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Acoustic Evaluation of the Helmholtz Resonator Treatment in the NASA Lewis 8- by 6-Foot Supersonic Wind Tunnel

Laurence J. Heidelberg
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

and

Elliot B. Gordon
Sverdrup Technology, Inc.
NASA Lewis Research Center Group
Cleveland, Ohio

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Laurence J. Heidelberg
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

and

Elliot B. Gordon
Sverdrup Technology, Inc.
NASA Lewis Research Center Group
Cleveland, Ohio 44135

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SUMMARY

The acoustic consequences of sealing the Helmholtz resonators of the NASA Lewis 8- by 6-Foot Supersonic Wind Tunnel (8x6 SWT) were experimentally evaluated. This resonator sealing was proposed in order to avoid entrapment of hydrogen during tests of advanced hydrogen-fueled engines. The resonators were designed to absorb energy in the 4- to 20-Hz range; thus, this investigation is primarily concerned with infrasound. Limited internal and external noise measurements were made at tunnel Mach numbers ranging from 0.5 to 2.0. Although the resonators were part of the acoustic treatment installed because of a community noise problem, their sealing did not seem to indicate a reoccurrence of the problem would result. Two factors were key to this conclusion: (1) A large bulk treatment muffler downstream of the resonators was able to make up for much of the attenuation originally provided by the resonators, and (2) there was no noise source in the tunnel test section. The previous community noise problem occurred when a large ramjet was being tested in an open-loop tunnel configuration. If a propulsion system which produced high noise levels at frequencies of less than 10 Hz were tested, the conclusion on community noise would have to be reevaluated.

INTRODUCTION

Sealing off the Helmholtz resonators from the tunnel was proposed in order to avoid entrapment of unburned hydrogen gas while testing advanced hydrogen combustion engines in the 8- by 6-Foot Supersonic Wind Tunnel (8x6 SWT). The purpose of this investigation was to evaluate the acoustic consequences of sealing these resonators. Limited measurements were made with five microphones--two internal and three external to the tunnel. Since the Helmholtz resonators were designed to absorb energy in the 4- to 20-Hz range, this investigation was primarily concerned with infrasound. There was concern that a community noise problem might be created, as was the case with the open-loop configuration before acoustic treatment was installed and the tunnel loop was closed. Since there were no sources of high intensity noise, such as a hydrogen-fueled engine, in the test section during these tests, the conclusions drawn from this study apply only to an empty test section or a low-noise model installation.

TUNNEL AND TEST DESCRIPTION

Tunnel Acoustic Features

The 8x6 SWT at NASA Lewis Research Center was subjected to extensive acoustic treatment in the early 1950's as a result of a severe community noise problem. A complete description of the design and development of this treatment can be found in references 1 and 2.

Figure 1 shows the main features of the acoustic treatment. The diffuser has five Helmholtz resonators along its length that are designed to absorb energy in the 5- to 11-Hz frequency range. The diffuser exit is 26 ft in diameter. The muffler section is composed of six parallel ducts, each a 10-ft square (100 ft^2) on the inside. The upstream section of each duct consists of a 62-ft length of resonators in all sides of the duct. These resonators have a design frequency range of 12 to 20 Hz. The remaining 90-ft length of each duct is surrounded by fiberglass panels 6 in. thick with 2-ft cavities behind them. The design frequency range of this fiberglass-treated section is 20 to 800 Hz. An additional set of parallel baffles, designed to handle frequencies above 800 Hz, is located at the exit of the second plenum.

In this investigation, all the Helmholtz resonators (diffuser and muffler) were sealed off from the tunnel flow with metal plates. This eliminated all treatment for frequencies below 20 Hz. In addition to taking data with and without the resonators, data were also obtained with both doors 1 and 2 open and closed (see fig. 1). Test section Mach numbers ranged from 0.5 to 2.0.

Instrumentation and Data Reduction

The microphone locations are shown in figure 1. The three outdoor microphones were 1/2-in. condenser types. They were placed on the center of 2-ft square plywood sheets with hemispherical foam wind screens. In addition, a 16-mesh wire wind screen was placed over the plywood squares as shown in figure 2; this was done to minimize wind noise, which can cause serious contamination of the data in the infrasound frequency range. The two inside microphones were 1/4-in. condenser types with nose cones attached to reduce turbulence noise. These microphones were mounted on plywood squares that were bolted to the tunnel floor. All microphones were calibrated with a piston phone just before and after each test. Both the 1/4- and 1/2-in. microphones have a low-frequency roll-off of 3 dB at 3 Hz. Data below 3 Hz should not be regarded as accurate.

In order to prevent contamination of the data from aircraft, nearby auto traffic, and high wind gust noise, a man was placed in the field to act as a spotter. The microphone signals were amplified and recorded on FM tape along with the voice of the outdoor field spotter.

Narrow band spectra of 1/2 Hz were obtained from the data by using a fast Fourier transform (FFT) spectrum analyzer. No attempt was made to separate sound from pseudosound (pressure disturbances traveling at other than the acoustic velocity, i.e., turbulence).

RESULTS AND DISCUSSION

Data taken with both active and sealed Helmholtz resonators were obtained for all five microphone locations. Four test section Mach numbers, 0.5, 1.0, 1.5 and 2.0 were run. In all cases, the Mach 2.0 data had the highest noise levels. For this reason most of the data is presented for the Mach 2.0 condition. Tests were conducted with both doors 1 and 2 in the open and in the closed positions for all conditions.

There were no significant noise sources in the test section for these tests. Only a limited amount of data is presented for the outdoor microphones because of high and variable levels of low-frequency pressure fluctuations in the background.

Interior Noise

The location of the two interior microphones (3 and 4) is shown in figure 1. Microphone 3 was located in the second plenum and, thus, shows the acoustical effects of the long, lined duct. Microphone 4 was located in the first plenum, where the noise exiting the diffuser was measured. The separated and turbulent air flow in the diffuser is the primary noise generator in the 8x6 SWT.

Figure 3 shows the effect of sealing the resonators in the diffuser section. Here the spectra for both active and sealed resonators are compared at Mach 2.0 with doors 1 and 2 open. The shaded area between the curves represents the attenuation of the diffuser resonators. There is significant attenuation below 15 Hz, with a peak of 18 to 19 dB in the 8- to 9-Hz range. The attenuation then decreases to 7 dB at 3 Hz, where the microphone roll-off becomes large. The design attenuation value of 20 dB at 5- to 11-Hz is consistent with the measured values. Note that the measured attenuation may be low because of the presence of noise floors due to local flow noise and/or pseudosound (turbulence).

The effect of sealing all the resonators can be seen in figure 4, which compares spectra at the muffler exit (second plenum). Although the effect of sealing both sections (diffuser and muffler) of the resonator is included in these data, less noise difference was observed than at the diffuser exit. This is a result of the fiberglass section of the muffler attenuating noise below its low-frequency design point, 20 Hz. The performance of the 90-ft fiberglass section can be seen in figure 5. Here the resonator-sealed spectra at the diffuser and muffler exits are compared. The shaded area represents the attenuation due to the fiberglass treatment. Even though there was no treatment designed to remove energy below 20 Hz, attenuation of 20 dB and more can be seen between 10 and 20 Hz. At frequencies below 10 Hz the attenuation rapidly decreases until it reaches zero at 4 Hz. The greater than expected low-frequency attenuation of the fiberglass section was also noted in reference 1. The attenuation increases with frequency and approximates 45 dB at 100 Hz. Here again, noise floors caused by local flow and pseudosound limited the ability to measure the treatment attenuation. The extra low-frequency attenuation of the fiberglass section of the muffler compensated in part for the loss of attenuation due to sealing the resonators.

When the resonators were active, the noise level difference measured across the muffler was actually less, as shown in figure 6. This was a result of lower noise levels entering the muffler at the diffuser exit and exit levels being controlled by noise floors. With the resonators in the diffuser removing significant energy below 15 Hz, as was shown in figure 3, there was less attenuation measured across the muffler at these same frequencies. Above 15 Hz the muffler attenuation was much the same as without the resonators.

The effect of opening the doors can be seen in figure 7, where the spectra at the diffuser exit are compared. Opening the doors apparently increased the pressure drop in the diffuser thereby generating more noise. Below 10 Hz there was a noise increase of up to 5 dB. This represents a source noise increase since the resonators were not active. A similar but somewhat smaller increase at the muffler exit as a result of opening the doors is shown in figure 8.

The effect of varying the Mach number from 0.5 to 2.0 at the diffuser exit is shown in figure 9. Since there were no resonators active, these data represent a change in source noise level. The noise level above 10 Hz increases by 10 dB for this change in Mach number. As frequency decreases below 10 Hz, the noise increase falls off to only 3.5 dB at 3 Hz.

Exterior Noise

Three microphones were placed outside the tunnel in an attempt to measure far-field noise: one 200 ft from the doors, one 300 ft from the doors, and one 200 ft from the first plenum (see fig. 1). Noise measurements were made on five nights. The background noise levels at the frequencies of interest were high and variable, as shown in figure 10. The two spectra shown here represent the quietest and noisiest backgrounds recorded during the test series. At the lowest frequencies the difference approaches 25 dB and tends to decrease rapidly with frequency. Because of these large differences, only very limited data are available for useful comparisons.

The noise difference between Mach 2.0 and background, measured at microphone 2 with the doors closed and the resonators active, is shown in figure 11. Although these data were chosen because of the low background noise during this test period, the tunnel noise was, for the most part, only 5 to 8 dB above the background, with a peak of 16 dB. Thus, with the doors closed and resonators active, the tunnel-generated noise levels were not significantly above that of the background, even within a 200- to 300-ft distance. This is certainly not a community noise problem.

The effect of the resonators on the far-field noise when the doors were open is shown in figure 12. These spectra are for microphone 1 (300 ft from door 2). Sealing the resonators caused an increase in noise level over a frequency range of 3 to 25 Hz. The largest increase was about 15 dB, which occurred around the middle of the frequency range (8 Hz). This noise increase is somewhat larger than the one measured at the muffler exit (fig. 4). The muffler exit data have a flow noise floor, thereby masking some of the differences due to the resonators.

The effect of the doors on the far-field noise without the resonators is shown in figure 13. These spectra are for the microphone 1 location with the tunnel at Mach 2.0. Below 10 Hz there was a 10- to 20-dB increase in noise when the doors were open. A smaller noise increase was observed in the 10- to 20-Hz range. The significant effect of the doors indicates that the reinforced concrete tunnel walls transmit very little sound, even at these low frequencies. The combination of open doors and sealed-off resonators produced the highest far-field noise levels. Although the noise levels below 20 Hz were more than 20 dB above the quietest background levels at 300 ft, when extrapolated (spherical spreading assumed) to the nearest neighbors at 2500 ft, these levels are reduced by 18 dB. Thus, it is felt that the tunnel with the sealed-off resonators and no significant noise source in the test section poses no community noise problem. However, if a model that generates significant noise below 20 Hz were to be placed in the test section, further testing would be recommended.

Presently there are no criteria for comfort or annoyance for the spectral region below 32 Hz; however there are many documented community noise problems related to low or infrasonic frequencies (ref. 3). Work on the effects of infrasound has indicated that the threshold of annoyance may be only slightly above the hearing threshold (ref. 4). Thus, that which can be heard is likely to be annoying. In addition to the direct effects of infrasound, indirect effects, such as window pane and wall vibrations, can reradiate sound in the audio spectrum. These indirect effects might prove to be a problem at levels well below the hearing threshold of infrasound.

SUMMARY OF RESULTS

1. The resonators in the diffuser provided attenuation below 15 Hz, with a peak of 18 to 19 dB at 8 to 9 Hz. This performance was generally consistent with the design values.

2. The noise increase resulting from the removal of both the diffuser (5 to 11 Hz) and muffler (11 to 20 Hz) resonators, measured at the muffler exit, was less than the design attenuation of these resonators. This was due to the fiberglass section of the muffler compensating for much of the attenuation originally provided by the resonators.

3. The fiberglass treatment produced measured attenuations of over 45 dB. At frequencies below design, the attenuation was greater than the original design prediction.

4. There are indications that a noise floor, such as locally generated flow noise or pseudosound, was limiting the measurements at the muffler exit.

5. Opening the doors caused an increase of 3 to 4 dB in the noise generated in the diffuser at frequencies below 20 Hz.

6. Varying the test section Mach number from 0.5 to 2.0 resulted in a noise level increase of 10 dB at the diffuser exit for most of the spectrum below 100 Hz.

7. Very large differences in far-field background noise (25 dB) in the range between 3 and 20 Hz limited the ability to measure differences caused by the tunnel.

8. With the resonators active and the doors closed, far-field noise levels were not much higher than the background noise on a quiet day.

9. Sealing the resonators and opening the doors added noise over the 3- to 25-Hz range, with a peak far-field noise increase of 15 dB.

10. Opening the doors, with the resonators sealed, added more than 20 dB to the far-field background noise below 10 Hz.

11. Even though the noisiest condition was 20 dB above the background noise at 300 ft, it would not be significantly above the background when extrapolated, based on spherical spreading to the nearest neighbors at 2500 ft. Although the tested condition, with sealed resonators and open doors, does not pose a community noise problem, no such prediction can be made for the case when a model generating significant infrasound is in the test section.

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2. Beranek, L.L.; Labate, S.; and Ingard, U.: Acoustical Treatment for the NACA 8- by 6-Foot Supersonic Propulsion Wind Tunnel. NACA TN-3378, 1955.

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4. Moller, H.; and Andresen, J.; Loudness of Pure Tones at Low and Infrasonic Frequencies. J. Low Freq. Noise Vibration, vol. 3, no. 2, 1984, pp. 78-87.

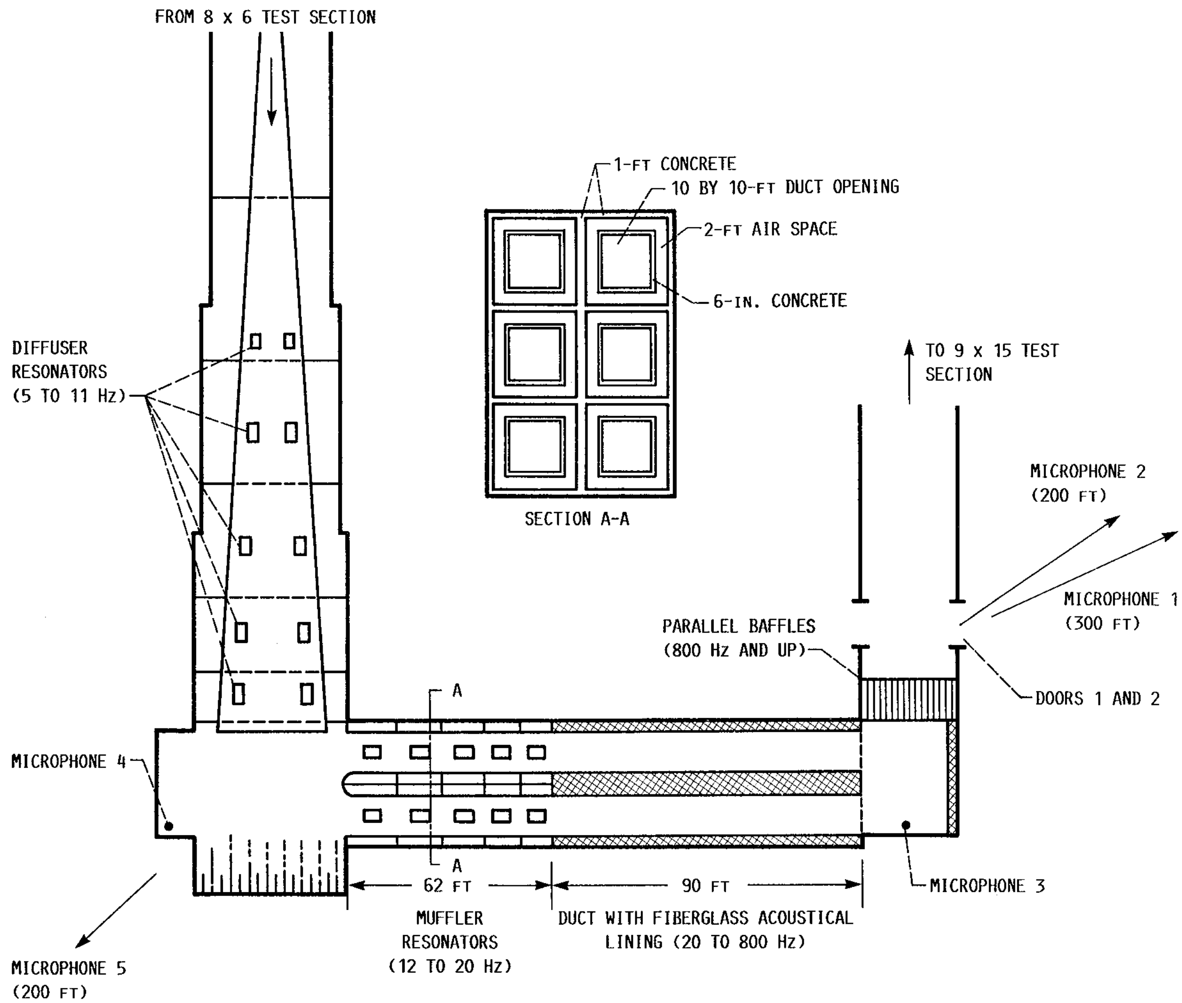

FIGURE 1. - ACOUSTIC FEATURES OF DIFFUSER AND MUFFLER SECTIONS OF 8 x 6 SWT.

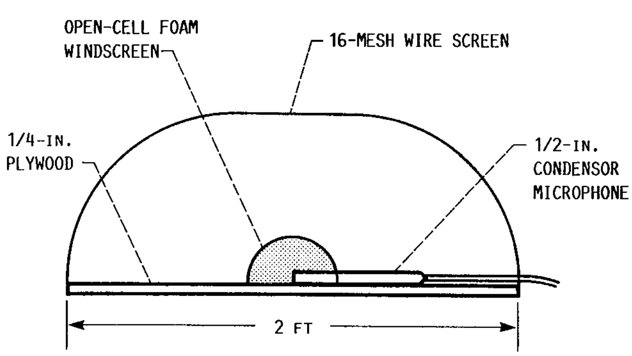

FIGURE 2. - OUTDOOR MICROPHONE CONFIGURATION.

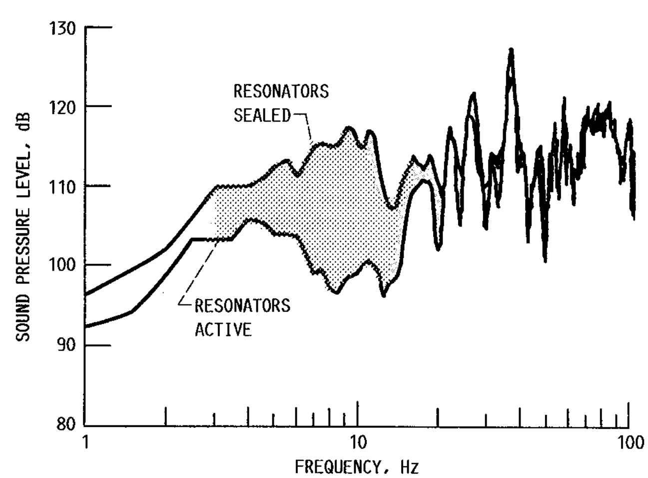

FIGURE 3. - EFFECT OF SEALING RESONATORS IN DIFFUSER ON NOISE LEVEL AT DIFFUSER EXIT (MICROPHONE 4) FOR MACH 2.0 WHEN BOTH DOORS ARE OPEN.

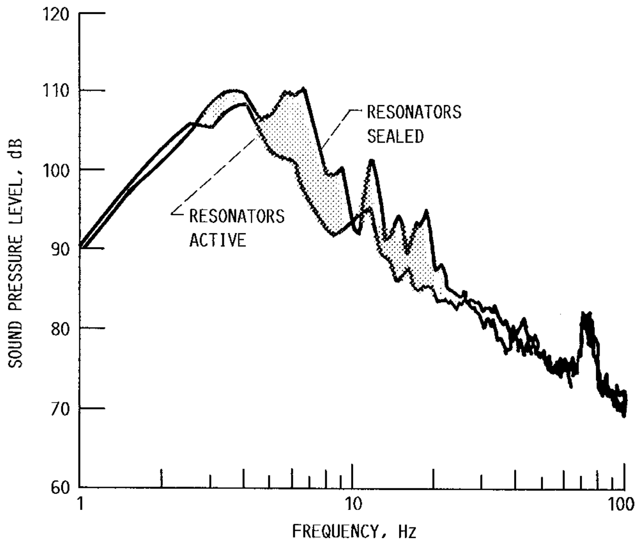

FIGURE 4. - EFFECT OF SEALING ALL RESONATORS ON NOISE LEVEL AT MUFFLER EXIT (MICROPHONE 3) AT MACH 2 WHEN BOTH DOORS ARE OPEN.

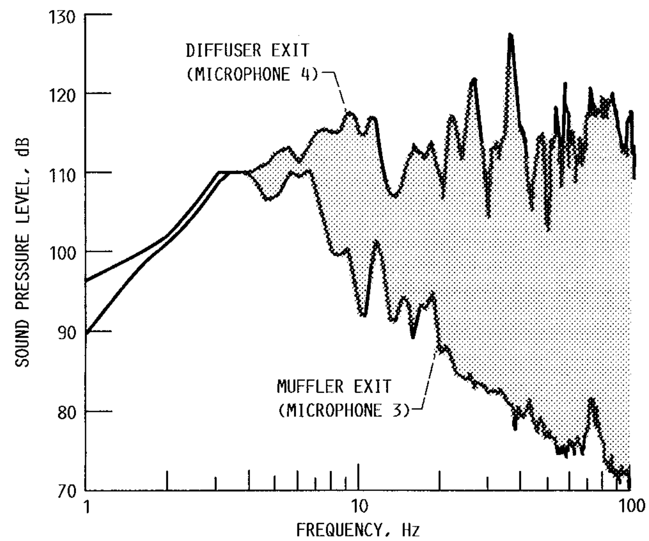

FIGURE 5. - PERFORMANCE OF FIBERGLASS LINED SECTION OF MUFFLER AT MACH 2.0 WHEN DOORS ARE OPEN, AND RESONATORS ARE SEALED.

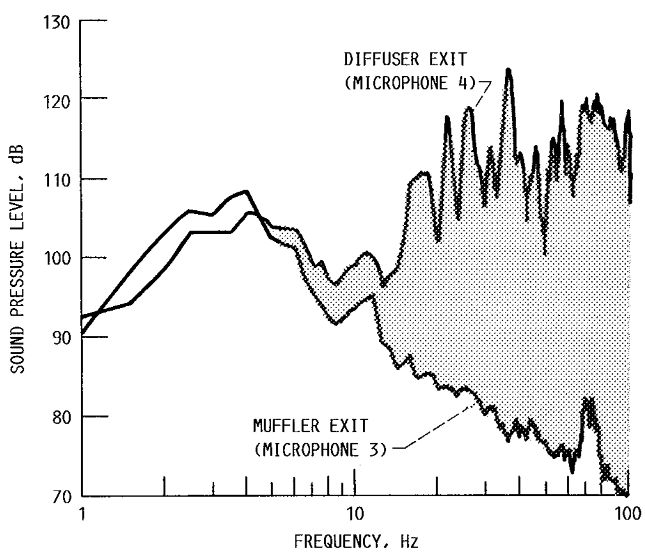

FIGURE 6. - PERFORMANCE OF MUFFLER WHEN ALL RESONATORS ARE ACTIVE AT MACH 2.0 WITH DOORS OPEN.

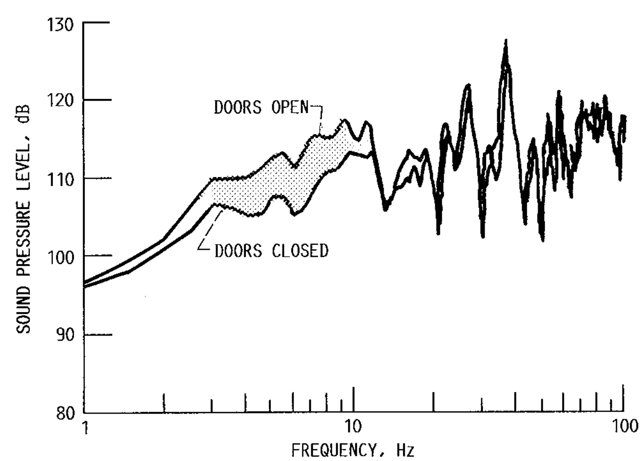

FIGURE 7. - EFFECT OF DOORS ON NOISE LEVEL AT DIFFUSER EXIT (MICROPHONE 4) AT MACH 2.0 WITH RESONATORS SEALED.

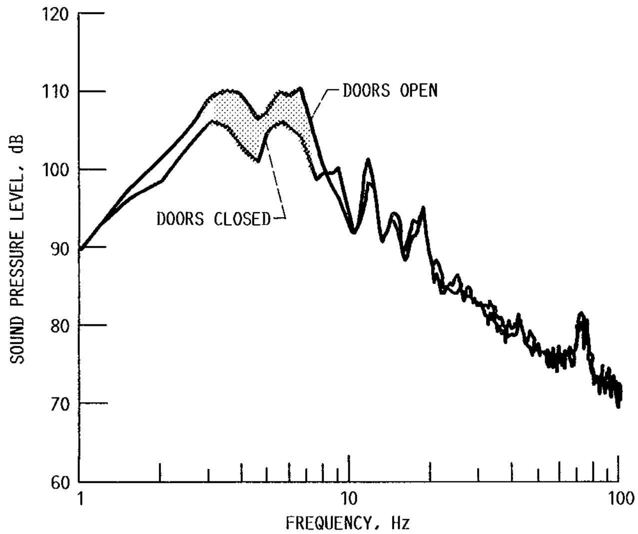

FIGURE 8. - EFFECT OF DOORS ON NOISE LEVEL AT MUFFLER EXIT (MICROPHONE 3) AT MACH 2.0 WITH RESONATORS SEALED.

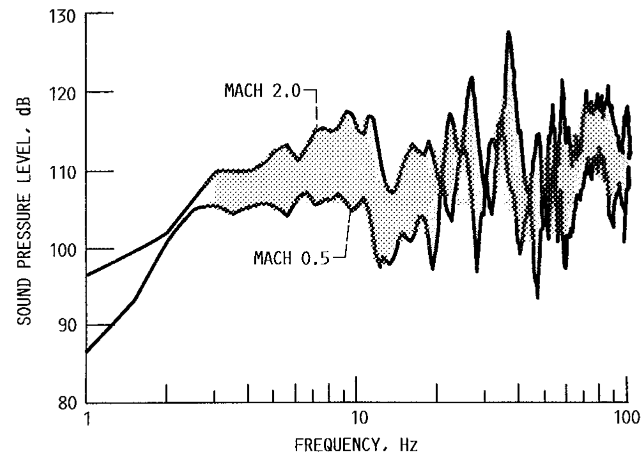

FIGURE 9. - EFFECT OF TEST SECTION MACH NUMBER ON NOISE LEVEL AT DIFFUSER EXIT (MICROPHONE 4) WITH DOORS OPEN AND RESONATORS SEALED.

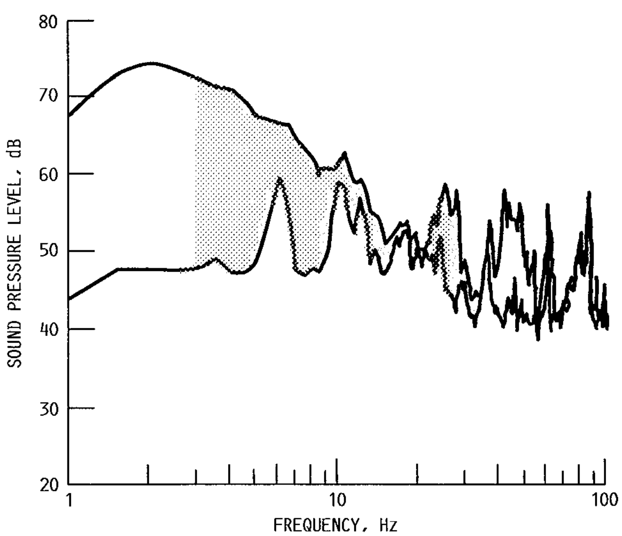

FIGURE 10. - VARIATION IN BACKGROUND NOISE LEVEL AT MICROPHONE 1, 300 FT FROM DOOR 2 (MACH 0).

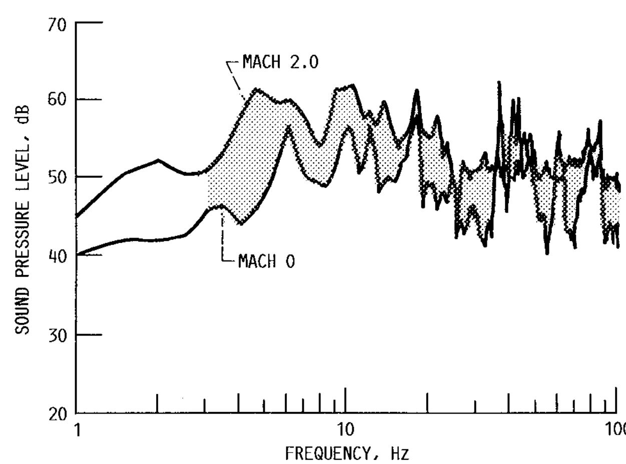

FIGURE 11. - COMPARISON OF NOISE MEASURED 200 FT FROM DOORS (MICROPHONE 2) AT MACH 2.0 AND MACH 0 WITH RESONATORS ACTIVE AND DOORS CLOSED.

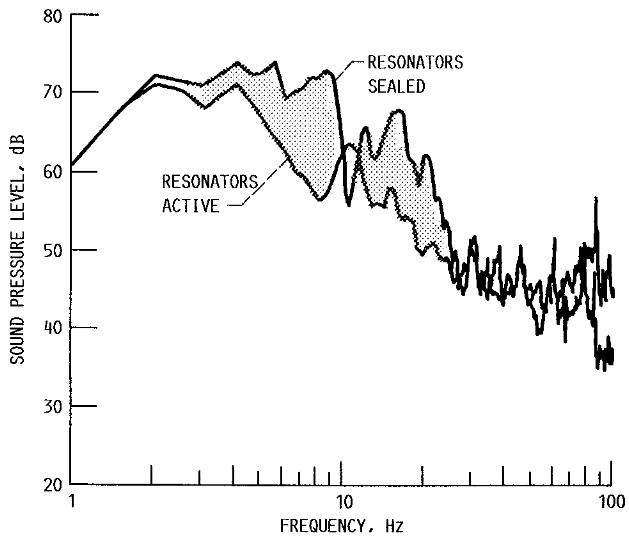

FIGURE 12. - EFFECT OF RESONATORS ON NOISE MEASURED 300 FT FROM DOOR 2 (MICROPHONE 1) AT MACH 2.0 WITH DOORS OPEN.

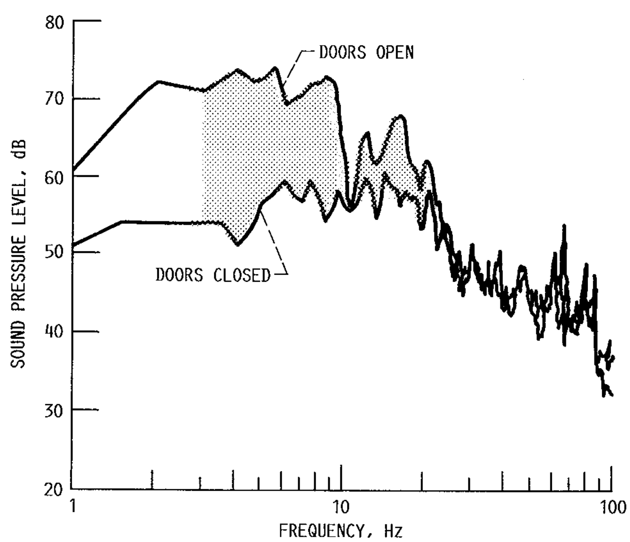

FIGURE 13. - EFFECT OF DOORS ON NOISE MEASURED 300 FT FROM DOOR 2 (MICROPHONE 1) AT MACH 2.0 WITH RESONATORS SEALED.

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15. Supplementary Notes

Laurence J. Heidelberg, NASA Lewis Research Center; Elliot B. Gordon, Sverdrup Technology, Inc., NASA Lewis Research Center Group, Cleveland, Ohio 44135.

16. Abstract

The acoustic consequences of sealing the Helmholtz resonators of the NASA Lewis 8- by 6-Foot Supersonic Wind Tunnel (8×6 SWT) were experimentally evaluated. This resonator sealing was proposed in order to avoid entrapment of hydrogen during tests of advanced hydrogen-fueled engines. The resonators were designed to absorb energy in the 4- to 20-Hz range; thus, this investigation is primarily concerned with infrasound. Limited internal and external noise measurements were made at tunnel Mach numbers ranging from 0.5 to 2.0. Although the resonators were part of the acoustic treatment installed because of a community noise problem, their sealing did not seem to indicate a reoccurrence of the problem would result. Two factors were key to this conclusion: (1) A large bulk treatment muffler downstream of the resonators was able to make up for much of the attenuation originally provided by the resonators, and (2) there was no noise source in the tunnel test section. The previous community noise problem occurred when a large ramjet was being tested in an open-loop tunnel configuration. If a propulsion system which produced high noise levels at frequencies of less than 10 Hz were tested, the conclusion on community noise would have to be reevaluated.

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