ASPECTS ON A CUBESAT PROJECT

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Abstract: *This research focuses on the design of the nacelle and CubeSat and their structural analysis. The innovative design is well aligned with the objectives of the multifunctional platform, generically named STRATOTEST, as well as with the current research trends in this field. Therefore the use of composite materials, PLA materials and their 3D printing comes as no surprise in order to build a robust and durable structure..*

Keywords: *CubeSat, stratosphere, structure design*

1. INTRODUCTION

STRATOTEST is the acronym for a project that proposes the development of a multi-functional platform (for astronomical research, flight and ground testing of aerospace industry systems and materials and added educational value by providing access to master and PhD students to the „ close to” space environment. The main objective of the project is industrial development speed growth in the aerospace sector and growth of the research capabilities of small enterprises and of the two partner educational and research institutions. STRATOTEST project circumscribes to the Romanian Space Agency and Romanian organizations efforts for the creation of new assets adapted to European Space Agency's specific programs Technology Science Support (TSS) and Space Situational Awareness (S.S.A.)

CubeSat is a concept derived from micro satellites research that has been embraced by all the aerospace researchers whom adapted the concept to other similar uses. Its cubic shape and its modularity offer mor flexibility in the design process and a higher redundancy by means of other unit task allocation Once the tasks are redistributed, the failure of one cubesat will not mean the mission has also failed [1].

2. CUBESAT STANDARD AND DESIGN

The paper focuses on the design of the nacelle and a CubeSat and its structural analysis. The accepted standard for a CubeSat unit is 100x100x100mm, the equivalent volume of a litre. Beyond this is the design freedom of each engineer under the constrains of the project.

The material selection process is highly important to the structural design of the CubeSat as it effects the design parameters such as weight, strength, rigidity, thermal conductivity, as well as construction variables such as manufacturing capability, reproductability and last but not least, cost effectiveness.

As the nacelle containing 3 CubeSat units will be launched via a weather balloon to the stratosphere, the takeoff weight estimate of 5 kg gave way to the structural design of a CubSat 3U (3 unit CubSat) with the Solidworks software.

The next step that followed was a numerical simulation. Using Ansys as a software environment and the finite element method as the numerical method, the CubeSat was structurally analyzed to see if the concept structure can withstand the loads and stresses its suppose to in its flight and most of all, throughout its landing.

After CAD tailoring and design of the structure the chosen materials were as follows: for the nacelle the *Al 6061*, a high strength aluminum alloy with very good material properties, often used in the aerospace industry; for the CubSat unit *carbon fiber composite side panels* connected on *PLA 3D printed struts* that are also fitted for the electronic onboard components (Fig. 1)

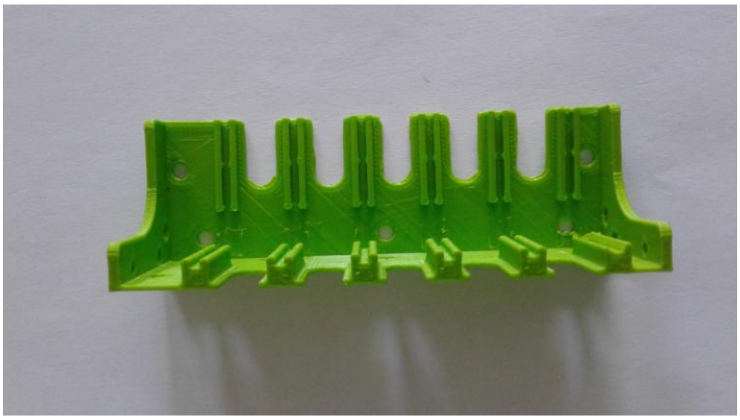

FIG. 1 3D printed PLA frame strut with configurable slots for electronic circuit boards

The design specifications for the CubeSat unit, that represent constraints and requirements kept in mind throughout the entire process are presented below, with the note that not all the recommendations made by the Nasa Goddard Space Flight Center [3] were considered as the flight will only be limited to the stratosphere.

Mechanical constraints were:

- All the structural elements and assemblies must remain fixed and immobile during the flight mission;
- High risk materials will not be used in the manufacturing of the CubeSat;
- Each CubeSat unit fully equipped with electronics will not weigh less than 1 kg;
- The center of mass for the equipped nacelle will be within a virtual 4,5 cm distance away from the geometric center;
- For the nacelle frame anodized aluminum alloy AA6061 will be used, because it has standardized properties unanimously accepted in the aerospace industry;
- The contact between the nacelle and the CubeSat must be made with minimum tolerances,
- The overall dimensions of the CubeSat unit in the xY plane must be 100+-0.1mm and on the Z axis 110+-0.3mm,
- Not one of the electronic or mechanical components onboard must exceed 1cm measured from the surface of the CubeSat.
- The nacelle structure must be at least 3mm thick, to ensure structure safety upon landing ;

The choice of materials is an important step in designing the nacelle, because the weight is a factor in determining the maximum altitude and also because the small structure alterations can offer valuable space for onboard components. The environment plays a significant role in the choice of materials as well, therefore:

- The thermal expansion coefficient of the CubeSat has to be the same with the one of the nacelle.
- The yield strenght of the material has to be higher than the numerically determined maximum von Misses stress in order for the material not to deform under the loads.
- The material has to be easy to manufacture
- The material has to be of low density to minimize the overall weight
- The volatility of the material and its components has to be kept to a minimum,
- The material has to have a minimum out-gassing; [3]

Table 1 below shows the material characteristics of the aluminum alloy selected for use in the nacelle’s structure frame.

Table 1. Material characteristics of AA6061

Mechanical Properties		Thermal Properties	
Brinell (Hb500)	96	Specific heat coefficient	0.896
Yield strenght	310MPa	Thermal conductivity (W/m-K)	167
Point yield	276 MPa	Melting temperature	582-652
Elasticity modulus	68.9GPa		
Poisson’s ratio	0.33		
Strength fatigue	96.5MPa		
Machinability	50%		
Shear strength	207MPa		

For the nacelle and CubeSat shell we opted for carbon fiber composite materials custom designed panels. This choice offers many benefits out of which the main one can be the possibility of designing the strength characteristics of the material according to the directions were the loads will be prevalent.

The carbon fiber we selected is a $160g/m^2$ twill woven together with Epiphen 4020 epoxy resin and the specific hardener in 30g to 100g proportion. The technology employed for the manufacturing of the composite plates involves standard manual lamination techniques, vacuum infusion and a standard $20^{o}C$ 24h curing process. Due to the known issue that manual lamination techniques can determine poor quality parts, mainly because of the high ratio of resin to the carbon fiber in the part, the vacuum infusion was selected in detriment of higher cost.

All the onboard electronics are placed on circuitboards that need to be imobile, cooled and protected from potential damage. For all those reasons a custom design printed PLA frame was designed and printed.(fig 1) This material has a quality that is considered necesary for unstandardized parts and specific to the exploratory research that is printability, that offers options for other configurations on a cost effective basis. PLA material characteristics allow its use in space [4], as well as the stratosphere. According to [4] the procentage of mass loss is 0.56% out off 1% that is admited for space applications.

Designing a modular three unit CubeSat nacelle that is easily assembled and reconfigurable was an innovative process. The solution offers the needed flexibilitySoluţia oferă flexibilitatea necesară ingineril to develop more applications and to test them as a full system. More specific the position of the subsystems can be modified and new configurations can be acomplished according to the new missions specifics, without the need to redesign the nacelles structure.

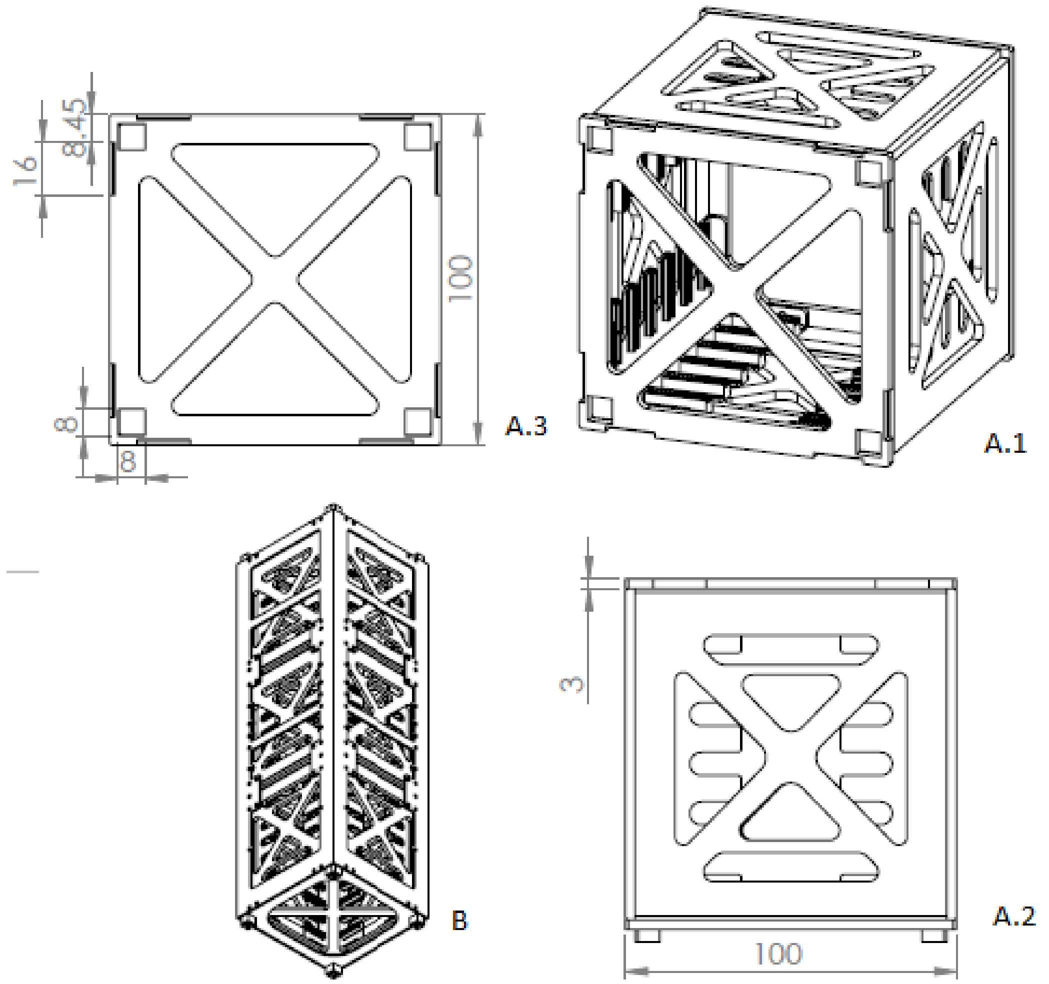

FIG. 2. Nacelle and CubeSat structures. A.1 Isometric view of a CubeSat unit A.2 Side view of the CubeSat unit with dimensions of the composite side panels(thickness and width) A.3 Top view of the CubeSat unit with the given dimensions for protruding legs of PLA structure(8x8mm) B. Nacelle isometric view

The nacelles and CubeSat's dimensions was determined by following the standards and constrains in [5]. Solidworks was the choice software for computer design, as Ansys was used for material characteristic implementation, weight estimation and mass center determination.

4. NUMERICAL EVALUATION

Once designed in Solidworks, the CAD model was exported towards Ansys as a compatible file for the static analysis. The loadings and constraints were set after the nacelle was meshed with tetra elements acording to the specifics of the finite element method. The virtual loadings set on the nacelle model were set to 200N, 300N and 500N as distributed loads on one side of the frame, while the other side was fixed.

The first step of the static analysis was done with more than three times the possible load in order to set safety measures for potential unforseen problems on the landing. The second step was meshing the frame. Tetra elements with the maximum dimension of 1mm, in total more than 148000 meaning more than 300 thousand nodes were used (Fig 3).

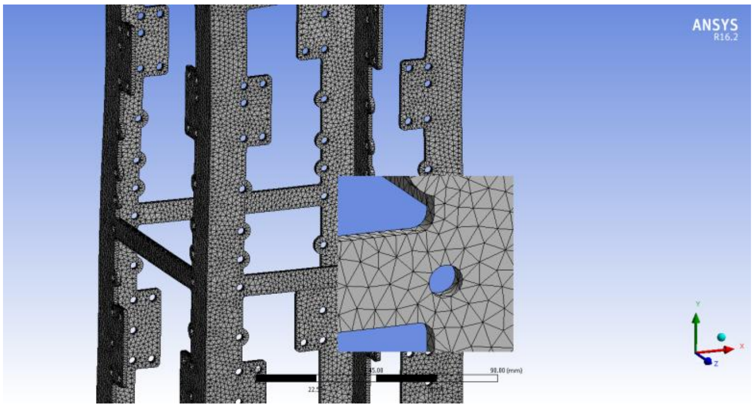

FIG. 3 Meshing of the Nacelle with detail on a rivet hole meshing

For the meshing of the carbon fible composite side panels of the CubeSat triangular elements were also used with the maximum width of 0.8mm generating more than 40000 nodes. The figure below shows the mesh and the measures that were taken in designing the side wall as not allow any sharp corners that could concentrate stress.

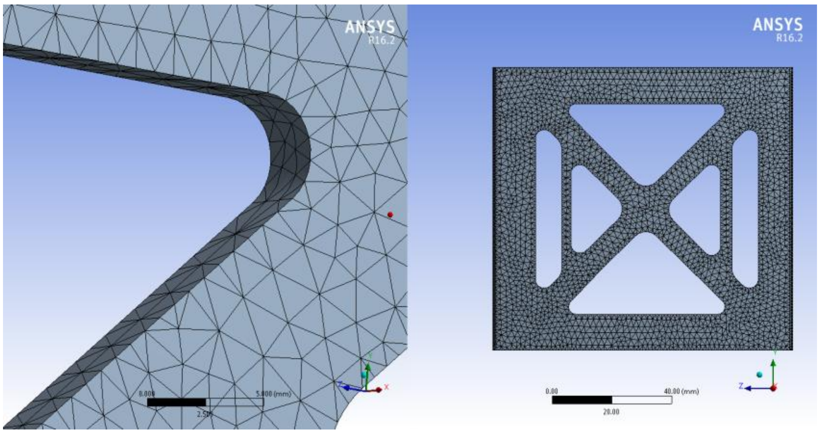

FIG. 4. The meshing of the side composite panels with details on the rounded corners

Another relevant case study considered was imposing a point force on one corner of the frame, to account in some measure for the forces developed in case of low hight ground impact. This was the second solution tested. The value of the forces and pressures applied was the same as presented before, 200N, 300N and 500N.

The maximum obtained displacements obtained for a uniform loading of 500N, on one of the nacelle basis was $84x10^{-4}$, and for the same point force, positioned on a base corner was of $63x10^{-3}$. The figure below (fig 5) presents with a standard code of colors the stress on the structure for the first test case and then figure 6 shows the stress for the top corner loading case.

5. CONCLUSIONS

This paper presents the conceptual design and static structural testing of a type 3 nacelle, able to house three standard CubeSat units. A new design for the CubeSat unit is also proposed, with panels out of carbonfibre composite materials and frame suport from 3D printed PLA material. The nacelle has a suficient volume for all the CubeSat units and is made out of aluminum alloy AA6061.

Professional design and simulation softwares were used to determine the strenght characteristics of the nacelle and CubeSat. SolidWorks was employed for CAD modelling and Ansys for the static analysis with the finite element method.

Through design calculations and numerical validation the maximum allowed weight of the unequiped structure will be of 1 kg. Therefore the computed maximum stresses of (aprox 20MPa) will be much smaler than the yielding stress of 274MPa the aluminum alloy AA6061 offering the needed safety of the structure. The maximum strains of $9x10^{-3}$ mm shows that the loads acting on the structure on this test case induce a small amout of deformation in comparison with the structures thickness of 9mm, therefore the structure will resist even three times that load.(fig 5 and 6)

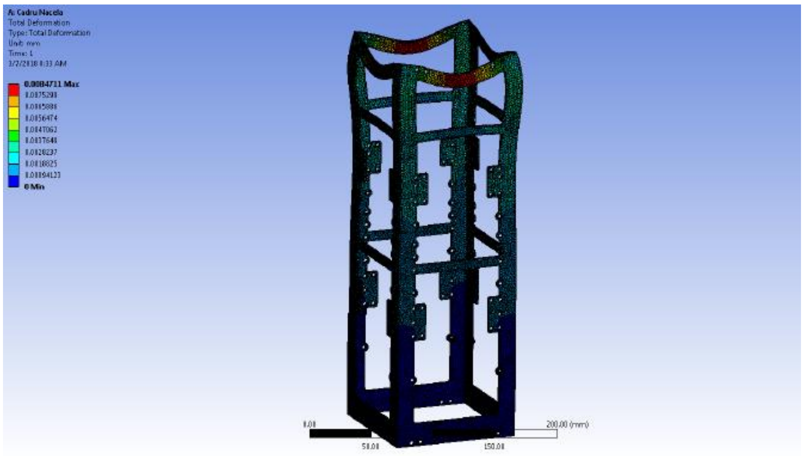

FIG. 5 The numerical solution for the deformation on the nacelle after the 500 N loading

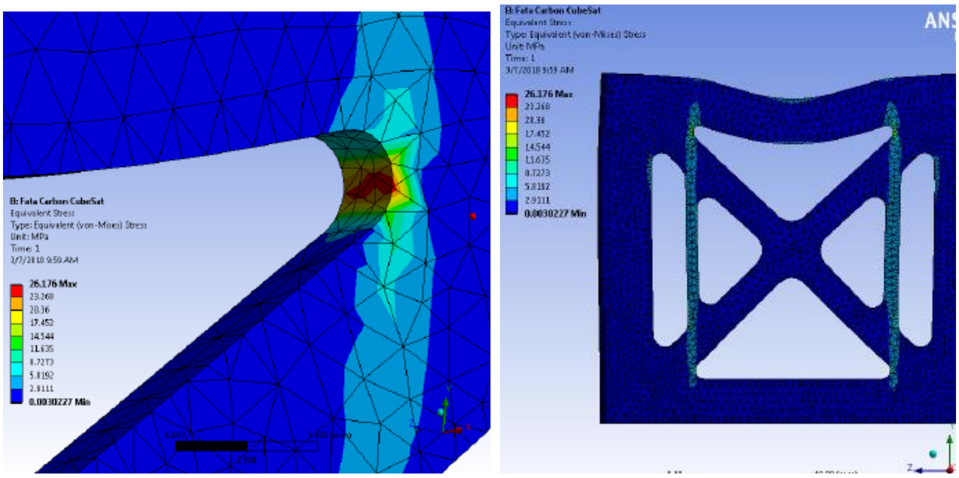

FIG. 6. Stress distribution on the carbon fibre composite plates after 500N loading

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