Structure Design for TUUSAT-1A Microsatellite

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Abstract: - One of the main advantage of microsatellites is their small size. The reliability, safety, and effectiveness of the satellite structure play an important role in the normal operation of the satellite. The satellite structure should be designed that it supports all subsystems, and payloads. The satellite structure should be stable against vibration and environmental factors during the rocket launch, in order to ensure normal operation of the other subsystems and payload. When designing a satellite, we take into account the features of the attitude control subsystem, thermal control subsystem, and solar energy subsystem, which are essential for stable operation, as well as the reliability of the structure. In this article, we discuss a structure design for the Taiwan Universities United Satellite NO.1A (TUUSAT-1A) microsatellite. The satellite is a cube with an edge of 28 cm. The surface of the satellite is covered by six aluminum plates, each of which has a solar chip attached to it. The satellite mainly comprises four layers-each layer is an aluminum plates that form a single aluminum alloy block.

Key-Words: - structure, microsatellite, reliability, safety, effectiveness, stable operation.

1 Introduction

Countries all over the world have been developing microsatellites. The full name of the microsatellite TUUSAT-1A is Taiwan Universities United Satellite NO.1A. This was developed by a microsatellite research team comprising scholars from Tamkang University, China Institute of Technology, National Formosa University, National Taiwan Ocean University and National Chiayi University. Figure 1 shows the logo of TUUSAT-1A. Table I lists the features of the TUUSAT-1A microsatellite. TUUSAT-1A includes various electrical and mechanical systems. The electrical systems include an electrical power subsystem, a satellite computer subsystem, a communication subsystem and a payload subsystem. The mechanical systems include a structural subsystem, a thermal control subsystem, and an attitude determination subsystem. The microsatellite is designed to be 40 kg in weight and 28 cm in height and is powered by solar energy. It is expected to operate in 500 km altitude, 21 degree inclination circular orbit for 3 to 12 months for global positioning systems (GPS) and complementary metal-oxide-semiconductor (CMOS) sensor image payload

Table I The features of the TUUSAT-1A micro-satellite

Mission	(a)GPS receiving; (b)Earth imaging and transmission; (c)Space qualification for COTS components:(i)onboard computer; (ii)transceiver; (iii)camera; (iv)structure; (v)battery charger & regulator.
Orbit	500 km altitude; 21 deg inclination circular orbit.
Volume	Weight < 40 kg; Height < 40 cm; Diameter <40 cm.
Mission Life	3 months
Design Life	1 year
Power	GaAs Solar Panel; Surface Mounted; NiCd Flight Cells x 8.
Attitude Control	Passive Magnetic Control; Magnets; Hysteresis rod; Shorted coils.
Communication	Amateur radio satellite communication, Downlink/ Uplink on 435MHz, Transmission rate up to 9600 bps.
Onboard computer	16-bit command processor and 32-bit image processor
Structure	6061 Aluminum Alloy
Thermal	Passive thermal

Figure 1 TUUSAT-1A Logo.

experiment. The uplink and downlink for the communication band are both 435 MHz UHF band at a transmitting speed of 9600 bps. TUUSAT-1A is built with a 16-bit command processor and a 32-bit image processor as the computer for the satellite.

2 Related Work

Generally, the design of the structure of microsatellites should take into consideration the following factors: need for attitude control, thermal control, solar energy panel area, ease of inspections for modules, methods of line assemblies, structural safety, centre of gravity and centre of area. Owing to the consideration for attitude control, most satellites are symmetric in structure, e.g. spheres, tetrahedrons, hexahedrons and octahedrons. In addition to space utilization, the main consideration for the shape of any satellite is whether the number of solar panels is sufficient to power the satellite. Graziani *et al.* [1], mention that the larger the number of angles in a given shape, the greater in the area that is capable of absorbing sunlight and the greater is the solar energy provided. In theory, the best shape one that is close to a cylinder. However, typical shapes are designed to satisfy cost considerations. The most frequently used shapes are tetrahedrons and hexahedrons. In general, satellite structures can be divided into the following categories on the basis of their structural modules:

(1) Multiple aluminum boxes stacked into main body structures:

Examples are the AMSAT series [2] and the UoSAT series [3] developed by the University of Surrey, UK. This type of satellite is known for the structures stacked up with multiple layers of aluminium boxes. Each layer of aluminum boxes is developed into a subsystem and the layers are stacked and locked together. Each side is then covered with solar panels. This structural method reduces assembly complexity and simplifies inspection processes. Meanwhile, all the connectors can be concentrated on a single side to facilitate management.

(2) Multiple aluminium plates and aluminum rods constructed into main structures:

Examples include microsatellites developed by Stanford Audio Phonic Photographic Infrared Experiment (SAPPHIRE) [4] and UniSAT satellite developed by Gruppo di Astrodinamica dell in Italy. The main structures are composed of square aluminum plates held together with aluminium rods. Buses are then fixed to the plates and solar panels are installed. The benefit of this type of structures is that it provides greater space. However, inspections are not very easy; other components have to be removed if certain components are to be replaced during the inspections. It is not only time-consuming, but also increases the risk of component damage.

(3) Aluminum plates with slots on the side for assembly into main structures:

A U-shape main structure with square edges is constructed with the aluminum plates. There are slots on the side of the main structure to allow components to be attached to other aluminum plates. Layers are inserted and installed into the slots. The greatest advantage of this method is the ease of assembly and inspections. However, this structure may be slightly weak so a robust structural analysis is required to ensure its safety. One successful microsatellite with this type of structures is the Students for the Exploration and Development of Space Satellite (SEDSAT) developed by the University of Alabama in 1991. The main structure of the SEDSAT consists of a hexahedron composed of six aluminum plates made of 6061-T6 aluminum alloy. There are slots on these plates. Circuit boards and components are first installed on the aluminum plates to enhance their structural strength and individual systems are inserted into the slots. The ejection interface below is a 7075-T73-alloy ejection dish with a diameter of 9 inch, in a height of 0.94 inch, and a thickness of 0.5 inch. In addition to the abovementioned commonly seen structures, there are other structures developed for various tasks. For example, an amateur satellite developed by the US Naval Academy in 1998, the Petite Amateur Navy Satellite (PANSAT) [7], consists of a decahedron structure. The eight sides (other than the top and tail) are covered with solar panels; the top and tail have five sides of panels supported with four tripods. Such a design aims to increase the space for solar panels in order to provide sufficient electricity. The main structure, made of 6061-T6 aluminum, consists of two layers of aluminum plates and a basket-shape supporting frame. The internal system is composed of three subsystems, a telecommunications susystem (COMM), an electronic power subsystem (EPS) and a digital control subsystem (DCS). Lahcène *et al.*[8] discussed the UHF transmitter amplification chain of the satellite engineering model communication subsystem, which is part of the Alsat-1 project. Mohammed *et al.*[9] discussed the magnetorquer control for orbital manoeuvre of low-earth-orbit microsatellites. In our previous studies [11-20], we focussed on mobile telemedicine and biomedical signal processing. In [21], we discussed the TUUSAT-1A microsatellite. The structural subsystem is described below.

3.Structure Design of TUUSAT-1A Microsatellite

This study examines and analyzes the structure and design of TUUSAT-1A, a microsatellite. The introduction section covered the concept of microsatellites, definitions of subsystems and function requirements. After providing an understanding of the basic structure of microsatellites, this article explains the structural designs, allocations of internal components, space utilization, attachment methods, assembly methods, and sequences of component assembly. The basic concept of the structural design of microsatellites will be revisited. In short, the structure has to withstand the massive load generated by the acceleration and the oscillations during the launch of the rocket. The concept of structural design will be applied to structural subsystems for design and a thorough analysis.

3.1 Material Selections

The functionality of satellite structures is often dependent on the features of the materials used. The selection and application of materials is a critical issue. In addition to meet with the requirements of a particular orbit environment, the selection of structural materials should take into account the following factors: strength, stiffness, fatigue failures, thermal parameters, manufacturing and ease of modifications, costs, etc. Given the limited budgets and concerns over manufacturing and maintenance costs, 6061-T6 aluminium was used to construct TUUSAT-1A. The alloy is mainly composed of aluminum, with small amounts of magnesium, silicon and copper. The alloy was subject to T6 thermal processing to enhance the yield stress and shear strength. 6061-T6 aluminum alloy is light, erosion-resistant and highly heat conductive. It is also good for surface treatments.

3.2 Main Structure of TUUSAT-1A

In addition to space utilization, the design of the main structure of a microsatellite should also take into account the total weight, thermal control, attitude, solar panel area and manufacturing costs. The design concept for the main structure of TUUSAT-1A was based on the payload size, cost and maintenance difficulties of its ground simulation system. The design aims to facilitate dissembles for tests and replacements in the future. Figure 2 illustrates the rectangular aluminum box, the square of dimensions of 28 cm x 28 cm x 7 cm. Figure 3 shows the stacking of the four aluminum boxes into one piece as the main structure of the satellite. The four corners of these boxes have holes and four stainless steel rods of 8 mm are inserted into these holes. Screws are used to fasten each layer together. Each of the six sides of the main structure is covered with aluminum plates of 5 mm in thickness for attachment. Figure 4 shows the square of dimensions of 28 cm x 28 cm x 28 cm, which is the main structure.

3.3 TUUSAT-1A System Allocations

The first step is the coordinates for the satellite. The origin is defined as the centre of the TUUSAT-1A main body. The coordinates are determined by the attitude control system. This system is installed with different layers. The internal one consists of four layers of aluminium boxes. Individual subsystems are connected

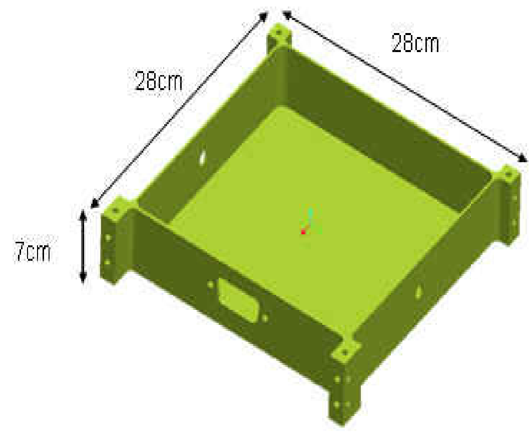

Figure 2 The rectangular aluminum box

together. Figure 5 illustrates the details of the electronic machinery system and payload system. The heavier layer is placed in the middle and the layout is constructed on a bottom-up principle. After the completion of the assembly, solar panels are installed on the outer aluminum plates. Antennas are placed on the surface of the top layer. The weight budget of TUUSAT-1A microsatellite is shown as Figure 6. Figure 7 illustrates the first layer, i.e. the computer layer at the bottom of the main structure of the satellite. This layer controls the onboard computers, GPS instruments and payloads. Figure 8 shows the second layer, i.e. the power supply layer. It contains two cell modules and four hysteresis rods, wrapped around with hysteresis loops. The power supply subsystem is usually the heaviest of all the subsystems. In addition, the power supply system is installed as close to the centre of the main structure as possible. The third layer is the communication layer (Figure 9), which consists of communication modules and the two magnetic rods and two camera modules forming the attitude subsystem. The fourth layer, the BCR layer, is illustrated in Figure 10. It consists of a battery charger and regulator（BCR）, low-pass filter（LPF）, high-pass filter（HPF） and a camera control circuit module. Figure 11 is the TUUSAT-1A microsatellite

3.4 Centre of Gravity

Carriers have strict restrictions on the weight and centre of gravity of any satellite. This is to limit the moment of the force generated by the ejection dish, in order to ensure the safety during ejections. In general, it is easy and time-efficient to measure the centre of gravity and moment of inertia with sophisticated engineering CAD software. These discussions can be calculated with the component parameters of any geometric shape. Based on the requirements of TUUSAT-1A, we found that centre of gravity and geometry centre cannot exceed 20 mm. The deflection of the centre of gravity and geometry center is in compliance with design needs.

4. Analysis Results

The main body of TUUSAT-1A is a tetrahedron satellite of dimensions 28 cm x 28 cm x 28 cm. The interior is staked with multiple layers of aluminum boxes. The corner pillars of the four sides are locked in and fixed with four stainless rods. The thickness of the aluminum plates on the side is 3 mm. According to the verified payload equation for microsatellites, the structure of TUUSAT-1A has to be able to withstand an acceleration greater than 19 g of the inertial load in the +Z direction. Generally, a safety factor of 1.25 is required for most space vehicles, considering the maximum acceleration. However, a safety factor of 2 should be applied in the absence of experimental tests. According to the vibration modal analysis, the frequency of natural vibrations should be higher than that of rocket carriers in order to avoid resonance of the launch and carrier and the resulting damages to the satellite. Generally, the frequency of natural vibrations for payload satellites should be no less than 35 Hz. To ensure safety, the value for the frequency of natural vibrations of satellites is usually recommended to 50 Hz. The TUUSAT-1A analysis also determined that the natural frequency should be at least 50 Hz. According to the design of the ejection interface for carriers, the satellite should stay upright at the time of launching carriers. In other words, the TUUSAT-1A satellite should remain upright, facing the pre-defined +Z direction. The stress analysis is based on assumption that the satellite is subject to a 319 Kgf in spring pressure from the ejection system on the four corners of –Z aluminum plates. Tetrahedral elements are used for grid segmentations. Figure 12 shows the mesh analysis in the TUUSAT-1A microsatellite, and the model is divided into 135852 nodes and 511864 elements. Figure 13 depicts the distribution of stress and deformation computed with the finite element analysis software. According to the calculations by the finite element analysis software, the maximum stress is 13.5 Mpa and the maximum deformation value is 0.00285 mm. As the weight of the satellite is concentrated around on the centre of the vertical axis, it is subjected to a greater vertical acceleration. The greatest deformation of the outer aluminum plates occurs on the centres.

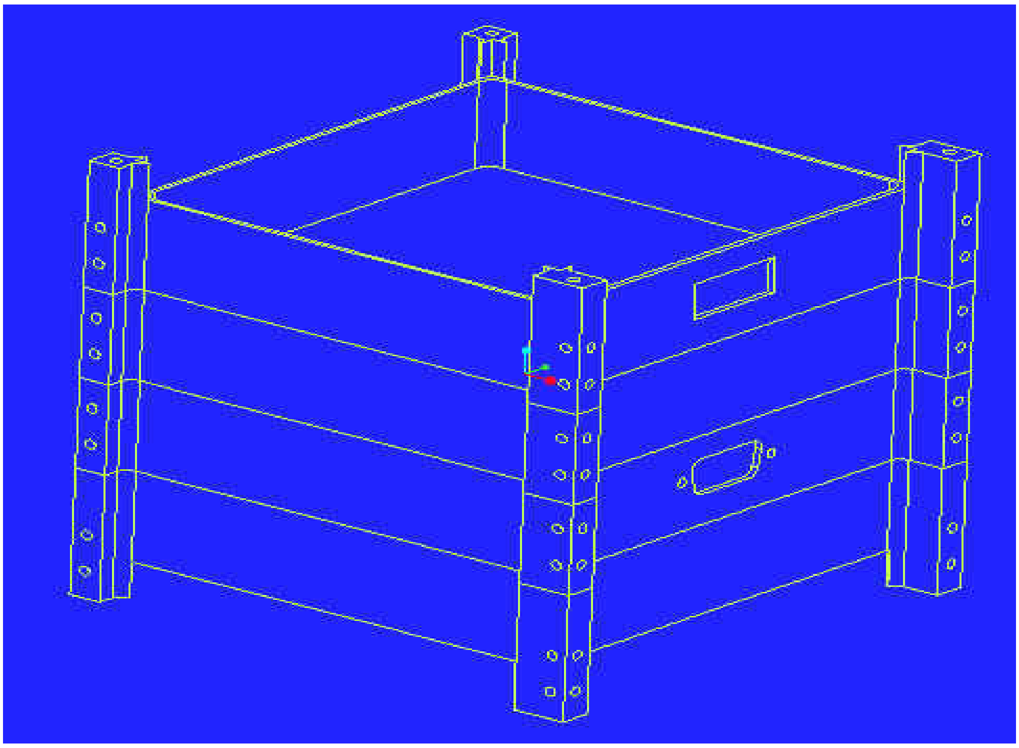

Figure 3 The stacking of the four aluminum boxes into one piece as the main structure of the TUUSAT-1A micro-satellite.

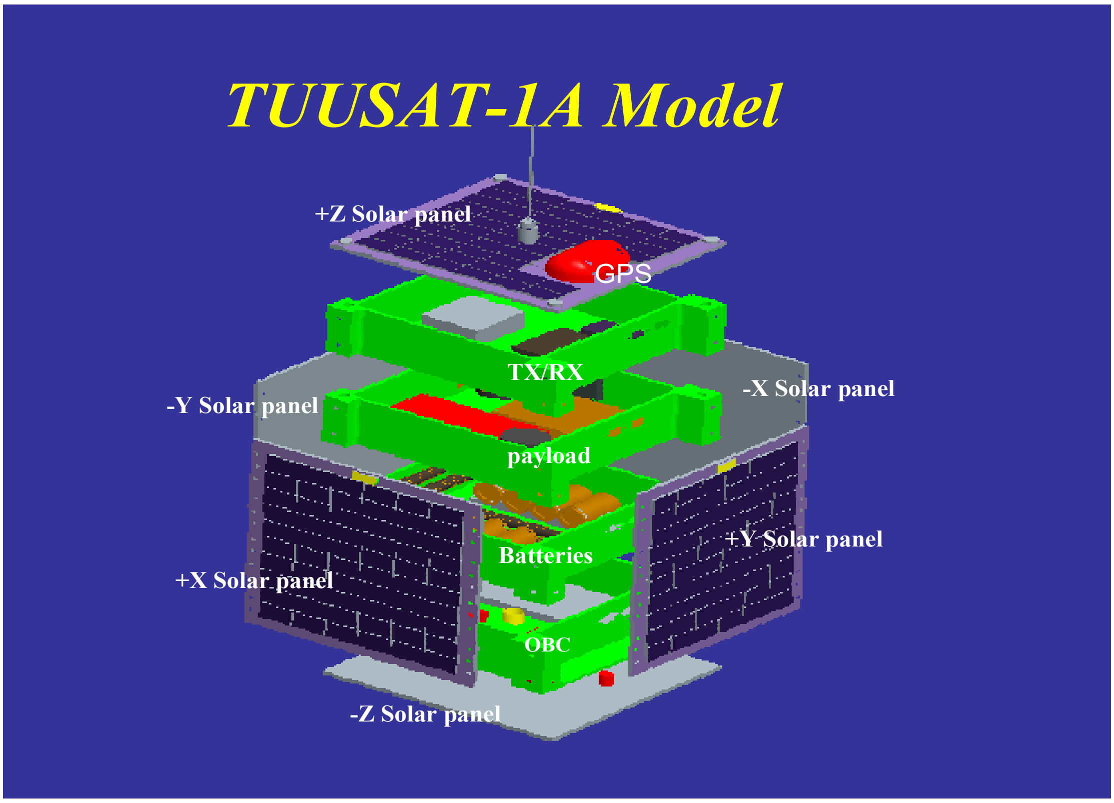

Figure 4The structure of the TUUSAT-1A.

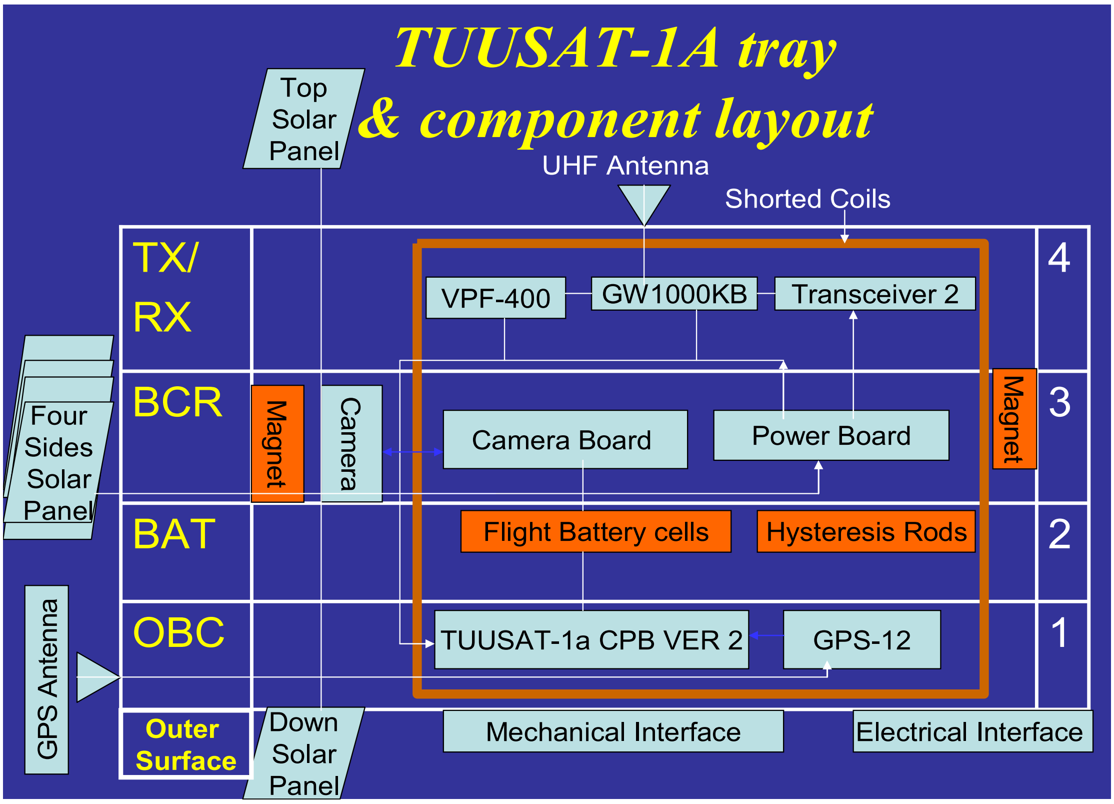

Figure 5 Structure Mechanical System of the TUUSAT-1A

Layer	Components	Volume(mm^3)	Weight(kg)	Weight ration (%)
Tray1	TUUSAT-1A CPB VER 2	190*90*20	0.110	0.48
	GPS-12 Receiver Splitter	98.5*69*20 32.5*23*23	0.207	0.9
	Tray1	280*280*70	2.6	11.3
Tray2	BAT-4 Flight Cells*8	33*60	1.28	5.6
	Hysteresis rods*4	Φ13*200	1	4.3
	Tray2	280*280*70	2.6	11.3
Tray3	Magnet*2	Φ51*50	1.5	6.5
	Camera main board	140*95*20	0.1	0.44
	Power board	155*100*20	0.15	0.65
	Camera Module	35*40*20	0.06	0.26
	Tray3	280*280*70	2.6	11.3

(a)

Tray4	GW1000KB	80*68*16	0.06	0.26
	Transceiver 2	160*120*16	0.12	0.52
	Tray4	280*280*70	2.6	11.3
Interface	LV機械介面	TBS	1.5(TBR)	6.5
Outer surface	outer aluminum plate*6	280*280*2	3.8	16.6
	SP-XX Solar Panel*6	280*280*1	0.6	2.6
	UHF Antenna*1	Φ6*251	0.0092	0.04
	GPS Antenna*2	87*57*16	0.256	1.12
	hysteresis loop	Φ0.1	0.5	2.18
	fixed material	Magnetic bar*4	0.13	0.57
		Hysteresis rods *8	0.6	2.6
	line,Cable, Connector	15pin cable the length 190mm 25pin cable the length190mm	0.21 0.35	0.91 1.52
	Margin		7.06	30.77
total weight			30	100

(b)

Figure 6 TUUSAT-1A Weight Budget

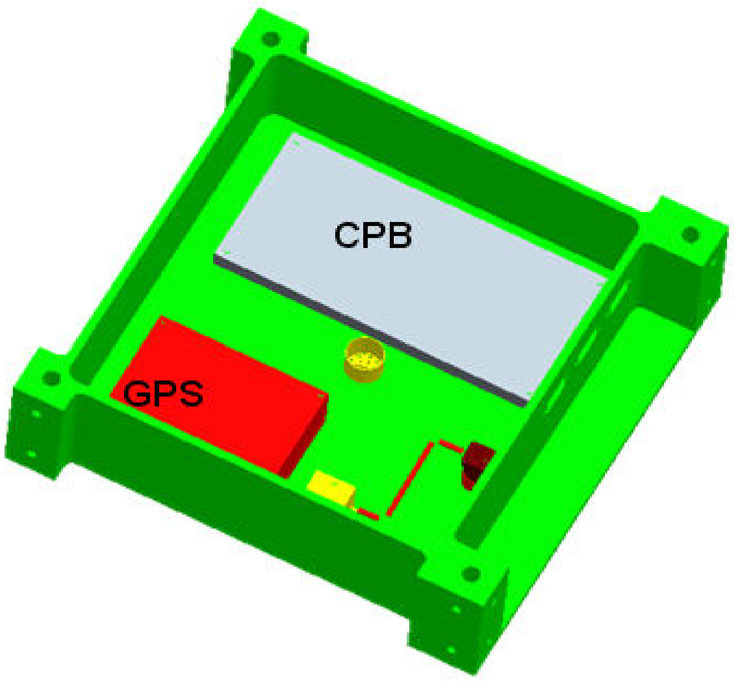

Figure 7 The allocation of the first layer in TUUSAT-1A

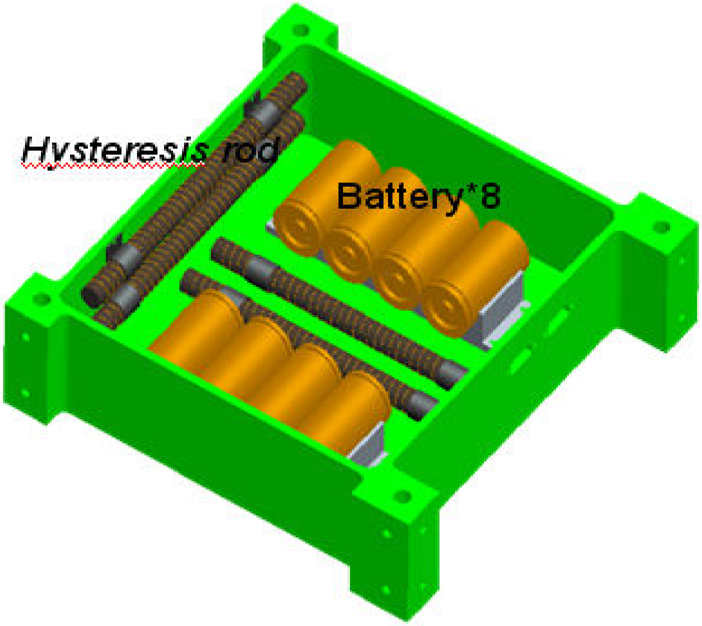

Figure 8 The allocation of the second layer in TUUSAT-1A

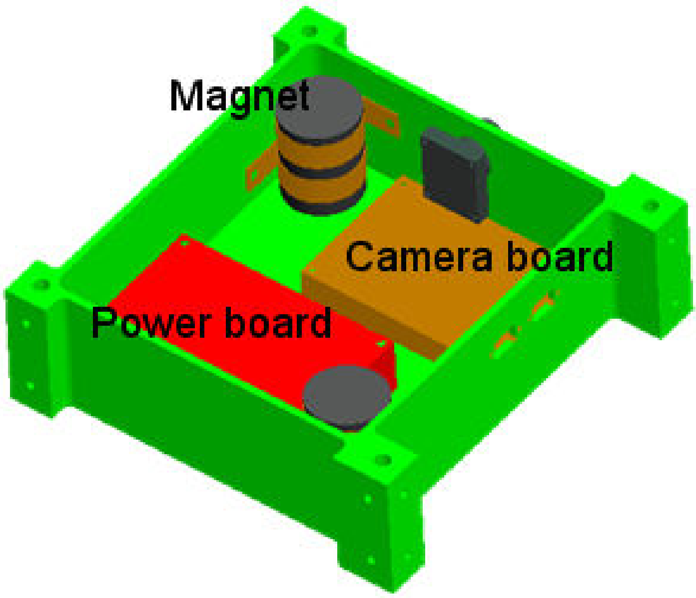

Figure 9 The allocation of the third layer in TUUSAT-1A

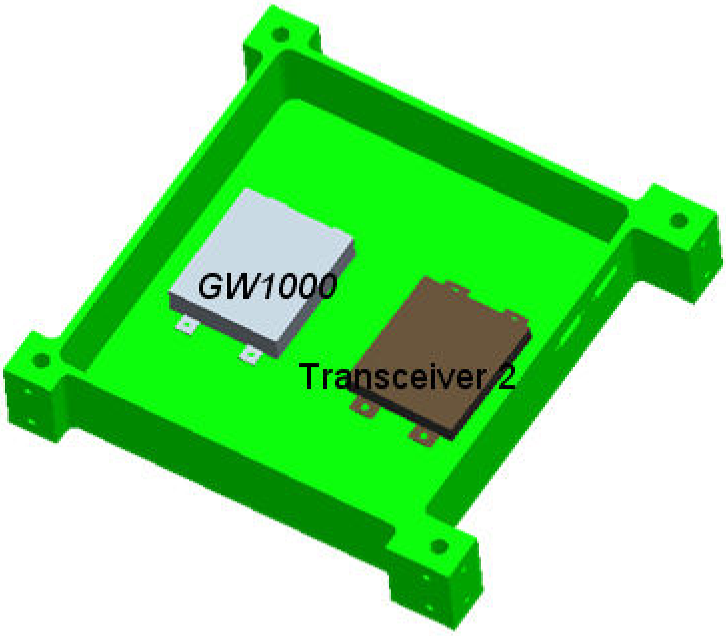

Figure 10 The allocation of the fourth layer in TUUSAT-1A

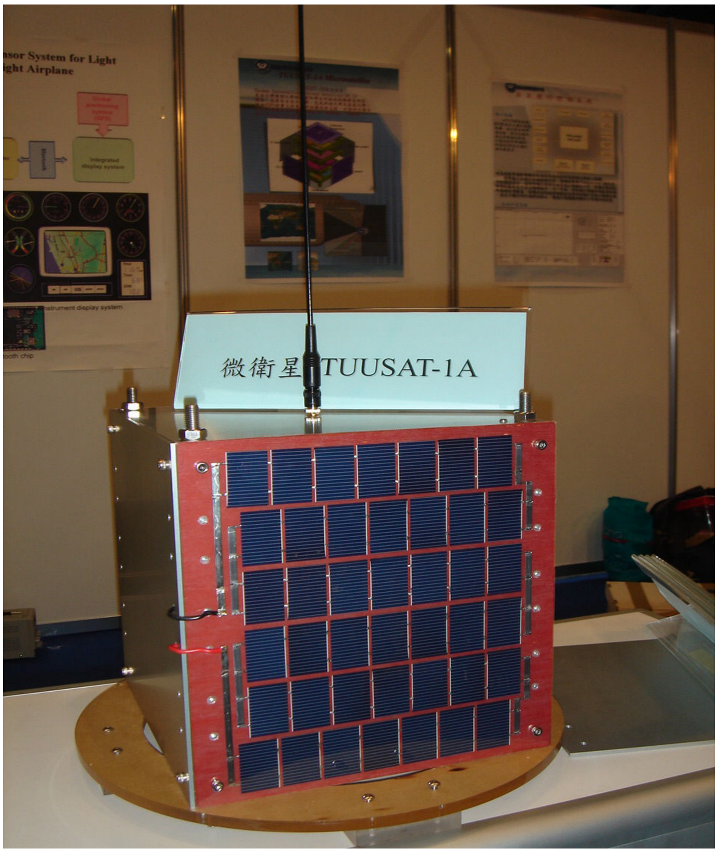

Figure 11 The TUUSAT-1A microsatellite

In addition to the impact of acceleration, the plates are also influenced by the inward force of the four bending corners. The analysis compares the stress withstood by the satellite and the yield stress of different materials. The deformation values are all very low. Therefore, it is expected that there will be no damage to the overall structure from the acceleration during the uplift of the carrier. Tetrahedral elements are used for grid segmentations, based on the set-up in the stress analysis. According to the analysis run by a software on the design of the main structure, the first modal frequency is 288.75 Hz and second modal frequency is 289.15 Hz, as shown in figure 14 and figure 15, respectively. The natural frequency of the first modal vibration frequency has to be higher than the required 50 Hz. The analysis indicates that the natural vibration frequency of TUUSAT-1A is 288.75 Hz, higher than the required 50 Hz. It can be inferred from this that the design is satisfactory.

5. Conclusion

The analysis indicates that the largest stress of 13.5 MPa occurs at the four pillars at the bottom of the satellite. The same spots also experience the maximum deformation of 0.00285mm happens. This is because in addition to gravity and acceleration, the four pillars at the bottom have to withstand the weight of the satellite itself and the elastic force of the ejection mechanism. However, such a burden does not yet damage the structure because a safety factor of 2 in used in compliance with the design standards. The model analysis suggests that the first model frequency (natural frequency) is 288.75 MHZ, occurring at the side of TUUSAT-1A. As the natural frequency of this microsatellite is much greater than the safety threshold of 50Hz, the design is able to avoid resonance and any resultant damages. Compared with large satellites, microsatellites have higher natural frequencies (much higher than the safety threshold) because of their sizes. As a result, the issues regarding resonance are less of a concern. Therefore, this study focussed on the locking-in assembly of the structure and fixation of individual modules when it comes to oscillations. The purpose is to ensure the locking-in status does not cause any oscillations or even result in the loosening of screws and modules. As long as the lock-in parts are sturdy and able to hold together all the components, the damage caused by resonance will not affect the safety of the satellite.

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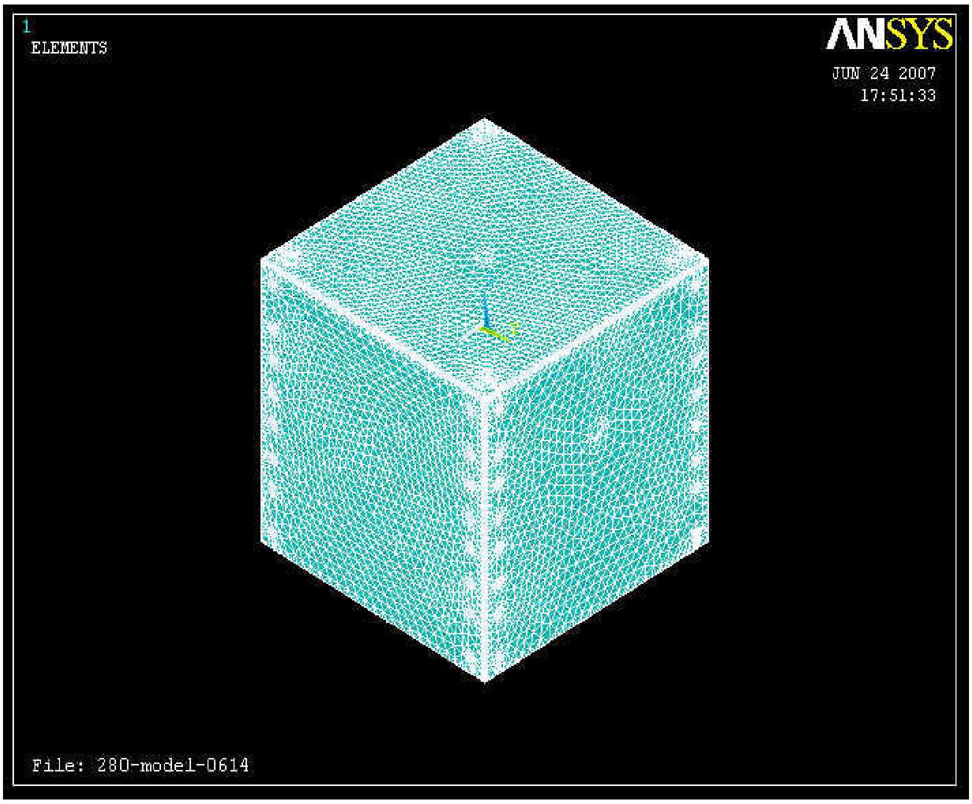

Figure 12 The mesh analysis in the TUUSAT-1A micro-satellite.

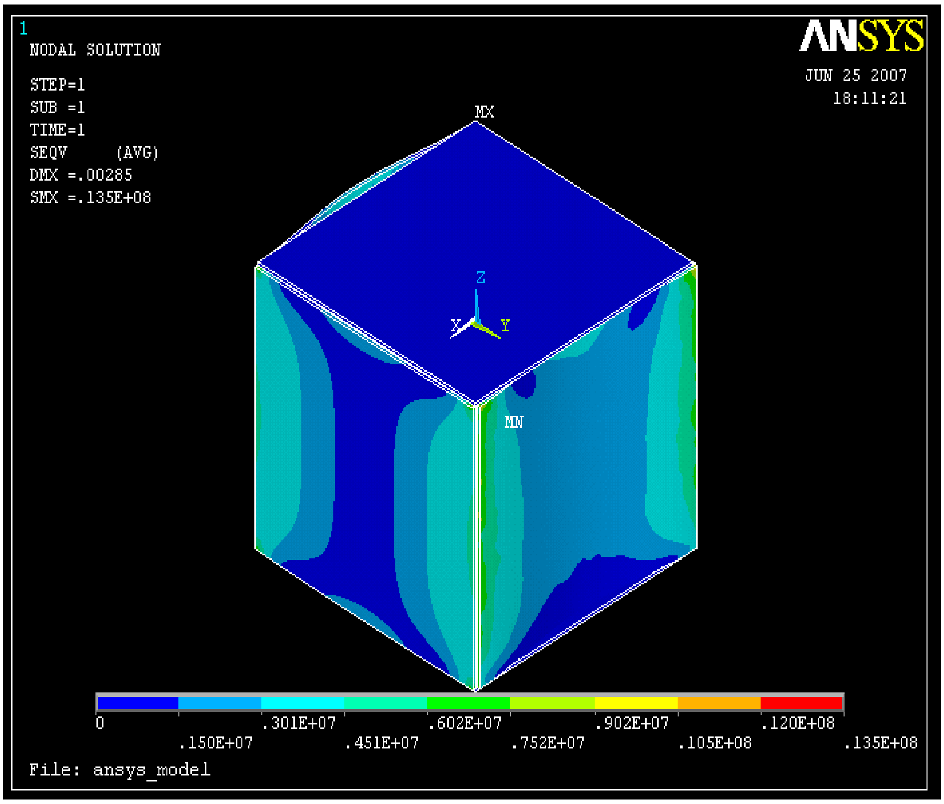

Figure 13 The stress distribution in the TUUSAT-1A micro-satellite.

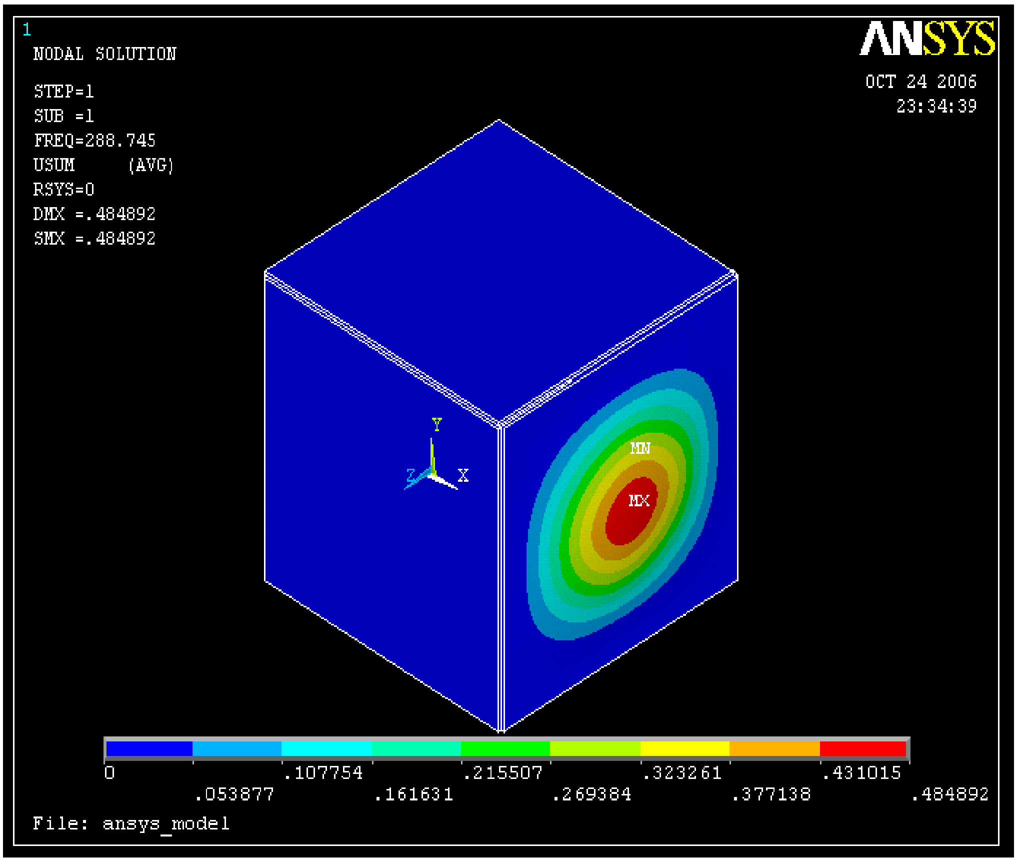

Figure 14 Simulation of the first modal frequency.

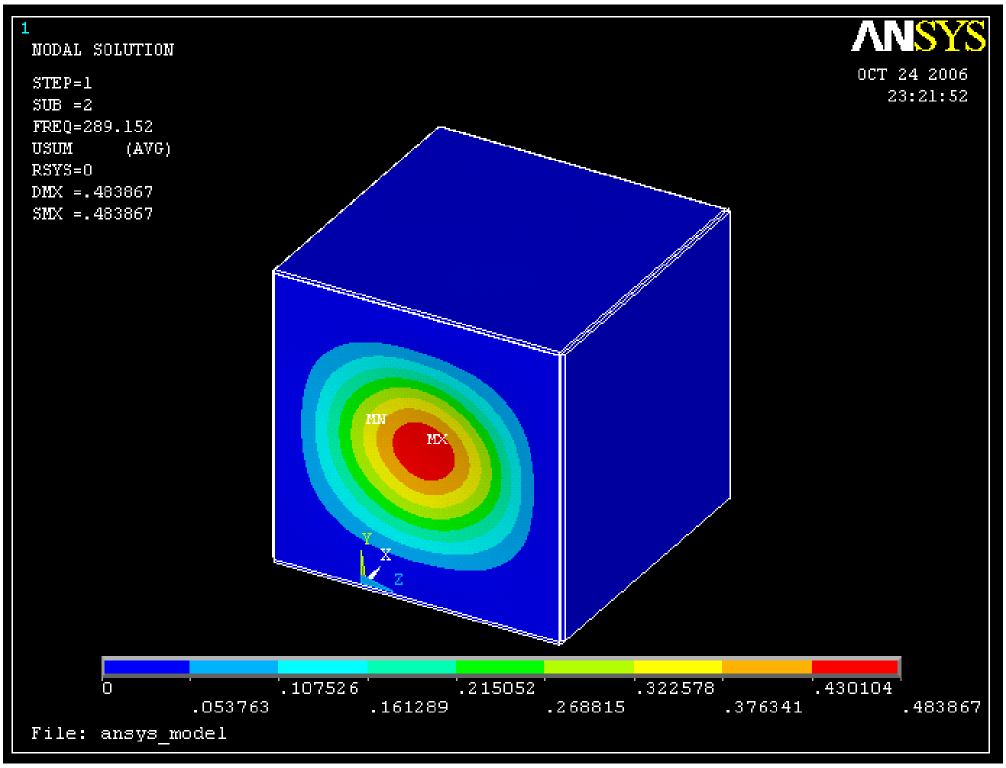

Figure 15 Simulation of the second modal frequency.

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