DESIGN OF AN 1U CUBESAT PLATFORM FOR EDUCATIONAL PURPOSES

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Abstract: Nowadays, with new technologies, smaller and cheaper satellites have been designed and launched. Such satellites fit as educational tools to future engineers. With few kilograms and reduced dimensions, they have simple operation, despite being complete systems capable to perform real missions. Having short life cycles, from design to disposal, they allow students to follow a complete project during academic lives. In this paper a generic platform for an 1U CubeSat is proposed, designed according to NASA and CubeSat Initiative standards. For so, typical loads during flight trajectory were considered. Cost, related to mass and benefits were contemplated for materials choice. Simulations on testing and launching conditions were performed in a systemic analysis. The structure was chosen using comparative method and possible arrangements of components were examined. The behavior of the structure both empty and with components was studied using FEM, with static load, natural frequencies, random and sinusoidal vibrations and impact analyses. The mass of the structure was reduced and the geometry adapted to allow better attachment of components. The final 1U structure is not heavier than commercial ones and allows mass reduction. It fulfills main structural requirements for 1U CubeSats imposed by CDS. This result is ready to be used by educational initiatives.

1. OBJECTIVE

This paper aims to design and to analyze an 1U CubeSat platform for use in academic projects using standards defined by CubeSat Initiative and NASA. For so, accelerations and loads during launch and flight were considered. Using typical components and payload, the CubeSat structure was designed to minimize the total weight of the structure. Another objective was to completely model the structure using 3D CAD, following the standard of certifier agencies.

2. INTRODUCTION

Technological advances in Aerospace Engineering provide means to develop a simple, cheap but still complete satellite to apply knowledge and technology. Such a project offers the opportunity of joining students in the whole lifecycle of the device, known as CubeSat [1]. The CubeSat consists of a 10cm x 10cm x 11cm satellite, weighting at most 1.33kg, being easier and cheaper to design, build and launch than a conventional one. One of the advantages of using a CubeSat as an educational tool is that its lifecycle is short, making it possible for the students to take part of the whole project, from early design to disposal. As the project got more successful, a standard was developed and NASA decided it was mature enough to be applied for other purposes than academic missions, addressing real needs.

3. SYSTEMIC ANALYSIS OF THE CUBESAT

Any satellite, including the CubeSat, can be described as a complex system of individual elements with different functions that, together, attends the mission requirements. A systemic analysis helps decision making during the design and helps to carry on modifications.

3.1 System Hierarchy

The analysis of a complex system can be performed considering functional blocks of the system divided in physical hierarchy of components [2]. The highest level of the hierarchy is the system, being followed by subsystems, components, subcomponents and parts. In case of the structure, the system is the CubeSat, subsystems can be Energy Power Supply, Control and Structure, among others. Structure components can be brackets, frames and rails. A subcomponent of the frames can be the faces, and finally the faces parts are plates, screws, screw-nuts and bandages.

3.2 System Environment

To design a CubeSat structure properly, one must consider the environment it will operate, existing interfaces and how information flows between the two of them. Functional and Physical limits must be determined as well. In this paper the CubeSat interacts with the P-POD and after launching with space environment. The interaction between the CubeSat and the P-POD is critical for this design, provided that elements (forces, vibrations, heat) will be transmitted mainly by structural subsystem.

3.3 Conceptual Development

The conceptual development consists of analyzing the requirements that will lead to a new product design, the expected performance and the architecture to be used in order to accomplish the mission.

It is composed by necessary analysis, responsible for studying the feasibility of the CanSat, operational limitations in existing systems and technological advances; operational analysis, responsible for defining the objectives the new system is to achieve; functional analysis, that will settle the technical means to assure the system will fulfill the objectives; feasibility definition, that will determine the possibility of the system to viably attend the needs.

4. STRUCTURAL REQUIREMENTS FOR AN 1U CUBESAT

To design a CubeSat there is a set of rules imposed by space agencies, the CubeSat Design Specifications (CDS) [3]. Those rules not only specify materials and dimensions for the CubeSat but also demand it to go through some tests: vibration, impact and heating tests. Those tests are divided into Qualification Tests, Protoflight Tests and Acceptance Tests. They aim mainly to assure the reliability of the system. According to the CDS, the exigency levels of the tests depend on the launch, being specified by the mission leader. The designer, however, must use documents LSP-REQ-317.01 [4] and MIL-STD-1540 [5] to comply with the requirements. Those standards impose: random vibration test, sinusoidal vibration test, impact test and thermal test.

5. INITIAL DESIGN

The initial design started with a comparative method to compare already existing options. This method is largely used in Engineering while designing a new system.
Among the available options in the market, usually the structure is built with aluminium (ISIS 1-U [6], EnduroSat 1-U [7], CubeSatkit 1-U [8], CubeSat SwissCube 1-U [9] and CubeSat AAU [10], for example). Their masses can vary from 98g (EnduroSat 1-U) to 300g (CubeSatkit 1-U). The internal configuration can be horizontal (CubeSat SwissCube 1-U), vertical (CubeSat AAU) or interchangeable (ISIS 1-U).
The structure can be monocoque, panel structure or individual parts. Monocoque structure is a whole piece obtained by processing an aluminium block. The panel structure uses two faces as main panels, so needing connections to assembly the satellite. The structure made of individual parts is produces in pieces that are assembled with screws. In this project the monocoque structure was chosen for its reduced weight and structural stiffness, along with being easy to build. The main disadvantage is the reduced flexibility for arranging the internal components.

5.1 Preliminary Model

The preliminary modelling considers the dimensional requirements of the CubeSats [3] and basic components usually found in satellites. Those components can be found in Table 1 [11].

	Supplier	**Dimensions (mm)**	**Weight (g)**
OBDH	ISIS	96 x 90 x 12.4	94
Reaction wheel	CubeSpace	57 x 57 x 31.5	200
Batteries (6 Ah/ 22Wh)	CrystalSpace	96 x 90 x 13	80
Solar Sensor	CrystalSpace	27.4 x 14 x 5.9	4
Transmitter	IQ Wireless	95 x 46 x 15	75

Table 1: Basic components used for the analysis of the structure

In order to place the components in the structure, the distance between the internal plates was set to be uneven, so as to fit all of them. This distance was previously calculated, for a monocoque structure has fixed supports. The initial structure is shown in Figure 1, both empty and with components.

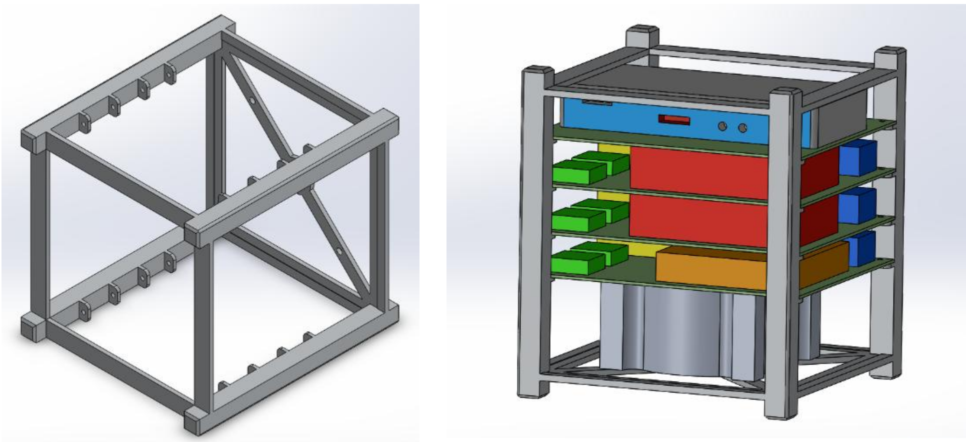

Figure 1: Initial design, empty and with components

6. STRUCTURAL ANALYSIS

The structural analysis was carried on based on the test procedures described in Section 4. The study was carried on using a Finite Elements Method (FEM) software in order to predict, with reasonable reliability, the behaviour of the structure when under different conditions. The mass of the device was calculated as 1215.5 g, leaving 114.5 g to add joints, solar panels and circuit components.

6.1 Static Analysis

During launch, the acceleration of the launcher produces an inertial force on the CubeSat, proportional to the weight of the other CubeSats in the P-POD. In order to perform the static analysis, one must know the maximum acceleration acting on the device. Since this acceleration depends on the launcher, typical values must be used. For example, Ariane 5 is submitted to 4.25Gs [12], Soyuz to 4Gs [13] and Vega to 5.1Gs [14].

Thus, the static force acting on the CubeSat is given by Equation 1:

$$F = \sum F_i = 3 \times m \times a_g \times F.S. \cong 240\ N \qquad (1)$$

and each corner of the CubeSat is submitted to one quarter this value: $F' = 60\ N$. With this value and using simulation tools, the maximum von Mises tension is calculated as 2.1MPa, and the deformation is 26μ. Thus, even when this maximum tension is acting on the CubeSat the security margin is very high, equal to 238.5.

6.2 Dynamic Analysis

In order to perform dynamic analysis, the natural frequencies of the structure was calculated both empty and with components, using FEMAP and Nx Nastran for FEM analysis. Figures 2 to 5 show the mass allocation for each mode in all orthogonal directions.

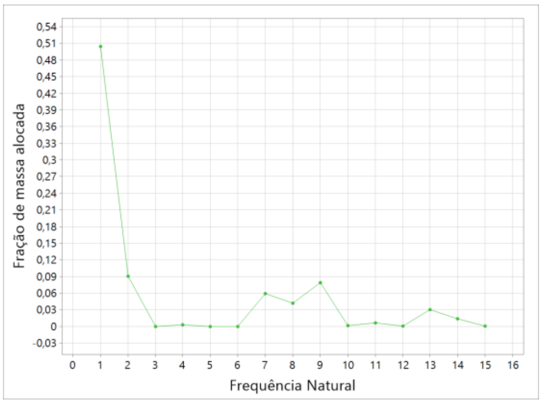

Figure 2: Mass allocation in X direction

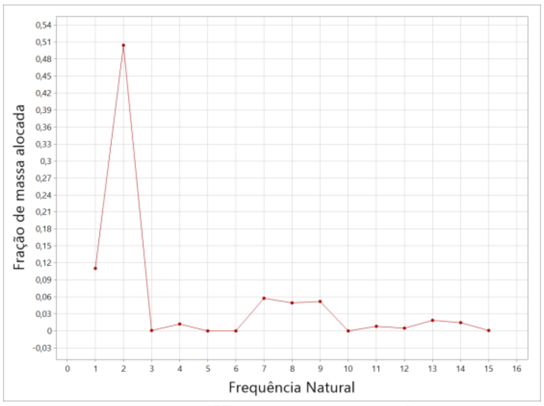

Figure 3: Mass allocation in Y direction

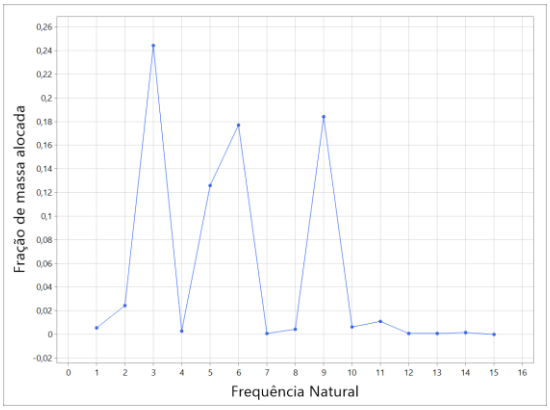

Figure 4: Mass allocation in X direction

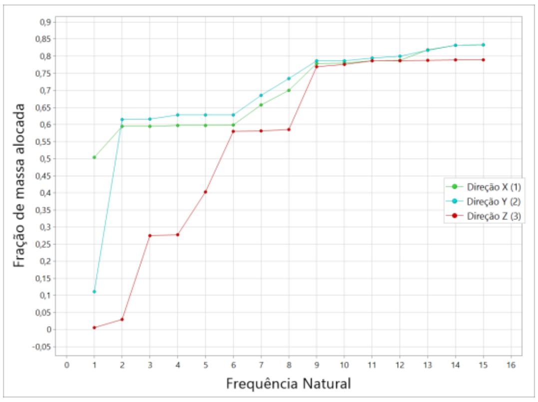

Figure 5: Sum of mass allocations X, Y, Z

Figure 5 shows that for the first 15 natural frequencies, approximately 85% of the mass in X and Y are captured, and 80% for Z direction.

6.3 Power Spectral Density (PSD) Analysis

PSD analysis aims to determine the behavior of the structure when submitted to a source of random vibration. Figure 6 shows von Mises tension distribution obtained with this simulation. The maximum tension calculated for 3σ (99,73% of the cases) was also calculated, along with security margin for failure for plastic deformation. The complete version of this paper [15] shows that the device is also resistant to fatigue.

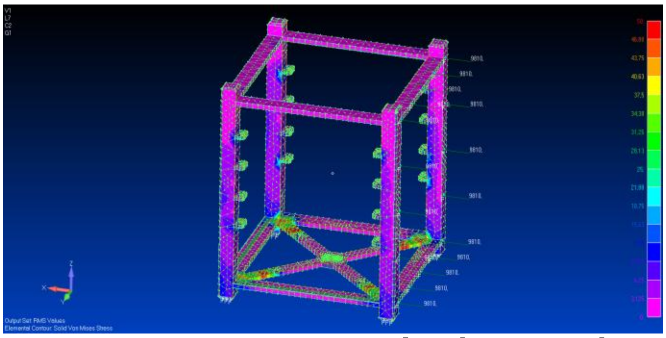
Figure 6: von Mises tension distribution on the CubeSat

$$\sigma_{MAX(Z)} = 131{,}82\ MPa$$
$$\sigma_{MAX(X)} = 61{,}17\ MPa$$
$$\sigma_{MAX(Y)} = 62{,}28\ MPa$$

$$(M.S)_Z = 2.81$$
$$(M.S)_Z = 7{,}22$$
$$(M.S)_Z = 7{,}07$$

6.4 Sinusoidal Vibration

This test allows to evaluate the resistance of the structure to vibration during launch. It tests the structure to sinusoidal vibration in several different frequencies. The worst case was considered (Vega) and the simulation was performed in Z direction, for being the most critical during launch. The results are shown in Figure 7. Again, the tension levels are not sufficient to deform the structure considerably and no damage due to fatigue is expected.

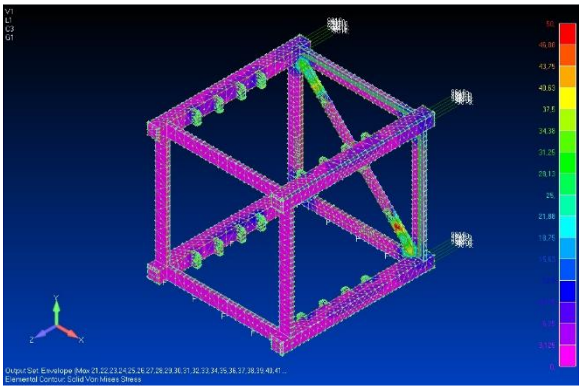

Figure 7: von Mises tension distribution on the CubeSat for sinusoidal vibration

$$\sigma_{MAX(Z)} = 33{,}06\ MPa$$
$$\sigma_{MAX(X)} = 15{,}61\ MPa$$
$$\sigma_{MAX(Y)} = 33{,}06\ MPa$$

$$(M.S)_Z = 14{,}21$$
$$(M.S)_Z = 31{,}22$$
$$(M.S)_Z = 43{,}04$$

6.5 Impact

During launch the satellite is submitted to different impact events, like stage and payload separation. The impact is represented by a spectrum showing acceleration vs frequency. Again, Vega was considered because it presents the worst case between the three launchers considered in this paper. The results are shown in Figure 8. Results show that the tensions levels are not sufficient to permanently deform the structure.

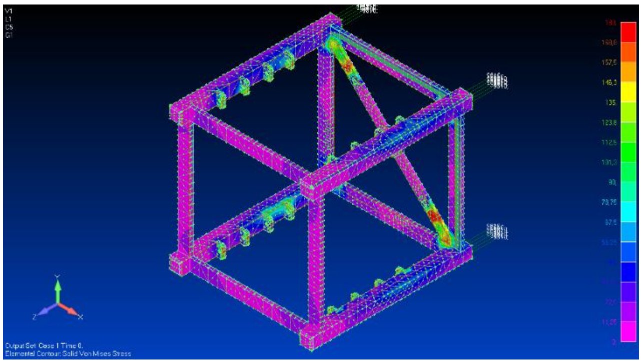

Figure 8: von Mises tension distribution on the CubeSat for spectral response

$$\sigma_{MAX(Z)} = 173{,}29\ MPa$$
$$\sigma_{MAX(X)} = 150{,}31\ MPa$$
$$\sigma_{MAX(Y)} = 148{,}12\ MPa$$

$$(M.S)_Z = 1{,}90$$
$$(M.S)_X = 2{,}34$$
$$(M.S)_Y = 2{,}39$$

7. DESIGN MODIFICATIONS

The test results shown in Section 6 suggest that it is possible to improve the structure. Figure 9 shows one of the modifications, where the dimensions of the rods were reduced. This could be done because simulation showed that this part of the structure was not highly demanded.

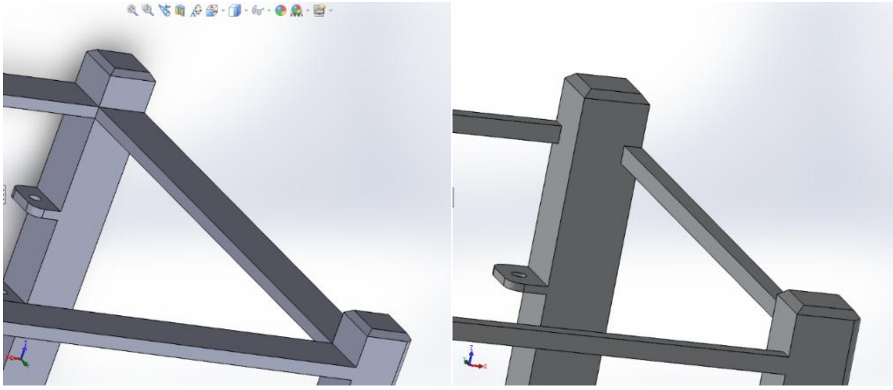

Figure 9: Modifications of the design - reduced rods

Also the base was redesigned in order to better accommodate the reaction wheels, considering that the region is the most demanded in terms of forces Figure 10 shows both the original and the modified version of the CanSat base and their tension distribution. For the modified base a curvature was used in order to better distribute the tension along the structure.

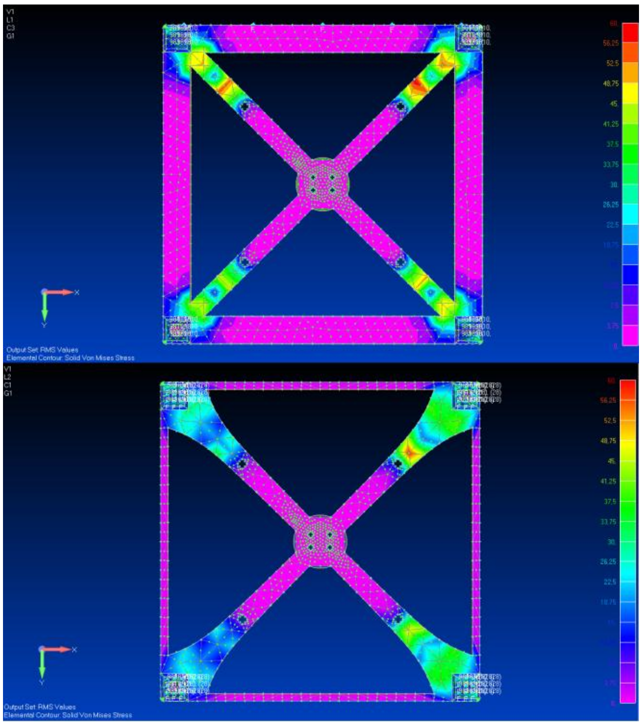

Figure 11: Tension levels at the base of the CubeSat for original and modified structure

8. CONCLUSIONS

In this paper the CubeSat was considered as a complex system with subsystems, including the structure. This systemic analysis showed the interfaces of the structure and the functions it had to fulfill. The requirements were those defined by the CDS, including the tests to be simulated.

Using the comparative method, the configuration for a monocoque structure was chosen, being changed so as to fit the components suitably.

FEMAP and Nx Nastran were used as tools of FEM to simulate the structure, both empty and with components.

Accelerations and forces of typical launchers were used to perform static, dynamic, sinusoidal vibration and impact simulations. For all simulations it was shown that for a typical launch there should be no permanent damage to the structure for deformation and also not for fatigue with confidence level of 99.73% during the three minutes defined by the standards.

9. ACKNOWLEDGEMENTS

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