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DETERMINATION OF MATERIALS' SOUND ABSORPTION COEFFICIENT FOR APPLICATION IN THE SATELLITE LAUNCHER VEHICLE (VLS) FAIRING

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Abstract. *The acoustic loading of launch vehicles occurs mainly during liftoff, transonic flight and maximum dynamic pressure phases, being the liftoff the most critical phase among them. The high intensity generated during the boosters operation, is reflected against the launch platform and excite the structure of the launcher, creating a severe acoustic environment. This acoustic excitation presents spectral contents of higher orders and the SPL (sound pressure level) values on the upper parts of the VLS are estimated varying from 140 to 160 dB OSPL. The VLS does not have any acoustic noise control treatment (NCT) design, so far. As such, the payload and the electronic equipments embedded in the inner cavity of the fairing are submitted to high SPL during the flight mission. Some analysis where done in the Laboratory of Acoustic Measurements of IAE to characterize acoustic blanket materials for application in the VLS fairing. This work describes the comparative results of the sound absorption coefficients, measured in an impedance tube, for different acoustic materials, in one-third octave band frequency, in order to create a database for NCT design application as well as in noise prediction computation models. The adopted measurement method was the transfer function in impedance tube, based on the ISO 10534-2 standard.*

Keywords*: Sound Absorption, Noise Control Treatment, Acoustic Materials*

1. INTRODUCTION

The acoustic noise, generated in the phases of lauchers' flight, as the liftoff, the passage for the regime of transonic flight and during the maxim dynamic pressure produces excitations of high intensity. These excitations can damage the payload (satellite) as well as the onboard electronic equipments. The Figure 1 shows the propagation of the acoustic noise generated by the displacement of the gasses ejected by the VLS´ boosters.

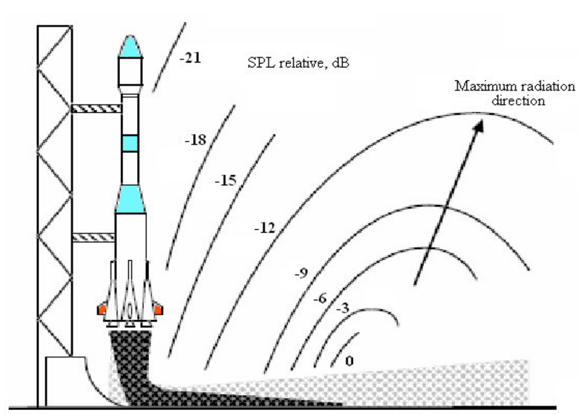

Figure 1: Acoustic excitations during the lift-off

The VLS' fairing is the structural compartment where the payload is during the atmospheric flight of the VLS launcher. This structure has as main objective to protect the payload as well as giving adequate aerodynamic shape to the launcher. It is constituted of aluminum covered by cork line, which has as function the thermal protection of the satellite during the flight. Acoustic test and virtual simulations of the fairing were performed to verify its acoustic behavior. In this test the fairing was submitted to a diffuse acoustic excitation in order to simulate the lift-off acoustic loads. Pirk (2008) describes the results of such acoustic test, performed in the Acoustic Reverberant Test Facility (ARTF) of the National Institute for Space Research (INPE). In this test, microphones were positioned outside and inside the fairing for the measurement of the external and internal SPL. The acoustic excitation level of the external environment of the fairing was 145 dB OSPL, while inside the fairing one measured of 128 dB OSPL. With difference between captured sound pressure levels, the current acoustic transmission loss (TL) of the fairing was determined. Figure 2 shows the fairing positioned in the ARTF INPE.

Figure 2: Fairing test in acoustic reverberant chamber

Another acoustic test was done by positioning the fairing close to a rocket motor of the VLS launcher during stand test, as shown in Figure 3. In this test the fairing was submitted to an acoustic excitation of high intensity due to the gasses expelled by the referred rocket motor. In the same way as in the acoustic reverberant chamber test mentioned previously, microphones were placed inside and outside the fairing. The sound pressure levels were measured and presented 159 dB OSLP for the external environment and inside the fairing one captured 142 dB (OSPL).

Figure 3: Fairing close to the rocket motor S43

2. ACOUSTIC MATERIALS

Materials with high acoustic absorption are usually porous or fibrous. In the porous materials the acoustic incident energy enters by the pores and is dispersed by multiple reflections and viscous attrition, becoming thermal energy. In the fibrous materials the acoustic incident energy enters by empty spaces among the fibers, making them vibrate with the air, and is dispersed by being transformed in thermal by attrition among the fibers. The absorption mechanism for porous and fiber materials are shown in Figures 4 and 5 respectively, both extracted from Gerges (1992).

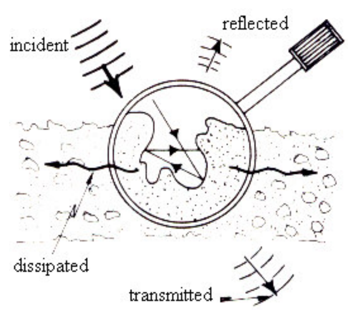

Figure 4: Porous materials (reflection in the porous)

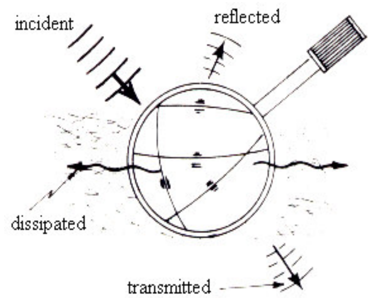

Figure 5: Fibrous materials (vibration in the fiber)

According to Gerges (1992), the characteristic of acoustic absorption of a material is given by a coefficient of sound absorption (α), defined for the ratio among the absorbed acoustic energy and the incident acoustic energy.

The value is always positive varying from zero to one and it depends mainly on the frequency, angle of incidence of the sound, type of sound field, material density, thickness and internal structure of the material.

3. THE TWO-MICROPHONE METHOD

The ISO 10534-2 standard describes what has come to be known as the “two-microphone” or “transfer-function” method of measuring absorption and impedance of acoustical materials. This standard establishes acceptable conditions under which reliable data may be obtained; however, good practice suggests equipment and test conditions to exceed the minimal requirements of the standard (Seybert and Ross, 1977).

A two-microphone method test rig is shown schematically in Figure 6. A sample of the material to be tested is placed in a sample holder and mounted on one end of a straight tube. A rigid termination with an adjustable depth is placed behind the sample to provide a reflecting surface. A sound source (loudspeaker) generates broadband, stationary random sound waves. These propagate as plane waves in the tube, hit the sample and are reflected. Therefore, standing-wave interference pattern results due to the superposition of forward and back ward-travelling waves inside the tube. By measuring the sound pressure at two fixed locations and calculating the complex transfer function (H_{12}), using a two-channel digital frequency analyzer, it is possible to determine the complex reflection coefficient, the sound absorption coefficient and the normal acoustic impedance of the material. The usable frequency range depends on the diameter of the tube and spacing between the microphone positions (ISO 10534-2, 1998).

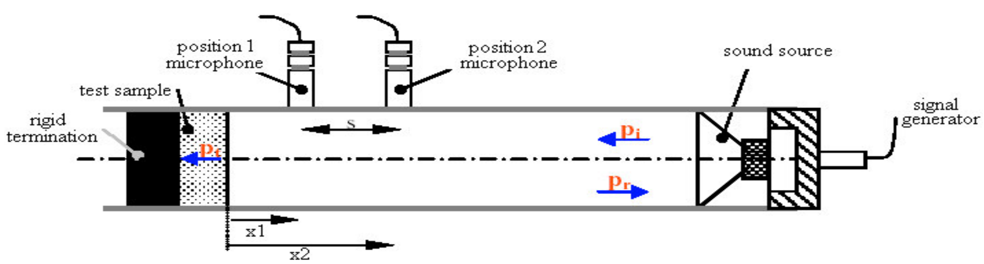

Figure 6: Impedance tube

According to (Chang and Blaser, 1980), the transfer function method is based on ratio of the sound pressure of the reflected wave to the sound pressure of the incident wave at the termination (at x=0), give by as in Eq. (1):

$$R = \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} e^{j2kl} \tag{1}$$

where:
k is the wave number;
s is the distance between the microphones;
l is the distance between the material under test and microphone number 1

The absorption coefficient of the materials is given by:

$$\alpha = 1 - \left| R^2 \right| \tag{2}$$

4. RESULTS

In view of having a data base of acoustic blankets to be used as NCT design for the VLS fairing, some materials were studied and their acoustic absorption coefficients were measured in an impedance tube or Kundt tube. Simple-, double- and multi-layer materials were analyzed in this research.

The used impedance tube covers a broad band frequency from 125 Hz to 3200 Hz. It has two ¼" microphones needed to measure the acoustic pressure levels, which are specially designed to reduce pressure leakage errors in higher frequencies.

The samples of the absorbent materials were cut with a diameter of 60 millimeters (internal diameter of the impedance tube). Acoustic materials of different densities and thickness were used in this work.

Figures 7, 8 and 9 present the measured acoustic absorption coefficients concerning the simple-layer tested acoustic materials. These materials are related according to their low-, medium- and high-frequency absorption efficiency, taking as reference 630 Hz, 1,000 Hz and 1,600 Hz, respectively. The densities of the materials are expressed in "pcf x inch", where 1 pcf is equivalent to 16.02 kg/m^3.

Figure 7 shows the comparison for materials which presented efficient sound absorption in low-frequency range (630 Hz and higher). In this curve, glass wools and rock wools are considered.

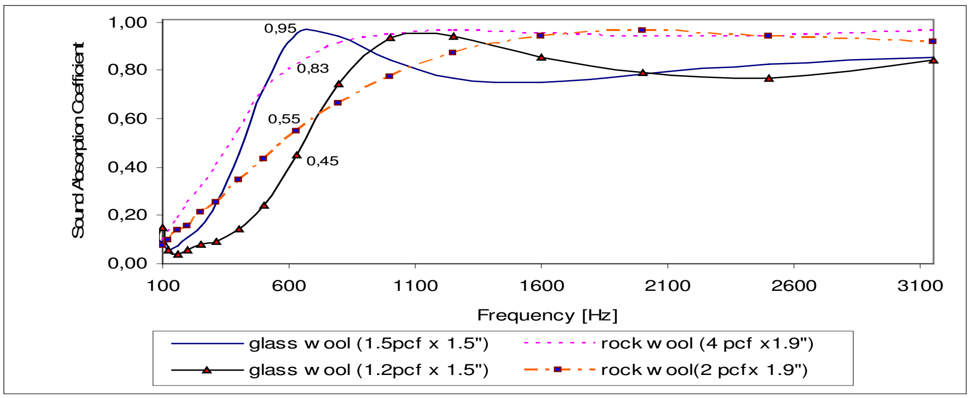

Figure 7: Results of materials with good sound absorption starting from 630 Hz

Among the results presented in figure 7, the only material that didn't reach 50% of sound absorption starting from the frequency band of 630 Hz was the glass wool 1.2 pcf x 1.5". However, in the next frequency band, around 1,000 Hz, this material reached higher absorption coefficients than those presented by the rock wool 2 pcf x 1.9" and glass wool 1.5 pcf x 1.5". The decreasing of the sound absorption coefficients presented by the glass wool 1.5 pcf x 1.5", starting from 800 Hz and by the glass wool 1.2 pcf x 1.5", starting from 1,250 Hz, can be explained by the application of ink and anti-fire materials.

In Figure 8, all the measured materials presented sound absorption coefficients higher than 0.50, taking 1,000 Hz as reference. One can see that in the high-frequency range these materials present absorption coefficients close to the unity.

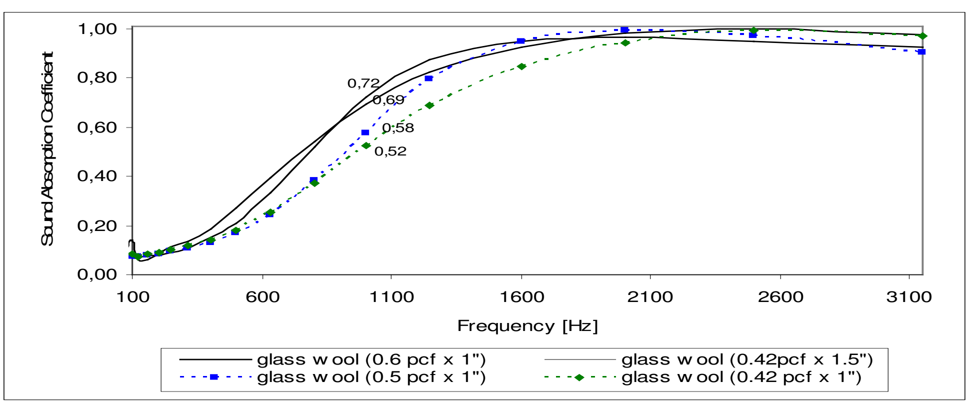

Figure 8: Results of materials with good sound absorption above 1000 Hz

Figure 9 shows the measured results for the high-frequency performing materials.

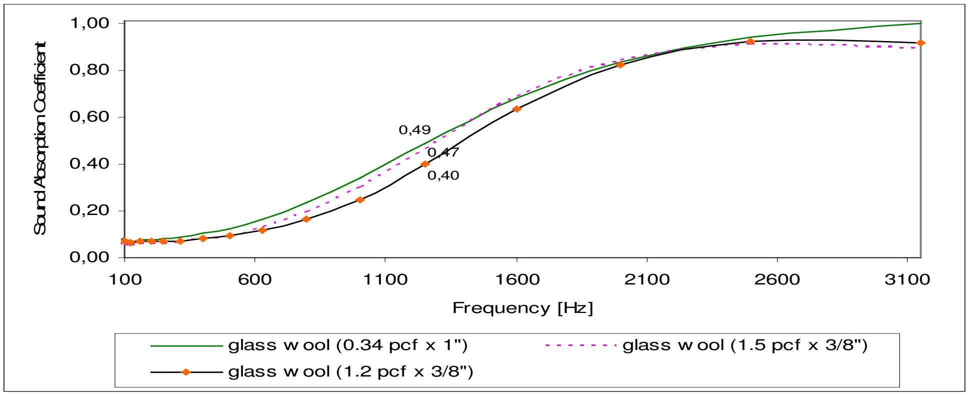

Figure 9: Results of materials with good sound absorption above 1,600 Hz

Below one describes the obtained results for a double-layer sample material. Two glass wool samples of densities 1 pcf x 0.6" (orange) and 0.42 pcf x 0.6" (yellow) were combined to assemble a sample. Figure 10 shows the double-layer sample.

Figure 10: Double-layer sample

The purpose was to verify the behavior of the sound absorption curve related to the material and the first hit by the incident wave in the combined sample. It can be noticed in Figure 11 that the acoustic absorption is more performing when the density of the material is larger. The blue curve shows the acoustic absorption coefficients when the incident wave hits the orange material (1 pcf x 0.6"), while the mauve curve presents the absorption coefficients when the incident wave first hits the yellow material (0.42 pcf x 0.6").

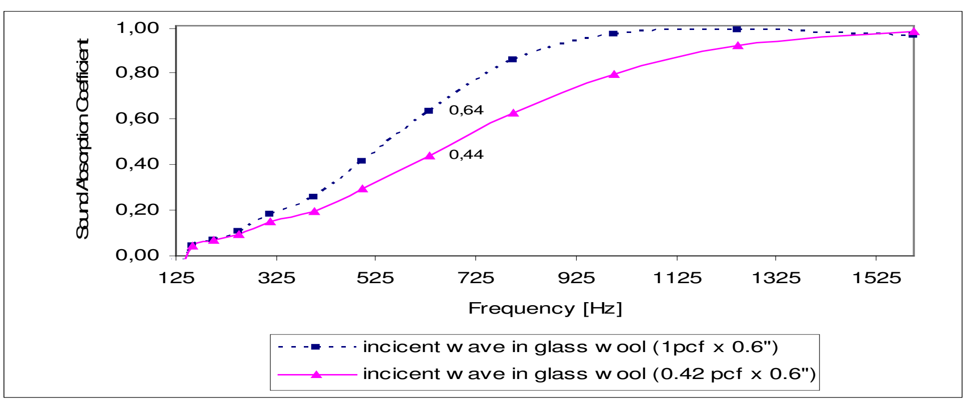

Figure 11: Influence of different densities in the sound absorption

One carried a multi-sample research, on which an air gap was added to two layers of a blanket acoustic material. The chosen material was the glass wool 0.42 pcf x 0.6". According to (Cummings, 1991 and Allard, 1993), an air gap between materials increases the acoustic absorption at low-frequencies. The Figure 12 shows the obtained results, verifying the influence of the air gap of 1 cm and 3 cm between the parts. It can be easily seen that the bigger is the air gap, the higher is the absorption coefficient.

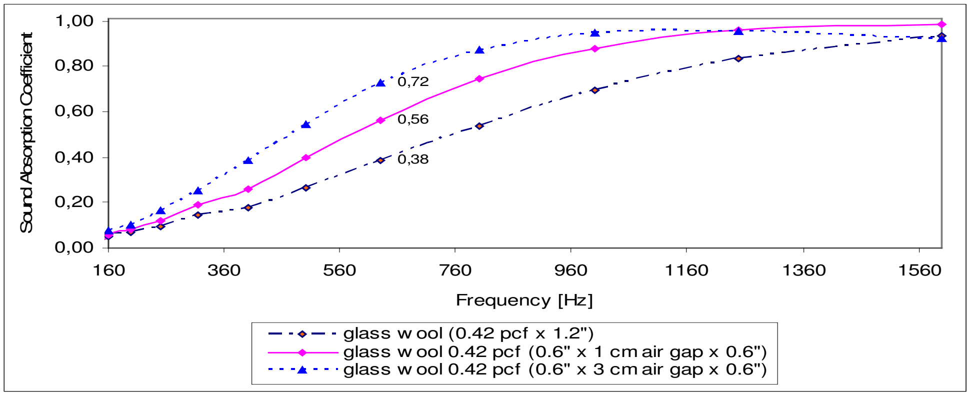

Figure 12: Influence of the air gap in the sound absorption of the glass wool of 0.42 pcf

The best performing single-layered blanket materials presented in Figure 7 are now compared with the absorption coefficients obtained by the multi-layered sample composed by the glass wool 0.42 pcf (0.6" x 3 cm air gap x 0.6"). Fig. 13 shows this comparison.

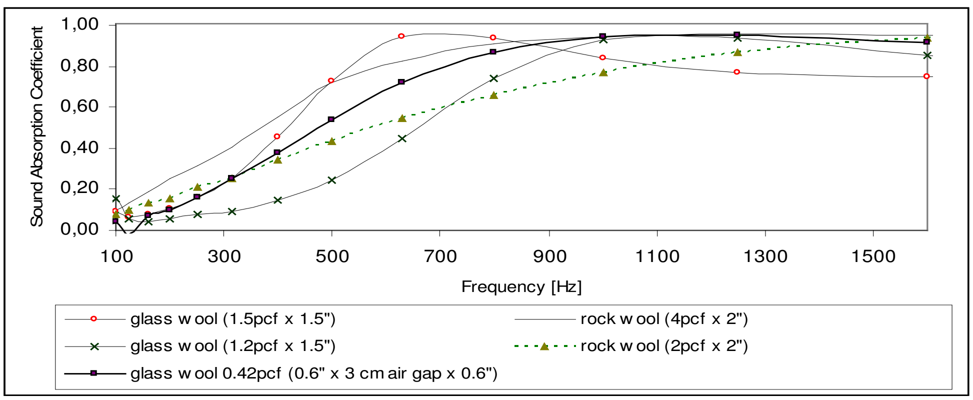

Figure 13: Absorption coefficients for multi- and single-layered materials

In space industry, a trade-off between NCT weight and TL must be considered, once the cost of a space mission is a very significant parameter. Therefore, a relation between the mass and the superficial density of the NCT must be considered. Table 1 describes the mass and the superficial density of each sample for the materials analyzed in Figure 13.

Table 1. Sample mass and superficial density for the materials analyzed in Fig. 13

Acoustic Materials	Sample mass [kg]	Superficial density [kg/m^2]
rock wool (4 pcf x 2")	0.00920	3.254
rock wool (2 pcf x 2")	0.00460	1.627
glass wool (1.5 pcf x 1.5")	0.00258	0.912
glass wool (1.2 pcf x 1.5")	0.00207	0.732
glass wool 0.42 pcf (0.6"x 3 cm air gap x 0.6")	0.00058	0.205

6 CONCLUSIONS

In this work we obtained comparative results of sound absorption coefficients for materials with different densities and thickness, creating a database for application in computational models of noise prediction in acoustic cavities, using vibro-acoustic techniques.

The mass increment in launchers' higher parts is extremely undesirable. By this way the possibility of combining an air gap with a small density absorbing material seems to be a quite simple and effective way of improving the sound absorption coefficient and reduce the weight of the NCT design. The necessary next step of this work is to search for possible devices to place the two blankets of acoustic absorbent material together keeping the air gap among them.

These devices must support the strong dynamic lift off and flight loads and be very lightweight in order to keep the superficial density of the whole NCT system above the values of heavier acoustic materials, like the ones described in Table1.

7. ACKNOWLEDGEMENTS

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