Response Analysis Of Payload Fairing Due To Acoustic Excitation

Annu Cherian, P. Geena George, Dr. C. Prabha

Abstract: During flight missions, launch vehicles are subjected to a severe dynamic pressure loading, aero-acoustic and structure-borne excitations of various circumstances, which can endanger the survivability of the payload and the vehicles electronic equipment, and consequently the success of the mission. The purpose of the fairing is to protect the satellite from damage during launch until deployment in space. Both the structural and acoustic loads are significant during the first few minutes of a launch and have the potential to damage the payload. This paper describes the analysis of mechanical structure and the inner acoustic cavity of the payload fairing subjected to acoustic field. The vibro-acoustic behaviour of the fairing is analyzed using Statistical Energy Analysis (SEA) Model. The software VA One is used for the statistical energy analysis of launch vehicle payload fairing due to acoustic excitation.

Keywords: Cone-Cylinder, Diffuse Acoustic Field (DAF), Payload Fairing, Statistical Energy Analysis (SEA), Vibro-Acoustic

1. Introduction

In recent years, the need for acoustic shielding of payloads has acquired greater importance since the introduction of light-weight composite launch fairings [1- 2]. The purpose of the fairing is to protect the satellite from damage during launch until the atmospheric phase of flight is over, but phenomena such as airflow along the walls of the fairing and booster, the rocket engines, rocket exhaust wave reflections from the ground and shocks experienced during stage separations produce an intense vibro-acoustic environment inside the fairing [3,4]. Aerospace structures are generally characterized by the use of exotic composite materials of various configurations and thickness, as well as by their extensively complex geometries and connection between different subsystems. It is therefore of crucial importance for the modern aerospace industry, the development of different vibro-acoustic response analysis of large composite structures of various geometries and subject to a combination of aero-acoustic excitations [5]. The standard payload fairing is typically a cone-cylinder combination, due to aerodynamic considerations. Different techniques are developed for predicting the acoustic response and radiation properties of complicated structures [6-8]. Great number of structures is subjected to vibration and acoustic excitation at high frequencies. The most famous method in theoretical modelling and analyzing high frequencies is Statistical Energy Analysis (SEA) method. This method is "energy based" in contrast to the classical methods that are based on quantities such as force and displacement. SEA method is based on energy dissipation. The main idea of SEA method is that one has to divide analyzed structure into "subsystems". All energy analysis is done between those subsystems. SEA provides an alternative form of model that represents the average response behaviour of a population of systems. The vibrational state is expressed in terms of vibrational energies of individual components, where applied excitations are expressed in terms of input powers and the couplings between the components are expressed in terms of energy flows [9-11]. This paper discusses the use of Statistical Energy Analysis (SEA) for high frequency analysis (upto 8kHz) of the payload fairing. The launch vehicle payload fairing is modeled and analysed for acoustic load in the vibro-acoustic software VA One, using the statistical energy analysis method. The launch vehicle payload fairing is modeled and analysed for acoustic load in the vibro-acoustic software VA One, using the statistical energy analysis method.

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2. Modelling of Payload Fairing in SEA

2.1 Structure Modeling

The modeling was done by using the software VA One. The different portions of payload fairing (PLF) modeled in SEA were nose cap, nose cone, cylinder, boat tail, payload adaptor and wooden covers and is shown in Fig.1. Nose cap was modeled as a doubly-curved shell. Nose cone was modeled using two singly-curved shells. The cylindrical portion of the payload fairing was modeled as two cylinders. Boat tail portion was modeled using two singly-curved shells. The inner payload adapter was also modeled using two singly-curved shells. The openings in the structure had two wooden covers, one each at the top and bottom of the payload adapter for acoustic testing. Wooden covers were modeled as SEA flat plate. All portions were connected with proper junctions.

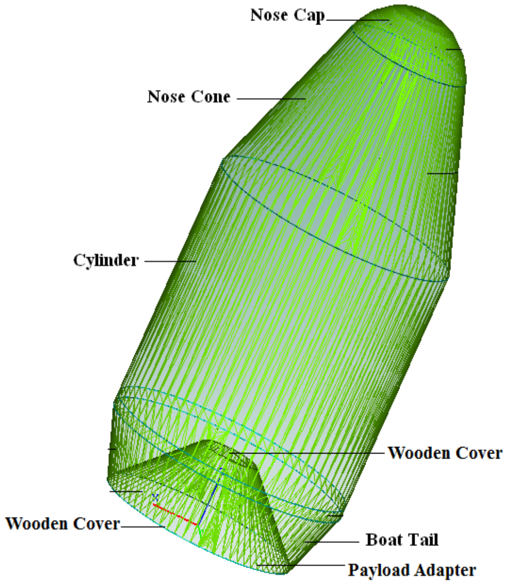

Fig. 1. *Different portions of PLF*

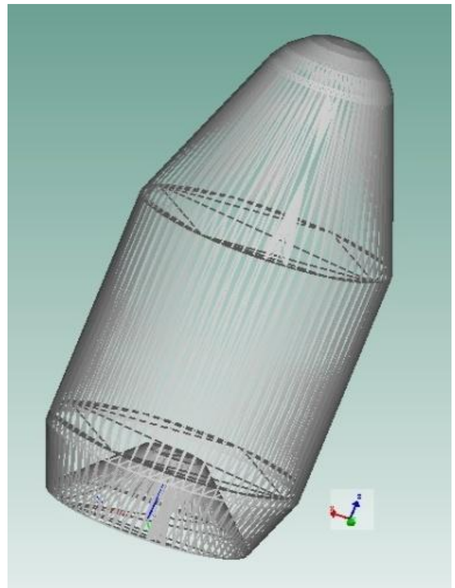

Fig. 2. *Cavity modelled in SEA*

Five ring beams were also modeled. The ring beams were provided between nose cap and nose cone, nose cone and cylinder, between cylinders, cylinder and boat tail and bottom of the PLF structure. Composite material properties were assigned to the PLF subsystems. Skin with CFRP (graphite/epoxy) and core with aluminum honeycomb structure. A uniform plate of plywood was provided as the wooden cover. A semi-infinite fluid (SIF) subsystem was added to the model, in order to predict the noise level due to the acoustic radiation from the structure and also for creating an air medium outside the PLF. Semi-infinite fluid was connected to the face of a given subsystems using an exterior radiation connector.

2.2 Cavity Modelling

Cavities were created inside the PLF subsystems. It helps to find out the inner acoustic fields due to the external sound pressure levels. The inner cavities created in four parts were shown in Fig. 2 for the nose cone, cylinder, boat tail and payload adapter. These cavities were connected to the subsystems with the area junctions.

2.3 Acoustic Excitation Modeling with Diffuse Acoustic Field (DAF)

This type of source is used to model a diffuse acoustic pressure load applied to a face of a SEA plate, shell or cavity subsystem. A truly diffuse acoustic field generally only exists in lightly damped rooms or other reverberant enclosures. However, a diffuse field is often a good model for acoustic excitations in which the precise details of the excitation (angles of incidence etc.) are unknown. In effect, it represents an average over all possible types of acoustic excitation. The sound pressure levels (SPL) were applied to the exterior of the subsystems using DAF. PLF modeled in SEA with DAF were shown in Fig. 3

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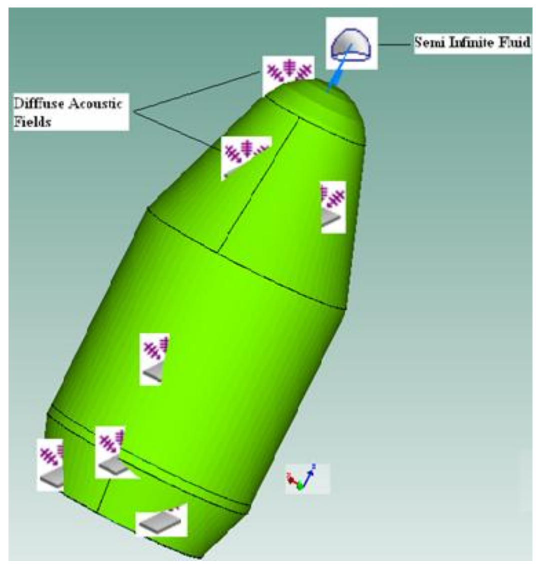

Fig. 3. *PLF modeled with DAF*

2.4 Acoustic Excitation Modeling with Chamber

A model was also created with external acoustic field applied using chamber instead of DAF, with a size of 8.3m x 10.3m x 13m, where energy constraint is provided in the outer chamber cavity. Model created with sea subsystems, beams, cavities, and SIF. Properties were assigned to different subsystems. Chamber sides were created by using plates. Chamber cavity was created between the chamber plates and PLF external subsystems. Chamber cavity and PLF subsystems were properly connected. Energy constraint provided to the chamber, instead of the DAF to the subsystems. PLF modeled within a chamber were shown in Fig. 4.

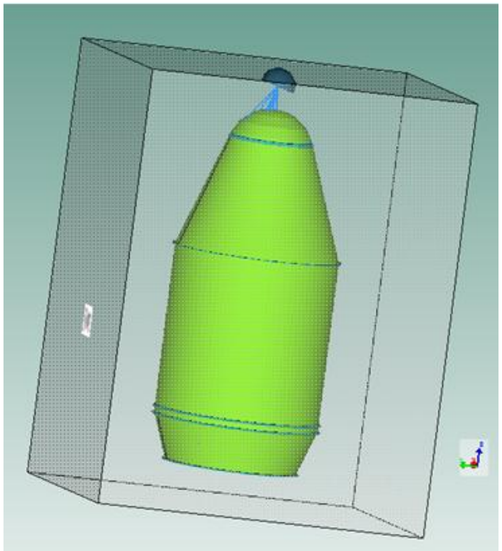

Fig. 4. *PLF modeled within the chamber*

2.5 Payload fairing with and without Noise Control Treatment (NCT)

Noise control treatment is provided on the fairing inner surface to reduce the acoustic levels inside the fairing. The fairing modeled with chamber was used for the comparison of with and without noise control treatments. The fairing models created with and without noise control treatments were solved and the results of inner acoustic fields and the vibration responses of cylinder were obtained for both the cases. Polyurethane forms of 75mm thick were used for the noise control treatments on the exterior subsystems. The treatments were applied to the inner side of the nose cone, cylinder and boat tail portions.

3. Results and Discussions

3.1 Inner Acoustic Fields of Cylinder with Chamber and DAF

PLF model created with chamber and DAF in VA One were solved and the results of inner acoustic fields of cylinder were obtained for both the cases. The test results for the PLF subjected to the uniform SPL were also available. The SPL obtained in the cylinder portion as a function of frequency, for the external field and the inner acoustic fields from the tests and PLF modeled with chamber and DAF in VA One are shown in Fig. 5. The difference in the OASPL from external field to the internal field obtained from the test, and chamber and DAF in SEA were 3.1dB, 3.5dB and 2.1dB respectively. It is seen that the inner acoustic field of the fairing with chamber is closer to the test results. Comparison of the test results with the results of PLF with chamber in each frequency band shows that the differences in inner acoustic field lie within the 5dB. Comparison of the test results with the results PLF with DAF in each frequency band shows that the differences in the inner acoustic field lie within the 6dB. The variation of inner acoustic field of cylinder, for the PLF modeled with DAF and from test at 31.5Hz was observed as 5.6 dB.

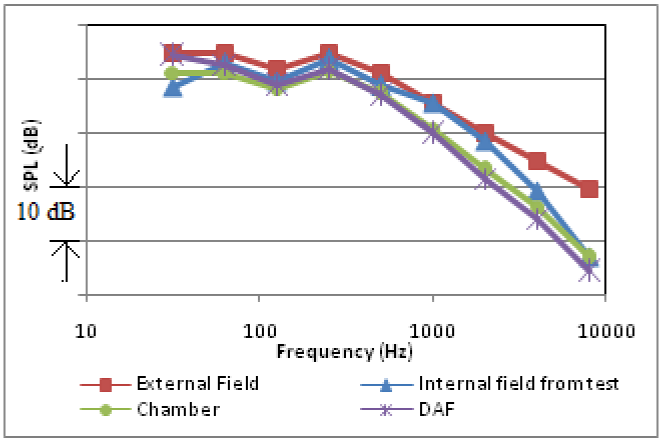

Fig. 5. *Comparison of inner acoustic field of cylinder with excitation modeled as chamber (energy constraint) and DAF with that obtained from test*

3.2 Inner Acoustic Fields of Cylinder with and without Noise Control Treatment

The comparison of the inner field in the cylindrical portion for the payload fairing modeled with and without noise control treatment (NCT) with the external field is shown in Fig. 6. The difference in the OASPL from external field to the inner field obtained for the bare and acoustically treated payload fairing in SEA were 3.8dB and 8.3dB respectively.

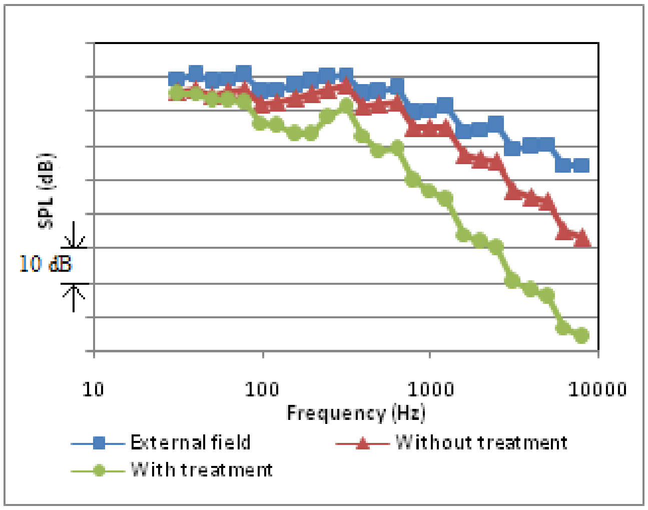

Fig. 6. *Inner acoustic fields of cylinder with and without NCT*

The OASPL differences between the PLF with and without NCT were obtained as 4.5dB. Comparing the results of cylinder portion with and without NCT, poor results were obtained in the low frequencies especially at 31.5Hz. From 100Hz to 400Hz, differences of 5dB to 11dB were obtained. The reduction in inner field is higher at high frequencies. For the frequency range of 500Hz to 8000Hz, the reduction obtained was in the range of 13.3dB to 28.9dB.

3.3 Vibration Response of Cylinder with and without Noise Control Treatment

The comparison of vibration response on the payload fairing cylinder with and without NCT are shown in Fig. 7.

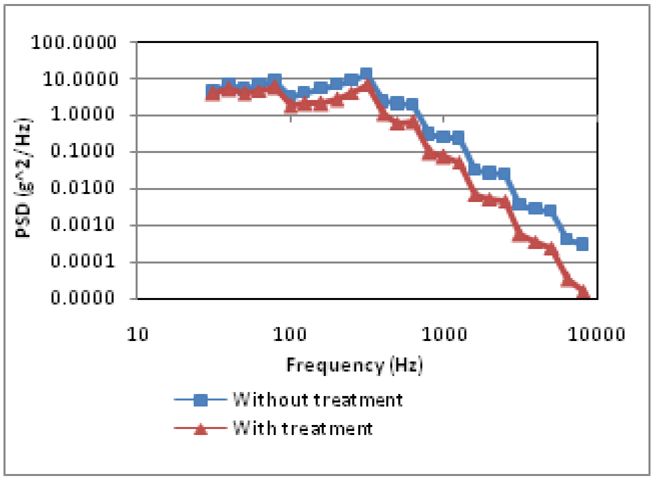

Fig. 7. *Vibration response of cylinder with and without NCT*

The overall responses of the fairing with and without NCT for the cylinder portion were obtained as 60.3 grms and 41.6 grms respectively. The differences in the overall response of the bare and acoustically treated PLF in SEA were given by 18.7 grms.

4. Conclusions

The sound pressure level of the inner acoustic cavities of the SEA subsystems were obtained analytically and compared with the test results for the PLF without noise control treatment. The comparison of inner field obtained with payload fairing modeled with energy constraint on chamber and DAF shows that fairing with energy constraint on the chamber gives lesser inner field. From the results, it is also clear that the inner acoustic field of the fairing with chamber is closer to the test results. The deviation from the test result is more at the 31.5Hz octave band. Both the results of fairing modeled with chamber and DAF show this deviation. The sound pressure levels (dB) in the acoustic cavities decreases with the increase in the frequency (Hz). Bare fairing structure provides an overall attenuation of about 3.3dB and 3.8dB for the cylinder portion. Attenuations were less in the lower frequencies of the one-third octave bands. Attenuation provided by the acoustic protection system was least at 31.5 Hz ocatve band. Attenuation provided by acoustic protection system was very good from 125 Hz and beyond. The differnce in the overall response of the bare and acoustically treated PLF in SEA were obtained in the range of 14.1 grms to 18.7 grms respectively. Increased mass and damping provided by the acoustic protection system reduces the response of the structure.

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