SCHOOL OF AEROSPACE ENGINEEERING

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PRELIMINARY DESIGN ANALYSIS AND FABRICATION OF MYSAT STRUCTURE

BY

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ABSTRACT

MYSat is the first satellite ever in which is built by the university student from (Universiti Sains Malaysia) USM. The structural subsystem of MYSat is specifically designed to support the mission of MYSat. The external dimension of the CubeSat must be compatible with the deployer interface, which in this case is the Japanese Experiment Module Small Satellite Orbit Deployer (J-SSOD). Besides, the CubeSat structure must also undergo several structural analysis as required by a J-SSOD service provider, Japan Aerospace eXploration Agency (JAXA).

This thesis focuses on the chassis design of MYSat to refine structure subsystem's requirements according to the mission objectives. The structure has been designed and fabricated by 3D printer and then CNC Machine to examine the design flaws and fitting and suitability of manufacturing process. The structural analysis has also been performed on the model using ANSYS to demonstrate the ability of MYSat structure to withstand the loads. Two type of chassis have been studied which is modular frame and monoblock. The result shows that monoblock have higher frequency in modal analysis 219.52Hz compare to modular frame which is 247.32. Monoblock approach offers the best relationship between rigidity and mass but has the disadvantage of significantly increase the complexity of assembly procedures. Lastly, at the end of this work, there will be a few future recommendation for future research in regards to this project.

ABSTRAK

MYSAT adalah satelit pertama yang pernah di mana dibina oleh pelajar universiti dari (Universiti Sains Malaysia) USM. Subsistem struktur MYSAT direka khusus untuk menyokong misi MYSAT. Dimensi luaran iaitu CubeSAT mesti serasi dengan antara muka deployer, yang dalam kes ini adalah Eksperimen Jepun Modul kecil Satelit Orbit Deployer (J-SSOD). Di samping itu, struktur iaitu CubeSat juga perlu menjalani beberapa analisis struktur seperti yang dikehendaki oleh pemberi perkhidmatan J-SSOD, Jepun Aerospace Exploration Agency (JAXA).

Tesis ini memberi tumpuan kepada reka bentuk casis MYSAT untuk mendapatkan hasil keperluan struktur subsytems ini mengikut objektif misi. Struktur ini telah direka dan dibina oleh pencetak 3D dan kemudian CNC Mesin untuk memeriksa kelemahan reka bentuk dan kesesuaian pemasangan dan proses pembuatan. Analisis struktur juga telah dilakukan ke atas model yang menggunakan ANSYS untuk menunjukkan keupayaan struktur MYSAT untuk menahan beban. Dua jenis casis telah dikaji iaitu bingkai modular dan monoblock. Hasilnya menunjukkan bahawa monoblock mempunyai kekerapan yang lebih tinggi dalam analisis modal 219.52Hz bandingkan dengan bingkai modular yang 247,32. pendekatan Monoblock menawarkan hubungan terbaik antara ketegaran dan besar-besaran tetapi mempunyai kelemahan ketara meningkatkan kerumitan prosedur pemasangan.Pada akhir karya ini, akan ada cadangan beberapa masa depan untuk kajian akan datang dalam hal projek ini.

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF ABBREVIATIONS

CubeSat	Cube Satellites
USSL	Space System Laboratory, Universiti Sains Malaysia
Cal Poly	California Polytechnic State University
JAXA	Japan Aerospace Exploration Agency
JEM	Japanese Experiment Module
Kibo	Japanese Experiment Module (nickname)
S3FL	Student Space System Fabrication Laboratory
LEO	Low Earth Orbit
FEA	Finite Element Analysis
PSD	Power Spectral Density
NASA	National Aerospace
RBF	Remove Before Flight
CNC	Computer Numerical Control
SSDL	Space Systems Development Laboratory
ULF	Ultra low frequency
ELF	Extremely Low Frequency

NOMENCLATURES

BN	:	Ballistic Number
F	:	Force
Cd	:	Coefficient of Drag
A	:	Ampere
a	:	Acceleration Load
ng	:	Gravity-Load
MoS	:	Margin of Safety
SF	:	Safety Factor
J	:	Joule
V	:	Voltage
P	:	Power

CHAPTER 1
INTRODUCTION

1.1 General Overview

The evolution of technologies utilized as a relationship for the advancement of spacecraft. Once, all computers were gigantic machines. At that point the advancement of hardware permitted the making of what were known as small computers that extended the quantity of associations that could manage the cost of the computer. Facilitate development conveyed the computer to billions of individuals, and now the advanced cell enables a huge number of utilization to convey phones in our pockets. So also, planetary rocket initially had a tendency to be huge missions. NASA's New Frontiers and Discovery program empowered a progression of lower cost missions that can be contrasted with smaller than expected computers.

CubeSats were started decade ago by specialists at the California Polytechnic State University (CalPoly) and Stanford University to make a standard for college constructed spacecraft.[1] As the name recommends, the essential setup is a cube shape. At only 10 centimeters on a side (or 1unit (1U) in CubeSat speech) and weighing roughly one kilogram, CubeSats rely on upon the hardware scaling down that has empowered computers and cell phones. In the event that an examination group needs a bigger shuttle, blocks can be stacked together to make bigger volumes with standard designs up to six units and even twelve units. The little size of CubeSats enables them to be conveyed into space efficiently as optional payloads on dispatches of bigger Earth satellites.

The CubeSat program initiated at California Polytechnic State University and Stanford University has been ongoing since the year 2000. During this time, over 40 universities, high schools, and private firms have participated in the program to create many different satellite designs. From analyzing different trends in the design of the CubeSat structure, it can be determined which types of designs are best suited to meet various needs such as low price, low mass, simplicity of machining, and ability to support deployable components[1]. With the knowledge of these trends, a new CubeSat can be designed with similar characteristics to suit the specific needs of a particular mission.

Besides that, due to the successful operation and launch of the CubeSat missions, low costs, low risks (due to low impact) and short buildup time, this technology is now also being used as situated (space environment) platform to test new technologies by international space agencies (NASA for example), commercial, military agencies, and private organizations and it is a practice in universities as a hands-on way of learning aerospace disciplines. CubeSats have also become a very high cost-effective mean to realize space science experiments, as well as advance the creation of several aerospace branch companies through university projects.

1.2 Problem Statement

Designing and launching a satellite is essential of aerospace engineering. Small space exploration are set to make a giant leap away from Earth's neighborhood. Small and low cost CubeSats already eye our planet from orbit. But such a tiny craft are about to start pushing out into deep space, helping researchers explore and study the asteroid, moon and other distant bodies.

Thus, CubeSats are already a presence in Earth orbit, and their numbers and influence there are sure to increase. But some researchers are also working and studying for sending the tiny spacecraft much farther afield in the near future. Plans call for that tiny spacecraft to get about 930,000 miles (1.5 million kilometers) from Earth during the course of the three-month mission[3].

There are a few types of loads and stresses must be done, including random vibration, structural loads, sine vibration and mechanical shock. The analysis that is most critical and most physically taxing to the structure of a CubeSat is the random vibrational analysis which ensures the structure survives the launch and can be ejected from the launch vehicle safely. Many program's capabilities and limitations have been research. The research primarily consisted of choosing a program that had the ability to do random vibration analysis.

1.3 Objective

The objectives of this study are:

- To design and improvise the main chassis for structural system of 1U CubeSat.
- To study the structural analysis of 1U CubeSat.
- To fabricate the structure of 1U CubeSat.

1.4 Thesis Layout

This thesis is divided into 5 chapters where every chapter includes details on the overall project. In the 1st chapter, topic overview, problem statement and objectives are stated to provide a big picture of the whole project. Next, Chapter 2 will discuss on the literature review, including previous studies and researches which had been carried out related to this project. Structural analysis are also introduced. Moving on to Chapter 3, theoretical research and study method are described to give an overview of the method and technique used in completing the project. In addition, there will be a work breakdown structure (WBS) for used to define and organize the total scope of a project. Chapter 4 will detail the design of the main frame, the internal arrangement and the testing result of the structural system. Furthermore, in this chapter will describe the fabrication and testing. Finally, Chapter 5 is summarizing and concluding the thesis. The future works regard to this project also included in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Background Study

Satellite projects have historically been large and expensive operations. Because of this, reducing cost and size of satellites have become issues in engineering. Space industry, however, has moved towards larger, more elaborative spacecraft, because this may reduce launch costs and increase the longevity of space investments. This was one reason for building huge launchers, like the Ariane-5 of the European Space Agency. There has been considerable confusion whether a particular satellite is ’large’ or ’small’ as the definition varies, but the following classification has become widely accepted. Below table show the classification of satellite according to their own mass.

Category	***Mass***
Large satellite	> 1000 kg
Small satellite	500 - 100 kg
Mini satellite	100 - 500 kg
Micro satellite	10 - 100 kg
Nano satellite	1 - 10 kg
Pico satellite	< 1 kg

Table 2. 1 Classification of Satellite

As we know, every satellite have their own orbit. Thus, there are many different satellite orbits that be used. The ones that get the most consideration are the geostationary orbit utilized as they are stationary over a specific point on the Earth. The chosen orbit for a satellite depends upon its application. Those used for direct broadcast television for example use a geostationary orbit. Most communications satellites similarly use geostationary orbit. Other satellite systems such as those used for satellite phones may use Low Earth orbiting systems.

SATELLITE ORBIT DEFINITIONS

Orbit Name	Orbit Initials	Orbit Altitude (km)
Low Earth Orbit	LEO	200 - 1200
Medium Earth Orbit	MEO	1200 - 35790
Geosynchronous Orbit	GSO	35790
Geostationary Orbit	GEO	35790
High Earth Orbit	HEO	Above 35790

Table 2. 2 Satellite Orbit Definitions

Similarly CubeSat satellite systems used for any mission occupy a relatively low Earth orbit (LEO). There are also many other types of satellite from weather satellites to research satellites and many others. One other very important issue of any missions was to conduct in-orbit tests of modern devices in space radiation. In general, major areas of work for and nano satellites are:

- Specialized Communications
- Small-scale Space Science
- Remote Sensing
- Technology Demonstration
- Education & Training

Besides, satellites generally must operate with limited power budgets and in a space radiation environment that is harmful to the reliability of semiconductor micro-electronics. Nano satellites mostly operate at Low Earth Orbits (LEO). The altitudes of these orbits lie between 600 km and 2000 km. Below 600 km the orbital lifetime before the satellite re-enters the Earth’s atmosphere because of friction is too limited and unpredictable[5]. With increasing altitude the orbital lifetime and diameter of the satellite footprint increase, the radiation environment caused by the Van Allen belts also increases sharply, reducing the lifetime of electronic components and necessitating extra shielding.

2.2 Previous Mission

Cubesats have been mentioned as possible future platforms for scientific missions, and a number of surveys of nanosatellites, picosatellites, and CubeSats are available in the literature. Bouwmeester and Guo published a survey of pico- and nanosatellite missions. It gives a general overview of Cubesat capabilities. Klofas et al[6], wrote a survey of Cubesat communication systems. Woellert et al[7], have a section devoted to Earth observation in his paper on “Cubesats as cost effective science and technology platforms for emerging and developing nations”, but the section was not exhaustive. Greenland and Clark published an assessment of the capabilities of Cubesats as platforms for science and technology validation missions. However, to the best of our knowledge, no exhaustive survey has been done for Earth observation Cubesats.

As mentioned before, a big majority of Cubesat missions are primarily educational, or used as technology demonstrators (e.g., CP-1, BeeSat, and NanoSail-D). Therefore, most Cubesats do not have stringent scientific requirements. However, they sometimes carry some instruments related to Earth science, either as primary or secondary payloads, typically low resolution CMOS cameras, or space weather sensors. For instance, Aerocube-2 and 3, Compass-1, CAPE Libertad 1 , HiNCube, and ITÜpSAT and, carried modest resolution (e.g., VGA 640×480 pixel) CMOS cameras, and the KUTESat Pathfinder, ICECube 1 and 2, AAUSat-2 Explorer-1 Prime, Goliat, UniCubeSat, Heidelsat, XatCobeo, Robusta, AtmoCube, Sacred, HawkSat-1, and Merope all carried space weather sensors[7].

Below are table shows summary of four Cubesat from the previous mission:

Cubesat	*Institution*	*Payload*	*Measurements*	*Launch date*
QuakeSat	Stanford University and Quake LLC	AC Manometer	Ultra low frequency (ULF) magnetic signal from earthquake	2003 (success)
ION	University of Illinois at Urbana-Champaign	Photometer and 640x480 pixel CMOS colour camera	Oxygen emissions band in the 100km upper atmosphere	2006 (launch failure)
CanX-2	University of Toronto	Atmospheric spectrometer, and GNSS receiver in occultation geometry	1km horizontal resolution tropospheric total column	2008 (success)
SwissCube-1	Polytechnic School of Lausanne	Passive optical telescope with 188x120 pixel camera	Oxygen emission band in the 100km upper atmosphere	2008 (success)

Table 2. 3 Cubesat Previous Mission[8]

<u>QuakeSat</u>

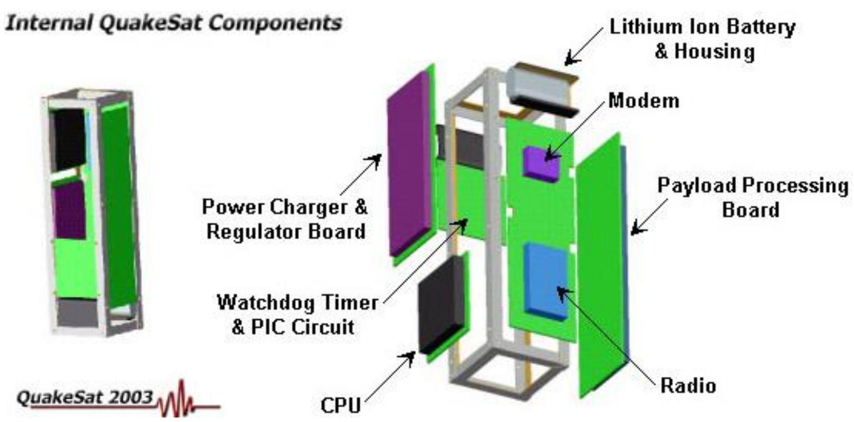


Figure 2. 1 Internal QuakeSat Components[9]

QuakeSat has been developed by the Space Systems Development Laboratory (SSDL) in order to study earthquake phenomena from space. It is primary scientific mission is to detect, record and down-link Extremely Low Frequency (ELF) magnetic signal data for predicting earthquake activity. The satellite was built using COTS components and is a "CubeSat" according to the standard proposed by Stanford University. It was deployed in a sun-synchronous, Low Earth Orbit with an altitude of 650 km and has an expected lifetime of one year[9].

ION-F

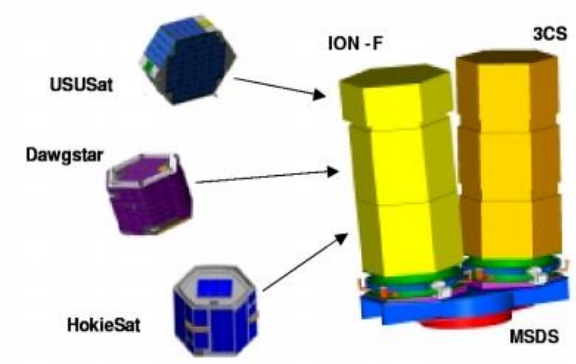


Figure 2. 2 Ion-F Satellite[9]

Founded by the United States Air Force Office of Scientific Research (AFOSR) and the Defense Advanced Research Projects Agency (DARPA), along with various industry partners, the Ionospheric Observation Nanosatellite Formation (ION-F) consists of ten nanosatellites designed and built by American universities. Key goal of this project was to demonstrate the military usefulness of nanosatellites in areas like formation flying, attitude control, maneuvering and communications. Again, the satellites will be carried in a piggy-pack manner as secondary payload of an upcoming International Space Station (ISS) construction mission[9].

CanX-2

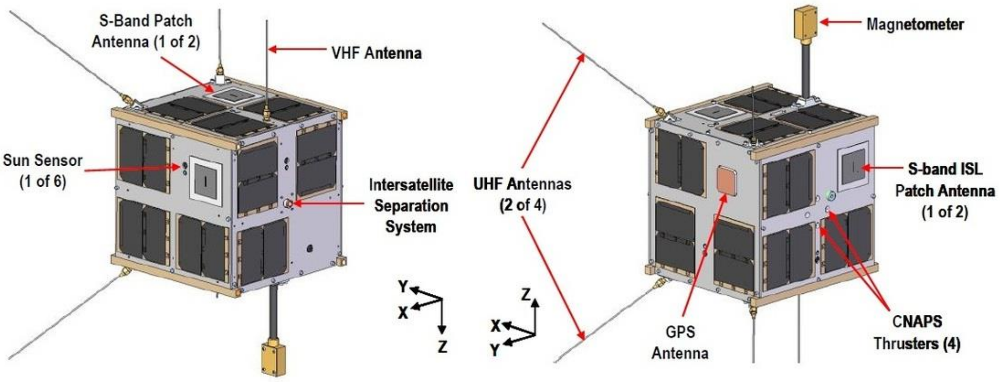


Figure 2. 3 Canadian Advanced Nanospace eXperiment (CanX)

The Canadian Advanced Nanospace eXperiment (CanX) 1U CubeSat program of the Space Flight Laboratory at the University of Toronto Institute for Aerospace Studies (UTIAS/SFL) developed the first Canadian CubeSat, CanX-1 (see figure 2.3). Main purpose of the CanX program is research and education, CanX-1 was launched in 2003 in order to verify several novel electronic technologies in orbital space. This satellite was built according to the CubeSat specifications and was equipped with color and monochrome CMOS imagers for imaging star fields, the moon, and the earth. Additional payloads include a GPS receiver and an active magnetic control system. It was deployed into a 650 km, sun-synchronous baseline orbit together with several other CubeSat[9].

SwissCube-1

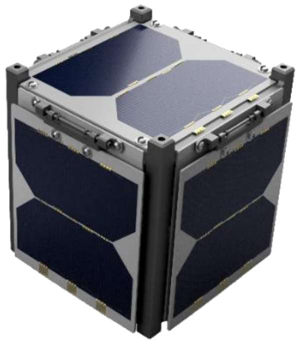


Figure 2. 4 SwissCube Satellite

SwissCube is the first entirely Swiss picosat program. The structural subsystem is unique as it interacts with all other subsystem. The structural configuration is limited by CubeSat specification, and thus it is the structural design that imposes physical constraints on other subsystems, which is different from other space mission[5]. This makes the structural subsystem unique as it interacts with all other subsystem. In the SwissCube mission, this subsystem needs to provide a simple sturdy structure and a suitable environment for the operation of all subsystems, while providing an easily accessible data and power bus. Moreover, the structural subsystem shall carry, support, and mechanically align the spacecraft equipment[5].

2.3 Chassis Design

The primary requirements on the structures subsystem are to satisfy the external requirements placed on the design by the CubeSat launch interface, as well as provide adequate interfaces to each subsystem to ensure safe passage through all phases of the mission. In additional, an ability to accommodate multiple science and payloads with little or no modification of the design is a strong driver[10]. A further requirement is ease of fabrication and assembly of both the satellite structure and the satellite as a whole.

From analyzing previous CubeSat projects, there are several design trends could be observed and then applied to selecting a CubeSat design. The structural designs come in two configuration: models formed from a solid block of aluminum (monoblock), and those assembled from multiple frames (modular frame). There are pros and cons associated with each design approach. Monoblock designs tend to be lighter and more rigid because they do not experience concentrated stresses due to fasteners during assembly. Because forming thin shapes from solid blocks of aluminum, however, can leave residual internal stresses in the structure, which can be difficult to detect. Machining models in this manner may also be very difficult or else can became impossible depending on the machining capabilities. Another disadvantages from forming shapes from a solid block of aluminum is that the material is not used efficiently, resulting in excessive waste of aluminum.

The structures subsystem design consists of three types of parts: rails, beams, and panels. The rails make up four parallel edges of the CubeSat and their dimensions are defined by the CubeSat launch interface. The beams are epoxied to the rails to create the other eight edges of the CubeSat. Three side panels are epoxied to the beams and rails in a U-shape to form half of the external surface of the satellite[11]. The final three sides are formed by a single U-shaped panel that can be fastened in place following integration of internal components. Internal components are fastened to the structure as a single package using brackets and fasteners. While, a modular frame which model assembled from multiple panels will typically be easier to machine and experience less residual stresses during assembly.

As an example, the previous flown model M-Cubed structure has been developed in-house according to CalPoly's CubeSat specification. This CubeSat model use multiple frame as their design approach and It consists of six iso-grid aluminum 7075 panels and four aluminum 6061 hard anodized rails. The current structure has a Safety Factor of 6 under the launch load of the Minotaur IV launch vehicle, the worst case scenario. The next iteration of the structure will reduce the safety factor to 1.5 or above in order to minimize the mass[1].

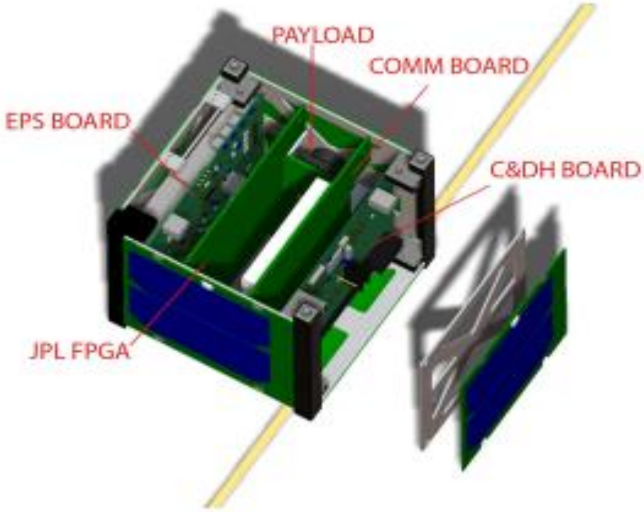


Figure 2. 5 M-Cubes CAD with JPL Payload

The structure has enough volume to add a secondary payload since only about half of the volume is being used. Currently 87% of the 1 kg allotted mass is being used, with 30% contingency on components that have not been measured and 5% for those which have been[3]. The mass budget also includes a 100 g system contingency allowing for the secondary payload to be accommodated within M-Cubed.

Next is a CUTE-1 CubeSat. Since there are shape limit, 10cm × 10cm × 10cm, and weight limit, less than 1kg, it is very important to achieve an efficient configuration of satellite components, and lightweight design. Figure 2.7 shows the CUTE-I structure.

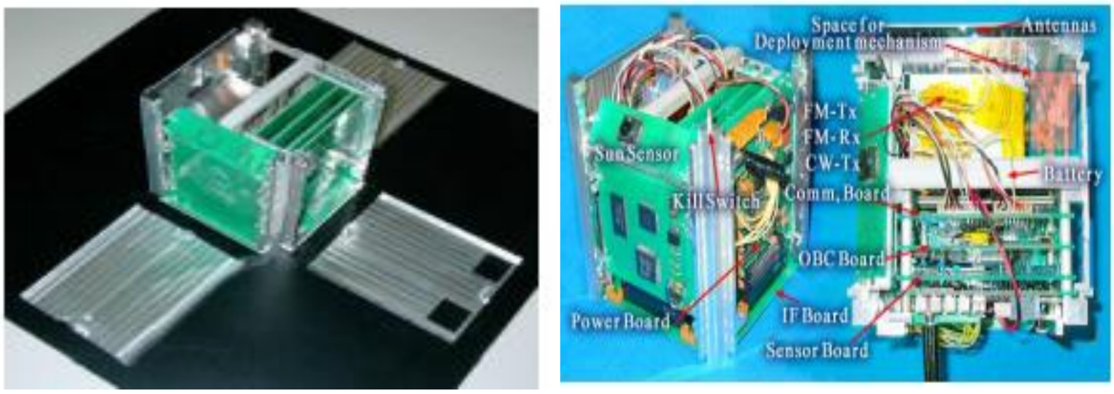


Figure 2. 6 Cute-1 Structure & Internal Configuration

The main structure consists of four pillars and walls. It also indicates the CUTE-I component configuration. As shown in figure above, CUTE-1 use layer structure to hold circuit boards, so that it can save space[9].

FOX-1 is the first CubeSat for (Amateur radio Satellite Organization Worldwide) AMSAT. The FOX-1 structure is a bent aluminum sheet metal in order to offer greater volume for internal PCBs and to eliminate a number of fastener joints. The PCBs are stacked with long corner screws and spaced with aluminum spacers for electrical and thermal conduction. The antenna is designed to wrap around posts above the +Y and -Y solar panels. The bend radius of this configuration is larger to overcome “sharp bend” problem which faced in previous FOX-1 design[9]. Figure 2.8 shows FOX-1 in stow configuration.

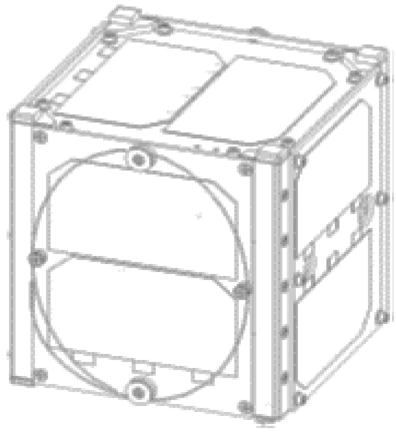


Figure 2. 7 Fox-1 in Stow Configuration[9]

One example of CubeSat which is using monoblock approach is EquiSat. It is still under development and targeted to fly in year 2018. It is first nano satellite designed by under graduated student from Brown University. Since monoblock approach is been used, EquiSat is milled out from a single block of Aluminum 6061. This approach is allows them to easily customize their design. The rails are designed in accordance to strict NASA specifications, so three can be stacked in a P-POD. The rest of the chassis was designed specifically to fit and properly secure their payload.

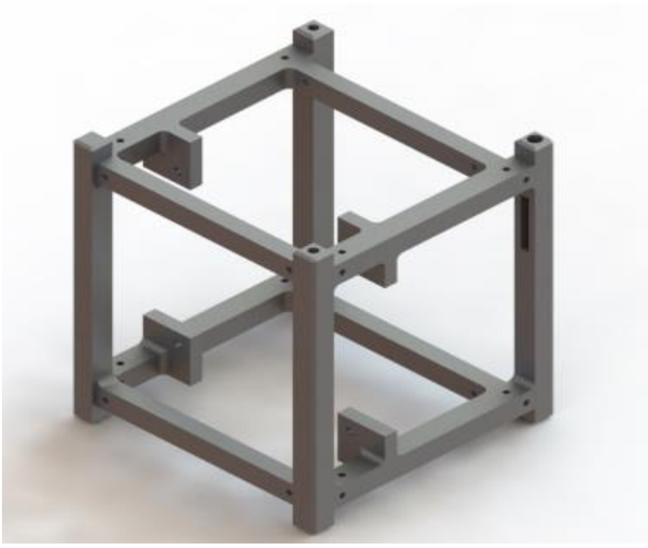


Table 2. 4 Monoblock CAD Drawing of EquiSat

2.4 Internal & External Configuration

Figure 2.10 is a series of diagrams outlining the spacecraft's external configuration. Based on the CubeSat missions, it have slightly different external configuration needs. Common external components include solar cells and a communications antenna, and both configurations provide access to an ethernet port and a kill switch as specified by the CubeSat specification[10].

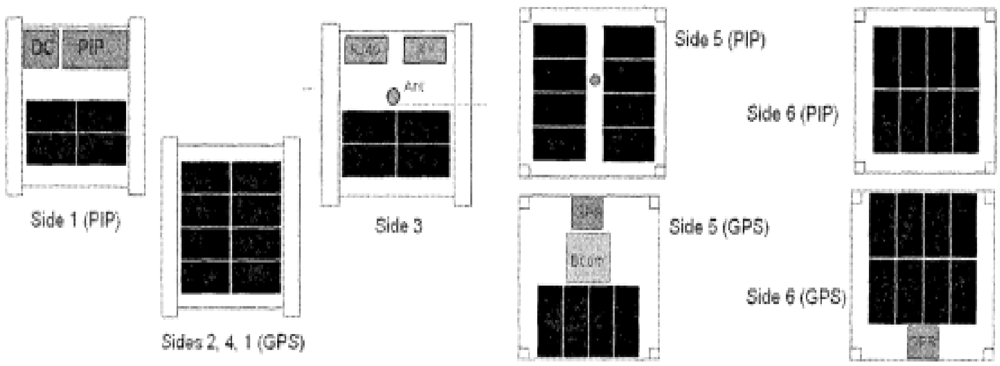


Figure 2. 8 Outline of External Cubesat

Based on OpenOrbiter CubeSat, it is a demonstration spacecraft for the Open Prototype for Educational NanoSats (OPEN) program. The OpenOrbiter mission is to implement the designs created by the program. Straub *et al*.[12] describe the technical advancements achieved by OpenOrbiter. It places the subsystem circuit boards on the four sides of the spacecraft and allows payload/mission-specific component placement in a 5 cm × 5 cm × 10 cm area in the middle of the spacecraft. This facilitating the effective use of the overhang space included in the CubeSat specification[12]. The CubeSat configuration has a tight dimension and volume constraints which make the effective usage of space will be very important. The OPEN design seeks to maximize the volume available for other subsystems and payload elements while minimizing mass consumed by the structure. Figure 2.11 shows the internal configuration of OpenOrbiter[12].

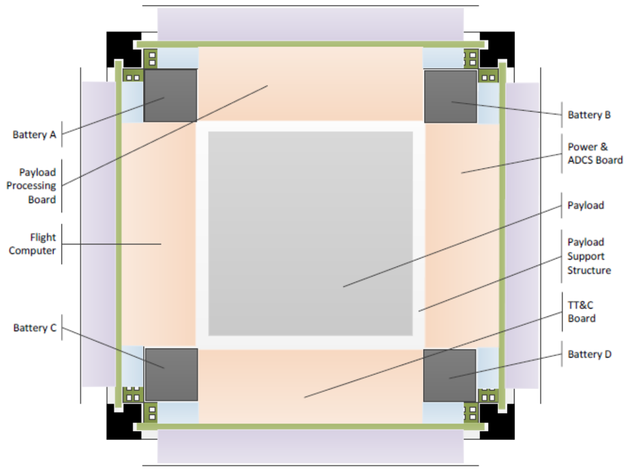


Figure 2. 9 Internal Configuration of OpenOrbiter

Arce *et al*.[7] describes three types of PCB board arrangement methods, stacking, slotting and sides in their study. The stacking method is commonly used. A secondary structure formed with all the subsystems stacked inside. The secondary structure will be fixed in the primary structure. This method provides high rigidity to the system. However, a secondary structure will add mass to the system and the connection between non-neighboring subsystems is difficult. Next, slotting is by placing all the PCB boards within a motherboard. With this arrangement, almost no wires needed to connect between subsystems. This can greatly reduce the risk of error during assembly. The last method is by attaching all the subsystem to the side plate of the CubeSat. The usage of space can be maximized and create more space at the center. The disadvantage of this method is the connection between subsystems is difficult.

Normally, there are three configuration methods are commonly used. First, by attaching all the subsystem to the side plate of the CubeSat. The usage of space can be maximized and create more space at the centre. The disadvantage of this method is the connection between subsystems is difficult. Complicated wiring has to be made to connect the electronic subsystems.

Next is stacking method. A secondary structure formed with all the subsystems stacked inside. The secondary structure will be fixed in the primary structure. This method provides high rigidity to the system. However, a secondary structure will add mass to the system and the connection between non-neighboring subsystems is difficult.

Lastly, slotting mechanism is by placing all the PCB boards within a motherboard. With this arrangement, almost no wires needed to connect between subsystems. This can greatly reduce the risk of error during assembly. Figure 2.15 shows all three example of internal configuration.

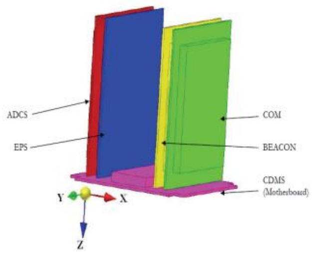
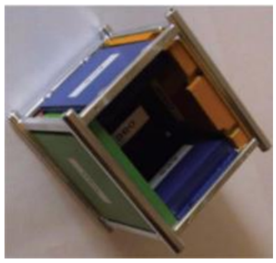
Stacking configuration	**Slotting configuration**	**Side plates**
		

Table 2. 15 Example of Internal Configuration

2.5 Material Selection

The selection of material is one of the significant steps on designing of satellite structure. Since weightiness is an important factor for on-orbit object. Specially, for a 1U CubeSat, small changes on the structure can result in valuable space for other subsystems and components. Not only weight factor, but also strength, stiffness, thermal conductivity, thermal expansion, manufacturability, and cost factor are considered during the satellite design. Material requirements, in line with the space environment, are given below:

- All materials that will use in satellite should be selected from list that NASA determined.
- Thermal expansion coefficient of the selected material should be similar with the material of deployment mechanism.
- Yield strength of the selected material should be bigger than max Von Mises stress.
- The material should be easy manufacturability.
- To minimize the mass the material that has low density should be selected.
- The material that has low out-gassing property should be selected.

CubeSat design specification (CDS) provides AL 6061 and AL 7075 as the mainstream two alternatives for CubeSat structure materials. By considering weight, strength, coefficient of thermal expansion, manufacturability, and the cost criteria, AL-7075 is selected for the material selection of the ITU pSAT II structure[13]. Even though AL 6061 T6 is lighter than AL 7075, we selected AL 7075 because of the fact that it has easier manufacturability. This is in compliance since the major material of the launch PODs is usually AL-7073-T73.

The Satellite Solutions CubeSat Design Team from University of Texas at Austin has developed a CubeSat to be launched on an ARLISS rocket in August of 2003. Grag *et al.*[1] discussed the consideration on material selection for the CubeSat. The criteria for selection were based on characteristics, strength, weight, machinability and cost. Generally, the material used for CubeSat is Al 7075-T6 or Al 6061-T6 as mentioned from the CubeSat specification.

Besides, magnesium alloy was utilised by Nakaya *et al.*[11] for some structure parts to achieve lightweight structure. Alloy other than aluminum requires verification to be used depending on the deployer used.

2.6 Structural Analysis

There are a few types of loads and stresses, including random vibration, structural loads, sine vibration and mechanical shock. The analysis that is most critical and most physically taxing to the structure of a CubeSat is the random vibrational analysis which ensures the structure survives the launch and can be ejected from the launch vehicle safely. The von Mises stress, a general stress term calculated from the stress tensor of a material at a given time, and structural deformation are important considerations in the vibrational analysis[14]. A material starts to deform when the von Mises stress reach the yield strength of the material. The Cal Poly CubeSat Specifications state that:

> *"Testing Requirements Testing shall be performed to meet all launch provider requirements as well as any additional testing requirements deemed necessary to ensure the safety of the CubeSats and the P-POD. If launch vehicle environment is unknown, GSFCSTD-7000 shall be used to derive testing requirements." (Calpoly 2009).*

Three different tools have been considered for performing structural analysis on the CubeSat: SolidWorks, NASTRAN (MacNeal-Schwendler Corporation Santa Ana, CA), and ANSYS (ANSYS Inc. Canonsburg, PA). Each program's capabilities and limitations have been research. The research primarily consisted of choosing a program that had the ability to do random vibration analysis[13].

ANSYS is capable of both structural static analysis and transient dynamic analysis. Transient dynamic analysis is used to determine the response of a structure under the action of any general time-dependent loads. ANSYS calculates the time varying values of displacement, strain, stress, and force as the simulated structure responds to any combination of static, transient, and harmonic loads.

OUFTI-1 structural analysis main result are summarized in table below.

Loading	***Max. Displacement (mm)***	***Max. Von-Mises stress (Mpa)***
X-Case	0.053	9
Y-Case	0.052	8.99

Table 2. 6 Static FEA Result [13]

Figure 2.12 present displacement in one of the case study of modular frame from OUFTI-1. The structure is pushed as a rigid body in a parallel direction to the P-POD while both upper and lower plated are deformed at the feet location. The maximum displacement occurs on the base plate, at the forces application points. This can be explained with global symmetry of the (CubeSat Kit) CSK structure. The maximum Von Mises stress appears on the end plate, at the joint with the chassis.

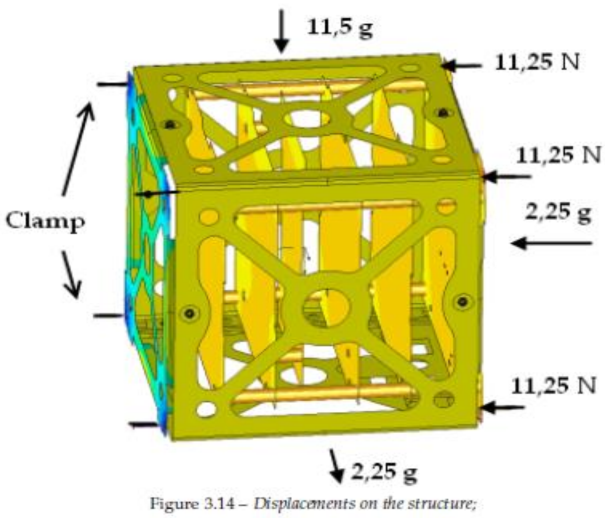


Figure 2. 10 Displacement of the Structure[15]

CHAPTER 3

METHODOLOGY

3.1 Design Process

The specification of CubeSat is provided by the manufacturer of CubeSat deployer which must be followed in the design of Mysat. The structural analysis on the chassis of MYSat will be done by using ANSYS to demonstrate the ability of MYSat structure to withstand the loads. After covered the structural analysis, structure will be fabricated by 3D printer and CNC machine to examined for design flaws, fitting and suitability of manufacturing process.

3.1.1 Work Breakdown Structure (WBS)

Figure 3.1 describe the process taken in conduction this project.

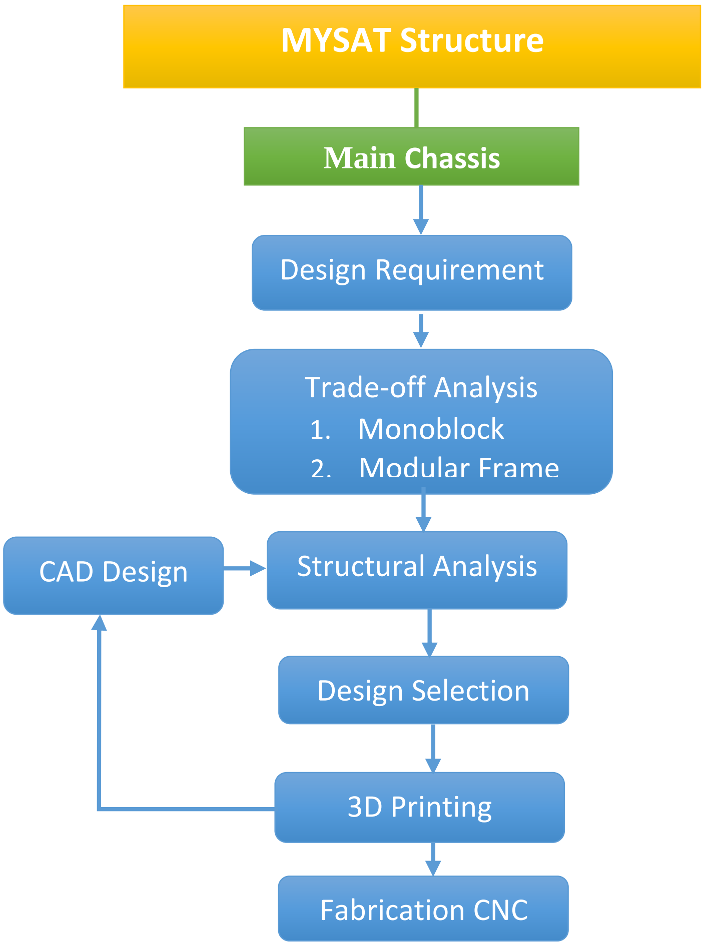


Figure 3. 1 Design Process of MYSat Structure

The above flow chart (figure 3.1) shows the design and analysis process of MYSat. The study begins with defining the functional requirement of structural subsystem. The design specification from J-SSOD and other subsystem requirement are defined in this step. Next, the study continues with the design of structural subsystem. The design process includes the trade-off studies of main chassis design, material selection, fastening selection and internal structure configuration.

The structural analysis of the main chassis is carried out after the design process. Static, modal and random vibration analyses are conducted on the main chassis design. If the design failed, modification will be done on the design. Modified design will reinsert in the structural subsystem and analysis will carries out again until the design pass the analysis.

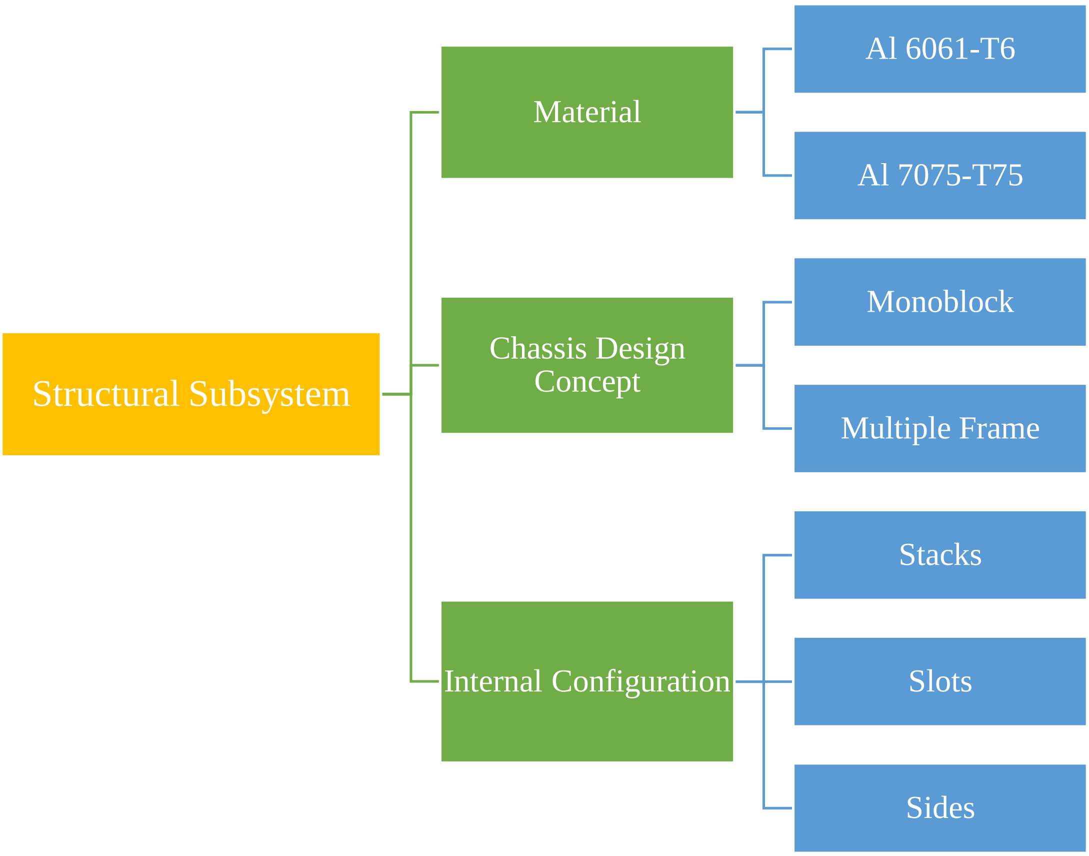


Figure 3. 2 Trade-off Studies of Structural Subsystem

On the other hand, the design process includes the trade-off studies of main chassis design, material selection, fastening selection and internal structure configuration. Figure 3.2 shows the trade-off studies conducted for the MYSat structural subsystem.

3.2 CubeSat Design Specification

Requirement of structural design is based on deployer interface and each deployer service provider has their own specific requirements. JAXA deployer, J-SSOD is one of the deployer used to deploy the CubeSat from the ISS. The requirements of deployer interface have been derived based on the "JEM Payload Accommodation Handbook - Vol. 8- Small Satellite Deployment Interface Control Document" is required to be followed in the CubeSat design. This document is issued by JAXA for the satellite to be deployed from the ISS Kibo[19].

3.2.1 Interface Requirements for 10cm Class Satellite

According to the handbook, when the CubeSat installs into the J-SSOD, the axes for both coordinate syst ems, CubeSat and J-SSOD must be aligned. The following figure shows the coordinate system definition from the handbook[19].

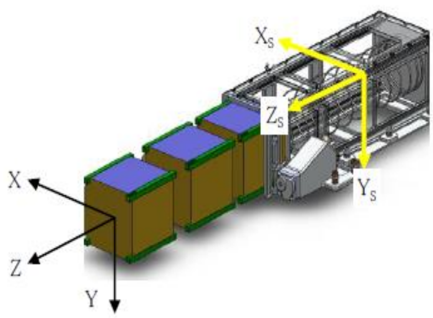


Figure 3. 3 Coordinate System Definition[19]