NASA/TM—2013-217885

Acoustic Performance of Drive Rig Mufflers for Model Scale Engine Testing

David B. Stephens
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June 2013

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Acknowledgments

The acoustic design of the Open Rotor Propulsion Rig (ORPR) muffler was by The Boeing Company, with engineer Stefan Uellenberg as the point-of-contact. The acoustic design included details on the depth and density of the bulk absorber, as well as the perforated face sheet dimensions. The structural design of the ORPR muffler was done at NASA Glenn Research Center (GRC) by ASRC Aerospace Corporation engineer Jim Buckley. GRC engineer Daniel Sutliff recommended the acoustic excitation system. Based on measurements made in the Advanced Noise Control Fan, it was expected that individually driven and azimuthally distributed white noise sources distribute roughly equal energy into a wide range of duct modes. This is important because the frequency range of interest (15 to 25 kHz) and the dimensions of the present experiment suggest there would be dozens of cut-on duct modes. Thanks to Gilcrest Electric & Supply Company mechanical test engineer Devin Podboy and Sierra Lobo, Inc. electrical engineer Joseph McAllister who tested the ORPR muffler at the ATL. This study was funded by the NASA Environmentally Responsible Aviation (ERA) project.

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Acoustic Performance of Drive Rig Mufflers for Model Scale Engine Testing

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Abstract

Aircraft engine component testing at the NASA Glenn Research Center (GRC) includes acoustic testing of scale model fans and propellers in the 9- by15-Foot Low Speed Wind Tunnel (LSWT). This testing utilizes air driven turbines to deliver power to the article being studied. These air turbines exhaust directly downstream of the model in the wind tunnel test section and have been found to produce significant unwanted noise that reduces the quality of the acoustic measurements of the engine model being tested. This report describes an acoustic test of a muffler designed to mitigate the extraneous turbine noise. The muffler was found to provide acoustic attenuation of at least 8 dB between 700 Hz and 20 kHz which significantly improves the quality of acoustic measurements in the facility.

Introduction

Aircraft engine component testing in the 9- by 15-Foot Low-Speed Wind Tunnel and 8- by 6-Foot Supersonic Wind Tunnel complex at NASA Glenn Research Center (GRC) utilizes compressed air turbines to drive fans and propellers. These turbines have good power density and provide reasonably steady output when used with feedback-enabled computer controlled valves. NASA GRC owns three drive rigs that have been used for acoustic testing: the Ultra-High Bypass (UHB) drive rig, the Open Rotor Propulsion Rig (ORPR), shown in Figure 1, and the Single Rotation Propeller (SRP) drive rig. An overview of the 9×15 LSWT is provided in the report by Soeder (Soeder, August 1993).

During the early part of the open rotor test campaign conducted during 2009 and 2010 (Van Zante, 2011), it became evident that the measurements being made in the 9×15 LSWT were louder than comparable measurements made by GE in their facility known as Cell 41 (private correspondence). The cited frequency range of concern was 15 to 25 kHz. The air turbine power system in the ORPR was identified as the likely culprit. A similar rig was previously used by GE in Cell 41, however the exhaust from that drive rig was ducted out of the facility while the ORPR turbine exhaust is directly into the wind tunnel in the immediate vicinity of the fan being tested. This drive rig has two separate two-stage turbines that are rated to produce 750 hp each and can run at more than 8000 rpm. Depending on the power output and rpm required by the fan, these turbines can combine to consume more than 30 lbm/s of 300 psi air. To reach certain engine operating conditions, the turbines may be operated far off of their design point, resulting in low efficiency and possibly contributing to excessive noise generation.

The remainder of the present document describes an acoustic test of the muffler designed for use with the ORPR, as well as performance measured during operation in the 9×15 LSWT. Results are also shown from applying the same acoustic testing scheme to other drive rig mufflers.

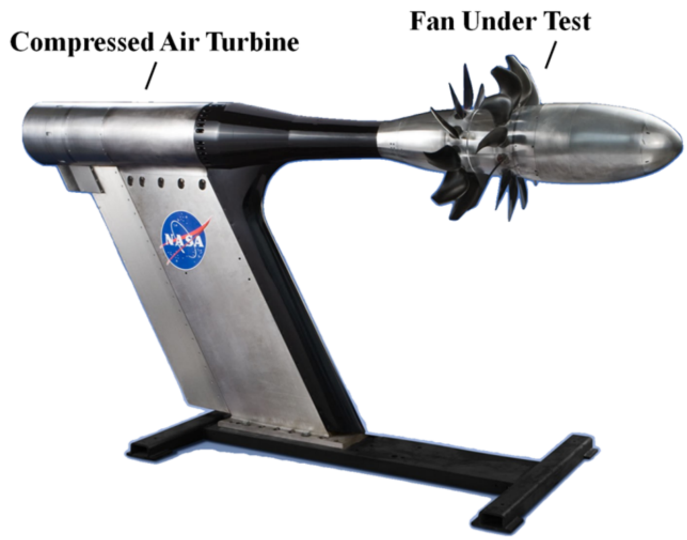

Figure 1.—Open rotor propulsion rig.

TABLE 1.—MAJOR DIMENSIONS OF ORPR MUFFLER

Length	45 in.
Inside diameter	10.5 in.
Treated length	42 in.
Acoustic material	Tex Tech P/N 8995 Unwoven Nomex 0.65 in. thick, 79 oz/sq-yd Not water repellant Not singed
Perforate sheet	300 Series stainless 0.036 in. thick 1/16 in. diameter holes 41% porosity

ORPR Muffler Description

The acoustic design of the ORPR muffler was specified by The Boeing Company. The specifications included the choice of perforated sheet steel, perforate size, sheet thickness and percent open area, as well as to the thickness and density of the liner, as summarized in Table 1. The mechanical design was done by ASRC Aerospace Corporation. A schematic of the muffler is shown in Figure 2. Mechanically, it is a perforated stainless steel tube with a cylindrical grid of ribs and stringers welded in place for structural reinforcement. The grid is filled with an unwoven Nomex fiber mat provided by Tex Tech Industries. A two-piece “clamshell” exterior cover provides access to the Nomex treatment in case replacement is required, and also serves to slightly compress the material. There has been concern that the oil used to lubricate the drive rig escapes into the turbine exhaust air stream and could saturate the Nomex treatment, resulting in reduced acoustic attenuation and requiring replacement of the material.

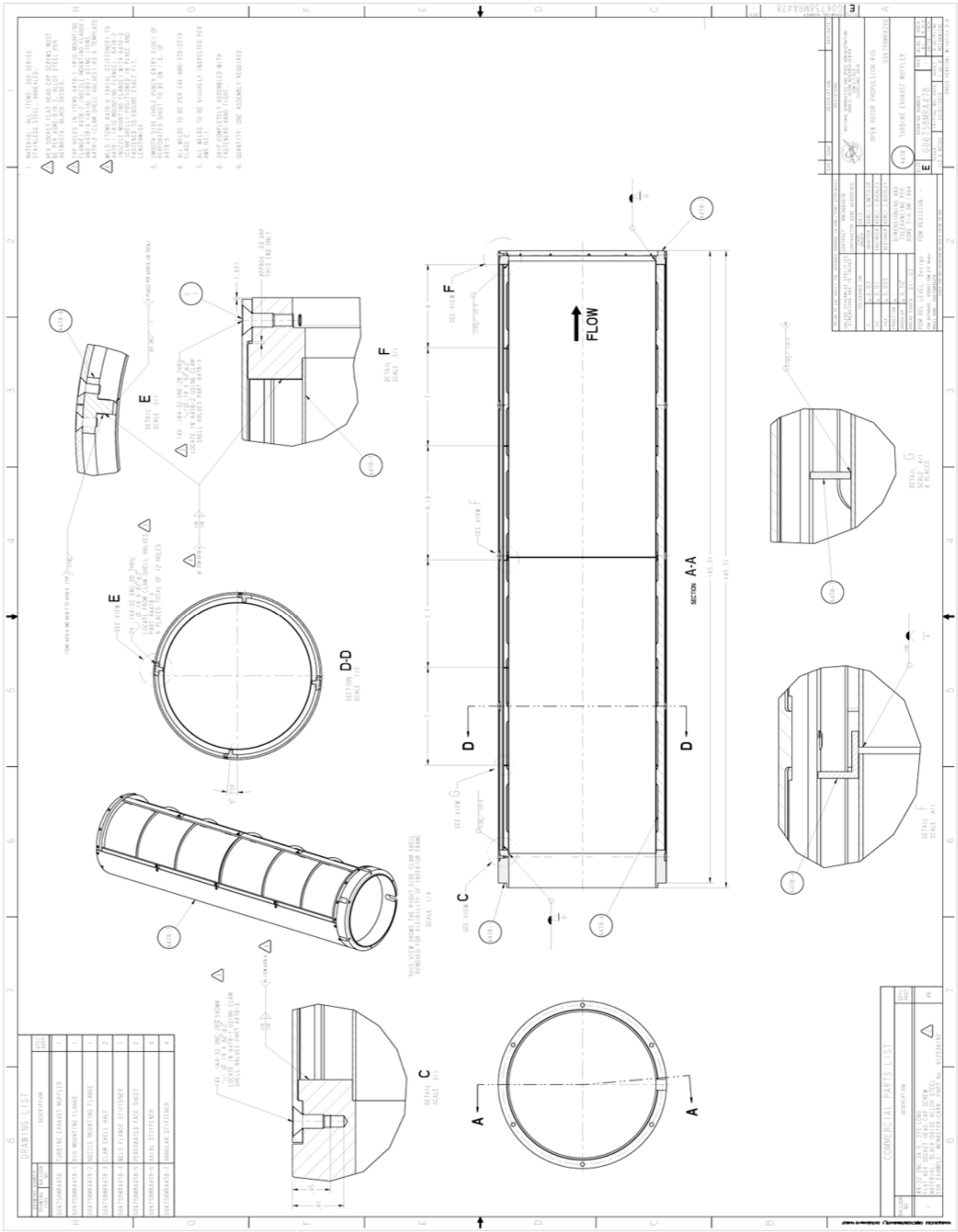

Figure 2.—Design drawing of ORPR muffler.

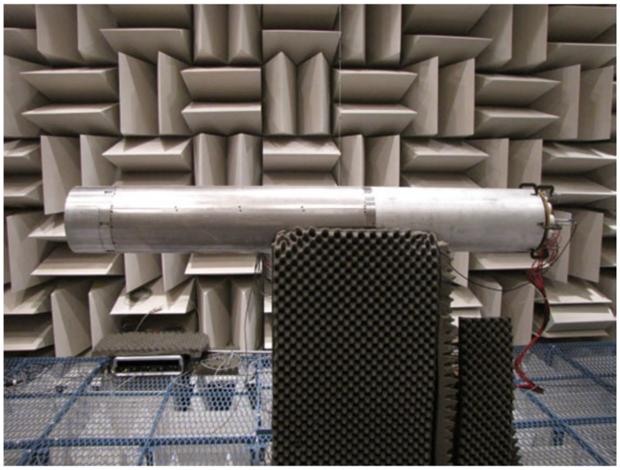

Figure 3.—Muffler on test stand in ATL. L-R: Exhaust nozzle, ORPR muffler, aluminum extension, speaker plate.

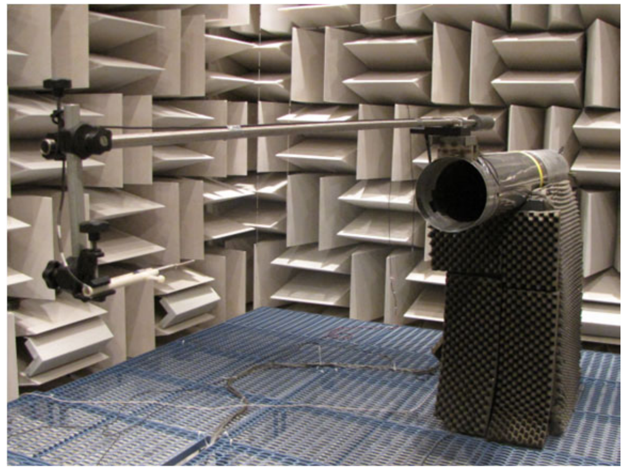

Figure 4.—Muffler on test stand in ATL. Directivity boom and microphone shown.

Facility

The Acoustical Testing Laboratory (ATL) is an anechoic chamber located at GRC that was utilized for this test. A report by Cooper (Cooper, 2000) describes the ATL. The chamber has usable interior dimensions of 21 by 17 by 17 ft. A 36 in. deep fiberglass anechoic wedge treatment with a high-open-area perforated metal facing provides 99 percent normal incidence sound absorption at frequencies at and above 100 Hz. Photographs of the ORPR muffler are given as Figures 3 and 4.

Equipment

Sound Source

A sound source for this test was constructed from ten D2004/602000 ScanSpeak 3/4 in. tweeters. These drivers were selected for their small physical footprint and significant frequency response up to 40 kHz. A circular plate was constructed to mount the 10 tweeters in an evenly spaced ring. The speaker plate is shown in Figure 5 and is shown attached to the ORPR muffler in Figure 6. The reverse side of each speaker was covered with a plastic cap, to keep sound from leaking out the back of the source plate. This aspect of the design could be improved, since noticeable sound was found to escape from the reverse of the source plate when it was installed on a muffler. This sound was clearly a tiny fraction of the sound generated in the front of the speaker plate, but was enough to be of some concern for cases when the measurement location was much closer to the speaker plate than the outlet of the muffler.

The source plate speakers were driven with 10 separate white-noise signals. At the beginning of the acoustic test campaign, the speaker plate was mounted on a tripod in the ATL and the radiated sound was measured with a single microphone along the axis of the plate at approximately 2 m distance. The measured sound pressure spectral density level is shown in Figure 7. This shows that the sound level was at least 40 dB at 2 m between 400 Hz and 47 kHz. The background noise level was typically around 2 dB, as shown.

It was decided that determining and reproducing the specific modal content generated by the drive turbine was beyond the scope of this project. The use of 10 speakers increases the noise level generated, and provides the potential for future mode-specific excitation.

Figure 5.—Speaker plate lying on the floor of the ATL. A reference microphone is mounted in the center and extends into the hard walled adapter.

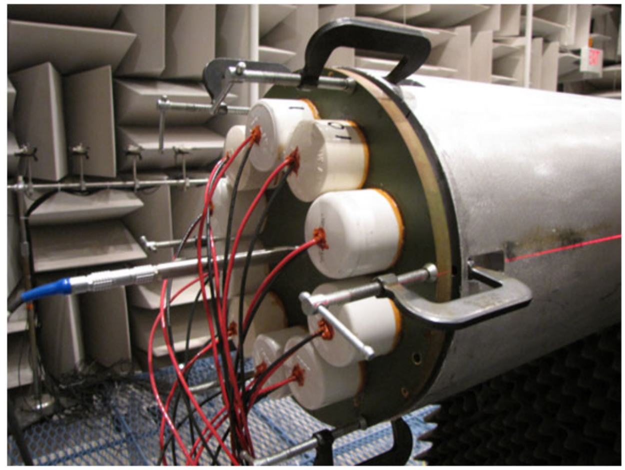

Figure 6.—Speaker plate installed on muffler. The outside of each speaker is covered with a plastic cap to ensure all sound reaching the far field microphones passes through the muffler.

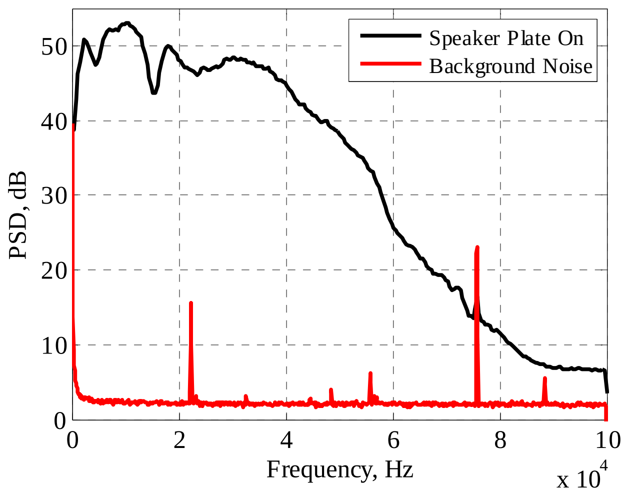

Figure 7.—Radiated sound level generated by speaker plate measured by a microphone at approximately 2 m distance along the axis of the speaker plate.

A National Instruments PXI chassis with analog output cards was used to generate the 10 separate white noise signals for the speakers. The signals were passed to two 6-channel Rane Amplifiers that were then used to drive the speaker plate. A microphone was located in the center of the source plate to provide a reference of the source during operation, as seen in Figure 5. The tweeters are highly directional, however, and this location was found to be less than ideal for monitoring their output.

Microphones

The microphones used for this experiment were Brüel & Kjaer 1/4 in. 4939 condenser microphones, powered by B&K Nexus amplifier/power supply units. They were calibrated at the beginning of each test day using a pistonphone. Data was acquired using a 32-channel Nicolet Odyssey data acquisition system, and exported to MATLAB (The Mathworks, Inc., Natick, MA) format for analysis. The microphone signals were low-pass filtered at 100 kHz and sampled at 200 kHz in 5 sec long records.

Hardware

The muffler was mounted on a test stand, as shown in Figure 3 and Figure 4. During testing, the stand was covered with acoustic foam in order to reduce reflections of sound waves. A separate hard wall adapter was used between the sound source and the muffler to reduce near-field effects in the vicinity of the speaker plate. Specifically for the ORPR muffler test, this hard wall adapter was the 23 in. long aluminum exhaust extension designed for use in the wind tunnel.

Test Procedure

Three test configurations were devised. Each configuration was run with the muffler treatment exposed, and with the treatment covered by aluminum tape in order to simulate a hard wall condition. The three test configurations are described in the following subsections.

Sideline Test

The sideline test was designed to replicate the geometry of the muffler installed on the ORPR in the 9×15 LSWT. In the wind tunnel, the measurement locations were a 5-ft sideline at specific angles from the center of the fan being tested. A line array of microphones was placed at the appropriate locations to represent the position of the measurement points in the wind tunnel, accounting for Mach 0.2 flow. Figure 8 shows the scale of the ORPR in the 9×15 LSWT, along with the acoustic array. Measurement locations 1, 5, and 9 are highlighted. Due to space limitations in the ATL, only the aft-most 9 microphone stations were used.

The sideline test was surprisingly ineffective because very little sound reached the microphones, even with the hard wall condition. When the ORPR muffler was tested with the treatment exposed, it was found that the attenuation was large enough that the signal was barely above the background level. Therefore, no data from the sideline test is reported in this paper. For this test to be successful a sound source dramatically louder than the speaker plate would be required.

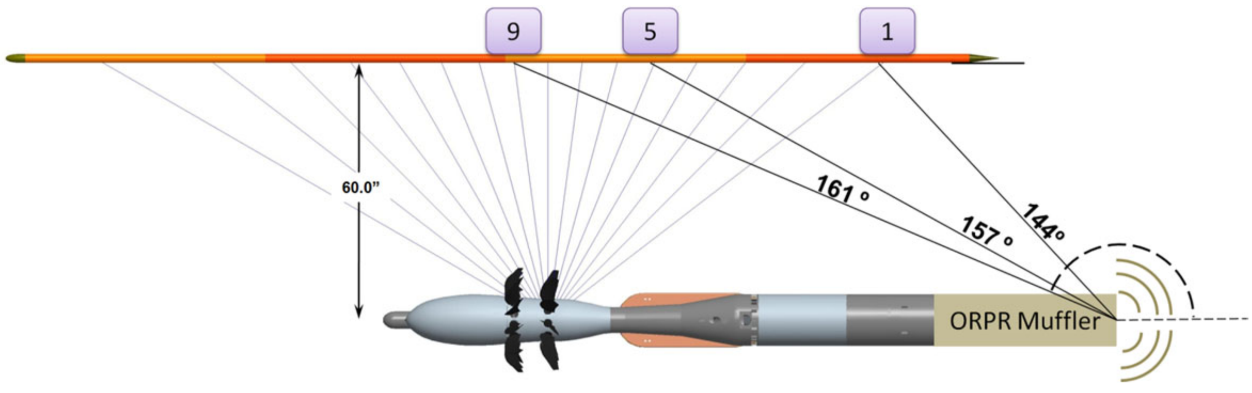

Figure 8.—Geometry of 9×15 LSWT showing a drive rig and muffler, along with acoustic array sideline measurement locations.

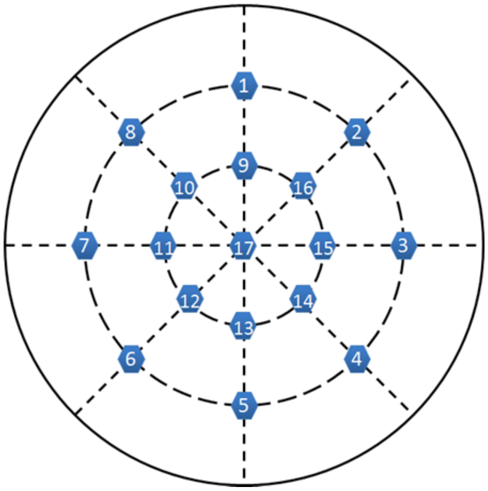

Figure 9.—Exit plane survey locations used for configuration 2 testing.

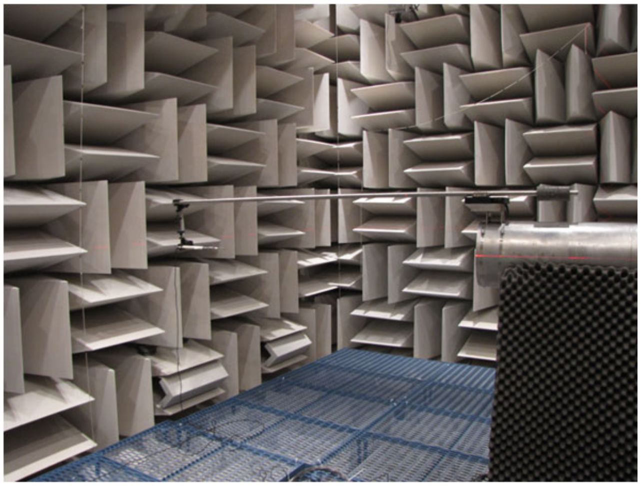
Figure 10.—Boom arm mounted to muffler for directivity survey.

Exit Plane Survey

This test was used to document the muffler insertion loss, defined as the acoustic power absorbed by the treatment. A spatial survey of the muffler exit plane was conducted by moving a single microphone around 17 locations, as shown in Figure 9. The survey locations were a combination of eight azimuthal angles (every 45°) and two radii (1/3 and 2/3 of the muffler inside diameter) along with the center of the exit plane. A cardboard template with the appropriate locations was used to align the microphone at each location, which was then tested individually. The signal-to-noise ratio was excellent for this configuration, even at frequencies above 60 kHz.

Directivity Survey

A microphone was traversed using a boom arm mounted to a turntable centered about the exit plane of the muffler. Angle increments of 10° between –170° and 170° (with the downstream axis of the muffler defined as 0°) provided a reasonable balance between resolution and acquisition time. This test served as a more thorough directivity test than the sideline survey, as well as a secondary insertion loss measurement. The muffler with boom arm attached is shown in Figure 10.

Data Processing

For all test configurations, microphone measurements were acquired both with and without the acoustic treatment exposed. Narrow-band spectral densities were then computed using Welch's method in MATLAB. The ratio between the two spectra is defined as the frequency dependent acoustic attenuation of the muffler, as given in Equation (1). This equation can also be expressed as the difference in decibel levels.

$$\text{Attenuation (dB)} = 10 \log_{10} \frac{\text{Hardwall}}{\text{Treatment Exposed}} \tag{1}$$

As defined in this report, attenuation is a point measurement quantifying the reduction in sound pressure level while *insertion loss* is the reduction in sound power level, calculated by integration of sound pressure over a surface.

Measurement Results and Discussion

Exit Plane Results

Measured sound pressure density spectra as measured by the microphone in exit plane location 1 are shown in Figure 11, both with acoustic treatment exposed and in hard-wall configuration. This result is quantitatively similar for all the exit plane survey locations, and is presented to show the total sound levels measured as well as to illustrate the variations between the different measurement locations. Measurements were found to be a slightly more dependent on radial location than on azimuthal location.

The spatially integrated attenuation can be considered the insertion loss of the muffler. This result is shown in Figure 12. The ORPR muffler has attenuation of up to 35 dB, including approximately 20 dB of attenuation between 1.2 and 7 kHz, and at least 10 dB of attenuation between 700 Hz and 20 kHz.

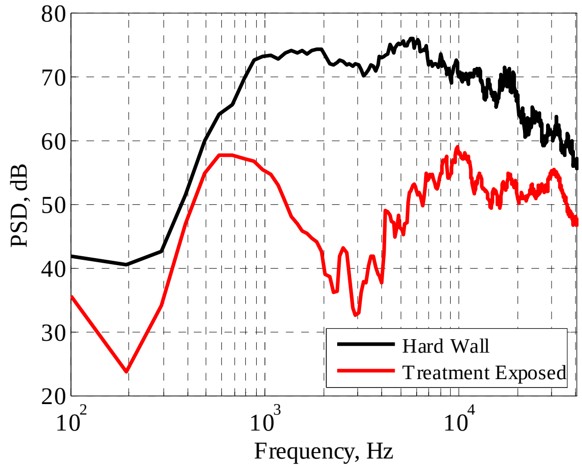

Figure 11.—Sound level measured at location 1 during exit plane survey.

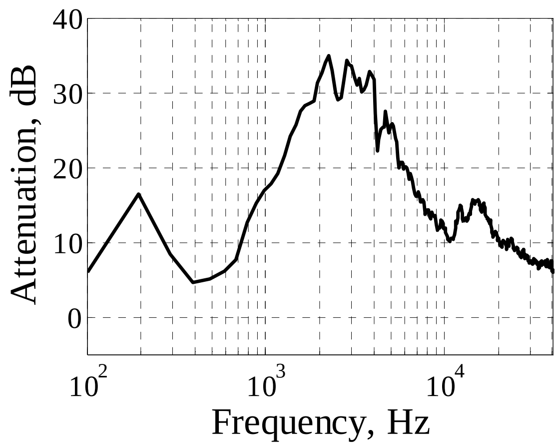

Figure 12.—Insertion loss of ORPR muffler measured by exit plane survey.

Directivity Survey

The directivity survey can also be used to quantify the insertion loss of the muffler, but it provides the additional detail about the effectiveness of the muffler in treating sound propagating at specific angles from the duct exit. The directivity of sound radiated from a circular pipe was considered by Levine and Schwinger (Levine & Schwinger, 1948). They defined a power-gain function $\frac{P(\theta)}{P_{rad}/4\pi}$ as the ratio of the power leaving the end of the muffler to that radiated at a specific angle. Using Equation (VI.9) in their report, this function was evaluated for the geometry of the ORPR muffler in order to estimate the expected directivity of the radiated sound. The result is shown in Figure 13, showing that higher frequencies tend to radiate along the axis of the duct, while lower frequencies tend to radiate more equally in all direction.

In Figure 14, the radiated sound level with the hard wall condition is shown, with the downstream axis of the muffler defined as 0°. The radiated sound directivity is seen to be nearly symmetric. Additionally, most of the sound is radiated between ±45°, while the angles where the microphone array is located in the 9×15 LSWT begin at 144°, as shown in Figure 8. The frequencies of interest (15 to 25 kHz) are 25 to 35 dB lower at 135° than on-axis.

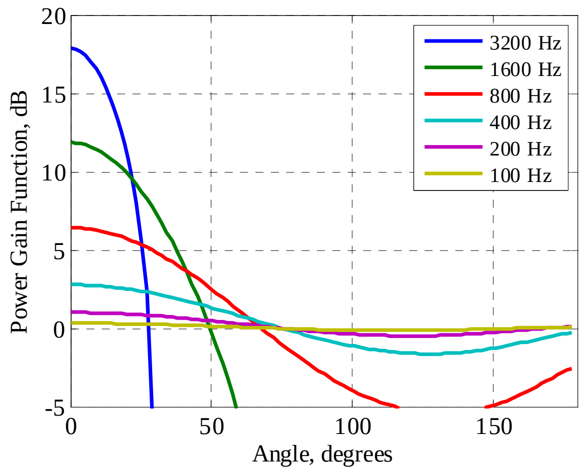

Figure 13.—Power-gain function for muffler.

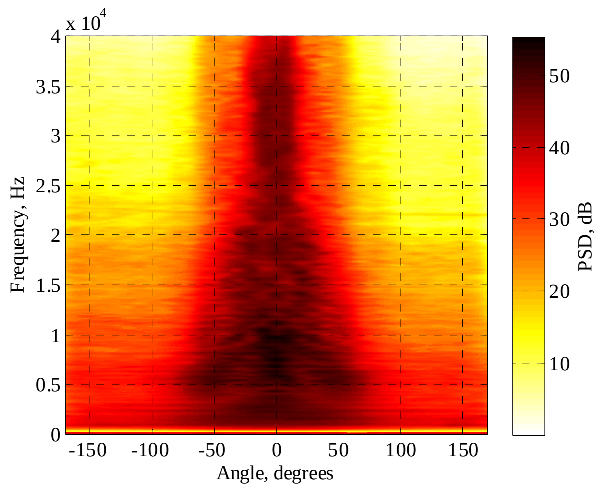

Figure 14.—Hard-wall directivity. Radiated sound normalized by on-axis spectra.

The directivity measurement was repeated with the acoustic treatment exposed. The attenuation is shown in Figure 15. The treatment was found to have little effect on the sound radiating along the axis of the muffler. This direction is downstream in the wind tunnel so it is not particularly important to sideline measurements. Peak attenuation was found to be 39 dB at +20° and 3.2 kHz. Significant attenuation is focused along ±45°, with around 25 dB attenuation up to 20 kHz. More relevant to the engineering problem at hand, 15 dB of attenuation was measured at all angles bigger than ±20° and up to 20 kHz.

The directivity survey provided another method for quantifying the insertion loss, shown in Figure 16. This result agrees reasonably well with the exit plane survey shown in Figure 12. The exit plane survey takes place in the acoustic nearfield of the duct exit, while the directivity survey would be considered a far field measurement at frequencies over 1 kHz. There may be effects due to diffraction of various duct modes around the muffler exit, which would not be measured by the exit plane survey.

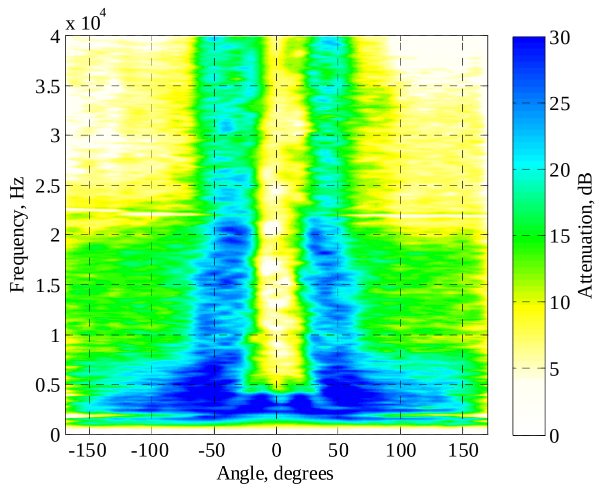

Figure 15.—Attenuation directivity of ORPR muffler. Difference between radiated sound spectra with hard-wall case and with treatment exposed.

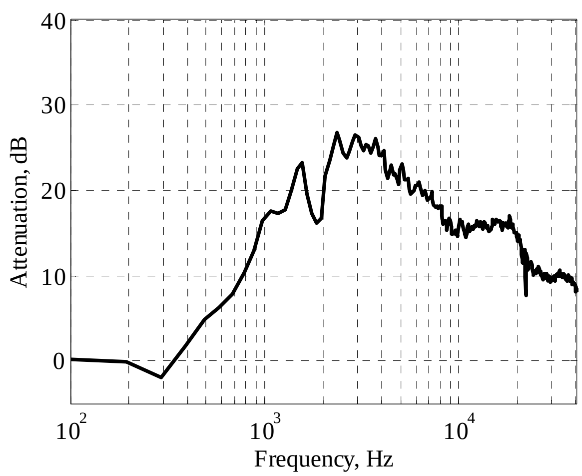

Figure 16.—Insertion loss of ORPR muffler measured by directivity survey.

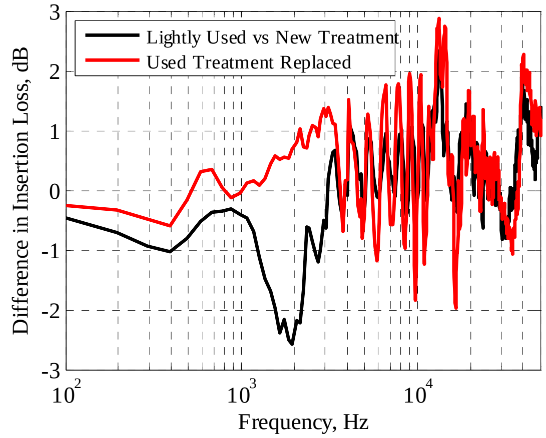

Figure 17.—Repeatability of exit plane test.

Repeatability

A significant motivation for this test was to quantify any deterioration in the acoustic performance of the muffler due to drive rig operation. The drive rigs leak oil during operation, and some of this oil ends up in the turbine exhaust, and thus in the muffler. The ORPR muffler was designed such that the acoustic treatment could be replaced, which provides a way to study the effect of oil saturation on acoustic performance.

The ORPR muffler was needed for testing in the 9×15 LSWT as soon as it was available. It was operated for 138 hr over six weeks before the tests documented here were performed. As part of the acoustic testing, the used treatment was replaced with new material, and the exit plane and directivity tests were repeated. The perforated steel sheet was noticeably oily, although the used material was not. The clean treatment was not found to provide any higher attenuation than the lightly used Nomex treatment, so the used treatment was replaced and re-tested before being returned to the 9×15 LSWT for further open rotor testing. The muffler was removed from the ATL and disassembled at the Aero-Acoustic Propulsion Laboratory (AAPL) at GRC for treatment replacement between each test.

Results comparing the new and used treatment and the two measurements of used treatment are shown in Figure 17, which compares the difference in exit plane surveys from each of the three tests. The same hard wall data was used for all three cases. The results suggest that the measurements are accurate to within ±2 dB, and that there was no measureable degradation of the treatment due to the 138 hr of run time. The differences reported in this figure may be because of actual attenuation differences of the muffler due to the way the treatment was installed. They could also be caused by imprecision in the setup in the ATL.

Wind Tunnel Measurements

The ORPR muffler was attached as designed on the drive rig in the 9×15 LSWT for open rotor testing. Radiated sound measurements were available of the F31/A31 blade set at the same operating conditions, with and without the muffler installed. The aft-most traversing microphone location was used for the example radiated sound measurements which are presented in Figure 19. This result shows approximately a 10 dB decrease in sound level over a very wide range of frequencies, essentially between 2 and 100 kHz. Besides attenuating drive rig noise in the exhaust, the muffler has the additional effect of moving any source of jet noise downstream by 3.5 ft. Neither jet noise nor turbine noise from the drive rig is expected to produce sound at these high frequencies however, so the noise source in these cases is unknown. With regard to improving the background noise level in the wind tunnel, the muffler was found to be a dramatic success. The ORPR muffler is shown installed on the rig in the 9×15 LSWT in Figure 18.

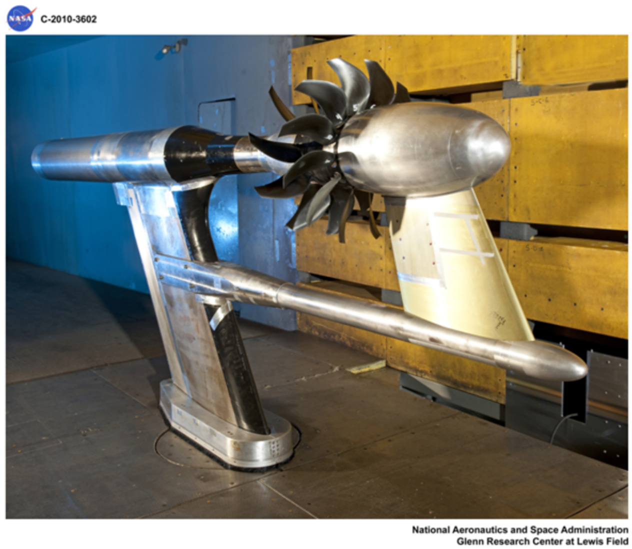

Figure 18.—Open rotor propulsion rig (ORPR) in the 9×15 LSWT with new muffler attached.

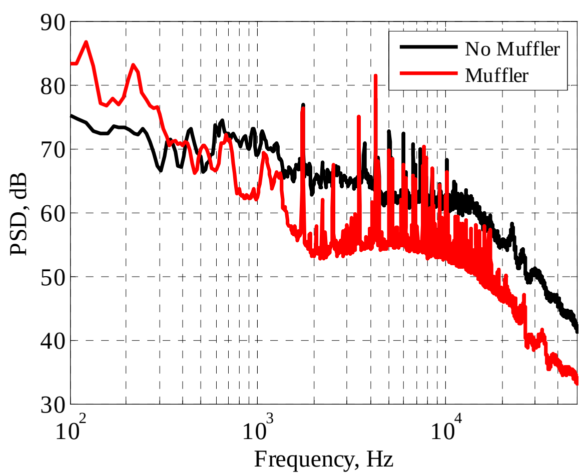

Figure 19.—Radiated sound measured from open rotor test in 9×15 LSWT using F31/A31 blades.

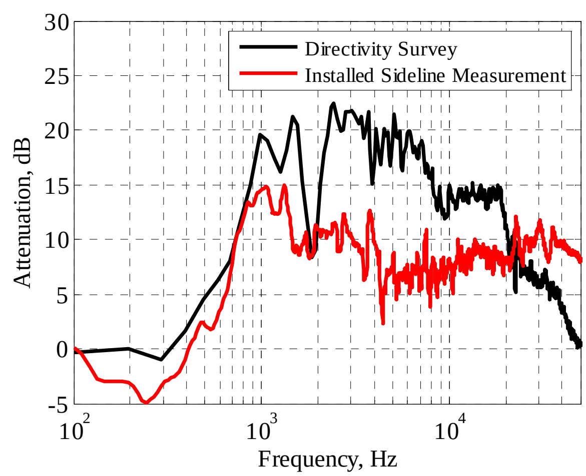

Figure 20.—Comparison of attenuation measured at sideline location in the 9×15 LSWT with measurement at 144° from directivity survey.

The total difference in measured sound level due to the muffler is shown in Figure 20, with the directivity survey for the appropriate upstream angle shown for reference. This installed attenuation was calculated as the maximum difference measured over a variety of test conditions, but is reasonably representative of any single run. The wind tunnel test shows less attenuation than the anechoic chamber below 20 kHz. This is probably because the fan model under test combined with tunnel noise defines the background noise level, so additional attenuation due to the muffler cannot be measured. Above 20 kHz, the wind tunnel test shows higher noise reduction than the anechoic chamber. This can be explained as a reduction in muffler noise due to the additional length between the muffler exit and the microphone location, compared to the “no muffler” case. Below 400 Hz, a 5 dB increase in radiated sound level was observed. This may be due to low-frequency resonance within the lengthened exhaust duct. The broadband level measured in the tunnel was lowered across a wide frequency band at all traverse locations, decreasing from around 7.5 dB at 10 kHz for the downstream most microphone location, as shown in Figure 19, to 3 dB at 10 kHz for the forward most location.

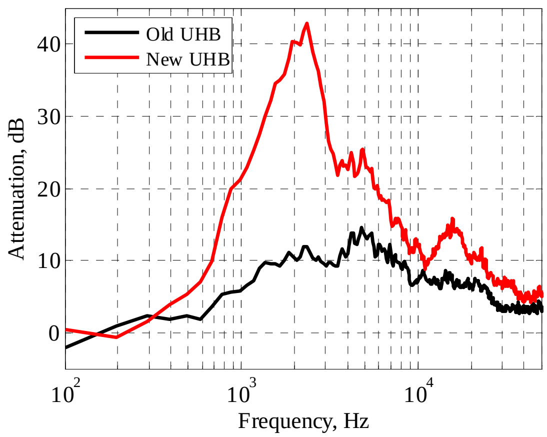

Figure 21.—Exit plane results of UHB mufflers.

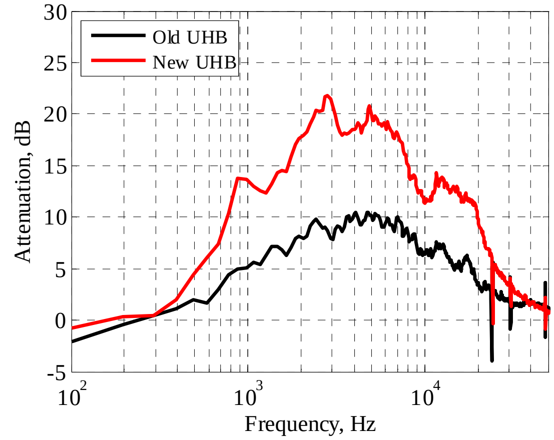

Figure 22.—Directivity results of UHB mufflers.

Other Mufflers

Based on the success of the ORPR muffler, a new muffler for the UHB drive rig was constructed. The same type of acoustic treatment and perforated face sheet were used, and a similar mechanical structure was used. The UHB drive rig is larger than the ORPR, so the new UHB muffler is slightly larger with an inner diameter of 11.375 in. compared to 10.5 in. for the ORPR muffler. The same L/D ratio was kept, and additionally the UHB muffler has a treated diffuser piece that is 16.365 in. long. The speaker plate was designed to fit the ORPR muffler, so a tapered plastic adapter was used to accommodate the diameter difference. The net result is slightly greater attenuation than the ORPR muffler, but a very similar overall spectral attenuation curve. It is a dramatic improvement from the much shorter and heavily used old UHB muffler, which was also tested in the ATL. Exit plane and directivity attenuation measurements are shown in Figure 21 and Figure 22, respectively. The new UHB muffler will be used in upcoming tests in the 9×15 LSWT.

Conclusions

The acoustic performance of three drive turbine mufflers has been documented, and a test procedure established. The ORPR muffler provides 10 dB of attenuation between 700 and 20 kHz, and 20 dB of attenuation between 1 and 8 kHz. Above 25 kHz, attenuation drops to around 8 dB, as measured by the exit plane survey. By the same method, the new UHB muffler was found to have 10 dB of attenuation between 800 Hz and 9 kHz. No measureable attenuation loss was found after 138 hr of run time on the ORPR muffler, and very little oil was observed to be present in the treatment. The muffler significantly improves the acoustic environment of the wind tunnel test section during ORPR operations.

Bibliography

Cooper, B.A. (2000). Design and Construction of a Convertible Hemi/Anechoic Acoustical Laboratory for Testing Space Flight Hardware at the NASA Glenn Research Center. *Proceedings of NOISE-CON 2000.* Newport Beach, CA.

Levine, H., & Schwinger, J. (1948). On the Radiation of Sound from an Unflanged Circular Pipe. *Physical Review* , *73* (4), 383-406.

Soeder, R.H. (August 1993). NASA Lewis 9- by 15-Foot Low-Speed Wind Tunnel User Manual. *NASA Technical Memorandum 106247*.

Van Zante, D.E. (2011). NASA Technical Reports Server. Retrieved from ntrs.nasa.gov: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110011377_2011011975.pdf

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14. ABSTRACT
Aircraft engine component testing at the NASA Glenn Research Center (GRC) includes acoustic testing of scale model fans and propellers in the 9- by15-Foot Low Speed Wind Tunnel (LSWT). This testing utilizes air driven turbines to deliver power to the article being studied. These air turbines exhaust directly downstream of the model in the wind tunnel test section and have been found to produce significant unwanted noise that reduces the quality of the acoustic measurements of the engine model being tested. This report describes an acoustic test of a muffler designed to mitigate the extraneous turbine noise. The muffler was found to provide acoustic attenuation of at least 8 dB between 700 Hz and 20 kHz which significantly improves the quality of acoustic measurements in the facility.

15. SUBJECT TERMS
Acoustic measurement; Mufflers; Turbines

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