Vibro-Acoustic Response Analysis Of LAUNCH VEHICLE INTER-STAGE

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Abstract: Right from lift-off, launch vehicles are subjected to extreme dynamic pressure, aero and structure borne excitations. Inter-stage is fundamental to the vehicle as it houses the different control equipments, actuators, sensors, motors and avionic packages. This paper involves the creation of two different models so as to study the correlation using two approaches, Finite Element method and Hybrid Method, involving Statistical Energy Analysis and Finite Element Analysis. The correlation of the response obtained on the Inter-stage from an acoustic ground test to that from the analytical test results carried out with VA One is also addressed in this paper.

Index Terms: Diffuse Acoustic Field, Finite Element Analysis, Inter-Stage, Launch Vehicle, Statistical Energy Analysis, Vibro-acoustic

1 INTRODUCTION

aunch vehicles are subjected to high, low frequency loads and random vibration loads from various sources. At the time of static firing and lift-off, the vehicle engine generates tremendous noise, excitations, which on itself cause high frequency acoustic and random vibration loads. Apart from the noise generated, the in-flight pressure fluctuations also cause high frequency loads. Transitory loads, which may be categorised under low frequency loads, may arise during lift-off. From studies, it has been realized that high and low frequency loads occur simultaneously on the vehicle [1]. Most of the incoming loads are basically dynamic in nature, thus demanding dynamic analysis of the vehicle. The difficulties put forward by dynamic analysis are that of requiring many degrees of freedom and that the responses may be sensitive to the meticulousness of the system. Inter-stage is one of the most crucial elements of a launch vehicle. It separates the different stages of the vehicle and houses the various control equipments, actuators, sensors, motors that are essential for the functioning of the vehicle. The analysis and numerical simulation of the acoustic excitation and accruate prediction of the vibro-acoustic response of the structure is very important and crucial [2]. As mentioned afore, the launch vehicle is subjected to high and low frequency loads. Finite element analysis (FEA) and statistical energy analysis (SEA) are used in predicting the responses in such cases. To study low frequency response, FEA is generally used and for high frequency response, SEA is used. At high frequencies, while investigating the response of vibro-acoustic system, it is enviable to take on an analysis method that provides statistical information and requires comparatively fewer degrees of freedom. Thus came into light the use of SEA in the vibro-acoustic response of launch vehicles. SEA offers the structure to be modelled with few subsystems and presume weak modal coupling and equal mode energies in analysis bands to analyze the energy shared between dynamic systems. SEA gives the vibrational energy averaged across the group of identical subsystems, thus giving the ensemble-mean. At high frequencies, this ensemble mean response proves to be a useful contrivance to characterize the response of the system [3]. However, at low frequencies, generally $f < 150$ Hz, this assumption of averaging the response may not be valid and the number of modes contained by a bandwidth depends on the structure stiffness. Hence, FEA is used in place of SEA in low frequency region, so as to obtain more accurate results. Combining FE predictions and SEA, giving way to a hybrid analysis technique, predictions in the overall vibration milieu would be constituted [4]. The aim of this paper is to conduct a comparison of the Inter-stage model in the Vibro-Acoustic software, VA One for two configurations, A and B using FE and hybrid analysis. Configuration A is for the Inter-stage deck with four isolated decks and one un-isolated deck and configuration B is with all the decks un-isolated. An attempt to assess the performance of the hybrid method is also carried out. The paper also carries out a comparison study of the acoustic response of the Inter-stage obtained from ground test and that from analysis using VA One. The scope of the study includes the modelling and analysis of Inter-stage in two ways- as a fully FE model (up to 250 Hz) and as a hybrid model (up to 2000 Hz) with SEA subsystems and finite elements.

2. MODELLING

2.1 Structure Modelling

Inter-stage is a cylindrical structure with decks/ platforms for housing all the electronic and mechanical control equipments and sensors. Inter-stage is modelled using the VA One software. A hybrid model and a fully finite element model of Inter-stage are created. Both models are analyzed for configurations A and B. For the hybrid model, the external structure is modelled using six cylinder sub-systems assigned with Aluminium property. The avionic packages are mounted on five honey comb sector decks. The honey comb decks and the connected cylindrical structure are retained as FE systems and the remaining as SEA sub-systems. Seven ring beams, one separating each cylinder, are also modelled. In order to accommodate the geometric configuration of the subsequent stage below the Inter-stage, the bottom is enclosed using a cylindrical dome structure, which is modelled using SEA singly curved shells, SEA doubly curved shells and a SEA flat plate. The top and base of the structure is enclosed using flat plates assigned with plywood properties. The hybrid model is shown in Fig. 1.a and Fig. 1.b.

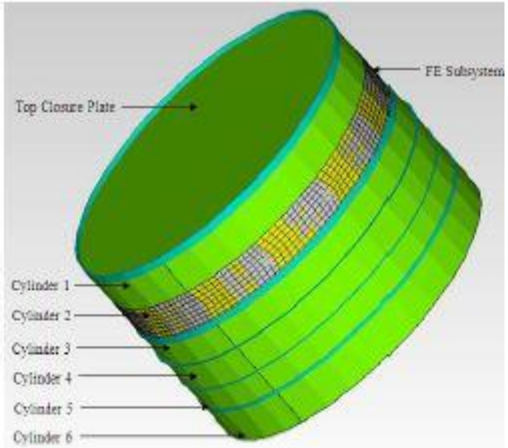

Fig.1.a Hybrid model of Inter-stage

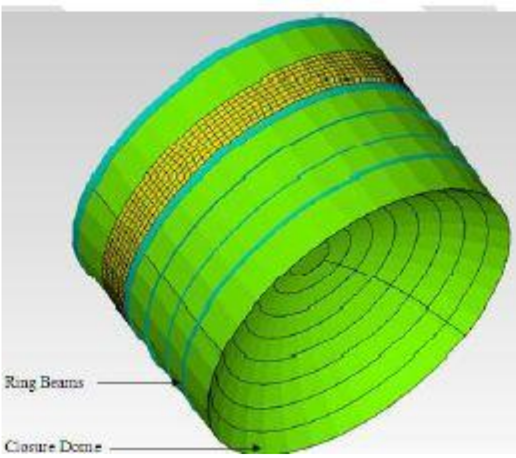

Fig.1.b Hybrid model of Inter-stage

For the finite element model, the external structure is modelled using two Aluminium cylinder sub-systems. Same as in hybrid model, the five honey comb sector decks houses the avionic packages and the decks and connected cylindrical structure is also maintained as FE systems. Fig. 2 shows the honey comb decks in hybrid model. The top and bottom of the structure is enclosed with FE flat plates. The FE model is shown in Fig. 3. All models are defined at 1% damping loss factor.

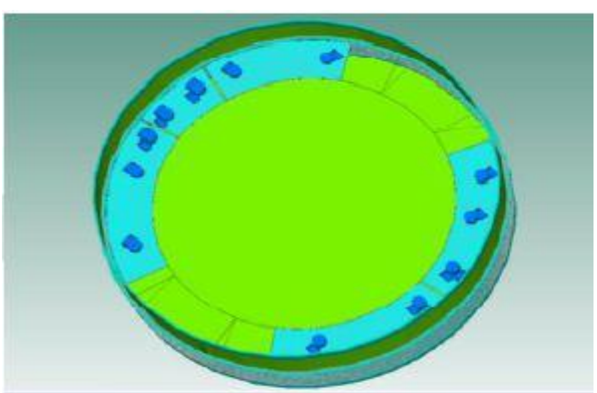

Fig. 2 Five honey comb decks of Inter-stage

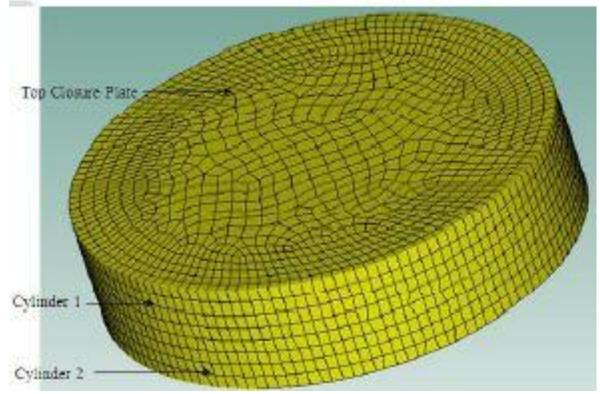

Fig. 3 Finite element model of Inter-stage

2.2 Acoustic Cavity Modelling

In order to predict the sound pressure levels inside the structure as a result of the external pressure loading, acoustic cavity, a volume modelling subsystem, is created. The inner acoustic SEA cavity is formed in four parts enclosed by the different singly curved shells and flat plates and is later merged to form one single cavity and connected to the structure subsystems with the aid of area junctions. Fig. 4 and Fig. 5 shows the SEA and FE acoustic cavities formed for the two models. In both models, the acoustic cavity is assigned an absorption coefficient of 0.1%.

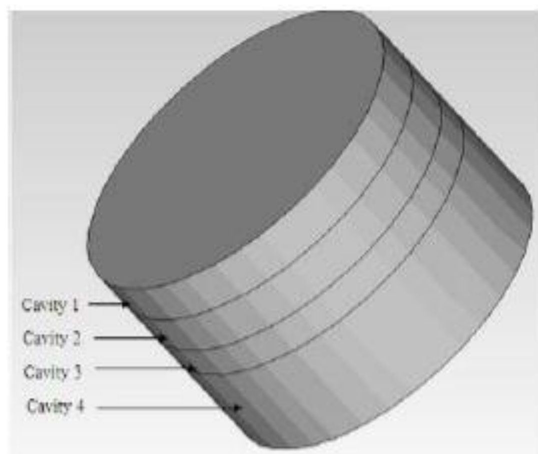

Fig. 4 SEA acoustic cavity

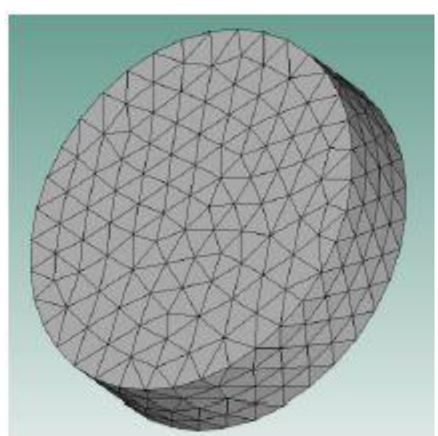

Fig. FE acoustic cavity

2.3 Diffuse acoustic field excitation modelling and semi-infinite fluid system.

A diffuse acoustic field (DAF) excitation is used to define the external pressure loading on the Inter-stage. A DAF is applied to the SEA singly curved shells, SEA doubly curved shells, SEA flat plates and FE structure. A semi-infinite fluid system (SIF) is an energy sink which does not reflect the incoming energy into a system. Each SEA singly curved shells, SEA doubly curved shells SEA flat plates and FE faces are individually connected to the SIF. Fig. 6 shows a hybrid structure with DAF defined.

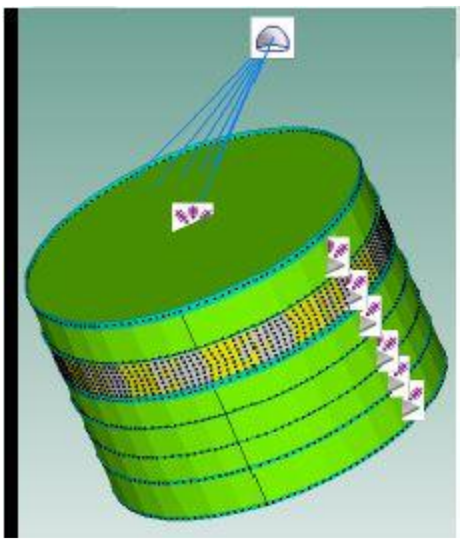

Fig. 6 DAF and SIF applied on SEA Sub-systems and FE Faces

3. RESULTS AND DISCUSSIONS

3.1 Configuration A: Model with decks Isolated

The FE model and hybrid model is analyzed up to 250 Hz and 2000 Hz, standard octave band, respectively. The response of sensor ISO 1, located on one of the isolated decks, is represented. Fig. 7 shows the responses of ISO 1 obtained from VA One FE and hybrid analysis and ground test in configuration A.

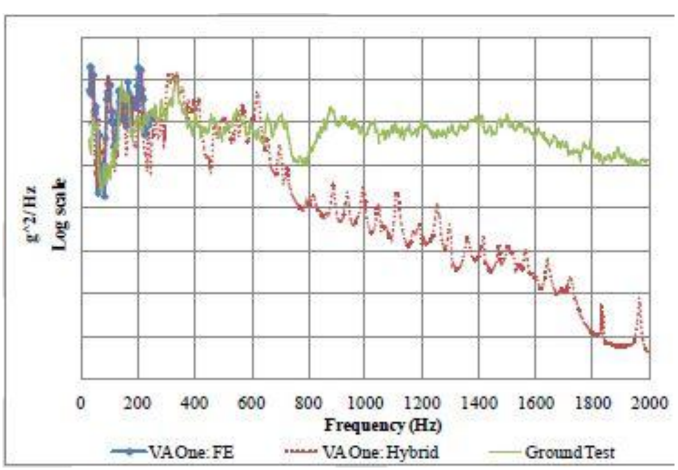

Fig. 7 Vibration response of ISO 1: Configuration A

The responses obtained show good correlation up to about 600 Hz. Beyond 600 Hz, the response from hybrid analysis deviates from the test response. In both analyses, the deck of the structure is retained as FE. The correlation in response would be improved if the entire structure was modelled with SEA sub-systems. For this the packages on the deck and isolators have to be modelled using SEA subsystems, which are not attempted here.

3.2 Configuration B: Model with decks Un-isolated

The comparison study of the structure response on a fully un-isolated configuration is also carried out. Fig. 8 shows the responses of ISO 1 obtained from VA One FE and hybrid analysis and ground test in configuration B.

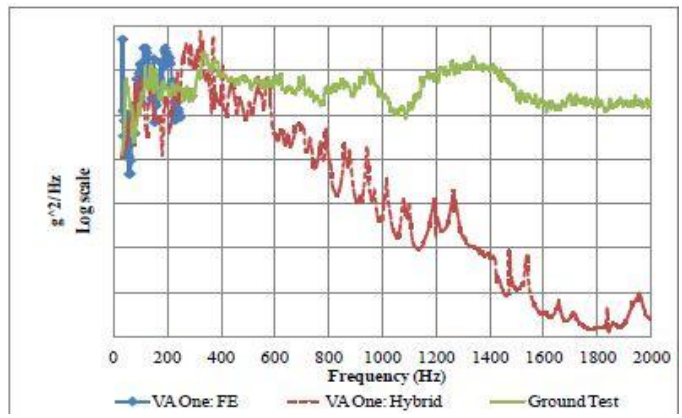

Fig. 8 Vibration response of ISO 1: Configuration B

Similar to the hybrid analysis response in configuration A, the response shows good correlation till about 600 Hz and falls from thereon. Beyond 600 Hz it is required to perform the SEA to obtain good correlation with the test results.

3.3 Inner field response: Ground test and VA One software

The inner acoustic field of Inter-stage subjected to DAF excitation are obtained. The test results of the Inter-stage subjected to an external uniform sound pressure level (SPL) as a function of frequency are also available. Fig. 9 shows the external SPL applied, resulting inner acoustic field from ground test and VA One model for the FE analysis. Accounting for transmission losses, it is witnessed that the deviation in OASPL of the inner acoustic field from ground test to the external SPL is as shown in Fig. 9. Also, the deviation in inner acoustic field of VA One model to that from the ground test is 2 dB. The field responses in finite element and hybrid models showed were observed to be similar. Tuning the damping and mass of the structure helps in tuning up or down the inner acoustic field responses.

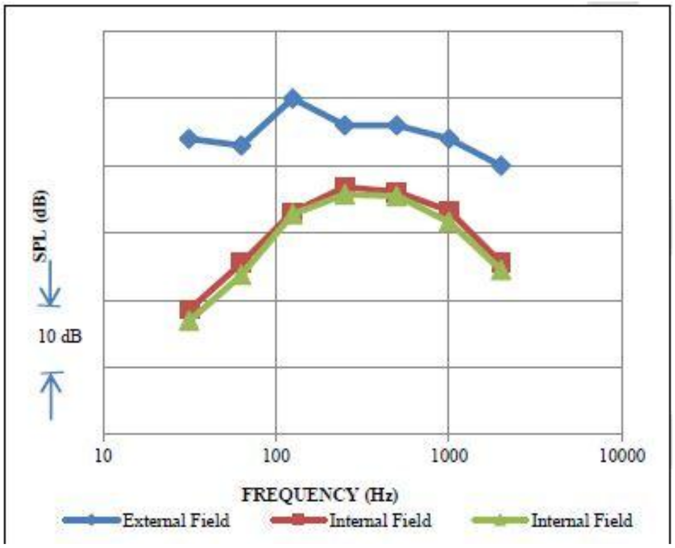

Fig. 9 Inner field response comparison

4. CONCLUSION

A correlation study of the vibration response of Inter-stage structure and the inner acoustic cavity sound pressure level is carried out by creating VA One models of Inter-stage for two configurations, A and B, and investigating it using finite element analysis and hybrid analysis. A diffuse acoustic field is applied on the structure. A SIF is created and defined on the model which acted as an energy sink, thereby reducing the reflection of energy. The entire structure is defined at 1% damping loss factor. In all cases of comparison study, for ISO 1 the correlation in response between the test and hybrid analysis was good up to about 600 Hz. The deck is retained as FE system and hence the results yielded are better in the lower frequency range. The limitation of not modelling the structure as a true SEA model accounts for the dependence on a hybrid analysis and therefore, a lack in correlation beyond 600 Hz. A comparison of the inner acoustic field of Inter-stage obtained from the ground test and prediction showed good correlation.

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