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MODELING THE BEHAVIOR AT LAUNCHING FOR A SATELLITE'S SUBASSEMBLY

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Rezumat. *Carcasele echipamentelor electronice ale unui satelit au fost în mod tradițional fabricate din aluminiu. Cu toate acestea, așa cum s-a arătat în alte aplicații aerospațiale, utilizarea materialelor compozite poate conduce la economii mari de masă. Date fiind costurile ridicate ale trimiterii unității de masă pe orbită, greutatea sarcinii utile ar trebui să fie redusă la minim. Materialele compozite pot fi în măsură să îndeplinească mai multe cerințe de performanță stabilite pentru carcase, și, de asemenea, materiale plastice armate cu fibre de carbon (CFRP), datorită rigidității lor specifice și rezistenţei ridicate pot obține o importantă economie de masă în raport cu reperele din aluminiu. Principalul obiectiv al studiului este stabilirea formei, precum și analiza cu elemente finite a unui subansamblu din materiale compozite ce găzduiește electronica într-un satelit, astfel încât acesta să corespundă cerinţelor impuse subansamblelor existente.*

Abstract. *The housings of satellite's electronic units have been traditionally made of aluminum. However, as it has been shown in other aerospace applications, the use of composite materials could potentially lead to large mass savings. With the high costs of sending a unit mass of payload into orbit, the mass should be minimized. Composite materials may be able to meet the multiple performance requirements set for the housings, and also carbon fiber-reinforced plastics (CFRP) due to their higher specific stiffness and strength can obtain an important mass saving over aluminum. The main objective of the study is the design and finite element analysis of a composite housing for electronics in a satellite that meets the structural requirements of an existing equipment unit made by aluminum.*

Keywords: carbon fiber-reinforced plastics, composite materials, housings of satellite, aerospace

1. Introduction

Aero spatial industry in general and satellites, in particularly, in recent decades have become part of the living standard, so we cannot conceive modern life in their absence. Communications satellites are those that transmit television signals and mobile phones between continents.

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Satellite networks enable location's exact position for objects and the use of GPS. Meteorological satellites are the basic tool in the weather forecast. Satellites allow scientists to expand knowledge of the Earth and the Universe.

Although to satellite utilization benefits are substantial, so are the costs that make this technology possible. These costs arise mainly from launch and because of the fact that satellites cannot be repaired when a malfunction accords in space. Exceptions are, of course, manned space stations or structures crucial to NASA, like space telescope, Hubble.

A satellite housing for electronic devices traditionally have been manufactured of aluminum. However, as noted in other aerospace applications, composite materials can lead to great mass savings. Given the high cost of sending mass unit into orbit, payload weight should be minimized. Therefore, the proposed application of composite materials in structures containing electronic equipment.

Composite materials can be able to meet several performance requirements set for enclosures, and also reinforced plastic carbon fiber (CFRP) due to their specific stiffness and strength can achieve significant weight savings compared to aluminum. Launch cost is determined overwhelmingly factor table, and at the same time launch costs have major relevance for the cost of the mission. For a low earth orbit launch (LEO) launch cost is 10,000 USD/kg [1]. From reducing the weight (and size) of a component is generated a cascade of masses and cost reductions, because it can be assumed to require an easier support structure, less fuel, etc. Therefore, even a relatively small reduction in the mass of the satellite component is an important aspect of economy of space flight.

2. Launch requirements

At launch, the satellite has to bear the electromagnetic field generated by both the plant launch site and launch vehicle systems, while mounted on the launch vehicle. These transmissions were reduced to a very low level in the vicinity of the launch complex. Launch vehicle satellite generates external forces due to the thrust of the engine and aerodynamic forces.

Table 1. Example of acceleration changes in different stages

No.		*LM-3A*	*LM-3B*	*LM-3C*
1.	During First Stage Flight	+5.0 g	N/A	N/A
2.	During First Stage Booster Flight	N/A	+5.3 g	+5.3 g
3.	During First Stage Core Flight	N/A	+3.6 g	+3.6 g
4.	During Second Stage Flight	+2.9 g	+2.8 g	2.8 g
5.	During Third Stage First Powered Flight	+1.6 g	+1.2 g	+1.2 g
6.	During Third Stage Second Powered Flight	+2.7 g	+2.5 g	+2.5 g

Typical maximum longitudinal acceleration of the vehicle steady during the flight of the launch is shown in Table 1. It can be seen that the maximum longitudinal acceleration occurs during first stage flight. Maximum acceleration will vary slightly with the satellite's mass.

Sinusoidal vibrations are present in low flight, but significant events vibration occurring during ignition and engine shutdown and during transonic flight and separations. An example of the sinusoidal vibration in the separation plane of the satellites is shown in Table 2.

Table 2. Example of sinusoidal vibration in separation's plane of a satellite

No.	*Direction*	*Frequency Range*	*Amplitude & Acceleration*
1.	Longitudinal	5 – 8 Hz	3.11 mm
2.		8 – 100 Hz	0.8 g
3.	Lateral	5 – 8 Hz	2.33 mm
4.		8 – 100 Hz	0.6 g

Regarding the random vibration levels are mainly generated by maximum noise during vehicle launch and transonic flight periods. Acoustic noise spectrum includes engine noise and aerodynamic noise in flight, with maximum acoustic noise faced by the satellite during launch and transonic flight phase.

This study aims to validate that a box made of composite material can withstand successfully launch conditions and can successfully replace aluminum boxes. The reference electronic house has been implemented on PROBA2, satellite that was launched by the European Space Agency in November 2, 2009. This paper aims to change the box that houses data modules and power management system (ADPMS). The changes will cover both design and materials used.

For a component to be viable in space, it must meet several conditions, the most important being:

- Vibration behavior;
- Structural strength;
- Resistance to extreme temperatures;
- Radiation Protection for interior components.

The objective of this study is to validate the proposed geometry of carbon fiber reinforced polymer (CFRP) in the vibration behavior and structural strength. Therefore, comparative studies were made between the existing geometry of the proposed geometries, using the finite element method where all the geometries are made of aluminum. The next step was to choose the new geometry to replace the old one, and to model it made by composite materials. We have made comparative studies between the current geometry made by aluminum and the new geometry proposed made by composites.

The new geometry has to provide the same general conditions and work requirements as the existing electronic housing. These are detailed in Table 3.

Table 3. General work and strenght conditions

No.	*Property*	*Aluminum*	*CFRP*
1.	Dimension	460 mm x 154 mm x 250 mm	460 mm x 154 mm x 250 mm
2.	Wall thickness	2 mm	≤ 2 mm
3.	Weight	standard	Minim
4.	Acces	standard	standard
5.	First frequency	> 150 Hz	> 150 Hz
6.	Structural strength	standard	Standard or better

3. Launch requirements

The performance of a component can be described by an equation of the form [2]:

$$p = f\,(F, G, M) \qquad (1)$$

in which:

p is performance;
F - functional requirements;
G- geometric parameters;
M - material properties.

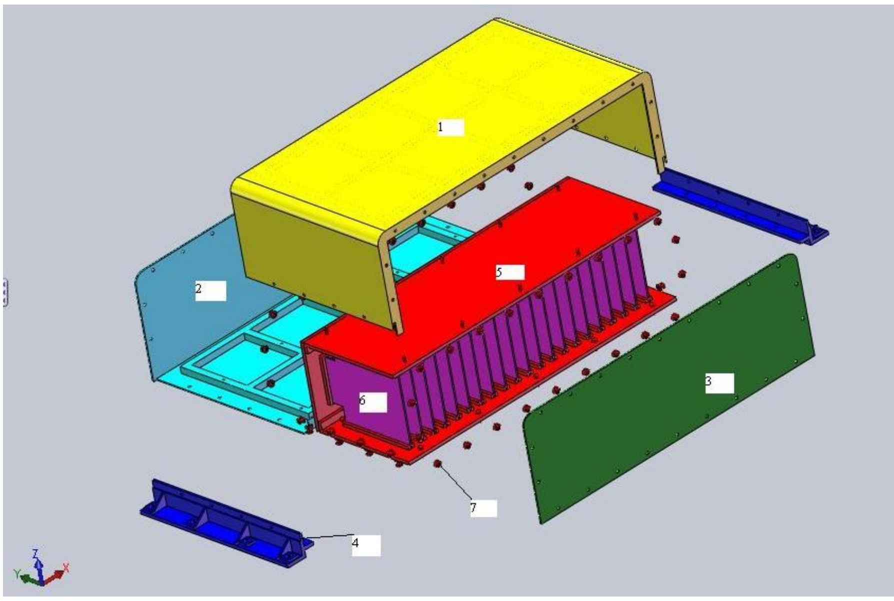

Fig. 1. Components for existing electronic housing on Proba2:
1- hat section; 2- base and rear panel; 3- front panel; 4- mounting rails; 5- wedge locks; 6-electronic plates; 7- Aluminum rivets.

Functional requirements are specified by design. Geometric parameters are derived from the specified geometry and boundary conditions. Functional requirements, geometric parameters, and material properties are generally separable. In this study, functional requirements are the same for the CFRP and aluminum housings. Therefore, the choice of material is independent of the geometry and function of the problem.

Shape and dimensions of the ADPMS housing are imposed by the constructive requirements and its position inside the satellite. However, optimization can be made by redesigning parts and removal of parasitic masses.

As a reference was adopted the existing satellite box PROBA 2 as described in [2]. The reached configuration is shown in Figure 1.

It was considered a box made up of fewer components generate a lot of advantages that are directly reflected in the total cost of the mission. These are:

a) Fewer molds needed for the components;
b) Fewer enterprises;
c) Rigidity;
d) Low weight.

For these reasons, we proposed two variants in which the box is composed of two components. These are shown in Figures 2 and 3 [4].

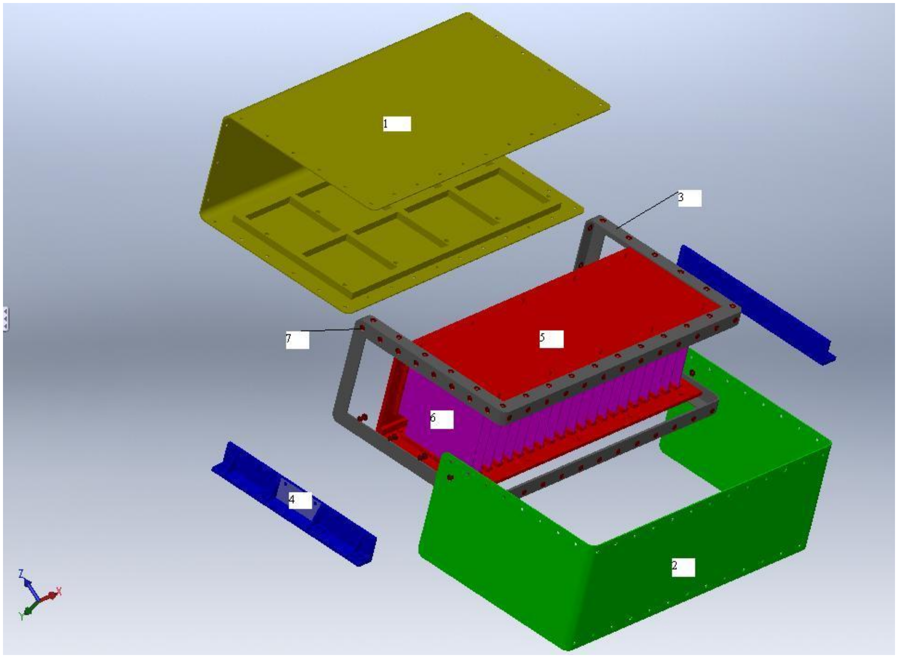

Fig. 2. Components for the first proposed electronic housing:
1- Upper and lower panels; 2- front and lateral panel; 3- aluminum rail; 4- mounting rails; 5- wedge locks; 6-electronic plates; 7- Aluminum rivets.

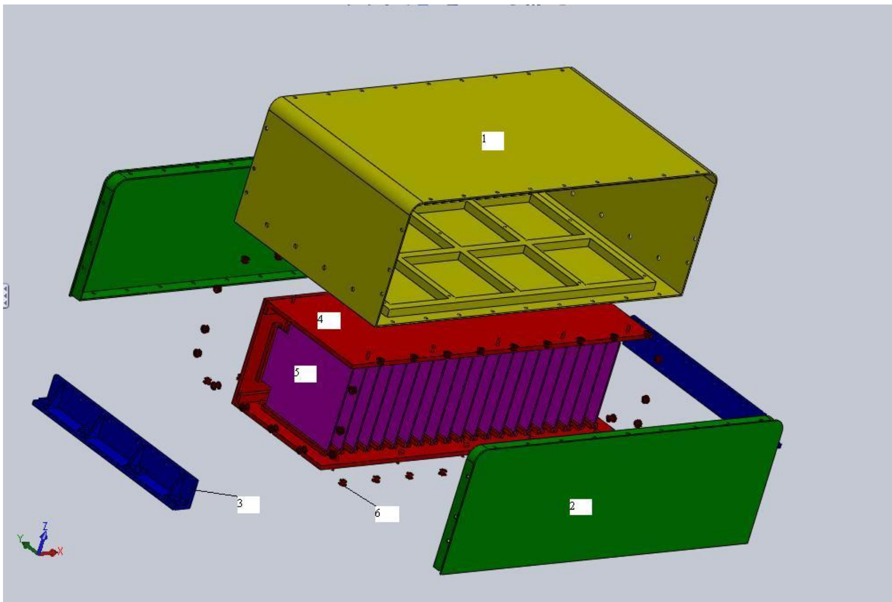

Fig. 3. Components for the first proposed electronic housing:
1- Upper and lower panels; 2- lateral panel; 3- mounting rails; 4- wedge locks;
5-electronic plates; 6- Aluminum rivets.

After the design of all components was accomplished the weight of each box was evaluated, and the results are in Table 4. It is worth mentioning that all components have been considered as aluminum, wall thickness of 2 mm. Only the holder of the electronic plates and the plates as well were considered to be a composite of glass /epoxy (FR4), used in most cases in the manufacture of electronic boards.

Table 4. Mass after modelation

No.	*Model*	*Mass [kg]*
1.	Existing one	7.3287
2.	First proposition	7.6021
3.	Second proposition	7.0115

It is noted that in comparison with the weight of existing box first design choice has a surplus of 3.07% weight and the second shows a 4.33% drop in weight.

In the first stage of the finite element calculation was aimed to choose the optimal case of the two proposed. For that there have been made finite element analysis of gravitational acceleration and vibration behavior relative to the existing box. In both simulations the following assumptions were made:

a) Do not take into account issues that arise at the interface between the contact box panels;
b) All the boxes are made of the same aluminum alloy (see Table 5);

c) Electronic components, including outlets that are installed are composite (FR4, see Table 5);
d) The attached side supports satellite box have all degrees of freedom suppressed on the underside.

Table 5. Materials used in finite elements analysis

No.	*Material*	E_x *[MPa]*	E_y *[MPa]*	ν_{xy}	ν_{yz}	ρ $[kg/m^3]$
1.	Aluminium alloy	71000	-	0.33	-	2770
2.	Glass/epoxy FR4	24000	21000	0.136	0.118	1850

There were obtained the following frequency for electronic housings analysis:

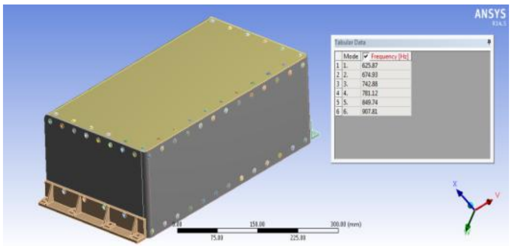

Fig. 4. a The first six natural frequencies for existing aluminum box.

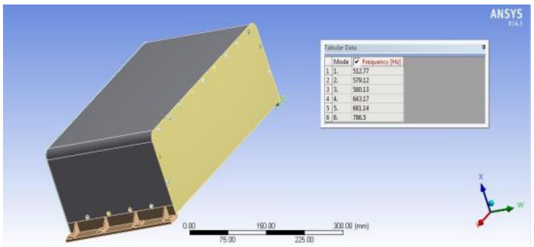

Fig. 4. b The first six natural frequencies for option one.

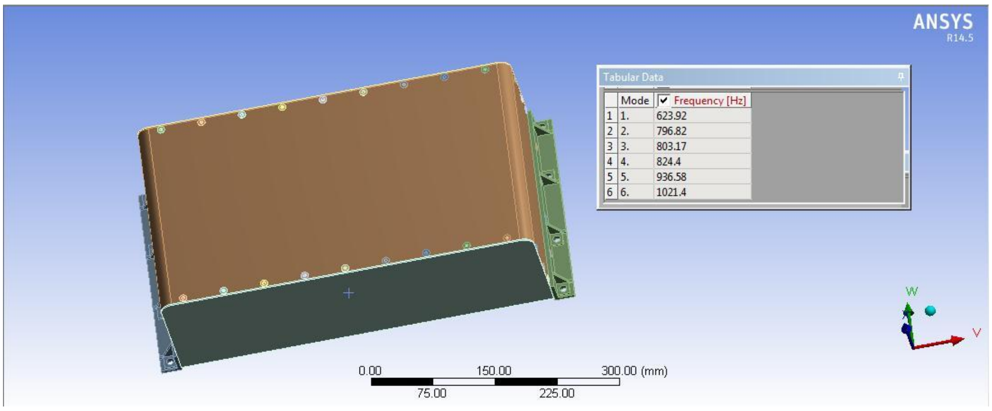

Fig. 5. The first six natural frequencies for option two.

For the finite element analysis of behavior that is subject to gravitational accelerations a subset of a LEO satellite during launch have considered the following loads:

a) X direction - 11g;
b) Y direction - 6g;
c) Z direction - 6g.

There were obtained the following stress and strain for the proposed variants and the existing one:

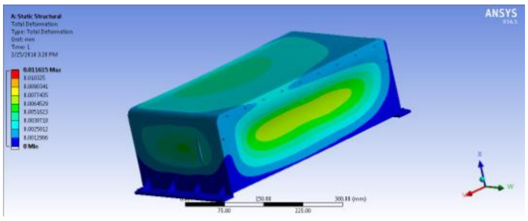

Fig. 6. a Deformations obtained for existing. aluminum box

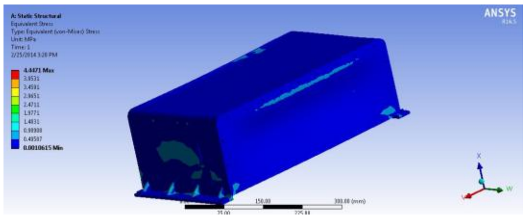

Fig 6. b Stresses obtained for existing aluminum box

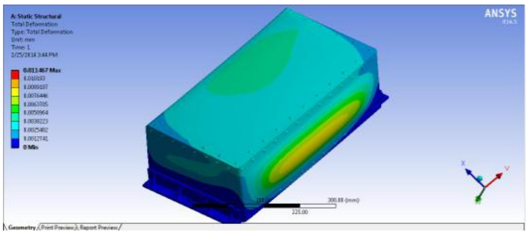

Fig. 7. a Deformations obtained for first proposed variant

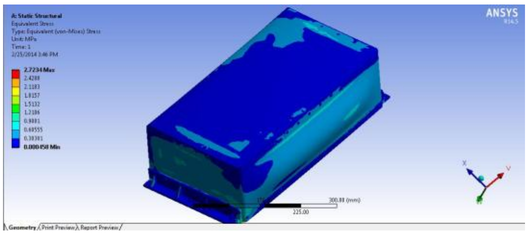

Fig. 7. b Stresses obtained for first proposed variant

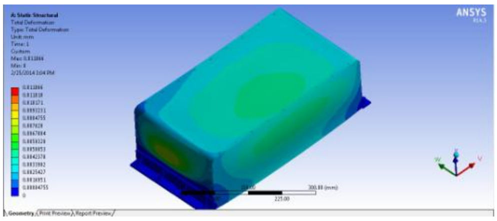

Fig. 8. a Deformations obtained for second proposed variant

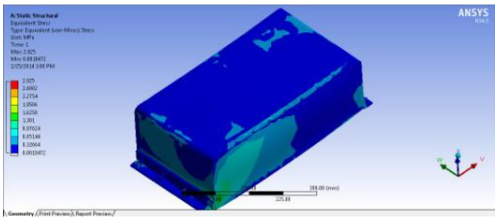

Fig. 8. b Stresses obtained for second proposed variant

Table 6. Comparative results of finite element analysis

No.	*Material*	*f [Hz]*	*σ [MPa]*	*u [mm]*
1.	Existing	512	4.44	0.010
2.	Proposed no. 1	625	2.73	0.010
3.	Proposed no. 1	623	2.95	0.011

After the results (shown in Table 6) were compared we can draw some preliminary conclusions:

a) If the proposed variants first characteristic frequency increases by 22.07 % in the first box and 21.67 % in the case of the second option;

b) The maximum stress decreases 38.51 % and 33.55 % for the variants of the proposed design in relation to the current box;

c) From the point of view of strains are comparable to the results obtained, with no significant differences.

It should be noted that both the maximum stress and maximum deformations do not appear on the outer shell of the box but in the electronic plates inside the box, but given the relatively small values each assembly can be considered viable for the application concerned.

Also, it can be seen that the first own frequency occurs every box well above 150 Hz imposed. Considering all these aspects it can be concluded that both of the proposed cases performs better than existing box have similar results , and model choice that will be made of composite will be based on weight.

4. Finite element analysis of composite geometries

In the second stage of the finite element calculation the behavior of composite box subject to the same requirements was of interest. To this was made the finite element analysis to track the behavior of the vibration and gravitational acceleration, as in the case of aluminum housing. For both types of simulations it was taken into account the following considerations:

a) do not take into account issues that arise at the interface between the contact box panels;

b) all the boxes are made of the same composite panel K1100/Wolfram/M46J (see Table 7);

c) 1.73 mm wall thickness is divided from the outside as follows: K1100 -0.815 mm; Tungsten - 0.1 mm; M46J - 0.815 mm (see Figure 9);

d) K100 and M46J composite materials were considered homogeneous and orthotropic;

e) all electronic components , including outlets that are installed , are in composite material (FR4, see Table 7);

f) the load and the constrains remains the same as in the case of aluminum boxes.

Table 7. Materials used in finite elements analysis

No.	*Material*	E_x [MPa]	E_y [MPa]	ν_{xy}	ν_{yz}	ρ [kg/m^3]
1.	K1100	931000	70000	0.85	0.3	2200
2.	M46J	265000	71000	0.87	0.3	1590
3.	Aluminium alloy	71000	-	0.33	-	2770
4.	Glass/epoxy FR4	24000	21000	0.136	0.118	1850
5.	Wolfram	411000	-	0.28	-	19250

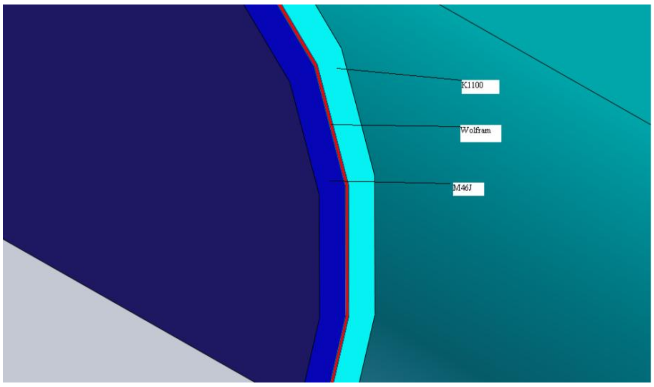

Fig. 9. The arrangement of material layers in composite panel.

The study that aimed vibration behavior shows that the first frequency of the composite box is 352 Hz (see Figure 10), a value that exceeds by 235% the amount required by the conditions of release.

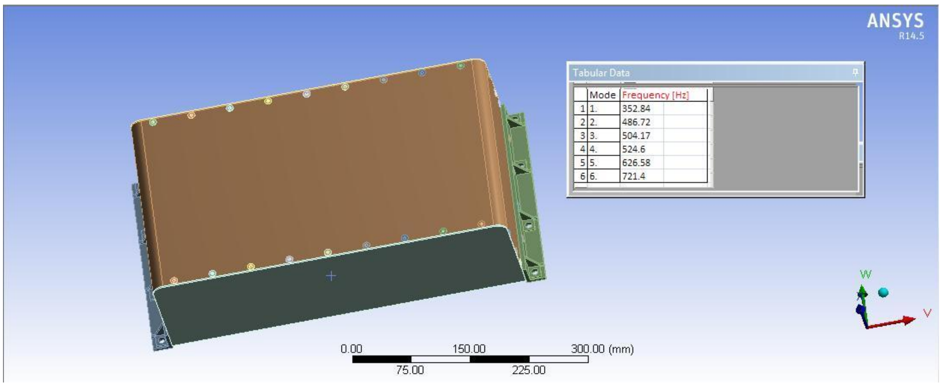

Fig. 10. The first six natural frequencies of composite box.

Regarding the stresses and strains that occur in the model studied it can be seen that in the composite panels the value is not exceeding 12 MPa, a value that does not jeopardize the structural integrity of the assembly (see Figure 11).

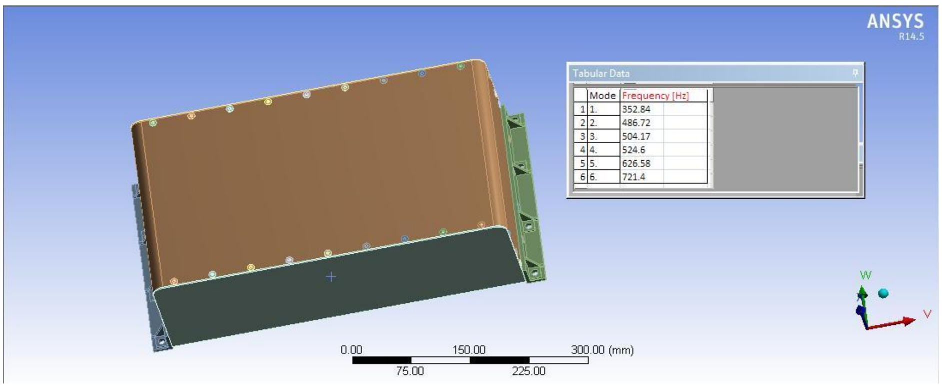

Fig. 11. The equivalent stress occurring in the walls of the box.

Maximum stress appears in a single point on a rivet that catch box to the mounting brackets satellite as can be seen in Figure 12. It is conceivable that this value occurs because of a deformed element mesh and is not relevant to the calculation performed.

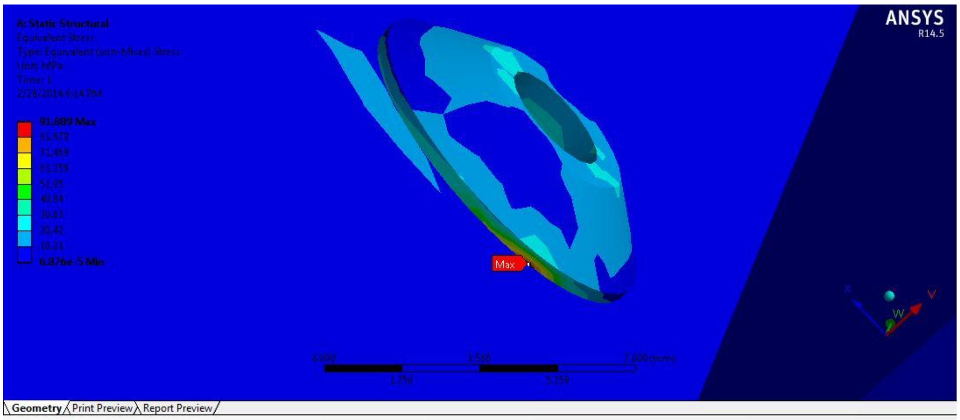

Fig. 12. Detail of the maximum stress.

Maximum deformations appear on the outside of the box cover and are with 0.28% below the maximum 1%, value given by the manufacturer [3] (see Figure 13).

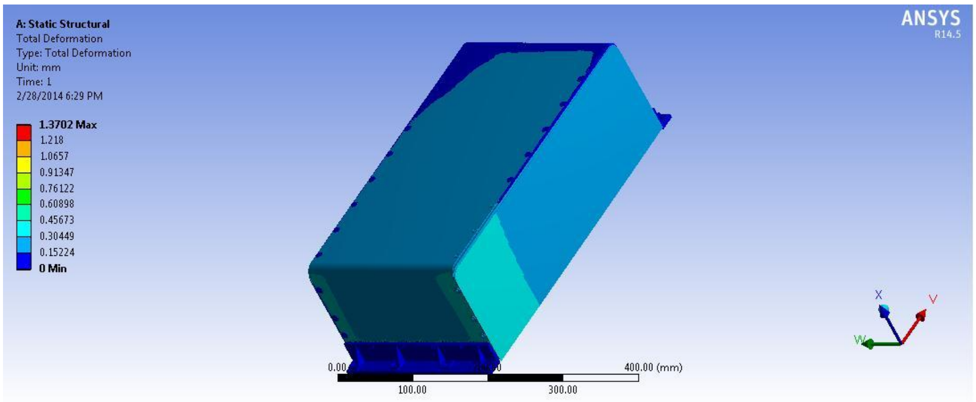

Fig. 13. Displacements that occur in the walls of the box.

5. Conclusions

After modeling it was concluded that the proposed variant of composite electronic housing reaches a weight of 6.015 kg this value represents about 80% of aluminum's box weight, so a significant reduction in mass is possible.

Further weight reductions are possible, giving up the riveting panels and introducing the seams between the common elements. It can also reduce the wall thickness to a minimum until they reach the maximum stresses and strains imposed.

It also notes that the proposed solution successfully meets all the requirements of release conditions, both in terms of the vibrational behavior and in terms of resistance to gravitational accelerations.

Of course, to fully validate the model space applications are required analyzes the thermal behavior and the behavior of the radiation. Furthermore, all analyzes should be coupled finite element analysis definite experimental validation of the proposed model.

R E F E R E N C E S

[1] Futron Corporation, *Space Transportation Costs: Trends in Price per Pound to Orbit 1990-2000* (Futron Corporation, Bethesda, MD, United States, **2002**).

[2] F. Garcia, K. Kurvinen, *Radiation Shielding Study of Advanced Data and Power Management Systems (ADPMS) Housing Using Geant4* (2006 IEEE Nuclear Science Symposium Conference, **2006**).

[3] Toray Carbon Fibers America, Inc., *M46J Data Sheet*, 2012. Web 28 Feb **2014**, web page's address http://www.toraycfa.com/pdfs/M46JDataSheet.pdf.

[4] S. Drăghici, F. Baciu, R. Voicu, A. Hadăr, *Equipment Design and Structural Analysis of CFRP Electronics Housing vs. Aluminium Electronics Housing for an ADPMS*, The 5th International Conference on "Structural Analysis of Advanced Materials", ICSAAM-2013 23-26 September **2013**, Kipriotis Village Resort, Island of Kos, Greece, on CD.