NOISE PREDICTION AND REDUCTION ON INTERIOR ACOUSTIC FIELD OF LAUNCH VEHICLE FAIRINGS

Xiuyan Cheng, Jili Rong and Xiangyu Chen

Beijing Institute of Technology, School of Aerospace Engineering, Beijing, CHINA
email: chengxiuyan@163.com

During flight, the severe external noise is a major factor threatening the safety of spacecraft and the instruments. It is very important to predict the internal sound field accurately and reduce the interior noise correspondingly. In this paper, the internal acoustic field of a certain launch vehicle fairing is calculated based on statistical energy analysis (SEA). Compared with the reverberation chamber test result, the applicable frequency range of SEA is confirmed, and the models are verified to get a good agreement with the experimental data, which shows that the fairing has a strong response at the cylinder coincident frequency of the fairing. The sound absorption properties of different melamine foams are researched. The optimum acoustical parameters of melamine foam are given to achieve best sound-absorption performance. With melamine foam pasting on the fairing inner wall, the noise attenuation effect is calculated with the SEA model. Results show that 10 dB noise pressure level reduction in applicable frequency range is achieved.

Keywords: statistical energy analysis, noise reduction, melamine foam

1. Introduction

Launch vehicle fairing is a key part of the rocket to protect the payload from the severe noise and vibration environment which could be locally above 180dB. By transmission and structure resonance, the aerodynamic noise transmits into the fairing, threatening the electronic devices, causing the fatigue damage of the structure, and reducing the reliability of the whole system [1]. The launch vehicle fairing prediction and reduction is a key process during rocket design stage. As the wave lengths are small at high frequencies, the FEM and BEM are hard to calculate the high frequency response. Statistical Energy Analysis was proposed by Lyon for prediction the mean energy of the subsystems of the aircrafts [2], which is an effective method for high frequency vibration prediction and widely used in vehicle design.

The passive noise control technology mainly contains the absorption material and the absorption structures. The acoustic parameters directly influence the noise attenuation effect of the porous material. It is very necessary to optimize the acoustic parameters to get a better sound absorbing effect.

In this paper, an SEA model of the launch vehicle fairing with payload is established, and verified by the reverberation chamber test result. The acoustic absorption coefficients of the melamine foam with different thickness are researched. With the transfer matrix method, the SEA model with trim of the melamine foam is calculated and the noise attenuation effect is predicted.

2. SEA theory and SEA model

2.1 SEA Theory

Statistical Energy Analysis is a method to analyse the response of the complex structures under external excitation from the point of view of energy. The structures are divided into subsystems, whose energy system is described by the power balance equations:

$$\omega[L]\{E\}=\{P\} \tag{1}$$

Where ω is the centre frequency of a frequency band, $\{E\}$ are the energy vectors, $\{P\}$ are the input energy vectors, and $[L]$ is the loss factor matrix including the damping loss factors and the coupling loss factors:

$$[L]=\begin{bmatrix} \left(\eta_1+\sum_{i\neq 1}^{N}\eta_{1i}\right)\cdot n_1 & (-\eta_{12}\cdot n_1) & \cdots & (-\eta_{1N}\cdot n_1) \\ (-\eta_{21}\cdot n_2) & \left(\eta_2+\sum_{i\neq 2}^{N}\eta_{2i}\right)\cdot n_2 & \cdots & (-\eta_{2N}\cdot n_2) \\ \cdots & \cdots & \cdots & \cdots \\ (-\eta_{N1}\cdot n_N) & \cdots & \cdots & \left(\eta_N+\sum_{i\neq N}^{N}\eta_{Ni}\right)\cdot n_N \end{bmatrix} \tag{2}$$

With the known loss factors and the input power, the energy of subsystems is obtained.

2.2 SEA model of the payload-fairing system

The rocket fairing and the internal payload are shown in Figure 1 [1]. The fairing is divided into 5 subsystems as 4 are cylinders and 1 double-curved shell. And the internal payload are divided into 13 plate subsystems, 5 single curved shell subsystems and 1 double-curved shell subsystem. The outside air cavity of the reverberation chamber is set to a cavity subsystem, and the payload contains 3 internal cavity subsystems. The air cavity inside the fairing but outside the payload is another cavity subsystem.

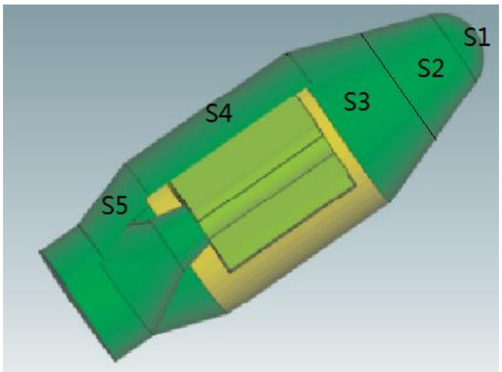

Figure 1: Rocket fairing and the internal payload

The SEA model of the payload-fairing system established in the software LMS SEA+ is shown in Figure 2. The structure subsystems are established within the real size of each part of the real test model of the payload-fairing system. The mass of the small structures ignored are added into the structure subsystems. The fairing cylinder subsystems are the single curved ribbed shells. The connections between the structure subsystems are mainly multipoints connections which are connected by rivets and line connections which are connected by soldering. The modes in band of the cavity subsystems are shown in Figure 3. Some of the damping loss factors of the subsystems are tested and the others are set the value as 0.1% according to the engineering experience [3]. The coupling loss factors are calculated by the software depending on the structures and the connections.

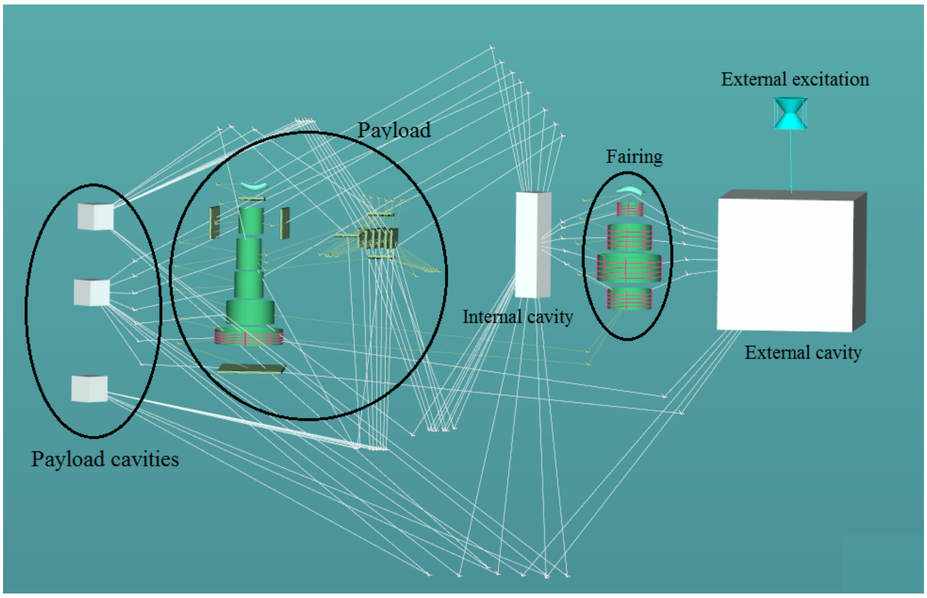

Figure 2: Statistical energy analysis model

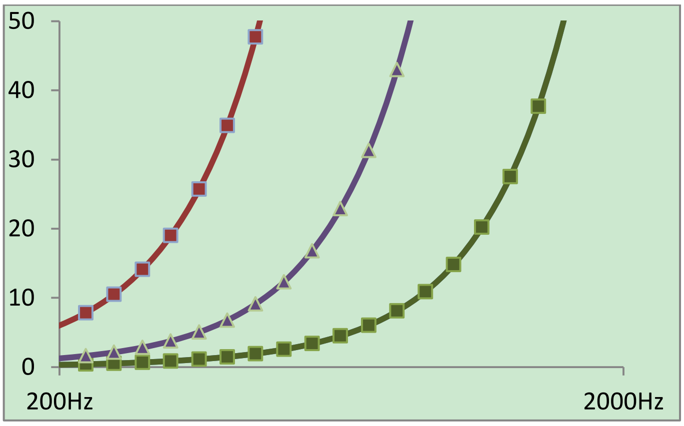

Figure 3: Modes in band of the cavity subsystems

2.3 Noise prediction and model validation

The external excitation is an acoustic energy constraints measured from the reverberation chamber test. The acoustic response of the internal cavity subsystem is shown in Figure 4. At the frequency range of 600~10000Hz, the calculation result error is less than 3 dB, which indicates that the model is reliable for interior noise prediction of the payload-fairing system. Compared with Figure 3, the modes in band of the subsystems are more than 4 in the frequency range of 600~10000Hz.

At about 8900Hz, there is a local maximum value on the response of the internal cavity subsystem, which is caused by the coincidence frequency. The coincidence frequency is the frequency at which the speed of the forced bending wave in the structure and the speed of the free bending wave are equal [4]. The sound transmission at the coincidence frequency is locally highest, which need to be paid attention in the design of noise attenuation. The power flow transmission at 9000Hz of the fairing is shown in Figure 5, which shows that the locally maximum response is mainly transmitted by the biggest cylinder subsystem.

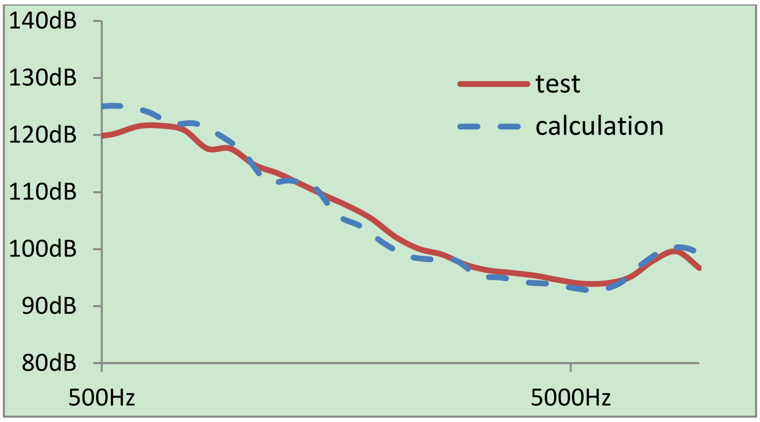

Figure 4: Acoustic response of the internal cavity subsystem

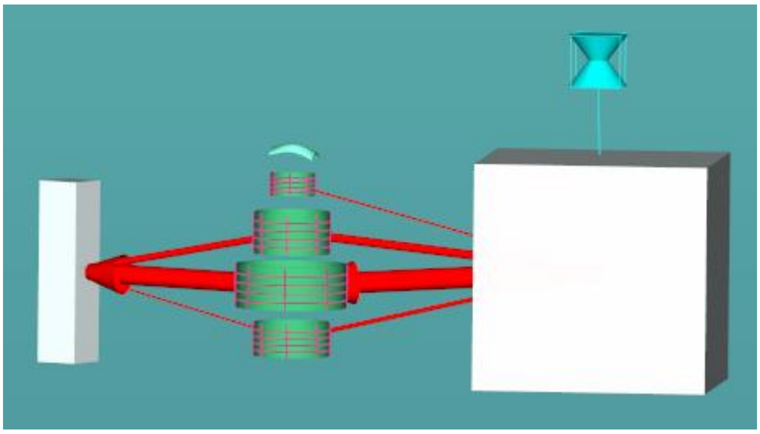

Figure 5: Power flow transmission at 9000Hz

3. Noise attenuation

3.1 Absorption coefficients of melamine foam

Based on Biot theory, JCA model is proposed to describe the sound absorption. With the acoustic parameters of melamine foam given by [5], the absorption coefficient of the melamine foam is calculated with JCA model. The absorption coefficients of the melamine foam with different thickness are shown in Figure 6. With the thickness increasing, the sound absorption coefficient increases. Above 50mm, the difference is much smaller. The maximum sound absorption coefficient of the melamine foam with the thickness of 50mm, 60mm and 70mm all achieve to 0.99.

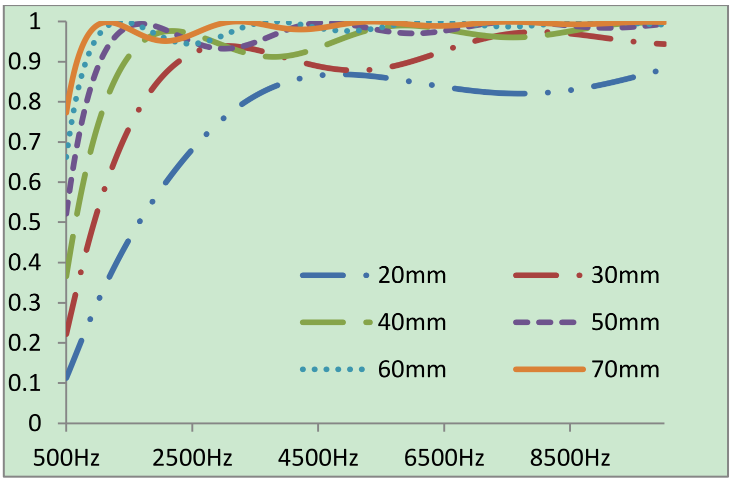

Figure 6: Absorption coefficients of the melamine foam with different thickness

3.2 Noise attenuation of launch vehicle fairing

Figure 5 indicates that the relative high response is mainly transmitted by the biggest cylinder subsystem. As the limitation of the mass of the noise attenuation material, the biggest cylinder is chosen to attach the melamine foam. The transfer matrix method is used to calculate the noise attenuation effect of the single trim layer of melamine foam. The response of the internal cavity subsystem with and without 50mm melamine foam is shown in Figure 7. This porous material has good noise reduction performance. The total sound pressure level at the range of 500~10000Hz reduces from 131.49dB to 121.91dB.

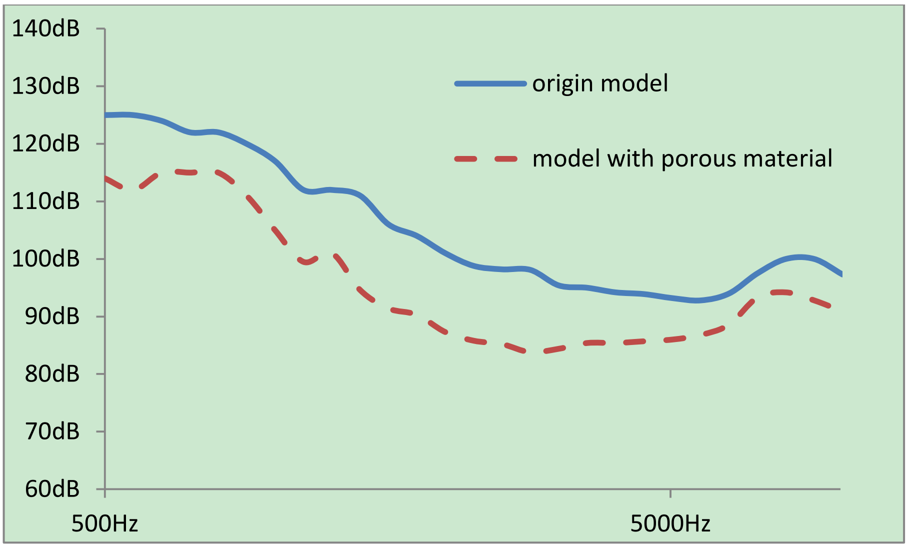

Figure 7: Comparison of the internal cavity subsystem response with and without the porous material

4. Conclusion

In this paper, the statistical energy analysis model of a payload-fairing system is established and verified by the reverberation chamber test. The simulation gives a good agreement with the test data at the frequency range at 600~9000Hz at which the modes in band of the cavity subsystems are more than 4. JCA model is used to calculate the sound absorption performance of the porous material. And transmission matrix method is used to predict the acoustic transmission of the trimmed layer. The calculation shows that the melamine foam has good noise attenuation performance and can be used on the internal noise attenuation of the launch vehicle fairing.

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