Sudan University of Science and Technology

College of Graduate Studies

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of M.Sc. in mechanical Engineering (Power)

Design and Thermal analysis of ISRASAT1 Cube satellite structure

التصميم و التحليل الحراري لهيكل القمر الإصطناعي المكعب إسراسات1

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August 2017

الآية

قال تعالى:

لِمُسْتَقَرٍّ لَهَا ذَلِكَ تَقْدِيرُ الْعَزِيزِ الْعَلِيمِ (38) رَ

ازِلَ حَتَّى عَادَ كَالْعُرْجُونِ الْقَدِيمِ (39) لَا الشَّمْسُ يَنْبَغِي لَهَا

أَنْ تُدْرِكَ الْقَمَرَ وَلَا اللَّيْلُ سَابِقُ النَّهَارِ وَكُلٌّ فِي فَلَكٍ يَسْبَحُونَ (40))

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ACKNOWLEDGMENTS

After an intensive period of 6 months, today is the day: writing this note of thanks is the finishing touch on my thesis. It has been a period of intense learning for me, not only in the scientific area, but also on a personal level. Writing this thesis has had a big impact on me. I would like to reflect on the people whom have supported and helped me so much throughout this period.

I would like to thank my thesis advisor, Dr. Eihab Abdelraouf Mustafa for his patience and critical opinions that have helped me tremendously during the initiating, developing and revising of this thesis. I also would like to thank the staff of institute of space research and aerospace (ISRA) particularly colleagues working on the ISRASAT1 cube satellite project in the institute, for continuous support and everlasting help, especially my colleague Yousf Sideeg who working together in the structure team.

Thanks also to Al Shashara Factory for manufactured the ISRASAT1 structure and good dealing. Especial thank for my colleagues Eng. Asia Saeed Kajo, head of Aerospace department in ISRA for her continuous support and help.

Finally, I want to give my gratitude to my family, my parents, my brothers and my sisters without whose emotional support the completion of my thesis be merely impossible.

ABSTRACT

ISRASAT1 is the cube satellite being devolved by the Institute of Space Research and Aerospace (ISRA) to orbits at 450 km above the Earth. The main mission of ISRASAT1 is to take images from space, transmit it to ISRA ground station while transmitting a beacon signal all the time. ISRASAT1 subsystems are the onboard computer subsystem (OBC), electrical power subsystem (EPS), attitude determination and control subsystem (ADCS), communication subsystem (COMM) and payload subsystem (PS), which are integrated to achieve its mission. All these subsystems of ISRASAT1 are enclosed in one structural unit that designed to meets the mechanical dimensions of P-POD launcher and to provide housing for ISRASAT1 subsystems, together with adequate interfaces to each subsystem to ensure safe operation through all phases of the ISRASAT1 mission. The structure designed to prevents ISRASAT1 subsystem form space environment such as the effect of the thermal transfer, radiation, and the solar particles energy. Also to absorb the shocks and vibrations during the launching phase and the different disturbance torques acting on it. Furthermore, the structure designed to ensure the continuity of power generation from solar cells for ISRSAT1 subsystems. This thesis discusses the design and manufacturing of ISRASAT1 structure, including material selection, 3D CAD design, yield strength analysis, weight distribution, mechanical antenna release and attachment, camera attachment, kill switch mechanism, power generation, and thermal analysis.

مستخلص

إسراسات1 هو نموذج لقمر إصطناعي مكعب صغير تم بناءه بواسطة معهد أبحاث الفضاء و الطيران لكي يدور علي بعد 450 كيلو متر من سطح الارض. الهدف الأساسي لإسراسات1 هو أخذ صور من الفضاء وا إرسالها لمحطة إسراء الأرضية مع الإستمرار في إرسال إشارات إرشادية للمحطات الأرضية الأخرى.

الأنظمة الفرعية لإسراسات1 هي نظام التحكم المركزي, نظام القدرة الكهربائية, نظام التموضع و التحكم , نظام الإتصالات و نظام الحمولة. والتي تتكامل مع بعضها لإداء مهمة القمر إسراسات1. كل الأنظمة الفرعية لإسراء توضع داخل الهيكل الخارجي الذي يوافق المقايس الميكانيكية للمركبة التي سيتم من خلالها إطلاق القمر (P-POD). وتوفير الحماية للأنظمة الفرعية و طرق توصيلها ببقية الأنظمة الفرعية الأخرى مما يضمن سلامة أدائها خلال المراحل المختلفة لإكمال مهمة القمر إسراسات1. صمم الهيكل لحماية الانظمة الفرعية لإسراسات1 من البئيه الخارجية, كتأثير الانتقال الحراري, الاشعاع, وجزئيات الطاقة الشمسية. أيضا صمم لإمتصاص الصدمات, والإهتزازات أثناء مرحلة الإطلاق و تأثير العزوم المختلفة عليه. إضافة الي ذلك صمم الهيكل للتأكد من استمرارية توليد القدرة من الخلايا الشمسية لأنظمة اسراسات1. هذا البحث يناقش تصميم و تصنيع الهيكل للقمر الإصطناعي المكعب إسراسات1 و الذي يحوى علي إختيار المادة, التصميم ثلاثي الابعاد و تحليلات قوة الخضوع, توزيع الأوزان,ميكانيكا إدخال و إخراج الهوائى و أضافة الكاميرا , مفتاح التشغيل للقمر,ضمان توليد القدرة و التحليل الحراري للهيكل.

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ABBREVIATIONS

ADCS	Attitude Determination and Control Subsystem
COTS	Commercial off-the-shelf
CS	Communication Subsystem
ECI	Earth Centered Inertial
EPS	Electrical Power Subsystem
FOS	Factor of safety
ISRA	Institute of Space Research and Aerospace
LEO	Low Earth Orbit
NCR	National Center for Research
OBC	On Board Computer
P-POD	Poly Picosatellite Orbital Deployer
PWM	PulseWidth Modulation
SPL	Single Pico-Satellite Launcher
T-POD	Tokyo Picosatellite Orbit Deployer
STK	Satellite Tool Kit

Chapter One

INTRODUCTION

1.1 Introduction

Recently, the developing of small satellite becomes significant trend in the area of space science and engineering research. Nanosatellite is the type of small satellite which has a mass range from 1 to 50 kg and it has advantages over traditional million dollar satellites due to their small sizes, light mass and needed short time for their manufacture.

The most representative class of Nanosatellite is the Cube Satellite which restricts developers to a volume of approximately 10 x 10 x 10 Cm^3 and its mass doesn't exceed 1.33 kg, it uses commercial off the shelf components (COTS) that make it of a low cost and commonly used for educational purposes in universities and institutions. The standard Cube Satellite size uses a "one unit" or "1U" and is extendable to larger sizes; 1.5, 2, 3, 6, and even 12U.

A cube satellite is a program birthed and developed by California Polytechnic State University (Cal Poly) and Stanford University's Space Systems Development Laboratory (SSDL) in 1999. It has achieved great success as a way to efficiently construct and orbit small, inexpensive satellites using commercial technology

Generally cube satellite is divided into several subsystems; onboard computer subsystem (OBC), electrical power subsystem (EPS), attitude determination and control subsystem (ADCS) , communication subsystem (COMM) and payload subsystem (PS), all these subsystems must work together to satisfy cube satellite mission, and all of them fit in box (cube sat structure) that satisfy the cube satellite specification .

The mechanism of satellites deployment in their orbits comes from California Polytechnic State University (Cal Poly) and Stanford University in 1999, it is called Poly Pico satellite Orbital Deployer (P-POD) .

P-POD standard plays a critical role as the interface between the launch vehicle and satellites. The Structure of cube satellite must satisfy the physical requirements of P-POD standard.

ISRASAT1 is a 1U cube satellite project initiated by the institute of space research and aerospace (ISRA) in Sudan. It developed by ISRA researcher's teams. The ISRASAT1 aims to transfer space technology and provide an educational and testing tool technology platform for researchers and students.

ISRASAT1 is designed to orbit at 450 km above the earth. The main mission of ISRASAT1 is to take an image when it reaches Khartoum state, and sent continues beacon signal to ground stations. ISRASAT1 has five subsystems onboard computer subsystem (OBC), electrical power subsystem (EPS), attitude determination and control subsystem (ADCS), communication subsystem (COMM) and payload subsystem (PS).

Satellite structure is the physical frame that the satellite is composed of. It houses all the electronics, communications and power equipment. According to cube satellite standard, weight and size shouldn't exceed 1.33 kg and 10*10*10 cm3 respectively. ISRASAT1 structure designed to satisfy the cube satellite and P-POD requirements because of that disturbance of weight between subsystems is a crucial point.

This project discusses the design and implementation of ISRASAT1 structure, including material selection, software analysis and design, weight distribution, antenna release and attachment, camera attachment and kill switch mechanism.

1.2 Problem Statement

While ISRASAT1 Cube Satellite payload was camera mission, and it had five subsystems fitted on it. The structure of ISRASAT1 cube satellite must be designed so it can with the standard of the P-POD (1.33 kg and 10*10*10 cm for mass and size respectively) to launch it on the space, and at the same time the structure must satisfy the constrains and avoidance of the electronic components from the difference disturbance, heat transfer and safe the power generation from solar cells or batteries to ISRASAT1 cube satellite which affect ISRASAT1 cube satellite subsystems functionality. So the design processes of the structure of ISRASAT1 cube satellite with the cube satellite specifications it will be Challenge and critical.

In this thesis the structure of ISRASAT1 cube satellite will disuses and address from start to completion, so all its hardware could fit and entire structure will purpose built.

1.3 Objectives

1.3.1 Main objective

Design and Implementation of ISRASAT1 Cube satellite structure.

1.3.2 General objectives

- To design structure that able to absorb the shocks and vibrations during the launching phase and the different disturbance torques acting on it.
- To design structure that able to prevents ISRASAT1 subsystem form space environment such as the effect of the thermal transfer, radiation, and the solar particles energy.
- To design the structure of ISRASAT1 cube satellite with standard specification.
- To select optimal materials for ISRASAT1 structure compatible with the space environment according to the selection criteria.
- To simulate the structure of the IRASTA1 cube satellite using software's.
- To position the component of ISRASAT1 such as battery pack, antenna and required launch deployment – switches.
- To integrate the ISRASAT1 cube satellite subsystems and fit it on ISRASAT1 structure
- To Implement the ISRASAT1cube satellite.
- To test the ISRASAT1 cube satellite structure against disturbance torques while it's in on orbit.

1.4 Methodology

- Acquire strong general mechanical concept development and materials selection of the satellite primary structure.
- Designing parameter of ISRASAT1 structure according to its specification.
- Modeling the main structure of ISRASAT1 software
- Modeling each subsystem individually.
- Assemble all subsystems in the main structure.
- Thermal analysis for the structure model using solid works software.
- Strengths analysis for the structure model using solid works software.
- Analysis main structure, subsystem and both of them after assembly.
- Implement ISRASAT1 final structure

1.5 Thesis Layout

This thesis is organized in five chapters, including this introduction. Chapter 2 contains a literature background and overview of cube satellite and their development in recent years, cue satellite subsystems, design constrain and shed a light into the structure subsystem in the cube satellite.

In chapter 3, summary of design and implementation of for ISRASAT1 cube satellite structure starting from the design specification of the cube satellite structure to the structure manufacture by using Software for designing and materials selection, then subsystems weight distribution forefather integration all subsystems together . After that, Chapter 4 presents a summary of thermal analysis of the cube satellite especially ISRASAT1 cube satellite at 450 km from the earth starting from the basic theoretical background to heat transfer, the space environment and analysis the data recoding used the software programs. Chapter five presented the thermal analysis results obtained from software simulation, software testing and manufacturing process of ISRASAT1 cube satellite structure. Finally, the result obtained from chapter 5 is discussed in Chapter 6that shows as well the overall comments of thesis in addition to conclusions and recommendation for future work. A list of references used during the research is shown at the end of the thesis.

Chapter Two

CUBE SATELLITES AND MECHANICAL STRUCTURE SUBSYSTEM

2.1 Literature Background

A cube satellite is a program started and developed by a collaborative effort between Prof. Jordi Puig-Suari at California Polytechnic State University (Cal Poly) and Prof. Bob Twiggs at Stanford University's Space Systems Development Laboratory (SSDL) in 1999.

Cube satellite program mission is to provide access to space using small payloads and it is purpose is put a standard for design to picosatellite, which can reduce the cost, development time for designing and launching and increase accessibility to space. Cube satellite has achieved very successfully in rent years all universities and institutions because it is using commercial technology and commercial off on shelf components (COTS) that make it low cost and commonly used. [1]

In the recent years, Cube Satellite projects have been highly successful and become global collaborative efforts. Such projects represent ideal platforms to demonstrate new technologies and concepts [2]. Multiple Cube Satellites were launched by many countries including Canada (CANX1), Japan (CUTE, XI-IV), Denmark (DTUSat), the Netherlands (AAUSat) and the United States (NarcisSat) [2].

Cube satellite is a type of Nanosatellites, which has light weight ranged from 1 to 50 kg, It’s developed in units that are each 10 cm x 10 cm x 10 cm, weighing about 1.33 kg maximum. And it frequently consists of multiple units of various configurations depending on the mission requirements [3].

Standard cube satellite is divided into many types depending on the dimensions, then start with smallest standard size is one unit 1U with size 10×10cm in X and Y directions and maxiumum113.5mm in Z direction while weighing no more than 1.33 kg and gradually increase the height to becomes 2U,3U,……6U. Figure (2.1) shows the cube satellite types according to the size and weight.

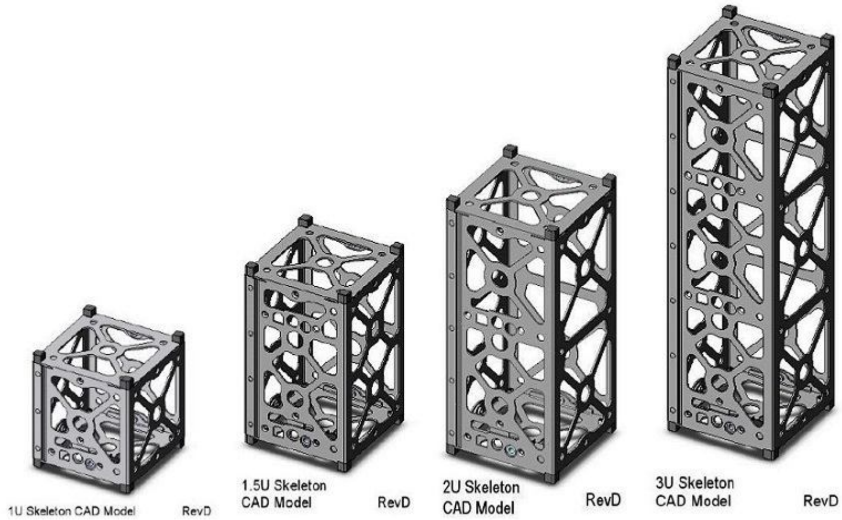
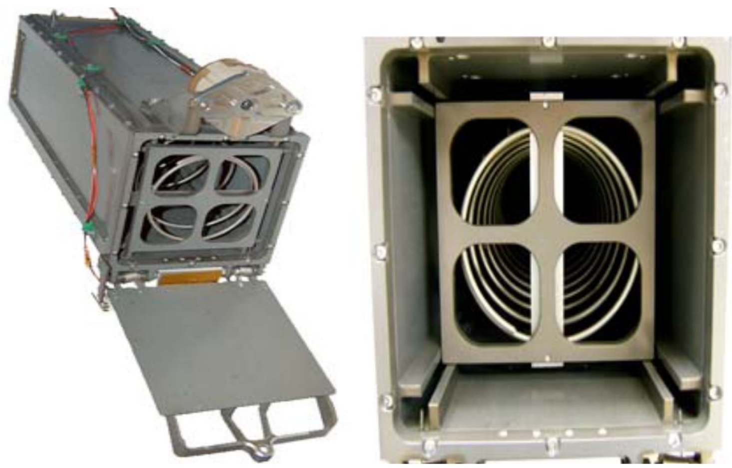


Figure 0-1: Cube Satellites Standards and Types.

The standardized size and mass would enable a standardized launcher to be developed, which would be suitable for secondary or tertiary launch opportunities. That would also enable the development of large numbers of experienced aerospace and astronautic engineers [4].

2.2 Cube Satellite Launch and Deployment

The mechanism of satellites deployment in their orbits comes from California Polytechnic State University (Cal Poly) and Stanford University in 1999, it is called Poly-Pico Satellite Orbital Deployer (P-POD) [1]. P-POD standard plays a critical role as the interface between the launch vehicle and satellites. The Structure of cube satellite must satisfy the physical requirements of P-POD standard [4]. The P-POD is a rectangular box with a back door and a spring mechanism once the release mechanism of the P-POD is energized by a deployment signal sent from the low volt (LV), a set of torsion springs at the door hinge force the door open and the Cube Satellites are deployed by the main Spring gliding on its rails and the P-PODs rails. The P-POD made of aluminum alloy to ensure safety and success of the mission. Currently, the P-POD developed for 1U and 3U Cube satellite. Now a day, there is currently research underway to develop a 5U P-POD and a 2 x 3 or 6U P-POD at Cal Poly. In order to ensure successful integration with the P-POD and standardization of all Cube satellite design specifications have been defined for developers by Cal Poly. Figure (2.2.a) and Figure (2.2.b) shows P-POD deployer and its dimension [2].



a. P-POD b. Cross Section

Figure 2-2: Poly Picosatellite Orbital Deployer.

2.3 General Cube Satellite Specification

Generally, the specification of the cube satellite classified into the mechanical, electrical and operational design constraints, all the mechanical and some general specification applied to the structure of the cube satellite.

The general specification also describes the steps process that must be followed when the satellite deviates from the specification set. Furthermore, the specification must also definethe testing requirements that must be met by the Cube Satellite to be accepted for launch. These testing requirements include Random Vibration, Thermal Vacuum Bakeout, Visual Inspection, Qualification, Protoflight, and Acceptance.

2.3.1 Mechanical and Structural Cube Satellite Specification

Generally, the dimensions of the cube satellites are the critical issue so, the standard specification must be followed to ensure compatibility between the cube satellite and the launch vehicle (P-POD). The basic configuration dimension of the cube satellite is listed in Table (2.1) while the schematic diagram of 1U cube satellite shown the figure (2.3).

As shown in the diagram, during the integration, the P-POD contacts the rails along the corner of the cube which has a size limited by 10*10*10 cm. [1]. A coordinate system defined in the design specifications [ ] orients the Z-axis parallel to the four rails.

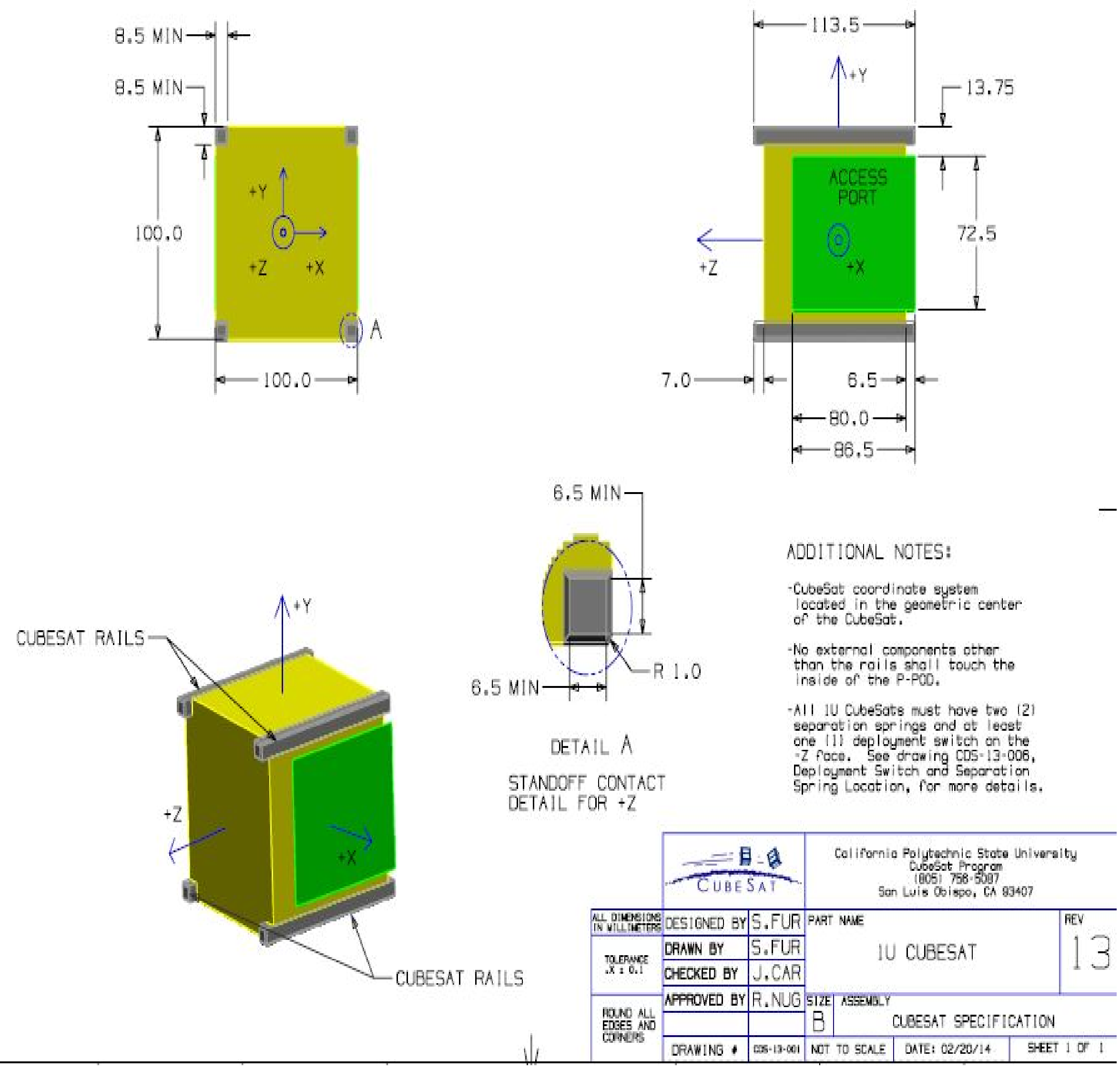


Figure 0-3: 1U Cube satellite specification diagram . [1]

Table 2-1:critical dimension for 3 primary cube satellite sizes[5]

Cube satellite size	**1U**	**2U**	**3U**
X and Y dimension [mm]	100 ± 0.1		
Z Dimension [mm]	113.5 ± 0.1	227 ± 0.2	340.5 ± 0.3
Rail Width [mm]	8.5 x 8.5 mm MIN		
Rail Contact w/ P-POD (75 % of Z Dimension) [mm]	85.1 (minimum)	170.2 (minimum)	255.4 (minimum)
Component Protrusion normal to cube surface [mm]	6.5 mm (maximum)		
Mass [g]	1330 (maximum)	2660 (maximum)	4000 (maximum)

The rails are the only cube satellite component that may directly contact the P-POD so deployer component of the cube satellite must restrict with the cube satellite specification rather than P-POD specification.

Separation springs have been built in one of the cube satellite rails when integrating 2U with 1U in the P-POD to separate from each other after deployment but in the 3U cube satellite, there is no need tobuild separation springs if its only one 3U fit into the P-POD.

The specification specifies that the 7075 0r 6061 Aluminum alloys as the rails structure material which prevent cold welding of the surfaces of the Cube satellite to the P-POD and ensure the thermal expansion of structure material will be similar to P-POD.[5]

2.4 Cube Satellite Architecture and Subsystems

Cube satellite consists of several subsystems that play vital roles to carrying out the mission of the satellite developed for it, all these subsystems accomplish its function and other subsystems and work together to achieve cube satellite design requirements, these subsystems are communication, payload, power, onboard computer and the attitude determination and control subsystem.[2]

2.4.1 On Board Computer

The onboard computer is the heart of the cube satellite system which plays a critical role in data exchanging and synchronization between satellite subsystems.

OBC subsystem composed of both hardware and software components. Hardware component contains all the physical components and consists essentially of a micro controller with the various peripherals interface and supporting hardware with a memory module to store program data. [2]

2.4.2 Electrical Power Subsystem

The electrical power subsystem (EPS) is responsible for providing the power needs of the cube satellite are met. This includes generating power, conditioning and regulating power, storing energy for use during periods of peak demand or eclipse operation, and distributing power through the cube satellite.

Power subsystem consists of three basic building blocks: power sources, energy storage, and power management and distribution. A typical Cube Satellite design uses solar cells for power generation and a small battery for storage. [2]

A solar cell is an electrical device made of semiconductors and chemical materials that converts light energy into electrical energy by the photovoltaic effect. There are several different types of solar cells with different efficiencies. [2]

2.4.3 Communication Subsystem

The Communication Subsystem (COMM), which is also called telemetry, tracking, and command (TT&C) subsystem, provides the link between the satellite and ground station. Essentially, there are two free space link channels between the satellite and ground station; namely uplink (from the ground station to satellite (telecommand)) and downlink (from satellite to ground station (telemetry)).

The communications link is made possible by applying RF transmitters and receivers that are coupled to high gain antennas, onboard the satellite and on the corresponding ground station [2].

2.4.4 Payload Subsystem

Satellite mission is determined by payload subsystem (PS), which may include communication system imager or scientific measurements probes. In order to increase effectiveness in terms of cost and integration, it is common to combine two or more types of payloads on a single satellite, specifically the payload always camera [2].

2.4.5 Attitude Determination and Control Subsystem

The Attitude Determination and Control Subsystem (ADCS) subsystem is a stabilization mechanism made of actuators and sensors connected in a loop in order to keep the satellite's orientation steady and ensure it operates efficiently.[2]

2.4.5 Mechanical and Structural Subsystem

The structure in the satellite that is designed to provide the desired stiffness of the construction. It is made of a lightweight material that provides adequate interfaces to each other subsystem to ensure safe passage through all phases of the mission and has the ability to suspend all loads that affect the satellite on the space.

Generally, small satellite structure divides to two group that can flow in design procedures; the first group is made all structure as one unit called external structure as shown in figure (2.4), and the second group divides the structure into two part the main structure which is the outside and it is made contact with P-POD and have the standard dimensions, and secondary structure called internally structure which responsible for supporting the subsystems and share the load with main structure as shown in figure (2.5) .[5]

Generally, which design is following have external structure, so the structure specification are Rails shall have a minimum width of 8.5mm in X, Y directions which to made contact at least 75% of the rail with P-POD rails, the edges of the rails will be rounded to a radius of at least 1 mm, and The Cube Satellite center of gravity shall be located within 2 cm from its geometric center in the X, Y, Z directions.[1]

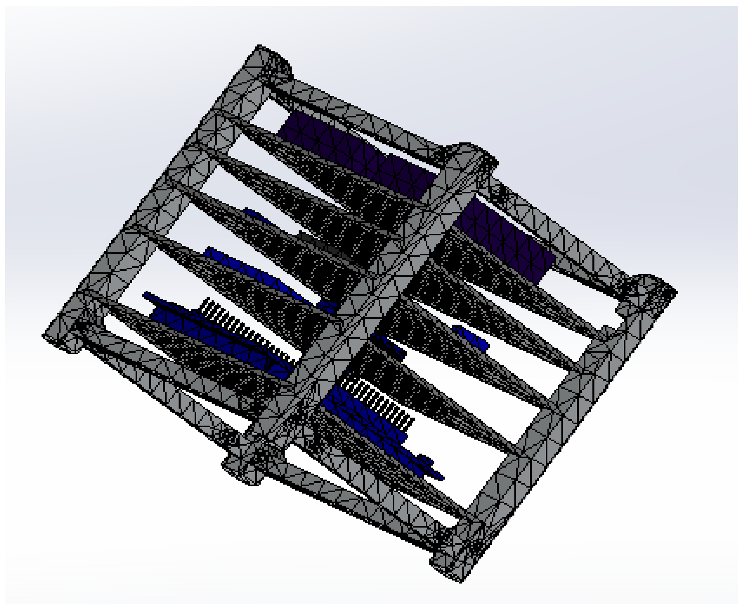


Figure 0-4: external of 1U cube Satellite structure.

Figure 0-5: external and internal of 1U cube Satellite structure.

2.4.6 Cube Satellites Center of Mass and Subsystem Weight Distribution

The distribution of weight of the cube satellite subsystems plays crucial roles into the stabilization of the cube satellites and its center of mass. Each subsystem has a limit of weight according to the standardization and specification of cube satellite that must never exceed it. According to standardization of the cube satellite and the specification of the Cube satellite the standard weight of each subsystemshown in the table (2.1). [1]

Table 2-2:1U cube satellite weight budget

	S/C (kg)
Payload	0.43
Onboard Processing	0.16
ADCS	0.08
Power	0.14
TT&C	0.16

2.5 Cube Satellite Testing Requirements

Testing requirement is one of the requirements that must be satisfied before launch the cube satellite into space and it considers as a necessary requirement because it ensures the safety of the P-POD, primary mission and cube satellite after the launch.

Generally, there are many standards of testing cube satellite; one of them is a The General Environmental Verification Standards (GEVS, GSFC-STD-7000) and MIL-STD-1540 which subjected to derive testing requirements if the launch vehicle environment is unknown. Also, GSFC-STD-7000 and MIL-STD-1540 are useful references when defining testing environments and requirements. Any Test requirements and levels that are not coming from launch provider or P-POD Integrator are classified to be unofficial. According to standard, before integrated cube satellite into the P-POD, the

P-POD must be tested with similar fashion to ensure the safety and workmanship. At the very minimum, all Cube Satellites will undergo the following tests. [1]

2.5.1 Random Vibration

Random Vibration Testing is one of the more common types of vibration testing, services performed by vibration test labs and Test specifications can be established from real environment measurements using an acceleration spectral density ASD envelope or a fatigue damage equivalence criterion. Random vibration testing shall be performed as defined by the launch provider. [1]

2.5.2 Thermal Vacuum Bakeout

Thermal vacuum bakeout testing is performed to ensure proper out gassing of subsystems components using thermal vacuum chamber by applying the satellite orbit conditions. It is specification will be outlined by the launch provider. [1]

2.5.3 Shock Testing

The shock testing is the acceptance of the cube satellite to the mechanical shock and verifies the good functionality of it after the shock .also the Shock testing shall be performed as defined by the launch provider. [1]

2.5.4 Visual Inspection

The visual inspection testing is testing to ensure the cube satellite isn’t suffering from Visual defects and it will be performed per the appropriate Cube Satellite Acceptance Checklist (CAC). [1]

2.6 Cube Satellite Testing Philosophy

The Cube Satellites in generally follow the procedure of testing include all different types of testing mentioned above. The figure (2.6) shows the standard step levels followed in cube satellite testing. The test levels will be supplied by the launch provider or P-POD integrator. [1]

Qualification testing is the first step that followed to identifies and determines if the engineering model identical to the flight model or not. And it's determined by the launch vehicle provider or P-POD integrator. The Qualification testing levels shall be subjected to the Both MIL-STD-1540 and LSP-REQ-317.01. Finally, to accept the level in a Test POD the random vibration test on the flight model will be done. Secondly, the proto-flight testing is determined by the P-POD integrator, the MIL-STD-1540 and LSPREQ-317.01 are used as guides in testing levels calculation before a final acceptance test. After the proto-flighttest, the cube satellite shall never disassemble or modified. Finally the acceptance after cube satellite integrated into the P-POD, to ensure the proper integration additional testing must be done using both MIL-STD-1540 and LSP-REQ-317.01 for guiding to determining testing levels. The developer will be responsible for any additional testing if the cube Satellite failure during integration. [1]

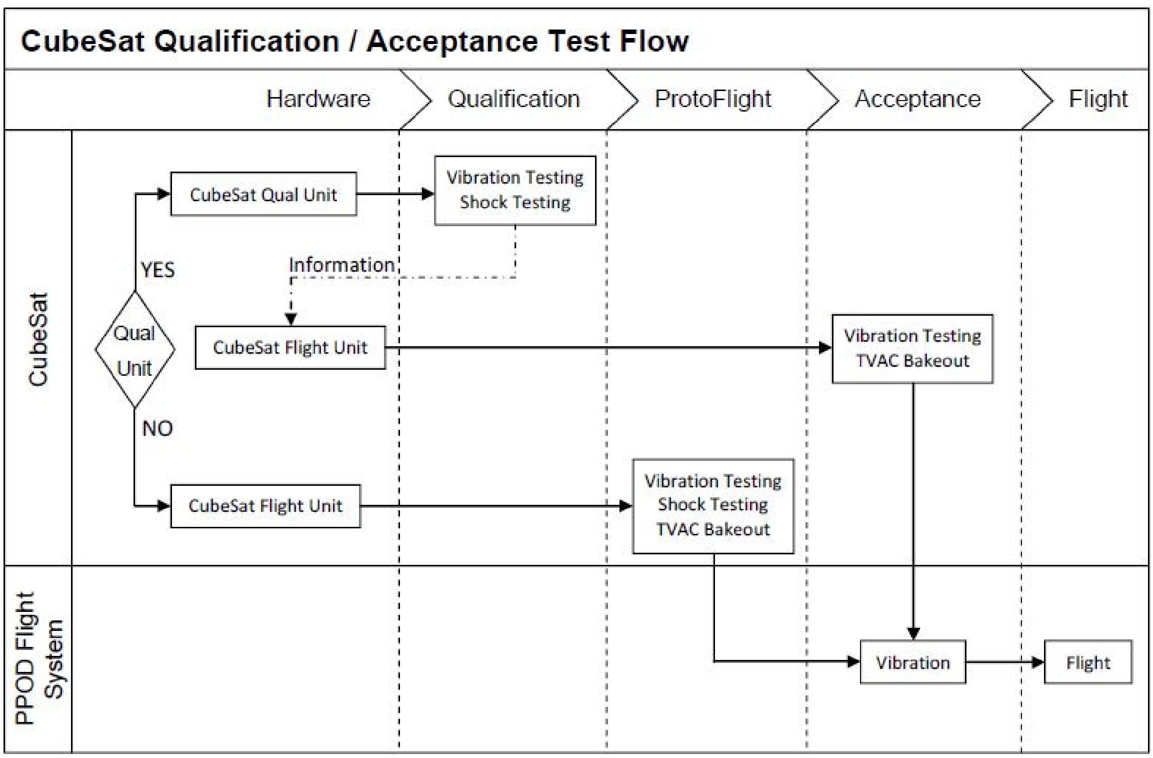


Figure 0-6: Cube Satellite General Testing Flow Diagram .[1]

2.7 Survey of Cube Satellite History

The cube satellite structure can be prefabricated with the vendors which provide structure according to the structure of the satellite, there are different companies that provide design and manufacture structure to the customers. Pumpkin and Innovative Solutions in Space (ISIS) are the biggest companies in prefabricated structure. The pumpkin manufacture only for cube satellites rather than ISIS which provide structures to the Micro and Nanosatellites.[6][7]

In another hand, the cube satellites structure can be built and manufacture from scratch by a servant. AAUA and DTUSAT-1 are the cube satellites developed by Demark. They were a simple structure consisted of one piece of aluminum 7075-T6 with the total mass equal to 123.8 g for AAUA. The second version of the DTUSAT consisted of a monolithic semi-cube (a cube with four faces instead of six) constructed from four printed circuit boards soldered together creating a sturdy structure with high resonance frequencies. [8]

SwissCube was cube satellites projects developed by the Switzerland goals to realistic learn the environments. As the AAUA structure, the SwissCube had a simple structure with low cost and maximum usable interior space. The structure manufactured using aluminum alloys with weight equal to 95 g. [9]

The Canadian Advanced Nanospacee Xperiment 1 (CanX-1) was a Cube Satellite built by the University of Toronto [10]. The total mass of the structure was 376 g used aluminum 7075 and 6061 alloys. [10]

The CUTE-1 Cube Satellite was a satellite developed by Tokyo Institute of Technology [11]. Also used aluminum alloys on its primary and secondary structure.

ITU was 3U Turkish Nanosatellite designed by Faculty of Aeronautics and Astronautics With one main structure with weight equal to 560 g [12] also KarpagaVinayaga College of Engineering & Technology was built 2U cube satellite with two structure internal and external structure and its weight was 400g.[13] NTNU, and STEP all of them were a Cube satellites projects consist of aluminum alloys in its structure[13] [14].

Chapter Three

Design and Implementation of ISRASAT1 cube satellite structure

3.1 Preface

This chapter introduces a brief abstraction about ISRASAT1 cube satellite with their specification and subsystems, also showed more details about the ISRASAT1 cube satellite requirements specifically mechanical structure for the ISRASAT1 Cube satellite.

The main contributions of the chapter are design process of the ISRASAT1 cube satellite structure and the manufacturing procedure which the structure followed. The chapter also presents the software and hardware integration of all ISRASAT1 subsystems on the designed structure. Furthermore software and hardware testing to cube satellite structure according to the specification.

3.2 ISRASAT1 cube satellite

ISRASAT1 is a cube satellite that is being designed at the Institute of Space Research and Aerospace (ISRA). It is designed to orbit at 450 km above the Earth. Itis developed to send a beacon signal to ISRA ground station and take an image when it reaches Khartoum state.

ISRASAT1 consists of five subsystems which are Electrical Power Subsystem (EPS), the Onboard Computer (OBC), Communication Subsystem (COMM), Attitude Determination and Control Subsystem (ADCS, and the Payload Subsystem (PS). All those subsystems work together to meet ISRATSAT1 mission requirements. ISRASAT1 structure designed to satisfy the cube satellite and P-POD requirements because of that disturbance of weight between subsystems is a crucial point.

3.3 Subsystem of ISRASAT1

3.3.1 Electrical Power Subsystem (EPS)

The Electrical Power Subsystem (EPS) of the ISRASAT1 responsible of generating, storing, controlling and distributing the ISRASAT1 subsystems electrical power. The EPS receives power from solar cells and stored it in a number of battery cells as a backup. Also, ISRASAT1 has requirements provided by the launcher and it has two deployment switches on the rail standoff at –Z plane and a Remove Before Flight (RBF) pin in order to prevent the electrical activation of the satellite in the deployer's Satellite Install Case.

3.3.2 Communication Subsystem

Communication subsystem provides the link between the ISRASAT1 and the ground station. It's responsible of transmitting telemetry (data gathered by ADCS and Camera) to ISRA ground station. It also transmits a beacon signal to ground stations. So the communication subsystem has a two antenna one for telemetry and second one for beacon.

3.3.3 On-board Computer (OBC)

The OBC subsystem is the subsystem responsible for synchronize and handling mission of ISRASAT1. Its main target is to collect data from different subsystems and housekeeping data according to its priorities. In addition, the OBC processes collected data and control the transceiver operation. OBC board consists of one microcontroller which represents brain of the ISRASAT1 cube satellite

3.3.4 Attitude Determination and Control Subsystem (ADCS)

The Attitude Determination and Control System ADCS is responsible for maintain the ISRASAT1 in the desired orientation by controlling the attitude of the satellite according to the attitude sensors reading. The ADCS subsystem consists form sensors to get the attitude of the satellite and actuators to control its orientation which can be located inside or outside the satellite. So it must be considered in the mechanical design of the satellite.

3.3.5 Payload description

Camera payload is implemented in ISRASAT1 prototype to take images of the Earth. The camera module must be mounted in to place that it can take high resolution images to transmit it to ground station.

3.4 Mechanical specification

ISRASAT1 followed the specification of the cube satellite which has size, mass and weight constrains, also it had a constrains and specification according to its mission, so far it has a mechanical subsystem specification according to the standard of cube satellite and ISRASAT1 mission. The points below show the general mechanical structure specification for ISRASAT1 cube satellite.

- The dimensions shall be 10*10 in X, Y directions and 11.5 in Z direction.
- Rails shall have a minimum width less than 8.5mm
- The ends of the rails on the +/- Z face shall have a minimum surface area of 6.5 mm* 6.5 mm contact area for neighboring Cube Satellite rails
- Rails will have a surface roughness less than 1.6 micrometer
- The edges of the rails shall be rounded to a radius of at least 1 mm
- At least 75% of the rail shall be in contact with the P-POD rails. 25% of the rails may be recessed and no part of the rails shall exceed the specification.
- The maximum mass of 1U Cube Satellite shall be 1.33 kg
- 1U Cube Satellite center of gravity shall be located within 2 cm from its geometric center in the Z direction.
- The designed structure shall be able to house all subsystems.
- The dimensions of the solar cells shall be 82*100 mm for four sides and 83*83 mm for the top side.

3.5 Mechanical Requirements

According to the specification of ISRASAT1 cube satellite; there are strict requirements on mass, and volume. These requirements are non-negotiable as they are required for the cube satellite to fit properly and launch correctly from satellite deployer which is the standard satellite deployer (P-POD) and it used successfully in each satellite mission to date. The points below shows the ISRASAT1 mechanical requirements according to the standard deployer.

- ISRASAT1 cube satellite structure shall have enough spaces for its subsystems.
- ISRASAT1 cube satellite selected material for structure shall be able to sustain to the drag forces at about 450 km above the earth
- The position of the mission camera of ISRASAT1 cube satellite shall be located in manner that makes able to point to the nadir when the ISRASAT1 cube satellite reaches Khartoum state.
- The method of the Antenna deployment after ISRASAT1 cube satellite launch to the orbit shall be taking into the account of the structure.
- The structure design shall be able to verify the Safety launching of ISRASAT1 cube satellite.
- The structure of ISRASAT1 cube satellite should pass the harmonic and random vibration tests.
- The distribution of ISRASAT1 components on each subsystem shall be balanced, so the center of mass of ISRASAT1 cube satellite must be within 2 cm from the geometric center.
- The total weight of ISRASAT1 cube satellite should not exceed the 1040 g, so the weight of each subsystems in the ISRASAT1 cube satellite calculated to be 200 g, 300g, 80 g, 140 g, 160 g and 160g for structure, Payload, ADCS, EPS, communication and OBC subsystems respectively.
- The total power output from the EPS subsystem not less than 5 watt.

3.6 Design of ISRASAT1 cube satellite Structure

The ISRASAT1 cube satellite is developed to take an image to the Khartoum state when it reached it, so the structural design of ISRASAT1 cube Satellite is primarily influenced by the combination of the performance and characteristics of the launch vehicle, the characteristics of the useful equipment or payload (mission camera), and the geometry of the selected orbit.

The structural design is to provide adequate strength and stiffness to ensure the survival of the ISRASAT1 Cube satellite under launch and orbital conditions during all phases of the mission. The structural design of the ISRASAT1 Cube satellite meets the structural requirements derived from the mission requirements of ISRASAT1 Cube satellite as mentioned in section (3.5) and the 1U cube satellite standard.

3.6.1 Methodology

The design process of the structure of the ISRSAT1 cube satellite is undergoes into many steps, the first step in the design is suitable material selection for the structure which based on the selection criteria limited by the ISRASAT1 mechanical requirements and specification.

After that, the design process specified by the ISRASAT1 design constrains and mission are done continuously till the design satisfy the mechanical requirements. So far the software that is used to simulate the design, and verify the standard and required testing of Cube satellites. Software also used to analyze obtained results from simulation. Furthermore, the hardware design and its standard testing also are required. Finally the hardware implementation to the software simulated structure of the ISRASAT1 for each subsystem is done. And integrate it together according to the depolyer specification too. The design procedure of each step mentioned above is detailed in the block diagram in figure (3.1).

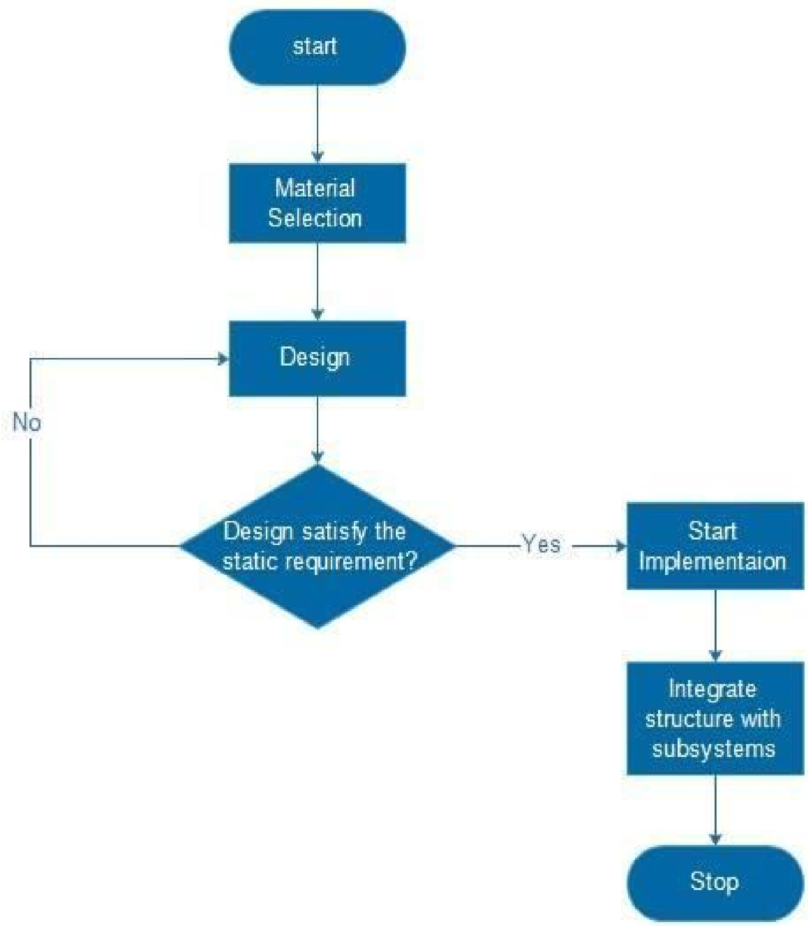


Figure 0-1: Design procedure of ISRASAT1 mechanical structure.

3.6.2 Drug forces at 450 km above the earth

According to the data from the orbit specification on the 450 km above the earth the material of structure must satisfy the parameters in table (3.1) which are the maximum and minimum temperature and the total torques acting on the ISRASAT1 cube satellite.

Table 3-1: orbit specification at 450 km above the earth.

Minimum temperature	T_{max}	-60	C
Maximum temperature	Tmin	100	C
Disturbances torques		0.6	Nm
moment		$2.4 * 10^{-2}$	Am^2
Normal temperature	Tnor	20	C

3.6.3 Material Selection

The vital work start before the design of the structure for ISRASAT1 cube satellite is the material selection which done according specific criteria such as weight, yield strength, density, machinability, cost, availability, mass density, elastic module, shear stress and thermal conductivity. The candidate materials for ISRASAT1 cube satellite structure are Aluminum 7075 or 6061,Stainless Steel, Titanium, Composites, and Honey Comb which are vary in their properties as shown in the table (3.1).

Table 3-2: comparison between several materials.

Material	Yield Strength	Density	Machinability	Avalibility
Stainless Steel	790 MPa	7760 kg/m3	Easy	√
Titanium	900 MPa	4429 kg/m3	Hard	×
AL-6061-T6	320 MPa	2850 kg/m3	Easy	×
AL-7075-T6	340 MPa	2796 kg/m3	Easy	×
Composites	640 MPa	~1000kg/m3	Hard	×
Inconel	848 MPa	8321 kg/m3	Hard	×
Al-6063	~250MPa	2700 kg/m3	Easy	√

3.6.4Software Simulation (CAD Modeling)

Generally, the simulation is the major step that must be done after the selection of the material to verify and analyze the properties of the selected material and it's allowably to use it in the space with the altitude define by the ISRASAT1cube satellite requirement. Furthermore, the simulation is used to test the conceptual design of the each subsystem in ISRASAT1 cube satellite and the calculation of the center of gravity according to the distribution on each component in subsystems layer and simulate a three direction (3D) model separately of the each subsystem too . Software simulation determines and verifies the ISRASAT1 cube satellite weight isn't exceeding required weight. Also assemble subsystems together in one cubic unit according to the standard. So the final software generated file can be passing to the CNC machine to implement hardware model. By following software procedure the manufacturing faults, time and cost are reduced.

There are many software used to design, analyze and test the satellites structure, their properties and capabilities differ from one to another, the most familiar design software are AutoCAD, ANSYS and Solid works.

But according to availability and functionality of the Solid works software program, it was selected to be used in structure design of ISRASAT1 cube satellite. It is powerful software that provides tools to analyze the design behavior and analysis the structure depends on many things, such as stress, strength, static and thermal analysis. The solid works software guaranteed that, the designed model able into specified altitude without being prone to failure or be destroyed.

3.6.4.1 Main Structure

According to the studies and survey of launched cube satellite during last year's, ISRASAT1 followed the second class of structure which is one unit structure as main structure and there is no internal sub-structure. The second class of structure has a strong and good ruggedness.

Generally the second class of structure has two types of design; firstly, design multiple parts and assemble them together as one unit cube. Secondly, designed it as one unit part.

The ISRASAT1 passed with several models, starting with version 01 till final model (version 03). As detailed below:

3.6.4.1.1 ISRASAT1 Cube Satellite First Model:

The first model of TSRASAT1 structure was designed to be one unit divide in to two parts (sub rails). It was contain these parts with four rails and four sub rails to connect between the main parts used screws. The total weight of the first model was 160g. Figure (3.2) shows the first modeling of ISRASAT1 structure.

After tested the model the software showed the design unsatisfied static requirement, the yield strength obtained from the model were too low according to desired value of yield strength. Furthermore the model didn't give the suitable factor of safety. So the model will never be suitable to be the optimal design of ISRASAT1 cube satellite. Figures below shows the analysis software results of ISRASAT1 cube satellite first model. Figure (3.3) shows the von mises, figure (3.4) shows the strain analysis and figure (3.5) shows the displacement.

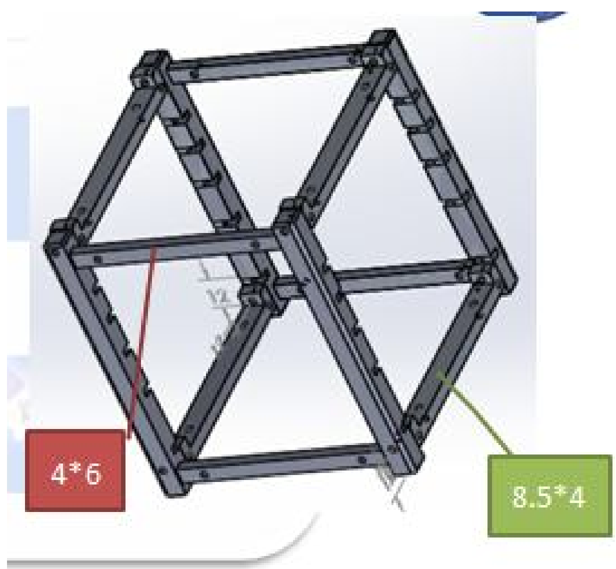


Figure 0-2: the first modeling of ISRASAT1 structure.

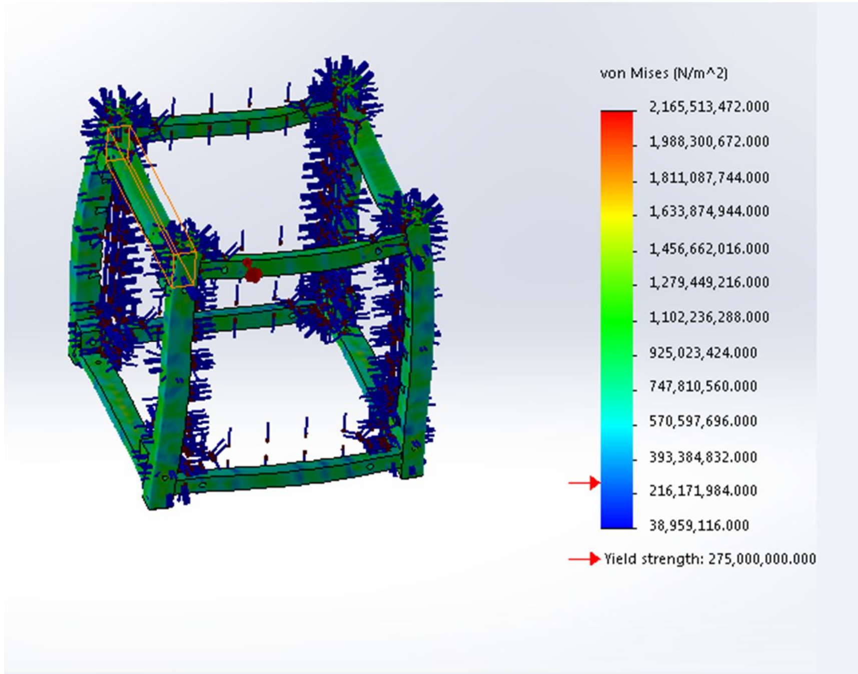


Figure 3-3: the von mises result of first model.

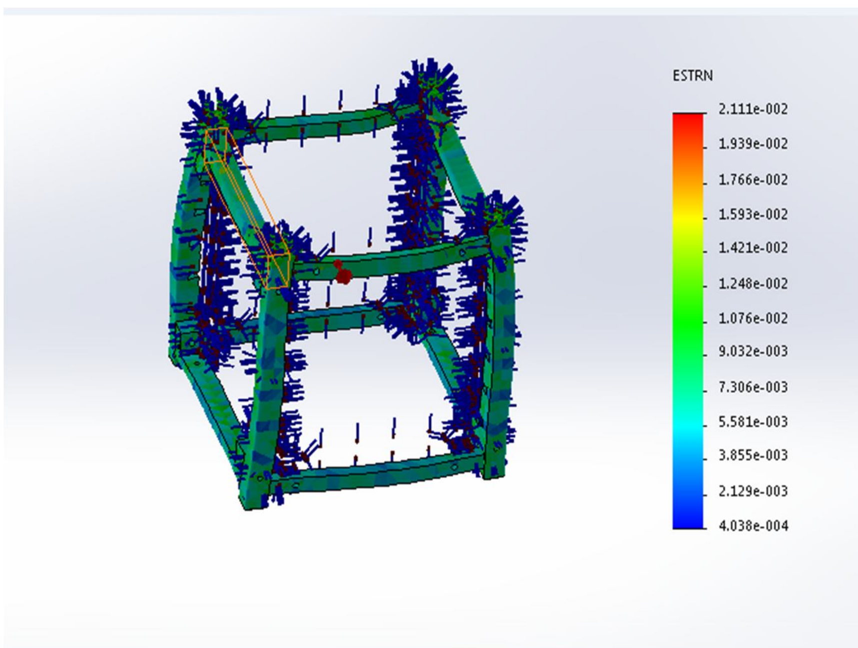


Figure 3-4: the strain analysis result of first model.

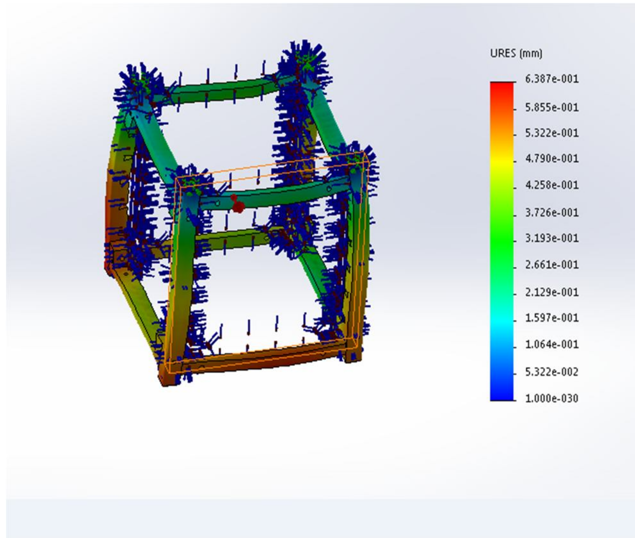


Figure 0-5:displacement result of first model.

3.6.4.1.2 ISRASAT1 Cube Satellite Second Model:

The second design of TSRASAT1 structure also was one unit without connections between the rails and sub rails, which means it design as one block unit. It designed the sub-rails with dimensions 4*7 mm and another sub-rails with dimensions 6*4 mm. Figure (3.6) shows the second modeling of ISRASAT1 structure. According to the software analysis this model also unsatisfied the static requirements and the yield strength which are very small too equal 279953.408 N\m2.

The factor of safety (FOS) in the second model was less than 1 which means the design was unsuited to orbit at 450km for the earth. Figure (3.7) shows the von mises, the strain analysis and displacement.

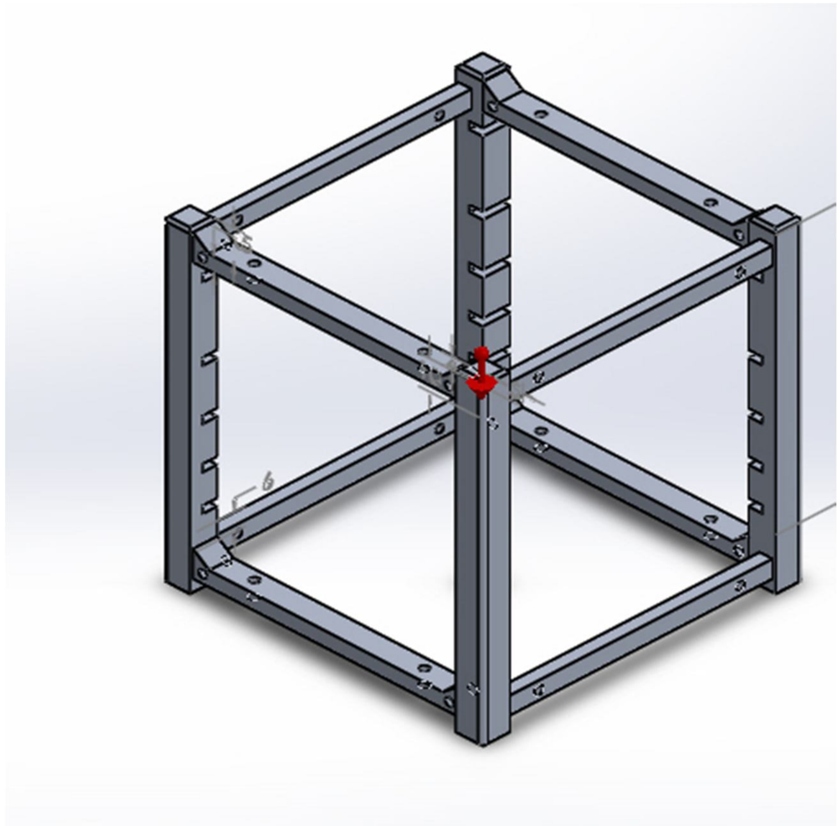


Figure 0-6: shows the second modeling of ISRASAT1 structure.

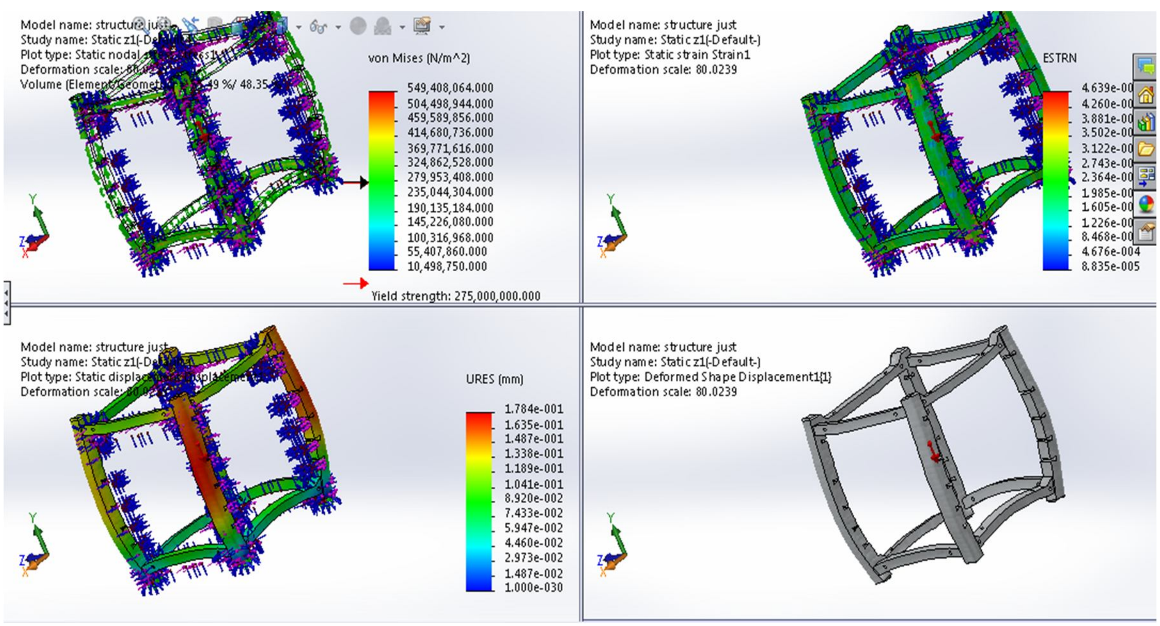


Figure 3-7: the second model of ISRASAT1 structure result; von mises, the strain analysis and the displacement.

3.6.4.1.3 ISRASAT1 Cube Satellite Third Model:

Finally, ISRASAT1 was designed as a one block unit after modified the second model to satisfy the static requirements to ensure it's able to save the subsystems after launching, which all subsystems layers inter throw the rails in Y direction, according to the weight distribution, highest of components and center of gravity will range the subsystem numbering. Figure (3.8) shows the ISRASAT1 cube satellite software model for the final version.

The final model was test under software which it analyze the design and it gave a good static requirements and yield strength. The factor of safety (FOS) was greater than 1 which means the design was suited to orbit at 450 km from the earth. Figure (3.9) shows the von mises, figure (3.10) shows the displacement and figure (3.11) shows the ISRASAT1 cube satellite analysis of final model including the strain analysis.

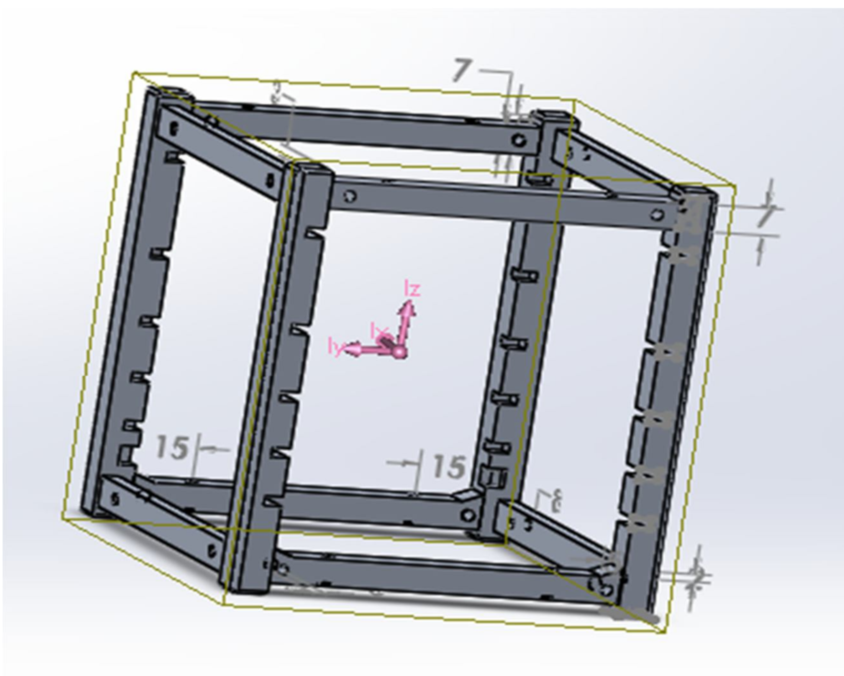


Figure 3-8: final version the ISRASAT1 cube satellite structure software model.

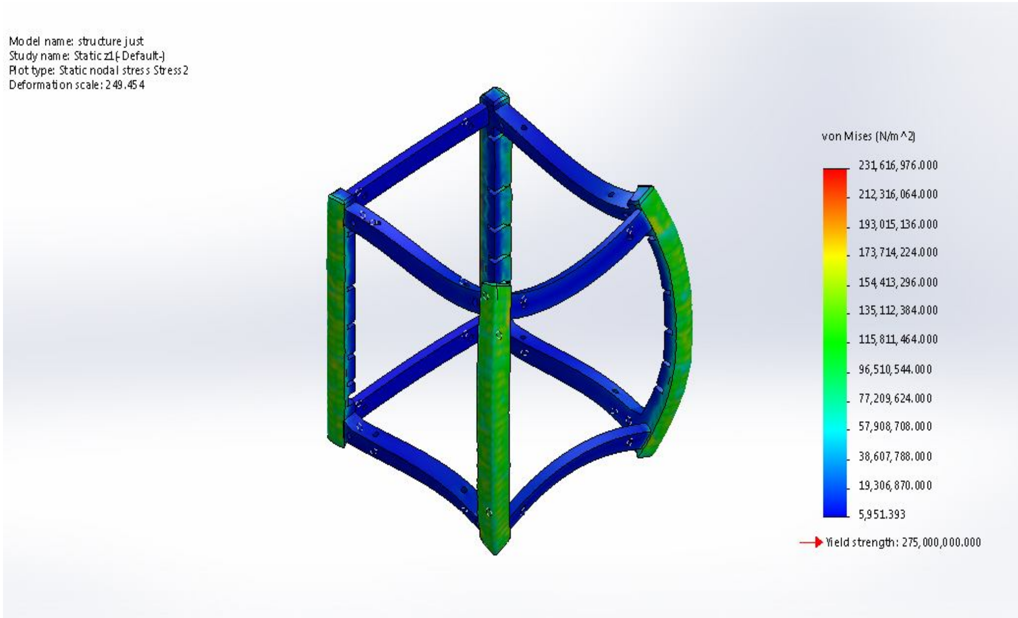


Figure 0-9: the von mises result of ISRASAT1 cube satellite structure.

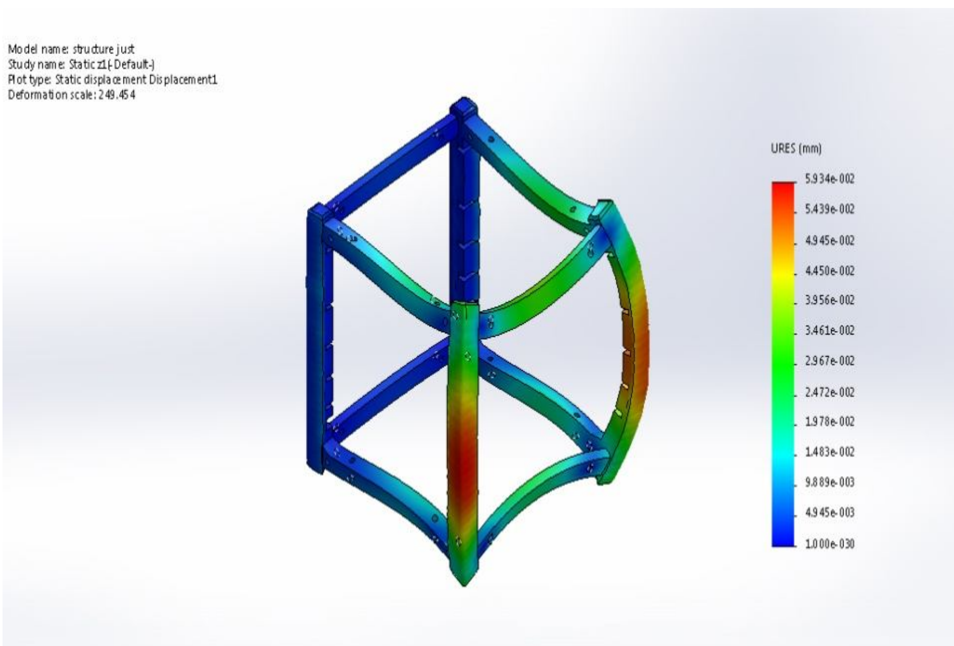


Figure 0-10: displacement result of ISRASAT1 final model.

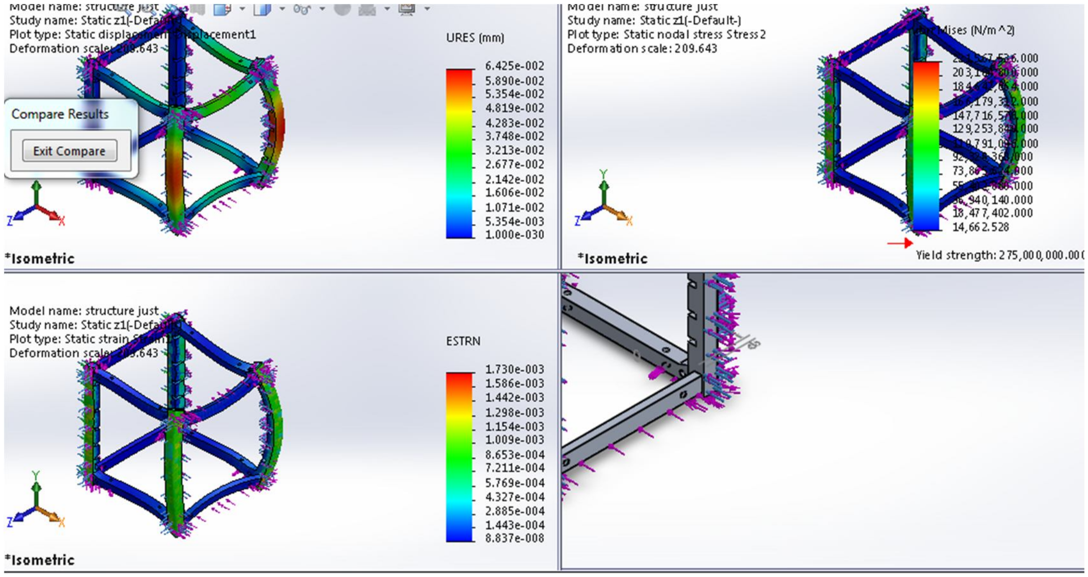
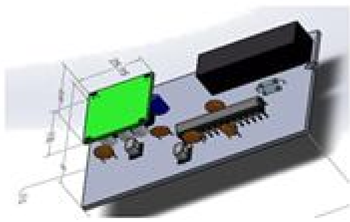
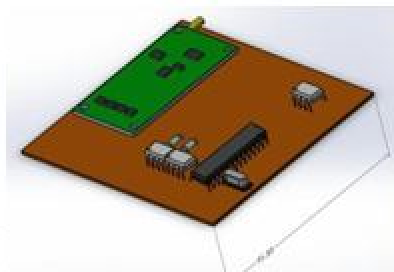
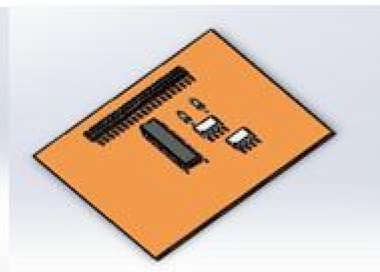


Figure 3-11: ISRASAT1 cube satellite analysis of final model.

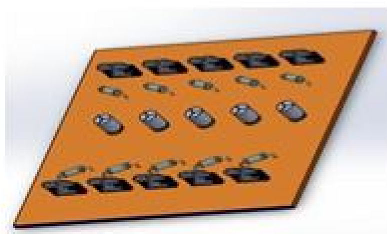
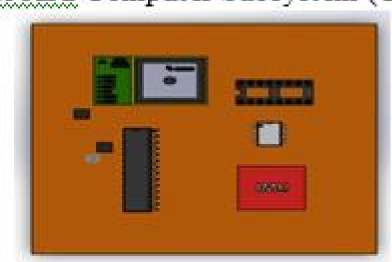
3.6.4.2 Design of ISRASAT1 subsystems

The distribution of the components on layer of each subsystem play circuital role in determining the center of gravity and make weight balance in all subsystems.

The components have a weight and size which affect in the distance between the different layers (subsystems). As mentioned in the previous selection ISRASAT1 cube satellite has a five subsystem include a different components according to the components need by each of them. Some subsystem components didn't attached to its layers according to their mission (camera must attached to the external side of the cube satellite and the antenna also must be attached to the external side of the cube satellite which they shall be carefully take in account in the cube satellite balance). ISRASAT1 camera and antenna fixed outside cube satellite with the same direction. Figure (3.12) shows the CAD modeling includes the weight distribution on subsystem boards.

Payload Subsystem   communication subsystem Onboard Computer Subsystem (OBC)

Electrical Power Subsystem (EPS)   Attitude Determination and Control Subsystem (ADCS)

Figure 0-12: CAD modeling of ISRASAT1 includes the weight distribution on subsystem boards.

3.6.4.3 Design of ISRASAT1 Electrical power Subsystem (power generation)

According to the ISRASAT1 mechanical specifications power generations must be a batteries which charges by the solar cells fixed on the cube satellite covers, the solar cell must satisfy the cube satellite specifications and should be capable to safe its properties within ISRASAT1 orbit at 450km from the earth without reduce the power output from EPS to other subsystems. The most efficient solar cells currently in production are multi-junction photovoltaic cells and it generates 5w which is selected to be ISRASAT1 solar cells because it satisfies its design requirements.

The multi-junction photovoltaic cells are able to work within drugs disturbances, sun radiation forces acting on the ISRASAT1 cube satellite orbits and it has ability to prevent the internal components fixed on the ISRASAT1 cube satellite subsystems from the influence of the thermal transfer. Figure (3.13) shows the ISRASAT1 cube satellite selected solar cells.

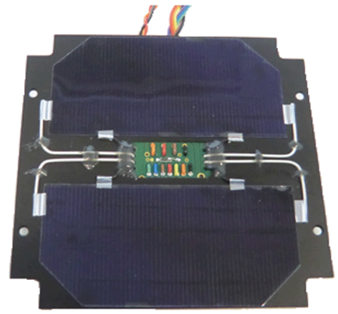


Figure 0-13: selected solar cell for ISRASAT1.

3.6.5 ISRASAT1 Subsystems Software Integration

Firstly the ISRASAT1 cube satellite subsystems were design separately take into account the components shape and the distance between them. After that they assemble into ISRASAT1 structure frame. The layers attached to cube satellite from Y- direction and it must take space in the three directions to pass the wires connection between the subsystems without affecting the rails strength of the cube satellite. The figure (3.14) shows the overall software simulation for ISRASAT1 cube satellite with its subsystems and figure (3.15) shows the methodology used to attach the subsystems inside the ISRASAT1 structure. The final software integration of the subsystem with attached antenna and solar cells fixed on its sides showed in Figure (3.16)

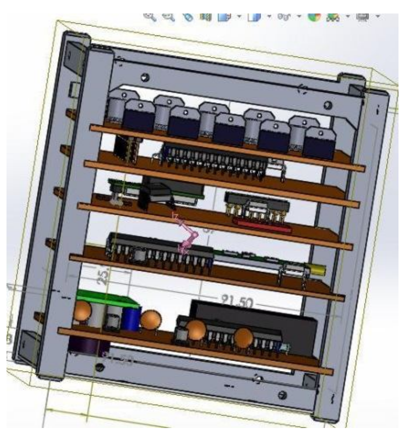


Figure 0-14: overall software simulations for ISRASAT1 cube satellite with their subsystems.

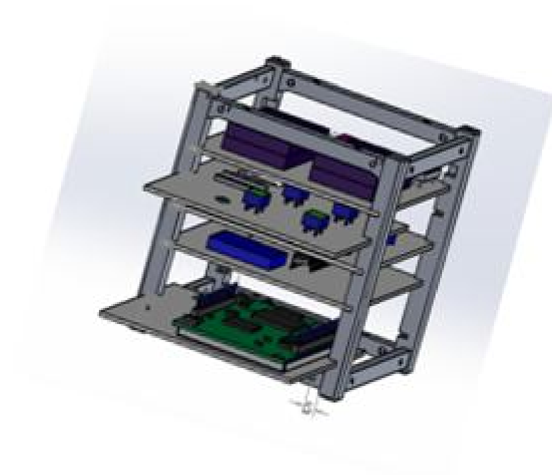


Figure 0-15: methodology of entering the subsystems into the ISRASAT1 structure.

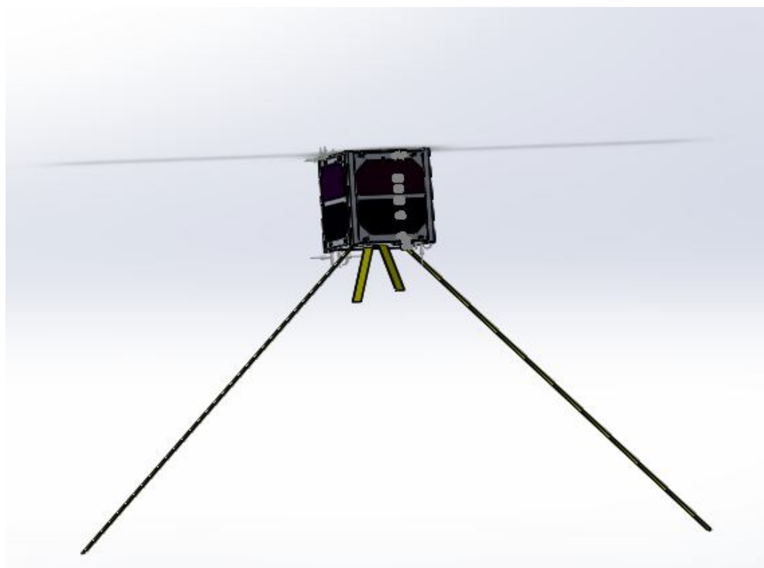


Figure 3-16: final integration of ISRASAT1 cube satellite.

3.7 Manufacturing of ISRASAT1 cube satellite structure

ISRASAT1 cube satellite **structure** manufacturing followed many steps. Actually the process of manufacturing depends on the shape of the main material, type, and availability of machines. According to the available machines in Sudan which are lathe machine, Wire Cutting Machine, EDM Cutting Machine and Drilling Machine, ISRASAT1 structure was manufacture using them. The following subsections show the detail steps followed by each machine.

3.7.1 Lathe Machine

Lathe machine is a normal type machine which used to manufacture the materials which prepare and creates first shape before inter the Computer numerical control (**CNC**) machine. It is used to shape the selected material in appropriate dimensions calculated for the cube satellite structure. The material papered and shaped to be with the height equal to 110mm (cylindrical shape). Figure (3.17) shows the material after lathe machine.

Figure 0-17: materials after lathe machine.

3.7.2 Wire Cutting Machine

Wire Cutting Machine is Computer numerical control (CNC*)* machine which it uses the wire with different types and diameters to manufacture the models with accuracy about 0.1mm. It is contains the main machine which include the cutting machine, fixing tools, cooling liquid and helping tools. Wire Cutting Machine also contains standing panel with computer and software used to draw path to wire according to desired one, and able to compact with different file extensions such as Auto Cad, Solid Works,..…. etc. figure (3.18) shows the Wire Cutting Machine.

Figure 3-18: Wire Cutting Machine.

Wire Cutting Machine was used to cut the outer and inner dimensions of the ISRASAT1 cube satellite from cylindrical material to be with dimensions equal to 10*10*110 mm which make ISRASAT1 cube satellite being as designed structure (software design output). Figure (3.19) shows the process of the manufacturing in the Wire Cutting Machine and, figure (3.20) shows the final appearance of cube after finished in Wire Cutting Machine respectively. Finally, Wire Cutting Machine was used to cutting the cube side covers, which will be attach to the solar cells in their sides.

Figure 0-19: processing of the manufacturing in the Wire Cutting Machine.

Figure 0-20: final appearance of cube after finished in Wire Cutting Machine.

3.7.3 Spark EDM machine

Spark **EDM** machine is CNC machine uses electrical current and contains special type of oil to cool a material and it has ability to transfer the current. Spark EDM used to makes narrow shapes cutting in difficult positions by digging which depends on the shape passed to master (cutting tool).

Spark **EDM** machine was used to make a rectangle path to the ISRASAT1 cube satellite subsystems in the main rails. Figure (3.21) shows the Spark **EDM** machine and the ISRASAT1 cube immersed in the oil and figure (3.22) shows the ISRASAT1 cube after process finished on the Spark **EDM** machine.

Figure 0-21: Spark EDM machine and the ISRASAT1 cube immersed in the oil.

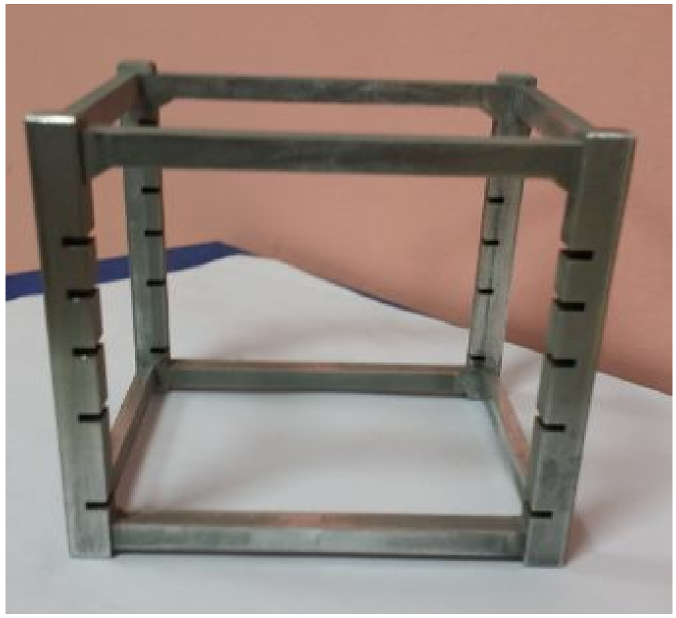


Figure 3-22: cube after EDM machine.

3.7.4 Drilling machine

Drilling machine is machine used for drilling the material to make holes. It's used to open holes in the sub rails of ISRASAT1 cube satellite structure and make a screw to fix the covers on the cube sides. Figure (3.23) shows the drilling machine.

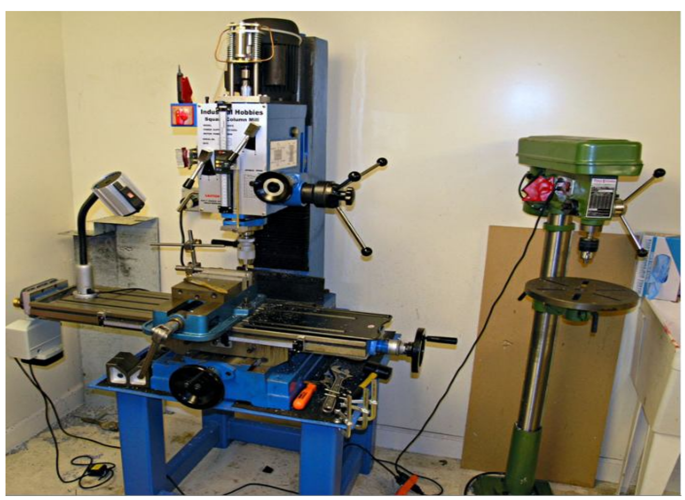


Figure 3-23: drilling machine.

3.8 ISRASAT1 cube satellite Hardware Integration

After the software design and integration, so far verfing the all software steps using software testing tools embeddded into the solid works program. The process of the hardware design started and done using a vailable machines for maufucturing as mentioned in above section, there is a final step after all these steps called hardware integration.

In the hardware integration all layers of the ISRASAT1 cube satellite housed into the hardware structure designed model. And the solar cells was fix of the covers of the cube satellite,. Futhermore the antenna and the switch before flight, mount to the final model. Also the camera postion determined according to the needs of the attitute subsystem to be point to the earth, and that is same reason make the antenna to be at same side to the camera while final assambely, to achieved maximum antenna gain and a high resolusion image.

3.8.1 Solar Panel

ISRASAT1 cube satellite has five silicon solar cells were fixed on covers of cube satellite in each side with dimensions 80*80*1 mm and integrated with EPS to charge the batteries. It was selected to satisfy the orbit specifications. Figure (3.24) shows the solar panel integrated on the covers.

Figure 0-24: Solar Panel Integration.

3.8.2 Antenna

ISRASAT1 cube satellite has double antennas and it has length 900 mm divided into two parts and connecting with the COMM subsystem to transmit the data to ground stations. ISRASAT1 antennas integrated on the sixth cover which didn't contain the solar cell, the antenna fixed use small screws. Figure (3.25) shows the antennas after fixed into the cube satellite.

Figure 0-25: ISRASAT1 cube satellite antennas fixing.

3.8.3 Antenna Release

After the deployment of ISRASAT1 cube satellite in its desired orbit, the antenna release system will release the antenna immediately by applying current through a heating element that generates heat enough to cut a fish line. The fish line warps the antenna, when the heating element equal to the desired heating degree it cuts the fish line causing switch pushed to stop the current flow and make the antenna deployed. Figure (3.26) shows the antenna release mechanism.

Figure 3-26: Heating Element of ISRASAT1 cube satellite antennas Release.

3.8.4 Hardware Subsystems Integration

After software design, the ISRASAT1 subsystems have been integrated in their board including components and wires connecting between them making their ready to assemble together. Figure (3.27) shows the ways used to assemble the components in the board.

After that all subsystems layers attached carefully in structure separately. The layers attaching done according to which subsystem connected to other subsystems and arrangement of the subsystems. All these done after Suring that, all wires tide properly without losing. After that the ISRASAT1 covers attached including the solar cells used the screws which connected with the power subsystem. Figure (3.28) shows the subsystems attached into the structure and the figure (3.29) shows the covers attached to the ISRASAT1.

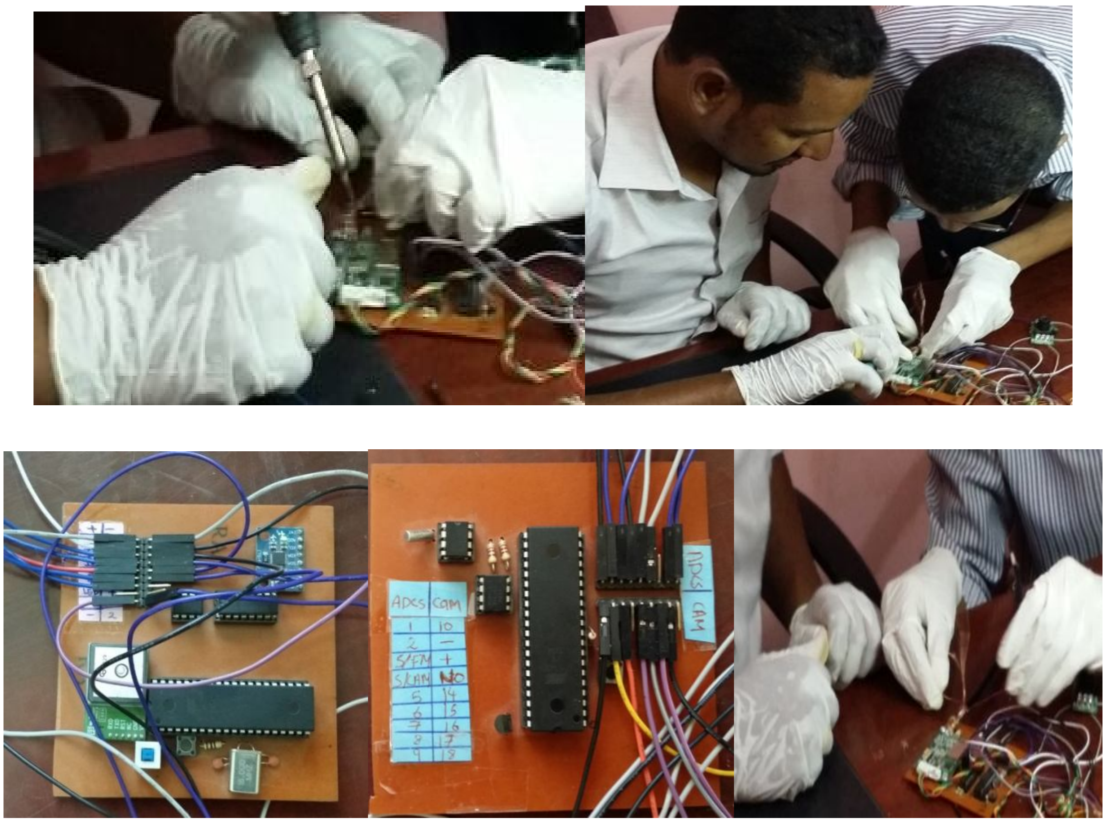


Figure 3-27: ways used to assemble the components in the board.

Figure 0-28: ISRASAT1 subsystems attached into the structure.

Figure 3-29: covers attached to the ISRASAT1.

Chapter Four

Thermal Analysis of ISRASAT1 Cube satellite

4.1 Preface

This chapter introduces a brief abstraction about the basic theoretical background to heat transfer, heat transfer types in the space environment which affect satellites structure while orbiting the earth. Specially, thermal space environment to ISRASAT1 cube satellite that depends on dynamics of ISRASAT1 cube satellite at 450 km from the earth.

Furthermore the main contributions of the chapter are thermal analysis of the ISRASAT1 cube satellite structure and the effect of the heat transfer on the ISRASAT1 cube satellite internal and external body, by explaining basic equations represents modes of heat transfer from the Fundamentals of Heat and Mass Transfer using different scenarios.

4.2 Heat transfer

Heat transfer defines by the movement of thermal energy from one thing to another thing and it occur when the temperatures of objects are not equal to each other and refers to how this difference is changed to an equilibrium state. The objects which heat transfer occur between them could be two solids, a solid and a liquid or gas, or even within a liquid or gas.

There are three different mechanisms that the heat can transfer between things: conduction, convection and radiation mechanism. In the space environment (high altitude) the density of the air is very low when it compared with the low earth orbits. for that reason the heat transfer in the space environment result from the conduction and radiation just without convection mechanism which makes electronics overheat and more likely result in higher temperature compare with electronics operating at sea level.

4.2.1 Types of the heat transfer acting on space environment

As mentioned in the above section in the space environments the heat transfer between things by conduction and radiation. This section defines a brief introduction about them

4.2.1.1 Conduction Heat Transfer

Conduction is the transfer of heat from one part of a body at a higher temperature to another part of the same body at a lower temperature, or from one body at a higher temperature to another body in physical contact with it at a lower temperature. Also it defines in the microscopic scale as transferring of the heat energy between adjacent atoms and molecules when they moving or vibrating. Significantly the heat conduction transfer mechanism means heat transfer with the solid or two solid objects in physical contact.

The heat transfer between two bodies governed by Fourier's Law as

$$q''_x = -k\frac{dT}{dx} \qquad (4.1)$$

Where:

Q = heat flow rate (W),

K= thermal conductivity (W/mK) of the material,

$\frac{dT}{dx}$= temperature differential over the length.

4.2.1.2 Radiation Heat Transfer

Radiation is the electromagnetic radiation emitted by a body by virtue of its temperature and at the expense of its internal energy. Thus thermal radiation has the same nature of visible light, X- rays, and radio waves, the difference between them being in their wavelengths and the source of generation. Radiation heat transfer depends on the temperature of the source and the coating of the radiating surface.

The radiation heat transfer is based on the Stefan-Boltzmann law, which relates the energy flux emitted by an ideal radiator (or blackbody) to the fourth power of the absolute temperature:

$$E = \sigma T^4 \qquad (4.2)$$

Where:

σ = Stefan-Boltzmann constant, 5.67x10-8 W/m^2K^4 **or** 1.714 x10 -9 Btu/ ($h.ft^{2.}\,{}^{\circ}R^4$).

The amount of energy that transfer through radiation between two bodies having specific temperatures of T1 and T2 is calculated by

$$q_r = \varepsilon \sigma F_{1,2}\ A(T_1^4 - T_2^4) \qquad (4.3)$$

Where:

Q = amount of heat transfer by radiation (W),

ε = emissivity of the radiation surface (reflective = 0, absorptive = 1),

$F_{1,2}$ = the shape factor between surface are of body 1 and body 2 (≤1.0).

4.3 Thermal space environment

Generally, the performance of space is strongly influenced by the near-Earth space and atmospheric environments. For cube satellites orbiting at low orbits which approximately orbiting at the International Space Station (ISS) orbit about 400km altitude, the atmospheric pressure and drag were very small, and hence aerodynamic heating and convective heat transfer was negligible. Therefore, the radiated heat from the sun, the albedo (the reflection of solar radiation) and planetary heating from the Earth (black-body radiation of the Earth) are the mainly three kind of heat that shall affect the cube satellite in the near-Earth environment (low orbits). Figure (4.1) show the space environment and the sources of heat that must affect the cube satellite in its orbit. This section presented the information about the performance of space environment and how it relates to the thermal simulation of the Cube Satellites.

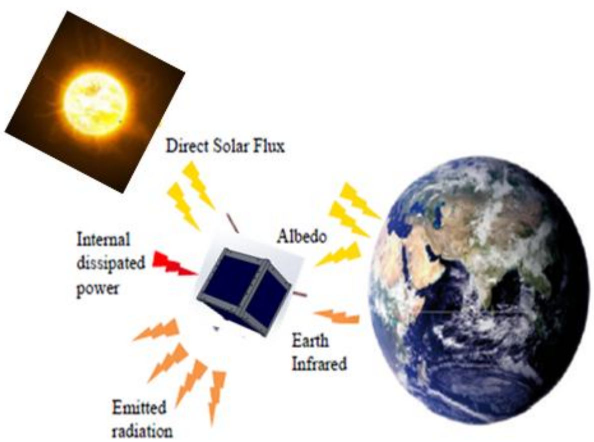


Figure 0-1: Space Thermal Environment for ISRASAT1 Cube Satellite.

Daily the solar radiation varies between the maximum and minimum often affect the design of the spacecraft. However, most of the cube satellites were designed to do its mission for only a short period of time and the average solar flux over an extended period of time was sufficient for the radiation analysis. Because of this short period of time the solar flux used in thermal analysis was 0.874 W/in2

(1354 W/m2). Another type of radiation is Albedo, which is the reflected sunlight off the Earth's surface. Generally, used 3% of all sunlight that radiated to the earth. Also the Planetary Infrared for the planet Earth.

4.4 Thermal Analysis of ISRASAT1 Cube Satellite

The thermal analysis was done for the ISRASAT1 cube satellite at 450 km from the earth and the temperature reach to 380 F. The orbital dynamics of the ISRASAT1 cube satellite is the polar orbit which it is exposed mostly to the direct sun light during orbiting the earth. Also the space environments mentioned in section (4.3) was used as ISRASAT1 cube satellite environment.

ISRASAT cube satellite spins around itself while orbiting around the earth, so there is a normal thermal control to the ISRSAT1 cube satellite and the temperature isn't makes a crucial affect.

4.4.1 Internal and External Thermal Analysis of ISRASAT1 Cube Satellite.

The internal electronic of ISRASAT1 cube satellite subsystems need to worm up to its operating temperature, so the heat that comes from the sun has advantage but at same time when the temperature increase it may makes a harmful overheating in the internal subsystem of the ISRASAT1cube satellite.

The external structure of the ISRASAT1 cube satellite consists of the solar cells covering its five sides. And the solar cells itself needs the sun radiation to convert it into electrical signal to power up internal subsystems components. Furthermore solar cells needs 40% for heating and 45% of the energy reflected to nearby surfaces.

4.4.2 Thermal Analysis Scenarios of ISRASAT1 Cube Satellite

The ISRASAT1 cube satellite tested under different scenarios taking into its account the orbital dynamics and altitude of ISRSAT1 cube satellite. The scenarios configure according to the number of the solar cells side that exposed to the direct sun light.

There are two configurations, first one when the ISRASAT1 cube satellite has a multiple solar cell side exposing to the direct sun light. Especially at worst case there are a three solar cells exposed to the direct sun light when the self spins occur. The second configuration when the sun light directly affecting one side of the ISRASAT1 cube satellite solar makes the effect of the temperature on the solar cell side may damage the solar cell design.

4.4.3 Thermal Software Simulation of ISRASAT1 Cube Satellite

For thermal of ISRSAT1 cube satellite the Solid works software used to analysis the thermal heating from environment space which affect the ISRASAT1 cube satellite external and internal structure (solar cells internal component relatively) so far heat flux and temperature performances on ISRASAT1 cube satellite at 450km above the sea level. Also satellite tool kit (STK) software used to simulate the ISRASAT1 cube satellite at 450 km from the earth.

4.4.3.1 First scenarios

In the first case the ISRASAT1 cube satellite has direct contact with the sun radiation for three sides. According to ISRASAT1 cube satellite orbit the sun light might exposed to the solar cells in the polar orbit (inclination = 90). Solid works and STK software used for analyzing. Figure (4.2) show ISRASAT1 cube satellite and the space environments. Figure (4.3) shows the lighting adjustment of ISRASAT1 cube satellite which exposed to direct sun light. Figure (4.4), (4.5) shows the thermal analysis and power generated by ISRASAT1 solar cells respectively.

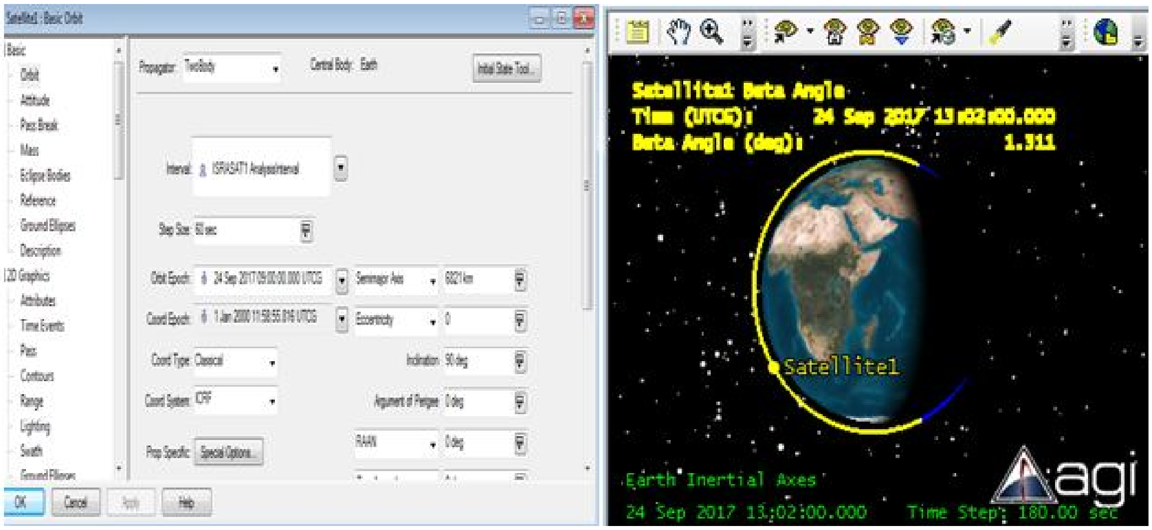


Figure 0-2: ISRASAT1 at 450 km and ISRSAT1 orbits with inclination equal 90◦

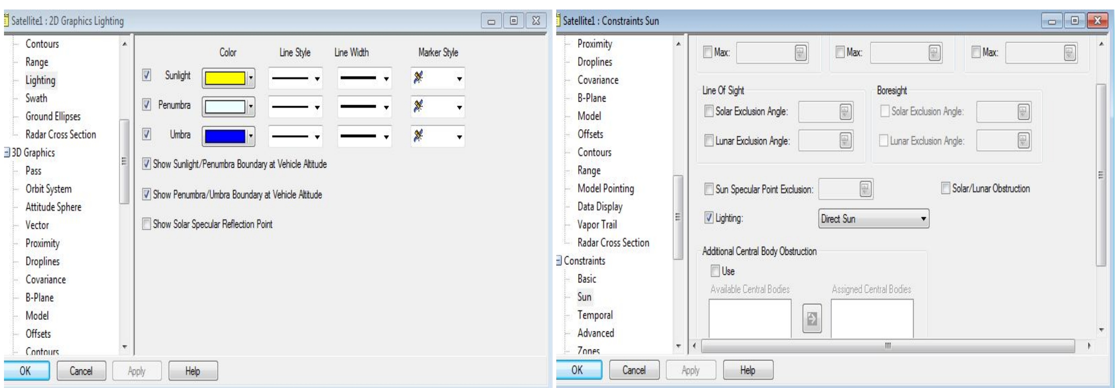


Figure 4-3: sun light adjustment of ISRSAT1 cube satellite.

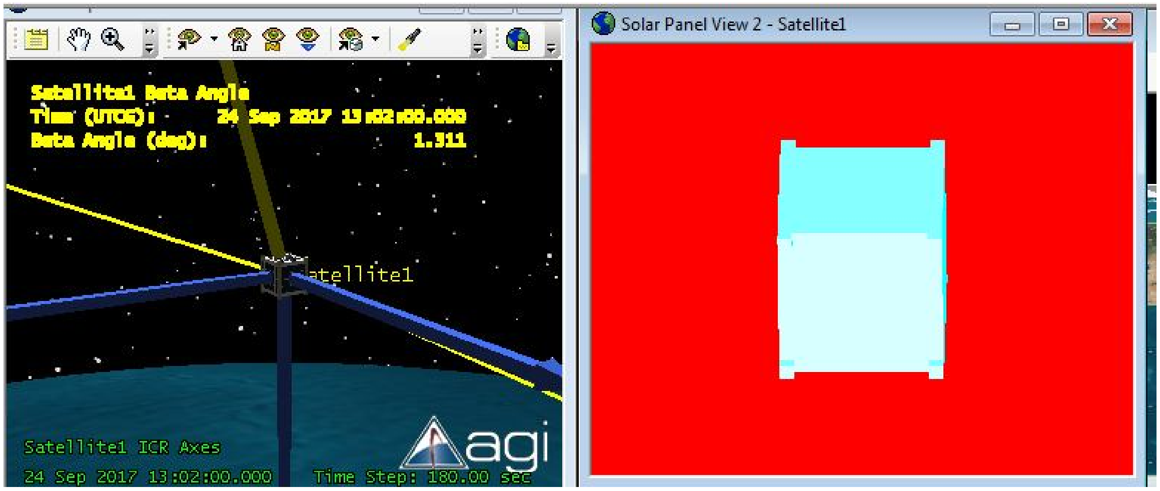


Figure 0-4: thermal analysis of ISRSAT1 cube satellite.

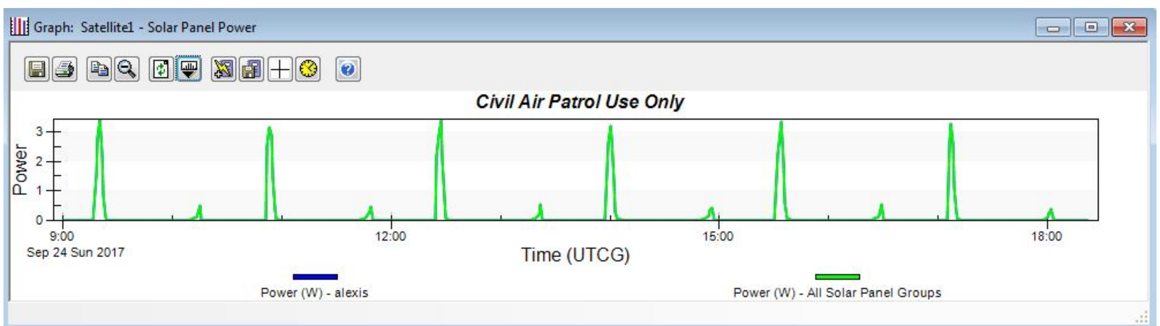


Figure 0-5: STK ISRAST1 cube power generation.

After simulated ISRASAT1 cube satellite space environments, the first sceneries done by applied thermal heat to external body of the ISRASAT1 cube satellite, the total absorbed heat flux and temperature profile of the ISRASAT1 Cube Satellite when the radiation exposed direct to the three sides, and obtaining that, the heat flux that affects the ISRASAT1 cube satellite is 1354 w/m^2 and temperature is about 380 ^{o}k. Figure (4.6) shows the ISRASAT1 cube satellite when its three solar panels faced the direct sun radiation using solid works software.

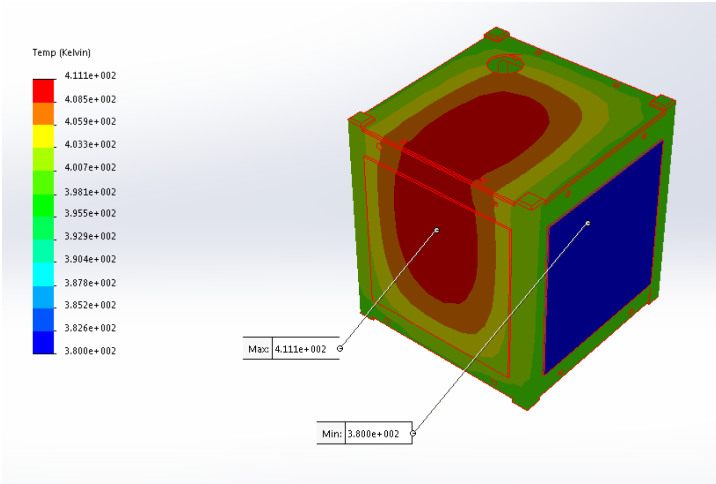


Figure 0-6: performance of heat flux and temperature of three sides of ISRASAT1 cube satellite (solid works software).

4.4.2.2 Second scenarios

In the second case under same environment, the ISRASAT1 cube satellite faced the sun radiation directly at one side of ISRASAT1 cube satellite solar cell. Figure 4.7 show the external total absorbed heat flux and temperature profile of the ISRASAT1 Cube Satellite.

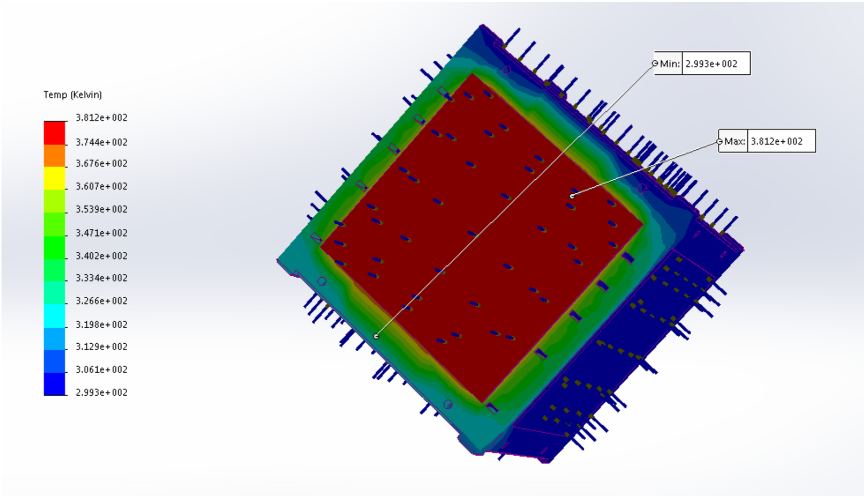


Figure 0-7: performance of heat flux and temperature of one side of ISRASAT1 cube satellite.

In the two cases mentioned above, the thermal configuration didn’t affect the cube satellite external solar cells depend on the solar cell absorption low which state that: “the solar cells must absorbs 45% of the heat to generate electricity”. Generally, the selection of the solar cell affecting by solar cell thermal conductivity. And almost vendors support solar cell with specification that has ability to prevent the cube satellite internal components and generate enough power to all subsystems.

Finally, after thermal analysis of ISRASAT1 cube satellite, the ISRASAT1 will be able to orbits at 450 km from the earth without affecting functionality of ISRASAT1 cube satellite due to the thermal and sun radiation.

Chapter Five

RESULTS AND DISCUSSION

5.1 Preface

This chapter discusses the results that were obtained from the design of ISRASAT1 cube satellite according to the specification of the cube satellite and the requirement determined and mentioned in chapter three. So it presents the details of the output from each step of design stages according to the order mentioned in previous chapter.

5.2 Material Selection

The aluminum 6063 alloy was select to be the material for ISRASAT 1 Cube satellite structure according to data analysis on the table (4.1) which represents the candidates material that satisfy the requirements of ISRASAT1 cube satellite. As shown in the table 4.1 the aluminum material had suitable properties which make it a first chose for design.

Table 0-1:candidate materials for ISRASAT1 structure.

Material	Yield Strength	Density	Machinability	Availability
Stainless Steel	790 MPa	7760kg/m3	Easy	√
Titanium	900 MPa	4429 kg/m3	Hard	×
AL-6061-T6	320 MPa	2850 kg/m3	Easy	×
AL-7075-T6	340 MPa	2796 kg/m3	Easy	×
Composites	640 MPa	~1000kg/m3	Hard	×
Inconel	848 MPa	8321 kg/m3	Hard	×
Al-6063	~250MPa	2700 kg/m3	Easy	√

5.3 Software simulation (CAD Modeling)

5.3 1 Main Structure

After analysis many models of structures the ISRASAT1 structure designed as shows in figure (5.1). Its contains five passes to the ISRASAT1 subsystems with 2mm* 4mm throw the first rails, 2*4*4.25 mm for the next rails and two space to the kill switches in two main rails.

The main rails dimension is 8.5*8.5*110 mm, their faces are 6.5*6.5 mm and corner radius is 1mm. the center of gravity of ISRASAT1 cube satellite structure in XYZ mm: X=49, Y=54.79, Z=48.98 and its weight 154.23 g.

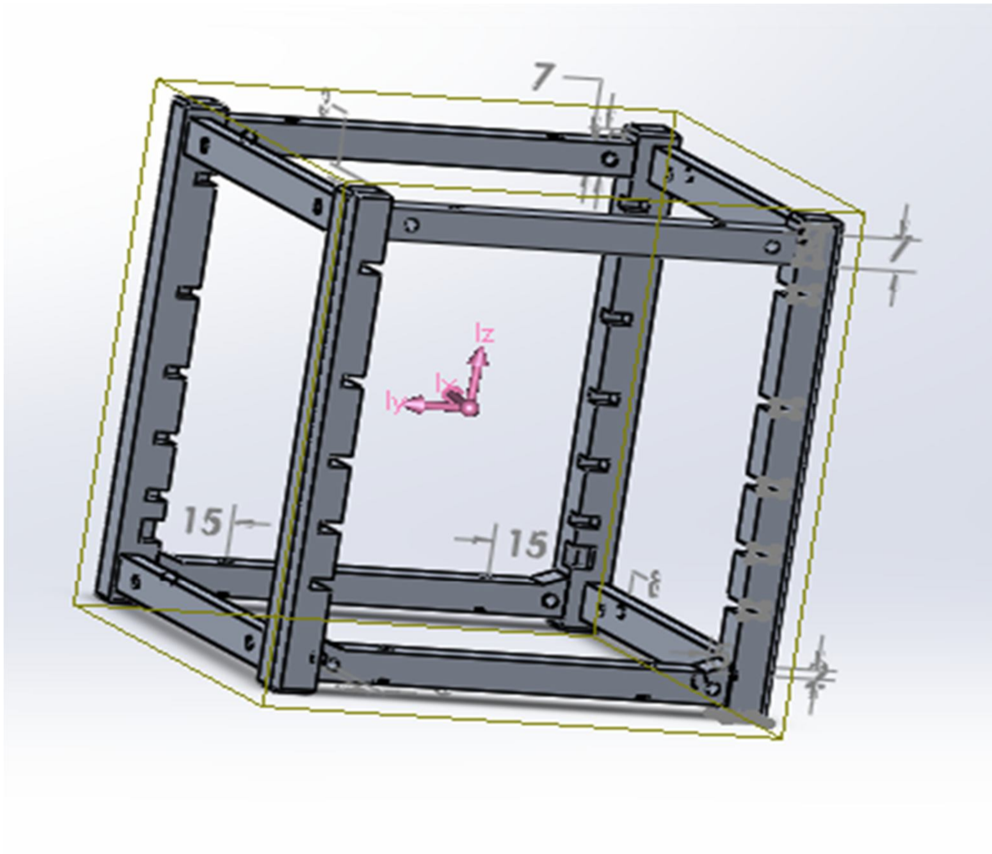


Figure 5-1: CAD modeling of ISRASAT1 cube satellite structure.

Also the ISRASAT1 cube satellite static analysis had maximum yield strength equal to 275000,000.000 N/m2 and the maximum load will affect the ISRASAT1 cube satellite structure on the space is 231,616,975.000N/m2 which make the factor of safety (FOS) be greater than 1. Figure (5.2) shows the yield strength and maximum load affect ISRASAT1 cube satellite structure.

IRSASAT1 have a maximum displacement and static strain equal to 0.006425 mm and 0.00173 respectively as shown in figure (5.3).

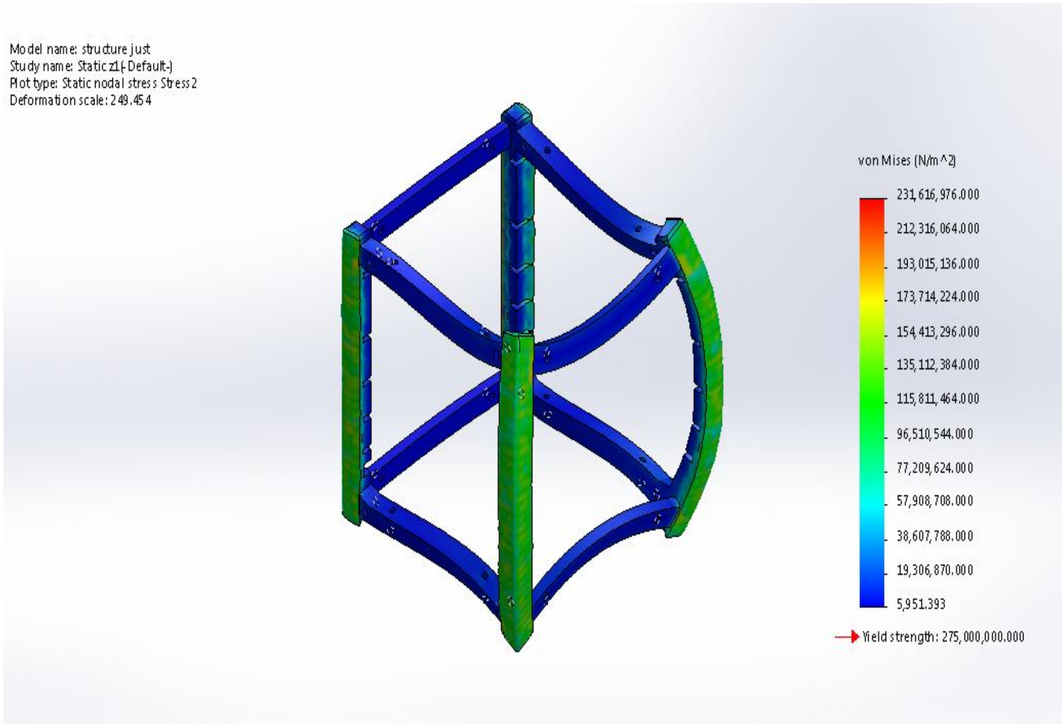


Figure 0-2: the von mises of ISRASAT1 cube satellite structure.

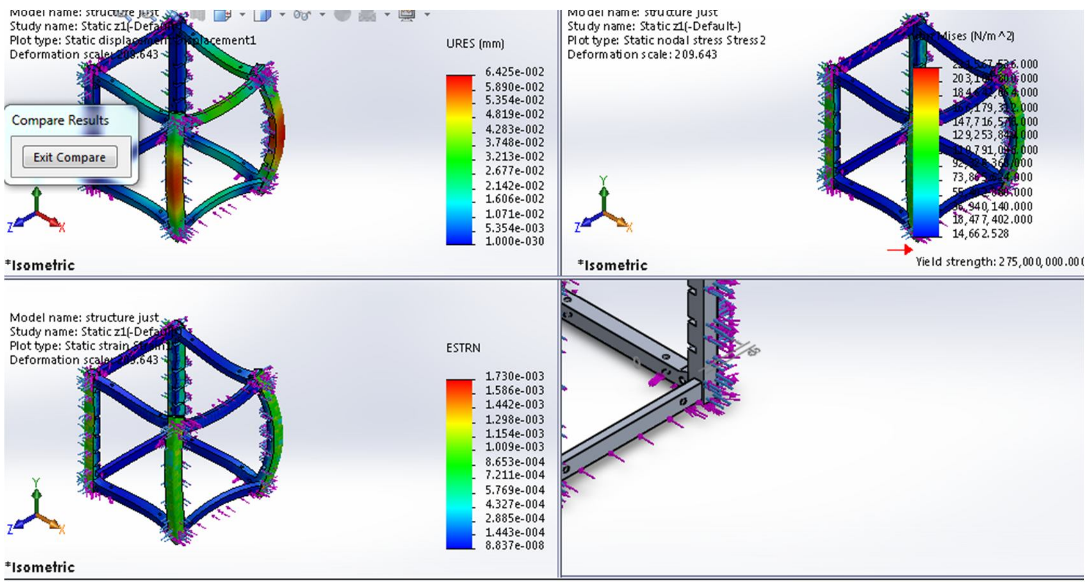


Figure 0-3: ISRASAT1 cube satellite analysis of final model (displacement and strain).

5.3.2 ISRASAT1 Subsystems Software Integration

After design each of ISRASAT1 cube satellite subsystem separately it was integrated in software as shown in figure (4.4), and take into account the center of the gravity should be as standard by the distributing the ISRASAT1 components as shown in the figure (4.5) which shows components in final software integration

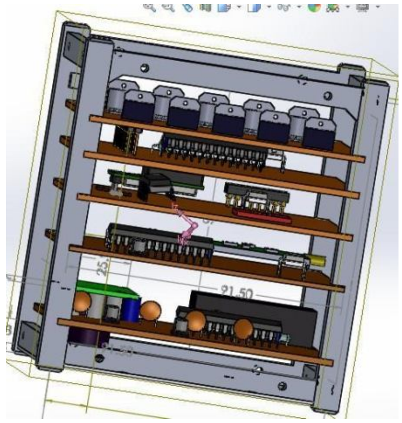


Figure 0-4: Overall software integration for ISRASAT1 cube satellite with their five subsystems.

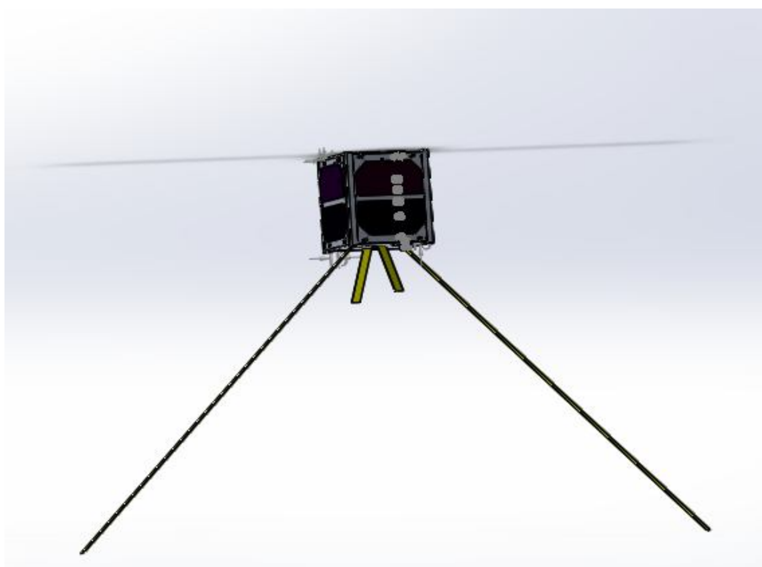


Figure 0-5: final software integration of ISRASAT1cube satellite.

5.4 Manufacturing of ISRASAT1 cube satellite structure

After the software design of ISRASAT1 cube satellite structure the manufacturing process started and the final model before drilling the screws to the covers holes designed and implemented as shows in the figure (5.6).

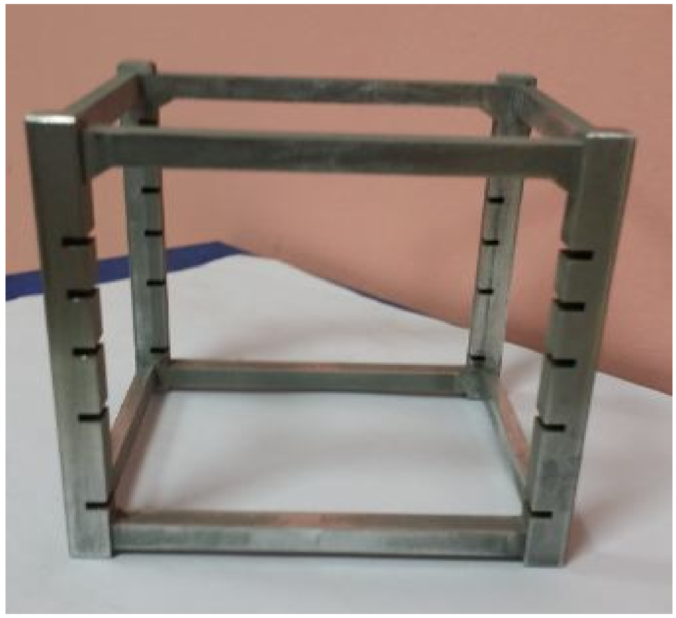


Figure 5-6: ISRASAT1 cube satellite structure implementation.

5.5 ISRASAT1 cube satellite Hardware Integration

The final stage of the ISRASAT1 is to integrate it in hardware and assemble its subsystems and housed it in the final hardware structure model. Figure (5.7) shows the final ISRASAT1 cube satellite prototype with their interfaces with the weight equal 733.7 g.

Figure 0-7: Final weight of ISRASAT1 cube satellite.

Chapter six

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

In this thesis, the Design and Thermal analysis of ISRASAT1 cube satellite structure has been presented and discussed. In order to design a satisfying structure meets ISRASAT1 cube satellite, good knowledge of the cube satellite standard, P-POD launcher specification and software modeling tools are required. It should take into consideration design requirements of ISRASAT1 cube satellite constrains that match Cube Satellite specification.

A general summary of structure for cube satellites, different materials which used of structure design and a different design types was presented. After that, the hardware selection criteria for material and design type chosen for the ISRASAT1 cube satellite. Furthermore, overall software design for ISRASAT1 structure according to the cube satellite constrain and overall cube satellite budget were thoroughly discussed and calculated.

The five subsystems of ISRASAT1 cube satellite, software integration, hardware integration and its interfaces were described. It was demonstrated that according to the design structure of ISRASAT1 and its requirements, aluminum 6063 is an appropriate choices for ISRASAT1 structure and designed to be one module. A thermal analysis of the ISRASAT1 cube satellite and power generation of the solar cell designed and tested used solid works and STK tool software. Also CAD software use for full structure design Finally, the results obtained from software simulation were presented and have shown good results. Hence, the designed and simulated structure is ready to be implemented and to the ISRASAT1 subsystems.

6.2 Recommendations

The structure designed during this thesis does not address the calculation of the space between the subsystems accurately because ISRASAT1 cube satellite subsystem wasn't use the real components for subsystem with their real dimension due to the less availability of them in the market. So a more dimension consideration must be taken into account after deliver the real components.

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