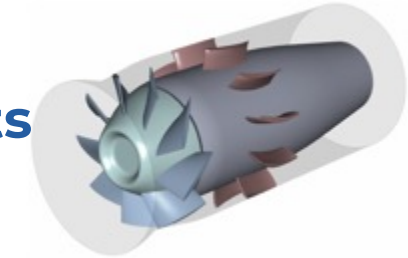
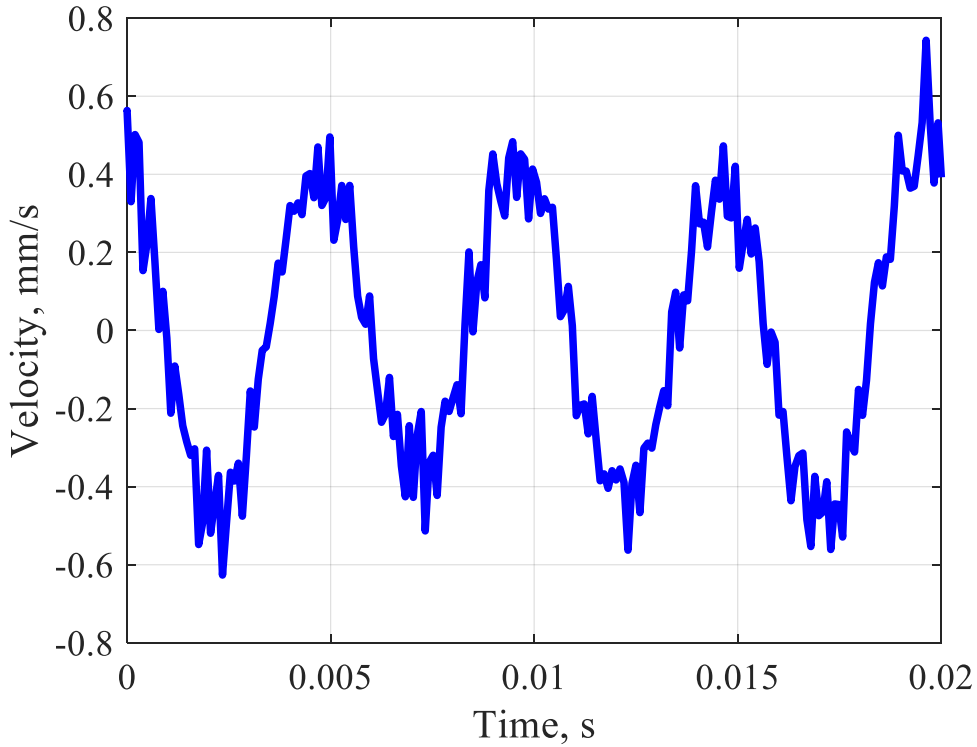
Results of 2023 vibration test

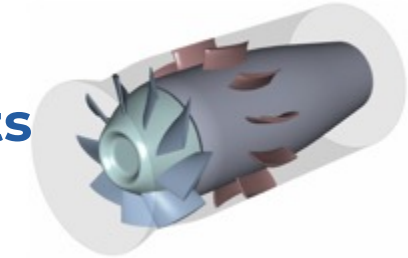


Vibration measurements--2023

- Fan was not tested with a backpressure.
- Fan was tested at design speed of 12,000 rpm.
- Acceleration was monitored in real time using LabVIEW software as a time-trace and as a scrolling root mean square (RMS) level.
- The peak velocity measured was 0.6 mm/s, suggesting an effective vibration grade of G 0.6.

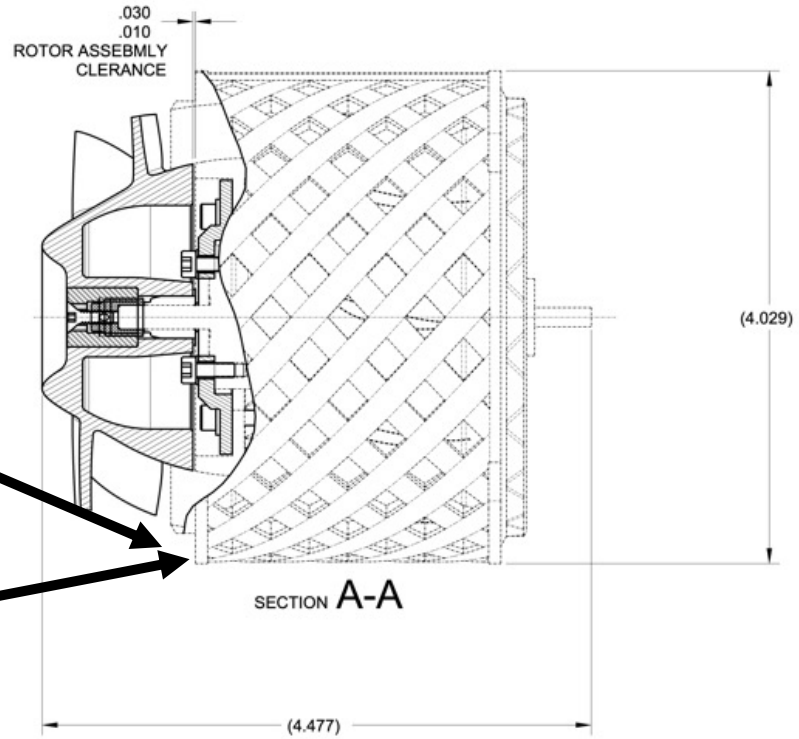


Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results
Recommendations

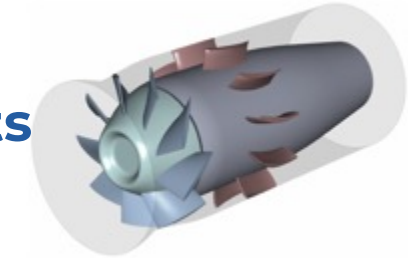


Recommendations

- It is possible to improve the performance of this fan and a few design changes to the duct pieces mating surfaces are recommended.
- The duct pieces were additively manufactured using Direct Metal Laser Sintering (DMLS). While the fit of the printed parts was very good, the fit would be improved if the mating surfaces were designed to be machined after printing.
- Pilot surfaces would help to locate the rotor in the center of the duct more precisely.



Quiet Spacecraft Cabin Ventilation Fan: Vibration Measurements Results
Conclusion



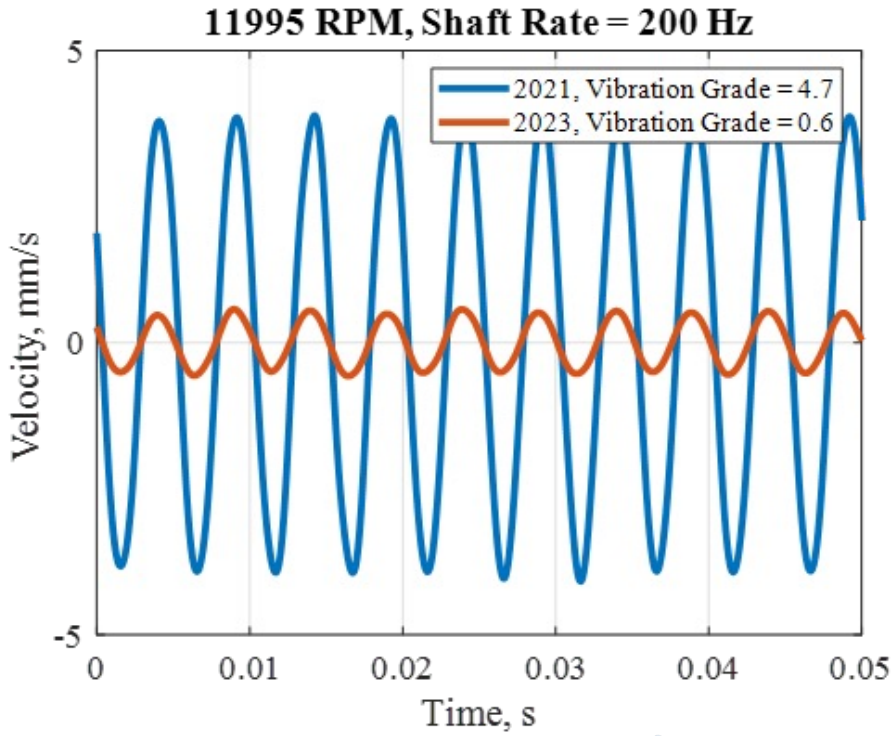
Conclusion

- Measured vibrations of the fan tested in 2021 were greater than desired.

- The fan was redesigned in 2022 to try to reduce those vibrations.

- Design changes included a new lighter rotor with a tighter balance tolerance, a new collet to attach the rotor to the motor shaft more securely and repeatably, and a new bracket to center and hold the motor.

- The redesigned rotor was tested in 2023 and measured peak vibration was reduced from 4 mm/s to 0.6 mm/s (G 4 to G 0.6 vibration grade)



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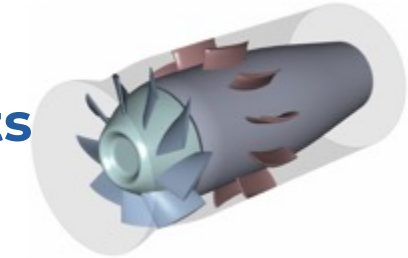

NASA Glenn Research Center:

Daniel Graf, Technical Services Branch, for expertise in balancing the redesigned rotor.

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Ann Delleur, Power Architecture and Analysis Branch, for project engineering support.

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NASA Johnson Space Flight Center:

Christopher S. Allen,
Manager JSC Acoustics Office

Christopher M. Matty, JSC International Space Station Integration Lead

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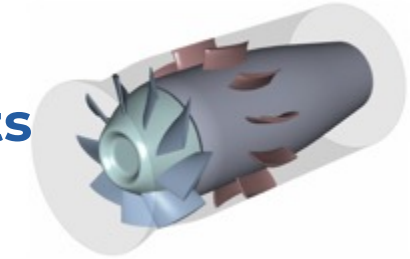

Thank you!

Questions?