

Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

L. Danielle Koch

Clifford A. Brown

Tony D. Shook

James Winkel

John A. Kolacz

Devin M. Podboy

Raymond A. Loew

Julius H. Mirecki

NASA Glenn Research Center

InterNoise 2012 ♦ New York, New York ♦ July 19-22, 2012

Glenn Research Center at Lewis Field



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Outline

A prototype of a spacecraft cabin ventilation fan has been built and tested at the NASA Glenn Acoustical Testing Laboratory.

- Motivation
- Description of prototype
- Description of experiment
- Discussion of results
- Recommendations
- Conclusion

Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Motivation

Designing systems to meet acoustic requirements for spacecraft remains a challenge.

Acoustic goals have been established to protect hearing, ensure effective communication, and provide suitable habitability for astronauts living and working in space.

NASA's Man-Systems Integration Standards –Volume 1, NASA STD_3000-Vol 1, 1995 gives an overview of the acoustic challenges and system design goals.

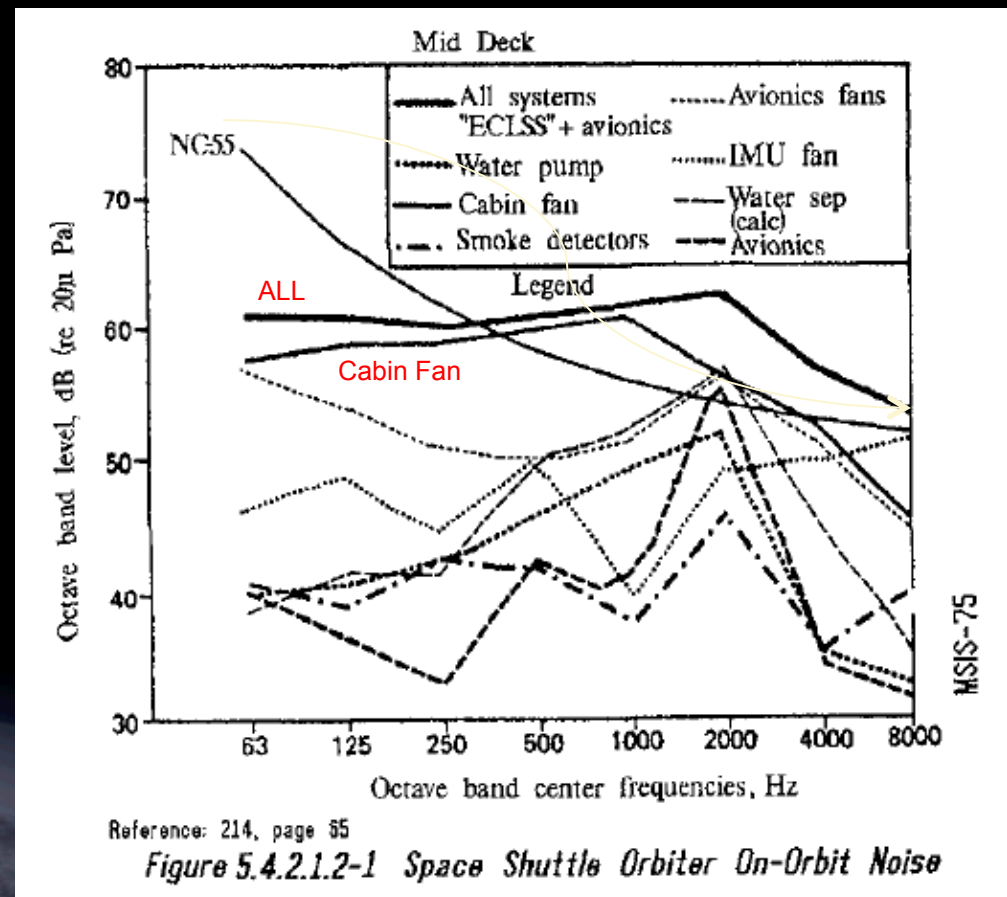


Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Motivation

Cabin ventilation fans have been found to be dominant sources of continuous broadband and tone noise for the Space Shuttle and the International Space Station.

Some requirements for broadband and tone noise have been established.



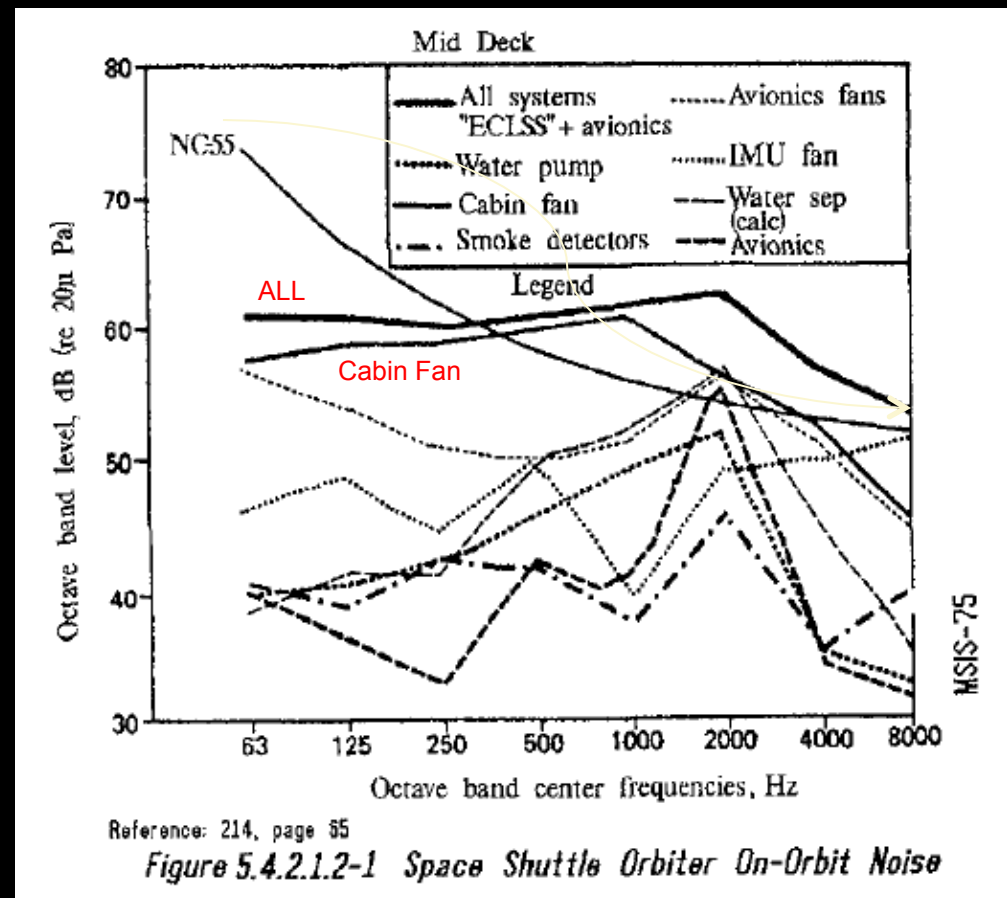
Source: Man-Systems Integration Standards--Vol I, NASA-STD-3000 Vol 1, 1995

Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Motivation

“The maximum allowable continuous broadband sound pressure levels produced by the summation of all the individual sound pressure levels from all operating systems and subsystems considered at a given time shall not exceed the Noise Criteria NC-50 contour for work periods and NC-40 contour for sleep compartments...”

“The relative sound pressure levels of narrowband components, pure-tones, and beat frequencies shall be limited to a level at least 10 dB lower than the allowed maximum sound pressure level of the octave band that contains the component.”



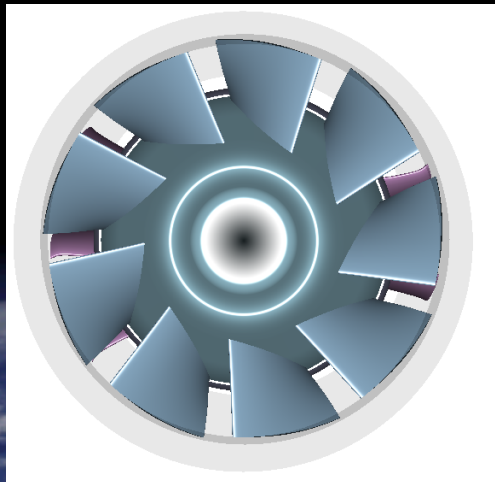
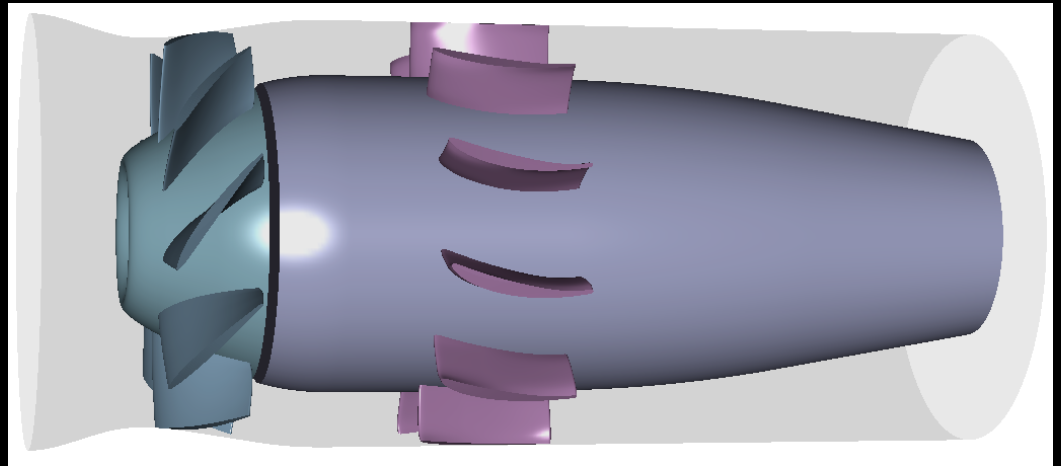
Source: Man-Systems Integration Standards--Vol I, NASA-STD-3000 Vol 1, 1995

Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of prototype

Design Point Conditions

Flow rate: 150.3 cfm
Total pressure rise: 3.64 in H₂O
Inlet total pressure: 14.7 psia
Inlet total temperature: 70 F



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

Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

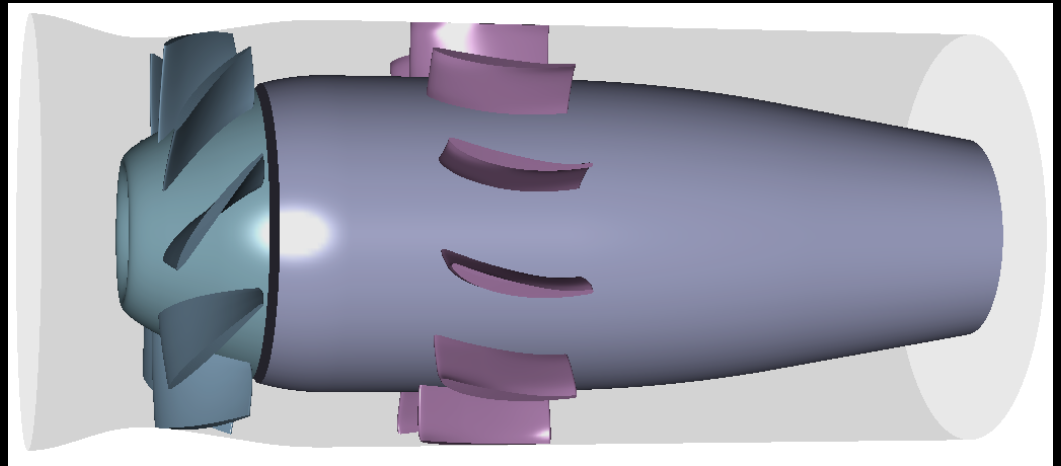
Description of prototype

Aerodynamic Design Features

Computational Fluid Dynamics was used to analyze the performance of preliminary designs and refine input to the compressor design code used to develop the fan.

Fan rotational speed was minimized.

Blade/vane count chosen to cut off first three harmonics of blade passing tone when ducted and operating at design point conditions.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of prototype

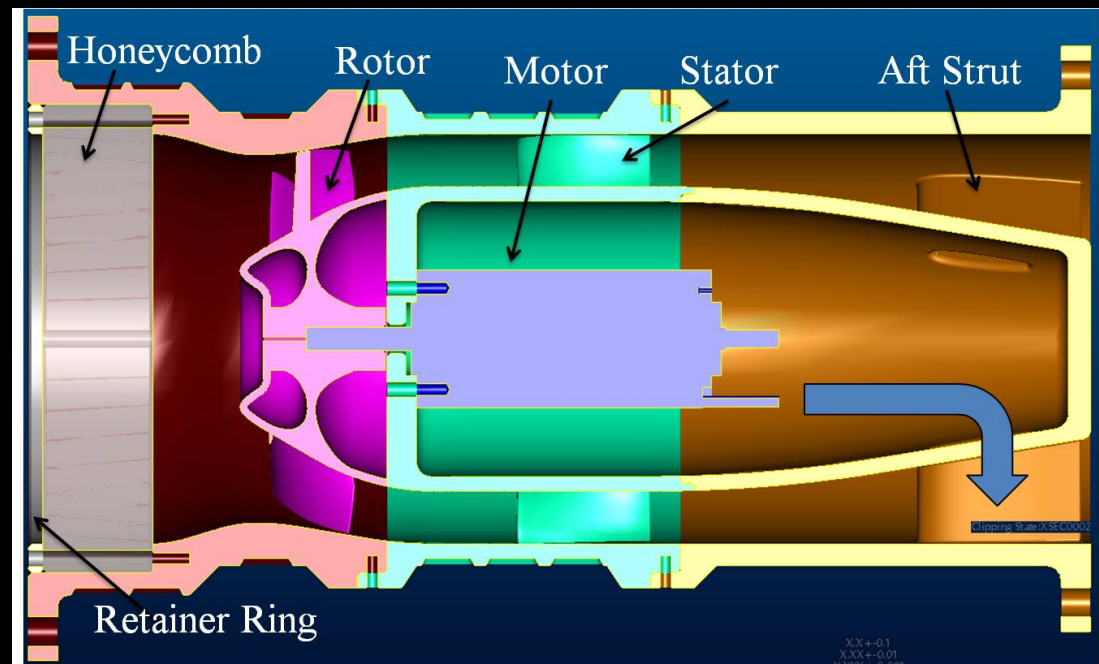
Mechanical Design Features

A **modular design** was chosen to facilitate development of passive and active noise reduction methods and instrumentation installation.

Honeycomb was added to protect the fan from ingesting foreign objects and to straighten the inflow.

Three **struts** were added to accommodate motor wiring and thermocouple.

Stereolithography was chosen to minimize prototype cost



MSC Nastran was used to perform finite element rotor stress analyses, rotor modal analyses, and containment analyses.

Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

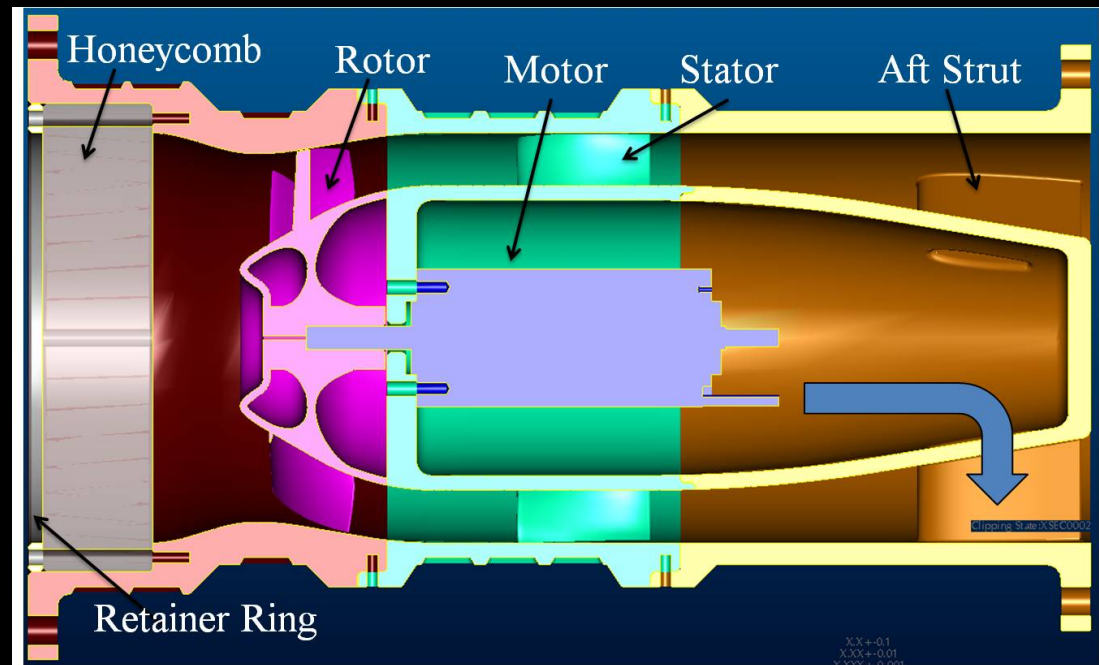
Description of prototype

Electrical Design Features

A brushless DC motor small enough to fit within the fan centerbody was chosen.

A simple controller was built to drive the motor consisting of a servo amplifier and digital potentiometer to set motor speed.

An emergency stop relay circuit was provided.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of prototype

Prototype Instrumentation

Optical Speed Sensor

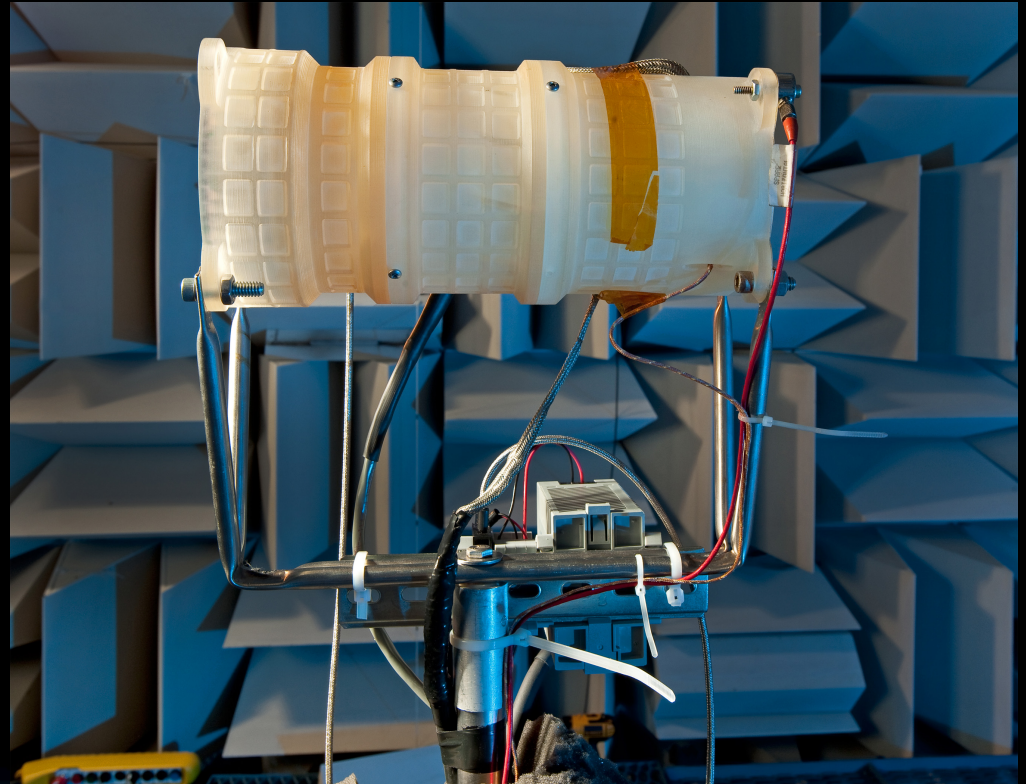
Mounted in a hole in the inlet duct, triggered off of white tape stripes on the rotor hub.

Accelerometer

Mounted to the aft flange, monitored vibrations parallel to the flow direction.

Thermocouple

Used to monitor motor housing temperature.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of experiment

The fan was tested in the NASA Glenn Research Center Acoustical Testing Laboratory.

No ducting was attached to the fan—installed conditions were not simulated.

A 13-microphone traversing array was used to measure the sound pressure in the vicinity of the fan.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of experiment

The first test objective was to run the fan and determine if it operated mechanically and electrically as expected.

The second test objective was to collect sound pressure measurements in the vicinity of the fan for six rotational speed settings, ranging from 6,000 to 13,500 rpm.



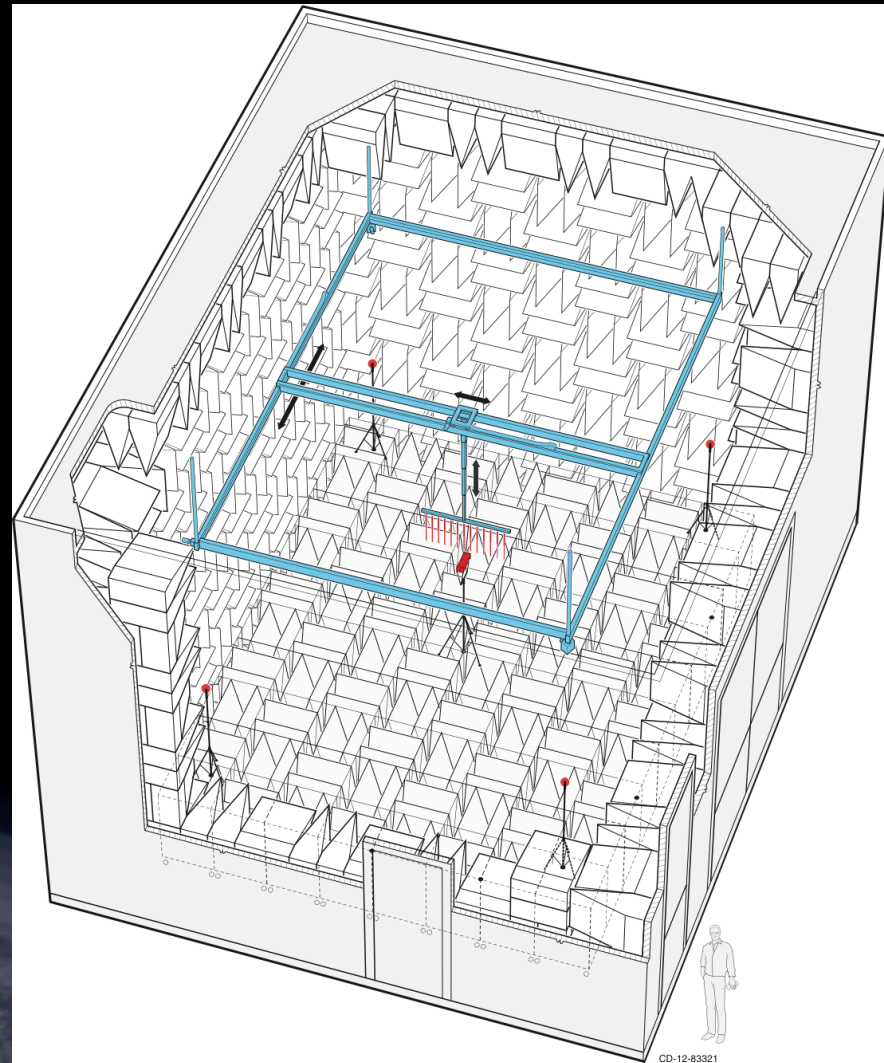
Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of experiment

The Acoustical Testing Facility was configured as a fully anechoic chamber for this test.

Chamber internal dimensions are 7 m x 5.2 m x 5.2 m.

The fan was mounted in the center of the chamber.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

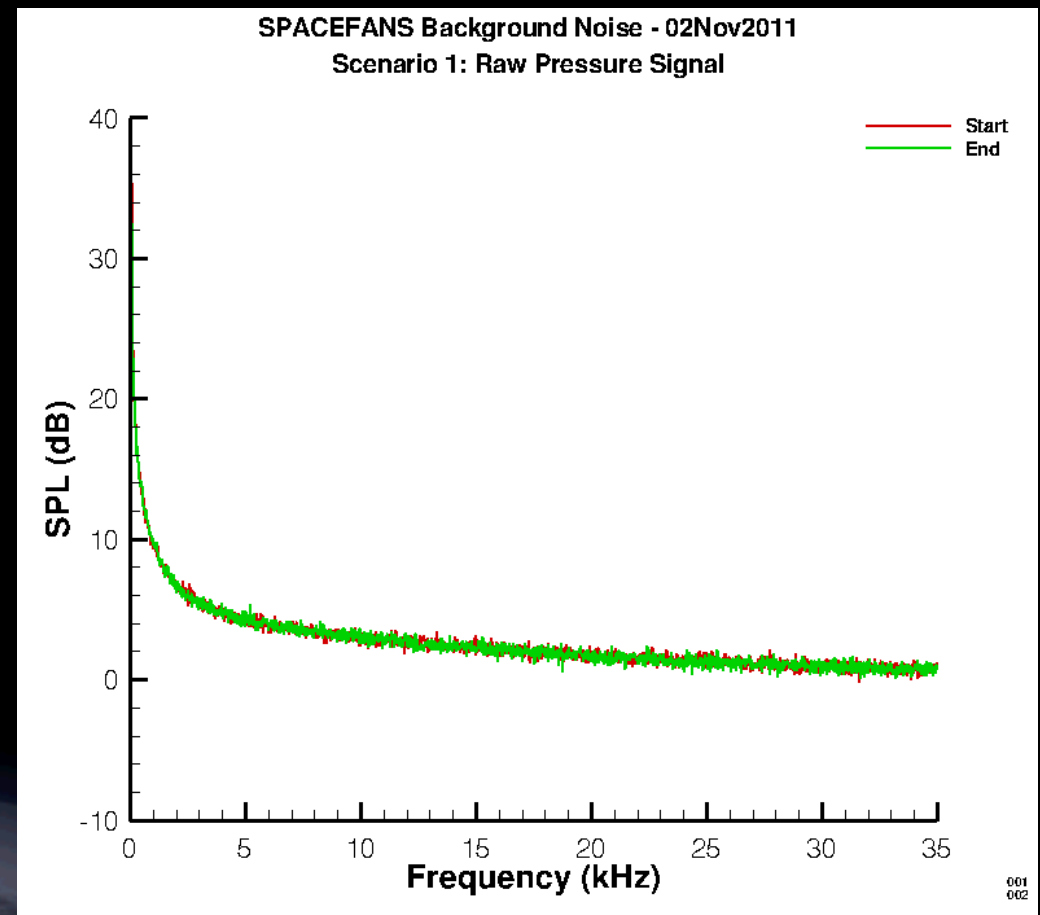
Description of experiment

The Acoustical Testing Facility was configured as a fully anechoic chamber for this test.

Chamber internal dimensions are 7 m x 5.2 m x 5.2 m.

The fan was mounted in the center of the chamber.

The background sound pressure levels were recorded to be less than 5 dB from 5 to 35 kHz.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

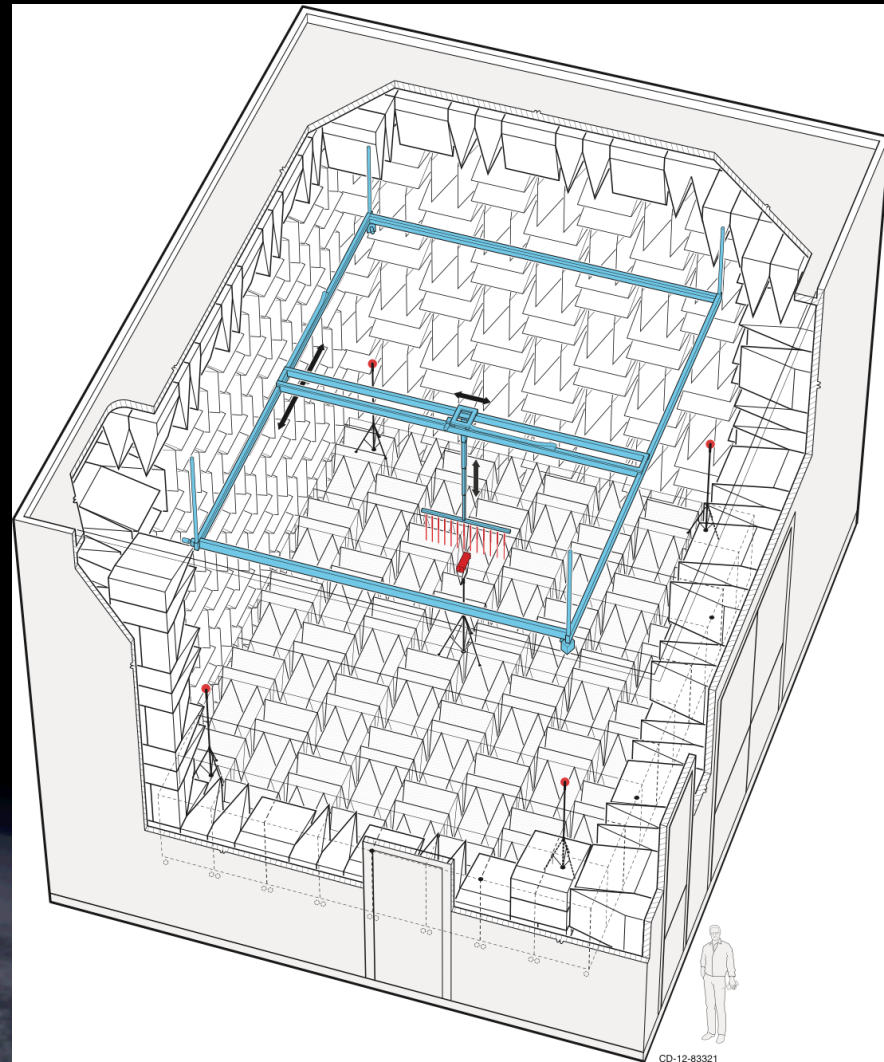
Description of experiment

An overhead three-axis traverse was used to remotely position the 13-microphone array.

The array microphones were each 0.64 cm (0.25 in) condenser microphones mounted so they all pointed downwards.

Four stationary reference microphones were placed in the corners of the chamber.

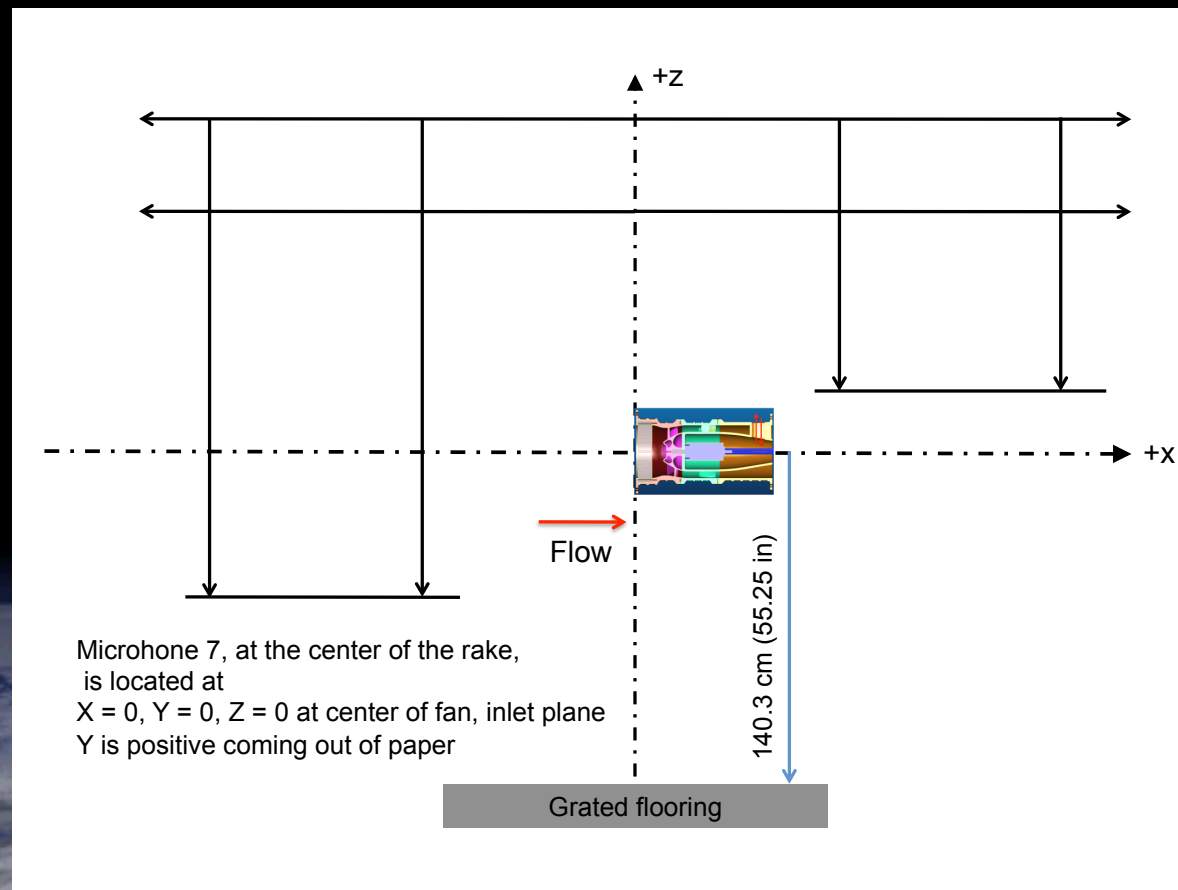
Test chamber temperature, atmospheric pressure, and humidity were also recorded.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of experiment

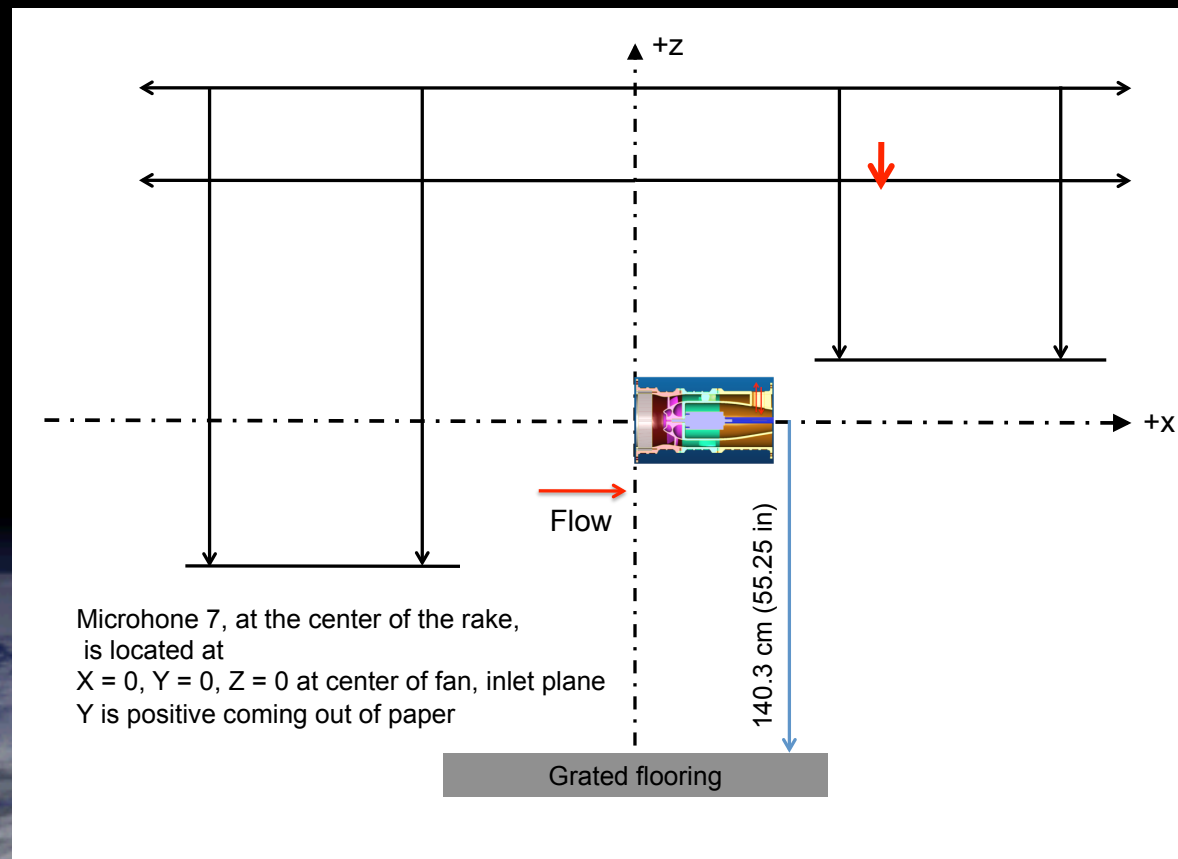
The microphones were traversed in six different planes.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of experiment

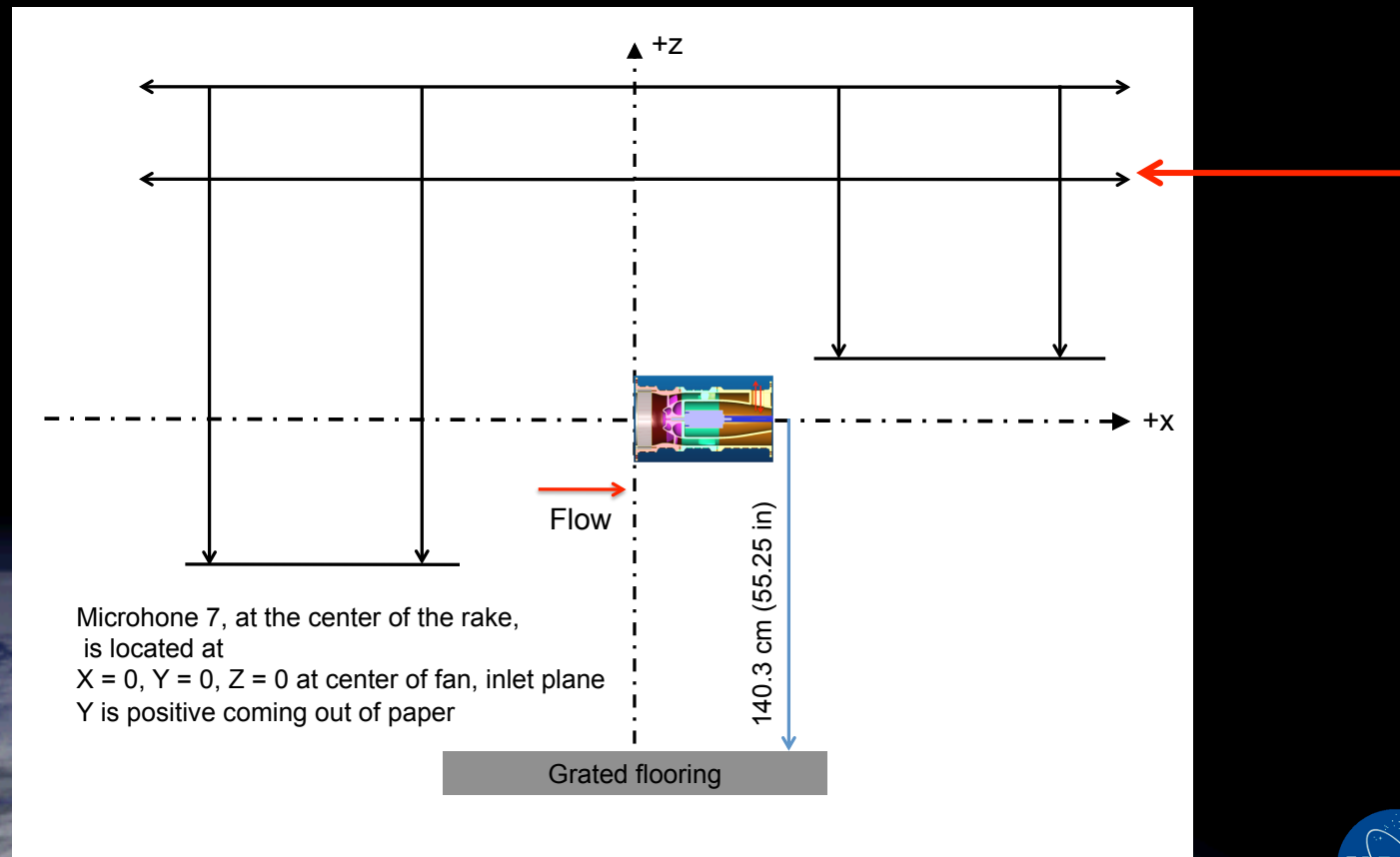
Narrowband spectra will be shown for selected fan speeds from one microphone at a fixed position downstream of the fan.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Description of experiment

Narrowband spectra will also be shown for selected fan speeds from one microphone traversed directly above the fan from upstream to downstream.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Discussion of Results

The fan performed mechanically and electrically as expected.

Three struts vented the enclosure around the fan. The fan housing remained within an acceptable temperature range throughout the entire test.

Vibrations in the axial direction were low.

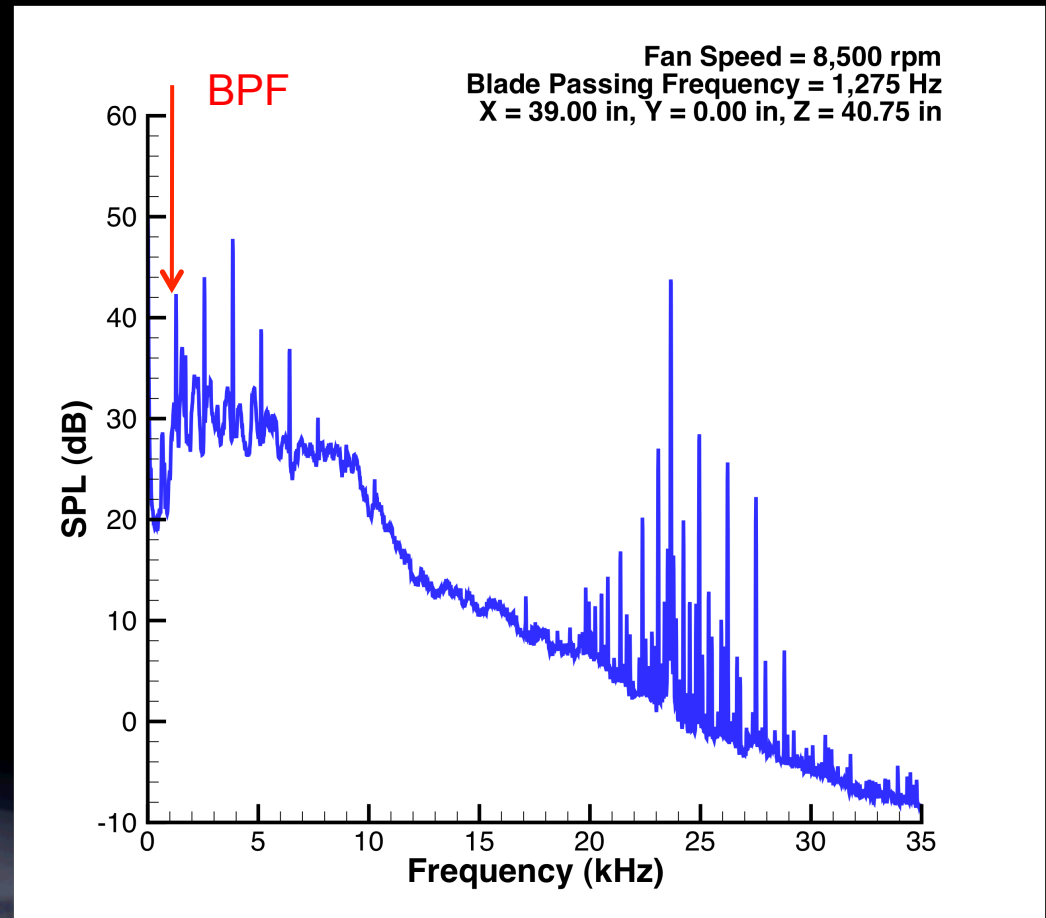


Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Discussion of Results

Measurements from a single microphone positioned at a point downstream of the fan will be presented for selected speeds.

Results indicated that tones at blade passing frequency harmonics were the dominant sources of audible noise for all speeds tested.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

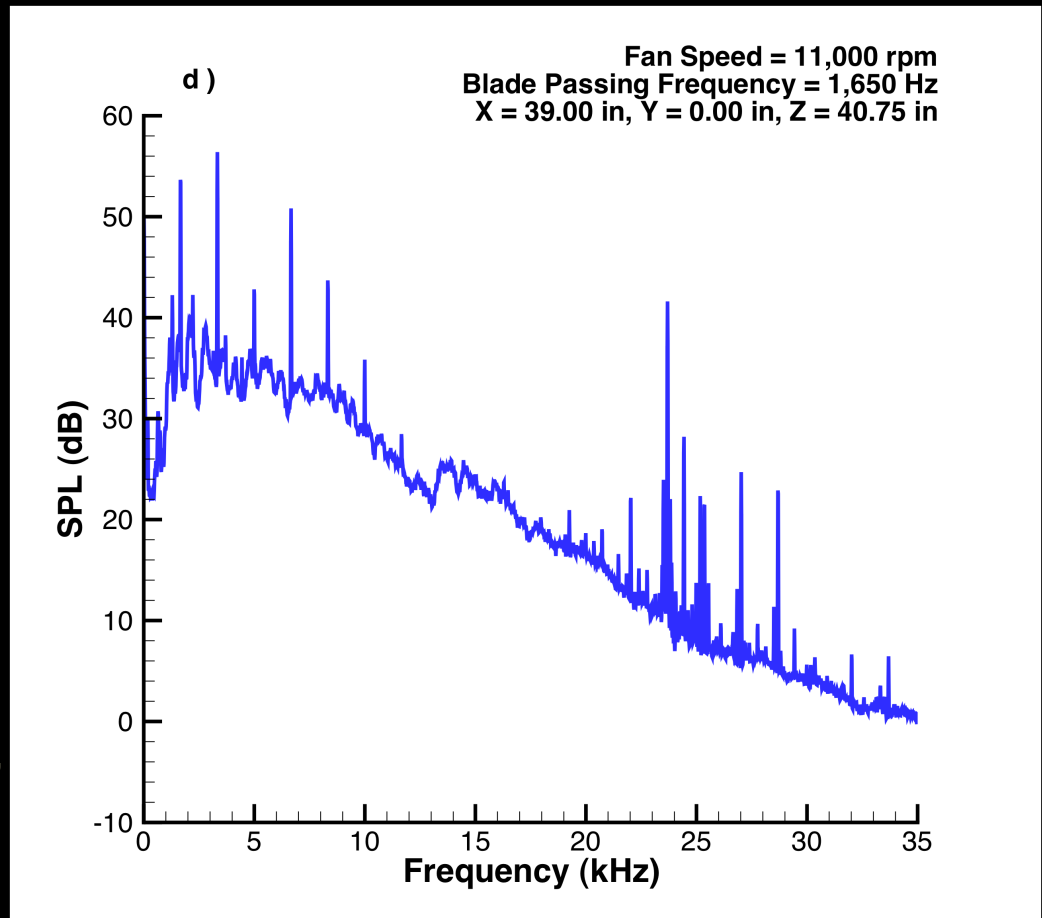
Discussion of Results

The motor was observed to be a source of audible broadband noise, but acoustic measurements of the uninstalled motor were not recorded.

Ultrasonic signals are thought to be associated with the motor and motor controller.

Further testing is needed to determine if the ultrasonic signals are acoustic or electrical noise.

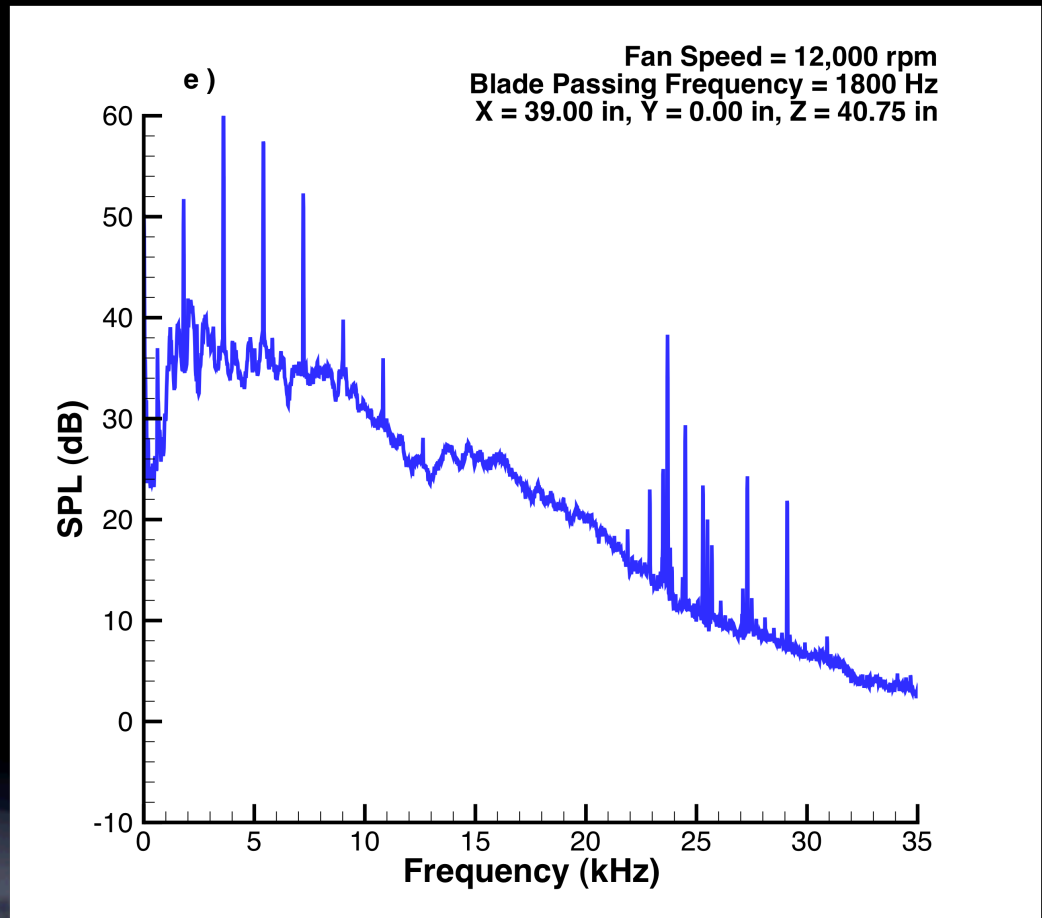
If they are ultrasonic acoustic tones, they are below recommended limits for spacecraft, though they are sufficiently high to potentially interfere with onboard animal experiments.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Discussion of Results

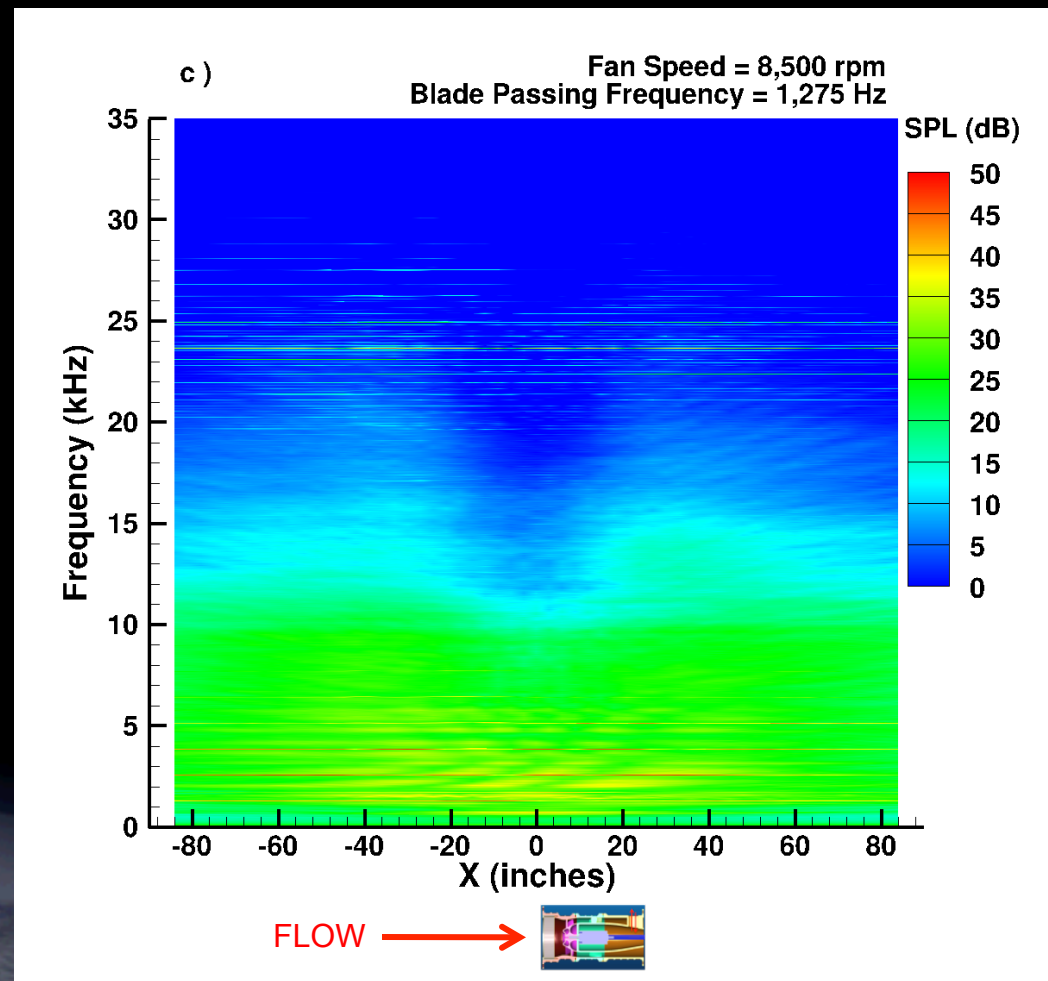
Further testing is required to determine if the blade passing tones are cut-off when the fan is ducted and backpressured to design point conditions, as the theory of Tyler and Sofrin predicts.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Discussion of Results

Measurements from a single microphone stepped in 7.6 cm (3.0 inch) increments from the inlet to the exhaust will be presented for selected speeds.

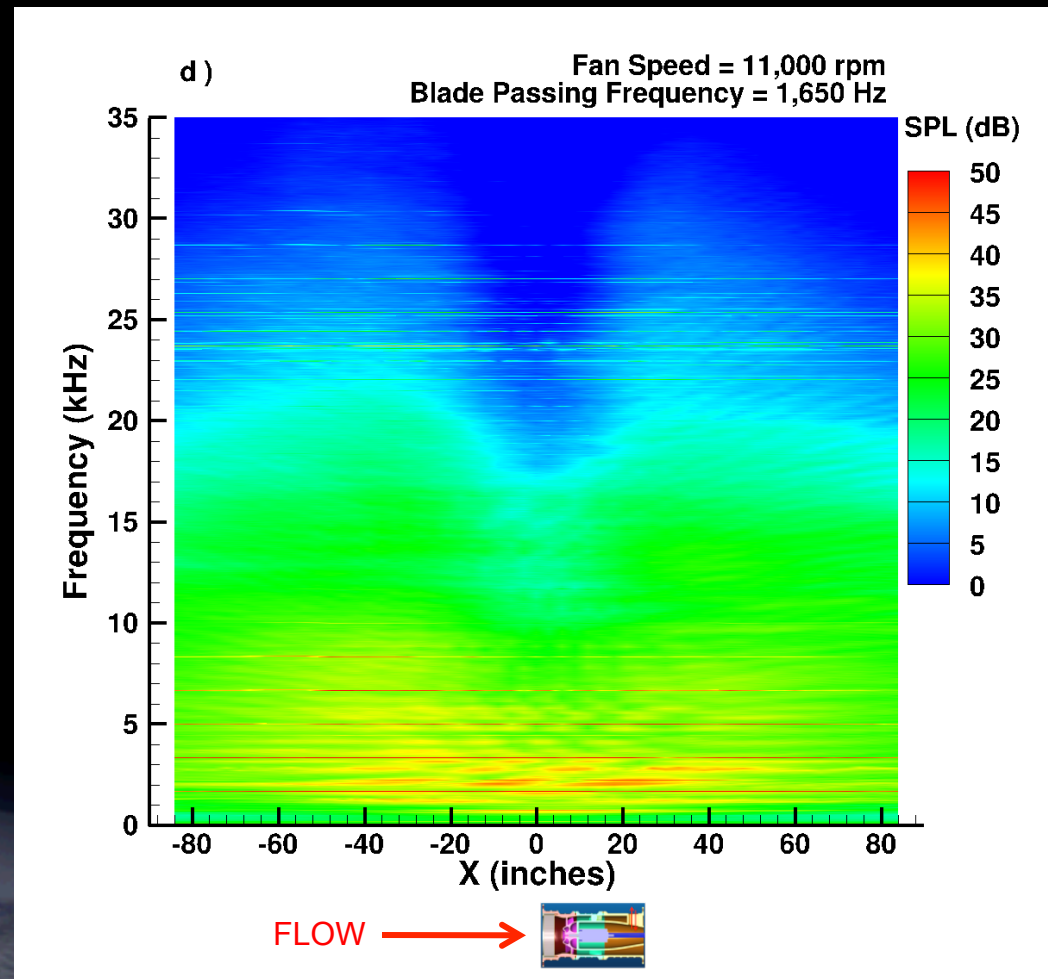


Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Discussion of Results

Faint “ripples” in the sound pressure levels are evident in these plots for all speeds tested.

The nature of these variations is currently unknown, but thought to be associated with the electromechanical performance of the microphone traverse system.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

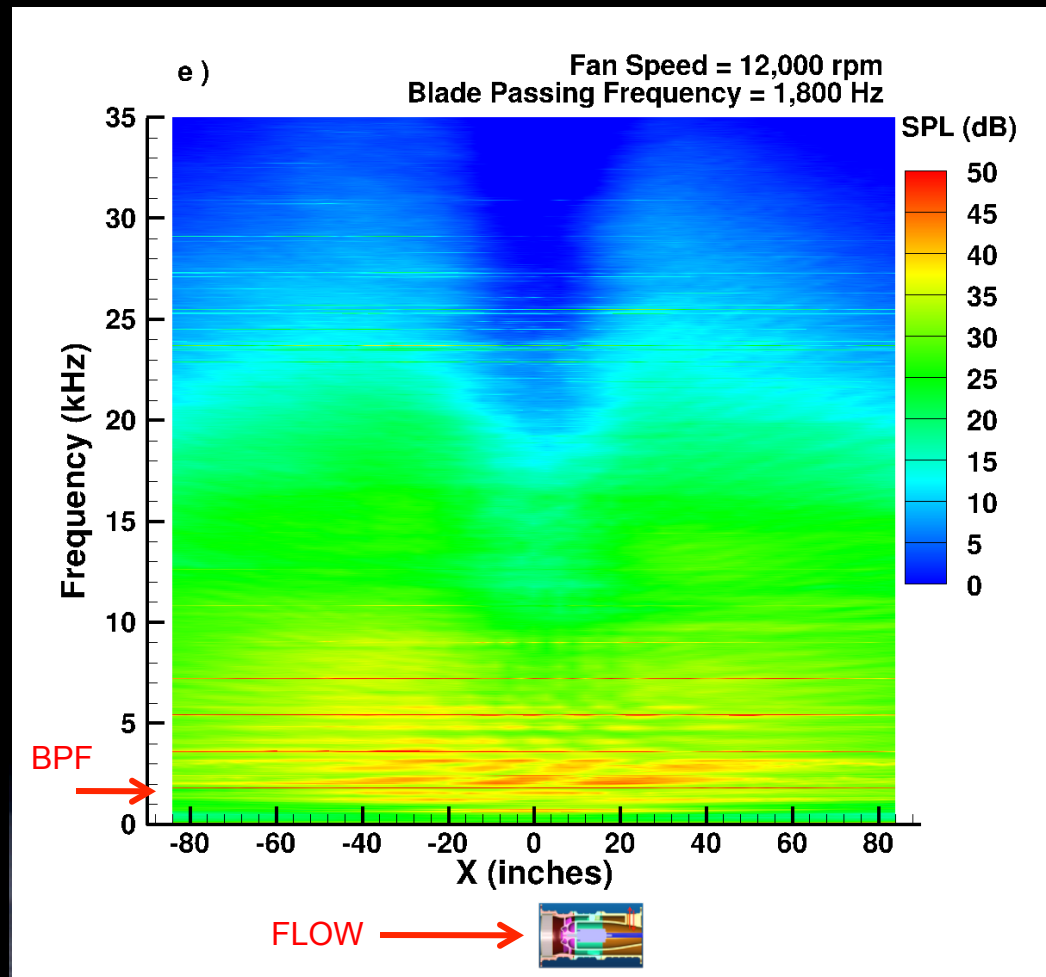
Discussion of Results

Results indicated that tones at blade passing frequency harmonics were the dominant sources of audible noise for all speeds tested in both the inlet and exhaust regions.

Tone noise at blade passing frequency harmonics are associated with the aerodynamic design of the fan.

Blade passing tones may be created by the interaction of the rotor wake with the stationary vanes downstream of the rotor.

Fans ingesting distorted inflow may also create tones at blade passing frequency harmonics.



Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Recommendations

- Efforts could be made to identify a motor speed encoder suitable for the speed range that fits on the aft end of the motor shaft so that the optical speed sensor does not need to be mounted in the fan inlet.
- Efforts could be made to identify different motor controller designs to minimize audible broadband noise.
- Efforts could be made to identify a different way to attach the rotor to the motor to enhance the modularity of the prototype.
- A speed feedback loop in the motor controller would be useful in maintaining the fan at constant speed settings during proposed aerodynamic and acoustic tests that involve backpressuring the fan.
- Additional analyses and structural tests are needed to determine if the operational speed range of the fan can be safely extended.
- The aerodynamic performance of the fan should be experimentally measured for a range of fan speeds and flow rates.
- Acoustic measurements of the fan at design point conditions are needed.
- Once the fan's aerodynamic and acoustic performance is fully mapped, investigations to further improve the fan could be conducted.

Acoustic Measurements of an Uninstalled Spacecraft Cabin Vent Fan Prototype

Conclusion

Early attention to the aerodynamic and acoustic design of spacecraft cabin ventilation fans is intended to enable engineers to design, select, install, and operate quieter, more efficient fans that minimize weight, volume, and power.

Engineers need accurate aerodynamic and acoustic prediction tools to design quieter small fan systems.

NASA can play a unique role in raising the bar on small fan aerodynamic and acoustic performance by developing a set of well-characterized, government-owned, publicly reported baseline fans nominally suited for spacecraft ventilation and cooling systems.