SEA MODEL OF TYPICAL SPACECRAFT STRUCTURES; GAP INFLUENCE ON ACOUSTIC RESPONSE

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ABSTRACT

The most widespread methodology for the analysis of vibro-acoustic response at high frequencies is the Statistical Energy Analysis (SEA). SEA studies the structural elements through their energy level under certain power input. SEA subsystems are mainly characterized by their modal density and the SEA loss factors: dissipation and coupling. The balance character of the SEA methodology makes very important de adequate modelling of the interaction between structural elements. On spacecraft structures is common the presence of gaps between panels. This kind of joins (gapped) change drastically the behaviour of the systems, especially on the interaction with interior acoustic cavities. A study of the influence of this gapped joins and its influence on the response of the system is presented. The study of interior acoustic cavities response for Structural Health Monitoring is also presented.

1. INTRODUCTION

The structural design of spacecrafts is highly affected by acoustic loads, which in addition with the shock loads, are the main design loads of spacecraft structures. Acoustic loads are highly related with the vibro-acoustic response of the different elements of the system but specially related with the presence of interior acoustic cavities in the design. When these kinds of elements are present, a solution to reduce the pressure difference between the interior cavity and the surrounding air is to include venting holes in the structure that allow the interchange of energy between both regions. Depending on the availability to include this kind of elements (because of structural restrictions) is usual to add a separation, or gap, between the panels to open the interior cavity to the outside.

The Statistical Energy Analysis [1,2] is an energetic formulation that analyzes the vibro-acoustic response of structures at high frequencies. This methodology studies structural elements as energy systems having in account only the energy balance between the different elements [3]. At high frequency range structural elements tend to present a high number of normal modes making unapproachable the use of discrete formulations (as Finite Elements Modelling), SEA analyze the energy balance studying the average response of the system elements [4].
With this approach structural elements are only characterized by their capacity to store and transfer energy to and from other elements (or subsystems). As can be seen, this methodology exposes clearly the influence of elements interaction, making it ideal for a sensitivity study of the gap influence in vibro-acoustic problems due also to its low computational costs that allow cheap sensitivity studies [5].

The simple formulation of SEA, analyzing the sensitivity of the acoustic response on interior cavities is studied as an indicator for damage detection in the framework of Structural Health Monitoring (SHM) [6,7].

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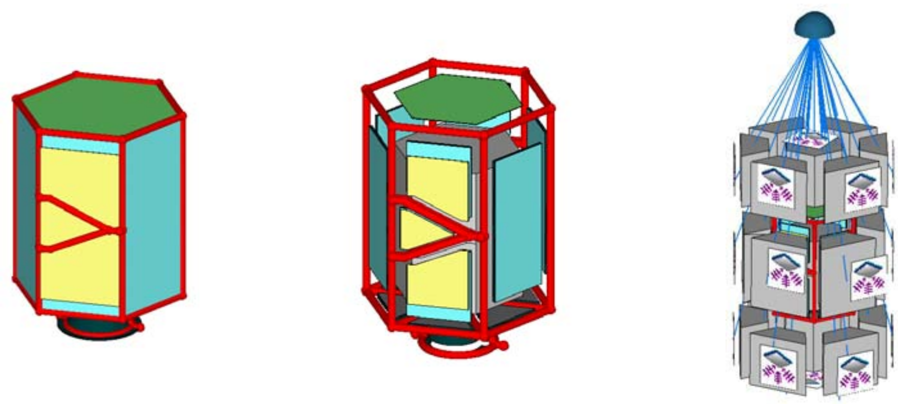
2. BENCHMARK CASE

A test case, representing a typical satellite structure, has been designed applying SEA formulation to the structural behaviour. The model reproduces the typical satellite structure: adaptation cone to the launcher, lower platform, lateral faces, external appendages for solar arrays and an upper platform.

The basic model consists in the satellite body simulated by six lateral panels forming a hexagon with properties of polycarbonate, of 6 mm thickness. Two hexagonal aluminium plates corresponds to the lower and upper platforms of the satellite; properties are the one corresponding to aluminium of 1 mm of thickness for the upper, and 10 mm on the base plate. The cone simulating the adaptation system is aluminium of 4 mm. The appendages are simulated using three sub-plates, in aluminium of 1 mm. The appendages are attached to their corresponding lateral face in three points. A view of the model is shown in the Figure 1.



(a) (b) (c)

Figure 1: Study case: a) Typical satellite structure with main elements (adaptation cone, platforms, lateral faces, appendages, interior cavity) modelled through SEA. b) Exploded view of structural elements and SEA interior cavity. c) Near field cavities surrounding structural subsystem, with diffuse acoustic field (spectral density of 1 Pa^2/Hz) applied. Semi-infinite fluid linked to external cavities.

The presented model is slightly modified to study the influence of joins modelling in the vibro-acoustic response. Two main analyses are performed: a) Influence of gap presence, and sensitivity of the response due to relative gap width; and b) modelling of structural damage, and study of the interior cavity response as method for Structural Health Monitoring (SHM).

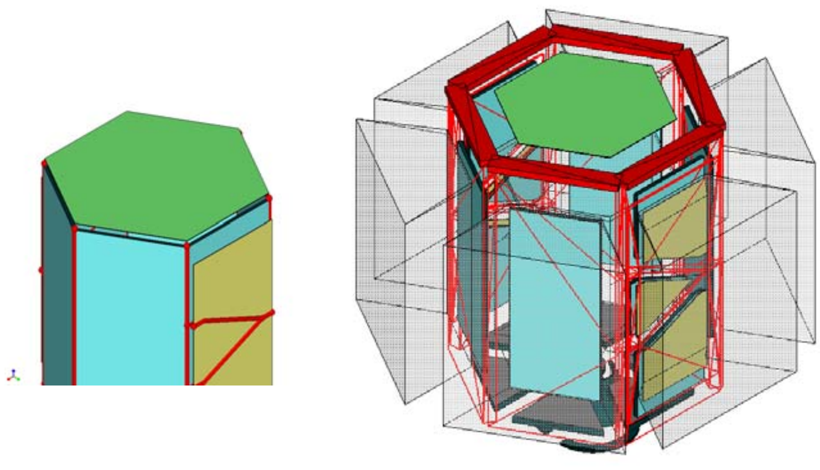
The gap presence is simulated rearranging the upper platform of the model. The join of the upper platform to the lateral faces is studied through different cases:

- In the case of closed interior cavity:
    - Punctual and Linear junctions between the upper platform and the lateral faces.
    - Punctual junctions between the upper platform and the lateral faces (Nominal configuration).

(a) (b)

Figure 2: Designs of attachment of the upper platform to the lateral faces for a closed interior cavity: a) punctual and linear junctions; b) Nominal configuration: punctual junctions.

- For the case of opened interior cavity (gap):
    - Punctual junctions in the vertexes of the hexagon for several gap widths. The gap area becomes the junction between the interior cavity and the outside (through external cavities).



(a) (b)

Figure 3: Designs of attachment of the upper platform to the lateral faces for an open (gapped) interior cavity: a) View of the gap between the upper platform and the lateral faces; b) view of the new junctions (solid red) for direct energy interchange between interior cavity and outside, indirect interchange through the lateral faces modelled through lateral faces junctions (wire frame red)

The analysis of the interior cavity response as an structural health monitoring (SHM) factor is studied as a limit case of the interchange of energy between the outside and the cavity itself. The SHM configuration is derived from the nominal closed configuration, redefining the indirect connection between the interior cavity and the outside through the lateral faces. The energy interchange through the lateral faces is increased to simulate an energy leakage equivalent to an area of 1 square millimetre per face.

Summarizing, in the following the vibro-acoustic response of seven configurations are presented:

- Closed Lines: Closed configuration with a punctual and linear attachment of the upper platform.
- Closed Points: Closed configuration with a punctual attachment of the upper platform (Nominal Configuration)
- Open *d* mm: Open configuration with upper platform attached in the vertexes at a distance (gap width) of 1, 3, 10 and 30 millimetres (four configurations).
- Closed Points SHM: Closed configuration with a punctual attachment of the upper platform (Nominal Configuration) and energy leakages in the lateral faces equivalents to 1 mm^2 per face.

The response of the system is shown in terms of the averaged mean response of the structural elements (upper platform, lateral face and appendage) and the interior cavity in exact third octave bands from 31,25 Hz to 50.800 Hz to a diffuse acoustic field of 1 Pa^2/Hz spectral density.

The modal density of the elements analyzed, to evaluate the applicability of the SEA formulation is derived from the number of modes per band (Figure 4) assuring a high modal density over the band of 1000 Hz.

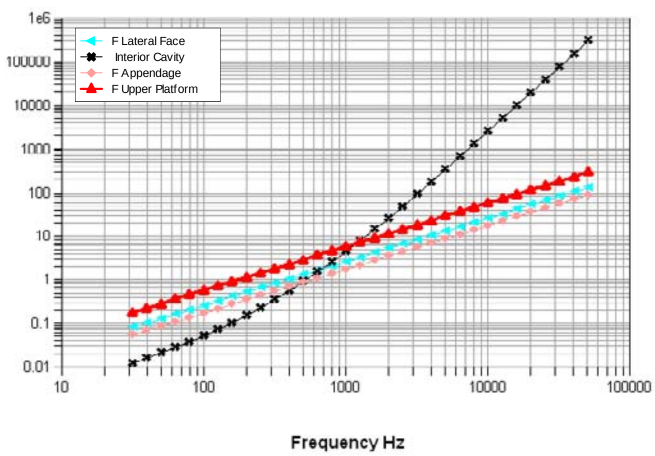
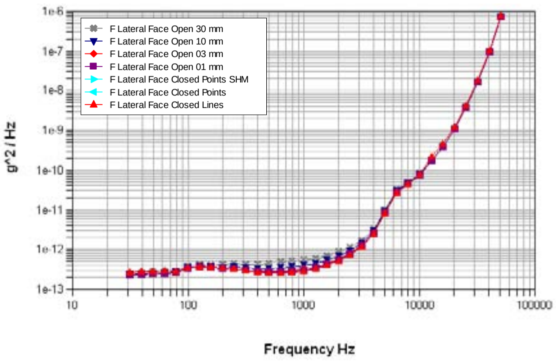


Figure 4: Number of normal modes in each exact third octave bands for the elements studied.

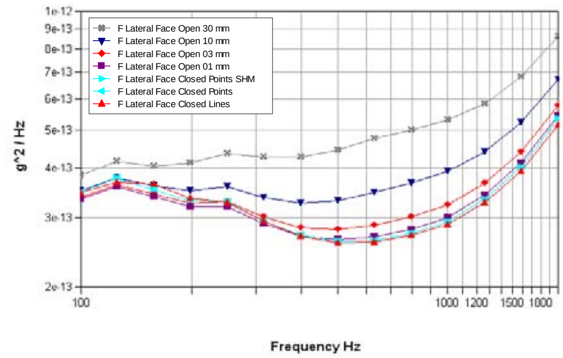
3. RESPONSE OF BENCKMARK CONFIGURATIONS

This paragraph presents the response of the different analysis configurations presented in the former paragraph.

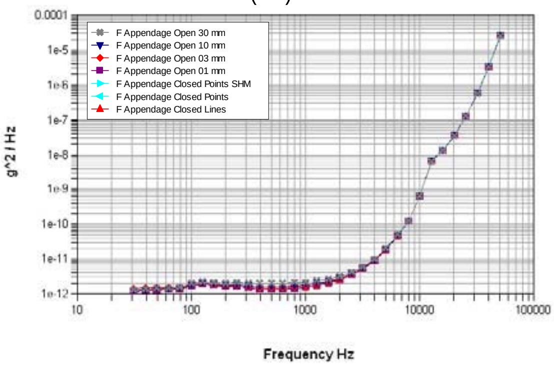
The response (through the average acceleration spectral density) of the lateral face and the appendage is shown in Figure 5.



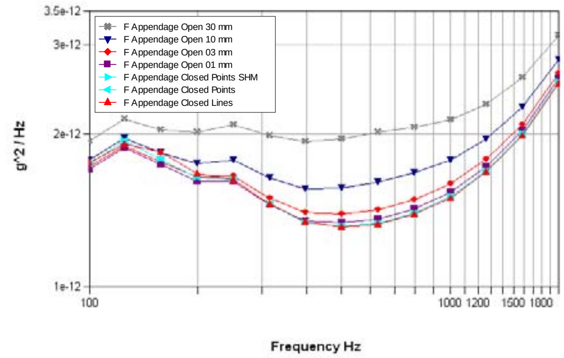
(a.1)



(a.2)

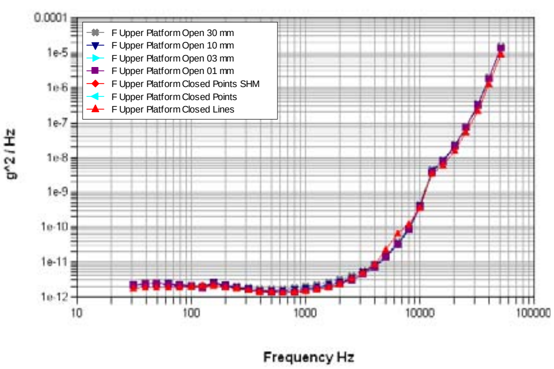


(b.1)

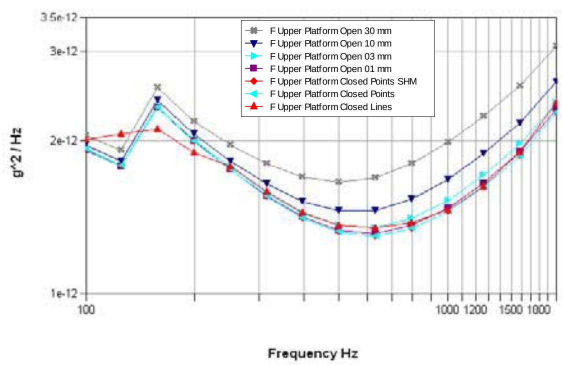


(b.2)

Figure 5: Response of lateral face (a) and appendage (b) for the different configurations. Range from (31.5 Hz to 50800 Hz) (.1) and detail form 100 Hz to 2000 Hz (.2)



(a)



(b)

Figure 5: Response of the upper platform for the different configurations. Range from (31.5 Hz to 50800 Hz) (a) and detail form 100 Hz to 2000 Hz (b)

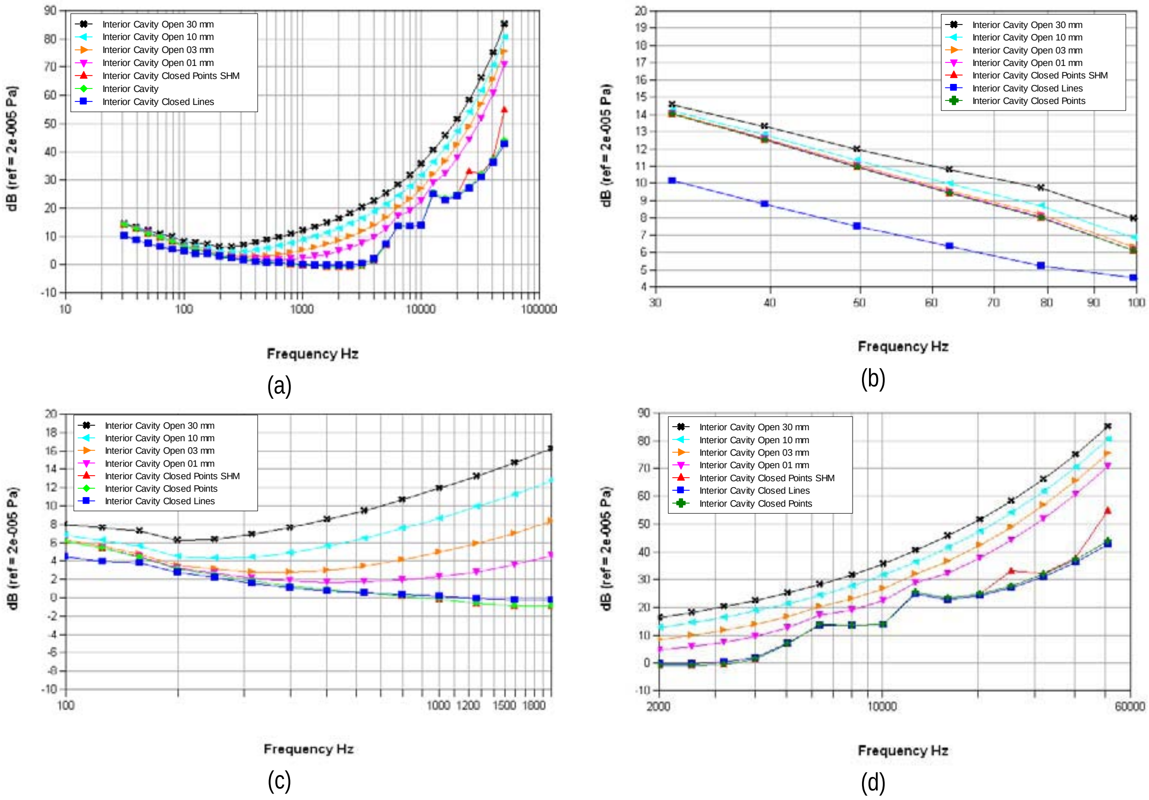


Figure 6: Response on the interior cavity for the different configurations. Whole frequency range (a), low (b), medium (c) and high (d) frequency ranges.

4. ANALYSIS OF RESULTS

From the several results shown in the previous paragraphs the influence of join type as well as the gap influence can be deducted.

Influence of upper platform attachment

The change in the attachment produce a change in the behaviour of the structural elements in the low frequency ranges due to the change in the cut-off frequency. This influence can be clearly observer in the range of the 100-200 Hz on the response of the upper platform.

Although this and that the variation is inside of the range of sensibility of the models developed, the response of the structural elements is only very slightly affected by the variations in the upper platform-lateral faces junctions. In particular, the change of attachment from linear and punctual to only punctual produces almost null variations in the response of these elements. In the case of the most affected element (the upper platform), the variation in the response is more noticeable, producing a lower response above the cut frequency.

The response of the interior cavity is some more influenced by this variation in the model, specifically in the very low frequency range, below 100 Hz. Below this frequency, the most stiffed junction (punctual plus linear) produce a clearly lower level in the response. Above this range, although a minor change in the trend is noted (lower levels for the less stiff junction) the variations are small.

Influence of gap presence and width

Analyzing the global response of the structural elements, the influence of the gap presence and its width is very low, and although there are some minor behaviour changes (on the upper platform above 6000 Hz) the differences are not of importance.

Where the influence of the gap presence shows great importance is in the response on the interior cavity: The inclusion of the gap, independently on its width, produces an important change in the response. As is shown in figure 6.a, the level of the response not only increase, but a change in the trend is shown between the closed and the open interior cavities.

Regarding the gap width, the responses of the gapped configurations show a linear dependence with the gap size.

Acoustic Cavity response for Structural Health Monitoring

To analyze the applicability of the acoustic response for SHM, an energy leakage in the closed configuration (SHM configuration) has been defined to allow the direct transfer of energy between the interior cavity and the outside without the presence of a gap.

As can be seen in Figure 6.a and 6.d, an important variation on the response of the interior acoustic cavity happens. Although the response at high frequencies doesn't reach the level of the open configuration, it is important having in account that the gap area is around two hundred and fifty times the equivalent area of the energy leakage defined.

To analyze more closely this problem, two additional configurations (with equivalent areas of the energy leakage of 2 and 4 square millimetres per face) are analyzed. The responses of the acoustic cavity for the closed configuration and the three SHM configurations are shown in Figure 7.

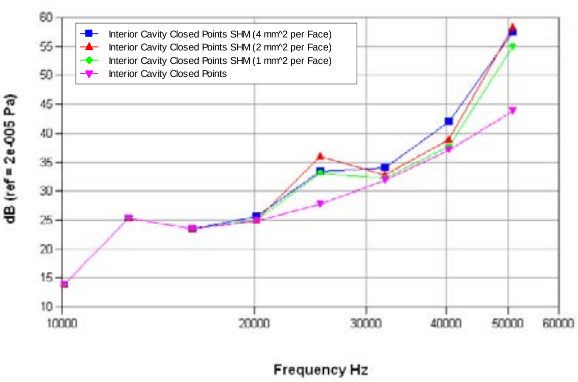


Figure 7: Response on the interior cavity for the nominal configuration (punctual attachment of the upper platform) and three SHM configurations of equivalent energy leakage are of 1, 2 and 4 square millimetres.

Figure 7 shows that the influence of the simulated structural damage affects only to the response on the higher frequencies independently of the increase in gap size. The typical frequency dependence with size (cut off frequency) can be observed as the resonance behaviour evolves.

5. CONCLUSIONS

The applicability of SEA as practical formulation for sensitivity studies due to its low computational cost has been presented. The influence of subsystems joins on the response of SEA models has been analyzed through a benchmark case representing the typical geometry and elements of spacecraft structures.

The influence of gaps to communicate interior acoustic cavities with the outside has been studied. It has been shown that it affects only very slightly to the structural elements that compose the walls of the cavity, being more important in the structural element modified to include the gap in the configuration, due to the variation on the energy path that connects this subsystem to the others.

The influence of the gap shows importance in the case of the interior acoustic cavity, which response changes drastically, mainly registering a change in the high frequency trend, producing an increase in the pressure level in the interior of the cavity.

The applicability of the acoustic response on interior cavities for SHM has been presented through the simulation of structural damage that allows the energy transfer from closed cavities to the outside.

6. ACKNOWLEDGEMENTS

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