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13. ABSTRACT (Maximum 200 words) High sound levels transmitted inside payload fairings at launch account for 40% of the satellite damage in the initial phases of the launch. Numerous experiments conducted on the advanced composite acoustic heterogeneous blankets (HG blankets) have shown their great potential in reducing the vibration and sound levels inside payload fairings. This work presents the development and validation of the finite element (FE) models of HG composite blankets in order to understand the physics behind the functionality of the new acoustic material. The development of the FE model can be broadly classified in to three stages; (i)FE models of the individual component were developed and validated,(ii) the fully coupled 3D-FE model of the HG blankets were developed and validated, and(iii). Fully coupled 3D-FE models of the HG blanket coupled to the structural and acoustics domains were validated. Parametric studies were then performed on these fully coupled 3D-FE models in order to understand the effect of the variation in the material properties and geometrical configuration of the HG blanket on their behavior and acoustic attenuation capabilities. The knowledge base built from the parametric studies was later used for the deve[illegible] optimized designs of the HG blanket material.

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1. Introduction

1.1 Motivation for the research

Over the years there has been marked development in the noise control techniques using various materials and noise control devices for reducing the sound inside the payload fairing. However the control of payload interior noise remains a challenging problem. With the advent of the new composites payload structures promising lighter and more cost effective satellite launches, there comes the bane of high interior noise in the payload fairings causing acoustically induced satellite damage. The primary source of the interior payload noise is the sound radiated by air borne vibration induced in the flexible structures of the payload. These structure being efficient radiators of sound cause the sound pressure level (SPL) to rise in the payload interior. Thus one of the main approaches for sound attenuation in payload fairings is the control of the efficient radiating modes of the payload structure surrounding it. The use of the standard passive treatments such as acoustical blankets, viscoelastic damping and constraining layers are proving ineffective in meeting the sound attenuation requirements posed by the use of new composite payload fairing. To overcome these constraints of the conventional passive treatments there is an impending need for the design and development of optimized light weight devices that combine together in an efficient manner different features of noise control to meet the challenge of reducing interior payload noise.

The techniques used for the vibration control of flexible structures (panels and plates) and noise induced by them into the coupled acoustic cavities can be broadly divided into three categories: passive, reactive and active. *Passive devices* use friction to dissipate the vibration energy and acoustic energy into heat. Passive treatments such as acoustic foam blankets and constrained layer damping work well at high frequencies, but are not equally effective at the low frequencies. The passive treatments are not effective at lower frequencies because the acoustic wavelengths are longer at these frequencies and hence thicker foam blanket are required to provide high material damping properties to result in an effective vibration and acoustic attenuation. *Reactive noise control techniques* such as the Helmholtz resonators and tuned vibration absorbers, work by creating high impedance in a narrow frequency bandwidth. These devices are good for low frequency noise and vibration attenuation but only in a very narrow frequency range. In addition to the aforementioned problems, the major disadvantage encountered in the use of the reactive devices for vibration control of continuous structures is that they act at a single point and hence a large quantity of these vibration absorbers is required for effectively controlling the dynamics of a large continuous structure *Active control devices* work by generating an out of phase signal to cancel the noise field by destructive interference. In an active control mechanism, sensors are used to measure the vibration levels of the structure to be cancelled and the actuators are used to generate a counter signal to cancel the noise field. These systems generally have a high operating and maintenance cost. Furthermore, they require additional equipment for functioning, which increases their mass and space occupancy.

In order to over come the aforementioned constraints encountered in the use of the existing noise and vibration control devices, distributed vibration absorber (DVA) and the heterogeneous blanket (HG) were developed in Vibration and Acoustics Laboratories (VAL) at Virginia Tech. Extensive experiments have indicated that the use of the HG blankets can significantly reduce the interior noise in the launch vehicle payload fairings in the 50-200 Hz low frequency bandwidth with only a marginal(less then 10%) increase in the total weight of the payload fairings. Other tests at NASA on the tilt rotor fuselage and on Boeing 757 fuselage section have also shown large increase in the tonal and broad band transmission loss with these lightweight treatments. There are two primary reasons for the improved performance of these vibration absorbers. First, these vibration absorbers are distributed over a surface area and hence provide the reactive force over a distributed area rather then on a point. Second, due to the presence of the foam in these vibration absorbers, they act both as a vibration absorber at the tuned frequency and also provide high damping at all the acoustic modes of the structure. These properties of the advanced vibration absorbers lead to a broadband attenuation of the vibration levels of the base structure and the SPL's inside the radiating acoustic domain. The physical implementation of these devices is now discussed.

HG blankets, shown in Figure 1 comprise of a foam layer having mass in-homogeneities inside it. The foam acts as a damped spring with distributed mass and the mass in-homogeneities act as the additional point masses inside the foam layer increasing its vibration absorption capabilities.

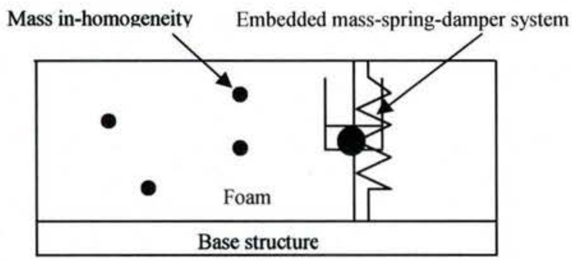

Figure 1. Heterogeneous Blankets (HG-Blanket)

In spite of the good performance of the HG blankets in controlling the noise and vibration magnitudes, little is known of the specifics of how it is achieved. The influence of the geometric layout, choice of material and device attachments on the behavior of these devices is also poorly understood. In order to optimize the design of the HG blankets and realize their full potential for vibro-acoustic attenuation control, a detailed understanding is required of the physics behind their behavior and the influence of the controlling parameters on their vibro-acoustic attenuation capabilities.

To achieve the aforementioned insight in the functionality of these advanced noise and vibration control devices, detailed finite element (FE) models of the the HG blankets were developed and validated. Based on the knowledge base built by the validation of these numerical models, advanced fully coupled FE models were developed to study the interaction of these devices with the structural and the acoustic domains. These numerical models enable the development of advanced designs of these noise control devices in order to efficiently and effectively control the noise radiated inside the acoustic cavity(such as a payload fairing)by the coupled vibrating structures.

The HG blankets shown in Figure 1 typically consist of a standard passive matrix material such as urethane, polyurethane or fiberglass embedded with small randomly distributed mass in-homogeneities. These embedded masses have two main effects. First, in conjunction with the surrounding "springiness" of the support matrix material they act like many vibration absorbers (mass-spring-damper system) with different resonant frequencies. Second, it is theorized that the solid shape of the masses leads to increased wave scattering /conversion with the blanket matrix leading to an increased passive damping of the sound waves. The experimental tests have shown that the treatment of the HG blanket have significantly reduced the sound radiated by the base structure with a marginal increase in the overall mass of the base structure

While these tests have unequivocally demonstrated the high potential of the HG blankets, little is known about the detailed mechanism by which it is achieved. In order to fully realize the potential of the HG blankets, comprehensive experimental and numerical modeling of a fundamental nature is required. In the present work numerical models of the HG blankets have been validated by comparing the numerically computed results with the results from the experimental investigation of similar systems. These models have been further used for conducting parametric studies on the controlling parameters of the HG blankets for developing more effective designs.

Objectives of the research

Experimental and analytical models of the HG blankets have been developed to study the functioning of these vibro-acoustic attenuation devices. To gain a deep insight in the physics behind the functionality of these vibration absorbers and to understand their interaction with the structural and acoustic media, three dimensional fully coupled finite element (3D-FE) modeling of a fundamental nature is required. The main objectives of this research are as follows;

- To develop and validate numerical models for the HG blankets to predict their response for different design configurations and excitation conditions.
- To develop fully coupled FE numerical models for predicting the reduction in the vibration levels of the base structure caused by the HG blankets treatment on them.
- To develop the fully coupled 3D-FE numerical model for predicting the reduction in the sound pressure levels (SPL's) inside the radiating acoustic cavities coupled to the elastic structures having an attached HG treatment.

To complete the aforementioned objectives, the following targets had to be achieved.

Reduction of the scale of the system under study:

The system under study given in Figure 2 consists of a payload exposed to the airborne excitation in the initial phases of the launch. The large scale physical phenomenon of the sound radiation caused by airborne excitation of the frame of the fairing was reduced into a small scale experimental model. The exterior domain of the fairing, the fairing structure and the interior acoustic domain of the fairing were modeled by an incident acoustic domain, a plate and a radiating acoustic domain respectively. The airborne excitation in the original physical phenomenon was modeled by a volume displacement imparted at one of the corners of the incident acoustic domain. The acoustic treatments on the fairing structure were modeled HG blanket treatments on the plate.

Validation of the individual component models:

A methodical approach was followed for the development and validation of the numerical models of the individual components the acoustic domain, the panel and the porous domain of the system under study shown in Figure 2. The finite element (FE) models of these individual components were validated by comparing the numerically computed results with the available experimental and analytical results.

Validation of the DVA and the HG blanket numerical model:

HG blankets are the vibration absorbing devices used for reducing the base structure vibration and the sound radiated by them into the coupled radiating acoustic field. FE models for the HG blankets were validated by comparing the numerically computed response of these vibration absorbers to their response obtained from the experimental investigation of similar models. These numerical models have been used to understand the physics behind the functionality of these noise control devices and to perform parametric studies on their controlling parameters. The development of the FE models for an insight in the functionality of these vibration and noise control devices was one of the key deliverables of this research.

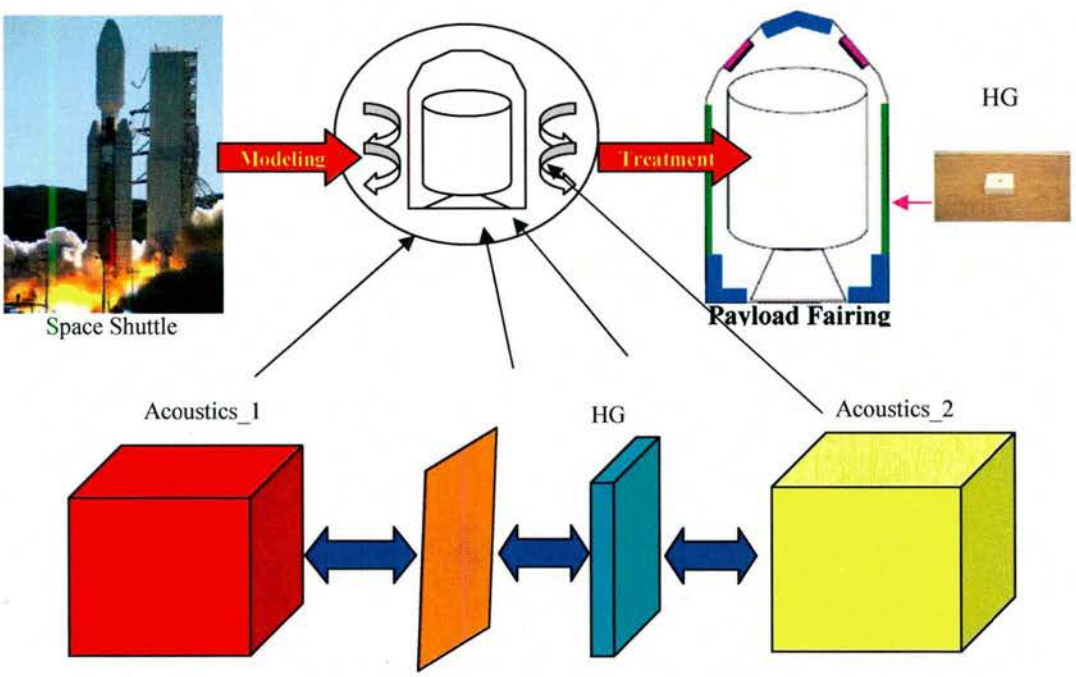

Figure 2. Reduction of the physical phenomenon into a numerical model.

Validation of the coupled plate-HG model:

Fully coupled 3D-FE models of the plate-HG blankets were developed to understand the interaction of the HG blankets with the structural elements. These numerical models have been validated by comparing the numerically computed results with the results obtained from the experimental analysis of similar systems. These models have been used to predict the effectiveness of these devices in controlling the vibration levels of the base plate.

Validation of the Acoustic-Plate-HG-Acoustics model:

Fully coupled 3D-FE models consisting of a coupling between the acoustic domains, the noise control devices (HG the blanket), and the structural domains were developed. These numerical models were validated by comparing the numerically computed results with the results obtained from the experimental investigation of similar systems. These models have been used for estimating the effectiveness of these noise control devices in reducing the sound radiated by the plate into the radiating acoustic domain.

Results, Conclusions and Future work

The effectiveness of the various HG blankets designs and the multi-porous layers (MPL) are firstly discussed. Suggestions are then made for further improvements in the modeling and designing of the HG blankets to achieve optimum performance. Full details of the FE modeling, validation and results are available in Ref 1. Figure 3 shows various example FE meshes and configurations used in the FE models. The poro-elastic material was modeled using a discrete form of the Biot equations(see Refs 1 and 2). Figure 4 presents example results from the FE model and comparison between previous results used to validate the model. Agreement is good.

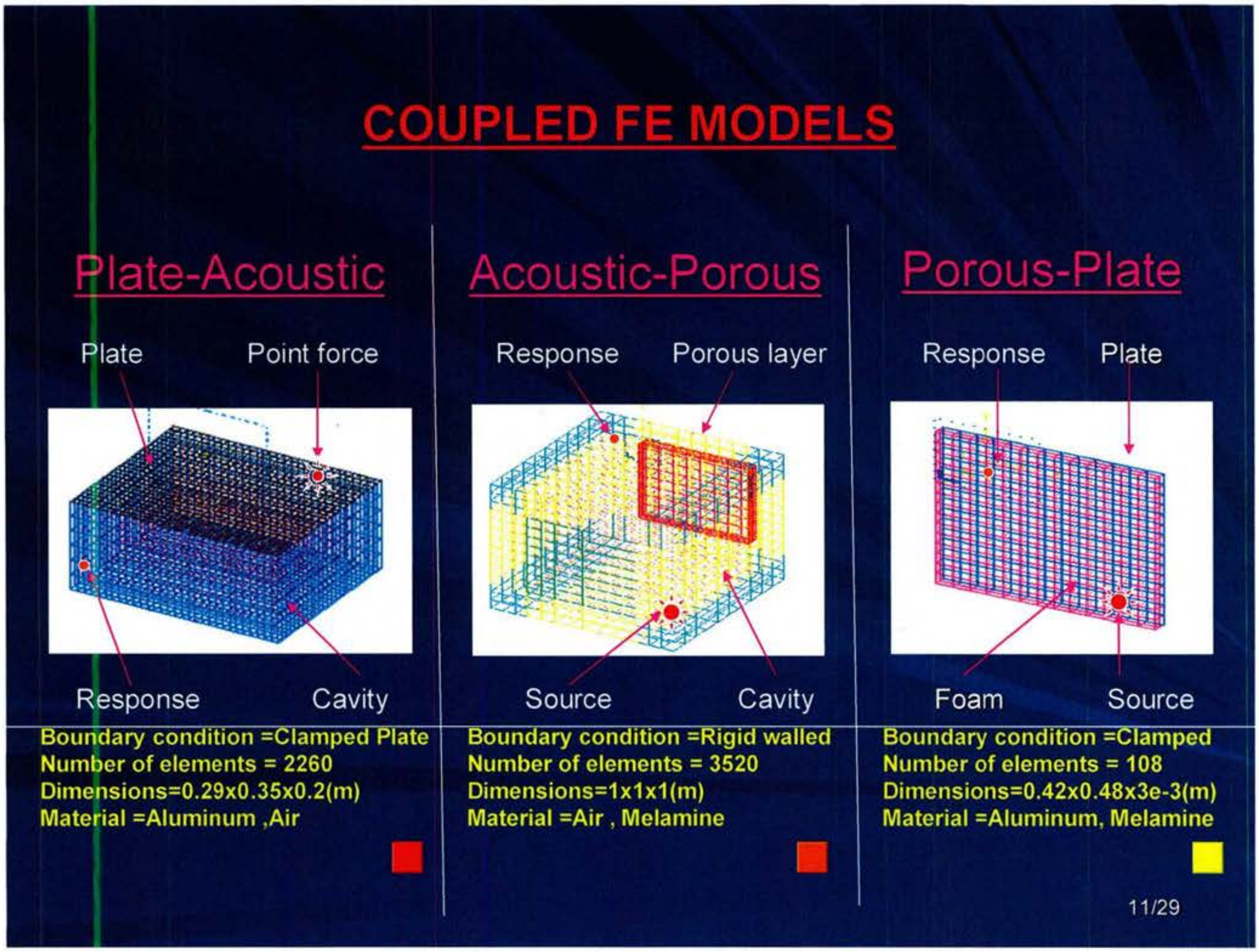

Figure 3. FE meshes and systems used in the FE modeling.

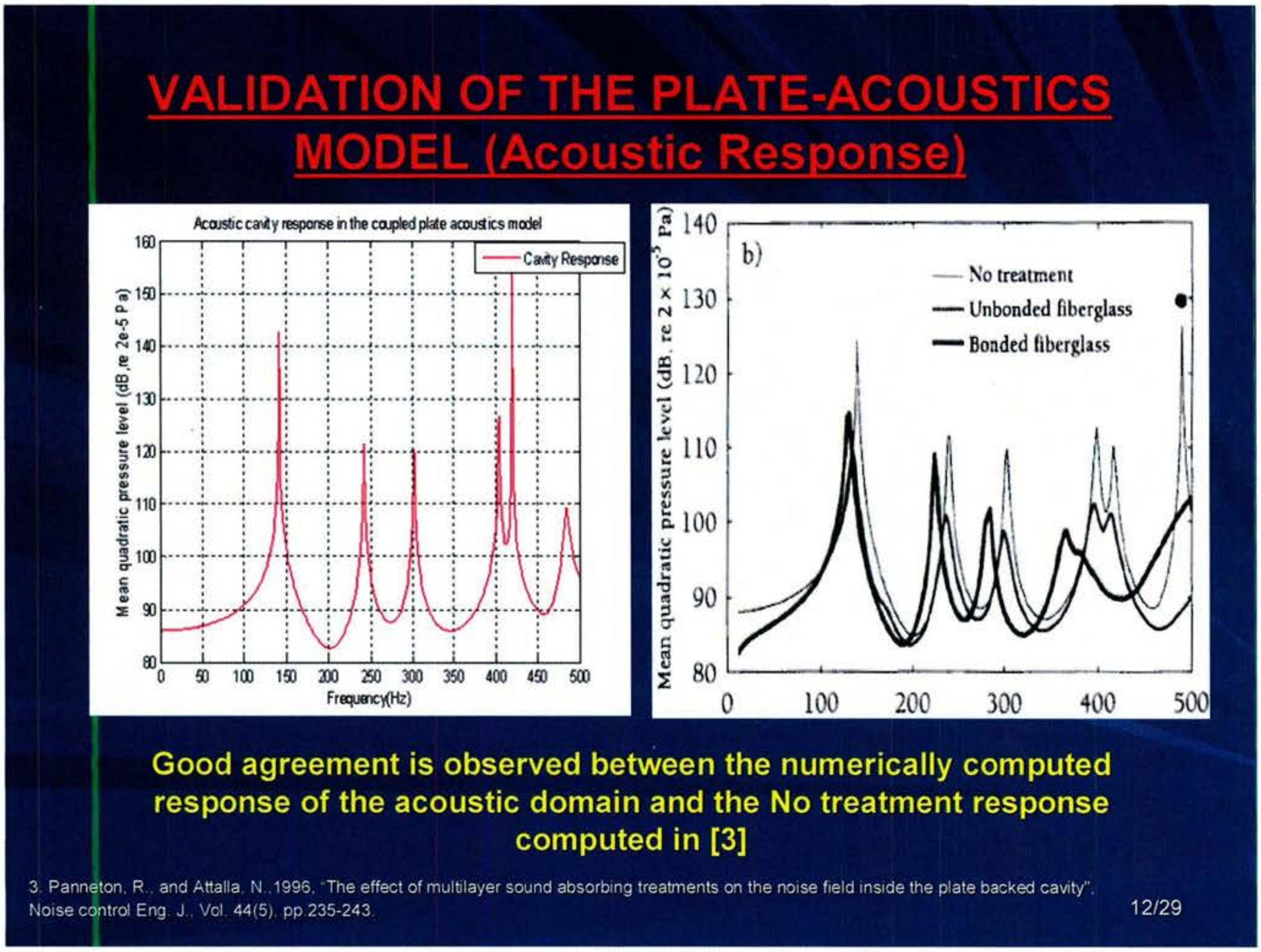

Figure 4.Example comparison between FE results and previous predictions.

Figure 5 shows an experimental set up for validating the FE model of an element of the HG blanket and the FE model of the HG blanket. In this case a small block of poro material containing one embedded mass is studied as a single element of a HG blanket. The single element of HG blanket is placed upon a shaker table driven by broadband vibration. The transfer function between the base vibration and the acceleration of the embedded mass was measured with small accelerometers. The finite element of the mesh used to model the single element of the HG blanket is shown on the right.

Figure 6 shows a comparison between experiment results and FE predictions and the results are very good thus validating the model. The results show the classic frequency response function of a damped SDOF mass spring system due to the embedded mass combining with the natural elasticity of the poro material. The results of Figure in addition to validating the model allow estimation of the natural dynamic stiffness and damping of the poro material by analysis of the FRF.

Figure 7 shows some example results for the FE model of the base plate and HG material system. The addition of the masses to the uniform foam can be seen to cause significant attenuation of plate vibration over a wide frequency range centered on 250Hz. Some frequency splitting due to the addition of the coupled mass-spring systems to the plate dynamics is evident. Later work has generated results for sound transmission through the plate with and without a HG blanket attached to its surface.

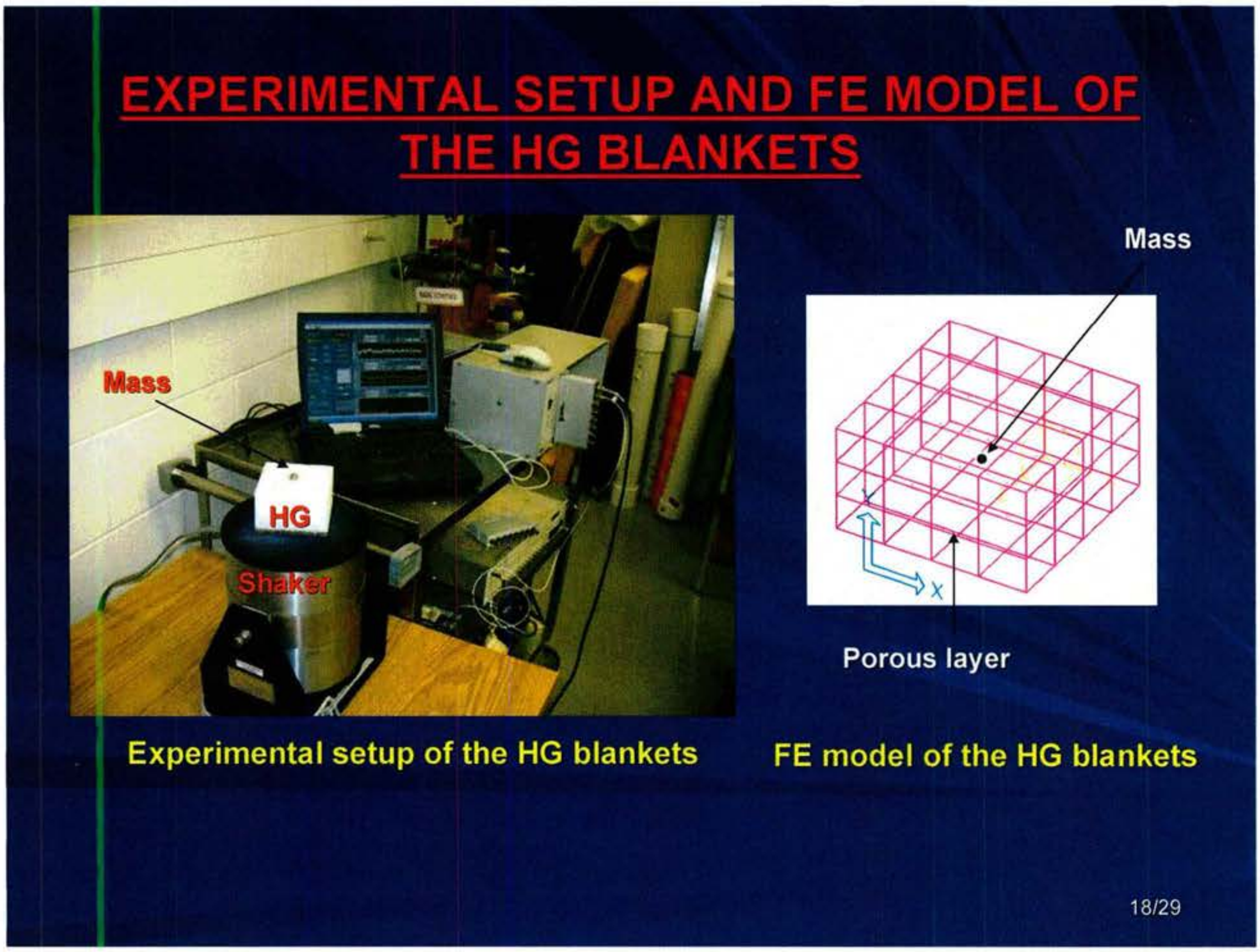

Figure 5.Experimental test set up to validate FE model of HG blanket element.

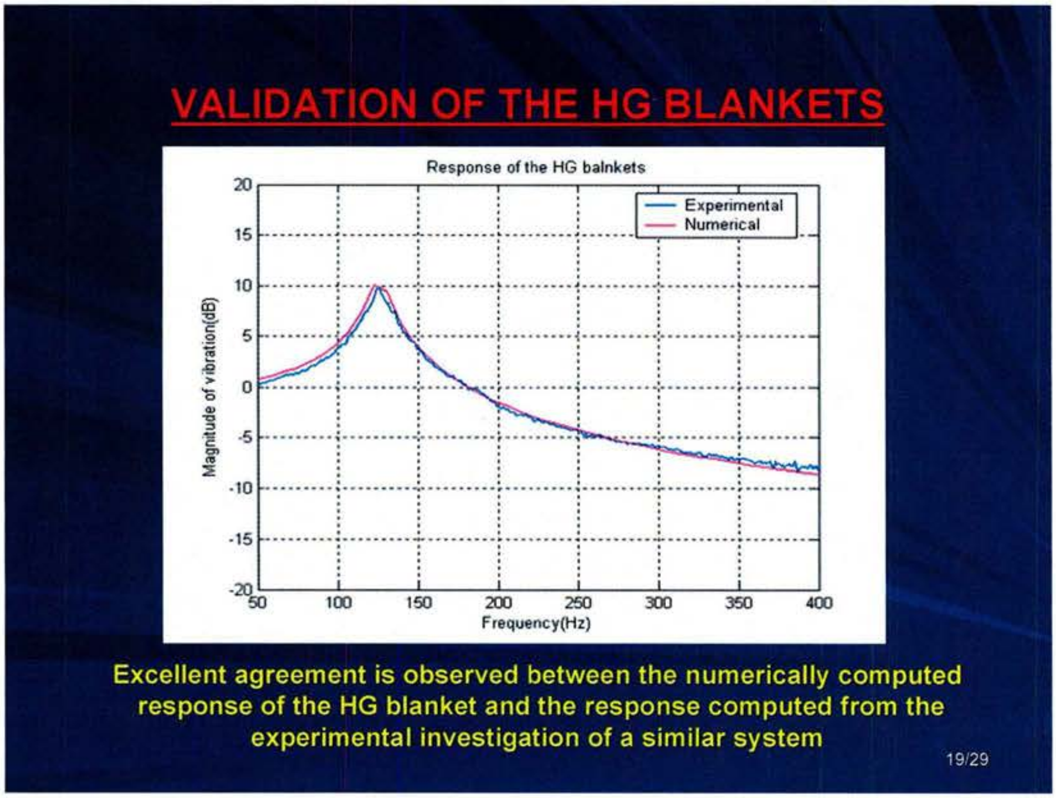

Figure 6. Comparison between measurement and FE prediction for HG blanket element.

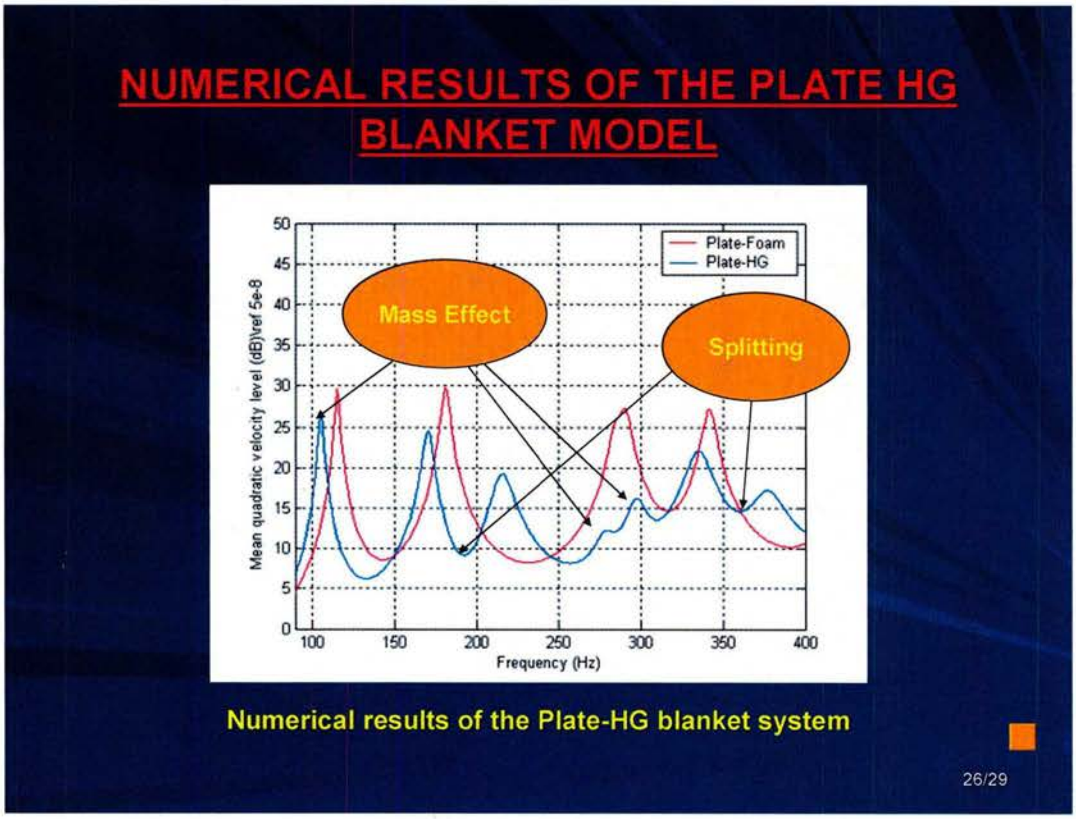

Figure 7. Example numerical results fro the plate HG system.

The finite element models of the HG blankets and the 3D-FE fully coupled model of the plate-HG-acoustic assembly has been validated. These fully coupled models were later used for conducting parametric studies on the controlling parameters of the HG blankets to understand the physics behind their functionality. It was seen from the parametric studies conducted on the HG blankets that resonance frequency of the HG blankets is dependent upon the mass of the in-homogeneity and the shear modulus of the foam layer of the HG blanket. It can also be concluded that the damping capabilities of the HG blankets is primarily influenced by the value of the shear modulus loss factor rather then the viscous damping of the porous media.

In addition, it can be concluded that the modeling of the mass in-homogeneity as a point mass gives reasonably accurate results at low frequencies but as the target frequencies of the HG blankets increases the geometric configuration of the mass in-homogeneity starts to effect the response of the HG blankets. This observation calls for the numerical modeling of the mass in-homogeneity when designing the HG blankets to target high frequency modes of the base structure.

The studies conducted on the fully coupled plate-HG-acoustic 3D-FE model indicates that as the depth of the mass in-homogeneity increases it leads to an increase in the effective bandwidth of the HG blanket. It can be concluded from the aforementioned observation that for designing the HG blankets to target high frequency response of the base structure the mass in-homogeneities of the HG blankets should be placed at a greater depth from the free surface. In addition, it has been observed from the parametric studies on the fully coupled plate-HG-acoustic model that for relatively less modally dense base structures the vibro-acoustic attenuation capabilities of the HG blankets having the mass in-homogeneities at designed location and designed depths is superior as compared to the case in which the mass insertions are placed randomly but at designed depths. This is due to the fact that in the less modally dense base structures the deterministic computation of the resonance frequencies and their corresponding mode shapes of the base structure is computationally feasible. This provides us the ability to find the optimum location of the mass insertions in the porous media for optimal performance of the HG blanket. On the other hand the deterministic estimation of the modal resonance frequency and their corresponding mode shapes for a modally dense base structure is computationally expensive and cumbersome. This is the reason that the random allocation of the masses in the HG blankets becomes necessary for the vibration attenuation of the high modal density base structure.

Results and conclusions are also drawn from the results obtained from the multiple porous layers treatment on the base structures. It can be concluded that the shift of the resonance frequencies of the base plate is dependent upon the relative coupling strength of the collective mass and collective stiffness effect of the MPL blanket with the modes of the base plate. In addition, it can be observed that the use of more foam layers of the porous media as compared to one homogenous porous layer on the base structure keeping the thickness of the treatment unchanged causes increased damping characteristics, which leads to reduced vibration response of the base structure. The MPL blankets although result in a broad band attenuation of the vibration levels of the base structure can not be used as a improvised vibration absorber as they cannot be tuned to a particular resonance frequency of the base structure. The primary source of the reduction of the vibrations levels of the base structure and the SPL's in the radiating acoustic domain due to the MPL blanket treatment is the interaction of the passive damping of the porous layers of the MPL blankets with the structural and acoustic media.

In summary the HG blankets and the MPL blankets have been shown to have great potential to reduce the vibration response of the base structures and the sound radiated by them into the coupled radiating acoustic domain. The heterogeneous blankets (HG blankets) are very effective in reducing the vibration levels of the multiple efficient radiating structural modes. This is due to the fact that multiple mass in-homogeneities inside the foam layer of the HG blanket can be tuned to different resonance frequencies of the base structure. The dynamics of the HG blankets only couples into the modes of the base structure for which they are designed and hence the effect of the HG blanket on the other modes of the base structure is primarily restricted to the mass, the stiffness and the passive damping effect of the foam layer of the HG blanket. The multiple porous layer blankets (MPL blankets) treatment on the other hand is primarily good for improving the effectiveness of a single porous layer treatment by substituting the thickness of the porous layer treatment with a bunch of thin porous layers having different material properties. The MPL blankets are primarily used as a broad band attenuation device rather then an improvised vibration absorber as they don't have the capability to target any particular resonance frequency. The HG blanket and the MPL blankets have shown great promise in reducing the vibration response of the base structure and reducing the sound radiated by them into the coupled radiating acoustic domain. The HG blanket has its strong points and limitations and the numerical models developed in this project provides a tool to exploit the strong points of these devices to come up with customized solutions for the vibro-acoustic attenuation problems.

A number of suggestions for the future work are as follows;

Develop 3D-FE models by modeling the inserted mass in-homogeneities. The parametric studies conducted on the HG blankets have shown that though the modeling of the mass in-homogeneity as a point mass in the FE model gives reasonably accurate results at low frequencies but as the target frequency of the HG blanket increases the geometrical configuration of the inserted masses starts playing a significant role in capturing of the HG blanket response. In future fully coupled numerical models of the plate-HG, the plate-HG-acoustic and the acoustic-plate-HG-acoustic assemblies can be developed taking into consideration the geometric configuration of the mass in-homogeneities. Studies performed on these models would enable optimizing the design of the HG blankets for targeting the high resonance frequency modes of the base structure.

Accelerate computation: In order to provide faster optimization and to solve large scale vibro-acoustic problems, increased computational efficiency of the code is required. In the future there could be effort on increasing the computational efficiency of the code. This can be done by computationally parallelizing the code.

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