Rogerio Pirk
rogeriorp@iae.cta.br
Institute of Aeronautics and Space
Division of Integration and Tests
São José dos Campos
12228-904 SP, Brazil

Carlos d'Andrade Souto
carloscdas@iae.cta.br
Institute of Aeronautics and Space
Division of Integration and Tests
São José dos Campos
12228-904 SP, Brazil

Implementation of Acoustic Materials to the VLS-1 Fairing – A Sensitivity Analysis Using SEA

Satellite launchers are submitted to severe acoustic loads mainly during lift-off where SPL achieve, at the upper parts, values within the range of 140-160 dB. Such an excitation can damage embedded elements, if energy attenuation measures are not adopted. In view of managing the PLF vibro-acoustic environment, numerical techniques are applied to predict elasto-acoustic behavior. This manuscript presents a numerical study on the design of acoustic insulation for the VLS-1 fairing compartment. An excitation profile based on the literature is applied on a SEA coupled model of this structural-acoustic system and absorbing materials are added to the model. Two parameters of the absorbing material layer are analyzed: thickness and covered area. Two NCT modeling approaches are used to simulate the effect of blanketing the VLS-1 fairing: acoustic materials Biot´s parameters, given by the manufacturer, and material samples absorption coefficient, measured in a Kundt Tube. Results show that an increase in the blanket thickness from 7.62 to 12.7 cm results in a TL of 1.7 dB OSPL, while variations of up to 3.0 dB OSPL are calculated if the fairing cavity blanketed area varies from 30% to 100%.
Keywords: *statistical energy analysis, acoustic materials, sound attenuation, launchers, fairing*

Introduction

The structural design of ELV payloads is driven by the severity of the launch environment. The loads transmitted from the PLF structure to the payload during lift-off are more severe than any load the payload can experience during its flight mission. Therefore, payloads must be qualified by being subjected to loads whose magnitude and spectral content are representative of the launch environment inside the fairing cavity (Scott et al., 1996). The more severe the launch environment is, the more expensive is the cost of placing the payload into orbit, considering that the cost of a space mission is estimated around US$ 259,000/Kg (James, 1996).

Acoustic loads due to rocket motors operation at lift off and external loads as transonic and maximum dynamic pressure are significant loads. These air-borne excitations have as main characteristics their broadband and random nature as well as high intensity acoustic levels. The induced acoustic and vibration environments may damage structures and embedded equipment and, therefore, must be considered still during the launch vehicle developing phase.

Passive techniques can be used to attenuate structure-borne vibration and the use of viscoelastic materials adding structural damping to reduce structural vibrations is a well-known solution, usually applied in space and aeronautical industries. Another important technique is the use of AVC as described by Glaese and Anderson (2003).

For acoustic noise attenuation, designers may consider the upper parts of launchers as the main elements to be treated, as is the case of the PLF and bays. Passive techniques with acoustic blankets were used by Glaese and Anderson (2003) and Weissman (1994). The standard practice is to use blankets to attenuate sound energy by trapping the energy and dissipating it as heat (Bolton, 2005). However, in space industry, the weight of the NCT is a limitation that must be accounted. Another important issue to be considered is that blankets are typically 5.08 to 10.16 cm thick, making them more effective in frequencies above 300 to 400 Hz. Nevertheless, even though these NCT are more effective from medium- to high-frequencies in low-frequency range, the relation between the speed of sound and frequency makes the acoustic wavelength too long for sound waves to be trapped in the blanketed treatment. As a result, other techniques as active noise control (ANC) and Helmholtz resonators may be applied to reduce noise (Glaese and Anderson, 2003; Defosse and Hamdi, 2000). Several approaches that can be grouped into passive and active attenuation techniques can be applied to reduce acoustically induced vibration during launch. For the passive approaches, the structure can be modified by changing masses or stiffness or by including damping in discrete points (dynamic vibration absorbers) or in large areas (viscoelastic layers attached to the structure skin). The acoustic cavity can be modified by adding acoustic-absorbing material to its boundaries or by using acoustic resonators. The first strategy can reduce SPL on a large frequency interval while the second one is able to reduce SPL in tuned frequencies.

The vibro-acoustic behavior of the VLS-1 fairing was studied by Pirk, (2003). In this work, the PLF low-, medium- and high-frequency bands were defined as up to 150 Hz, from 150 to 300 Hz and above 300 Hz, respectively. Furthermore, low-frequency coupled techniques like FEM/FEM and FEM/BEM as well as SEA for high-frequencies were applied to obtain the PLF acoustic and skin responses due to an acoustic diffuse field, simulating the lift-off acoustic loads.

An acoustic test was done to validate the referred model. In such test, the VLS-1 fairing was submitted to 145 dB OSPL acoustic diffuse field in a 1,200 m^3 acoustic reverberant chamber. Experimental and theoretical data were compared and showed good agreement (Pirk and Góes, 2006).

At this phase of the VLS-1 project, the assessment of different passive techniques for acoustic environment alleviation to be applied to the PLF is an important issue, since this fairing has not an efficient NCT, so far. One of the main applications of numerical control prediction is the decision, still in the early product development phase, about which design version is the most appropriate, from the noise control point of view. By introducing the concept of sensitivity analysis, product development can be performed in a more systematic way. In order to predict the efficiency of a NCT, one compares the effect of a design modification.

This work aims to predict the inner acoustic environment of the VLS-1 PLF by virtually adding acoustic blankets. The basics of the SEA technique as well as the modeling procedures for creating different virtual prototypes of the fairing are presented. A SEA vibro-acoustic model of the referred PLF is built, accounting for the structural and acoustic subsystems, external acoustic diffuse field excitation and connections involved on such model. Afterwards, different blanket layers are implemented on this elasto-acoustic

Paper received 2 June 2011. Paper accepted 31 August 2011.
Technical Editor: Marcelo Trindade

virtual prototype and the effects of these NCT implementations are assessed. Since blankets acoustic absorption depends on certain material parameters, two blanket modeling approaches are assessed as follows:

i) material physical Biot´s parameters as density, porosity, resistivity, tortuosity, viscous and thermal characteristic lengths, given by the blanket manufacturer;

ii) measured normal incidence absorption coefficients of material samples.

Finally, the influence of the percentage of the treated surface, the NCT thicknesses and the presence of air-gaps between blankets are analyzed.

Nomenclature

PLF = *payload fairing*
ELV = *Expandable Launch Vehicle*
BEM = *Boundary Element Method*
c = *speed of sound*
E = *Young´s Modulus*
E_i = *lumped total energies*
FEM = *Finite Element Method*
H_{12} = *complex transfer function*
K = *wave number*
L = *distance between the material under test and microphone number 1*
n = *systems modal densities*
NCT = *Noise Control Treatment*
OSPL = *Overall Sound Pressure Level*
Pij = *input power*
R = *plane wave reflection coefficient*
S = *distance between microphones*
SEA = *Statistical Energy Analysis*
SPL_1 = *external SPL (dB, ref. 20 exp -06)*
SPL_2 = *internal SPL (dB, ref. 20 exp -06)*
TL = *sound transmission loss*
Wt = *sound power transmitted by a barrier*
Wi = *sound power incident*
Pcf = *pounds per cubic feet*
ηii = *internal loss factors*
ηij = *coupling loss factors (CLF)*
VLS-1 = *Brazilian Satellite Launcher Vehicle*

Greek Symbols

α_t = *transmission coefficient*
α = *normal absorption coefficient*
ω = *angular frequency*
ν = *Poison´s Modulus*
μ = *air dynamic viscosity, dynamic viscosity, kg/(m s)*
ρ = *mass density, kg/m*^{3}

Subscripts

i = *relative to the subsystem i*
j = *relative to the subsystem j*
1 = *relative to the microphone 1*
2 = *relative to the microphone 2*

Acoustical Characterization of Sound Insulation

Acoustic layers are not effective barriers when used to reducing sound transmission. However, they are used to suppress the effects of the mass-air-mass resonance and inter-panel depth resonances and to enhance the TL at medium- to high-frequencies (Bolton, 2005). The acoustical performance of blanket materials can be characterized in many ways, since different parameters as Biot´s parameters, thickness etc. are significant when acoustic NCT designs are specified.

The Biot´s parameters are physical properties as density, porosity, resistivity, tortuosity, viscous and thermal characteristic lengths of the material. These properties are usually given by the material manufacturer or can be measured in laboratory, as pointed by Lauriks (2005).

The material absorption coefficient (α) is another important parameter related to sound absorption, which is characterized by its normal or random incidence characteristics, and can be measured by using an impedance tube. The ISO standard 10534-2 (1998) describes the well-known “two-microphone” or “transfer-function” method for measuring absorption and impedance characteristics of acoustic materials as shown in Fig. 1.

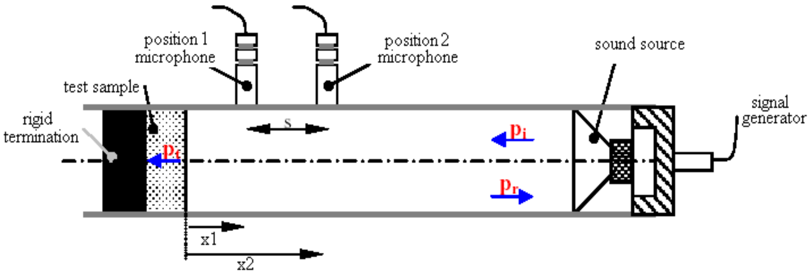

Figure 1. Impedance Tube.

The transfer function method is based on the ratio of the sound pressures of the reflected wave and the incident wave at the termination (at x = 0), given by Eq. (1) (Seybert and Ross (1977)):

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

The absorption coefficient of the materials is given by Eq. (2).

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

The random incidence absorption coefficient can also be measured in a reverberant room, where the acoustic diffuse field can approximately be simulated.

In this framework, the characterization of acoustic materials using impedance tube is an important issue, when one considers sensitivity analyzes by adding different NCT designs. By using the PLF vibro-acoustic SEA model, the effect of addition of acoustic liners is assessed and the fairing internal acoustic environment can be calculated. This way, the NCT efficiencies and TL can be evaluated. The two approaches described in this item are considered in the modeling techniques of the VLS-1 fairing. The Biot’s parameters are taken into account in the PLF SEA model and different NCT efficiencies are assessed. On the other side, an impedance tube apparatus was used to determine the absorption coefficients of different materials and these parameters were implemented on the fluid-structure SEA model of the fairing.

Model Description

VLS-1 fairing description

The VLS-1 fairing is the compartment where the payload is placed during flight and has as function to give aerodynamic shape to the launcher as well as to protect the payload. The PLF is hammerhead geometry, with a diameter of 1.2 m and 3.5 m height. Built on aluminum plates, reinforced by beams, its exterior surface is lined in cork material for heating protection and no acoustic blankets are provided inside the fairing cavity, so far. The total weight of the fairing is approximately 150 kg, including the structure, functional components as the electric and pyrotechnic systems, mechanisms and the exterior cork liner. Figs. 2a and 2b show the PLF.

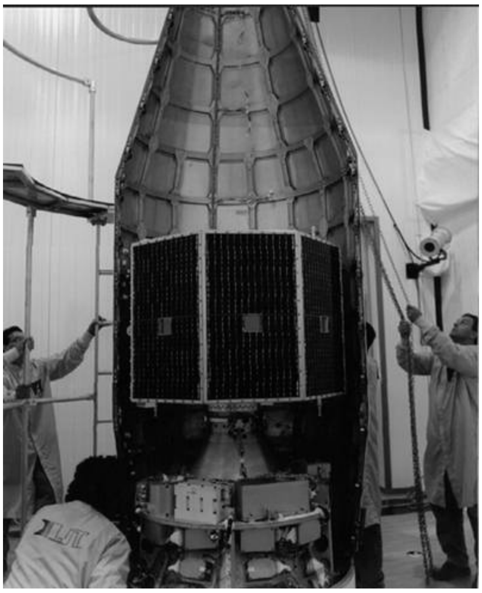

Figure 2a. VLS-1 fairing structure.

Figure 2b. VLS-1 fairing structure.

SEA Modeling Methodology

Deterministic techniques as FEM and BEM have limitations for high-frequency analysis. Considering the appropriate number of elements per wavelength, smaller elements are needed, increasing significantly the number of degrees of freedom. This refinement imposes limitations, once the allocated memory and processing time increase; mainly for coupled analysis (Pirk, 2003). Also on high frequencies modal parameters show great sensitivity to small variations of geometry, construction and properties. In light of these limitations and uncertainties, the use of a statistical model seems an appropriate choice for high frequency analysis and the SEA technique is proposed to assess the inner cavity behavior of the VLS-1 fairing.

The basic SEA equations express the energy balance of the subsystems in the model. Some subsystems have direct power input of an independent source, e.g. an excitation on a structural component, a sound power source in an acoustic medium etc. As an example, Fig. 3 shows a SEA model with three connected subsystems and the global SEA equations of such dynamic system can be obtained by the balance of each subsystem, individually.

As stated by Lyon and DeJong, 1995, in many practical situations, the system will be composed of many multi-modal subsystems, where each subsystem may be physically coupled to more than one subsystem. The whole system can be modeled as a set of modes that constitute the energy store locals. In SEA, it is assumed that the energy flow between two subsystems is given by the energy flow describing a two subsystem model and the reciprocity equation, as shown in Eq. (3).

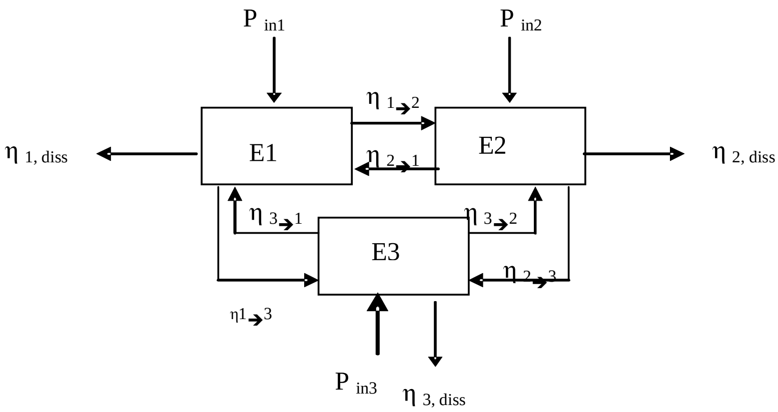

Figure 3. Energy balance of a 3 subsystems coupled model.

$$\begin{cases} P_{ij} = \omega(\eta_{ij} E_i - \eta_{ji} E_j) \\ n_i \eta_{ij} = n_j \eta_{ji} \end{cases} \tag{3}$$

The temporal average of the dissipated energy in a subsystem i is given by:

$$P_{i,diss} = \omega \eta_i E_i \tag{4}$$

Mathematically, the energy balance of the subsystem i is given by:

$$P_i = P_{i,diss} + \sum_{j \neq i}^{n} P_{i \to j} - \sum_{j \neq i}^{n} P_{j \to i} \tag{5}$$

The substitution of the basic SEA Eqs. (3) and (4) in Eq. (5), gives:

$$P_i = \omega \eta_{ii} E_i + \sum_{j \neq i}^{n} \omega(\eta_{ij} E_i - \eta_{ji} E_j) \tag{6}$$

The corresponding SEA equation of the 3 subsystems coupled model takes into account the input powers $P_{,i}$ to subsystems i, a vector with lumped total energies E_i and the SEA matrix [γ] which depends on the frequency and the SEA parameters as internal loss factors (*ηii*), coupling loss factors (*ηij*) and modal densities (*ni*), and is described in Eq. (7).

$$\omega \begin{bmatrix} \left(\eta_{11} + \sum_{j \neq 1}^{n} \eta_{1i}\right) n_1 & -\eta_{12}.n_1 & .... & -\eta_{1n}.n_1 \\ -\eta_{21}.n_2 & \left(\eta_{22} + \sum_{j \neq 2}^{n} \eta_{2i}\right) n_2 & ... & ... \\ ... & ... & ... & ... \\ -\eta_{n1}.n_n & ... & ... & \left(\eta_{nn} + \sum_{j \neq n}^{n} \eta_{ni}\right) n_1 \end{bmatrix} \begin{Bmatrix} \frac{E_1}{n_1} \\ \frac{E_2}{n_2} \\ ... \\ \frac{E_n}{n_n} \end{Bmatrix} = \begin{Bmatrix} P_1 \\ P_2 \\ ... \\ P_n \end{Bmatrix} \tag{7}$$

SEA Vibro-Acoustic Model of the Fairing

The VLS-1 fairing was divided into four surfaces, as shown in Fig. 4. To account for the rib-stiffened plates of the surfaces 2, 3 and 4, the SEA structural model considers connected plates and beams (longitudinal and circular). The fairing structural mesh was generated on a pre-processor and imported into VAOne software in order to create the SEA structural model. The plate subsystems were generated as singly curved shells and uniform plates, with damping loss factors of 1% (for flexure, extension and shear propagating waves), which account for the internal loss factors. These subsystems were connected to each other by line connections to account for coupling loss factors. Shell surface 1 has a thickness of 3.0 mm and was modeled as a simple plate of aluminum (E = 72 GPa, ν = 0.29, ρ = 2750 kg/m^3), while the other three surfaces are 0.8 mm thick, made of an aluminum alloy (E = 72 GPa, ν = 0.29, ρ = 7000 kg/m^3). The circular and longitudinal beams were modeled with the same aluminum alloy of the surfaces 2, 3 and 4. The damping loss factors of 1% were assigned to all the beam subsystems. The external liner of cork on the surfaces 2, 3 and 4 was simulated as material addition. The layered area and cork density were assigned by considering the cork thickness and mass per unit of area.

A total of 72 beams (44 longitudinal and 28 circular) and 8 shells (02 singly curved shells of the adaptor, 02 singly curved shells of the lower cone, 02 singly curved shells of the main cylinder and 02 singly curved shells of the upper cone) compose the structural SEA model. Figure 4 shows the SEA plates and beams generated to model the VLS-1 fairing structure.

The PLF acoustic cavity was created considering air as the fluid and the dimensional parameters of the fairing. As such, a mass density ρ = 1.225 kg/m^3 and a speed of sound c = 340 m/s were assigned to create this subsystem. The top and bottom face of the cavity were assumed to be acoustically closed. Figure 5 presents the 3D acoustic cavity of the fairing.

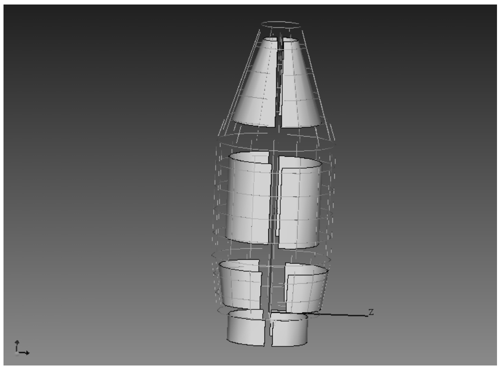

Figure 4. Structural subsystems (shells, circular and longitudinal beams).

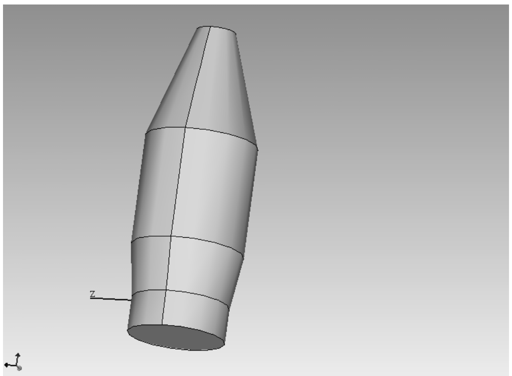

Figure 5. Acoustic cavity of the fairing.

The coupling boundary between all the structural and acoustic subsystems is modeled to consider the transmission of power across the junctions. A junction is comprised of connections of any number of coincident subsystems. As such, all the subsystems that share common nodes are connected by point, line and area junctions and all the appropriate wavefields are connected as well as the corresponding coupling loss factors (CLF) between subsystems.

Scott et al. (1996) described the OSPL and respective spectral distribution generated by ARIANE 4 rockets at lift off. For VLS-1, early simulations and measurements acquired during stand testing showed that the profile generated by ARIANE 4 can be assumed as the excitation profile at lift off of the VLS-1 simulations. This is done since the VLS-1 in-flight acoustic measurements were not characterized so far.

At the beginning of the flight ascent of ARIANE 4, the estimated OSPL is around 145 dB (Scott et al., 1996). A usual approach to simulate the launcher structure excitation is to consider the lift off noise close to a diffuse noise. In contrast with the aerodynamic noise at flight ascent, the nature of the lift off acoustic loading is close to a diffuse excitation, having a (nearly) uniform pressure distribution (Coyette et al., 1997). Only elements with large surface areas, as plates and panels, are susceptible to acoustic excitation (Defosse and Hamdi, 2000 and Thinh, 1994). In this framework, diffuse pressure field of 145 dB OSPL was applied to the plates of the SEA fairing model, which simulates the power input into a structural plate or shell element. As the surfaces have eight connected shells, the excitations are applied individually to each shell, as seen in the complete model (Fig. 7). The spectral distribution of this acoustic pressure diffuse field which simulates the air-borne excitation generated at VLS-1 lift off is shown in Fig. 6 (Scott et al., 1996). The complete SEA fairing model, with 80 structural elements (72 beams and 8 shells), 1 acoustic 3-D volume and 8 diffuse field excitations, is shown in Fig. 7.

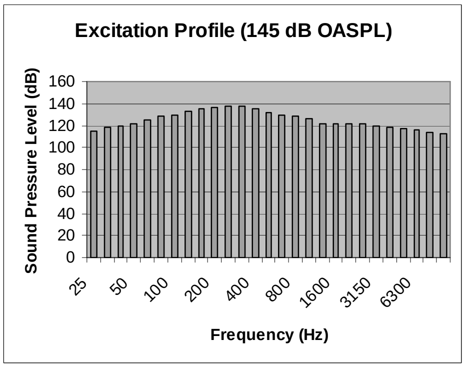

Figure 6. Diffuse pressure field at lift off.

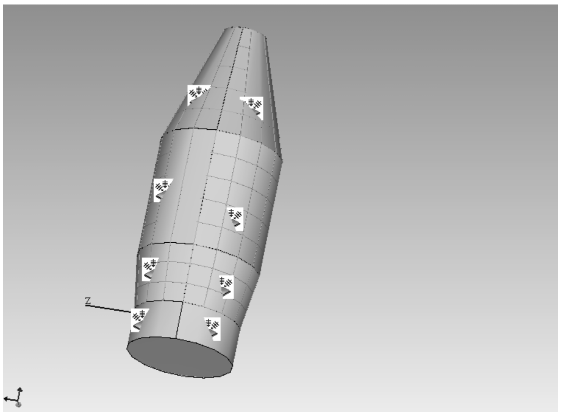

Figure 7. Complete model of the fairing.

Since the fluid-structure SEA model of the VLS-1 fairing was built, the effect of the NCT designs are evaluated. The two approaches assessed consider a SPL prediction with sensitivity analyzes of different material insertion on the PLF as well as different percentages of treatments.

Noise Control Treatment (NCT)

Pirk (2003) observed that the mass of cork material added to the fairing body as heating shield is the only material responsible for increasing the acoustic TL inside this compartment. Therefore, it is paramount that the acoustically induced vibrations be attenuated, in order to have a less aggressive environment for the payloads carried by VLS-1, during the flight mission. Surveys to assess influence of different configurations of blanket materials have been done, in view of having an extensive library describing the acoustical characteristics of such materials. Besides, different SEA modeling approaches have been studied (Pirk and Souto, 2008 and 2010). The acoustic blanket insertion technique is well applied for medium-to-high frequency noise reduction (Glaese and Anderson, 2003 and Bolton, 2005), depending on physical parameters based on the Biot´s theory of porous materials. NCTs are usually applied using single- or multi-layered materials specially designed to isolate plates/shells and acoustic cavities. With the sensitivity analysis, the development of a NCT design can be performed in a systematic way. The resulting SPL inside the fairing is calculated for different NCT designs. In the next paragraphs Biot´s parameters and absorption coefficient approaches are described. Both were implemented in the coupled elasto-acoustic SEA model of the PLF. For the Biot´s parameters approach, an explicit model of the inserted material was considered, based on the physical properties of individual layers, which are accounted in the SEA model. Six types of glass wools are assessed and the SPL inside the fairing were calculated. A thickness of 7.62 cm was adopted for almost all glass wools, but for the two 1.2 pcf glass wools (that presents particular behavior), one adopted thicknesses of 1.9 cm and 3.8 cm. The best performing material was chosen and a comparison between different thicknesses and percentages of layered surfaces of the fairing was done, considering the final weight of the applied NCT. Table 1 describes the materials applied to the SEA model as well as their physical parameters.

Table 1. Glass wools and physical parameters.

Characteristic/Material	0.34 pcf (3.00")	0.42 pcf (3.00")	0.60 pcf (3.00")	1.2 pcf (0.75")	1.2 pcf (1.5")	1.5 pcf (3.00")
Density (kg/m^3)	5.40	6.70	10.49	26.02	19.22	24.00
Mass per area (kg/m^2)	0.41	0.51	0.73	0.37	0.73	1.83
Porosity	0.9435	0.986	0.985	0.97	0.99	0.9999
Resistivity (Nx/M4)	26,890.62	21,649.86	27,337	206,041	96,967	125,647
Tortuosity	1.10	1.00	1.00	1.06	1.09	1.10
Viscous Char.Length (m)	1.65 E^{-4}	1.15 E^{-4}	3.53 E^{-5}	9.50 E^{-6}	8.95 E^{-5}	1.20 E^{-5}
Thermal Char.Length (m)	3.29 E^{-4}	2.31 E^{-4}	1.29 E^{-4}	7.19 E^{-5}	8.95 E^{-5}	6.00 E^{-5}

pcf: material density in pounds per cubic feet (1 lb/ft^3 = 16.02 Kg/m^3).

On the other side, the measured absorption coefficient of multi- and single-layered samples of glass wools of 0.42 and 1.0 pcf were considered. According to Allard, 1993, air gaps between materials increase the acoustic absorption at low-frequencies. In order to confirm this statement, samples with two different air gaps were also positioned into the Kundt tube. The single-layered samples are 3.50 cm thick, while combinations were done with samples of 1.75 cm thick. Other configurations were assembled with air gaps of 1.0

and 3.0 cm between samples. Figure 8a shows the sample combinations, while Fig. 8b presents the single layer samples. All the measured absorption coefficients are shown in Fig. 9. These absorption coefficients were assigned on the fairing vibro-acoustic model and SPL were calculated.

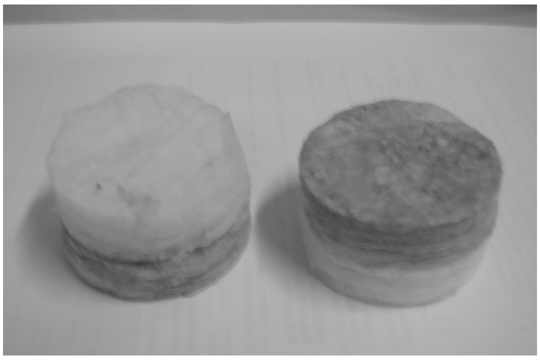

Figure 8a. Double-layered 0.42 pcf (light sample)/1.0 pcf (dark sample), 1.75 cm thick each.

Figure 8b. Single-layered 0.42 pcf (light sample) and 1.0 pcf (dark sample), 3.0 cm thick each.

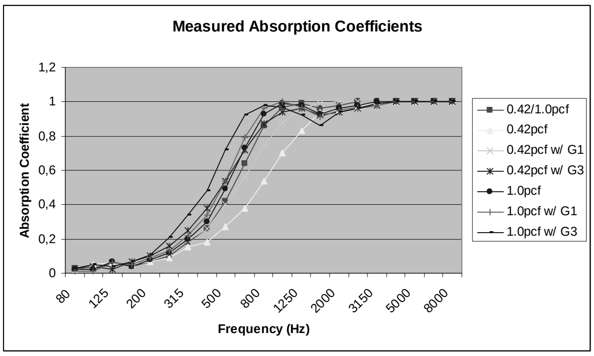

Figure 9. Measured absorption coefficients *G1 and G3: air gaps of 1.0 cm and 3.0 cm.

Results

The PLF acoustic responses for various NCT configurations, including the bare PLF, are shown in Fig. 10. The OSPL shows that the insertion of the 0.34 pcf glass wool – 7.62 cm yields almost 20 dB of attenuation, which was chosen as the best performing NCT.

The assessment of the thickness influence was done by assigning 0.34 pcf glass wools of 7.62, 10.16 and 12.7 cm thicknesses, which have total weights of 3.90, 5.30 and 6.60 Kg, respectively. Figure 11 presents the internal SPL one-third octave distribution, as well as the OSPL.

The 0.34 pcf glass wool – 7.62 cm was adopted in the assessment of the percentages of layered areas, which also considered the weight as a significant parameter. With the treated areas of 30%, 50%, 80% and 100%, the weights of the NCT design are 1.17 Kg, 1.95 Kg, 3.12 Kg and 3.90 Kg, respectively. Figure 12 shows the calculated OSPL.

Figure 13 shows the one-third octave SPL as well as the OSPL from 50 to 8,000 Hz, for the NCT described in Fig. 9, without air gaps. A 3.50 cm double-layered blanket (0.42 pcf/1.0 pcf) is compared with two single-layered NCT. Notice in this figure that NCT decrease the internal OSPL from 132 dB to 128 dB. It can also be seen that the double-layered configuration does not present significant gain, when compared to single-layered configurations.

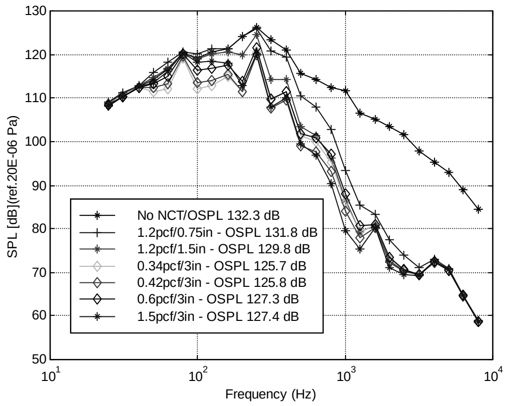

Figure 10. Internal SPL for different blankets.

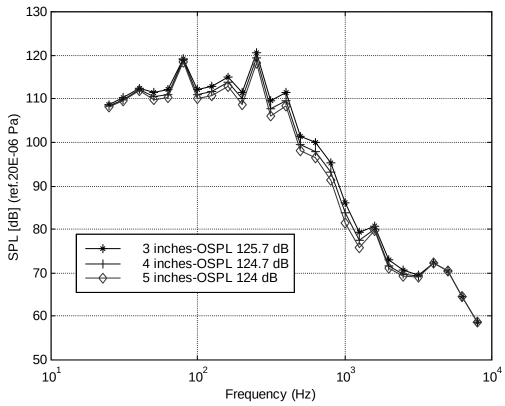

Figure 11. SPL for different thicknesses – 0.34 pcf.

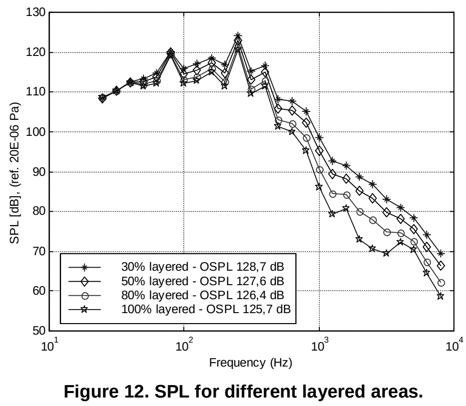

Figure 12. SPL for different layered areas.

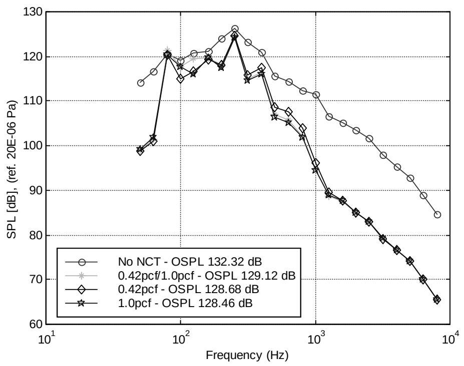

Figure 13. SPL for NCT without air gap.

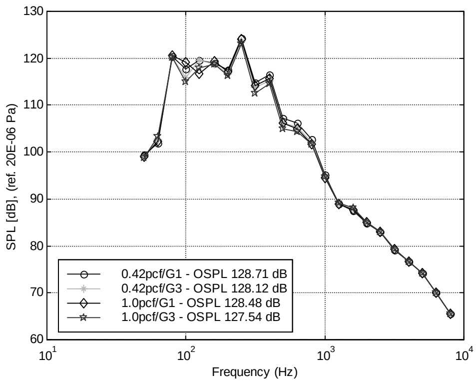

Figure 14. SPL for NCT with air gaps (*G1 and G3: air gaps of 1.0 cm and 3.0 cm).

Figure 14 shows that single-layered treatment with 1.0 pcf and air gaps presented better results. One can see the air gap effect, since the SPL close to 100, 315 and 500 Hz are higher, mainly when the 1.0 pcf material with 3.0 cm air gap is applied. The calculations yielded 127.5 dB OSPL inside the fairing cavity. This means that a gain of approximately 3.0 dB at 100 Hz bandwidth can be obtained, yielding an overall gain of 1.0 dB, approximately. However, it is important to highlight that air gap installation can be limited, due to fairing internal space. In this case, it is preferable to install the blanketed treatment distant from the panels by small air gaps, instead of bonded, once this installation configuration presents higher TL (Bolton, 2005).

Comments and Conclusion

The sensitivity analysis of blankets has shown to be an effective tool for the development of the VLS-1 fairing NCT design in a systematic way. The effectiveness of a NCT considering its weight and performance can easily be evaluated using SEA, still in the development phase, where detailed subsystems are not required.

As a statistical technique, SEA does not yield reliable results in low-frequency range, where the vibro-acoustic responses are dominated by long-wavelength standing wavefields. Nevertheless, in this first analysis of different NCT designs, the valid frequency range is not considered. However, from medium- to high-frequency, SEA has shown to be a significant tool for the VLS-1 fairing SPL predictions as presented by Pìrk and Góes (2006). Future works may consider other NCT to be applied in low-frequency, using techniques as FEM/FEM and FEM/BEM.

By analyzing many NCT configurations one can provide a library of performances and weights, important parameters that describe the ELV performance book. As in space the cost of a mission is a major issue, a trade-off between NCT weight and efficiency must be accounted. Acoustic testing in reverberant chamber may be conducted to validate the presented results and other porous-elastic materials may be investigated to complement the fairing NCT design library.

The current estimated OSPL inside the VLS-1 fairing is around 132 dB OSPL at lift off, which is not a compatible level for embedded equipment. Among the studied glass wools, the best performing blanket material was the glass wool 0.34 pcf – 7.62 cm. As it was expected, the increase in the thickness significantly increases the TL.

The variation of the material thickness from 7.62 to 12.7 cm showed that the gain in TL is 1.7 dB. From the acoustician side, this could be an important gain. However, one may consider that this gain results in heavier NCT designs ranging from 3.9 to 6.6 Kg and induced mission costs can be limited from the launcher manager point of view. On the other side, 100% blanketed area presented higher TL (around 20 dB). Varying the layered area from the total surface to 30%, one could see that the internal OSPL varies from 3.0 dB.

Concerning the air gaps, the low-frequency effect was assessed. However, NCT with air gap installation is limited, due to fairing internal space. In this case, it is preferable to install the blanketed treatment distant from the panels by small air gaps.

References

Allard, J.F., 1993, "Propagation of Sound in Porous Media – Modeling Sound Absorbing Materials", Elsevier Applied Science, London and New York.

Bolton, J.S., 2005, "Porous Materials for Sound Absorption and Transmission Control", Proceedings of the 2005 Congress and Exposition on Noise Control Enginnering, INTERNOISE 2005, Rio de Janeiro, Brazil.

Defosse, H., Hamdi, M.A., 2000, "Vibro-acoustic Study of Ariane V Launcher During Liftoff", Proceedings of the 2000 Congress and Exposition on Noise Control Engineering, INTERNOISE, Nice, France.

Glaese, R.M. and Anderson, E.H., 2003, "Initial Structural-Acoustic Modeling and Control Results for a Full-Scale Composite Payload Fairing for Acoustic Launch Load Alleviation". At: http://www.csaengineering.com/ techpapers/technicalpaperspdfs/CSA1999_Initial Structural.

ISO 10534-2: 1998, "Determination of sound absorption coefficient and impedance in impedance tubes - Part 2: Transfer-function method"

James R. Wertz (Editor), 1996, "Reducing Space Mission Cost (Space Technology Library)", Wiley J. Larson (Editor), Microcosm Press (June 1).

Lauriks, W., 2005, "Characterization of Porous Acoustic Materials", SAPEM, Symposium on the Acoustics of Poro-Elastic Materials, Lyon, France.

Lyon and DeJong, 1995, "Theory and Application of Statistical Energy Analysis", 2nd Edition.

Pirk, R., 2003, "Vibro-Acoustic Analysis of the Vehicle Sattelite Launcher´s (VLS) Fairing", Ph. D. Thesis, Technological Institute of Aeronautics (ITA), São José dos Campos, Brazil.

Pirk, R. and Góes, L.C.S., 2006, "Acoustic Theoretical x Experimental Comparison of the Brazilian Satellite Launcher Vehicle (VLS) Fairing", Proceedings of the ISMA 2006, Leuven, Belgium.

Pirk, R. and Souto, C.A., 2008, "Implementation of Acoustic Blankets to the VLS Fairing – A Sensitivity Analysis Using SEA", Proceedings of the ISMA, Leuven, Belgium.

Pirk, R. and Souto, C.A., 2010, "Implementation of Acoustic Blankets in the VLS Fairing, Using Multi- And Single-Layered Models – A Sensitivity Analysis Using SEA", Proceedings of the ICSV, Cairo, Egypt.

Seybert, A.F., and Ross, D.F., 1977, "Experimental Determination of Acoustic Properties Using a Two-Microphone Random-Excitation Technique", *J. Acoustic. Soc. Am.*, Vol. 61, No. 5, pp. 1362-1370.

Scott, J.M., Jay, B.G., Robert, C.B., 1996, "General Environmental Specification for STS and ELV – Payloads, Subsystems and Components, GEVS-SE", Rev. June, NASA Goddard Space Flight Center, Greenbelt, Maryland, 20771.

Thinh T. Do, 1994, "Vibroacoustic Modeling Study of the Delta II 10-Foot Composite Fairing", The Aerospace Corporation, El Segundo, California.

Weissman, K., McNelis, M.E. and Pordan, W.D., 1994, "Implementation of Acoustic Blankets in Energy Analysis Methods with Application to the Atlas Payload Fairing, *Journal of the Institute of Environmental Sciences – IES*, July/August.