Structural and Thermal Analysis of Carbon Composite Body of the Satellite

Stasevsky V.I.
Supervisor: Ivanova V.S., Ph.D., Associate Professor
Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk, Russia, 634050
E-mail: 3vityok3@mail.ru

Satellite payload includes various equipment units. The housings of these units have been traditionally made of aluminum. Composite materials have the potential to fulfill the multiple performance requirements set for the housings. A composite design can be lighter and thermo-mechanically compatible to the primary structure of the satellite, which is often carbon composite nowadays. Carbon composite electronics housing was designed according to the requirements set for an existing aluminum housing. The design and analysis of composite structures is more involving compared to metallic counterparts. This paper presents the different aspects considered in the thermal and structural analysis. Based on the design and analysis results a breadboard model was manufactured and tested. The correlation between analysis and test results is shortly discussed.

Technology participated in the European Space Agency (ESA) funded Advanced Equipment Design (AED) project. AED was a technology study to evaluate the feasibility of composite materials in satellite equipment units. The use of composite materials could improve the thermo-mechanical compatibility with the satellite and spacecraft primary structures, as they are often sandwich type composite elements. In addition, high thermal conductivity carbon fibers can increase thermal energy transfer capability in equipment units compared to aluminum counterparts. Carbon fiber-reinforced plastics (CFRP) have high specific stiffness and strength, thus giving an opportunity for mass savings over aluminum [1, 5].

The requirements for the CFRP housing were derived from the requirements specification of the ADPMS housing. For example, the goal in radiation protection was to provide shielding against spatial radiation in Low Earth Orbit that is comparable to the aluminum design with 2 mm wall thickness.

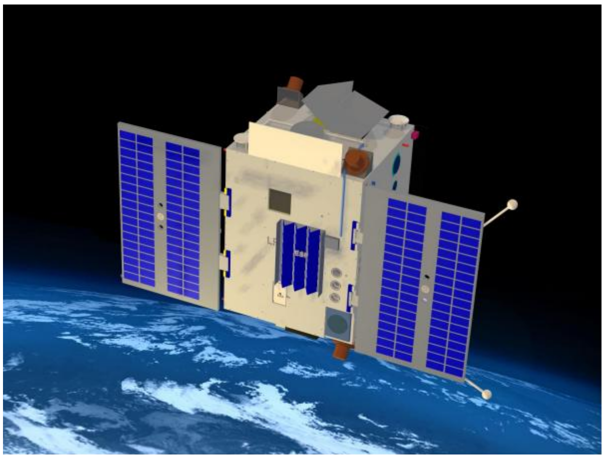


Figure 1 - Proba of micro-satellite

Proba is the second in-orbit demonstration micro-satellite developed by Verhaert for ESA - With the same focus on on-board autonomy as Proba new technologies are exercised in a real case, with payload instruments anticipating future operational missions. Apart from technology demonstration, the satellite contains novel instruments to observe the sun activity (in extreme UV) and plasma [1].

The AED study included two other sub-projects, which applied the same composite materials. The material survey and selection for all sub-projects were made collectively. In all sub-projects equipment units had multi-functional performance requirements. For particle radiation protection, the so-called Low Z – High Z – Low Z concept was applied. In this concept, a material having low atomic weight is on both sides of a material with the high atomic weight. Tungsten was used in this application as it is very effective in stopping electrons. Also, it has good thermal conductivity and mechanical characteristics.

The objective of the design was to gain considerable mass savings compared to the ADPMS housing. The CFRP concept aimed to minimize the number of aluminum parts and to implement parts integration as much as the accessibility of the housing allowed. The freedom of design was constrained, which led to some unfavorable details. The ease of manufacture and minimized production costs were kept in high priority. Traditional laminate manufacturing methods like vacuum bagging in an autoclave and curing in press were used [2, 3].

The design is shown in Fig 2 and the main parts are listed in Table 1. The mounting rails formed a link between the composite parts. The mounting rails were also used for mounting the housing to the satellite. Wedge locks were used to mount the plug-in PCB’s to the housing.

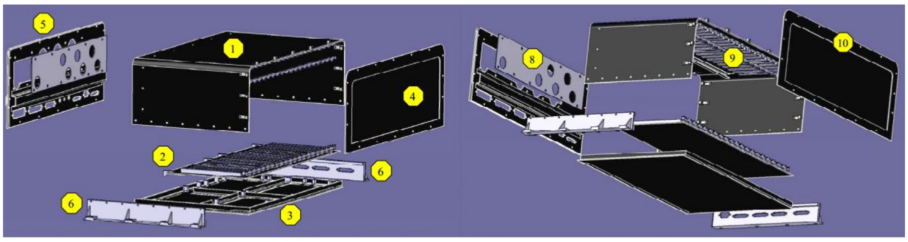


Figure 2 - Main parts of the composite housing

Table 1- Main parts and materials

Part No	Part	Material
1	Hat section	Hat section CFRP
2	Intermediate panel and wedge locks	CFRP + Al
3	Base panel	CFRP
4	Front panel	CFRP
5	Rear pane	CFRP
6	Mounting rails	Al
7	7 Front connector, top fixation	Al
8	8 Rear panel connector plate	Al
9	Wedge locks	Al
10	Sleeve	CFRP

The performance of a single component can be described by an equation of the form.

$$p = f(F, G, M)$$

Which means that performance is a function, f, of the functional requirements (F), Geometric parameters (G), and Material properties (M). Functional requirements are specified by the design.

In this study, functional requirements are the same for the CFRP and aluminum housings. Also, the shape of the housings must be practically the same. Therefore, the choice of material is independent of the geometry and function of the problem. The performance of the component can be optimized by maximizing (or minimizing) M, which is called the material efficiency coefficient, or material index. If we consider flat panels in designs limited by vibration or bending, the performance of different materials can be assessed using equation.

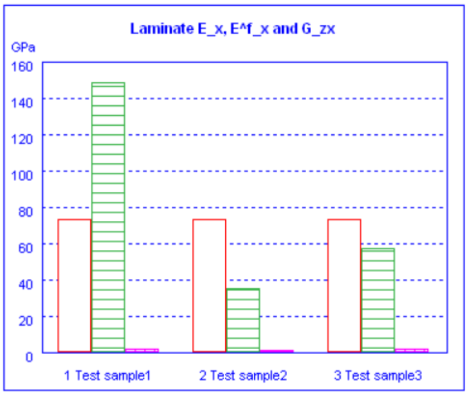
$$M = \frac{E^{\frac{1}{3}}}{P}.$$

Where materials having the same value of M perform equally. In the design, the stiffness of the panel is set by adjusting the thickness. Indices for interesting materials are presented in Table 2.

Table 2 - Material indices in plate bending

	M
Aluminun 1	1
K1100 CFRP laminate 2.1	2.1
M60J CFRP laminate 1.9	1.9
M46J CFRP laminate 1.8	1.8
Tungsten 0.2	0.2

It should be noted that for the laminates shown in Table 2, Young's modulus represents the in-plane stiffness of a quasi-isotropic lay-up and with fiber volume content of 60%. The effect of the stacking sequence in flexural stiffness for few quasi-isotropic lay-ups is presented in Fig. -3. Used material is M40J and the fiber volume content is 55%. Results presented in Table 2 and Fig. -3 3 demonstrate that in the stiffness point of view a mass saving of 50% would be realistic [4].



Laminate	Lay-up	E_x GPa	E^f_x GPa	G_zx GPa
1 Test sample1	((0a)2/(+60a/-60a)2)SE a M40J_6/1770/954-2A_1240/V_f=55,f_1=100 (1)	73.17	148.48	1.98
2 Test sample2	((90a)2/(+30a/-30a)2)SE a M40J_6/1770/954-2A_1240/V_f=55,f_1=100 (1)	73.17	34.75	1.25
3 Test sample3	((+30a/-30a)2/(90a)2)SE a M40J_6/1770/954-2A_1240/V_f=55,f_1=100 (1)	73.17	57.26	1.81

Figure 3 - Laminate x-directional in-plane stiffness, flexural stiffness, and laminate out-of-plane shear stiffness in the xz-plane for three quasi-isotropic lay-ups. Results were generated using a general purpose laminate analysis tool ESAComp

Based on the study, it can be concluded that there is a considerable potential for weight savings over traditional aluminum equipment housings by utilizing multiple properties of composite materials. The composite housing offered a mass saving of 29% over the aluminum housing. The housing included the composite structures and the wedge locks. The design and analysis of composite structures is more involving compared to metallic materials, but proper use of dedicated composite design tools helps in achieving good results [1].

References:

1. Harri Katajisto, Timo Brander, Markus Wallin, "Structural and Thermal Analysis of Carbon Composite Electronics Housing for a Satellite", Proceedings of Helsinki University of Technology, Espoo, Finland. Access mode: http://www.technet-alliance.com/uploads/tx_caeworld/Composite-Electronics-Housing-for-a-Satellite.pdf,free.

2. Brander, T. et al: "CFRP Electronics Housing for a Satellite", Proceedings of European Conference on Spacecraft Structures, Materials and Mechanical Testing, Noordwijk, May 10-12, 2005.

3. Jussila, J. et al: "Manufacture and Assembly of CFRP Electronics Housing", Proceedings of European Conference on Spacecraft Structures, Materials and Mechanical Testing, Noordwijk, May 10-12, 2005.

4. Marchetti M., Testa P. and Torrisi F.R., Measurement of Thermal Conductivity and Thermal Contact Resistance in Composite Materials for Space Applications, ESA Journal 1988 Vol 12, Carbon Composite Material, ESA/ESTEC Document No CCM-HTS-SR-001, Coswig, 2001.
5. Componeering Inc.Accessmode:http://www.esacomp.com/componeering/activities,free.

Comparison of Attitude Determination Methods for CubeSat

Matej Straka
Supervisor: Tamara G. Nesterenko, Tomsk Polytechnic University, Associate Professor
Jaroslav Laifr, Czech Technical University, Ing.
Czech Technical University
E-mail: strakmat@fel.cvut.cz

Introduction

Presented satellite is a 1U CubeSat, with dimensions of 10x10x10cm and mass less than 1kg, which is being developed at Czech Technical University (CTU) in Prague, Czech Republic. The main goals of this project are to build and fly the first Czech Republic's CubeSat, and to build reliable CubeSat electronics and mechanics. This is also motivated by the fact, that only approximately 55% CubeSat missions of all were operational [6]. The flight is planned in the first half of 2016 and it should fly in a sun synchronous orbit at an altitude of 600km and an inclination of 98°.

The Attitude Determination System takes measurements from the magnetometer, gyroscopes and sun sensors and process them to get an attitude quaternion which represents an orientation of the satellite. The results will be later used in attitude control. There are many algorithms that can be used for determining the attitude. One of the mostly used is Extended Kalman filter(EKF). Because our aim is to build systems reliable in outer space, the microcontroller chosen for this system was 8-bit one from Silabs, which is a commercial off-the-shelf component and despite having low computation power, is flight proven, and the risk, that it will fail during the mission, is much lower. Although this microcontroller can run on 100MHz, it's power consumption is in this case too high. Thus, also an another algorithm, QUEST (QUaternion ESTimation), was tested, which is less effective than EKF, but has lower power consumption.

Attitude representation

The attitude of the satellite can be expressed as a rotation of a satellite body coordinate frame (body frame) in an outer reference inertial coordinate frame (reference frame). There are several different ways how to express the attitude. Each of them express the rotation differently, and has its advantages and disadvantages. For Kalman filter, which works with dynamical model of the system, it is useful to work with the quaternion attitude representation, where the system model, although it is non-linear, doesn't have any non-linear functions inside, and it doesn't have any singularities. Quaternion can be defined using the axis-angle attitude representation as:

$$\mathbf{q} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{bmatrix} = \begin{bmatrix} \overline{\mathbf{q}} \\ q_4 \end{bmatrix} = \begin{bmatrix} \mathbf{e}\sin\frac{1}{2}\theta \\ \cos\frac{1}{2}\theta \end{bmatrix}, \quad (1)$$

where **e** is the axis direction vector and θ is the angle of the rotation about the axis. Dynamic model of the satellite rotation with quaternion attitude representation is [3]

$$\begin{bmatrix} \dot{\mathbf{q}} \\ \dot{\boldsymbol{\omega}} \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\boldsymbol{\Omega}\mathbf{q} \\ -\mathbf{J}^{-1}\left(\boldsymbol{\omega} \times (\mathbf{J}\dot{\boldsymbol{\omega}})\right) \end{bmatrix}, \quad (2)$$

where $\boldsymbol{\omega}$ is the angular velocity, **J** is the inertia tensor, and