Portland, Oregon
NOISE-CON 2011
2011 July 25-27

Tone noise predictions for a spacecraft cabin ventilation fan ingesting distorted inflow and the challenges of validation

L. Danielle Koch[1]
Tony Shook[2]
Douglas T. Astler[3]
Samantha A. Bittinger[4]
NASA Glenn Research Center
21000 Brookpark Road
Cleveland, OH 44135
USA

A fan tone noise prediction code has been developed at NASA Glenn Research Center that is capable of estimating duct mode sound power levels for a fan ingesting distorted inflow. This code was used to predict the circumferential and radial mode sound power levels in the inlet and exhaust duct of an axial spacecraft cabin ventilation fan. Noise predictions at fan design rotational speed were generated. Three fan inflow conditions were studied: an undistorted inflow, a circumferentially symmetric inflow distortion pattern (cylindrical rods inserted radially into the flowpath at 15°, 135°, and 255°), and a circumferentially asymmetric inflow distortion pattern (rods located at 15°, 52° and 173°). Noise predictions indicate that tones are produced for the distorted inflow cases that are not present when the fan operates with an undistorted inflow.

Experimental data are needed to validate these acoustic predictions, as well as the aerodynamic performance predictions. Given the aerodynamic design of the spacecraft cabin ventilation fan, a mechanical and electrical conceptual design study was conducted. Design features of a fan suitable for obtaining detailed acoustic and aerodynamic measurements needed to validate predictions are discussed.

1 INTRODUCTION

Stationary objects upstream of a fan, such as probes or struts, can distort the flow entering a fan. The inflow can also be distorted if the fan is attached to convoluted ducting, as is typical of a spacecraft ventilation system. Inflow distortion can reduce fan aerodynamic efficiency and increase fan tone noise. While inflow distortion is one of many possible sources of fan tone noise, it can be a dominant noise generation mechanism.[1]

Fan system designers need computer programs to estimate the tone noise produced when a fan ingests distorted inflow in order to develop quiet systems. With such tools, engineers can compare different inlet configurations and select a final design that minimizes fan tone noise. When inlet distortion cannot be eliminated, detailed tone noise predictions can be used to

[1] E-mail address: L.Danielle.Koch@nasa.gov
[2] E-mail address: Tony.Shook@nasa.gov
[3] Douglas Aster, NASA Cooperative Education Program, mentored by Tony Shook
[4] Samantha Bittinger, NASA Cooperative Education Program, mentored by Tony Shook

develop passive and active noise control methods that, ideally, would reduce tone noise without further sacrificing aerodynamic performance.

Fan inflow distortion tone noise is currently being studied computationally and experimentally at the NASA Glenn Research Center. SMK, a computer program that models fan inflow distortion tone noise based on the theory of Sofrin, Mathews and extended by Koch has been developed at NASA Glenn. Estimates from this tone noise model have been compared to data from prior experiments conducted in the NASA Glenn Advanced Noise Control Fan (ANCF) rig.[2] In the ANCF inlet distortion experiments, the inflow to the 1.2 m (48 in) axial low-speed fan was distorted by cylindrical rods inserted radially into the inlet duct. The rods were arranged in both symmetric and asymmetric circumferential patterns. In-duct and farfield sound pressure level measurements were used to validate predictions. These studies have been used to identify strengths and weaknesses of the theory, and to identify trends in the acoustic performance of the ANCF fan.

This theory has been used in the present report to predict the sound power levels in the ducting of a conceptual spacecraft ventilation fan 0.089 m (3.5 in) in diameter. Predictions have been generated for three inflow conditions--an undistorted flow, a circumferentially symmetric distortion pattern, and a circumferentially asymmetric distortion pattern. Again, it is assumed that cylindrical rods inserted radially into the inlet duct upstream of the fan distort the flow. These acoustic predictions complement aerodynamic predictions already published for this fan.[3]

Acoustic and aerodynamic measurements are needed to validate the predictions for this spacecraft ventilation fan. Using the aerodynamic design of the spacecraft cabin ventilation fan as a starting point, a conceptual design study has been completed. The goal of the conceptual design study was to identify mechanical and electrical design features that would be needed in order to collect detailed aerodynamic and acoustic measurements of the fan in ground tests. This study will be summarized here, and challenges associated with experimentally measuring the aerodynamic and acoustic performance of a small fan ingesting distorted inflow will be discussed.

2 FAN TONE NOISE PREDICTIONS

Details of the aerodynamic design of the spacecraft ventilation fan used in the acoustic study here have been published in Reference 3. As listed in Table 1, the axial fan has 9 rotor blades and 11 stator vanes. The blade-to-vane ratio was chosen so that the tones at the first three harmonics of blade passing frequency (BPF) were predicted not to propagate (cutoff) at design point speed of 12,000 rpm for the undistorted inflow condition. The fan aerodynamic design has been plotted in Figure 1.

Three fan inflow conditions were studied: an undistorted inflow, a circumferentially symmetric inflow distortion pattern, and a circumferentially asymmetric inflow distortion pattern. To create a symmetric inflow distortion, three cylindrical rods were assumed to be inserted radially into the flowpath at 15°, 135°, and 255° as shown in Figure 2a. To create an asymmetric inflow distortion, three cylindrical rods were assumed to be inserted radially into the flowpath at 15°, 52° and 173° as shown in Figure 2b. The angular positions of the distortion rods were chosen so they would not be aligned with any of the stator vanes downstream of the rotor.

Figure 3 summarizes the predictions for the sound power levels for the spacecraft ventilation fan generated by the interaction of the rotor, rods, and stator vanes using the SMK fan tone noise prediction code. When the fan rotates at design point speed, the first ten harmonics of blade passing frequency are potentially audible (1,800 to 18,000 Hz). The overall sound power level shown in Figure 3 is a summation over all duct modes of the sound power levels for each of the first seven BPF harmonics. Sound power levels evaluated at the inlet and far exhaust planes were predicted to contribute equally to the overall sound power level. When the flow entering the fan is not distorted, the first three harmonics of the blade passing frequency tone are predicted to be cutoff by design. When rods distort the fan inflow, though, sound power levels calculated at the inlet and exhaust planes indicate that tones at all BPF harmonics are produced. For nearly all BPF harmonics, the sound power levels produced by asymmetric inflow distortion are predicted to be greater than those of the symmetric distortion studied here. Previous tests in the large ANCF rig have indicated that the while the predicted overall sound power levels at the higher harmonics were significantly larger than measured values, examining trends in the first few BPF harmonics can be useful in designing low noise inlets. Experimental data is needed to validate the predictions for the smaller spacecraft cabin vent fan to determine if similar conclusions can be drawn.

Each blade passing frequency tone is examined more closely in Figures 4 though 6. Figure 4 shows acoustic predictions for the undistorted fan; Figure 5 shows acoustic estimates for the symmetric inflow distortion case; and Figure 6 shows acoustic predictions for the asymmetric inflow distortion configuration. All results are for the 12,000 rpm fan speed. Each figure contains seven plots--one for each blade passing frequency harmonic (1 BPF through 7 BPF). Each plot displays the estimated sound power level in the inlet duct for each propagating circumferential and radial mode. The rods upstream of the rotor are predicted to generate acoustic energy in more (but not all) circumferential duct modes (as compared with the undistorted case) that are allowed to propagate. Previous tests in the large ANCF rig have indicated that the theory did not accurately predict trends in radial mode sound power distribution, but that by examining trends in the first radial mode for the first few BPF harmonics, it can be useful in designing low noise inlets. Again, experimental data is needed for the much smaller spacecraft cabin vent fan to validate the predictions presented here.

The development of computer programs that can estimate duct mode sound power levels when an axial fan ingests distorted inflow is the subject of continuing research at NASA Glenn. Modeling more distributed inflow distortions, such as those that would occur if a fan were installed downstream of a convoluted duct, is a near term goal. When it is not possible to avoid fan inflow distortion, experiments on the larger Advanced Noise Control Fan at NASA Glenn have suggested that the SMK code might be able to be applied to aid in designing low noise inlets for some fans. Obtaining acoustic data for this spacecraft cabin ventilation fan is needed to determine whether the theory can be useful for parametric design studies for this class of fans.

3 CHALLENGES OF VALIDATION

Experimental data is required to validate the overall sound power levels for the spacecraft cabin vent fan. The results shown in Figure 3 could be validated either by farfield or in-duct sound pressure level measurements. Farfield sound pressure level measurements are required to determine if the motor is a significant source of noise for this spacecraft cabin vent fan. A test technique is needed to accurately measure the farfield sound pressure levels for the fan as it is throttled through its expected operating range. The pressure rise at design point for this fan (925 Pa) exceeds the maximum recommended (750 Pa) in ISO 10302—Method for the measurement of airborne noise emitted by small air moving devices. Reference 4 describes a modification to the ISO 10302 techniques that could be considered for testing this spacecraft cabin vent fan.

Previous tests in the ANCF rig have indicated that the SMK code predicted higher than measured values for radial mode sound power levels. In order to validate the predictions shown in Figures 4 through 6 in-duct sound pressure levels would need to be measured. While in-duct sound pressure measurements could also be used to validate the results shown in Figure 3, in-duct sound pressure measurements could not be used to quantify motor noise. Test techniques are also needed for these in-duct measurements. The duct diameter for this fan (89 mm) falls below the minimum diameter required (150 mm) by ASHRAE Standard 68—Laboratory method of testing to determine the sound power in a duct.

Experimental data is needed to validate the aerodynamic predictions reported in Reference 3. The aerodynamic predictions indicate that the rotor blade Reynolds number at design point is 75,000 and stator vane Reynolds number is approximately 60,000. Aerodynamic performance predictions were generated using both a low-Reynolds number turbulence model and a high-Reynolds number turbulence model. The fan performance at design point conditions was also estimated for three values of the rotor tip clearance gap. Aerodynamic data is needed to validate these Computational Fluid Dynamics code predictions in this low Reynolds number regime.

Using the aerodynamic design as a starting point, a mechanical and electrical conceptual design study has recently been conducted at NASA Glenn. A cross section of a fan thought to include features desirable for a series of acoustics and aerodynamic ground tests is shown in Figure 7. A modular design was chosen to facilitate the development of active and passive noise control methods. Struts downstream of the stator vanes were added in this conceptual design because the stator vanes are very thin and would be difficult to route the motor wiring through. A honeycomb section was added upstream of the fan to straighten the airflow and decrease the turbulence entering the fan. A tongue and groove method was chosen to join the modular components over flanged connections in an effort to accommodate instrumentation anticipated for possible in-duct acoustic and aerodynamic measurements.

Rapid prototyping (RP) technology is an effective way to quickly fabricate relatively inexpensive models of this small spacecraft ventilation fan that are suitable for research ground testing. Based on the conceptual design study conducted at NASA Glenn, a Selective Laser Sintering (SLS) or Direct Metal Laser Sintering (DMLS) rapid prototyping process is currently recommended. Using traditional manufacturing techniques to reproduce the contoured flow paths, fan blades, and stator blades would take weeks instead of days with a SLS rapid prototype process.

These RP methods are additive manufacturing process that uses a laser to fuse very small particles (20-50 microns) of plastic or metal powder into a solid part. The laser selectively fuses powdered material on cross-sections of a solid model part that is generated by a computer aided design (CAD) program. As each cross section is fused, the powder bed is lowered by one cross section thickness and a new layer is sintered. This process is repeated until the part is completed.

A preliminary rotor stress analysis was conducted for the conceptual design of the fan shown in Figure 7. The analysis determined stresses and displacements of the model components when specified loads were applied. Stress induced by loading, multiplied by a factor of safety, shall not exceed the material's ultimate strength properties. Additionally, displacements at the fan blade tips shall not exceed the blade/casing gap distance of 0.23 mm (0.0090 in), as prolonged rub may cause premature fan blade failure. MSC Nastran was used to perform the rotor finite element stress analysis. Aerodynamic loading was considered negligible in this preliminary analysis, so the only loading applied was the result of rotational speed of 14,000 RPM about the rotor's central axis. The results from this stress analysis indicated that three metals (17-4 PH Stainless Steel, EOS Titanium Ti64, Aluminum 6061-T6) and two plastics (3D Duraform GF, 3D Duraform HST) are candidate materials for the ground test fan.

A preliminary rotor modal analysis was also conducted at NASA Glenn. Modal analysis extracts frequencies of excitation from a model. If the motor were to vibrate at these frequencies, it could excite the rotor, causing resonance. During testing, it was assumed that the rotor would be run at various speeds in the test range of 6,000-14,000 rpm. Resonant frequencies may be passed through, but should not be dwelled at during testing. MSC Nastran was used to carry out finite element modal analysis. Resonant frequencies of the rotor were found for the five materials listed above. The analysis showed that the targeted test speed of 12,000 RPM is within resonance range for all five material candidates and rotor hub redesign is needed in order to mature this concept to test-worthy hardware.

Several commercially available motors were identified that could potentially be used to drive the fan. The controllable speed of the fan was assumed to range from 6,000 to 14,000 rpm ± 1.0 rpm as the fan flow is throttled through is expected operating range. While the prototypes may be useful for proof-of-concept tests, there may be differences in performance between a rapid prototype of the fan and a metal fan produced by traditional manufacturing techniques that is designed to meet spaceflight requirements. For example, a motor that is able to drive a plastic fan rotor may not be adequate for driving a heavier metal rotor, and the two motors may have different acoustic performance. So while rapid prototypes may prove to be useful in some research and development tests, acoustic tests of the fans produced for spaceflight should also be conducted. Comparisons should be made between acoustics tests of the rapid prototype fans and the spaceflight fans in an effort to identify any differences in performance and work towards future improvements.

Selecting and accommodating instrumentation for in-duct acoustic and aerodynamic measurements is expected to be a challenge. Annulus height at the stator leading edge is approximately 0.011 m (0.45 in) and the duct diameter is 0.089 m (3.5 in). If a hotwire probe were to be chosen for rotor wake velocity measurements, a hole through the duct wall would be needed to insert the probe. A radial traverse mechanism would also be needed to sweep the probe from hub to tip. If a hotwire probe were to be chosen for stator wake velocity measurements, a circumferential slot and seal in the duct may be needed in order to move the probe through the stator vane wake region. Measuring the inflow velocities upstream of the fan is a challenge, as well. The use of Particle Image Velocimetry to map the inflow velocities should also be examined more closely.

4 CONCLUSION

Tone noise predictions have been presented for a spacecraft cabin ventilation fan ingesting distorted inflow. Three inflow distortion patterns were examined--an undistorted inflow, a circumferentially symmetric inflow and a circumferentially asymmetric inflow. The SMK fan tone noise prediction code developed at NASA Glenn was used to estimate duct mode sound power levels. These acoustic predictions complement aerodynamic predictions previously reported.

Acoustic and aerodynamic data is needed to validate all predictions for this fan. Towards that goal, a conceptual design study has been conducted. Using the aerodynamic design of the spacecraft cabin ventilation fan as a starting point, a fan design suitable for a series of ground tests has been generated. Preliminary rotor stress analyses indicate that rapid-prototyping may be a cost-effective way to fabricate fan models for research. Preliminary rotor modal analyses indicated that several metal and plastic materials could be used, but a rotor redesign is needed to mature this concept to test hardware.

Test techniques still need to be identified for this fan, and the instrumentation needed for these tests must still be selected. Accommodating any instrumentation for in-duct acoustic or aerodynamic measurements is expected to be a challenge given the size of the fan.

6 REFERENCES

1. Fitzgerald, James M., Lauchle, Gerald C., Reduction of discrete frequency noise in small, subsonic axial-flow fans, Journal of the Acoustical Society of America, **76(**1), 158-166, (1984).

2. Koch, L. D., "Validation of the Predicted Circumferential and Radial Mode Sound Power Levels in the Inlet and Exhaust Ducts of a Fan Ingesting Distorted Inflow," To be presented at the 17th AIAA/CEAS Aeroacoustics Conference, Portland, OR, June 5-7, 2011, publication as a NASA Technical Memorandum (TM) pending.

3. Tweedt, D. L., "Aerodynamic Design and Computational Analysis of a Spaceflight Vehicle Cabin Ventilation Fan," NASA TM-2010-216329, (2009).

4. Bard, S. E. and Nobile, M. A., "Acoustical implications of airflow impedance on both the inlet and outlet of an air-moving device," NC08-179, (2008).

Table 1: Spacecraft Cabin Fan Design Point Goals and Predicted/Model Values

	Predicted/Model Value
Flow rate	0.710 m^3/s (150 cfm)
Total pressure rise	925 Pa (3.72 inches of water)
Pressure	101 kPa (14.7 psia)
Temperature	21° C (70° F)
Duct diameter	0.089 m (3.5 in)
Maximum axial length	0.22 m (9.0 in)
Rotor tip clearance gap	0.23 mm (0.0090 in)
Rotor speed	12,000 rpm
Number of blades	9
Number of vanes	11

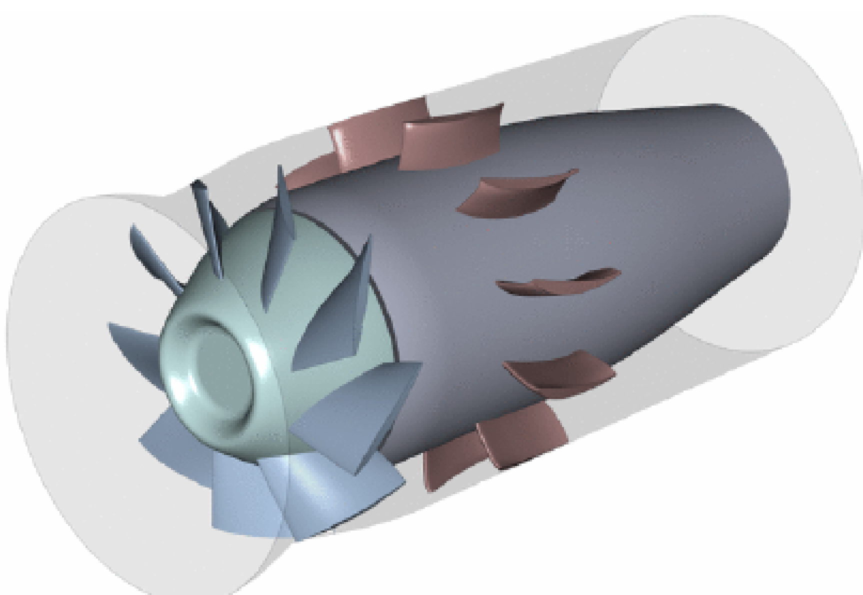


Figure 1: Spacecraft cabin ventilation fan aerodynamic design

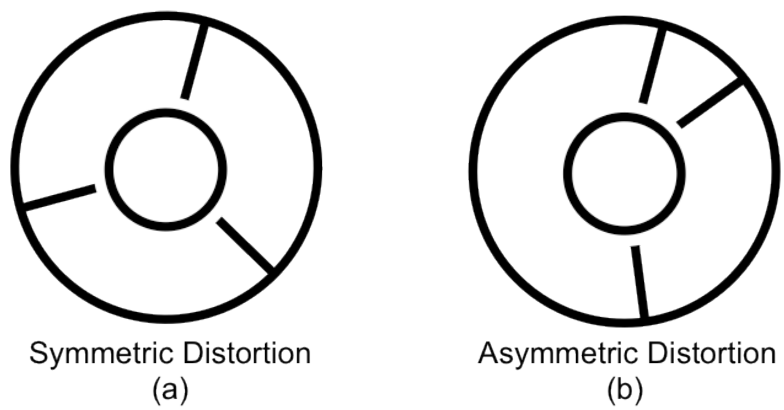


Figure 2: Fan inflow distortion rod configurations used for tone noise predictions.

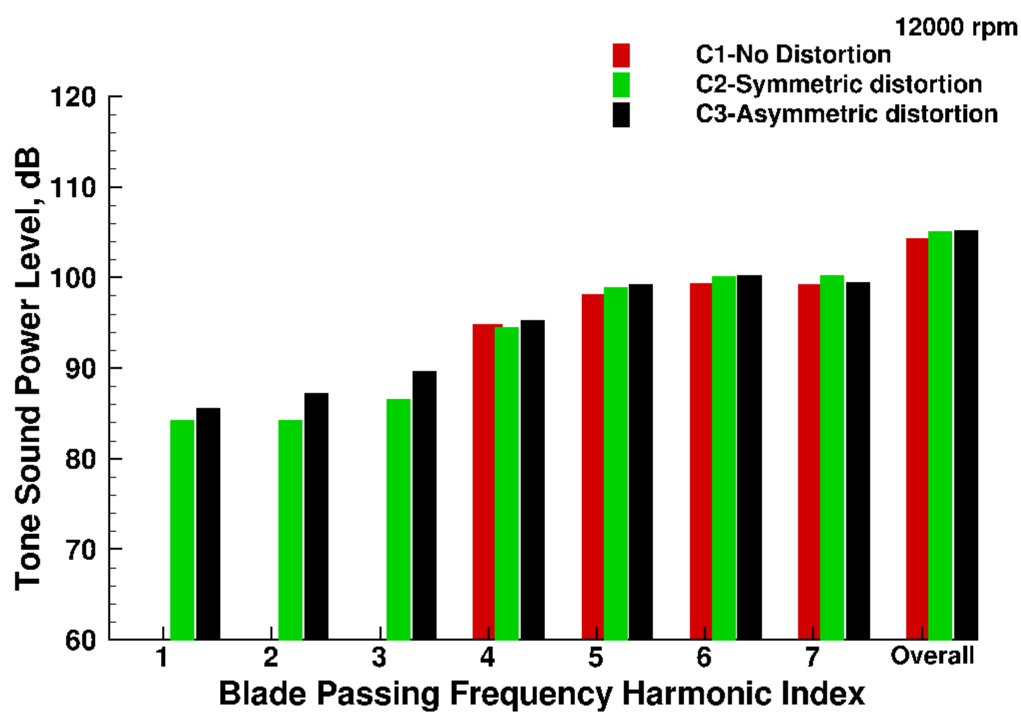


Figure 3: Predicted tone sound power levels for each blade passing frequency harmonic. The overall result is the summation of the first seven harmonics.

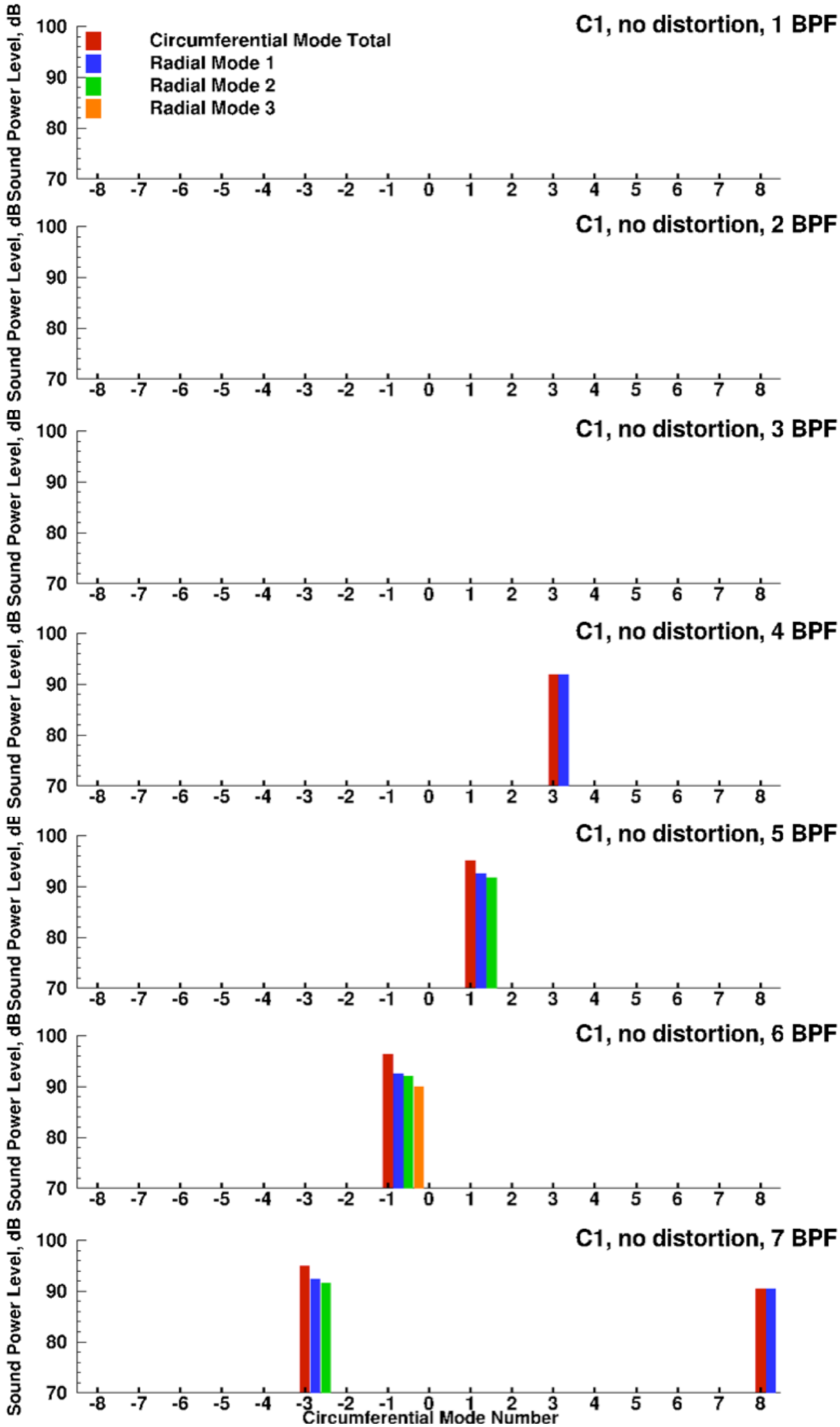


Figure 4: Predicted inlet duct mode sound power levels for the undistorted inflow case. Total circumferential mode sound power level is shown in red adjacent to the sound power level estimates for each propagating radial mode.

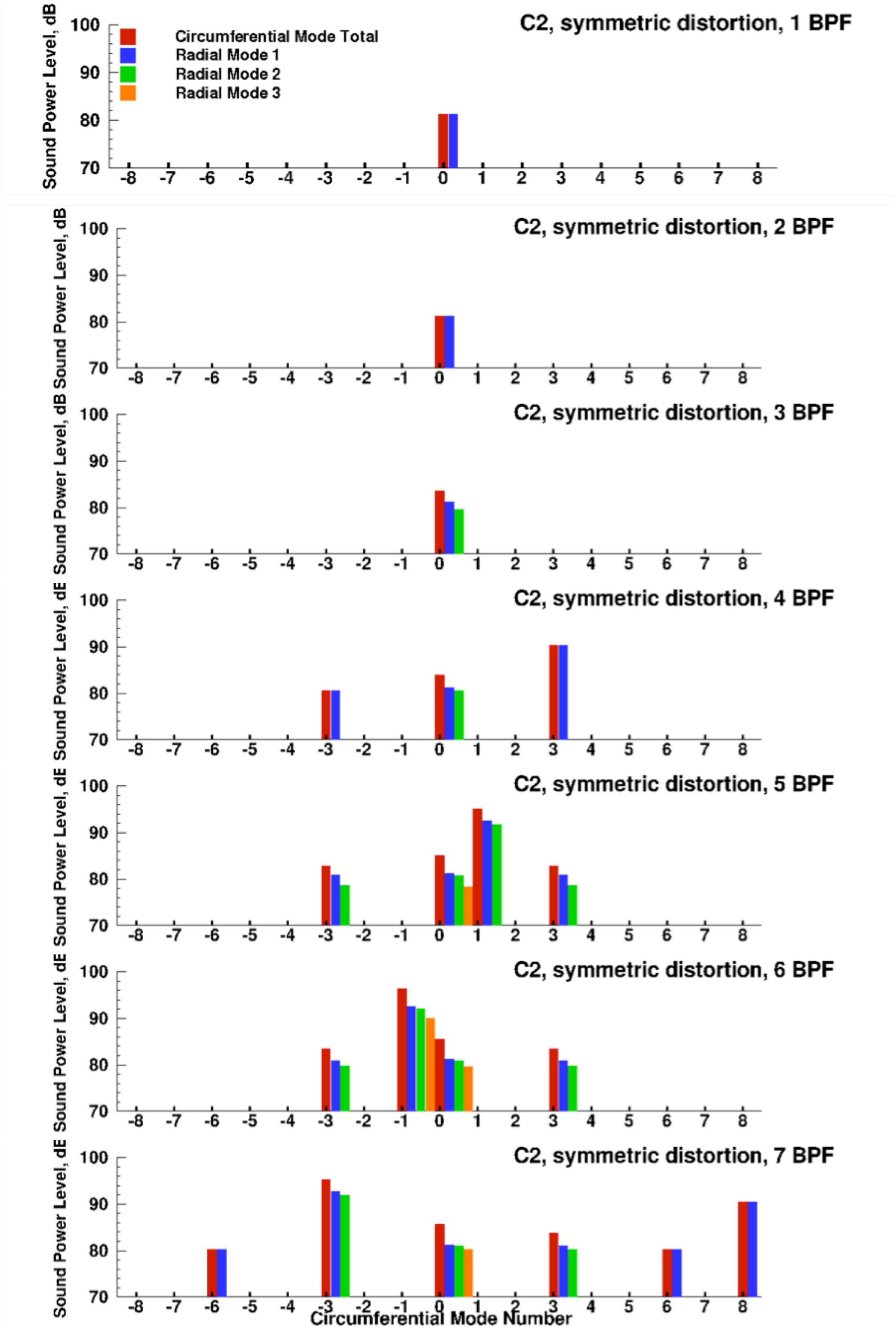


Figure 5: Predicted inlet duct mode sound power levels for the symmetric inlet distortion case. Total circumferential mode sound power level is shown in red adjacent to the sound power level estimates for each propagating radial mode.

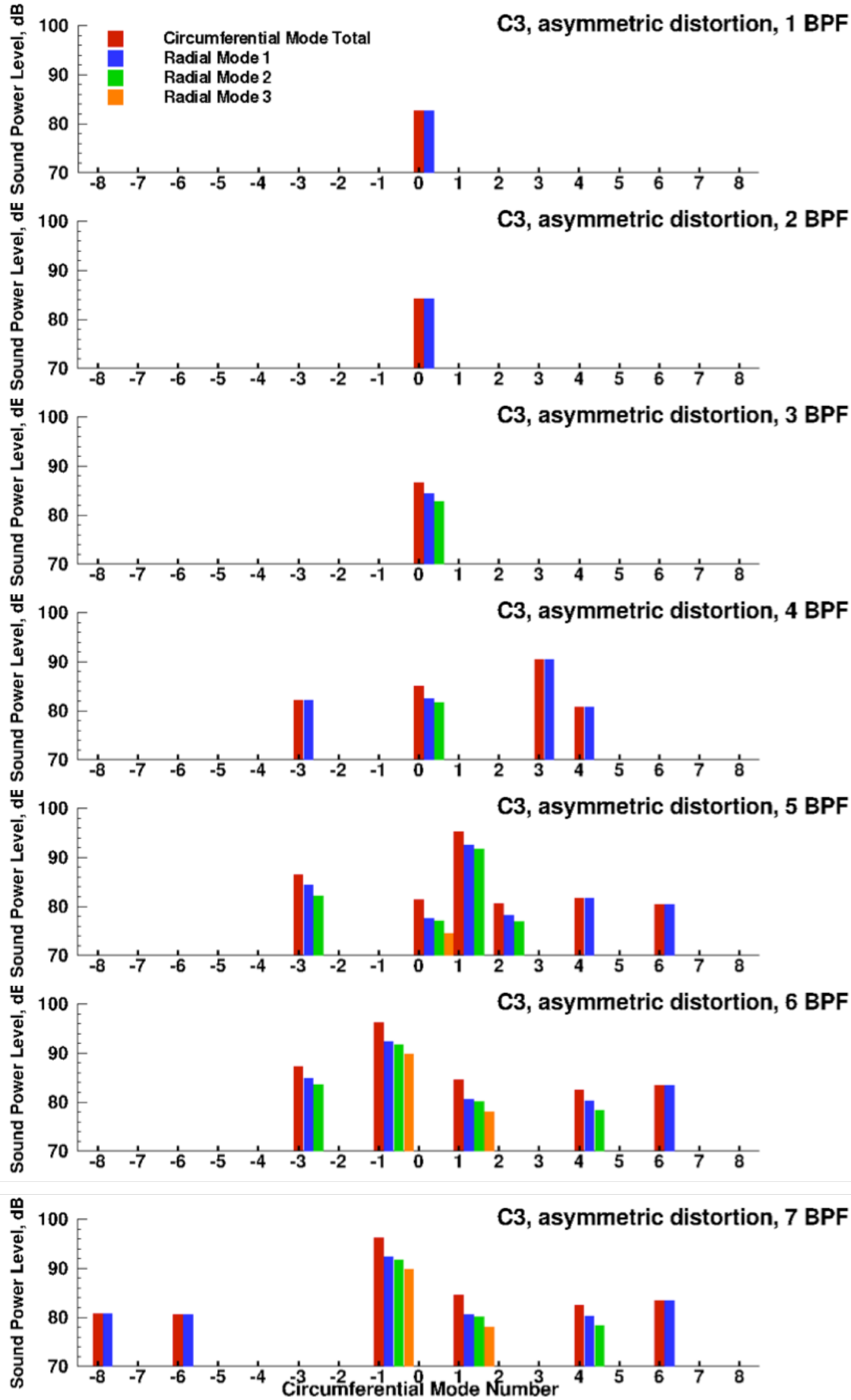


Figure 6: Predicted inlet duct mode sound power levels for the asymmetric inlet distortion case. Total circumferential mode sound power level is shown in red adjacent to the sound power level estimates for each propagating radial mode.

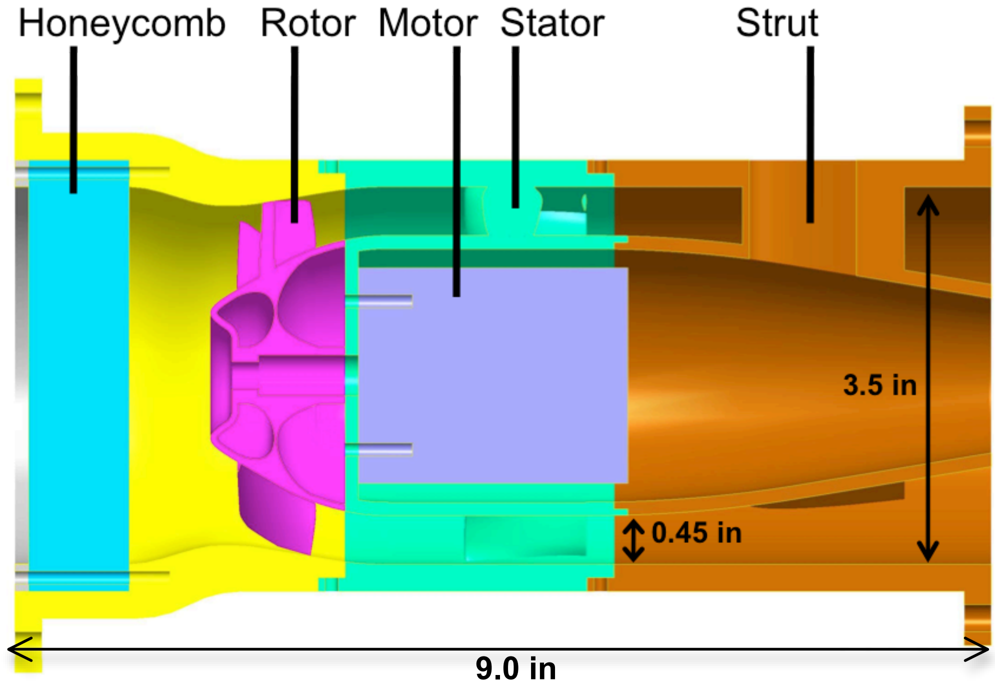


Figure 7: Fan conceptual design cross section.

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

L. Danielle Koch
Tony Shook
Douglas Aster
Samantha Bittinger
NASA Glenn Research Center

NoiseCon 2011 ◆ Portland, Oregon ◆ July 25-27, 2011

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Outline

- Motivation
- Description of fan concept
- Conceptual design study results
- Fan duct mode sound power level predictions
- Advanced Noise Control Fan validated predictions
- Challenges of validation
- Conclusion

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Motivation

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

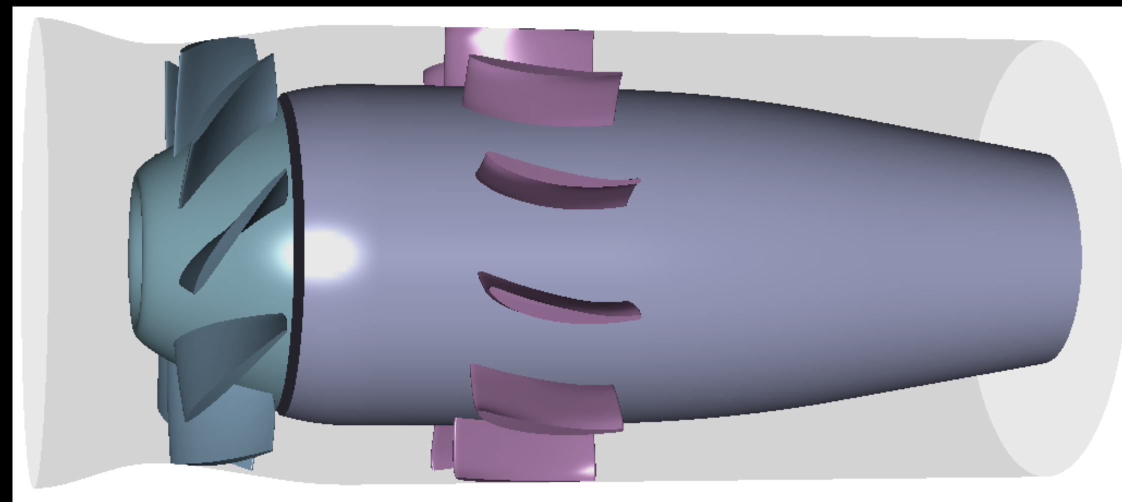
Stationary objects upstream of a fan can distort the flow entering the fan. Inflow to the fan can also be distorted if the fan is attached to a convoluted duct.

Inflow distortion can reduce fan aerodynamic efficiency and increase fan tone noise.

In order to develop quiet systems, designers need accurate computer programs to estimate the tone noise produced when a fan ingests distorted inflow.

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Description of fan concept



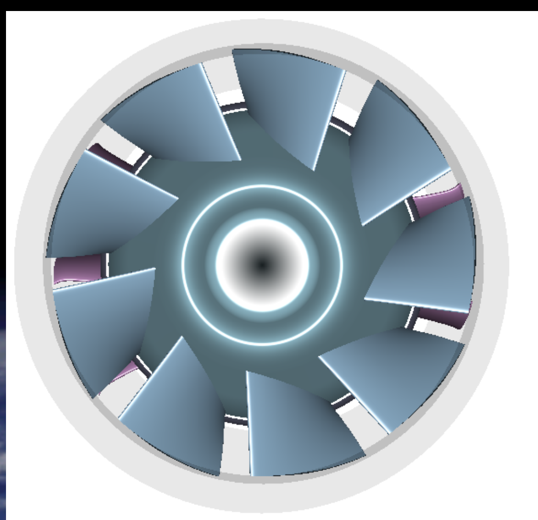
<u>Design Point Conditions</u>

Flow rate: 150.3 cfm

Total pressure rise: 3.64 in H_20

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

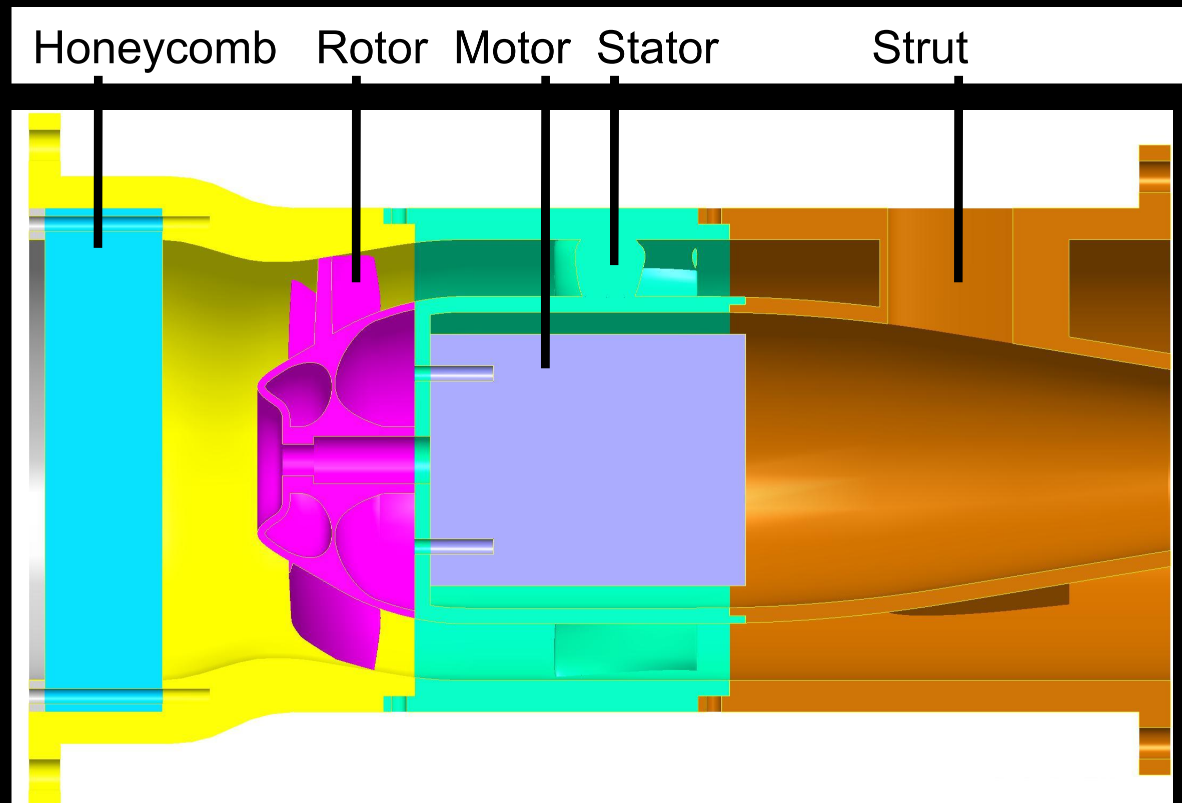
Rotational speed: 12,000 rpm

Tip clearance: 0.009 in

Overall axial length 9.0 in

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Description of fan concept



Features

Honeycomb section to straighten inflow and reduce turbulence

Modular design to facilitate development of passive and active noise reduction methods

Tongue-and-groove duct section connections to accommodate instrumentation for in-duct measurements

Struts to accommodate motor wiring

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Conceptual design study results

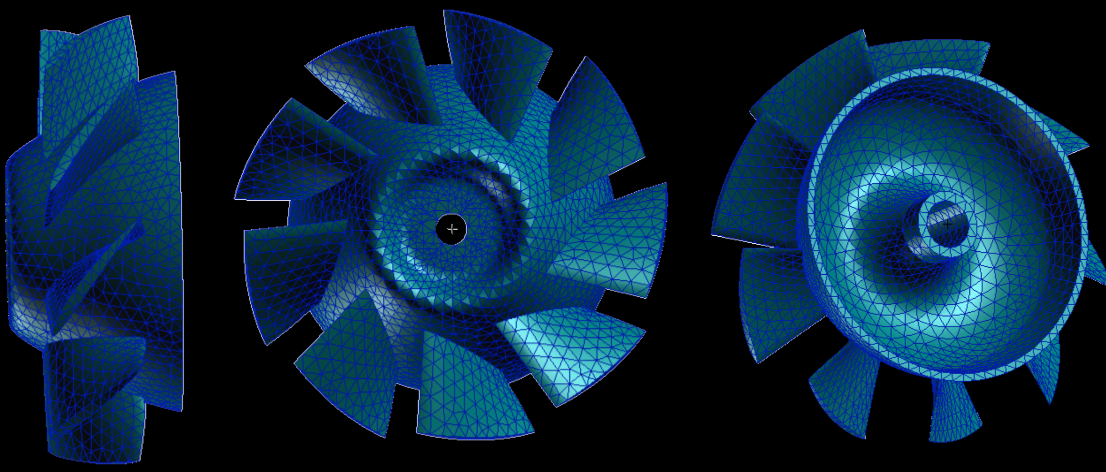
A preliminary rotor stress analysis was conducted using MSC Nastran Finite Element Analysis solver. Results indicated that rapid prototyping could be used to fabricate models of the fan suitable for ground tests. Selective Laser Sintering (SLS) or Direct Metal Laser Sintering (DMLS) rapid prototyping process are currently recommended.

DMLS Material Candidates

17-4 PH Stainless Steel
EOS Titanium Ti64
Aluminum 6061 T6

SLS Material Candidates

3D Duraform GF
3D Duraform HST



Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

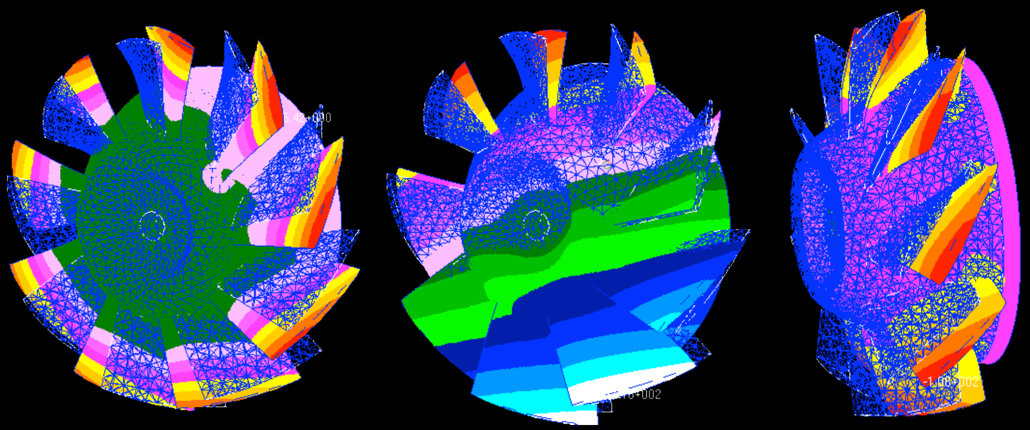
Conceptual design study results

A preliminary rotor modal analysis was conducted using MSC Nastran Finite Element Analysis solver. Results indicated that the targeted test speed of 12,000 rpm is within resonant range for all five candidate materials. Modifications to the rotor hub design are needed to mature this concept to test-worthy hardware.

DMLS Material Candidates
17-4 PH Stainless Steel
EOS Titanium Ti64
Aluminum 6061 T6

SLS Material Candidates
3D Duraform GF
3D Duraform HST

Aluminum Rotor Modal Analysis Results



1st Mode 2nd Mode 3rd Mode

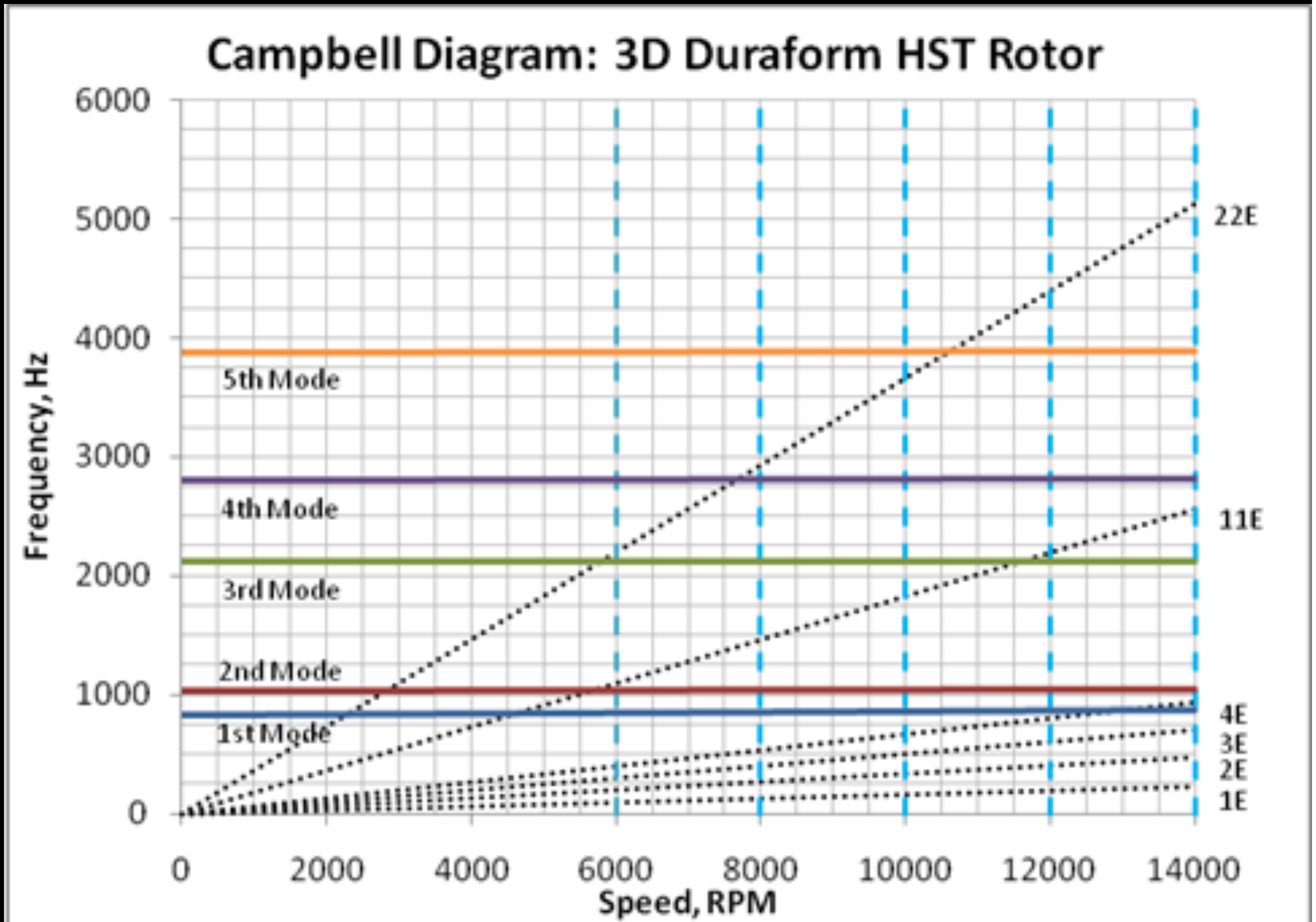
Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Conceptual design study results

A preliminary rotor modal analysis was conducted using MSC Nastran Finite Element Analysis solver.

Results indicated that the targeted test speed of 12,000 rpm is within resonant range for all five candidate materials.

Modifications to the rotor hub design are needed to mature this concept to test-worthy hardware.

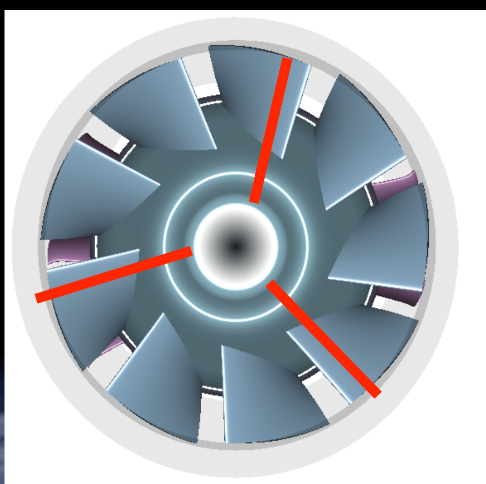


Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

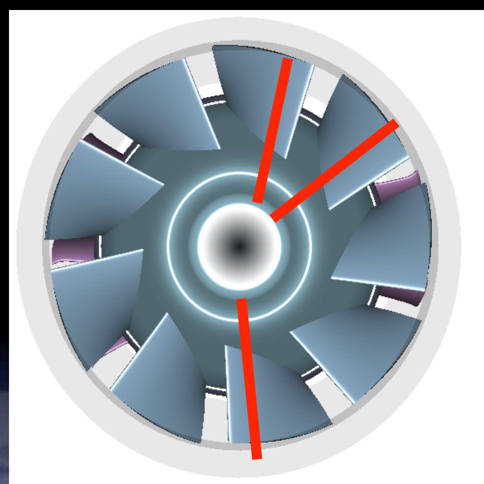
Fan Duct Mode Sound Power Level Predictions

Duct mode sound power level predictions for the conceptual spacecraft cabin ventilation fan were generated for three inflow conditions using the SMK code.

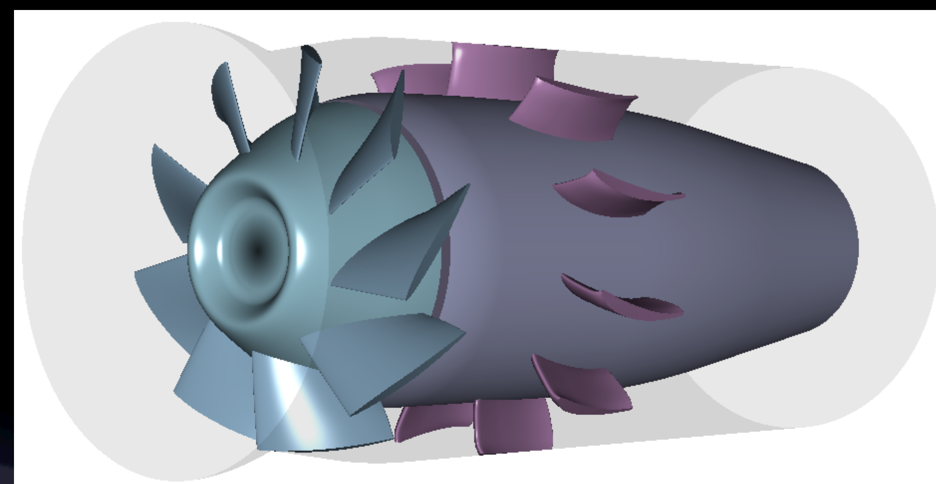
The SMK code is an implementation of the theory of Sofrin and Mathews that I extended to study asymmetric fan inlet distortions like those shown here.



Symmetric Distortion



Asymmetric Distortion

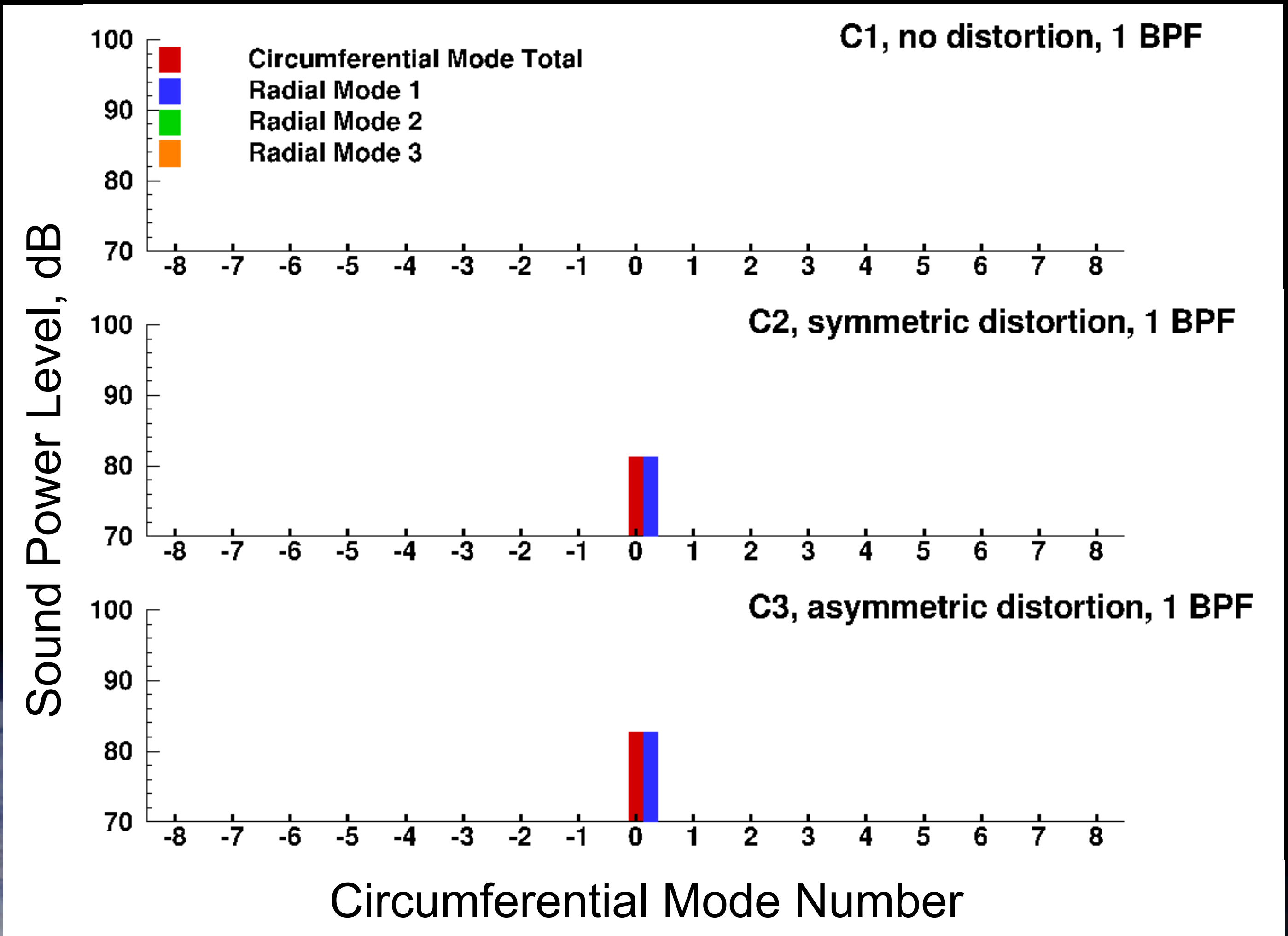


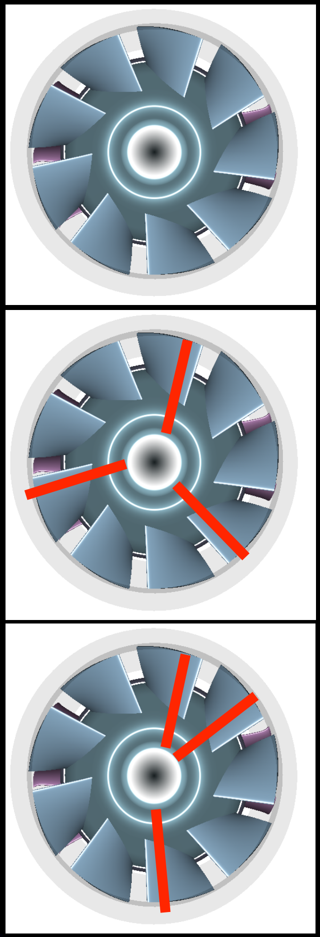
No Distortion

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Duct Mode Sound Power Level Predictions

1 BPF

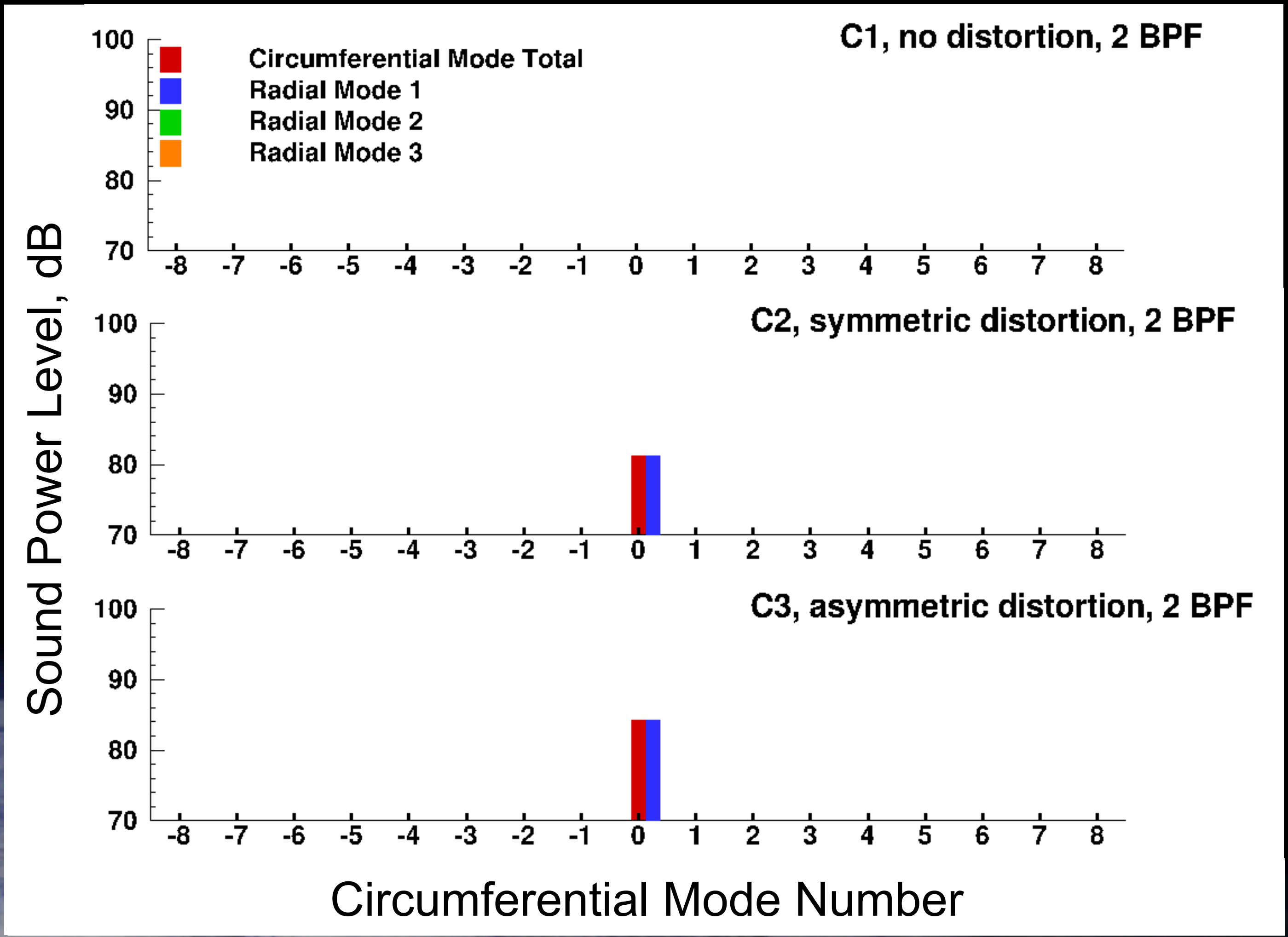


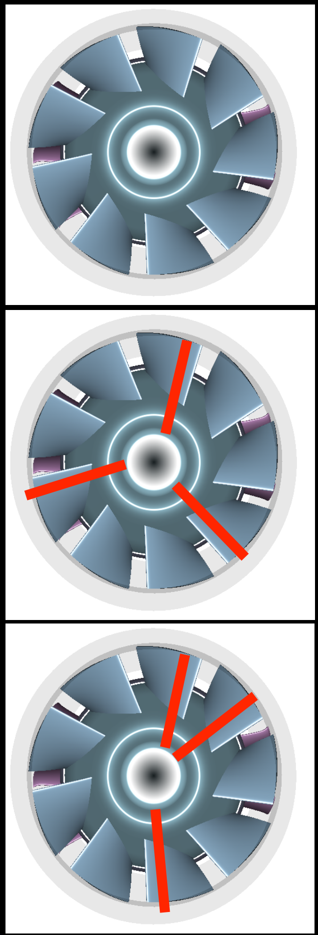


Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Duct Mode Sound Power Level Predictions

2 BPF

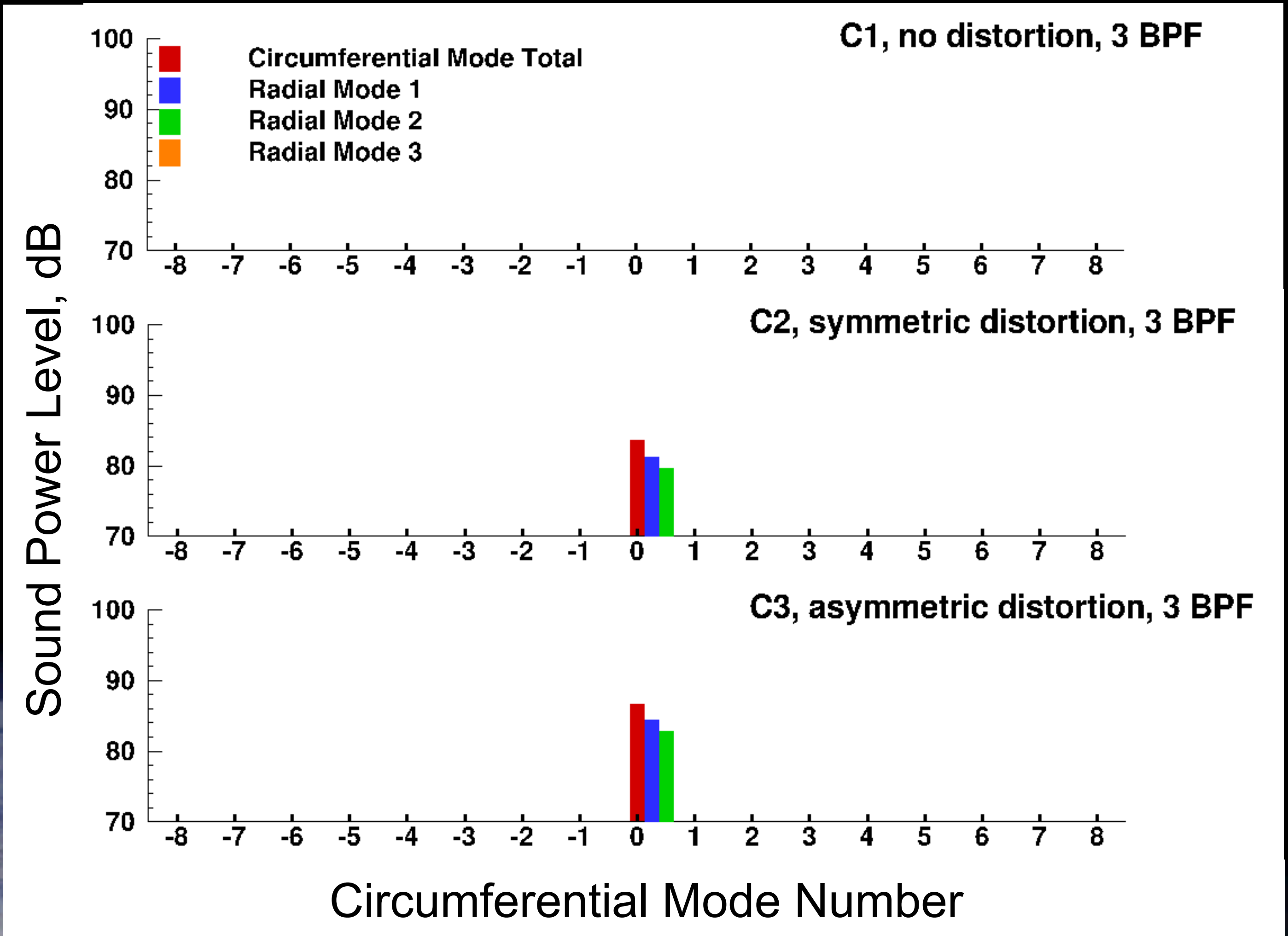


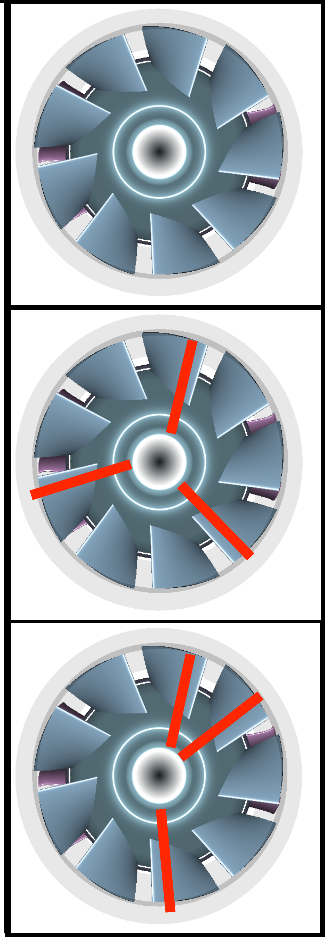


Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Duct Mode Sound Power Level Predictions

3 BPF

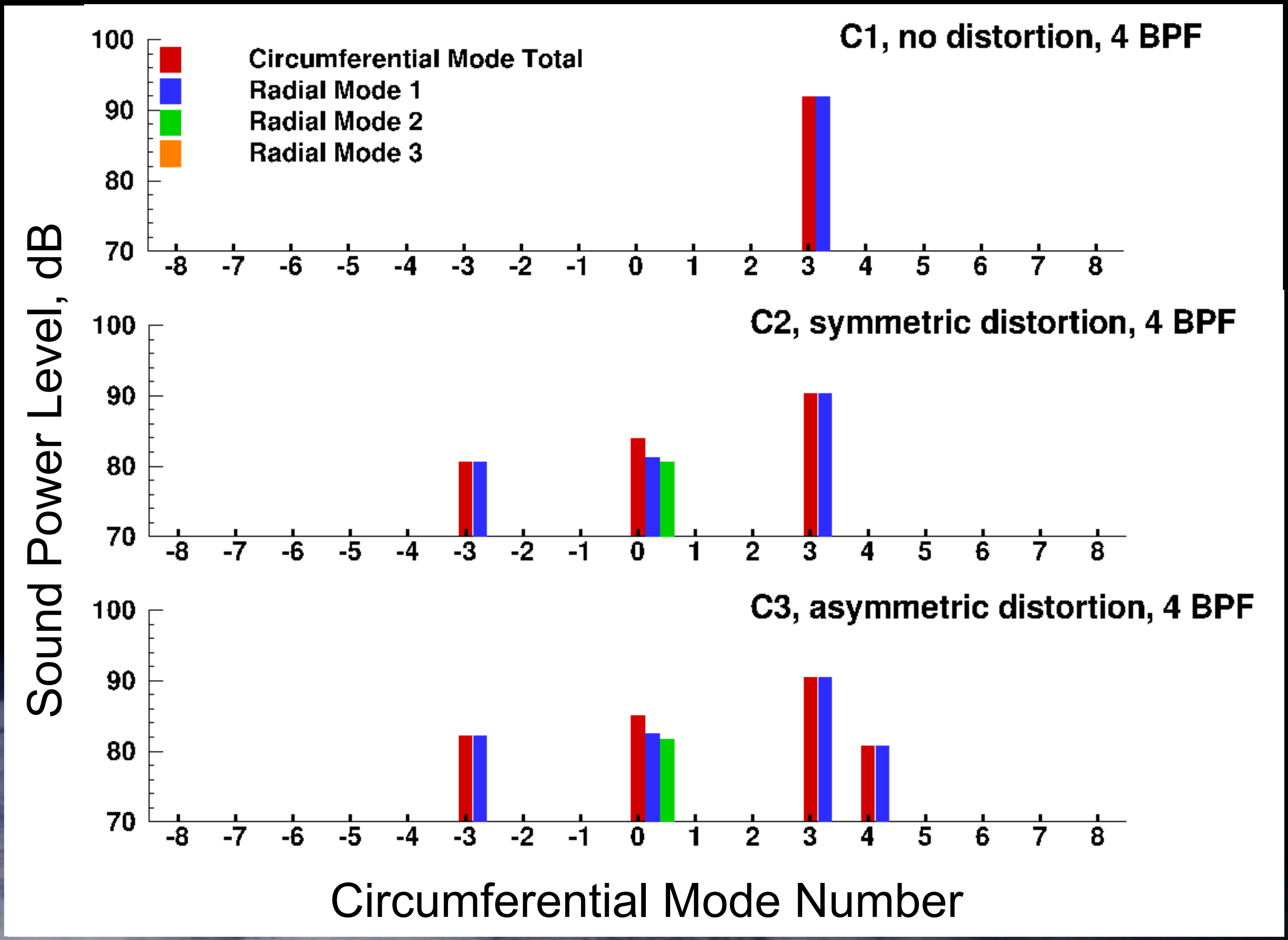


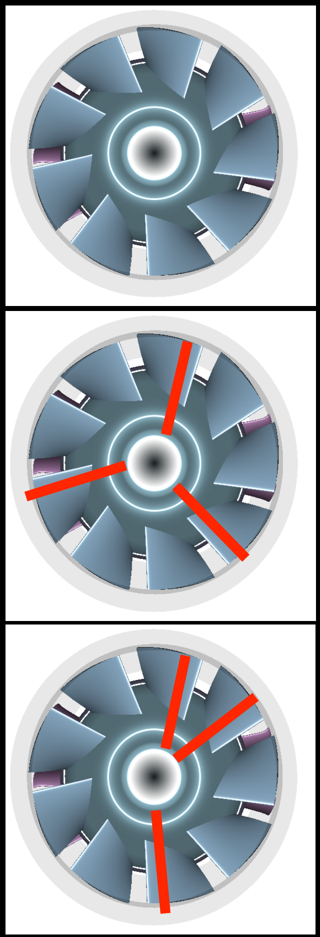


Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Duct Mode Sound Power Level Predictions

4 BPF

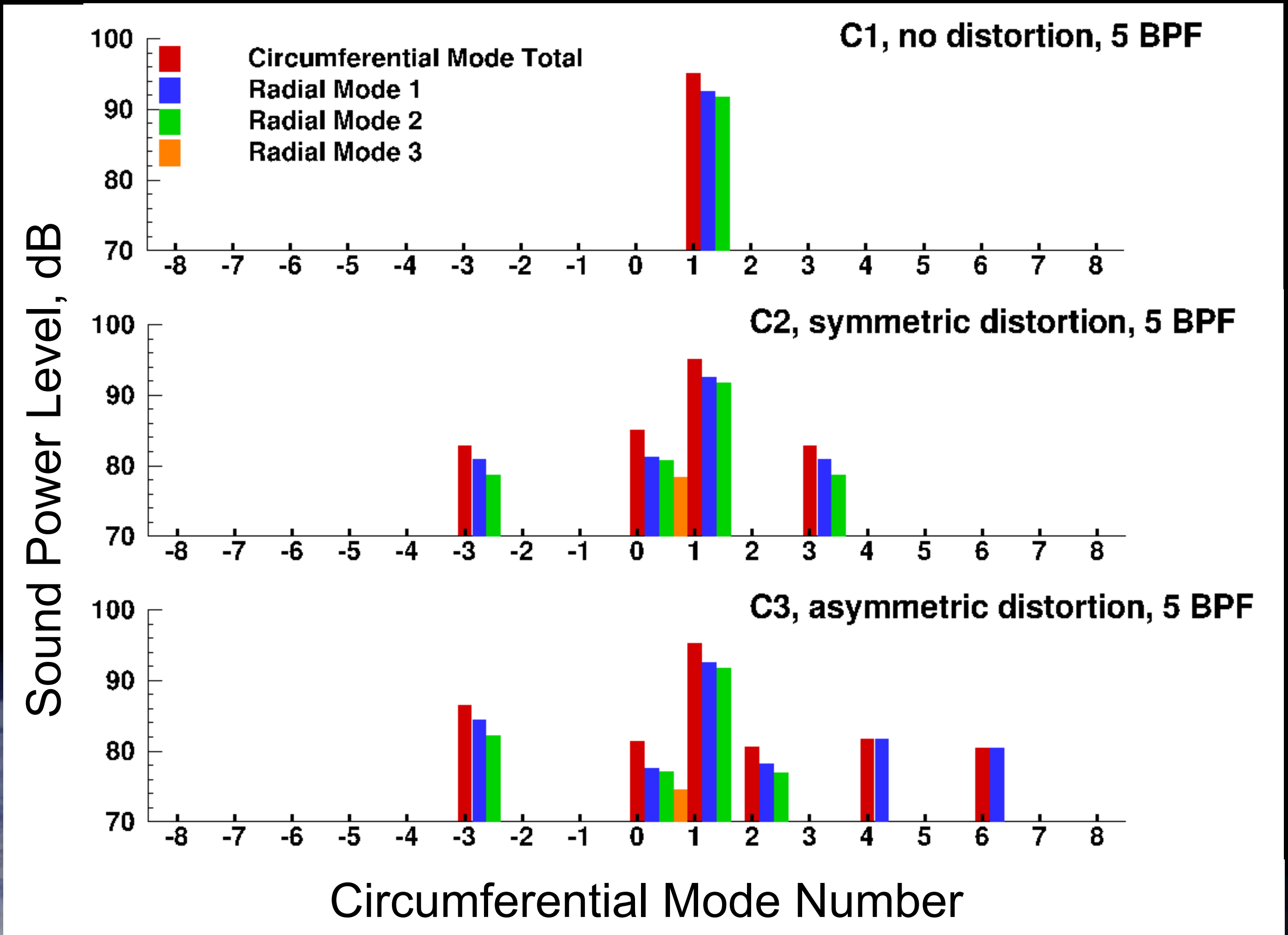


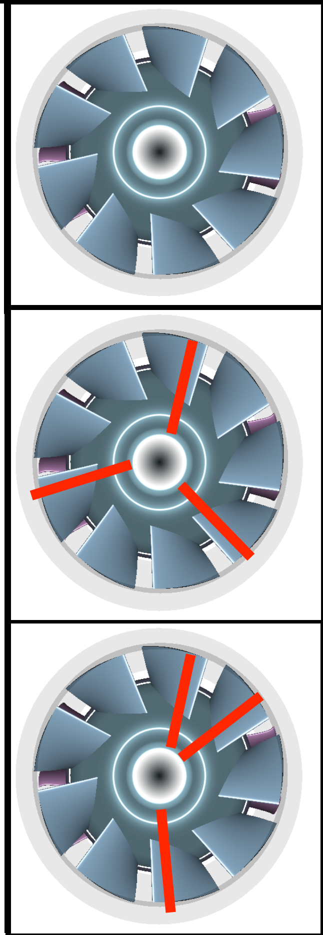


Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Duct Mode Sound Power Level Predictions

5 BPF

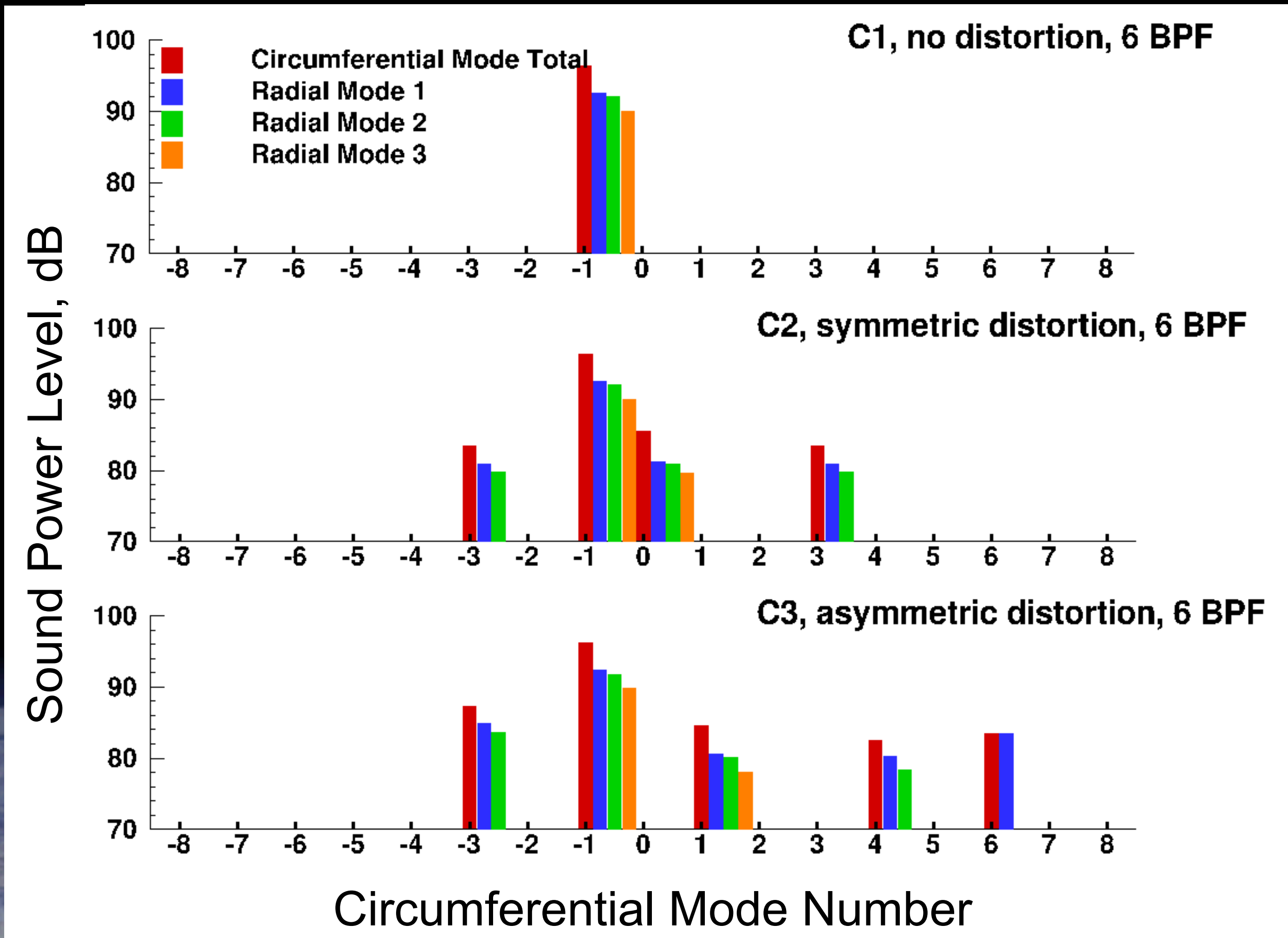


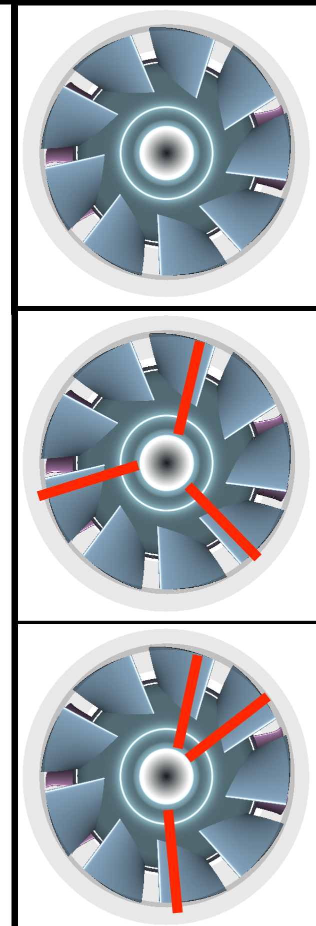


Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Duct Mode Sound Power Level Predictions

6 BPF

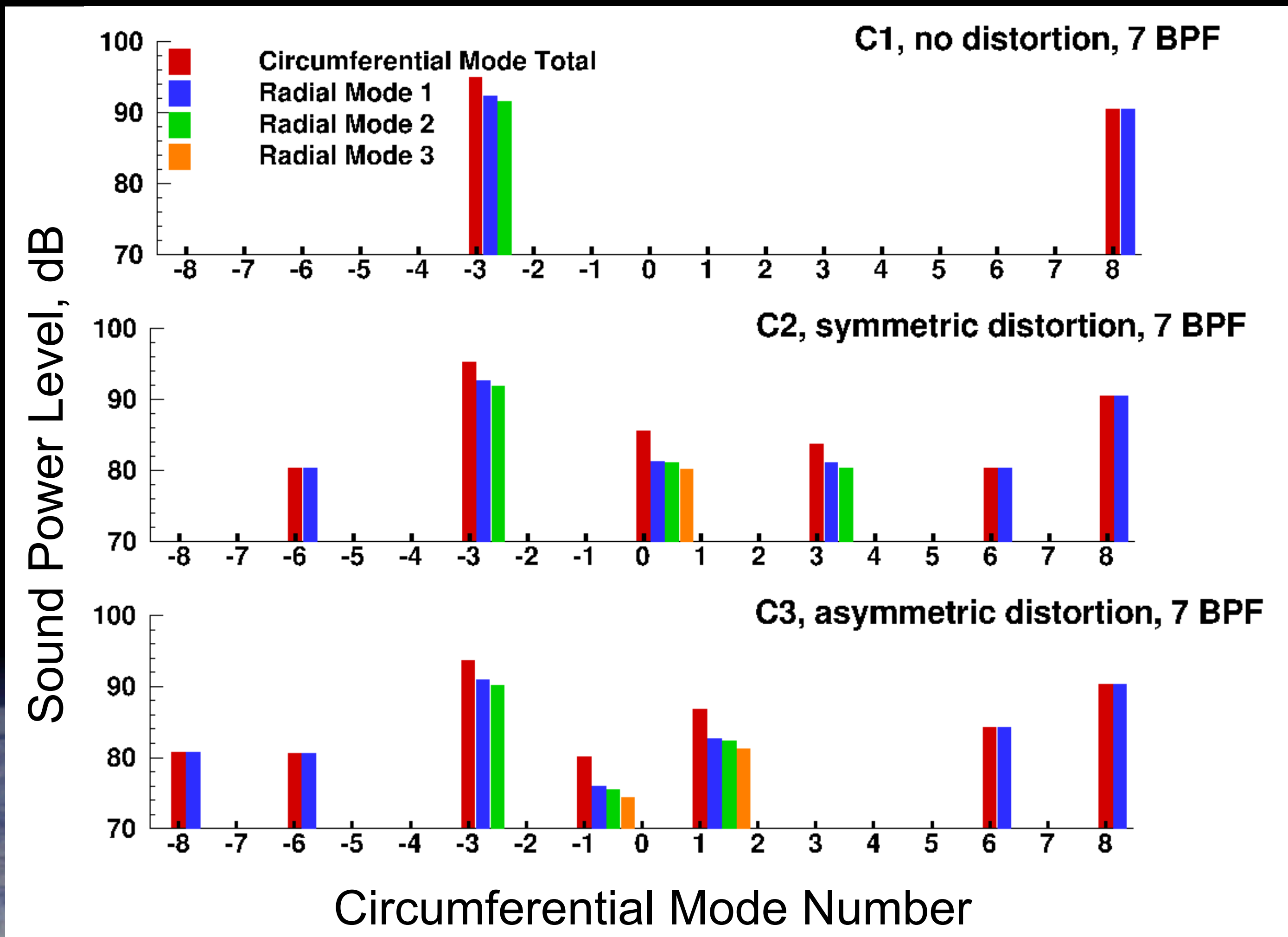


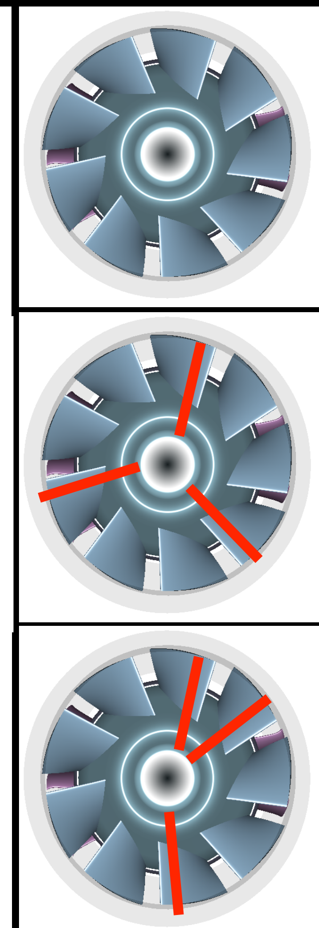


Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Duct Mode Sound Power Level Predictions

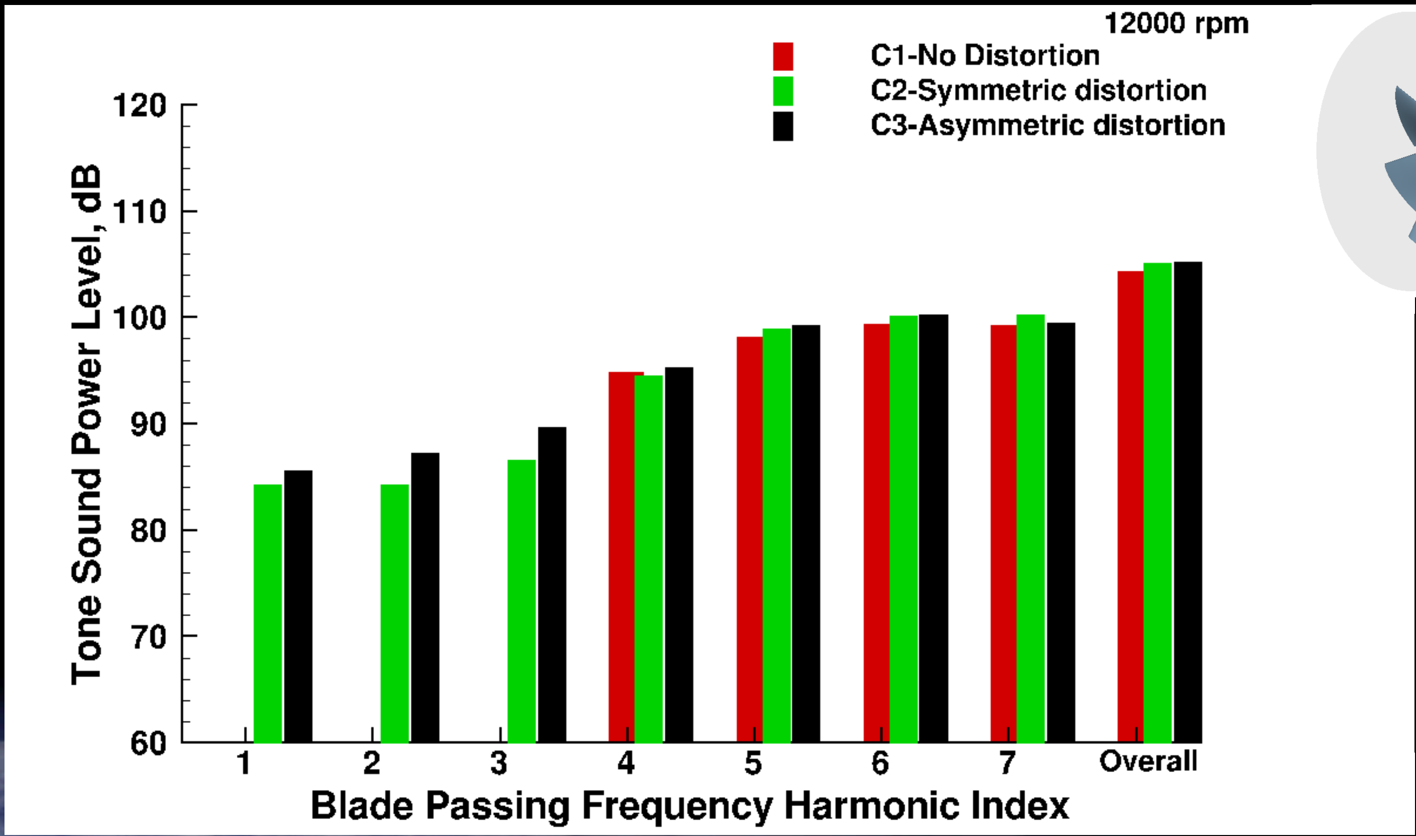
7 BPF

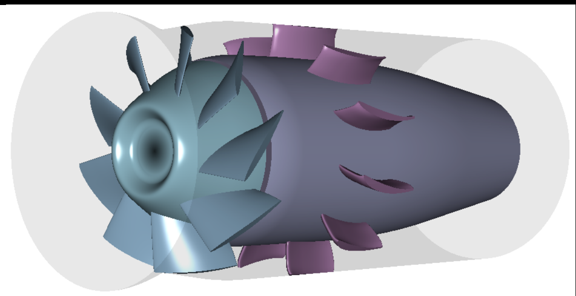




Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Tone Sound Power Level Predictions



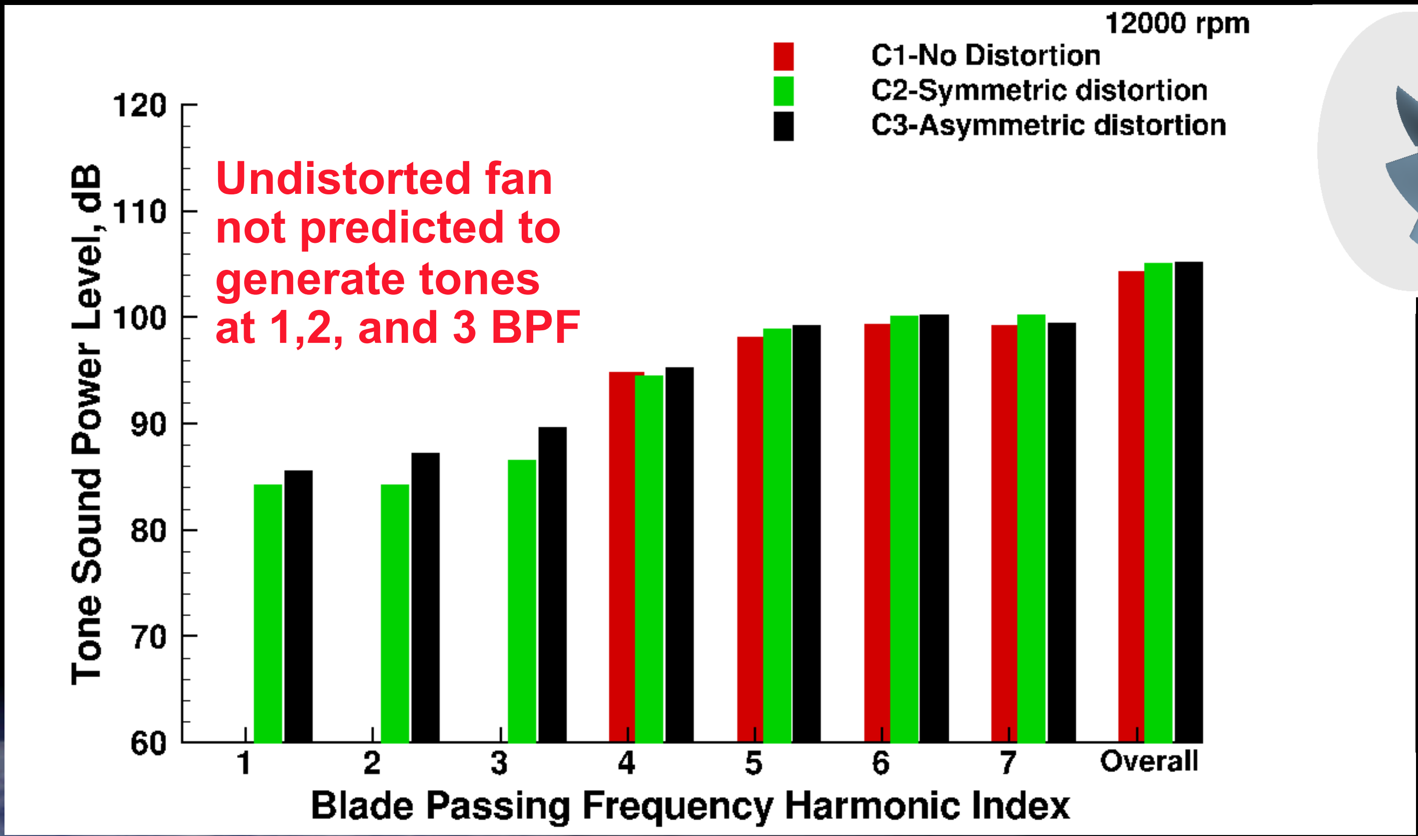


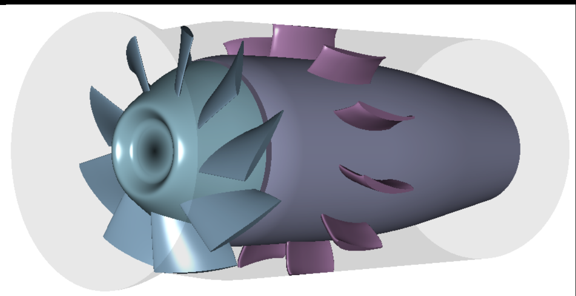
Conceptual Spacecraft Cabin Vent Fan
3.5 in. diameter
12,000 rpm
173 ft/s tip speed

Validation data is needed. Hypothesis: Predicted sound power levels at higher blade passing frequencies may be significantly higher than measurements, but trends in first few harmonics may aid in selecting low noise rod configurations.

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Fan Tone Sound Power Level Predictions



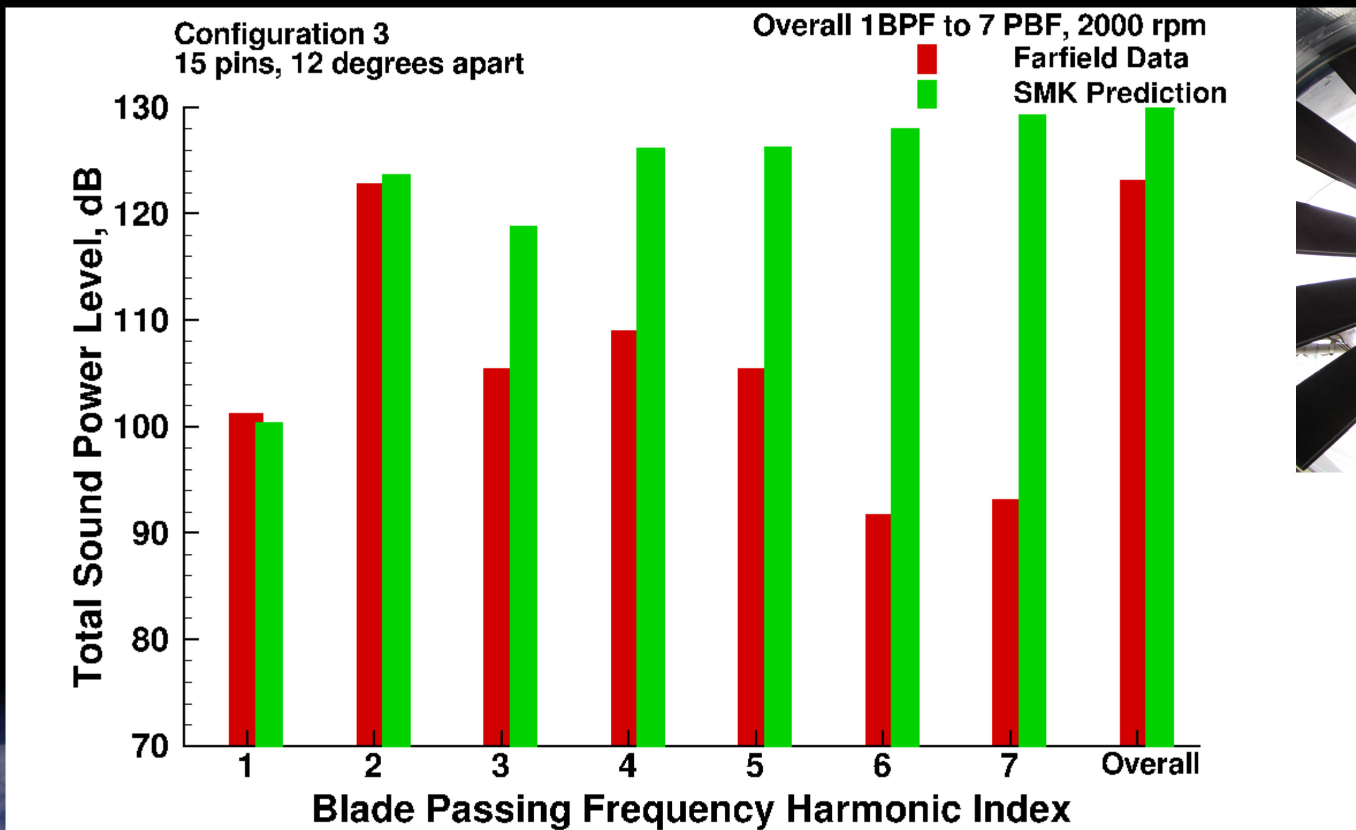


Conceptual Spacecraft Cabin Vent Fan
3.5 in. diameter
12,000 rpm
173 ft/s tip speed

Validation data is needed. Hypothesis: Predicted sound power levels at higher blade passing frequencies may be significantly higher than measurements, but trends in first few harmonics may aid in selecting low noise rod configurations.

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Advanced Noise Control Fan Validated Predictions

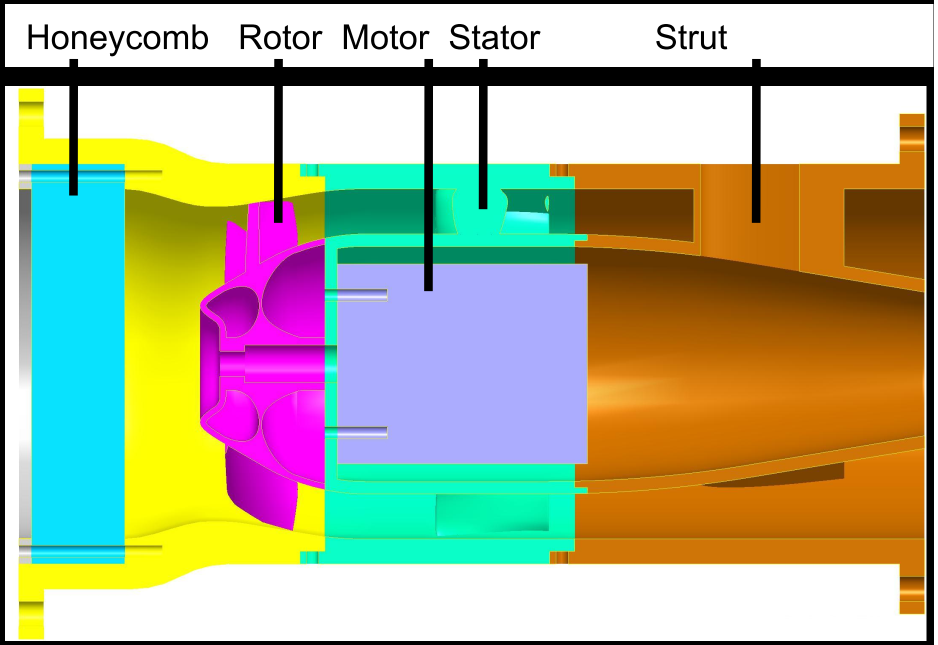


NASA Glenn
Advanced
Noise Control Fan
48 in. diameter
2,000 rpm
420 ft/s rotor tip speed

Validation data from this fan showed that predicted sound power levels at higher blade passing frequencies were significantly higher than measurements, but trends in first few harmonics were useful in selecting low noise rod configurations.

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Challenges of validation



Farfield sound pressure levels can be used to validate blade passing tone harmonic sound power level predictions. Test techniques may be needed.

Farfield sound pressure levels could be used to determine if motor noise is a significant source.

In-duct sound pressure level measurements are needed to validate duct mode sound power level predictions. Instrumentation may be a challenge given the size of the fan.

In-duct aerodynamic measurements are needed to validate aerodynamic predictions. Instrumentation may be a challenge given the size of the fan.

Tone Noise Predictions for a Spacecraft Cabin Ventilation Fan Ingesting Distorted Inflow and the Challenges of Validation

Conclusion

Tone noise predictions have been presented for a spacecraft cabin ventilation fan ingesting distorted inflow.

Acoustic and aerodynamic data is needed to validate all predictions for this fan. Test techniques still need to be identified for this fan, and the instrumentation needed for these tests must still be selected. Accommodating any instrumentation for in-duct acoustic or aerodynamic measurements is expected to be a challenge given the size of the fan.

Using the aerodynamic design of the spacecraft cabin ventilation fan as a starting point, a fan design suitable for a series of ground tests has been generated. Preliminary rotor stress analyses indicate that rapid-prototyping may be a cost-effective way to fabricate fan models for research.