

PLSS 2.5 Fan Design and Development

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NASA is building a high fidelity prototype of an advanced portable life support system (PLSS) as part of the Advanced Exploration Systems Program. This new PLSS, designated as PLSS 2.5, will advance component technologies and systems knowledge in order to inform a future flight program. The oxygen ventilation loop of its predecessor, PLSS 2.0, is driven by a centrifugal fan developed using specifications from the Constellation Program. PLSS technology and system parameters have matured to the point where the existing fan will not perform adequately for the new prototype. In addition, areas of potential improvement have been identified with the existing fan that could be addressed in a new design. As a result, a new fan was designed and tested for the PLSS 2.5.

The PLSS 2.5 fan is a derivative of the one used in PLSS 2.0. It uses the same non-metallic, canned motor, with a larger volute and impeller to meet the higher pressure drop requirements of the PLSS 2.5 ventilation loop. The larger impeller allows it to operate at rotational speeds that are matched to rolling element bearings, and which create reasonably low impeller tip speeds consistent with prior, oxygen-rated fans. Development of the fan also considered a shrouded impeller design that allows larger clearances for greater oxygen safety, assembly tolerances, particle ingestion, and improved performance.

Nomenclature

<i>ACFM</i>	Actual Cubic Feet Per Minute
<i>PLSS</i>	Portable Life Support System

I. Introduction

Exploration beyond low earth orbit will require an advanced extravehicular mobility unit (AEMU) to allow crew members to perform work and activities outside of their spacecraft, habitat or rover. NASA has been developing AEMU systems and technologies in preparation for these future missions. The first system, PLSS 1.0¹ was a breadboard that performed the functions of a PLSS, but without the tight packaging requirements or optimized components needed for a flight unit. A second PLSS was designed, built, and tested to advance key technologies, and progress the system and packaging towards a flight-like unit. This unit was designated as PLSS 2.0, and completed crewed testing at atmospheric conditions in 2015². The next system being constructed is designated as PLSS 2.5 and will use a balance of flight-like components in a package that is representative of a final volume.

The fan for PLSS 2.5 is based on the design used in PLSS 1.0 and PLSS 2.0. That fan used a non-metallic canned motor with rolling element bearings and a radial flow centrifugal impeller and volute³. It was shown to consume less than five watts into the motor at its nominal design point of 4.7 acfm, 2.7 inches of water head rise and

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4.3 psia operating pressure. The 2010 ICES paper titled, “Development of a Fan for Future Space Suit Applications” details the prior fan’s design and performance.

NASA’s PLSS design has matured through the PLSS 1.0 and 2.0 efforts, and requirements for the fan have matured with the system. With PLSS 2.5 now in the design stage, the previous fan is not expected to provide an adequate pressure head to the ventilation loop. The need for a new fan prompted a NASA and Hamilton Sundstrand Space Systems International (HSSSI) to develop the next iteration of the centrifugal fan (figure 1) while also evaluating a new, shrouded impeller design that is well-suited to this application.

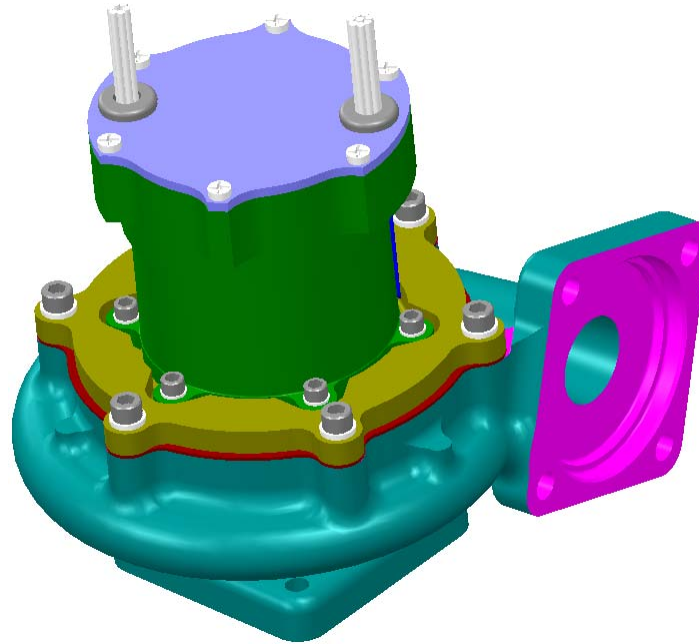


Figure 1. PLSS 2.5 Fan and Motor

II. Requirements and Analysis

PLSS 2.5 is being designed for a ventilation flow rate of up to 6.0 acfm at a nominal pressure of 4.3 psia of oxygen. The system pressure rise is 5.39 inches of water. In contrast, the previous fan’s nominal pressure rise was 2.7 inches of water at 4.7 acfm. As a result, the new fan will have to supply over two and half times more fluid power at its optimal design point. Table 1 shows the critical design criteria for the new fan, and how it compares to its predecessor and to the particular design requirements of PLSS 2.5. There are two differences between what the fan was designed to and what the PLSS 2.5 requirements state. First, the pressure rise needed for PLSS 2.5 was 5.29 inches of water, but the team designed the fan to optimally produce 6.0 inches of water head rise. The PLSS 2.5 requirements were not finalized at the time, and the choice was made to protect against increases in system resistance as the design PLSS design matured. Backing off on fan speed should give up little in efficiency if the system resistance is closer 5 inches while maintaining somewhat lower rotational speeds and tip velocities if the resistance grows slightly during design maturation. The second difference between the design point and the requirements is the operating temperature. The new fan uses the same motor as the previous fan, so 68 °F was carried over as the nominal operating temperature as well.

Table 1: Fan Design Criteria

	PLSS 1.0 Fan	PLSS 2.5 Requirements	PLSS 2.5 Fan Design Point
Flow Rate	4.7 ACFM	6.0 ACFM	6.0 ACFM
Pressure Rise	2.7 in H2O	5.39 in H2O	6.0 in H2O
Operating Temperature	68 °F	60 °F	68 °F

Operating Pressure	4.3 psia	4.3 psia	4.3 psia
Gas	Oxygen	Oxygen	Oxygen
Motor Input Power	6.0 W	N/A	12.1 W

The new fan should consume just over 12 watts into the motor at its optimal design point. Table 2 shows the predictions of fan performance, envelope and mass compared with the prior fan. The additional impeller torque puts the new fan onto a more efficient part of the motor curve, and the aero efficiency was predicted to be higher as well. As a result, the fan gains 7% in overall efficiency.

Concept	PLSS 1.0 Fan	PLSS 2.5 Fan
Flow (cfm)	4.7	6.0
O ₂ ΔP (in. H ₂ O)	2.70	6.0
Speed (rpm)	41,858	35,000
Impeller Torque (in-oz)	0.081	0.275
Motor Efficiency*	50.3%	59.0%
Aero Efficiency	55.7%	59.5%
Motor Input Power	5.51	12.1
Mass (lb _m)	0.91	1.08
Envelope (in ³)	29.7	27.3
Height (in)	2.600	2.60
Width (in)	3.460	3.00
Depth (in)	3.300	3.50

III. Design and Manufacturing

The fan was designed to re-use the high efficiency motor from its predecessor, along with the rolling element bearings, oxygen compatible bearing lubrication, and basic centrifugal approach that worked well for PLSS 1.0 and PLSS 2.0. Changes include a larger impeller and volute, the addition of an adapter plate to mate the existing motor with the larger volute, and a change to flanged face seals for the inlet and outlet ports. Figure 2 shows a scaled comparison of the two fans.

The fan's volute is machined from an aluminum casting, and its nominal impeller is machined aluminum. These are the same materials used in the prior fan, and in a similar fan designed for the Orion Multipurpose Crew Vehicle. The Orion fan was designed to operate with 100% oxygen at 4.3 psia as well, although it is larger, with slightly higher impeller tip speeds than either PLSS fan. The Orion fan was evaluated for oxygen compatibility by NASA's White Sands Test Facility and found to generally oxygen compatible, with little forward work. What does remain is a more thorough evaluation and test to determine if frictional heating of the impeller on the volute is credible. The low motor power and an anodized surface finish on the volute should both work to minimize or eliminate that ignition hazard, allowing the team to move forward with aluminum components at relatively low risk.

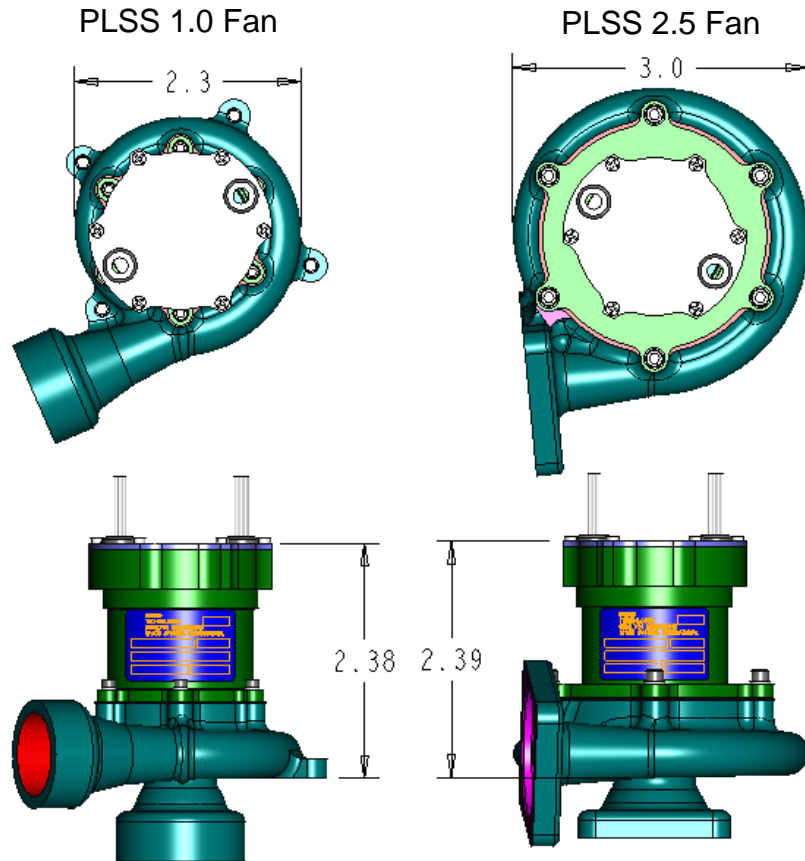


Figure 2. PLSS 2.5 Fan and Motor

Redesigning the fan for PLSS 2.5 provided the opportunity to evaluate an alternative impeller design that offered promise for the PLSS. The nominal impeller is shown in Figure 3a. It relies on very tight tolerances between the edges of the blades and the housing to achieve high aero efficiencies. Smaller gaps create higher efficiencies, but in fans as small as these, the ratio of blade height to clearance gap is still relatively low. Decreasing the gap height further creates increased difficulties with installation, temperature changes, deflections during operation, and poor tolerance to particle ingestion. A solution to these issues is to use a shrouded impeller, as shown in Figure 3b. The shroud eliminates the aero losses over the edges of the blades, but at the expense of increased drag between impeller. A first comparison of the two impellers was done via a student experiment at the University of Connecticut in 2011. Results from that experiment were inconclusive due to the use of a plastic housing rather than a more dimensionally stable metal housing, but they indicated that the shrouded impeller created a slightly more efficient fan. These positive results, combined with the potential benefits stated above, motivated the team to create a second version of the new fan, which used the shrouded impeller.

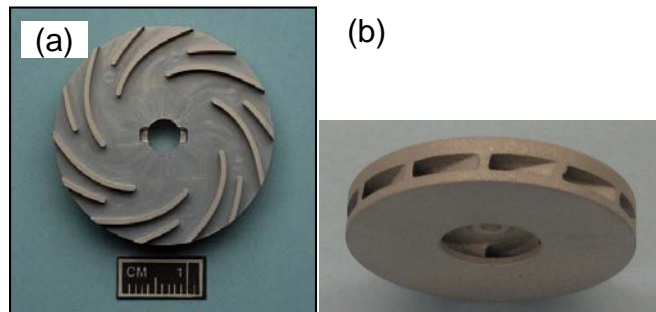


Figure 3. Open Impeller (a) and Shrouded Impeller (b)

The rough casting of the fan volute and housing is identical for both versions of the fan, with the same interfaces to the ventilation flow and motor. The final machining of the housing is slightly different to accommodate the different impellers. The greatest difference is that the shrouded impeller fan has three times the clearance gap between the impeller and the housing for most of its radius. The shrouded impeller itself is made from an aluminum casting with final machining steps for the critical dimensions. Figure 3 shows the rough casting of the shrouded impeller.

IV. Performance Testing

Both versions of the fan were assembled and tested using one of the spare motors from the prior PLSS 1.0 fan. The baseline open impeller fan was tested first, followed by the shrouded impeller fan. The fans were tested for performance at a range of speeds and head rise to create performance maps. Acoustic and thermal tests were also conducted on both fans. All testing was done using air as the operating fluid.

The fans were mounted in a $\frac{3}{4}$ " PVC circuit with a flow meter and a ball valve to vary system resistance. The setup is shown in Figure 4 and the fan test article is shown in Figure 5. The circuit was connected to a facility vacuum source. The circuit pressure was continually maintained at 4.3 psia.

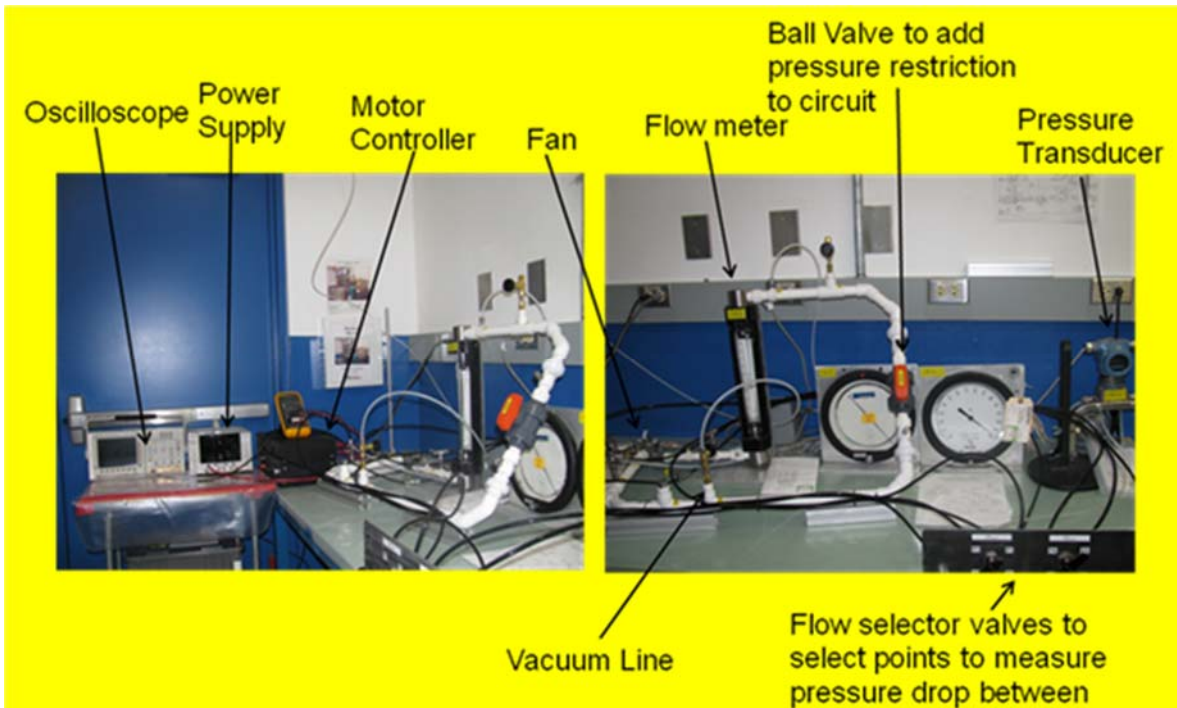


Figure 4. Fan Assembly Test Setup (Updated Photo due for final paper)



Figure 5. Fan Installed for Testing (Updated Photo due for final paper)

Figures 6 and 7 show the performance maps of the open impeller fan and the shrouded fan, respectively. Table 3 compares the performance for the fans at the design point.

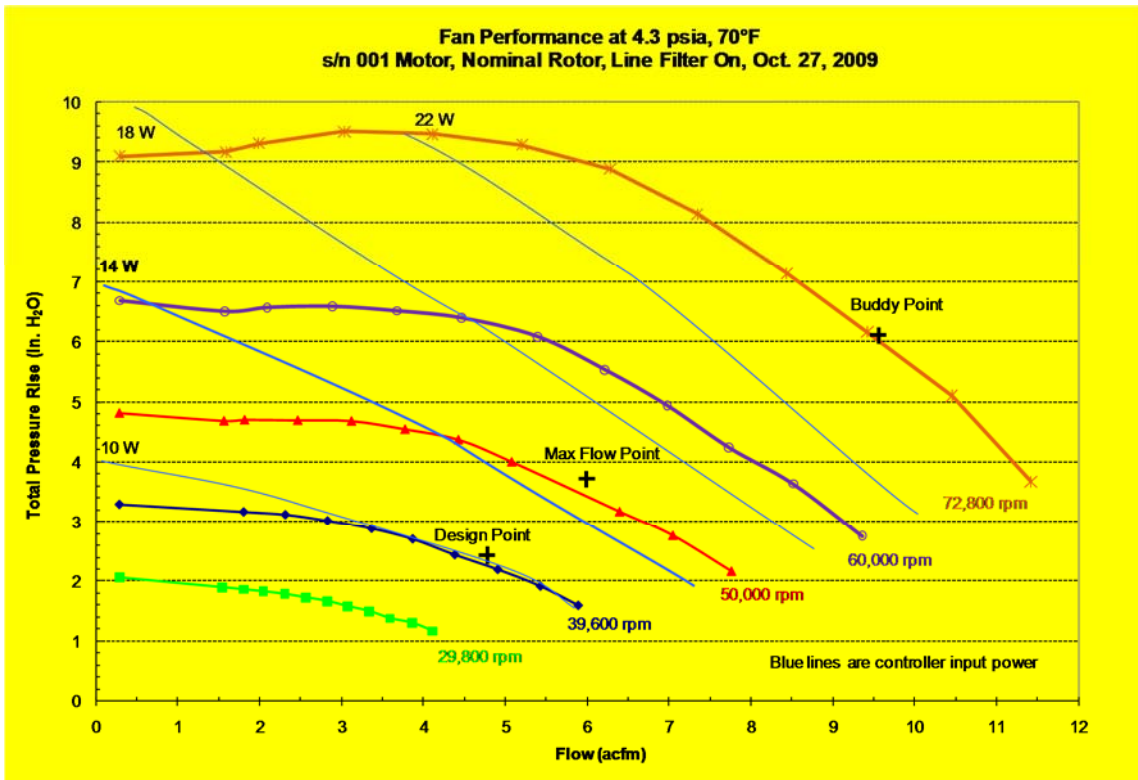


Figure 6. Performance map of open impeller fan at 4.3 psia (Updated flow map due for final paper)

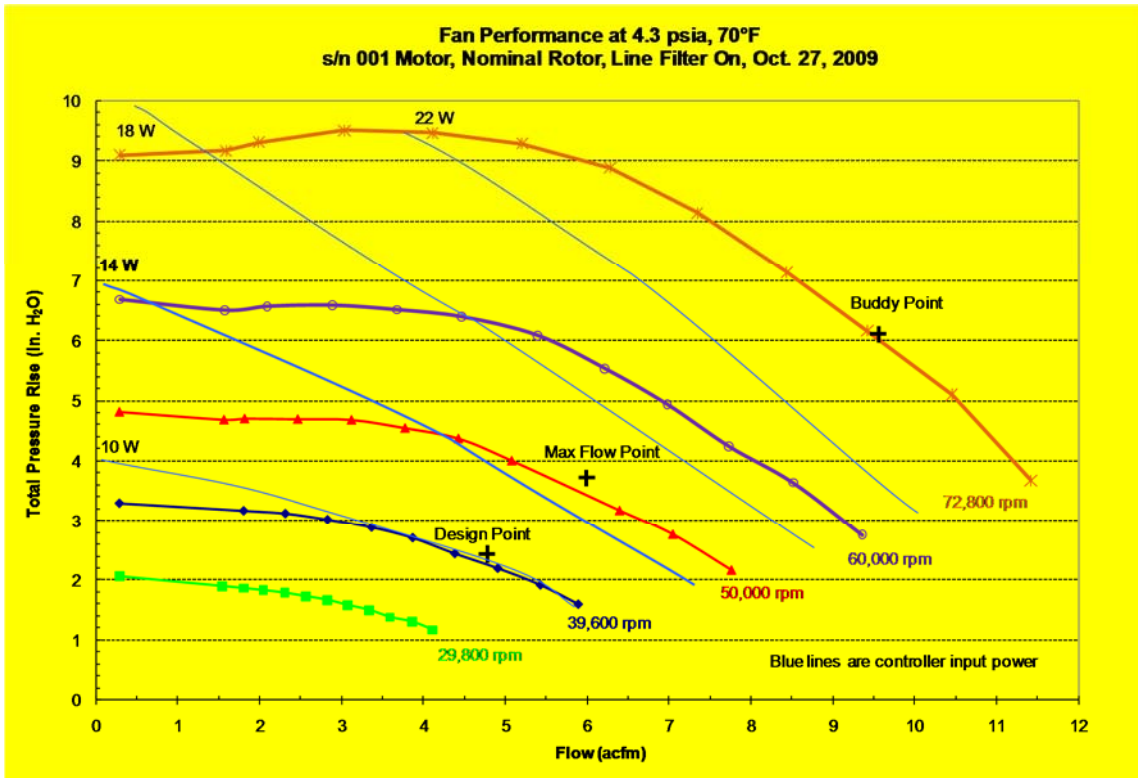


Figure 7. Performance map of shrouded impeller fan at 4.3 psia (Updated flow map due for final paper)

Results for the open impeller fan show that its efficiency is slightly higher than the PLSS 1.0 fan, which is consistent with the modeling predictions. The design point was met at [TBD] rpm and [TBD] watts. The power consumption was tbd % more/less than the model predictions. The shrouded impeller fan met the design point at [TBD] rpm and [TBD] watts, and proved...

The fans were tested for acoustic emissions at the design point. Acoustic test results are plotted in Figure 8, and show that both fans maintain the acoustic efficiency of their predecessor. They both exceed the NC-52 acoustic level target, but come within [TBD]% of the predicted noise level throughout the measured frequency range. Neither fan exhibits broadband noise as a result of turbulence or stall, but tonal noise does peak at the rotational and blade-pass frequencies (Figure 9). In the PLSS 2.5 design, the fan is located immediately upstream of the Rapid Cycle Amine carbon dioxide and humidity control system (RCA). The RCA is a packed chemical absorption bed that should provide significant acoustic attenuation, such that additional noise control methods might not be needed to meet the NC-52 level.

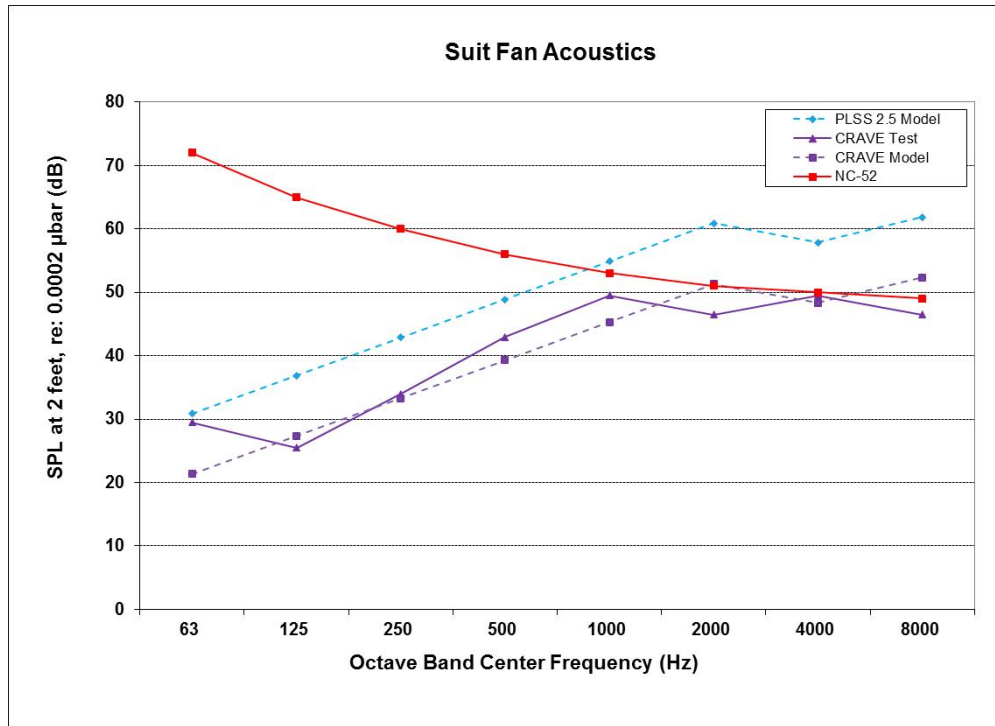


Figure 8. Acoustic Test Results Updated Acoustic Figure due for final paper

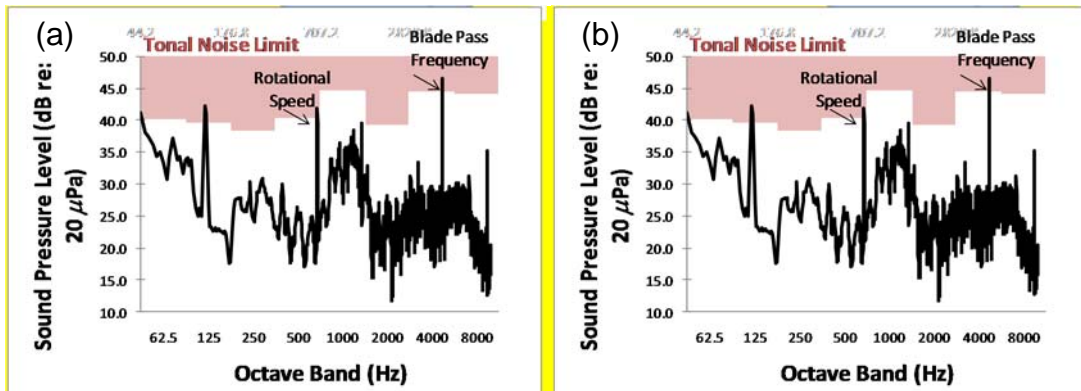


Figure 9. Tonal Acoustic Test Results a) Open Impeller Fan and b) Shrouded Fan Updated Acoustic Figure due for final paper

V. Conclusions

Two new centrifugal fans were designed to meeting the updated ventilation loop flow requirements of NASA's PLSS 2.5. The first fan is an upsized version of the ones used in PLSS 1.0 and PLSS 2.0, which used an open impeller design. The second fan used a shrouded impeller design, motivated by the potential for larger fan clearances and higher efficiency. White Sands evaluation of a similar fan for the Orion Multipurpose Crew Vehicle indicated that the oxygen flammability hazard for the fans was manageable, giving the team confidence in the continued use of aluminum housings and aluminum impellers.

Performance testing of the fans indicated that both designs met the predicted power consumption of less than 12.1 watts into the motor. The open impeller required [TBD] watts and TBD RPM to meet the design point conditions and the shrouded impeller took [TBD] watts and [TBD] RPM to meet the design point conditions.

Acoustic test showed that the fan outlet operates at [TBD] dB, which is above the desired level of 52 dB. However, downstream attenuation through the carbon dioxide and humidity removal system is expected to significantly attenuate the noise, such that fan design changes are not likely to be necessary based on acoustics. There was no significant difference in acoustic levels between the open and shrouded impellers.

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