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LIFT-OFF VIBRO-ACOUSTIC ANALYSIS OF THE UPPER STAGE OF SMALL LAUNCH VEHICLE

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Abstract

Lift-off acoustic loads (more than 150dB) cause severe random vibrations on electronic equipments and solar panels of a satellite. This excessive random vibration often breaks the payloads so that it causes the failure of mission. Appropriate prediction and reduction methods of the random vibration greatly reduce a possibility of mission failures. In this paper random vibration levels were predicted by statistical energy analysis (SEA) method. In order to verify the analysis procedure for our new small launch vehicle, SEA model of sub scale payload section was verified by an experimental way: The predicted level was compared with the measured one by the high intensity acoustic test. This paper also states that a method to reduce the random vibration level by reducing the acoustic level inside the payload fairing. Several acoustic blankets were designed and its transmission losses and absorption coefficients were measured. The measured results and the vibro-acoustic model enable us to predict the random vibration level on the upper stage structure at liftoff phase. The results showed that the vibration level on the payload can be greatly reduced by virtue of the acoustic blankets.

INTRODUCTION

Rocket propulsion systems generate very high-level noise whose source is supersonic jet emitted by rocket engines. The noise level is proportional to the thrust of rocket engines. [1] The propulsion systems of state-of-the-art launch vehicle generate acoustic loads whose level is more than 150 dB SPL during a lift-off. This lift-off acoustic load can be regarded as the most significant source of random vibration loads on payloads. High level of the random vibration increases a possibility of mission failure. Notice that the vibration transmitted through the structure of launch vehicle contributes to low frequency vibration load.

Every commercial launch vehicle has its own random vibration specification for payloads. The vibration specification can be verified by several flight tests. Payload, for example satellites and electronic equipments, should be designed and tested to withstand the specified vibration level. A newly developed launch vehicle must have vibration specifications to design its payloads. This vibration level could be estimated by analytical ways in early system design phase.

This paper discusses prediction procedures for vibration specification of payloads for the Korean satellite launch vehicle. The first step is to specify the acoustic load outside of the payload fairing during lift-off, which can be estimated by a semi-empirical method. [1,2] Then acoustical design of the composite payload fairing is performed. Several core materials were analyzed and tested so that a proper core material can be determined. [3,4] After basic design of the payload fairing is completed, the acoustic load inside the payload fairing is predicted by means of statistical energy analysis (SEA). The method is very effective not only for early design phase but also for wide frequency range estimation. In order to verify the prediction methodology, SEA analysis of a small payload section is performed and the prediction results are compared with those of measured ones. [5] An acoustic test was performed in the high intensity acoustic chamber in KARI. The test results showed a good agreement with the predicted results. This experience enabled us to predict the vibro-acoustic responses of our new satellite launch vehicle currently developed by KARI. The prediction results are also presented in this paper. Acoustic treatment methods to reduce acoustic and vibration responses are also discussed in the final section of the paper.

PREDICTION OF EXTERNAL ACOUSTIC LOADS

Acoustic loads outside payload fairing can be predicted by means of a semi-empirical method proposed by NASA. [1] This method assumes noise sources along the exhaust flume. Extensive measurement data for various kinds of jet streams, which is performed by NASA, enabled us to model the source strength, location and directivity of the assumed noise sources. Figure 1 illustrates the prediction method. We assumed that a slice of flume radiates band-limited noise.

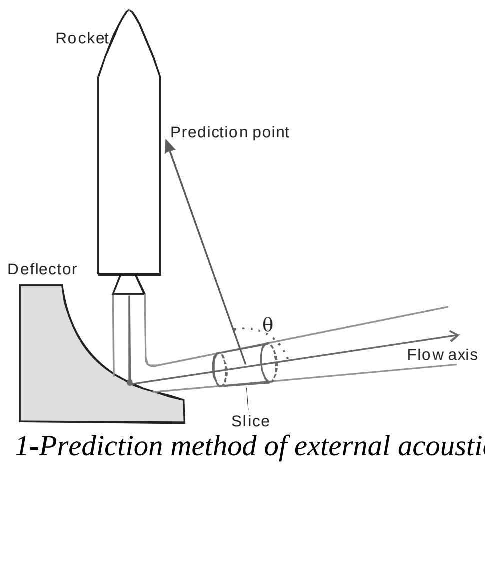


Figure 1-Prediction method of external acoustic loads

Notice that the prediction requires parameters related with the main engine of the launch vehicle. The thrust of main engine, the sound velocity in a flume, the fully expanded exit velocity in flume and the diameter of exit nozzle can be obtained from the specification of the main engine of our launch vehicle.[6] The predicted external acoustic load is shown in figure 2. The overall sound pressure level is 150 dB.

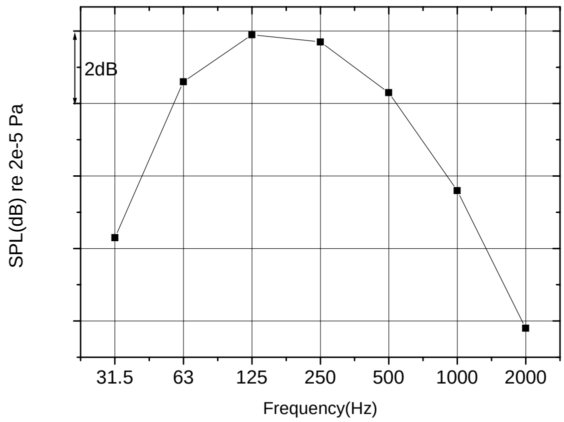


Figure 2- Predicted external acoustic load

DESIGN OF SANDWICH STRUCTURES FOR PAYLOAD FAIRING CONSIDERING SOUND TRANSMISSION

A payload fairing protects payloads from severe dynamic loadings and aerodynamic heating during ascent. A payload faring structure should have enough strength to resist flight loads. A honeycomb sandwich structure becomes more favourable than metallic (aluminium) one because of its stiff and lightweight characteristics. However, this property makes acoustic insulation become poor. This is not only because of its lightweight but also because of its dynamic behaviour. [7] This motivates a transmission analysis of honeycomb sandwich structures for the payload fairing. Four different sandwich structures having same face sheet were analyzed. The core properties are shown in table 1. [4]

Table 1- Properties of core materials of four sandwich structures

	*Mass per unit area of core (kg/m^2)	E3 (MPa)	G13 (MPa)	G23 (Mpa)
Core 1 (glass honeycomb)	1.8	296	48.3	103
Core 2 (glass honeycomb)	2.4	434	124	131
Core 3 (AL honeycomb)	1.92	1020	482	262
Core 4 (AL honeycomb)	1.64	1275	296	117

*Mass per unit area of face sheet is 5.12 kg/m^2 , **Direction “3” is normal to panel.

The transmission loss for an infinite plate can be predicted by wave impedance method proposed by Moore and Lyon. [7] For finite sized structure, SEA analysis can be utilized. [3,4] The analysis indicates that sandwich construction with core 4 can be appropriate for our payload fairing structure. The sandwich panel with core 4 showed good transmission loss in spite of its lightest weight. These analytical prediction results are compared with those of measurement in reverberant chamber (complies with ISO 140/3-1978). Figure 3 shows the comparison between prediction and test results of the sandwich panel with core 4.

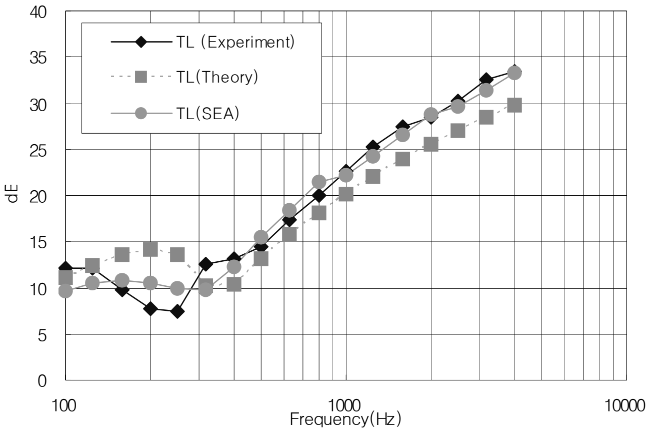


Figure 3- Comparison between predicted and measured TLs

PREDICTION OF VIBRO-ACOUSTIC RESPONSES OF UPPER STAGE DUE TO LIFT-OFF ACOUSTIC LOADS

Vibro-acoustic response analysis of payload section of KSR-III

A vibro-acoustic analysis was performed on the payload section of KSR-III rocket because it has composite fairings made by honeycomb sandwich construction and aluminum plate structures for electronic equipments. We constructed the SEA model of the payload section of KSR-III. The commercial AutoSEA2 software was utilized to predict responses. Figure 4 shows the analytical model of the payload section of KSR-III. Notice that cavity for acoustic chamber is modeled to excite external acoustic load. The predicted responses were compared with those of measurements in high intensity acoustic chamber. The acoustic excitation level adheres to the external sound pressure level measured during flight test of KSR-III.

Acoustic test for the payload section of KSR-III was conducted to verify the prediction. The test was done in the high intensity acoustic chamber in KARI. Four tri-axial accelerometers were installed to measure spatially averaged vibration response of equipment bay. Four microphones measured the internal acoustic level. Figure 5 shows the test specimen in the acoustic chamber and results of test compared with those of prediction. This enables us to updated the analytic model to produce better results

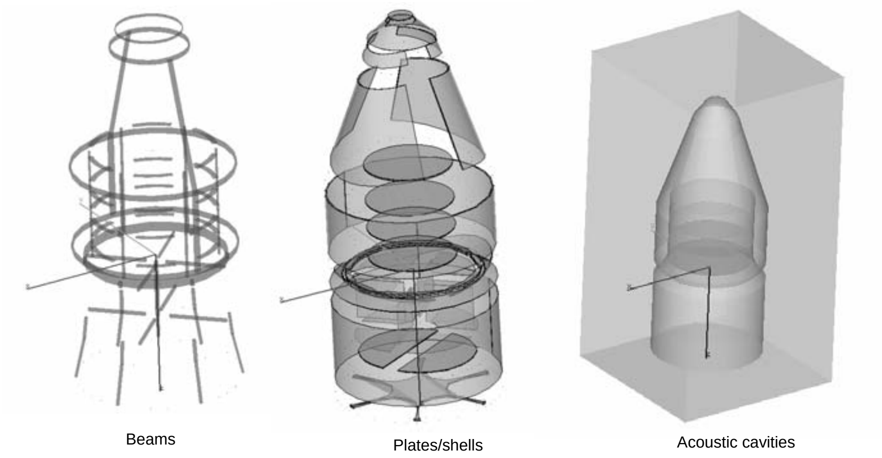
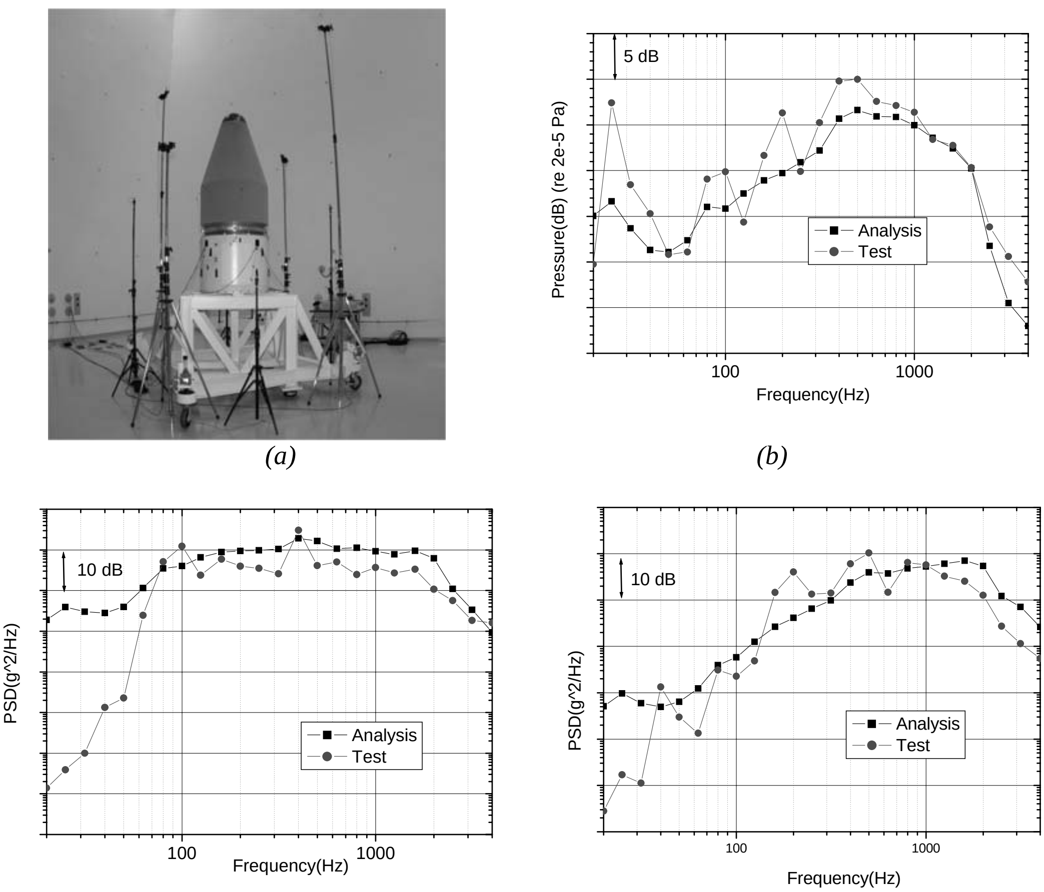


Figure 4-Vibro-acoustic prediction model of payload section of KSR-III



(a) *(b)*

(c) *(d)*

Figure 5- Comparison of acoustic test and prediction results
(a) Test specimen in acoustic chamber (b) Internal sound pressure level
(c) Vibration level of AL equipment bay (d) Vibration level of composite fairing

All the test results shown in the above figure is spatially averaged ones. The predicted acoustic load inside the fairing is within 5 dB except very low frequency region (See Fig. 5(b)). The predicted vibration level is within 5 dB above 60 Hz. Finite element analysis would be required to obtain better prediction result in the low frequency region. Note that the fluctuation in spectrum is mainly due to shortage of measurement points. The predicted results show quite good agreement with test results. This verifies our approach to predict responses due to acoustic loads.

Prediction of vibro-acoustic responses of Korean satellite launch vehicle due to lift-off acoustic load

The experience described the previous section enables us to make a reliable prediction model of the upper stage of Korean satellite launch vehicle. Figure 6 shows the prediction model which consists of 27 beams, 17 plates, 8 singly curved shells, 5 cylinders and 5 acoustic cavity subsystems. The payload fairing and the equipment bay is modeled by a composite sandwich construction. Lower frequency bound for the analysis can be determined by number of modes in an analysis band. The lowest analysis band is 125 Hz. The prediction results below 125 Hz may not be reliable. We apply external acoustic load (Fig. 2) to this prediction.

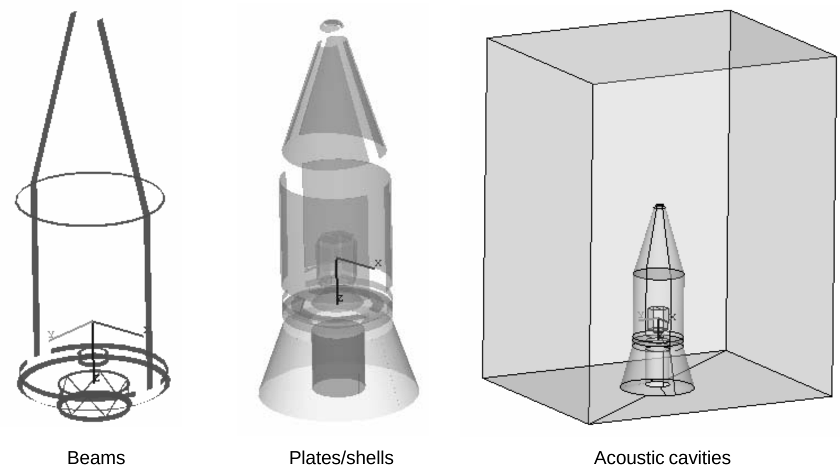
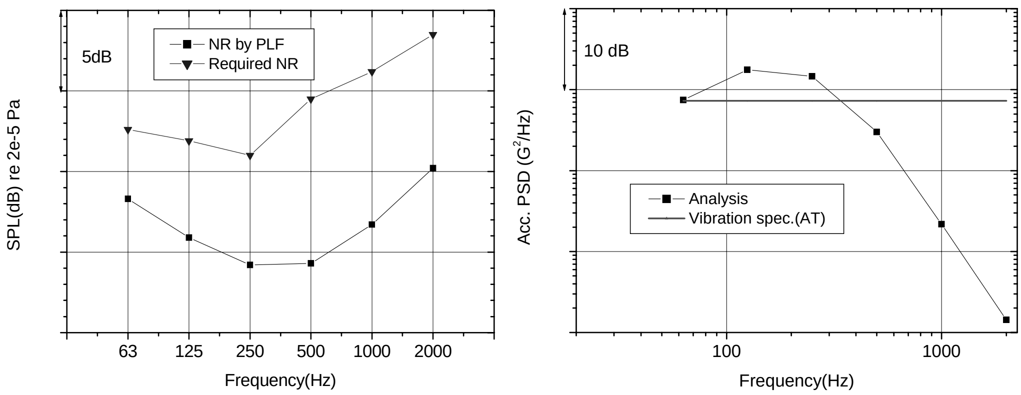


Figure 6- SEA model of upper stage of Korean satellite launch vehicle

Next figure summarizes predicted acoustic and vibration responses due to the lift-off acoustic load. Figure 7(a) shows the predicted noise reduction (NR) by the payload fairing. The required NR also presented in the figure. Figure 7(b) shows the predicted random vibration level on the equipment bay. Notice that the vibration level exceeds the required vibration specification in 125 and 250 Hz octave band. Additional noise reduction treatment is needed to suppress the vibration level.

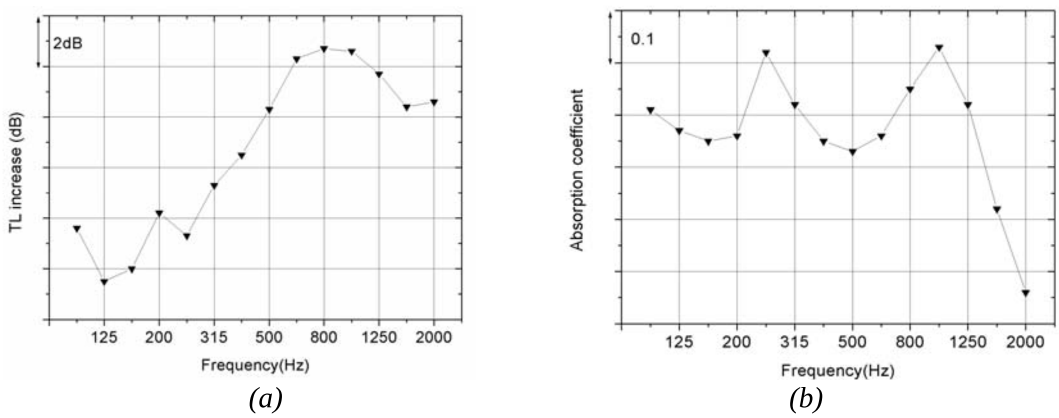


(a) *(b)*

Figure 7- Predicted acoustic and vibration responses.
(a) Noise reduction by payload fairing (b) Predicted vibration level on equipment bay

METHODS OF ACOUSTIC TREATMENT

Several acoustic treatment systems are designed to obtain addition noise reduction. The acoustic protection system for the payload fairing of Korean satellite launch vehicle consists of the array of acoustic resonators and acoustic blankets. [8] They reduce the internal acoustic load by increasing transmission loss and acoustic absorption. We measured transmission losses and acoustic absorption of several design variants in a reverberant chamber. Figure 8 shows the test result of one of acoustic blanket variants. Figure 8(a) represents increase of TL and figure 8(b) does its absorption coefficient.



(a) *(b)*

Figure 8-Test results of one of acoustic blanket variants
(a) TL increase (b) Absorption coefficient

We predict acoustic and vibration response by employing the measured transmission loss and absorption coefficient data. Next figure illustrates that the acoustic treatment enhances the noise reduction more than 8 dB. This satisfies the required noise reduction.

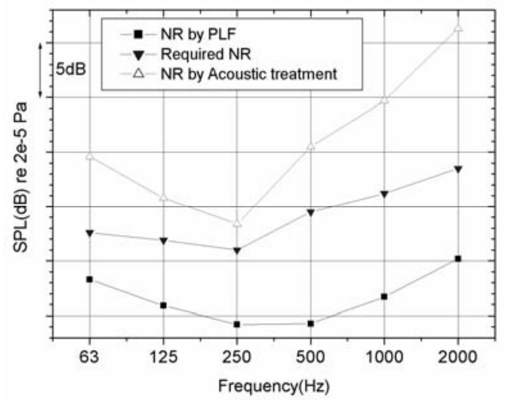


Figure 9- Noise reduction enhancement by acoustic treatment

It is noteworthy that the prediction result in low frequency region (especially in 63 Hz band) should be investigated again by finite element analysis. For example, noise reduction by acoustic absorption can be predicted by acoustic cavity analysis. In this analysis measured acoustic admittance can be applied.

CONCLUSIONS

The procedures of vibro-acoustic analysis of upper stage of Korean satellite launch vehicle were described. The acoustic protection system including acoustic resonators and blankets greatly reduces the internal sound pressure level. Acoustic test for the payload fairing with the acoustic protection system will be performed in the near future. Our acoustical treatment design can be verified and improved by means of the payload fairing acoustic test.

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