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THE INFLUENCE OF MASS COMPONENT DISTRIBUTION OVER PLATES FOR STRUCTURAL DESIGN OF ON BOARD ELECTRONIC DEVICES

Renato Grangeiro Buzzoleti
Centro Universitário da FEI
renato_buzzoleti@hotmail.com
Agenor de Toledo Fleury
Centro Universitário da FEI
agfleury@fei.edu.br

Abstract. *Each on board electronic equipment shall be subject to vibration during its life. It is expected that equipment suffer some vibration at least during its transportation, if not during its operational life. As the vibration is the second biggest source for electronic equipment fails (around 20% according to Steinberg, 2000), it is quite important to understand how better protect the on board electronic, mainly if it is under high acceleration levels as in satellite applications. For different reasons as accessibility, handling and maintenance, the electronic on board usually consists basically of modules (box or casing) which receive the printed circuit board where the electronic components are mounted. The printed board circuits are responsible for supplying mechanical support to electronics equipment and, at the same time, assure an electrical connectivity of the circuit. The aim of this work is to study how the arrangement of the component in plate should affect its dynamic behavior and, how this distribution can be used for structural design safety. For doing this, a finite elements model is proposed and natural frequencies and their respective mode shapes are analyzed. Six different types of mass distribution have been considered. In order to evaluate mass influence on the plate dynamic behavior, for all the arrangement proposed distribution of the masses, the mass amount was increased in three steps. The same has been done with the area of the mounting support that 5%, 10% and 15% of the plate area. After the finite element analysis, experimental tests have been performed and all results have been discussed.*

Keywords: *Vibration, Finite Element, Printed Circuit Board*

1. INTRODUCTION

On board equipment are often submitted to high levels of dynamic loads during its transportations or its operational life. Electronics components qualified can be used depending on the equipment's application as in space and defense areas for example. These types of component follow specific norms where assure that these components have been tested under many situations as mechanical vibration, mechanical shock, acceleration, thermal and others. Although the components have been tested, depending on its location on the printed circuit board (PCB), the level of the acceleration upon it can exceed its specification and can occur the damage. Most of electronic equipment on board used in space and defense products is made of aluminum boxes where the PCB is fixed (Figure 1). These boxes have mass, volume and fixture previously defined by the agency responsible for the program. Therefore it remains as design resource to work only inside the box, mainly in the interface between the PCB and the box's supports. This positioning and fixture between the PCB and the box has to satisfy all the electrical constraints. The electrical design is frequently made independently by the other department carrying out only the electrical necessities ignoring the mechanical and thermal demands. It is necessary to have more interaction among the areas that are involved with this kind of design and to find an agreement between the PCB's layout and the mechanical and thermal necessities.

This work intends to study two fundamental points in packaging design of electronic circuits. First of all, how the distribution of the electronic components mounted on the plate will affect its dynamic behavior and how the supports area will affect the plate's response. Therefore, this work intends to provide tools to help the electrical layout and the structural design as well. In other words, how the electronic layout can give support to structural design.

Many authors have studied plates with mass added under different aspects. Cifuentes (1994) did a FEM (finite element model) to study plates with mounted components. In three works Amy, *et al.*, (2009a, 2009b, 2010) have studied the effects of the simplification's errors used in FEM models in PCBs. Yu, *et al.*, (2010) have done a FEM model to studied cell phones PCB submitted to impact. Other authors as Low, *et al.*, (1998), Alibiglu, *et al.*, (2007), Chai (1993, 1995), Wong (2002) and Wang, *et al.*, (2010) have chosen to study plates with mass added through a model using Rayleigh-Ritz method and experimental tests.

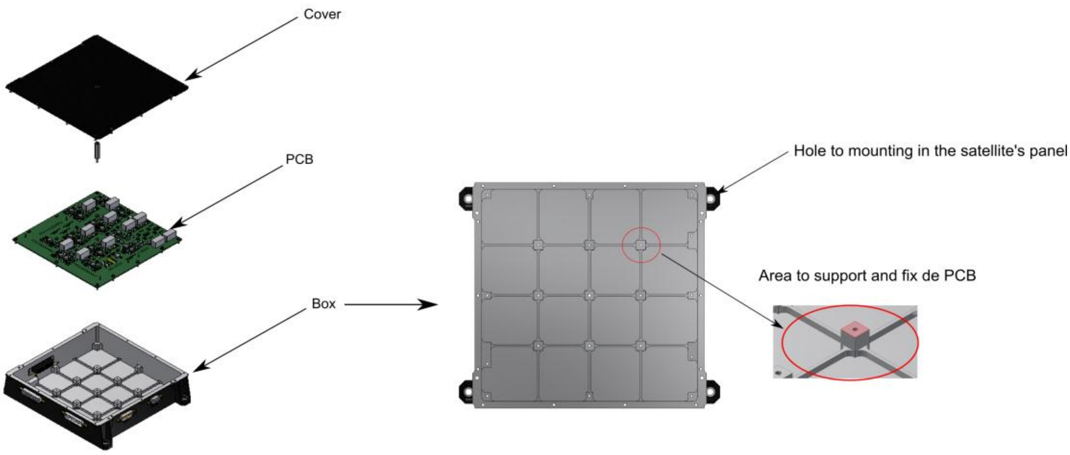

Figure 1. Example of space electronic equipment mounting

2. METHODOLOGY

Three variables have been analyzed to identify their influence in dynamic behavior of plates.

a) Position of the added mass;
b) Ratio between the added mass and the plate's mass;
c) Ratio between the sum of the supports area and the plate's area.

First, FEM models have been done and several simulations of the modal extraction have been carried out varying the position of the mass added and its amount and the supports area. After, the same results were obtained experimentally by sine sweep in electrodynamics shaker.

2.1 Set-up of test

In Figure 2 it is possible see the set-up of test. It consists of a plate fixed by nine supports and four masses on top of it to simulate electronic components.

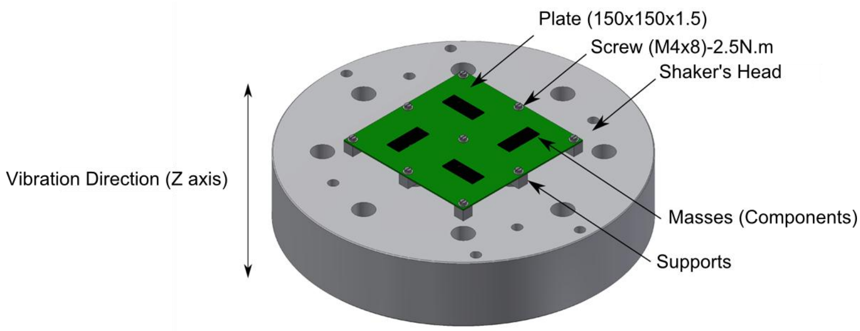

Figure 2. Set-up of test

2.2 Position of the added mass

As model, it was considered a critical component due to its dimension and weight according to Steinberg (2000). Four of these identical components were distributed in six different ways (Figure 3). The sum of the area of component is 10.1% of the plate's area.

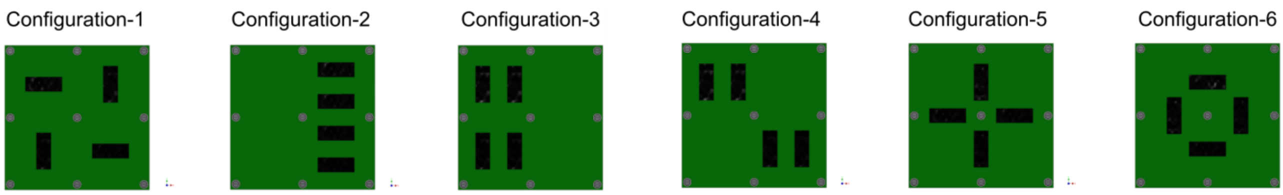

Figure 3. Types of the mass's distribution analyzed

2.3 Ratio between the added mass and the plate mass

In order to check how the increase of the mass on the plate affects its dynamic behavior, the first analyze was done with only the plate alone (without any component). After, for each configuration analyzed, the masses have been added in three steps: initially with a ratio equal to 22.9%, after 30.4% and finally with 39.7%. The reason for choosing these values was facilitate the experimental tests increasing the thickness of the masses on the plate (Figure 4).

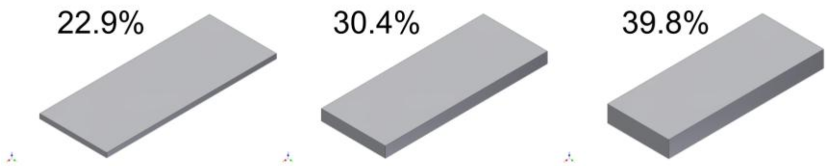

Figure 4. Steps used to increase the mass ratio

2.4 Ratio between the sum of the supports area and the plate's area

In order to check how the increase of the support's area of the plate affects its dynamic behavior, the first analysis was done with the plate supported with a ratio equal to 5%, after 10% and finally with 15%.

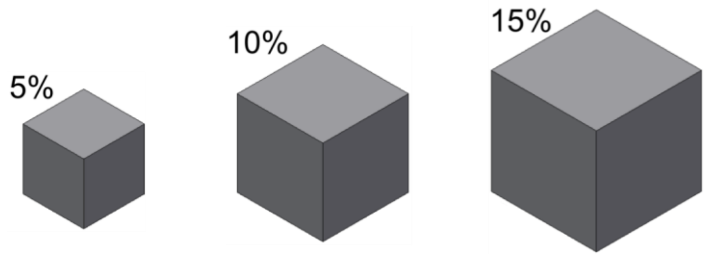

Figure 5. Steps used to increase the area ratio

2.5 Summary of the analyses

The Table 1 was created in order to consolidate all the tests done. In Table 1, the denominations S1, S2 and S3 correspond to 5%, 10% and 15% of the ratio between the sum of the support's area and the plate's area. The denominations M1, M2 and M3 correspond to 22.9%, 30.4% and 39.8% of the ratio between the sum of the component's mass and the plate's mass. Thus, for sample, the abbreviation S1M1 means that the test has made with the plate supported in 5% of its area and carrying 22.9% of its mass. This way, for each mass's positioning have been made nine tests. As there are six configurations, fifty four tests plus three tests with the plate alone (without mass) to each area ratio were made, thus fifty seven tests were made in total.

Table 1. Tests have been done for each configuration

Component's Position	Tests		
Configuration	S1M1	S1M2	S1M3
	1	2	3
	S2M1	S2M2	S2M3
	4	5	6
	S3M1	S3M2	S3M3
	7	8	9

3. FEM MODELS

Two FEM models have been done. The first model is simpler and cheaper computationally. The second model is more complex. The main difference between them is that in the model 1 the mass mounted on the plate is nonstructural while in the model 2 the thickness of the component and consequently its inertia of its cross section are considered.

3.1 Mesh and Material

The model 1 has been used 20449 elements S4R type shell with 4 nodes and 6 degree of freedom (DOF) per node. The model 2 has been used 23256 elements S4R (plate and components) and 349632 elements C3D4 (supports) type tetrahedral with 4 nodes and 4 DOF per node. These elements have been extracted from Abaqus CAE software library. The mesh convergence criteria adopted was an error less than 0.05%. The Figure 6 shows the mesh of the models. As it is possible to see, the model 1 consists only of the one part while the model 2 had all parts modeled. The plate, support and masses have been made in 5052-H34 aluminum alloy material. The main properties of this alloy are young modulus equal to 69GPa, poisson coefficient equal to 0.33 and density equal to 2700Kg/m^3.

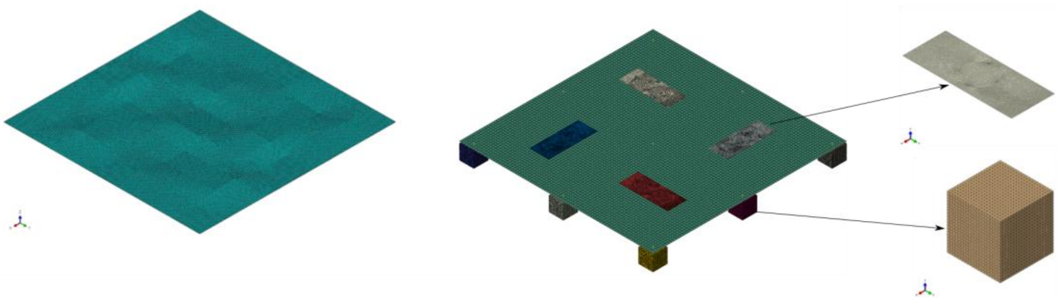

Figure 6. In the left is the mesh of the model 1 and in the right is the mesh of the model 2

3.2 Boundary conditions

In the model 1, the boundary condition has been defined through the restriction of the displacements and rotations of all nodes that are in support's area. In the model 2, the boundary condition has been defined through the rigid elements between the plate and support. These rigid elements have the function of representing the fasteners joints and are a Abaqus CAE's tool to this application.

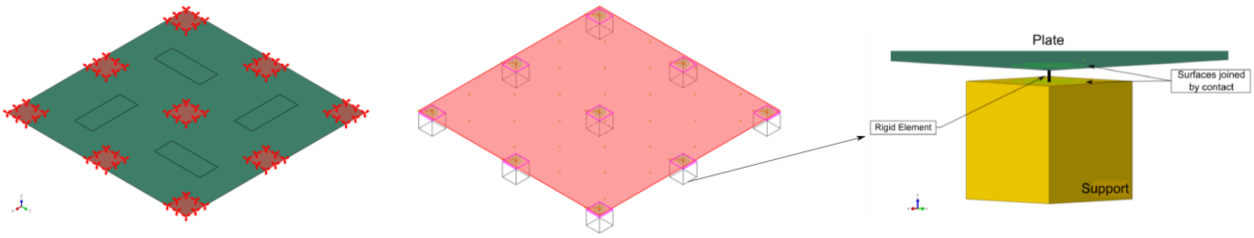

Figure 7. In the left is the boundary condition of the model 1 and in the right is the boundary condition of the model 2

3.3 Components's Effects

In the model 1, the components have been modeled through a partitioning and modification of the density of the elements situated in the area occupied by them. The mass of the component plus the mass of the accelerometer were homogeneously distributed in this area. In the model 2, the components have been modeled through independent parts which have been united through a contact definition. The contact chosen is called "Tie" and it is used to represent bonded and welded pieces, because it connects the nodes that are in contact. The accelerometer's mass in model 2 was represented through a partitioning and modification of the density of the elements localized the area occupied by it.

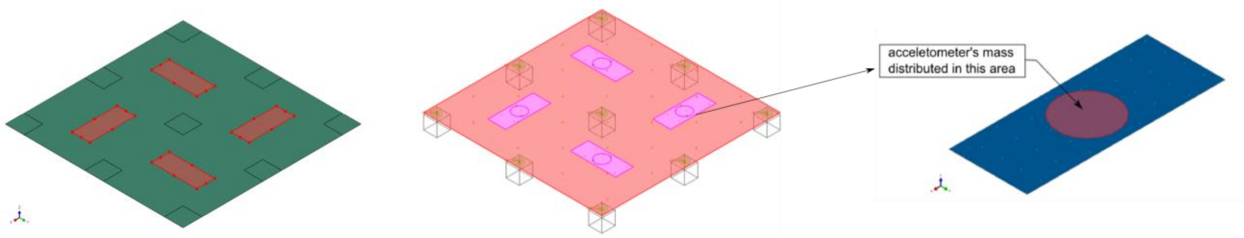

Figure 8. In the left is the component's effect the model 1 and in the right is component's effect of the model 2

4. EXPERIMENTS

The experimental tests have been done through an electrodynamics shaker of the ETS company model M232A/GT400M with 20kN of capacity. The controller which has been used is from the VR company model VT9500 Revolution. The software has been used is the vibration view version 11. The accelerometers have been used are from Endevco company model 256-10 (responses) and ETS company model J14100 (control).

The test was made with sine sweep with amplitude of the 1g and since 5 until 2000Hz of range. The sweep rate was 2oct/min. The criterion to choose the natural frequency was the first peak that appeared.

4.1 Experimental test's arrangement

The plate has been screwed on the supports and the whole assembly has been fixed to the shaker's head. The components have glued on the polyamide tape with silicone adhesive. This tape has a function of protecting the surface in contact. The accelerometers also have been glued using the same process (Figure 9).

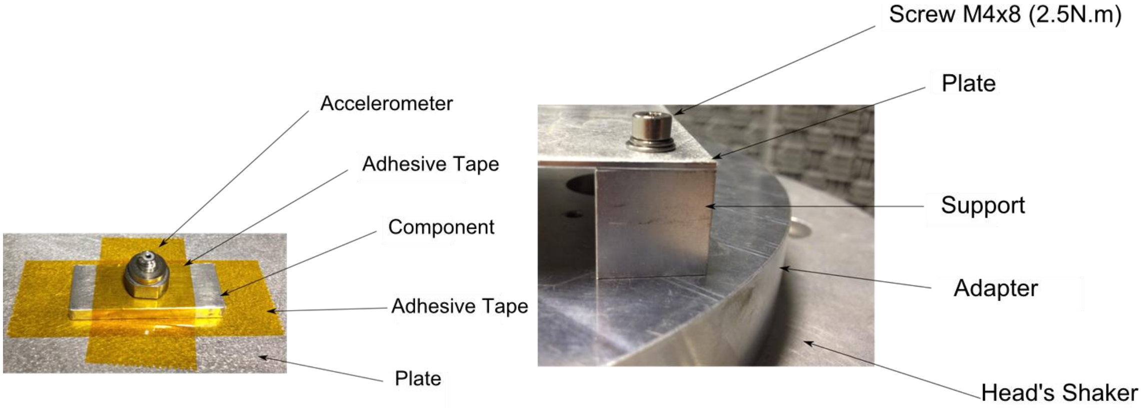

Figure 9. Component and accelerometer mounting

Four channels have been used to get a response and one channel has been used to do the control. In Figure 10 is shown the instrumentation of all configurations studied.

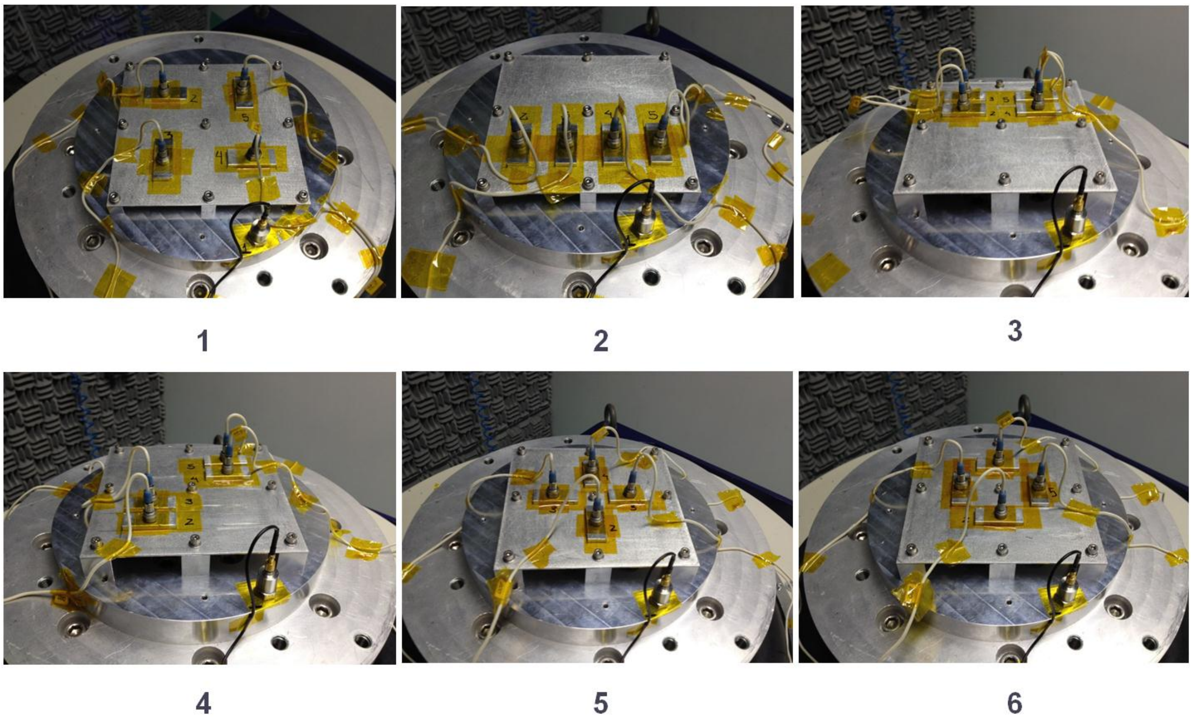

Figure 10. Intrumentation's detail of the experimental tests

5. RESULTS

The results obtained in the simulations done with the FEM models and with the experimental tests were consolidated and separate per configuration analyzed. The curves shown in the graphics were created through cubic splines interpolation using as controls' point the coordinates obtained in the simulation and experimental tests.

The Figure 11 shows the comparison done with the results of the experimental test. The aim this comparison is find out how is the first natural frequency increase, when it has tripled the supported area compared when it have changed the positioning of components to the configuration-5.

Configuration-1			
Tripling the supported area		Changing to Config-5	
D1-S1-M1	13.4%	D1-S1-M1	12.1%
D1-S3-M1		D5-S1-M1	
D1-S1-M2	18.7%	D1-S1-M2	18.0%
D1-S3-M2		D5-S1-M2	
D1-S1-M3	16.0%	D1-S1-M3	31.5%
D1-S3-M3		D5-S1-M3	

Configuration - 2			
Tripling the supported area		Changing to Config-5	
D2-S1-M1	27.2%	D2-S1-M1	20.0%
D2-S3-M1		D5-S1-M1	
D2-S1-M2	14.0%	D2-S1-M2	20.1%
D2-S3-M2		D5-S1-M2	
D2-S1-M3	27.8%	D2-S1-M3	39.2%
D2-S3-M3		D5-S1-M3	

Configuration - 3			
Tripling the supported area		Changing to Config-5	
D3-S1-M1	29.3%	D3-S1-M1	24.2%
D3-S3-M1		D5-S1-M1	
D3-S1-M2	27.1%	D3-S1-M2	25.7%
D3-S3-M2		D5-S1-M2	
D3-S1-M3	10.2%	D3-S1-M3	41.6%
D3-S3-M3		D5-S1-M3	

Configuration - 4			
Tripling the supported area		Changing to Config-5	
D4-S1-M1	15.3%	D4-S1-M1	24.9%
D4-S3-M1		D5-S1-M1	
D4-S1-M2	19.3%	D4-S1-M2	25.7%
D4-S3-M2		D5-S1-M2	
D4-S1-M3	27.8%	D4-S1-M3	47.4%
D4-S3-M3		D5-S1-M3	

Configuration - 6			
Tripling the supported area		Changing to Config-5	
D6-S1-M1	16.0%	D6-S1-M1	8.3%
D6-S3-M1		D5-S1-M1	
D6-S1-M2	10.9%	D6-S1-M2	11.5%
D6-S3-M2		D5-S1-M2	
D6-S1-M3	12.1%	D6-S1-M3	23.5%
D6-S3-M3		D5-S1-M3	

Figure 11. Comparison between to triple the supported area of the plate and to change the positioning of components

In the Figure 12 are shown the behavior to each configuration when the mass on the plate change. Each type of curve represents a ratio of the supported area and each color represents a model (1, 2 and experimental). In the model 1, in all cases, the plates had a linear behavior and areas with the bigger supports were less sensitive with the increase of the mass's ratio. In the model 2 and in the experimental test, inversions of sensibility occurred when the mass's ratio exceeded around 27%. The likely reason with respect to this is the fact that the inertia of the cross section of the added mass in the plate not to have been considered in the model 1, but is present in the model 2 and in the experimental test (Buzzoleti, 2015). The configuration 5 stands out among the others, because it had a different characteristic, where since 27% of the mass's ratio the frequency's ratio of the plate continued rising independently of the ratios of support's area and mass.

In the Figure 13 are shown the behavior to each configuration when the supports' area change. Each type of curve represents a ratio of the added mass on the plate and each color represents a model (1, 2 and experimental). The natural frequencies of the numerical models had a linear behavior with the increase of the support's area, while it did not happen in the experimental results. According with Buzzoleti (2015), probably the damping presence in the experimental tests is the reason. In the model 1, in all cases, the heavier plates were less sensitive with the increase of the supports' area. In the model 2 and in the experimental tests, the plate without components answered more significantly against the increase of the support's area while plates with mass's ratio equal 30 and 40% changed between themselves. Still, plates with mass' ratio equal to 23% were less sensitive with the increase of the supports' area. As mentioned before, the likely reason with respect to this is the fact that the inertia of the cross section. Here, the configuration 5 also had a different characteristic, where the heavier plate had a behavior similar to the plate without components. In other words, all added mass helped to increase of the plate's stiffness.

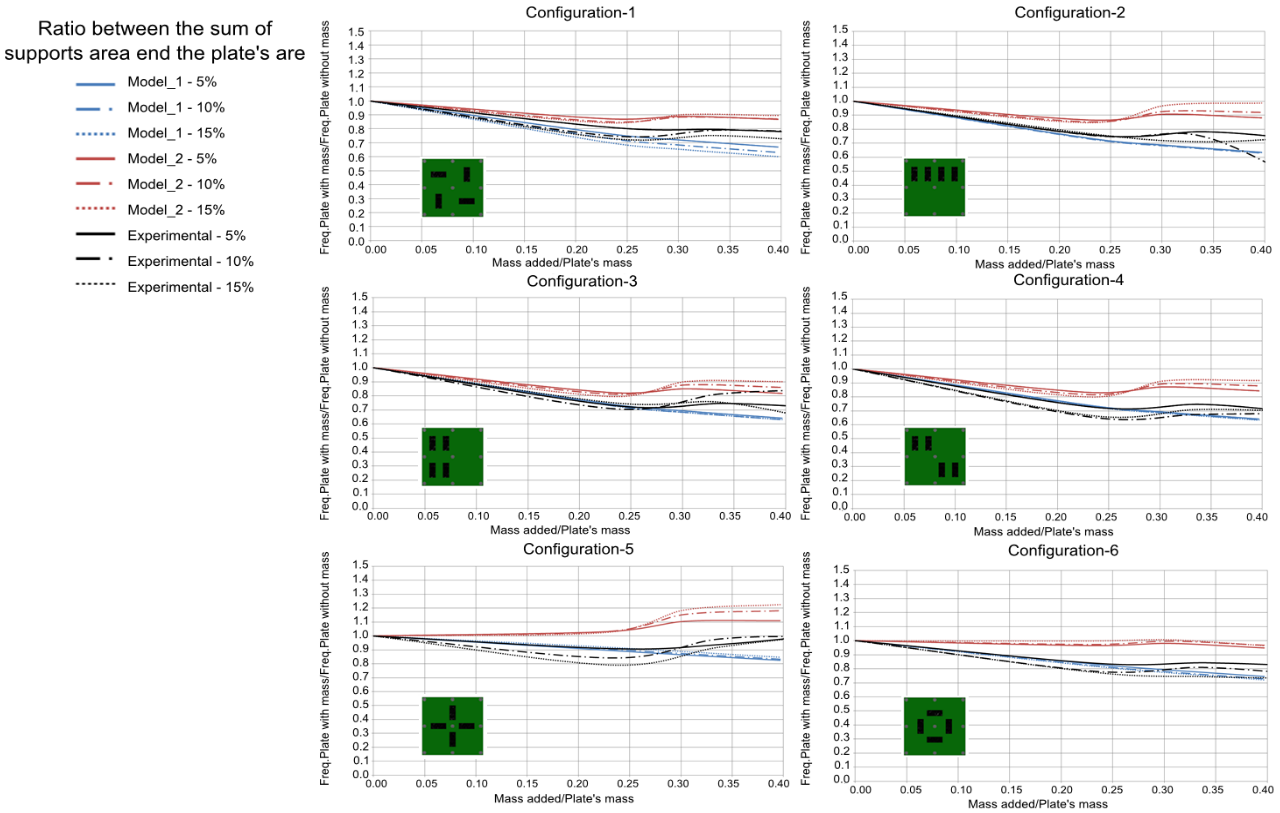

Figure 12.Ratio of frequency x ratio between the added mass and plate’s mass

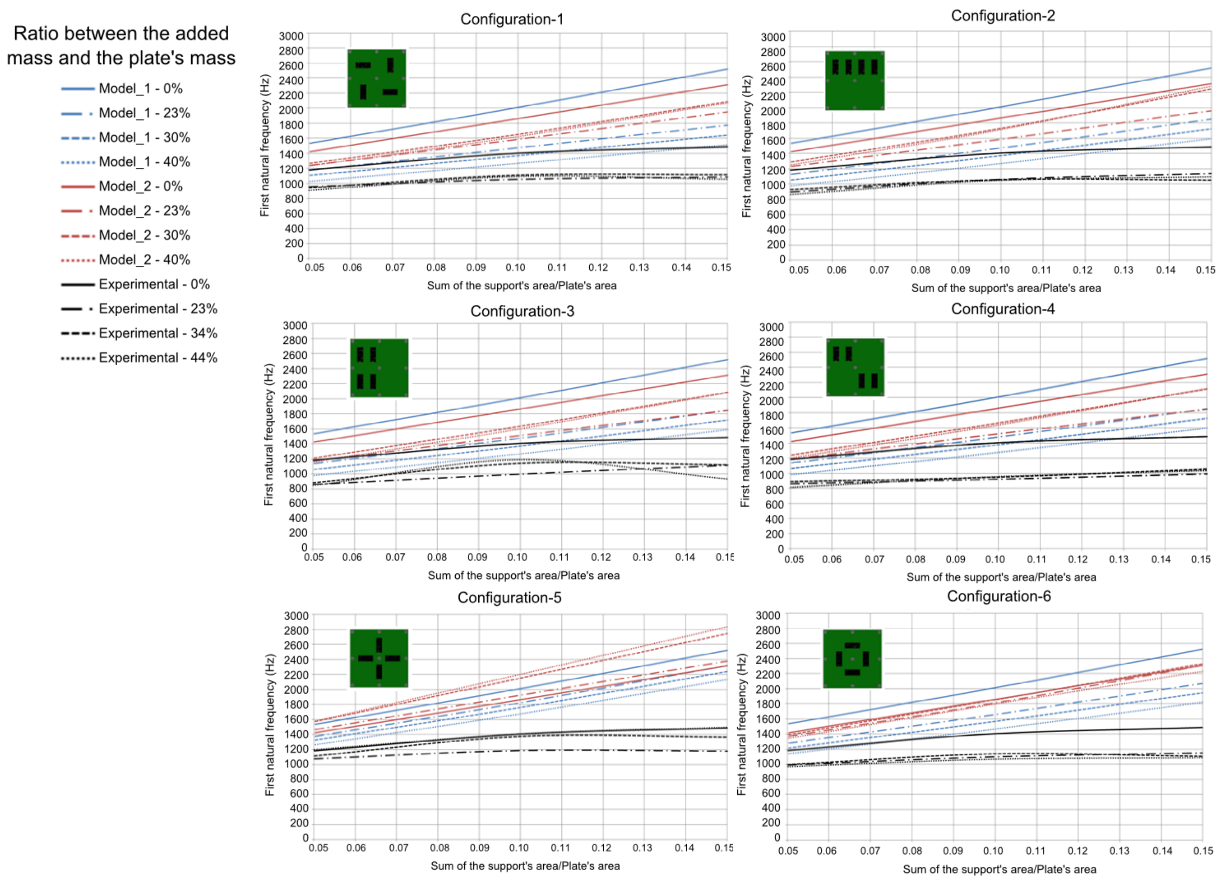

Figure 13. First natural frequency x ratio between the sum of the supports’ area and plate’s area

6. CONCLUSION

The aim of this study was to verify if the position of the components on the plate could be used as a tool to increase or decrease the first natural frequency and consequently help in the structural design. To answer this question, six different configurations of masses were chosen with three steps of added mass and supported area. Two FEM models have been created and experimental tests to.

In all cases studied the configuration 5 had a behavior completely different when compared with the others. This fact shows that certainly there is a region and orientation to each kind of component and mass that if positioned properly will increase or decrease the stiffness of the plate and consequently its natural frequency.

The results of this study show that is possible to use the positioning of the components mounted on the plate as design's resource. In the experimental model, the change of the components' position was more effective than tripling the supported area of the plate on average. It is an important fact, because most of time tripling the supported area involves the increase of the weight, what is critical in space products.

The likely reason to the position of the components increase the natural frequency is that the components can act as ribs in the plate making the stiffness of the plate increases. Thereby, if the electrical layout put the mechanically principal components (greater mass and larger) in the specific position, they will contribute more with the stiffness than the mass for themselves added. It can be verified by the difference between the model 1 and the model 2. In the model 1, the components were modeled as nonstructural mass, therefore as components' mass increase the natural frequency of the plate decrease. Unlike occurs in the model 2, where the increase of the mass contribute with the increase of the frequency of the plate. It shows how it is important to consider the component's inertia in the FEM models.

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