Design Project Team Report

Australia Environmental Inc.

Introduction to Engineering Design: Aerospace

Professor M. Bazzocchi

AE 212

CubeSat Design

Astro Team 5

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Executive Summary

In past years, there has been an increase in the amount of submarine groundwater discharges that have been occurring off the coasts of Australia. Australia Environmental Inc. is concerned with the increase of submarine groundwater discharges and their effects on the coastal ecosystems. AE Inc. has been contracted with collecting and analyzing data of SGDs by the Australian Government Department of Agriculture, Water and the Environment. Astro Team 5 has been assigned with the task of proposing a solution to collect SGD data.

The design that has been assigned has some freedom in the sense of the design options. AE Inc. is requesting a design developed as a CubeSat or as an Unmanned Aerial Vehicle. This design must be able to effectively observe the Australian coastlines on a regular basis for data collection. The CubeSat model was selected over the UAV approach. A CubeSat is a miniature satellite that is mostly purposed for research or information collection missions. The designed CubeSat will have thermal imaging capabilities that will be able to capture data regarding the SGDs. CubeSats are used all over the world from many large associations, such as NASA, all the way down to highschoolers designing them for a project. A key feature of CubeSats are their size. Most are very small, about the size of one's hand. Usually, they will be launched into a low-earth orbit (LEO) as CubeSats do not have the need nor complexity to orbit outside of LEO. The cost of CubeSats varies depending on the mission, with simpler missions being fairly priced and complex missions having the potential to be expensive.

The CubeSat that is planned to be deployed will be 3U and weight 3.6 kg. The difference between the geometric and mass centers will be within 2 cm. Within the structure, there will be an infrared camera capable of detecting the SGDs. It will be powered by batteries that are recharged from solar panels. In orbit, the Australian coastline will be scanned with the infrared camera. The data received will be transmitted to a ground station and supplied to AE Inc. and AWE. This is expected to occur about 140 times within a 2 week period. Overall, it is expected that the mission will be very successful.

Astro Team 5 consists of Tyler Brooks, Kevin Alvarado, Thomas Novitsky, Matthew Vines, and Vy Huynh. It is made up of sophomores and juniors at Clarkson University; coming from ranging backgrounds and experience. Team members, Brooks and Alvarado, both have field experience as they were hired for Co-ops with General Electric. Both having some background in aeromechanics and engine dynamics, and 3-D modeling. Novitsky, Vines and Huynh have backgrounds in coding such as Excel, MatLab and C++.

An issue that the team had to overcome includes online meetings to support social distancing due to COVID-19. Funding required for the components of the CubeSat was necessary. In addition, there were multiple issues that had to be dealt with such as compromises and planning that were overcome due to communication, and the help of planning with the use of a Gantt Chart. All team members have had experience working with a team of this caliber when designing for a problem. With the research done for this project, the team has become more knowledgeable on the problem and subsections at hand.

Table of Contents

I. List of Symbols and Abbreviations:

@ - At

< - Less than

ADN - Ammonium Dinitramide

AE Inc. - Australia Environmental Incorporated

AHP - Analytic Hierarchy Process

Al - Aluminum

AWE - Department of Agriculture, Water and the Environment

COG - Center of Geometry

COM - Center of Mass

COTS - Commercially Available off-the-Shelf

CPCI - Compact Peripheral Component Interconnect

EM - Electromagnetic

EPS - Electric Power System

EPSS - Electronic Performance Support System

Eqn. - Equation

Fig. - Figure

FPGA - Field Programmable Gate Array

GB - Gigabyte

I^2C - Inter-Integrated Circuit

ISIS - Innovative Solutions in Space

Krad - Kilorads

LEO - Low Earth Orbit

LVDS - Low Voltage Differential Signaling

MiPS - Micro Propulsion System

N/A - Not Applicable

NASA - National Aeronautics and Space Administration

OBC - Onboard Computer

PCDU - Power Control and Distribution Unit

PMAD - Power Management and Distribution System

PPT - Plasma Pulsed Thruster

QuIP - Quick Image Processing

RAAN - Right Ascension of the Ascending Node

RAM - Random Access Memory

SGD - Submarine Groundwater Discharge

SPI - Serial Peripheral Interface

STK - Systems Tool Kit

TID - Total Ionizing Dose

UAV - Unmanned Aerial Vehicle

UHF - Ultra High Frequency

VAC - Vacuum Arc Thrusters

VHF - Very High Frequency

II. List of Contributions

Thomas Novitsky - Title Page, Table of Contents, Initial Executive Summary, Introduction, Constraints, Criteria, Thermal Imaging Subsystem, COM/COG Calculations, Updated Stakeholders, Concept of Operations Figure, Outlined Budget, Mass /Size Budget Analysis, References, Citations, Formatting.

Vy Huynh - Background and Survey Research, Concept of Operations, Conceptualization, Conclusion Stakeholders, Team management, Stability

Kevin Alvarado - Outline, Editing, Revision, Citations, References, Orbital Calculations, Structures, Requirements, Conclusion, Symbols & Abbreviations, Introduction, Background, Executive Summary, Stakeholders, Tables and Figures.

Matthew Vines - Introduction, HLO, DO, Power, Communication, STK, Citations, Orbital Design, References, Cubesat Function Analysis.

Tyler Brooks - Background research, Executive Summary, Detailed Objectives, Criteria, Metrics, Propulsion, Team Management, Conceptualization, Idea Generation

1.0 Introduction

Along the Australian coastline, there are water discharges that flow into the coastal waters. These SGDs, otherwise known as “wonky holes” have been known to affect the coastal ecosystems. Australia Environmental Inc. is a small company that has worked on informing businesses and government agencies on best environmental practices. In the past few decades, there has been an increase in SGDs and their effects on the coastal ecosystem. The Australian government has recently awarded AE Inc. with a large contract to provide data and research on the SGDs that are affecting offshore coastal ecosystems. The importance of this mission is to create a better understanding about the effects of SGDs on the environment and to learn how certain precautions can keep the negative effects to a minimum. AE Inc. has asked for a product that can transmit data regarding the SGDs. Thermal infrared sensing will be used to detect these events on the coast. To satisfy this need, the choice was either an Unmanned Aerial Vehicle or a CubeSat satellite. In this instance, Astro Team 5 has decided to deploy a CubeSat. There will be an infrared camera component within the structure that will sense, receive and transmit data to a ground station as it fly-bys.

This report will contain the information necessary to make the decisions on what specific components will be utilized with this project. The composition of the satellite will determine the outcome and success of the mission. A set of requirements form AE Inc. will limit the scale of choices made and restrict the design process. Tasks will be utilized to ease the design process and organize the structure of our logistics. Each individual from the team will specialize on one specific subsystem for greater detail and analysis. A substantial portion of the work will pertain to this and determine the success of the mission.

Throughout the report, there will be a step-by-step analysis of the objective and completion. A Gantt chart is to be updated as tasks are completed. Each individual is responsible for their respective subsystem and tasks. Milestones are marked to indicate the progress of the research. By the end of the process, a CubeSat will be designed that will exceed the expectations of AE Inc.

2.0 Problem Formulation

2.1 Problem Definition

The coastlines of Australia experience submarine groundwater discharge which interrupts natural ocean environments. In order to detect these points of discharge our team has been tasked to use thermal imaging on board a CubeSat to point out these areas of impact.

2.2 Design Statement

Design a CubeSat that can transmit SGD data for the AWE.

2.3 Stakeholders

1. Australia Environmental Inc. is a small company interested in having a device that will be able to collect and transmit SGD data. They wish to satisfy the needs of the AWE to encourage sustainable activities, policies and practices in Australia. A government contract has provided for them to successfully complete this mission.
2. Australian Government Department of Agriculture, Water and the Environment is a government agency interested in data acquisition and minimizing environmental impact. There has been an increase in the study of SGDs on coastal reefs and eutrophication. They have requested Australia Environmental Inc. to create a CubeSat for data analysis that will help them study these events.
3. Ground Station Operators are interested in and involved with data collection. They need to know when they will be collecting data based on the transmissions with the CubeSat. This stockholder is very important because the end goal is to get the data collected and delivered back to the AWE for research.
4. CubeSat component manufacturers are interested in selling their products to create a profit. The manufactures components would be used in the CubeSat design to meet objectives stated below.
5. Aerospace Institutions, Companies, and Organizations that have pre-existing satellites in orbit. They may want to make sure that the CubeSat orbit will not be endangering other orbiting objects. Space debris may also be present that may damage our satellite.
6. Environmental groups that want to protect wildlife and fish species near and off the coast of Australia. They would want to know the data being collected and its use. The groups also would not want this project to harm the local wildlife

2.4 Requirements

The Australian Government Department of Agriculture, Water, and the Environment (AWE) has looked into two possible SGD detection systems, UAV and CubeSat, that will provide increase data on SGD locations.For the team’s solution, it must meet the specifications and needs from our client (AWE).The client requests that our solution must leverage thermal infrared remote sensing to detect SGDs and collect data for analysis. The client also requests that our Cubesat solution will have low environmental impacts. From the client statement, the following sections (2.4.1-2.4.5) are made to breakdown the objectives and criteria for the CubeSat.

2.4.1 High-Level Objectives

1. Create a CubeSat can detect SGDs (S-2, S-4, S-5)
2. Decrease the cost of the nano-satellite overall (S-1)
3. Provide SGD area of concentrations for analysis (S-2, S-3)
4. Allow the tracking of the satellite and nearby objects (S-5)
5. Limit the potential environmental harm to the ecosystem (S-6)

2.4.2 Detailed Objectives

1. Should be lightweight (HLO-2)
2. Should provide frequent observations of the Australian coastlines (HLO-3)
3. Should be compact (HLO-2)
4. Should be stable (HLO-3)
5. Should be energy efficient (HLO-2)
6. Should have cost-effective components (HLO-2)
7. Should be able to receive and transmit data (HLO-1)
8. Should carry a payload (HLO-1)

2.4.3 Constraints

1. Must be less than 4 kg
2. Must have a period of less than a 1 week (DO-2, M-2)
3. Must be 3U or less (DO-3, M-3)
4. Must have a center of gravity within 7 cm or less of the objects geometric center in the longest direction (DO-4, M-4)
5. Must contain less than 100 watt-hours of stored chemical energy (DO-5, M-5)
6. Must be in LEO (DO-2)
7. Must use COTS components (DO-6)

2.4.4 Criteria

1. Mass measured in kg, where less mass is preferred (DO-1, M-1)
2. Time is measured in weeks, where less time is prefered (DO-2, M-2)
3. Dimensions are measured in U, where less U's are preferred. (DO-3, M-3)
4. Distance is measured in cm, where less is preferred (DO-4, M-4)
5. Chemical Energy measured in Watt-hours, or Wh, where less wattage is preferred (DO-5, M-5)
6. Energy consumed per second in Joules per second, or W, where less wattage is preferred (DO-5, M-6)

2.4.5 Metrics

1. Units of [kg] (CO-1,CR-1)
2. Units of [Weeks] (CO-2,CR-2)
3. Units of [U] (CO-3,CR-3)
4. Units of [cm] (CO-4,CR-4)
5. Units of [Wh] (CO-5,CR-5)
6. Units of [W] (CO-5, CR-6)

3.0 Background and Surveys

Submarine groundwater discharges are defined as the flow of any and all water from the continental margins to the coastal ocean. SGDs are driven by hydrogeologic and oceanographic processes such as tidal pumping, and wave set-up, and most commonly occurs where an aquifer is connected to the sea and the groundwater is above sea level. SGDs have profound effects on the local ecosystem and coastal communities. SGDs carry nutrients, carbon, metals, and other materials that drive biological processes, and can vary in pH compared to the sea which can stress marine life. Some marine species such as oysters and harmful algae thrive in eutrophic environments, while others like fish are driven away from such areas. As a result, many local communities have seen reduced biodiversity and species richness [1]. The lack of biodiversity also has a crucial impact on local economies. For example, in the Mediterannean, mussels are a highly valuable species. Research shows that the Mediterranean mussels thrive in the eutrophic environment near the coastal water, which leads to an increased abundance and size of the species [2].

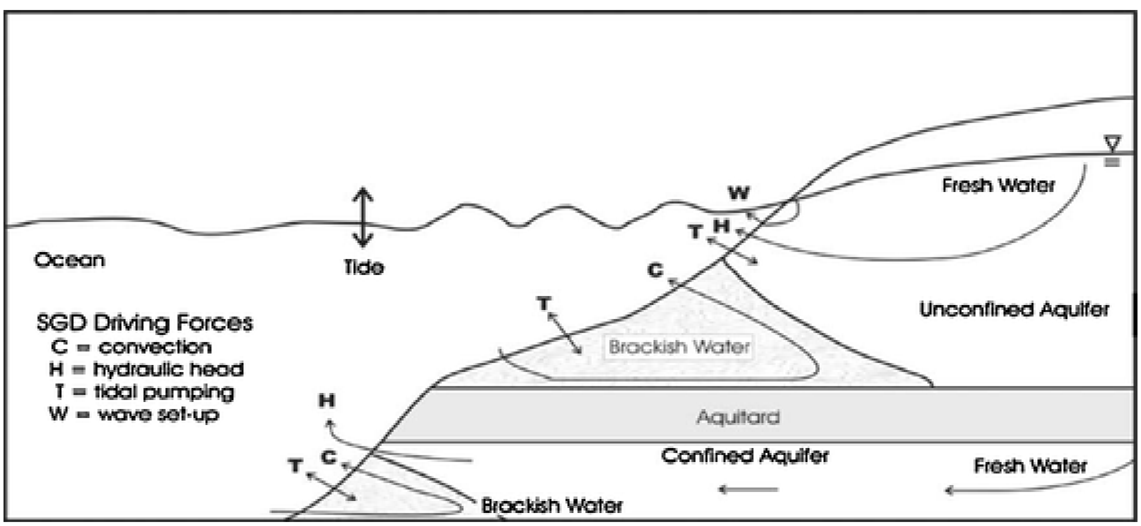


Figure 1: Geological processes associated with SGD

Fig. 1 shows the processes that are associated with SGDs. To detect the SGDs, a thermal imaging system must be used. The medium for which it must be is either aerial or spatial. Rather than using a UAV, for scanning and detecting these events, a satellite will be used. A CubeSat is the ideal choice in this scenario because there is a need to acquire data over a large area as well as data that is needed to be collected quickly. CubeSats are very common and have many purposes. In this instance, there will be scans each time it passes by the Australian coastline to analyze the SGDs.

For CubeSats, there have been many companies on the rise within the market. Many of these companies have produced dozens of CubeSats that have gone on successful missions. Since 2013, the company Planet has produced and launched more than 280 CubeSats for daily global coverage [3]. Most of these CubeSats are used to analyze river processes and hydrological models. NanoAvionics and Endurosat have made many CubeSats that are in low Earth orbit with the focus of optimization for inter-satellite applications and data analytics. Both NanoAvionics and EnduroSat offer a variety of readily available components that are specific to the client's requests such as CubeSat modules, communication systems, and power modules. They also offer services such as building a CubeSat to the client's request. Over the years, these companies have improved their CubeSats to have multi-purpose functions, have high performance, and overall better imaging [4].

One of the many CubeSats in space right now is the TEMPEST-D. The TEMPEST-D satellite has an average size of a cereal box and its purpose is to analyze the weather. It can reveal multiple layers of rains within clouds. For example, during Hurricane Dorian in 2019, TEMPEST-D was utilized to analyze the different rain layers in the hurricane using a microwave radiometer. The different concentrations of rainfalls can be analyzed by using different radio wavelengths [5]. In some ways, this is one of the most alike CubeSat that the team is planning on designing.

4.0 Conceptualization

To create the best CubeSat design, many different variations of the same model have been thought of. This will be described in better detail using specific subsystems and their value.

CubeSats are very small structures, so much so that a new measurement system was devised to describe the dimensions of the satellite. One unit, otherwise known as 1U, is a cube of size 10x10x10cm. With that, CubeSats can be measured easier and standardized [6]. For this specific satellite, the size of the CubeSat needs to be less than or equal to 3U (CO-3). Using a combination of research-based strategies and structured brainstorming, the team came up with several solutions to solve the problem and eventually converged on an agreed solution that meets our criteria. The team broke down the agreed solution into simple functions that are easier to analyze. The simple breakdown of the functions are as follows:

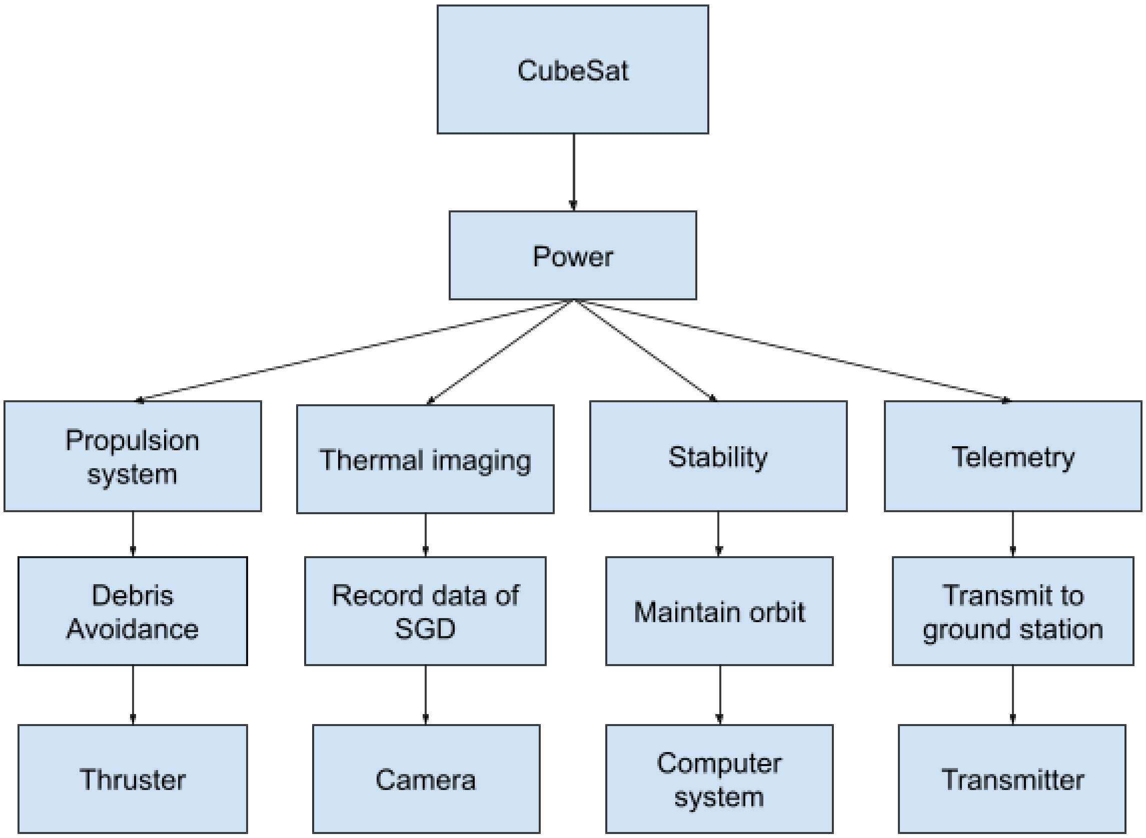


Figure 2: CubeSat Function Breakdown

As can be seen in Fig. 2, each subsystem has an important role in the completion of the mission. Each subsystem is broken down into their general objective and components that will contribute to the overall success of the CubeSat. Each subsystem will research their components and compare them using a matrix to pick the ideal component that will meet the criteria and objectives of AWE.

4.1 Supporting Calculations

There are parts of the CubeSat that are not actual components but rather spatial placements and external factors. One of those is the orbit of the satellite and its corresponding altitude, location with respect to the Earth.

For an orbital period of one week, a calculation for the distance between the earth and the satellite must be done. Using Kepler's 3rd Law, the approximate radius of our orbit can be determined. Eqn. 1 gives the foundation to determine this value.

$$m = \frac{4\pi^2 r^3}{GT^2} \tag{1}$$

The mass refers to the combined mass of the Earth and the satellite; The mass of the CubeSat can be negated as it is negligible compared to the Earth. The mass of the earth is approximately

$5.972 \ x \ 10^{24} \ (kg)$[7]. The Gravitational Constant, G, is a physical constant with a value of $6.674 \ x \ 10^{-11} (\frac{m^3}{kg-s^2})$, there is no influence on this value [8]. As per CO-2, there must be an orbital period of at least one week. Given that, the period must be at most 604,800 seconds. The only variable left unknown is the radius, which given the values, is 154,550 km. The radius is proportional to the orbital period. Thereby, the smaller the period, and more frequent the fly-by's, and the smaller the radius has to be.

Based on CO-5 the radius calculated is far too large for LEO. The maximum altitude for which LEO can be defined as is 2000 km.[9]. The radius of the Earth is necessary as the formula depends on orbital radius rather than altitude. The radius of the Earth is 6378 km [10]. Given that the radius of orbit must be 8378 km. Using Eqn. 1 again but this time solving for the period, the calculation gives a value of 2 hours and 7 minutes.

For simplicity, a period of 2 hours will be used. This will allow multiple fly-by's to be made at an altitude of 1680 km, from the difference of the radius of orbit and earth, thus satisfying CO-2. A more in depth analysis will be performed using STK.

4.2 Alternative Solutions

When formulating a solution that resolves the problem for detecting SGD's, there is an opportunity for many different solutions for a CubeSat. This is resulted from the potential of many alternative subsystems that are involved with the CubeSat have to be considered to fulfill the requirements. The subsystems that have the greatest dependency on the fulfillment of the requirements are propulsion, power, structures, telemetry, stability and thermal imaging.

For orbit modifications and debris avoidance, the CubeSat needs some sort of on-board propulsion system. This propulsion system needs to be included in the mass requirement of 4kg (CO-1), while not drawing too much power from the CubeSat's energy source. Size and energy usage are two of the most important factors for a CubeSat's propulsion system. Having a cap of 3U (CR-3) for the entirety of the CubeSat, the smaller the components are, the more instrumentation can be added. Therefore, the smaller the propulsion system, the better the option as long as the needs are met. In the prior years of space travel, smaller satellites have used very similar technologies for this very reason. There are two main propulsion systems, either in working order, or still in development. They are Chemical propulsion or Electrical Propulsion. For Chemical, there are two basic types, monopropellant and bipropellant. For Electrical there are a few types, whether it be Ion, ResistoJet, Electrospray, or Pulsed Plasma/VAC. Cubesats lead times range from months to years of service. During this time the need to change course, avoid debris, or rotate is inevitable. These important maneuvers are important to hundreds of thousands of dollars invested into CubeSats. These Propulsion systems vary in many factors such as weight and overall size, thrust, power usage, and specific impulse.

The structures subsystem has a large role in the success of the CubeSat since it is involved with key requirements. The size, weight and strength of the CubeSat all depend on the structural subsystem. The material that is chosen and the rest of the payload need to weigh less than 4 kg (CO-1). The material cannot be weak so it needs the strength to withhold the forces of the payload (DO-6). The strength of the material as well as the framework or construction of the will affect the size of the CubeSat. There are two materials for which the chassis can be made from. There are different structural arrangements for a CubeSat depending on the purpose and requirements. Different companies also sell the chassis for varying prices.

In order for our CubeSat to be fully functional and meet the design requirements, data collected from our thermal imaging camera must be relayed to and from Earth (DO-5). The data needs to be sent accurately and in a way that is reliable and able to be easily understood and decrypted. Without the ability to send data to Earth the mission is in vain and provides no purpose to our client. Additionally, the ability to receive data is important in case of emergencies.

The power system on the CubeSat is vital to its success. This is because everything on the CubeSat relies on the power source in order to perform their individual tasks. In turn, components that make up the power section of the CubeSat are quite important. These components are the: power generation source, power storage source, power distribution component, and the CubeSat computer.

The first component of the power subsystem is the power generation source. In the industry today there are a few different types of power developing methods aboard CubeSats. These include solar panels and single use batteries. Some new technologies on the horizon include hydrogen fuel cells and nuclear power [8]. In order to fulfil the requirements the CubeSat must be energy self-sufficient (DO-4) meaning that a power generation source is necessary.

An additional component that is needed in a power system aboard a CubeSat is something to store generated power, i.e. a battery. In order to meet the project requirement there is not allowed to be more than 100kwh of stored energy aboard the CubeSat (CO-5). A battery is necessary in order to harness and store the power generated from the power generation source.

After the power is collected and stored, in order to supply power to different elements of our CubeSat we need a power management and distribution system or PMAD. A PMAD is critical due to different voltages needed to power different elements at different times [11]. The PMAD system will connect to the computer or driver of the CubeSat in order to be told when to supply power and how much power to supply.

The final component enclosed in our power subsystem is an onboard computer or more specifically a microcontroller or field programmable gate array. These components can be very helpful on board a CubeSat due to the safety benefits that reap from them and the customizability that is allowed. The microcontroller should be very customizable and easily fit into our CubeSat mass and size constraints (CO-1, CO-3).

The stability and control subsystem is important in the functionality and orbit of the CubeSat. The control system needs to be smaller than 3U so that it can fit with the confines of the CubeSat (CO-3). The CubeSat must almost be lightweight and cannot exceed 4 kg (CO-1). The control system should be able to analyze its surroundings and adjust its position and orientation based on the surroundings or if it goes off its path. The control system should be able to determine where it is in orbit relative to Earth and store its flight information for future analysis.

The mission goal is to obtain data of SGD's, the imaging subsystem of the CubeSat is relied on in order to successfully meet the client's needs. It is given that the CubeSat's imaging should be completed with thermal optics since it is the best option for SGD detection. Another requirement that can accompany the thermal optics would be the desire for off-the-shelf components (DO-3). Two possible thermal imaging systems are SWIS and the QuIP Interpreter (DO-6). Both suggested imaging systems are creditable and can be considered COTS. [12][13]

4.3 Evaluation of Alternatives

In Section 4.2, many of the subsystems and their components were discussed by being compared to their requirements. Each subsystem now has many possible solutions that meet the requirements; it will be discussed which solution would be most ideal for each subsystem.

4.3.1 Propulsion

On CubeSats, weight and size are very important. In this particular case for example, the constraint size is a maximum of 3U (CR-3). This causes an important factor on which overall system to choose. Model size can change depending on the system types at hand. However, many of the newer technologies have the ability to fit this needed miniaturized space, but this first distinction helps weed out a few options. [14]

Overall, with the given constraints of size and power usage, chemical propellant thrusters have been the main focal point as an option. Nanoavionics is a company that specializes in propulsion systems for nanosatellites. Their EPSS system using an ADN-based monopropellant is the main choice. The usage of ADN over Hydrazine is preferred due to ADN (Ammonium DiNitramide) being both green propellant and having higher performance than other "density-specific impulse" says NASA's Brian Dunbar [15]. The EPSS system's smaller 1.3U size is ideal for smaller satellites. However, another option showed promise due to how similar the system was. VACCO's ArgoMoon Micro Propulsion System(MiPS) is a green monopropellant system that was made for ~14kg nanosatellites.[16] However, with size being the main factor of importance both fall short in being 1.3U. The need for space is of most importance, therefore an electric propulsion system was chosen to be the third option.

Table 1 : Propulsion System Comparison [14][16]

Thruster Name	Size (U)	Fuel	Power (W)	Mass (kg)	Specific Impulse (s)
Nano-Aviation EPSS C1	1.3	ADN-Based Monopropellant	Monitoring - 0.19 Preheat - 9.6 All Thrusters Firing - 1.7	Dry - 1 Wet - 1.2	210
VACCO ArgoMoon MiPS	1.3	Green Monopropellant	Standby - 1 Warmup -20 Thruster all firing -4.3	Dry - 1.43 Wet - 2.065	253
ExoTerra's Halo Micro Hall Thruster	0.4	Electric Based Propulsion - Xenon	Warm up - 20 Firing - 75 Max Thrust - 400	0.6	700

The main differences between the three thruster options are displayed in Table 1. These differences were decided to be the biggest factors in the final decision.

4.3.2 Power

Power generation:

Since this CubeSat is designed for longevity in space, a power source that can recharge and redevelop power is preferred. Our team explored options such as solar panels, single use batteries, hydrogen fuel cells and nuclear power. We found that single use batteries do not last long and are not a viable option [11]. This left us with a decision between solar panels, hydrogen fuel cells, and nuclear power. We found that generally for a CubeSat of our size the only viable option would be solar panels [11]. Additionally, we decided to use solar panels because of the dense knowledge on their performance and their tested reliability in previous missions. We also decided against the hydrogen fuel cell and nuclear power options due to the lack of testing and the fact that these technologies are new and not well tested in space [11]. Solar panels have a few drawbacks, including no energy generation during eclipse periods, along with efficiency degradation over time, large masses, surface area, and costs. Our team decided to overlook these drawbacks and use solar panels to power our CubeSat.

The solar panels equipped on CubeSats are made from thin semiconductor wafers that when exposed to light create an electric current. These types of solar panels are very efficient with efficiency rates nearing 30%. We have found multiple off the shelf solar cells that will satisfy the power constraints of our CubeSat [11].

The first off the shelf solar panel option our team is considering is solar panels designed by Blue Canyon Tech. This option is actually an entire power system rather than just solar panels. This means it includes the power storage and distribution along with power collection. Some characteristics of this power system are located below [17].

Table 2 : Blue Canyon Tech EPS

Product	**Blue Canyon Tech EPS**
Power	35W
Voltage Buses	9-23V
High current capability	Unregulated until 60mA
Energy Storage	75Wh

This table describes the characteristics and attributes of the Blue Canyon Tech EPS. The table lists the power this EPS can supply along with the voltage busses other subsystems can connect to. Additionally, the maximum stored energy and highest current possibilities are listed.

This option is a good candidate in the fact that it includes an entire EPS. It could be an easy solution to combine with a central CubeSat computer. Additionally, this product is well tested in space and very reliable. Some drawbacks of this component would be that it is less customizable to our exact CubeSat. Also, since it's only one product that controls multiple components if this product fails the entire power system also fails and our CubeSat shuts down The only drawback of this product would be that it will not be able to power all the elements in the cubesat simultaneously which although unlikely could lead to some issues.

The second off the shelf option for solar panels is made by DHV technologies. These solar panels are designed for a CubeSat of 3U, the same size as ours, and includes only the solar panels. The following table lists some key characteristics of this product that our team looked at when evaluating solar panel options [18].

Table 3 : DHV Tech Solar Panels

Product	**DHV Technologies**
Power	8.4W
Mass	<60g
Size	3U
Sensors	Magnetometer, Temperature, Sun

Table 3 lists key characteristics of the DHV solar panels. A few key features that were mentioned in the table above are that this solar panel has sun, temperature and magnetometer.

This option was prefered but there were details that were lacking form this design. These details include the fact that these cannot be custom wired to fit our CubeSats exact needs. Additionally, this solar panel option is heavier than the other options.

The third off the shelf solar panel our team discussed is Endurosat's 3U solar panels. These solar panels key characteristics were analyzed and are listed below in Table 4 [19].

Table 4 : Endurosats 3U Solar Panels

Product	**Endurosat 3U Solar Panels**
Max Power	8.4W
Sensors	Temperature, Sun
Mass	127g
Wiring	Series/Parallel
Max Voltage	16.8V
Max Current	504mA

Table 4 is a summary of the criteria analyzed in order to evaluate the Endurosat 3U Solar Panels. This criteria includes the power generated, possible sensors that can be incorporated into the solar panels, its mass and power connection details.

This option is a very strong candidate. The defining characteristics that set this option apart from others were that the solar cells can be wired to our specific needs. This means that the solar panels could either be wired in parallel or in series. Additionally these solar panels have a relatively low mass which is vital in order to satisfy CO-4. Our team believes that this solar panel is the best fit. Although the Blue Canyon tech. EPS was very highly considered, a full customization of an EPS will be more beneficial and fit the CubeSats needs better.

The key characteristics that our team looked at when evaluating these products were the max power, the mass and the customization factors of each component. We decided that all three of the products that were considered had qualifying power outputs. Our decisions came down to the masses and customization factors of the products. We decided to go with Endurosats's option due to both of these factors. We felt that it had more customization than both of the other two options and the mass was sufficiently low enough that it was the best option. We also liked the additional benefits that it had sensors for sun, and temperature and additionally could be wired in either a series or parallel configuration.

Power Storage

In order to harness the energy stored by the solar panels we need to include a battery on board our CubeSat. In the space industry today there are two major characteristic differences between the different types of batteries. The first is whether they are primary-type batteries, non-rechargeable, or secondary-type batteries, rechargeable. Our team looked at each type of battery and quickly decided that the non-rechargeable option would not qualify for our design specifications. For our purposes we will rely on secondary-type batteries for the main reason being the ability to recharge the batteries to enable longevity of our product. The second difference between the different battery options available for CubeSats is the metals that make up the battery. The most prominent secondary-type batteries in space today are, nickel-cadmium, nickel-hydrogen, lithium-ion, and lithium-polymer. One of the biggest aspects that our team looked at in order to evaluate the battery options one criteria looked at is the watt-hours to mass ratio. This ratio gives the efficiency of the battery with respect to how heavy the battery is, also called the specific energy. This is a critical measurement battery with units of Watts over Kilograms and where a larger ratio is preferred. This measurement is a useful tool to compare and analyze different battery options aboard CubeSats. We found that a lithium- polymer battery is highly used and well respected in the space industry. The lithium polymer type also has a very high Watt hour to kilogram ratio. We will now discuss the options we explored and discuss how we made our decisions. [11]

We found a few off the shelf battery options made by AAC Clyde Space. This company features a few different power storage options including the OPTIMUS-30, OPTIMUS-40 and OPTIMUS-80. The number following the name relates to the power storage capability of these where the number is measured in Watt-Hours. These batteries are made out of a lithium polymer. The characteristics of these different battery options are labeled below [20].

Table 5 : OPTIMUS Battery Options

Name	**OPTIMUS-30**	**OPTIMUS-40**	**OPTIMUS-80**
Storage (Wh)	30	40	80
Mass (g)	268	335	670
Length (mm)	98.89	98.89	98.89
Width (mm)	90.17	90.17	90.17
Height (mm)	21.55	27.35	56.94

The previous table lists the differences between all of AAC clyde's battery options. This table lists their mass, size and storage capacity for all three of the battery sizes.

Each of these options provide a lot of potential. According to (CO-5) our team's CubeSat cannot contain over 100 Watt-Hours of stored energy. In order to use one of these products and comply with this requirement, we would either choose using 3 OPTIMUS-30's for a total of 90 Wh, 2 OPTIMUS-40's for a total of 80 Wh, or simply just using the OPTIMUS-80. The benefit of using the OPTIMUS-30's or OPTIMUS-40's rather than simply having one battery is in case one battery fails there is still at least another battery to rely on. Due to the benefits of having multiple batteries on board rather than one just one we decided to go with 2 OPTIMUS-40 options due to the fact that there are 2 batteries available in case one malfunctions. We decided with this option because of the multiple batteries along with the higher Watt hour to mass ratio than the OPTIMUS-30 option. Additionally, we believe that since there are only two batteries rather than three it will be easier to fit both in the CubeSat structure.

Power Management and Distribution

The team reviewed the PMAD needs of the power subsystem and found a few characteristics that are worth noting. The first is that the PMAD systems need to be custom coded and designed for each mission. This is necessary because no two CubeSat missions are exactly the same. Each CubeSat mission has different analysis elements to collect data in space. These different elements all require different voltages and power supplies to operate. Our PMAD system will be connected to all the CubeSat elements through its power buses. These elements being the thermal camera, radio transceiver, stabilization methods ect. along with the battery. When reviewing different PMAD options it was clear to all of us that a very customizable option would benefit best and not limit options in other categories. In general we did not want our PMAD system to hold us back from choosing other preferred designs of other subsystems. Although there are few off the shelf products that fit this description the main problem with these is every CubeSat requires a slightly different PMAD. Our team analyzed the following PMAD systems and listed a few key points about each. We valued small masses along with high customization ability in order to make sure that our PMAD component does not hold us back in other fields. [11]

The first off the shelf component available to fulfil the PMAD needs is made by AAC Clyde Space Technologies. This product is called the STARBUCK-NANO. The STARBUCK-NANO key features are listed below in Table 5. [21]

Table 6 : Starbuck Nano PMAD

Product	**STARBUCK-NANO**
Mass (g)	86
Length (mm)	95.89
Width (mm)	90.17
Height (mm)	16.2
Power Buses (V)	3.3/5/12
Max Input Voltage (V)	8.2

This table mentions the characteristics analyzed in making our decision matrix for the PMAD system. These characteristics include the geometric size, mass, and how this PMAD is made to connect to other subsystems in a cubesat.

This product was a strongly considered option but lacks customization that other products have. We liked the low mass along with the multiple power buses. This product scored pretty evenly in the mass and size categories compared to the other two options and very high in the ease of use category which measures how well this component will interfere with the decision making techniques of other subsystems.

A second off the shelf component that has large potential to fulfil the requirements of a PMAD component for a CubeSat is a product made by SEAKR Engineering called the 3U CPCI. This product's description is listed below in Table 6. [22]

Table 7 : 3U CPCI PMAD

Product	**3U CPCI**
Power Buses	3.3V @ 15A, 5V @ 3.5A, 15V @ 0.33 A
Input Voltages	22 - 36 V

The characteristics of the 3U CPCI PMAD are listed in the table above. Listed are the characteristics that may separate this system from others. This includes the output power busses which lists the different possible voltages and current.

This product qualifies as an alternative but our team does not think it is the best fit. This is because it lacks the customizability that other products do. This product's mass and size are almost identical to the other two options. When ranking this product's ease of use this product scored fairly low. That is because of the limited voltage input and output buses. Additionally this option did not score very high in the customization category.

A third commercial product that was manufactured by Space Inventor is called the PCDU-P3. This product is a PMAD and its features are listed below[23].

Table 8 : PCDU -P3 PMAD

Product	**PCDU-P3**
Input Voltages (V)	6 - 28
Voltage Buses @ 3A (V)	1.8 - 24
Mass (g)	138

The PCDU-P3 PMAD characteristics are mentioned above. A few highlights include a large range of both input and output voltages. The mass is also listed in the table and is relatively similar compared to the other alternatives.

This option allows for maximum customizability and has proven well in space. The customizability of the output voltages plays a big role and allows for more products in other subsystems to be considered.

When analyzing the different options for a power management and distribution system, we evaluated the options based on a few criteria. These criteria are mass, size, customization, and ease of use. The ease of use was decided by how easily we thought that we could integrate the given option into our cubesat without having to make significant changes to other subsystems or power elements. The criteria were ranked in order of importance in the following order, ease of use, customization, mass and size. After analysis of our options based on these criteria we decided to to use the PCDU-P3 PMAD system. We thought this one would integrate easiest into our design with the high customizable voltage buses. Additionally all of the proposed options have relatively similar mass and size so there wasn't much discrepancy between the analysis of those. Since these very strong candidates we decided to use a decision matrix to help guide our team in the right direction. As seen in the following picture. In this decision matrix the customization ability was ranked between 1 and 10 and the ease of use was ranked between one and one hundred.

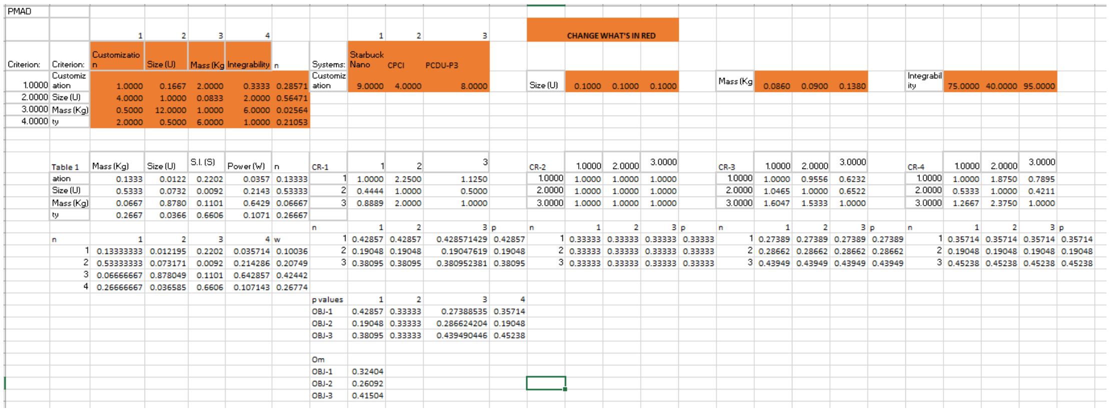


Figure 3: Decision matrix for PMAD system

After evaluation and completing the decision matrix as shown in Fig. 3, it was found that the PCDU-P3 PMAD system is the best option. This option was the front runner before the decision matrix was completed but was reinforced by having the highest overall score from the decision matrix.

Computers:

When looking at different options for an onboard computer we highly valued options with large computing power along with decent memory in order to store the code for the CubeSat. We valued these items because a powerful microcontroller on board can promote safety by turning off components when they are not being used and also protecting these components against radiation. Additionally powering components off when not being used saves memory on board the CubeSat along with power. Along with strong computing abilities and storage capabilities microcontrollers also allow for full customization aboard a CubeSat. Since no two CubeSats are the same the encoded microcontroller must be coded in a way to fulfil the design requirements of a mission. Our team valued this highly and wanted to ensure that our microcontroller was capable of full customization. There are many different types of microcontrollers available and range from smartphones to devices built to be mission specific. A few promising solutions we found along with their key characteristics are found below [21].

The first on board computer we analyzed and considered is the on board computer made by Endurosat. This computer's features are listed in Table 8 below [25]:

Table 9: Endurosat OBC

Product	**Endurosat OBC**
Processor	ARM Cortex M4
RAM	156 kB
Mass (g)	130

The previous lists the attributes that were analyzed when making decisions based on the OBC. The Endurosat OBC key attributes include a small mass and fast processor along with a good amount of RAM.

This product was a good option. Although we considered it at first we thought we could find something more lightweight and with higher computing capabilities and memory. We did although like how it has been flown in space before and its reliability is known.

The second on board computer we looked at is the IMT CubeSat OBC made by Ingegneria Marketing Technologia. This computer has very powerful processing capabilities along with large amounts of memory. The key characteristics of this product is listed in Table 9 [26]:

Table 10 : IMT OBC

Product	**IMT CubeSat OBC**
Mass (g)	38
Length (mm)	96
Width (mm)	90
Height (mm)	10
Power Draw @ 3.3V (mW)	300
Memory	8GB flash NAND/16MB RAM/64 MB flash NOR
Processor	PIC32MZ M14K
Devices	16 Allowed

The defining attributes of this cubesat are described in the table above. These include a really low mass, small size along with a large amount of memory and computing power. Additionally this computer would fit well and be easy to integrate into our design due to the fact that it can allow up to 16 devices and will fit into our PMAD system.

This computer is the one we will go with aboard the CubeSat. It has a low mass and power consumption but enough memory and processing capabilities to perform the tasks we need to do. Additionally, it takes up a low amount of space which is limited on board the CubeSat. This computer also will easily fit in our power distribution source. Lastly this computer has enough terminals that in case there needs to be more components added to our CubeSat there are enough terminals on the computer to add additional components.

When deciding which on board computer to choose we evaluated the alternatives based on their mass, size, customizability along with the computing power and storage, and power draw. The different options were evaluated by using criteria in the following order of importance, computing capabilities, mass, size and power draw.

4.3.3 Structures

For structures the material, which the chassis is constructed of, typically is Al 6061 T-6 or Al 7075 T-6 which have similar applications but different properties. Table 11 will compare the two metals in various aspects.

Table 11: A comparison between properties of different aluminum alloys [27]

Material properties	6061 Aluminum alloy	7075 Aluminum alloy
Primary Alloy	Silicon	Zinc
Yield Strength (MPa)	276	503
Thermal conductivity (W/m-K)	167	130
Electrical resistivity (Ohm-cm)	3.99×10^{-6}	5.15×10^{-6}
Hardness (Brinell)	95	150
Machinability	Good	Fair
Weldability	Good	Poor

Based on Table 11, there are many differences among the two alloys. The 7075 alloy is a stronger and harder metal as indicated by the yield strength and hardness. The 6061 alloy has better thermal conductivity and electrical resistivity. The weight of the two are indifferent at the scale of a CubeSat.

Though the 7075 alloy is stronger, it is a lot harder to deal with and fabricate. It cannot be welded and prone to cracking due to brittleness. The 6061 alloy has the advantage in that case which provides a better assessment of the situation. The strength is not as important as ease of manufacturing due to the size of the CubeSat. As of now, Aluminum 6061 T-6 is the better of the two alternatives.

Two different frame types can be used when regarding the skeletal structure. There are monocoque single body, and modular frames. The monocoque design is one that has a single piece of aluminum shaped into the size of the desired CubeSat. It is strong with few structural weaknesses due to the single piece design. There can be components preinstalled with multiple openings to insert the parts. That is limited to the size of the opening. A modular frame has the advantage of being disassembled which allows interchangeability of parts unlike the monocoque structure. Larger components can be installed as a result thus optimizing the volume within the structure which is in limited supply. There are more structural weaknesses with fasteners being used to hold the components together. All things considered, the modulus frame design will be more appropriate for this circumstance. The size of the CubeSat is small and it should be lightweight as by DO-7, thus the influence of volume efficiency is more important than strength.

There is a third frame type that could have been used for this CubeSat. The relevance is negligible as it pertains to specifically card slots. The satellite we are going to design has a purpose of using infrared to detect SGDs not for card storage.

Table 12: The comparisons of masses in grams of the various modulus frame designs [28]

Size (U)	NanoAvionics	EnduroSat	Innovative Solutions In Space
1	90	100	100
1.5	N/A	152	N/A
2	172	N/A	160
3	254	290	240

As shown in Table 12, the larger the size of the CubeSat, the more mass it carries. The mass is also influenced by the material being used as not all weight the same even though the sizes are the same.

The company NanoAvionics has created a structure design that has a lot of potential. The sizes are all in U increments which satisfies the requirement. The material used is Al 7075 T-6 which corresponds to the fact that it is tailored for larger CubeSats. The more common products sold are for large 6U and larger satellites. This type is not very useful for the design overall.

EnduroSat has premade CubeSats and chassis. There are many models that have both pre-made CubeSats and just frames. The material used within these chassis is different than that of the conventional. The aluminum alloy used is 6082 T-6. It is very similar to the preferred 6061 with slight variation. It is stronger but also a bit heavier. However, it compromises much better than the 7075 T-6 alloy. The base cost of the 3U series is about $3700. [29]

Innovative Solutions in Space Structure is another company that creates CubeSat structures of varying sizes. Many of its models have been used in LEO. The frames are very similar to the EnduroSat with the materials presumed to be the common Al 6061 T-6 alloy. There can be an option that contains detachable shear panels thus allowing for multiple configurations. However, that is an extra that costs more. The overall price is much higher as when compared to the EduroSat. The base model for a 3U is €3650, or about $4285 for a weaker structure that does not include the shear panels. [30]

The mass we are using is being limited by the requirements as stated in CO-1. The smaller the structure, the less weight since less material is used, but there could be a weaker structure. There has to also be a compromise between size as some components may need a lot of space to be useful. There were many more companies that had available CubeSats, a lot of issues arose with them though. Most were for larger and more robust satellites, or were mostly complete and therefore could not be modified for this mission. Taking all in consideration, the best design would be from EndoroSat. As it would be more cost effective and practical overall.

The U sizes are in play as there are 3 types that can be used as per CO-3. Using that company, the available options are, 1U,1.5U, and 3U. Any larger size is not permitted. The smaller sizes have less mass as expected with it containing less material. However, there is an issue with usable space. Some components may not fit into the smaller sizes. Therefore, the size of the CubeSat will be 3U as it is the upper limit of size. This will provide more volume for the overall design which will allow the larger components to be fitted within the satellite. The mass will increase, but only proportionally to its size. There is still room for CO-1 to be satisfied as the mass of the chassis is only a small part of the CubeSat.

4.3.4 Telemetry

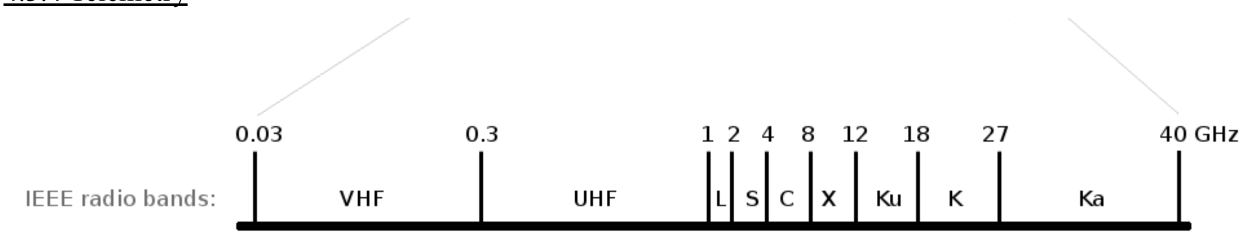


Figure 4: Graph of Different radio frequency [28]

When looking at different telemetry options we looked at what has been successful on similar CubeSat missions in the past. Most CubeSats use radio waves to communicate. As of right now there are a few different frequency ranges that are prominent for use in CubeSats today, S-band, X-band, L-band and UHF/VHF. Their frequencies can be shown in Fig. 4 above. The first is L-band frequencies. . They run at a frequency between 1-2 GHz. Although well proven and reliable due to low frequencies the L-band cannot transmit data at large rates. S-band frequencies are higher than the L-band and range from 2-4 GHz. Although S-band signals are widely used across the industry, there is a current crowding of S-band frequencies due to modern day cell phone use. S-band frequencies are used most and are the best option for our particular CubeSat. X-band frequencies are a newer technology being developed and have a frequency range of 8-12 GHz.[31] Since these have such high frequencies they pass data faster than the other. This is a critical component considering faster data transmission allows for more data to be recovered and thus overall better data. The final option is VHF and UHF. These frequencies are from 0.03-1 GHz. These frequencies are easy to use but the major problem is that they can be absorbed in the Earth's atmosphere. Although there is other technology being established to use other methods such as Lasercom, which uses lasers to communicate, and higher frequency bandwidth such as Ka-Ku band transmitters [31]. Since these technologies are still being developed and are not essential for our CubeSat we will not pursue those options. Rather we will use an S-band frequency transceiver and an S-Band patch antenna. We decided to use a transceiver rather than just a transmitter in order to fulfil requirements (DO-5) [31].

The first option for an S-band off the shelf transceiver is the ISIS S-band Transceiver. This transceiver paired with a S-band Patch antenna would satisfy the needs of the client very well.

Table 13 : ISIS S-Band Transceiver [32]

Product	Transmitter	Receiver
Length (mm)	99 mm	96 mm
Width (mm)	94 mm	92 mm
Height (mm)	15 mm	10 mm
Power Consumption (W)	13	1.2
Frequency Range (MHz)	2200 - 2290	2025 - 2110
Data Rate (Mbps)	10	9.6
Total Supply Voltage Range (V)	7 - 20	-
Total Mass (g)	217 g	-

The S-Band Transceiver is composed of the characteristics listed in the table above. Listed is the Transceivers mass, size along with transmit rates and capabilities.

This option is great and could be a key component in the final design. The key attributes that make this product stand out are the high transmission rate along with the low power consumption. Additionally, the fast data transmission is a beneficial attribute that could help when needed. This was one of the only options that was highly considered due to other options found not meeting the requirements of this mission. Another S-Band patch antenna from the same company can be paired with this device in order to generate the encrypted radio waves and data on submarine water discharge to send back to Earth.

4.3.5 Stability

In order to keep the satellite in orbit, a stability and control system is required. The control systems should take into account multiple factors such as LEO, gravity, and aerodynamic forces to keep its orbit. The control systems should be semi autonomous so that it can correct itself should it collide with space debris, and so that the operator can correct its orbit should it go off its path. There are several off-the-shelf control systems that are considered in the design. First, the team looked at the PhidgetSpatial gyroscope which has a built in 3-axis accelerometer, a magnetometer, and a 3-axis coordinate system. The PhidgetSpatial gyroscope is small and lightweight to fit in our CubeSat. It can store multiple inputs of data and comes with a USB port that allows for easy retrieval of the data. The PhidgetSpatial has a 3-axis accelerometer and can measure up to 8 Gs per axis. It can also measure static velocity, dynamic acceleration, and static acceleration. It also has a magnetometer that can help the CubeSat adjust its orientation based on the magnetic field of Earth. The product also has a 3-axis compass and can store motion data for analytical purposes [33].

The second off- the shelf product is the MPU-600 which has a 3-axis gyroscope with a 3 axis accelerometer. The control system is a small and light box with dimensions 4x4x0.9 mm. However, it does not have a magnetometer which can be important on a CubeSat. Magnetometers allow a CubeSat to determine its direction and orientation in space while it collects data [33].

4.3.6 Thermal Imaging

When finding thermal optics to capture data of SGDs, there are many off-the-shelf options. The most state-of-the-art options are the QuIP Interpreter and the Chameleon Imager. Both would be great options for collecting the SGD data, in an imaging sense. The QuIP imaging system is a little bit older, emerging around 2015 while the Chameleon Imager came about in 2018. When comparing thermal imaging systems, the key arguments are spatial resolution, mass, operation temperature and in this case size will play a large role. See comparison table below:

Table 14 : Comparing the QuIP and Chameleon Imaging Systems [12][13]

Name	QuIP Interpreter	Chameleon Imager
Spatial Resolution (m)	60	9.6
Mass (kg)	1.4	1.35
Operation Temperature (°C)	-213	-20

Size (cm x cm x cm)	10 x 10 x 20	9.4 x 9.4 x 20
Size (U)	2	< 2

(Disregard table gap, formatted to the best of our abilities)

As seen in Table 14 above, the QuIP system and Chameleon are very different when it comes to their imaging outputs. One thing both QuIP and Chameleon have in common is that they can both operate under non-ideal circumstances. They can both operate under significant temperatures; but seen in Table 14, the QuIP design can operate at an almost unbearable temperature of -213 degrees celsius [12]. The QuIP uses a miniature mechanical cryocooler to keep the system running under hot conditions; having a cooling system is rare. On the other hand, under warmer conditions, QuIP has a linear variable anti-reflection coating that absorbs; this increases operating temperature, which is more common. Another purpose of the anti-reflective coating is to increase the quantum efficiency. In the Chameleon design, it has capabilities of withstanding a great amount of radiation being to a TID of 20 krad.[13] A benefit to using the Chameleon Imager is its large storage capacity that can hold up to 160 GB when each digital photo taken has an average size of 10-bit which is extremely small . To compare, 10-bit can convert to just over 1 byte of storage. [13]

Overall, the Chameleon and QuIP are similar in calibration but the Chameleon results in better quality data and better resolution. As seen in Table 14, the spatial resolution on the Chameleon is 9.6 m as the QuIP has a spatial resolution of 60 m. This spatial resolution represents that there are more pixels per capture for the Chameleon than on the QuIP. This better quality leads the Chameleon to satisfying the requirements more efficiently than QuIP. One of the requirements was that the CubeSat should be no heavier than 4 kg (CO-1); both components met the requirements but every gram counts for the design so the Chameleon Imager has the upper hand for the mass comparison. Another important requirement to meet is the size constraint, the Chameleon has the ability to poke 4 cm out of the cubesat which makes its volume in the structure much lower than the QuIP Interpreter (CO-3). The Chameleon is the more relevant design that is relatively high-end and fits perfectly earning its niche. [12][13]

5.0 Selected Conceptual Design Specifications

After careful consideration and multiple iterations of the design process, there has been a chosen conceptual design. These specifications have been made with respect to the requirements requested. The environmental effects of the components were not of concern as the satellite will be orbiting in space. The only concern would be for the launch of the system, but that is not the purpose of this report.

5.1 Description of the Selected Conceptual Design

Using STK, the orbit of the CubeSat was changed to be at an altitude of 500 km. There will be ample opportunity for data collection of the SGDs as the cubesat will orbit and fly over Australia over 150 times every two weeks, thus satisfying CO-2. This means that the cubesat will be able to analyze and cover the entire coastline of Australia while being able to transmit data back to Earth. A further detailed analysis and description of the CubeSat will be in the subsystem section 5.2.

5.2 Division of Subsystems

Subsystems are important to moderate and control the CubeSat. It also allows for individuals to focus in detail about one aspect of the design rather than the whole design altogether. The categories are propulsion, power, structures, telemetry and stability. Taking into consideration all the factors for our design, the best design was one that consisted of the following details in parts 5.2.1-5.2.6.

5.2.1 Propulsion

Cold gas thrusters are among some of the most promising technologies. Their simplicity, and their reliability are why they were used throughout the history of larger satellites, according to Storck. [27] Micro-versions of cold gas thrusters have already been made and are used today. The ability to use them whenever possible is crucial, however, holding their propellant tanks is where the issue arises. Cold gas systems have storage tanks that are not ideal, if not usable for CubeSats. Overall, for most chemical based propulsion systems, creating a micro-version of already made systems is challenging for this reason; micro-electromechanical systems are difficult to make and increase the overall cost of the system. That being said, micro-mechanical systems are possible, just not available "for nanosatellites in their current form."[27] Therefore this rules out a lot of chemical thrusters in general. However, in microrocket form, monopropellant thrusters hold a lot of promise.[34]

Ion based thrusters like Hall Effect thrusters are powerful, miniature propulsion systems. These thrusters match up with the thrust and specific impulse of chemical thrusters, but consume an excessive amount of energy. With CubeSats, having everything function properly and have an adequate power supply is crucial. Seeing that the main objective of the mission is to observe, the higher that quality of these instruments are of higher importance. Therefore, with input needs of up to 60W, ion propulsion is very unlikely for this case. However, this is at full capability of the electric based thrusters. Not using full thrust capabilities offers some wiggle room for these thrusters to be of use on CubeSats.

Pulsed Ion Thrusters have been used throughout multiple missions. Their relatively simple design allows for micro-PPT to be utilized often. However, there are many disadvantages in using this system. EM interference and high voltage input is the two most concerning. According to Storck, EM interference will cause the micro-PPTs microprocessor to reset. These micro-PPTs have been linked to missions in university CubeSats, but have yet to be launched and are still in development on smaller satellites.[34]

After analysis and research monopropellants and Hall Effect Thrusters have the most promise of fitting the constraints of this mission. The three selected were one system from Nano-Aviation, VACCO, and ExoTerra. The two monopropellant thrusters are smaller 1.3U systems. Constraints ask for less power and size if necessary. However, similar in size, VACCO's system draws more energy than NanoAvionics while being almost double the wet mass. Between the two monopropellant thrusters, Nano-Aviation seemed to be the best fit. However, this initial assumption was wrong. Monopropellant thrusters are not adequate for this specific mission. The need for space outweighed the need to minimize power consumption, according to our decision matrix. Thus the overall system chosen was ExoTerra's Hall Effect thruster. Figure 5 and 6 are images of the final decision. Definitions for these propulsion systems are stated below.

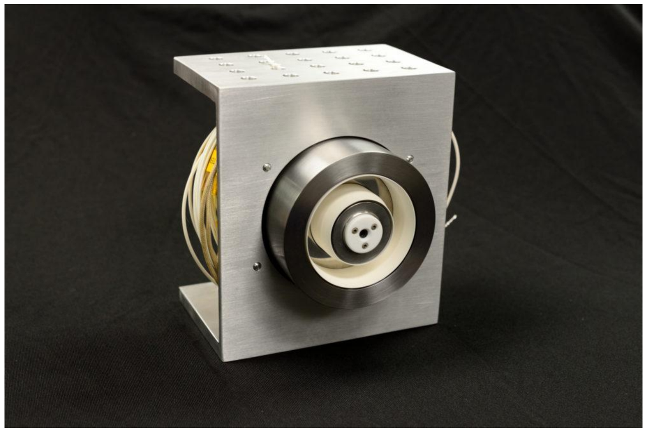


Figure 5: ExoTerra's Hall Effect thruster [35]

Table 15 : Propulsion Types [15]

Monopropellant	Single propellant thrusters utilizing either solid or liquid propellants I.e: Hydrazine
Bipropellant	Propellant thrusters utilizing two propellants I.e: N_2O_4
Pulsed Plasma and Vacuum Arc Thrusters	An electric thruster that uses Teflon as propellant. Teflon is ablated by high voltage and sends particles away from the CubeSat. Similarly, VACs use plasma, but from metallic propellant to minimize energy consumption
Hall Effect and Ion Propulsion	Hall Thrusters are ion thrusters that utilize ion emission, which are propelled by an electric field. The most common is utilizing Xenon.
Cold Gas Thrusters	Cold Gas Thrusters are simple systems that utilize compressed cold gas as their main form of propulsion
Resistojet Propulsion	Resistojets heat a propellant enough for it to expand and release out of a nozzle.

Table 15 explains the differences in both thruster type and fuel type.

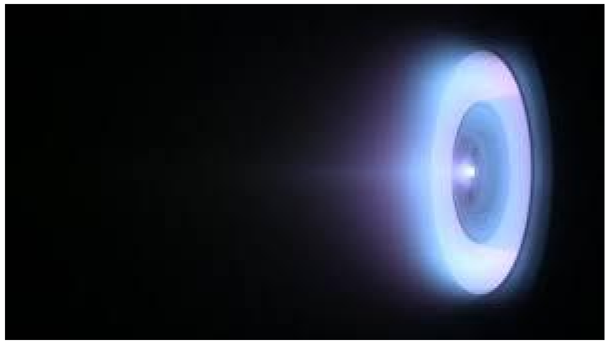


Figure 6: ExoTerra's Hall Effect thruster firing [35]

5.2.2 Power

The power system is critical to the performance, reliability, and the overall success of the CubeSat. In order for almost every other subsystem to function and perform its task the power subsystem must operate without any flaws and have methods to fix accidents before they become disastrous. In saying this that means that all the components of the power subsystem we reviewed in explicit detail and with precision.

The first component of the subsystem that we reviewed was the power generation component. Our team will use commercial off-the-shelf components for our power generation component as per DO-3. Our team will use solar panels for the power generation component of our CubeSat. We decided on Endurosat's solar panel option. This solar panel option is customized for 3U CubeSat which complies with our size requirements (CO-3). Additionally the Endurosat solar panel has a mass of 127 g which is a relatively light weight and will fit nicely into our weight requirements (CO-1). This option is complete with sun and temperature sensors along with an additional optional gyroscope and magnetorquer component. Additionally the solar panels can be connected in both series and parallel which allows for maximum customization of our CubeSat [19]. Endurosat has the optio

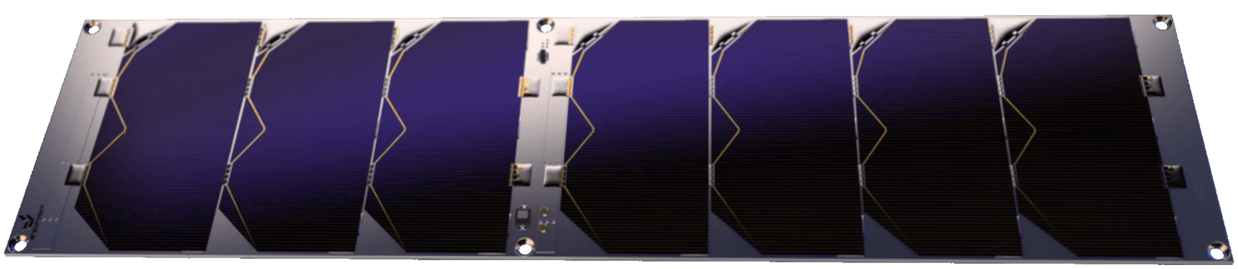


Figure 7: Endurosat 3U Solar Panel

The second component of the power subsystem that our team decided on was a Lithium polymer battery made by AAC Clyde Space technology called the OPTIMUS-40. We decided to use two 40 watt hour batteries in order to stay within our watt hour requirements (CO-5). This product has the power capacity to power our CubeSat during times of orbit where sunlight is not available for power generation and is small enough to fit within our limits. Additionally this battery has safety features in place such as under-voltage, overvoltage and overcurrent protection. Lastly, this option was preferred by all of us due to the production company and product in particular reputable success in previous missions in space. This battery has been on over 100 missions in space previously with success on each mission [20]. These two batteries will be wired in parallel in order to avoid accidents in case a battery fails. If wired in series and one of the batteries fails, the failure to pass current through the broken battery will make the working battery inoperable which then compromises the entire mission. Rather with these batteries wired in parallel there is another element of mission safety on board the cubesat. An image of a single OPTIMUS-40 battery can be seen in the figure below.

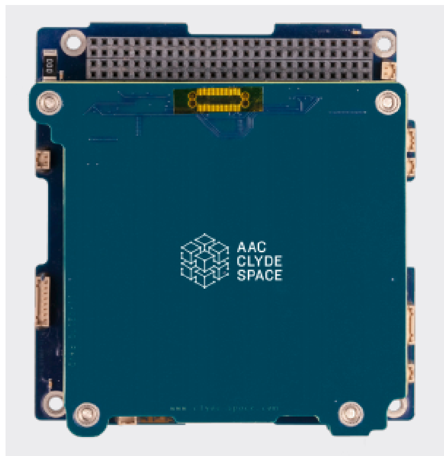


Figure 8: AAC Clyde Optimus-40 Battery

A third component of the power subsystem that needed to be evaluated and agreed upon was a PMAD or power management and distribution system. Since this is the component that controls the power supply to all the other devices on board the cubesat, a decision matrix was used as previously described to guide our decision. Our team decided to use a product made by Space Inventor called the PCDU-P3. This product is a power conditioning and distribution unit that allows for 12 different elements to be connected. We also liked the fact that the busses on this PMAD are customizable and can supply anywhere from 1.8 to 24 V of power depending on element specifications. Additionally this element has one boost converter that can reach up to 28 V of power if needed. We also valued the ability to turn elements on and off with this device and that it is radiation tested and safe [23]. The following figure is an image of the PCDU-P3 PMAD system.

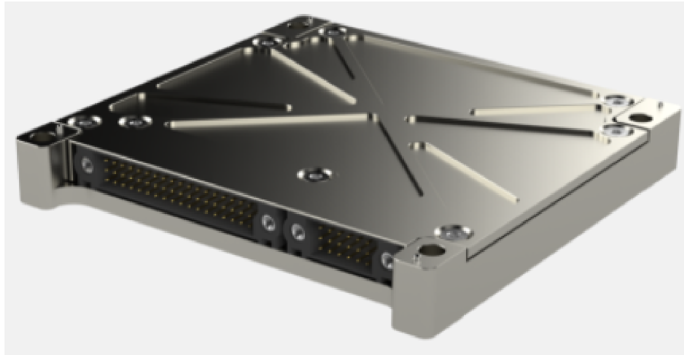


Figure 9: PCDU-P3 PMAD System

The last component of the power subsection that needed to be selected was a on-board-computing device responsible for controlling the different subsystems. We choose to use the IMT CubeSat OBC as our on board computer for this project. This computer has large memory capabilities with 16 GB of flash, 16 MB of RAM and 64MB of flash NOR. This OBC also has a PIC32MZ M14K processor which is more powerful than the other computers we considered. We also liked the fact that this computer weighs only 38 grams and still has the ability to allow up to 16 devices to be connected. The last characteristic that is very reassuring is that this OBC has the capability to keep real time for up to 5 days without power [26]. The following figure is what the OBC looks like.

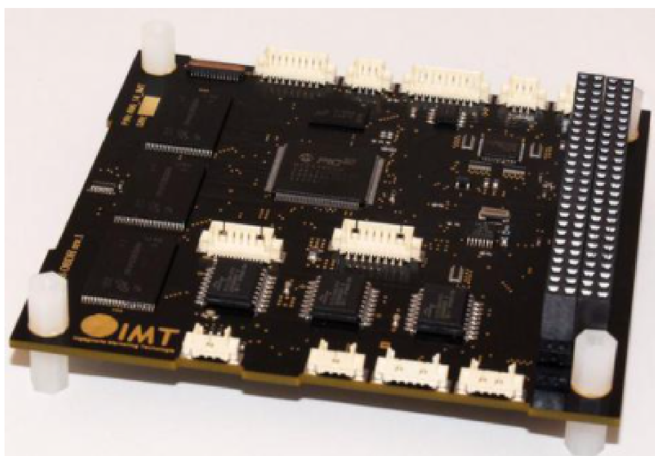


Figure 10: IMT Cubesat OBC

5.2.3 Structures

The primary structure of a satellite is vital for success of the payload. The structure carries and transmits all the external loads on the outer skeleton. Volume efficiency is of essence as to carry all the necessary components for the satellite to function. The chassis does more than just provide support for the loads, thermal management and radiation shielding is also a consideration.[28] If the outer structure were to fail, there would be catastrophic repercussions leading to failure of the mission. COTS components will be used for structural purposes as per DO-3. The only limitation this will bring is to the components if they cannot be installed within the CubeSat.

Figure 11: The EnduroSat 3U frame [29]

An EnduroSat of size 3U, as shown in Fig. 11, will be used as the external skeleton for the CubeSat. The choice of the material was related to the manufacturer. The aluminum alloy is 6082 T-6 which is very similar to the preferred one picked, 6061, as an alternative. This provides a strong structure albeit slightly heavier than appreciated. The exterior has a hard anodized finish giving it a good look and protection. There can be up to 2 kill switches if necessary for the device. Fasteners and 2 separation springs are provided as well.

The primary concern when deciding came to the size and cost. Even though there can be external loads, the magnitude of them would be relatively insignificant. Other components are likely to fail before the structure does. The size of this 3U CubeSat will be 10x10x34 cm^3. The 3U provides a lot of space for the multiple components to be installed. Most of the components will require a space greater than a single or double U. The modular frame picked also allows components to be swapped quite easily as when contrasted to the monocoque type. This specific model is also cheaper that alternative models which suffices HLO-4. [29]

5.2.4 Telemetry

Our CubeSats communication system is very important to the success of our product. We choose the ISIS S-band transceiver paired with the ISIS S-band patch antenna to complete the telemetry portion of our CubeSat. We chose to use the same company for both the transceiver and antenna in order to ensure that they would be functioning properly and compatible. This system is relatively lightweight with a total weight of 267 grams. Additionally this component uses low power draw when in use. The transceiver is small enough to fit into the chosen CubeSat structure and the antenna will fit on the outside of the CubeSat nicely. This system also has an adequate data upload and download speed.These speeds are measured in megabits per second and are 10 mbps for the transmit speed and 9.6 mbps. Its voltage input is not a set number and can be customized which is nice and allows for more PMAD options to be considered [32]. The following figure is the S-band patch antenna. This piece of hardware will be mounted on the outside of our cubesat and will generate the radio frequency that transmits data back to earth. Additionally, this antenna will also capture radio frequency that is sent from Earth to our cubesat.

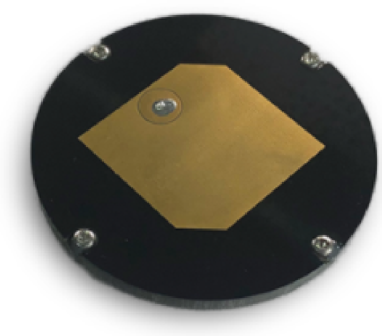


Figure 12: ISIS S-band Patch Antenna

The following figure shows the S-band transceiver that will control the S-band patch antenna. This transceiver will take stored image data from our computer and send the data to the antenna to send back to earth. This component will also handle the encrypting of the data into radio frequencies along with the decrypting of radio frequencies that are sent to our cubesat. This transmitter will be able to transmit the data needed in the given time. This was analyzed using the data sizes for images from the thermal image and the transmit data speeds. Since the thermal image camera takes photos with 1byte of size and our transceiver can send 10mbps it was determined that it was sufficiently fast. This means that it can send one million images per second. The following figure is a visual representation of the ISIS S-Band Transceiver.

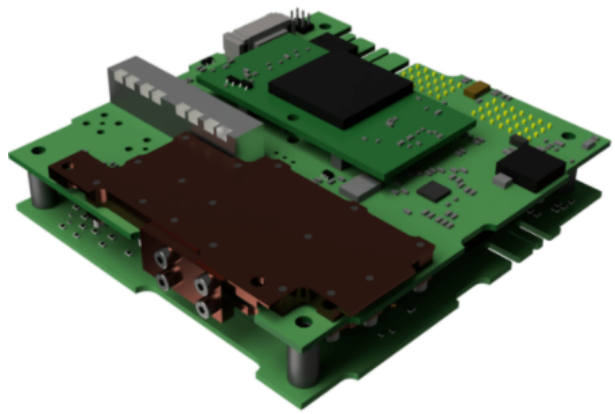


Figure 13: ISIS S-Band Transceiver

5,2.5 Stability

Stability is an important subsystem because it allows the CubeSat to sustain orbit while it collects data. Stability is important when considering the dynamics and statics of orbital motion. The PhidgetSpatial gyroscope is a great control system for the CubeSat. It is small and lightweight so that it can fit the criteria of our CubeSat. It has a 3-axis accelerometer and compass that allows the CubeSat to adjust its orientation and orbit motion if it were to collide with debris. It also has a magnetometer that can determine where it is relative to Earth and can adjust its position based on the magnetic field. It can also store flight input and flight information so that the operator can analyze the flight data.

The design specification of the stability component is crucial to the success of the CubeSat. The CubeSat has to weigh less than 4 kg, which affected the specifications of the stability component(DO-1, M-1). The PhidgetSpatial gyroscope has a mass of 0.045 kg which was ideal for the CubeSat. The PhidgetSpatial gyroscope must be small enough to fit in our 3U CubeSat. The gyroscope is 0.3U which is perfect when considering the components of our different subsystems.

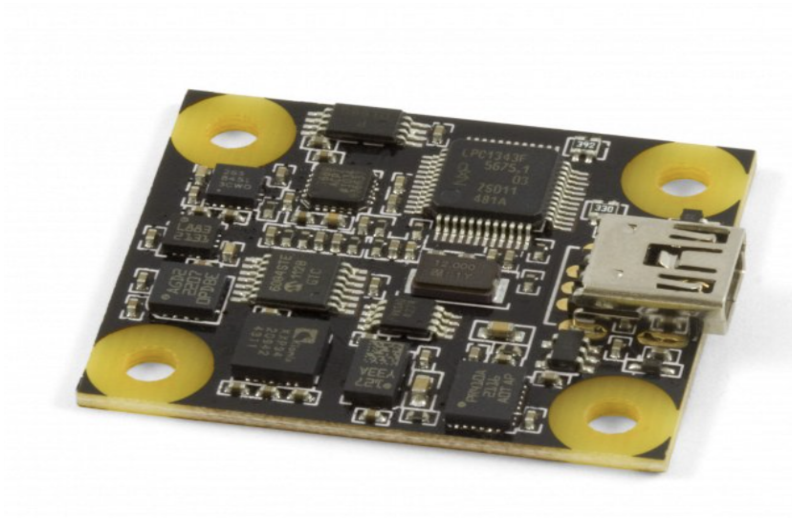


Figure 14: PhidgetSpatial gyroscope

In Figure 14, it can be seen that the PhidgetSpatial gyroscope is thin and relatively small compared to the other components. It has a few ports that are compatible with the onboard computer systems and will work in tandem with the onboard computer system to determine its position and orientation. It can also measure the acceleration of the Cubesat and reorient itself to avoid debris.

5.2.6 Thermal Imaging

All the subsystems play a very important role in the design of the CubeSat; the imaging subsystem has one of the most key roles to collect SGD data.The most effective way to include the thermal optic in the CubeSat is to use an off-the-shelf product. It has been discussed that there are a variety of types of thermal optics that are compatible with CubeSats and the thermal optic type would need to be suitable for SGD detection.

The Chameleon Imager would be a great imaging system to be used in the design. The Chameleon is very CubeSat friendly and is compact enough to be self-contained in a 3U CubeSat. The system itself takes up less than 2U of volume. The Chameleon has a spatial resolution of 9.6 meters from orbit; special resolution was given relative to a point 500 km away from Earth [13]. The special resolution regards the size of the pixels in the digital image. This is a very good special resolution compared to competitors and is considered top of the line. .In the optic, it contains the data interfaces LVDS, SPI and I^2C with the LVDS interface outping data at a rate from 1 to 240 Mbps. The amount of data collection complexity the Chameleon has is more than enough to satisfy the requirements. The data can be output into the following full frames: Raw, Lossless JPEG2000 or even a thumbnail. The raw image output could come out in 8-bit or 10-bit[13]. The Chameleon Imager is superior when it comes to data processing as well as quality. It was a very easy option since the process for integration into the overall design would be the most ideal. The Chameleon Imager can also be manufactured very easily and can be found easily on a “off-the-shelf” website[13]. Through the website, one can purchase a Chameleon Imager and receive it within 26 weeks.

One of the most dominant requirements that can be discussed with the Chameleon Imager is the size. The whole Cubesat must fit in a 3U structure. The biggest pro of the Chameleon is the ability to poke the lens of the cubesat structure which reduces the size consumed in the structure by 0.4 U.

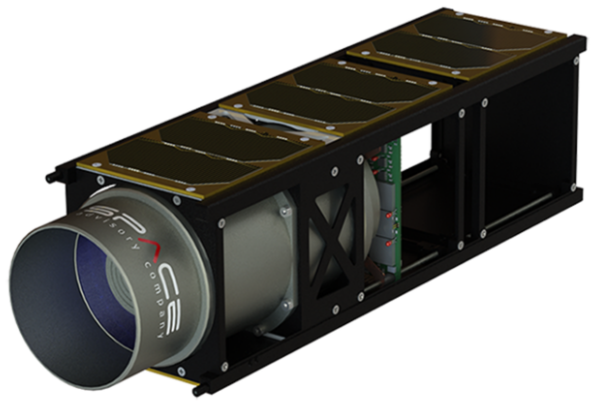


Figure 15: Chameleon Imager shown sticking out of Cubesat structure

As seen in Fig 15, it sticks out of this model 3U structure about 4 cm which is the reasoning behind why it takes up less than 2U inside of the structure. It can be said that the amount of space that the Chameleon takes up inside the CubeSat structure is 1.6 U, found from the basic rules that 1U is equivalent to 10 cubic cm.

5.3 Overall Design Specifications

The Cubesat design has a lot of goals in relation to each of it’s separate subsystems, this is important to notice but the main and most important goals only matter when all the subsystems are working in unison. There are major requirements that must be reached to satisfy the clients needs. Three main constraints are its mass, its power, and its size. There are other constraints that coexist with these main three, such as center of gravity, but they depend and are affected by the main constraints. The mass must be under 4 kg, the power supplied must be less than 100 Whrs, and the size must be no larger than 3U. Our design is broken down into how each of these requirements is met by each subsystem; this is shown below:

Table 16 : Overall Design Budget

	Power	Telemetry	Structure	Thermal Imaging	Stability	Propulsion	Total
Mass (kg)	1.073	0.250	0.29	1.35	0.045	0.6	3.608
Power (W)	N/A	13	N/A	3.5	0.21	75	91.71
Size (U)	0.5	0.1	N/A	1.6	0.3	0.4	2.9

One of the key arguments seen above in Table 16 is the budget mass. The total mass of the Cubesat, including all the systems, came to 3.608 kg which fits perfectly inside the required mass of 4 kg (CO-1). This is a great success for our system because as seen above, our components take up most of the space in the cubesat structure and it is to be 500 g under the maximum mass limit. It is also important to realize where the center of geometry and the center of mass lie inside the structure. Another requirement was that the distance between the two centers must not be greater than 7 cm (CO-4).

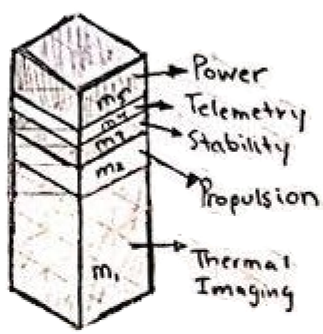


Figure 16 : Composition of the CubeSat

It was also assumed that the subsystems would be oriented in the order shown in Fig. 16. It was decided that this would be the way all the systems would be aligned by using the knowledge that the thermal imaging system would need to be positioned on the south end of the Cubesat and then the next heaviest object would be positioned at the north end to best station the center of mass close to the center of geometry. The next heaviest subsystem would be the power subsystem which is shown on the north end of the Cubesat in Figure 16. This process was then used for the rest of the systems. After each subsystem had a location, it's y-coordinate for its center of mass was found. This allows for the easy calculation of the center of mass.

The center of mass was found using the equation below:

$$y_{COM} = (\Sigma y_i m_i) \div (\Sigma m_i) \quad (2)$$

When finding the center of mass there were assumptions made to make the calculations easier yet more successful in analyzing the design. To start the cubesat was given an origin and x-y-z axes for ease of reference and calculation. The subsystems were regarded using a uniform mass distribution throughout their component since their volume would not affect the “x” and “z” directions as much as the “y” direction. It is also generally true that these subsystems' center of mass would be located relatively close to their center of geometry. That is why in Eqn. 2 does not contain “x” nor “z” , only “y”.

The final assumption was that the structure component’s center of mass was at the cubesats geometric center of mass which makes sense since the structure is the outside backbones of the cubesat.

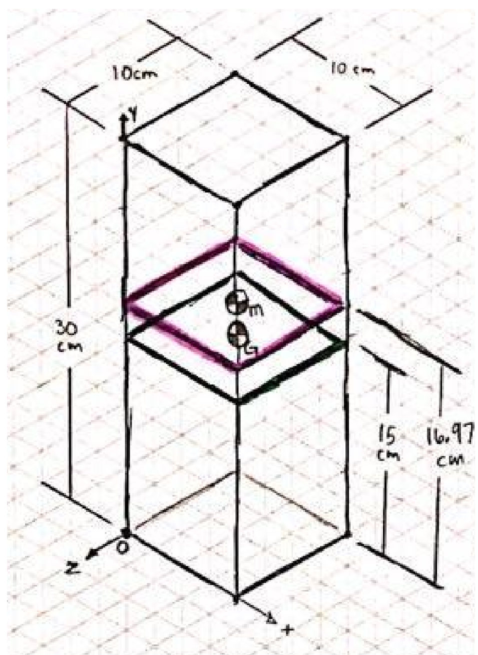


Figure 17 : Location of the Cubesats COM and COG

Given all that, the center of mass was located at 16.67 cm from the bottom of the Cubesat. Which comes out to be 1.67 cm away from the geometric center of the overall structure since the geometric center of a 3U Cubesat would be 15 cm above the bottom plane. It is visually shown in Fig. 17 that the center of mass and center of geometry are very close. The pink plane is represented as the center of mass plane and the dark green plane is represented as the center of the geometry plane. With these results,the orientation and generated subsystems satisfy the requirement of each center being no more than 7 cm away from each other (CO-4). The distance of 1.67 cm in separation is well within the requirements.

An additional requirement was the maximum stored energy allotted in the cubesat. As per CO-5 the maximum stored energy cannot exceed 100Wh. Our design satisfies that requirement by only having 80 Wh of stored energy. This energy is stored in the two OPTIMUS-80 batteries on board the cubesat.

Additionally the maximum power drawn at one instance was calculated to be 91.71 watts. Although highly unlikely this could happen if all subsystems are drawing their maximum needed power simultaneously. This unlikely scenario has been accounted for because of this it was decided that a PMAD that can supply up to 78 watts of power to any individual device is used.

Lastly, in order to make sure that our CubeSat does not draw more power than produced we analyzed the chosen solar panels. These solar panels produce 8.4 watts meaning that in less than 10 hours our battery will be completely recharged if drained. The orbit has periods of time where no subsystems will require significant power due to the fact that the cubesat will not be over Australia. The battery will have enough time to recharge and a power shortage will not be experienced.

The power of the CubeSat plays a vital role in the success of a CubeSat. Nearly every subsystem requires power and needs to be connected to the power network. The power system is made up of four different components, power generation, power storage, power distribution, and an on board computer. This subsystem is responsible for the success of the thermal imaging subsystem, the propulsion subsystem, and the telemetry subsystem.

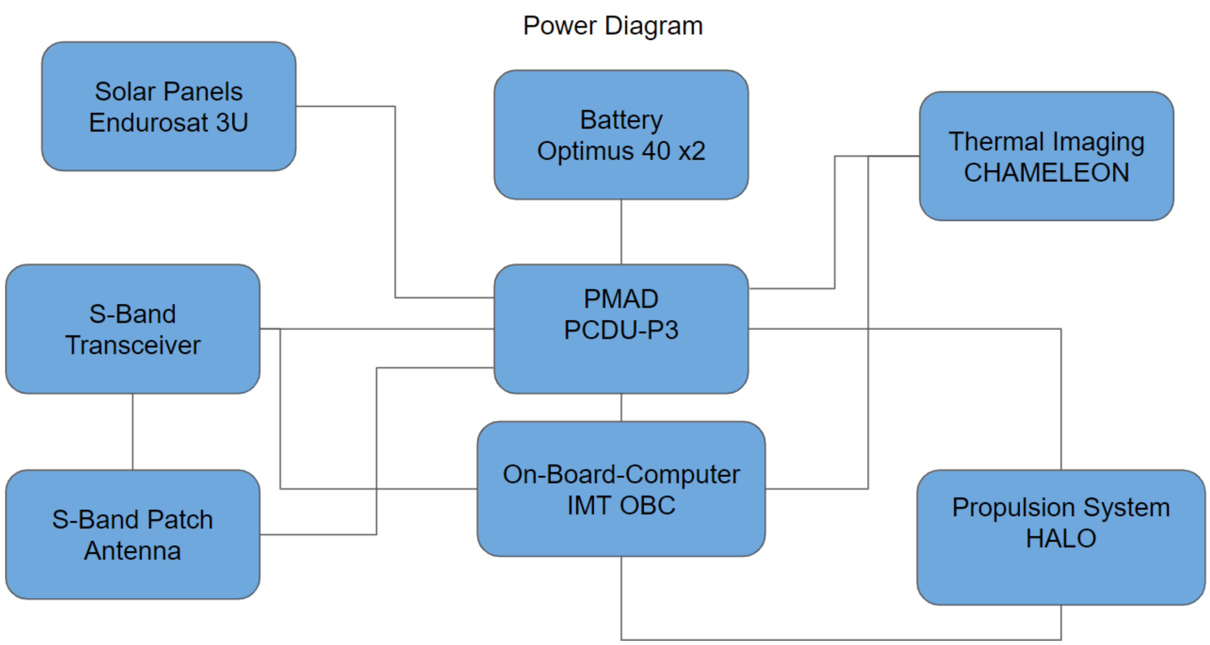


Figure 18: CubeSat Power Distribution and Connection Diagram

As seen in Fig. 18, the subsystems are all interconnected. The main two components of the subsystem which all other subsystems are connected to are the computer and the PMAD, or power management and distribution subsystem. These are connected to everything because the computer controls all the different subsystems and when and how they operate. The PMAD distributes power to the different elements when they are supposed to run. These two components are tightly linked together and are customizable in order to do so. Additionally the batteries are only connected to the PMAD along with the solar panels. This is because the PMAD will take care of transferring the generated power from the solar panels to the batteries and the stored energy from the batteries to the individual subsystems.

The last requirement used for evaluation in the budget (Table 16) was the size of the Cubesat. The client is requiring the use of a 3U or smaller cubesat structure (CO-3). The structural system selected is 3U in size which was a relatively easy task to complete. The more difficult part of the requirement to satisfy is fitting the rest of the components inside the structure. This was done by constant consideration of multiple subsystem combinations throughout the iterative process. Multiple great subsystems had to be dismissed based on the fact that the design as a whole would not meet the size requirements. One subsystem that had the most trouble with finding a sufficient size was propulsion. There were multiple propulsion systems that were perfect except there problem with size, two potential propulsion systems had a size of 1.3 U which was just too big considering the fact that the thermal imaging system took up 1.6 U of space, and that space for the imager took priority over the propulsion system. Other types of propulsion such as cold gas systems were researched but the Cubesat would not be able to bear the cold gas tanks that come along with it. One system was found that takes up 0.6 U, which fit perfectly into what was needed. Another factor that benefited our Cubesats size requirement is the fact that the Chameleon Imager that was used for the thermal optic takes up less space than its full size since it's lens sticks out of the structure 4 cm. Given that the Chameleon is 2U, it was settled that with the section outside of the structure it would only occupy 1.6 U inside the structure. The solar panels of the Cubesat also need to be considered when discussing the size. The benefit of using solar panels is that they take up no space inside the Cubesat. The panel's contribution to the total size is 0 U. With that being said, it can be concluded that the combination of subsystems selected meets the required size of under 3U since the total size comes to 2.9 U as seen in Table 16. It can be assumed that the extra 0.1 U can be used for space allotted to be taken up by wiring and such. Overall, the design of the CubeSat fits the requirements that were stated in the client statement.

6.0 Concept of Operations

6.1 Transmission and Stability

When the CubeSat is following a circular orbit around Earth, it will use the PhidgetSpatial gyroscope to determine its position relative to Earth. As the CubeSat encounters space debris, the PhidgetSpatial gyroscope can detect the object and will use its propulsion system to avoid them and then return to its original orbit. Assuming that the weather conditions are ideal when the CubeSat is doing a fly-by over Australia, it will use the Chameleon thermal imaging camera to take a picture of a segment of Australia's coast using multispectral imaging and directly store the picture on its built-in mass integrated storage unit. The data picture is streamed directly from the S-Band to the ground station. The CubeSat will do a fly-by over Australia over 140 times in two weeks to capture the entire coast. If the weather in Australia is subpar, a ground station operator can use the S-Band transceiver to change the type of imaging used to capture the picture. In this case, hyperspectral imaging would be used to identify the area of interest against the background clutter.

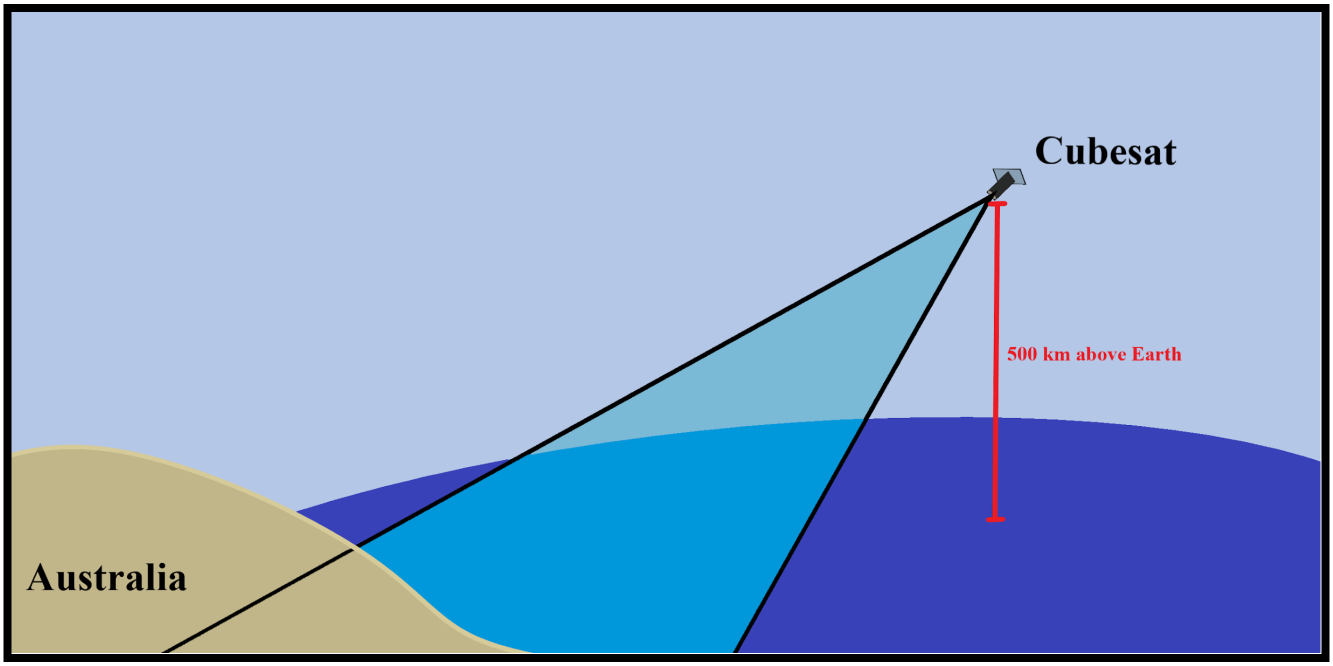


Figure 19 : Basic Concept of Operation (not to scale)

Fig. 19 shows the concept art of what the CubeSat will be performing as it orbits over the Australian coast. The altitude above Earth is shown in the figure, this will be discussed along with the Cubesats orbit in section 6.2.

6.2 Orbital Specifications

In order for our CubeSat to be effective and complete the mission assigned a realistic orbit needs to be calculated and selected. As required for DO-2 the satellite needs to pass by and collect data of the shoreline at least every two weeks.

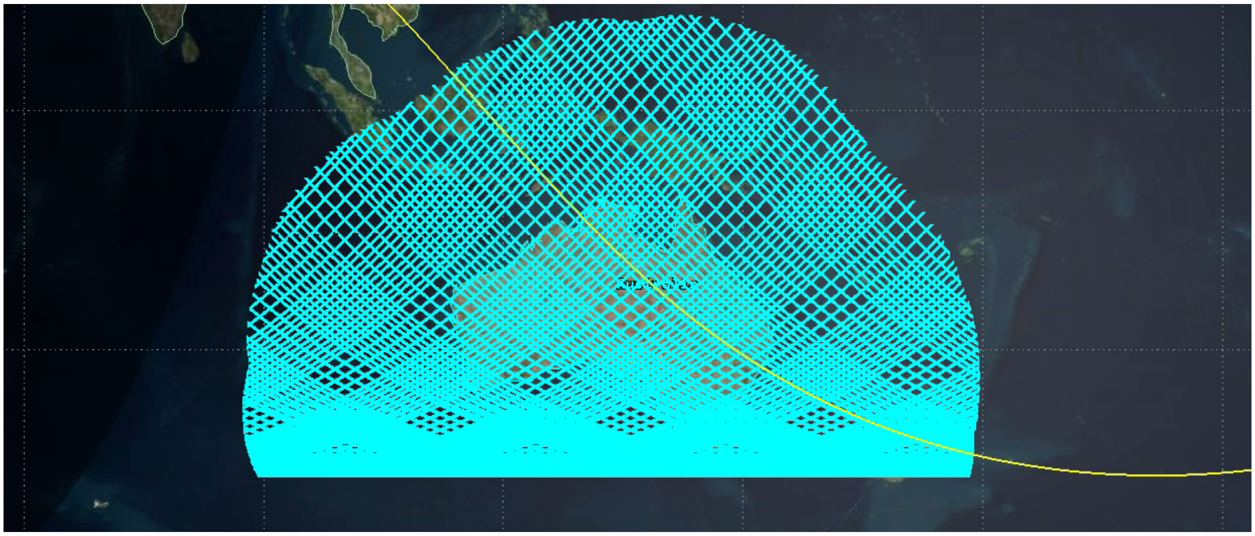


Figure 20: STK Ground view of CubeSat over Australia coastline

Fig. 20 shows the trajectory of the CubeSat as it passes over Australia. It covers the ground track of the CubeSat in a two week period. Every blue line is one time the CubeSat passes over. As seen below, this orbit will meet the constraints and be able to collect sufficient data on the coastlines. We decided to include areas outside of the border of Australia on the map due to that is where the data collection will take place. In order to find an orbit that would satisfy the needs of our mission a few things had to be accounted for. The first is the height of the orbit. This was important to ensure that our thermal imaging camera would still be able to produce the quality of images needed. Additionally, the height was also important to make sure that our S-band patch antenna and transceiver would still work at this range. A circular orbit was used so that the height of the orbit above earth remains constant on every pass by.

Table 17 : CubeSat Orbital Elements

Semi-Major-Axis	Eccentricity	Inclination	Argument Of Perigee	RAAN	True Anomaly
6900 km	0	45.5 deg	0 deg	0 deg	0 deg

Table 17 describes the CubeSat's orbit. The 6 orbital elements are listed in the table above. The values in the table were determined using a few different criteria. First we wanted the CubeSat to be in the range in which both the telemetry and thermal imaging subsystems would be optimal. We choose a height of about 500 km, as seen in our semimajor axis value, which is earth's radius, 6371 km, plus the orbiting height above earth. Additionally to ensure that our CubeSat actually passes over the needed area we used an inclination of 45 degrees. This value was chosen to keep the focus on Australia, and not have the scans provide data on unimportant areas. Additionally, this would allow for more frequent and closer passby's over the continent. The remaining values were set to zero in order to keep things simple.

The next image is a three dimensional picture of our orbit around earth. Our orbit track is in yellow and additionally Australia is outlined in blue. As seen our orbit's eccentricity is zero meaning that it is a perfectly circular orbit.

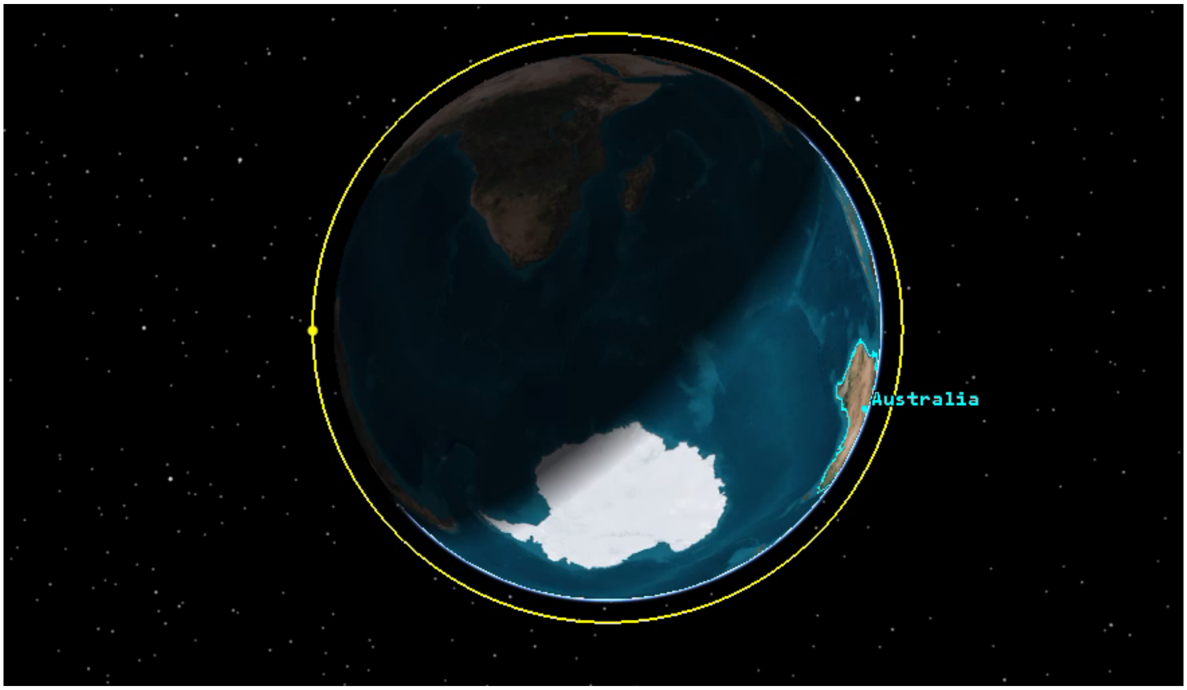


Figure 21 : 3D Image of Orbit Around Earth

Fig. 21 displays the orbit of the CubeSat around Earth. The final justification made from STK that was performed was whether or not our orbit would indeed capture the entire coastline in a two week period.

6.3 Surveillance Efficiency

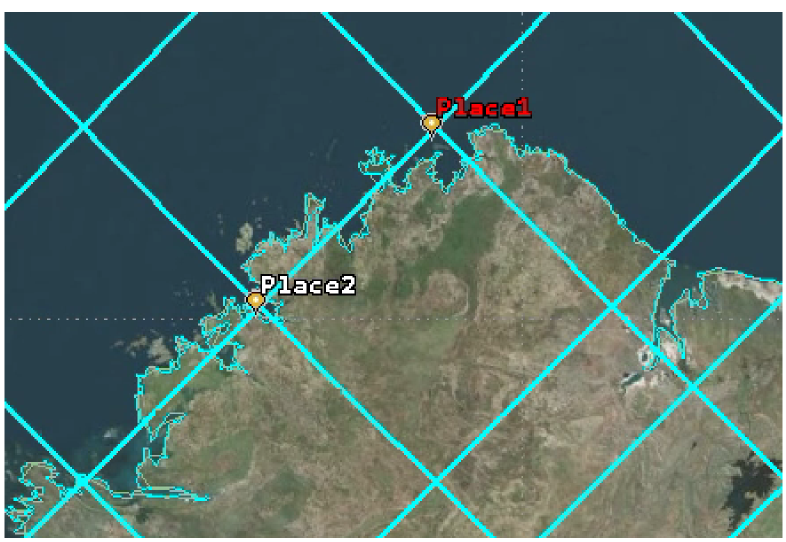


Figure 22 : Furthest Distance Between Two Points

In order to verify if this would actually work, we found the largest distance between two orbit tracks in a two week period shown in the Fig. 22. The two points labeled Place 1 and Place 2 were put on these track marks and the distance between them was calculated. This distance ended up being just about 200 km. That means that our orbit would satisfy the needs being that it will capture the entire area once every two weeks. This is because our thermal camera captures an area greater than 200 km in diameter. Fig. 22 displays the maximum distance between the areas analyzed.

7.0 Project Management

To have an efficient design, an organizational structure had to be developed. In the sections 7.1-7.3, the evaluations of our methodology and logistics will be described.

7.1 Gantt Chart

This project is large and complex. Many of the tasks at hand need to be done by individuals to have a detailed understanding of the topics. To organize and better improve our efficiency, a Gantt chart will be used to keep track of our progress.

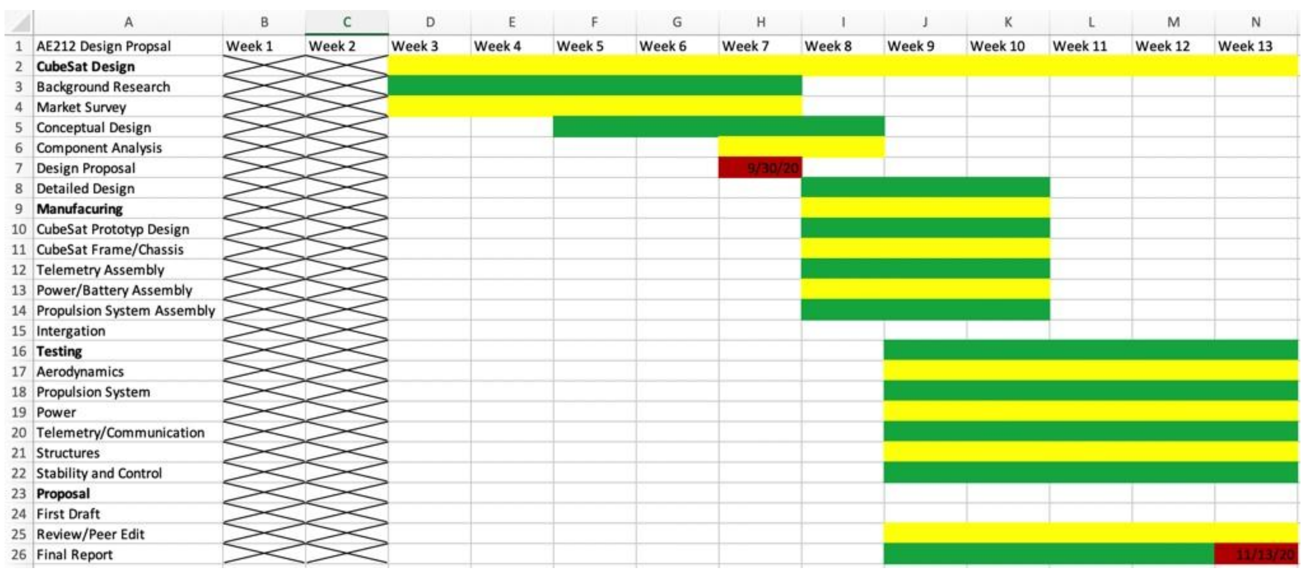


Figure 23: Gantt Chart of the AE212 Design Report and it Corresponding Sections

In Fig. 23, a Gantt chart is shown with the team's goals. The team will follow this chart to complete the expected and required work to meet the criteria and client statement. The green and yellow colors represent what is expected each week and the red represents crucial deadlines for our design project. A breakdown of the contributions given for the subsystems section are shown below in Fig. 24.

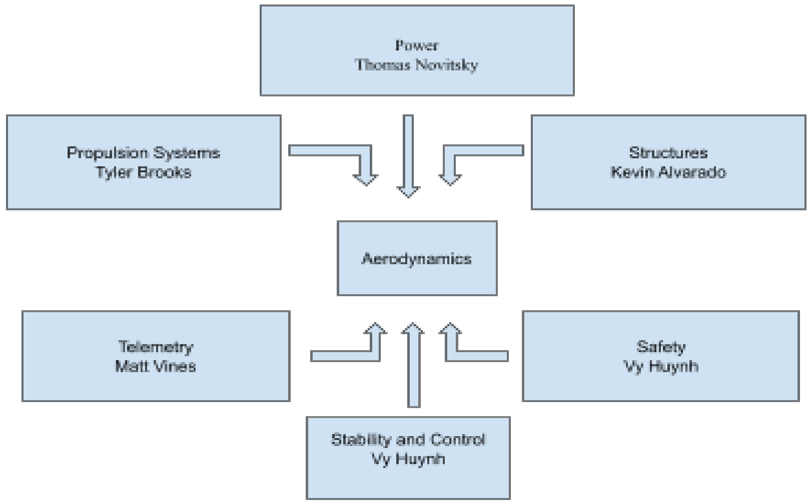


Figure 24: The distribution of subsystems related to the focus, the CubeSat

Aerodynamics: Conduct analysis for the aerodynamics of the CubeSat
Power: Determine the size of the motors and size of the battery
Propulsion System: Responsible for how much thrust is required for orbit
Structures: Provide analyses of the structural components of the CubeSat and strength of the material
Telemetry: Research and provide ways of transmitting and receiving data
Stability and Control: Determine the center of gravity for the CubeSat due to its geometric shape and sizing of control systems needed to keep the CubeSat in orbit
Safety: Responsible for maintaining the safety of the engineers and the CubeSat during design

Towards the end of the design, all the different systems came together to create the finalized CubeSat. For the structures aspect, the importance came to the material used and volume. For the power, the energy storage and rechargeability were of importance. Propulsion had to compromise between the size and mass with the thrust provided. Telemetry was to ensure that the data captured could be transmitted to the ground station and eventually AE Inc. and AWE. The most important part though was the infrared camera as the mission was based on the information it would capture. The purpose was to provide the data to study the SGDs. Eventually, the systems altogether would need to be integrated into the CubeSat and cooperate.

At the same time, the paper would be updated and so would a design notebook. Everytime the team would meet, notes were taken and discussions recorded. Research would be done and shared with a google drive that all the team members had. Since only part of the writing process was about the components, each individual did various other sections as was shown in the list of contributions. Throughout the week there would be a check on the completion of tasks. Conflicts with other classes and external activities had to be taken into consideration as well. A large part of the performance was logistical tracking and evaluation.

7.2 Idea Generation

The team plans on designing multiple prototypes to analyze and provide necessary changes in order to optimize the CubeSat. The CubeSat will be designed to meet all aspects of the criteria and fit the needs of our client. Fig. 25 below shows a manufacturing flowchart the team will follow.

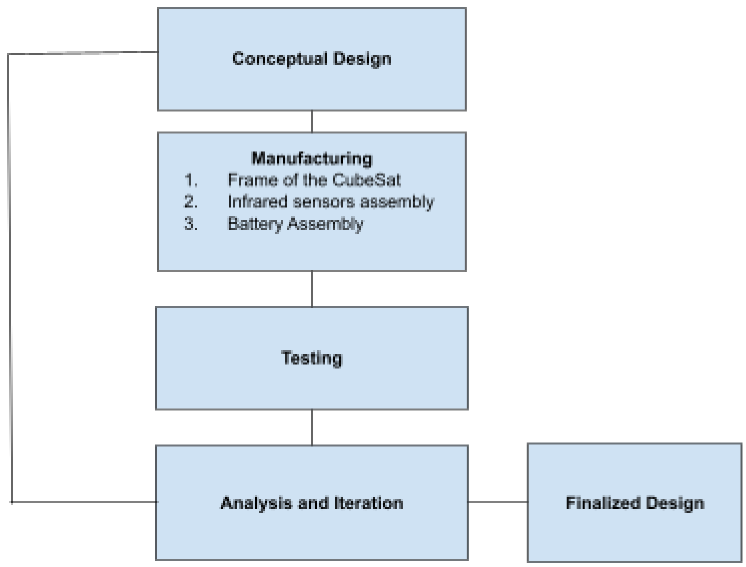


Figure 25: The Conceptual Design Process Used

As by Fig. 25, the process to develop a satisfactory CubeSat takes time. Multiple iterations are necessary to comfortably decide on the best design that will complete the task at hand. For each team members' case, background research was conducted on CubeSats components. After research was conducted, the team analyzed different options such as CubeSat structures, power, propulsion, stability, and telemetry to optimize for the CubeSat design. For the different components, there differing criteria and alternative analyses were done. Many ideas were considered but limitations imposed by the requirements reduced the amount of possibilities. Constant iterations of compromise with the different members took place to ensure that the components were utilized the best they could.

During the entire process of both design and formulation, idea generation was a must. In the initial stages, critical brainstorming was necessary in selecting the systems involved. Using the requirements, and having the stakeholders in mind, the systems needed fell into place by thinking of scenarios that could arise. Brainstorming led to research. Once the systems in general were determined, the understanding of these systems was needed. Each member decided on a system that was of interest, and went into depth of how each section would need to be implemented. After the research-based decision process was complete, tweaks and adjustments were needed throughout the lifespan of the proposal. This is where S.C.A.M.P.E.R. came into play. S.C.A.M.P.E.R. is a force fitting technique that forces the mind to make creative jumps. Substitute, combine adapt, modify, put, eliminate, and rearrange was the version that was used. Throughout the processes, multiple substitutions were made. This is because, due to more complex and critical decision making, the ability to substitute a better fit was always possible. Combining and adapting were the most important features of SCAMPER. Combining the CubeSat with all of its subsystems allowed for budgets to be made, thus allowing the team to see if and where the flaws are in the design. Then, once understanding the flaws, the team adapted by changing and returning to substitute sections of the systems. Modifying until the systems fit the requirements as best as they were able to. "Put" is the section of SCAMPER the team didn't use. The remaining steps were intertwined with the earlier, therefore, SCAMPER was put into use throughout the entire decision making process.

7.3 Decision Making Techniques

To make our final decision, after researching each subsystem, a decision matrix using Analytic Hierarchy Process (AHP) was used. This matrix created a much better system of finalizing a decision on which product fit the CubSat's needs the most. AHP works by using importance and preference matrices to come up with a conclusion that works in both aspects. Criteria are set by the important factors of each subsystem. For instance, a propulsion system needs to have criteria of mass, size, specific impulse, and power usage. However, these needs are not equal. Some criteria are more important than the others; creating a weight system allows for this importance to be quantified. This quantitative analysis is done with both the importance and the preference in mind. For the CubeSat in discussion, the size is of utmost importance. Using AHP, a decision method, allowed for importance and preference to be incorporated into finalizing the systems. Each system has a specified set of criteria needed to be differentiated for an adequate decision to be made. This decision matrix was created in excel. Each system was able to input their criteria and personal weighting into the matrix and output the option that best fit the need of the mission. Making conceptual decisions is key in the success of this mission. The final decisions due to the matrix's Om scores are listed below:

Table 18: The Om Score of the Different Components

Subsystem	Om Score	Final Decision
Propulsion	0.493336	ExoTerra's Hall Effect
Power-PMAD	0.4105	PCDU -P3

However, not all the decisions were made using the AHP method. Given for structures, a more basic approach was done. The different sizes were first compared with constants of the requirements. The following options were then determining the feasibility and usefulness of the components. Many of the other components were large and could not fit within the smaller volume. Once again, more options were eliminated. When all was considered, there were not many options. The most important features were then compared. The technique is similar to the graphical decision chart, although it was based mostly on structural features due to the similarities between the sizes and masses. A similar process was done for the telemetry subsystem along with a few of the components of the power subsystem. These power subsystem components were the OBC, Solar panels and batteries. The thermal imaging system also used a simple decision making process in which AHP would be unreasonable. Thermal Imaging was only comparing two imaging systems and the Chameleon Imager, the preferred one, was the obvious choice based on the evaluation of its size, mass and high-resolution image quality. Looking at the stability system, two gyroscopes, the PhidgetSpatial gyroscope and the MPU-600 were compared to each other to determine which gyroscope is preferred for our design. The PhidgetSpatial gyroscope is preferred over the MPU-600 because it is lighter and smaller which is needed to meet our weight constraint (DO-1, M-1).

8.0 Conclusion

Throughout the research process, there have been many variations of CubeSats which would be sufficient to complete the task at hand, having varying levels of satisfaction. The company Australia Environmental Inc. has requested, with multiple requirements, for a satellite that will allow data analysis to be collected. This data would then help the AWE for studying SGDs. The design made for the the CubeSat will consist of a Chameleon Imager Thermal Imaging System, EnduroSat 3U Frame, PhidgetSpatial precision gyroscope, NanoAvionics monopropellant EPSS C-1, and ISIS-S-band transceivers and patch antenna. It will be self-sustaining with a recharging power supply and stabilizing features. Once the satellite is in orbit, the infrared camera will photograph the Australian coast as it flies-by the region. This data received shall then be transmitted to a ground station for AE Inc. and AWE. It is expected that the amount of fly-bys within a two week period will be nearly 140 times.

Some of the improvements that could make this project better would be an increase in mass and size. As each of team members chose the components for their respective subsystems, There were very few options. One case especially came with structures, as a 1 and 2U satellite was not possible with the options of infrared cameras. Weather may become a nuisance if clouds cover the region being scanned. Increasing the mass limit would also allow more propellant for increased mission duration. Components from other manufacturers could have also been taken into consideration. It is also possible that some new subsystems can be added, of which the team has not thought of. A stronger camera could be used in a larger CubeSat for more in depth results. The stringent requirements forced a decision that the team undertook.

Although there could be better options if requirements were laxed, the design of this CubeSat still was on par. It satisfied the requirements stated by AE Inc. without loss of quality. The CubeSat will be cheaper than other options and require minimal maintenance. The device can be used continuously for a long time and constantly supply data. The logistical coordination will also be simple as the object is small and does not contain many components. Overall, once the CubeSat is completed and orbiting around the planet, it will be successful in its mission.

In this report, the design of the satellite was performed and a budget associated with it. However, the project is incomplete as the satellite needs to be in orbit to perform the tasks at hand. Aerospace companies will need to be contacted along with launch sites within the Australian continent. An analysis will be necessary to determine the rocket size and mass. Launch site locations need to be decided. Many of the stakeholders within the report will be interested in that aspect as well.

With the research performed, the knowledge of the team overall grew. Being sophomores and juniors, the background prevalent was that of regular students. Only two members had professional work experience relating to the aerospace fields. Many programs were utilized to determine the best decisions and specifications. Excel and STK were helpful for the analysis of the CubeSat. Many lessons learned throughout the AE212 course also guided the students and taught them to make rational decisions for the CubeSat. All the effort from the classroom came together to resolve the need that was presented.

9.0 References

[1] Taniguchi, Makoto, et al. “Submarine Groundwater Discharge: Updates on Its Measurement Techniques, Geophysical Drivers, Magnitudes, and Effects.” *Frontiers*, Frontiers, 10 Sept. 2019, www.frontiersin.org/articles/10.3389/fenvs.2019.00141/full.

[2] DM. Allen, M. Suchy, et al. “Submarine Groundwater Discharge (SGWD): an Unseen Yet Potentially Important Coastal Phenomenon in Canada.” *Natural Hazards*, Springer Netherlands, 1 Jan. 1970 link.springer.com/article/10.1007/s11069-011-9884-7.

[3] McCabe, M. F., et al. “CubeSats in Hydrology: Ultrahigh‐Resolution Insights Into Vegetation Dynamics and Terrestrial Evaporation.” *AGU Journals*, John Wiley & Sons, Ltd, 14 Dec. 2017. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017WR022240

[4] Rutkowski, Rob. “19 Popular Cube Satellite Companies in Today's Market.” *Inside Frequency Control*. https://blog.bliley.com/top-20-best-cubesat-satellite-manufacturers

[5] Jackson, Randal. “An Inside Look at Hurricane Dorian from a Mini Satellite.” *NASA*, NASA, 4 Sept. 2019. https://www.nasa.gov/feature/jpl/an-inside-look-at-hurricane-dorian-from-a-mini-satellite

[6] Mabrouk, Elizabeth. “What Are SmallSats and CubeSats?” *NASA*, NASA, 13 Mar. 2015. <www.nasa.gov/content/what-are-smallsats-and-cubesats>

[7]“By the Numbers.” *NASA*, NASA. <https://solarsystem.nasa.gov/planets/earth/by-the-numbers/>

[8] “Fundamental Physical Constants.” *CODATA Value: Newtonian Constant of Gravitation*, The NIST Reference on Constants, Units, and Uncertainty. <https://physics.nist.gov/cgi-bin/cuu/Value?bg>

[9] Zetie, Ken. “About Orbits.” *Space for Science*, WordPress, 20 Aug. 2015. <https://spaceforscience.wordpress.com/2015/08/20/about-orbits/>

[10] “Imagine the Universe!” *NASA*, NASA. <https://imagine.gsfc.nasa.gov/features/cosmic/earth_info.html>

[11] Kovo, Yael. “Power.” *NASA*, NASA, 12 Mar. 2020, www.nasa.gov/smallsat-institute/sst-soa/power.

[12]United States, Congress, NASA Tech Briefs, and Anonymous. *CubeSat-Compatible, High-Resolution, Thermal Infrared Imager*, Associated Business Publications, July 2015. <https://search.proquest.com/docview/1702084641?accountid=37646>

[13] Chameleon Imager. (2019, July 19). Retrieved November 11, 2020, from <https://www.cubesatshop.com/product/chameleon-imager/>

[14]“CubeSat Propulsion System EPSS.” NanoAvionics, <nanoavionics.com/cubesat-components/cubesat-propulsion-system-epss/>

[15] Kovo, Yael. “Propulsion.” NASA, NASA, 12 Mar. 2020, <www.nasa.gov/smallsat-institute/sst-soa/propulsion.>

[16]“ArgoMoon Propulsion System.” VACCO Industries, 15 Aug. 2017. <cubesat-propulsion.com/argomoon-propulsion-system/>

[17] *Blue Canyon Technologies* <bluecanyontech.com/components>

[18] “Products.” *DHV Technology*, www.dhvtechnology.com/products/.

[19]“3U Solar Panel CubeSat Solar Panel.” *CubeSat by EnduroSat*, www.endurosat.com/cubesat-store/all-cubesat-modules/3u-solar-panel-xy/?v=7516fd43adaa.

[20]“Batteries and Satellite Power Systems: AAC Clyde Space.” *And Satellite Power Systems | AAC Clyde Space*, www.aac-clyde.space/satellite-bits/batteries.

[21] “EPS Satellite Solutions: AAC Clyde Space.” *Satellite Solutions | AAC Clyde Space*, www.aac-clyde.space/satellite-bits/eps.

[22] “SEAKR Catalog – Space off the Shelf.” *SEAKR Engineering, Inc.*, www.seakr.com/catalog/.

[23] “PCDU - P3.” *Space Inventor*, 31 July 2020, space-inventor.com/pcdu-p3/.

[24] Kovo, Yael. “Command and Data Handling.” *NASA*, NASA, 30 Mar. 2020, www.nasa.gov/smallsat-institute/sst-soa/command-and-data-handling.

[25] “Onboard Computer (OBC).” *CubeSat by EnduroSat*, www.endurosat.com/cubesat-store/cubesat-obc/onboard-computer-obc/?v=7516fd43adaa.

[26]“Cubesat On-Board Computer.” *IMT*, www.imtsrl.it/obc-cubesat.html.

[27] Cavallo, Christian. “6061 Aluminum vs. 7075 Aluminum - Differences in Properties, Strength and Uses.” *Thomasnet® - Product Sourcing and Supplier Discovery Platform - Find North American Manufacturers, Suppliers and Industrial Companies*, Thomas. <www.thomasnet.com/articles/metals-metal-products/6061-aluminum-vs-7075-aluminum/>

[28] Dunbar, Brian. “Structures, Materials and Mechanisms.” Edited by Yael Kovo, *NASA*, NASA, 12 Mar. 2020. <www.nasa.gov/smallsat-institute/sst-soa/structures-materials-and-mechanisms>

[29] *CubeSat by EnduroSat*, EnduroSat, 2020. <https://www.endurosat.com/products/>

[30] *CubeSat Structures*, Innovative Solutions In Space, 2020. <https://www.isispace.nl/products/cubesat-structures/>

[31] Kovo, Yael. “Communications.” *NASA*, NASA, 30 Mar. 2020, www.nasa.gov/smallsat-institute/sst-soa/communications.

[32]“CubeSat S-Band Transceiver: ISIS - Innovative Solutions in Space.” *ISIS*, 8 June 2020, www.isispace.nl/product/s-band-transceiver/.

[33] PhidgetSpatial PrecisionGyroscope, RobotShop. https://www.robotshop.com/en/phidgetspatial-precision-3-3-3-high-res-3-axis-compassgyroscopeaccelerometer.html?utm_source=google&utm_medium=surfaces&utm_campaign=surfaces_across_google_us

[34] Storck, William, et al. "“Increasingly Safe, High-Energy Propulsion System for Nano-Satellites." USU 20th Annual Conference on Small Satellites, AIAA (2006).Tech. No. SSC061-VIII-3 <https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1587&context=smallsat>

[35]“Home.” *ExoTerra Resource*, 17 Oct. 2020, exoterracorp.com/. https://exoterracorp.com/

10.0 Appendix

10.1 Appendix of the Original Orbital Calculations

$$m = \frac{4\pi^2 r^3}{G T^2} \qquad M = 5.972 \times 10^{24}\,kg$$

$$G = 6.674 \times 10^{-11}\,\frac{m^3}{kg\,s^2}$$

$$r = \sqrt[3]{\frac{G T^2 m}{4\pi^2}} \qquad T = 1\,week = 604{,}200\,s$$

$$r = \sqrt[3]{\frac{(6.674\times10^{-11})(604{,}800)^2(5.972\times10^{24})}{4\pi^2}} = 154{,}550{,}000\,m$$

Too high.

$$LEO = 2000\,km \qquad r_e = 6378\,km$$

$$h_g = 2000\,km$$

$$h_a = h_g + r_e = 2000\,km + 6378\,km$$

$$h_a = 8378\,km$$

$$T = \sqrt{\frac{4\pi^2 r^3}{Gm}}$$

$$T = \sqrt{\frac{4\pi^2(8{,}378{,}000)^3}{(6.674\times10^{-11})(5.972\times10^{24})}} = 7632\,s = 2h\ 7min\ 12s$$

Best would be $T = 2h = 7200s$

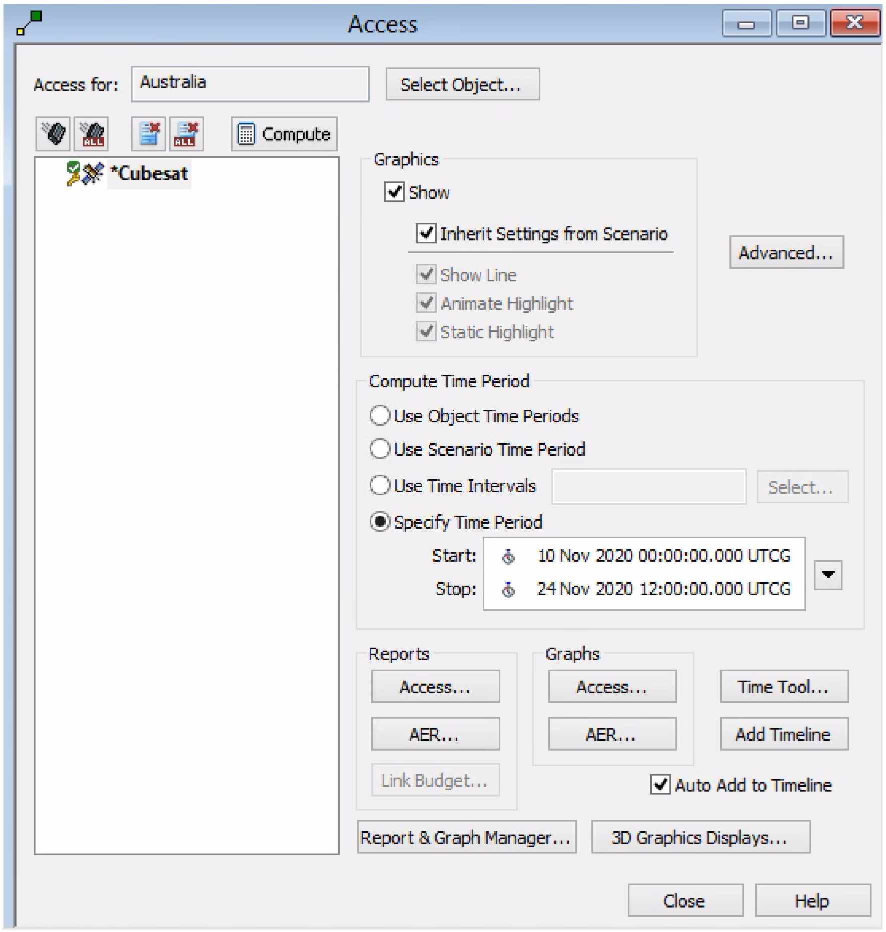
$$r = \sqrt[3]{\frac{(6.674\times10^{-11})(7200)^2(5.972\times10^{24}kg)}{4\pi^2}}$$

$$r = 8058800\,m = 8058\,km = h_a$$

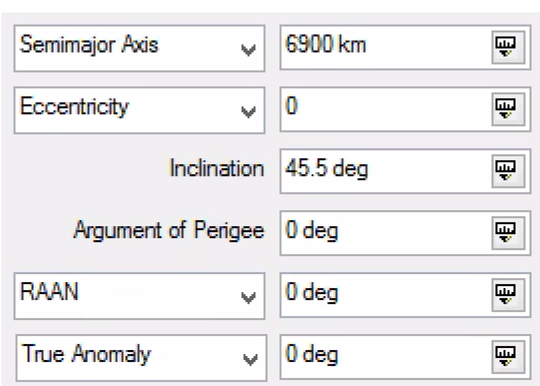
$$h_g = h_a - r_e = 8058\,km - 6378\,km$$

$$h_g = 1680\,km$$

10.2 Appendix of the STK fly-by calculations

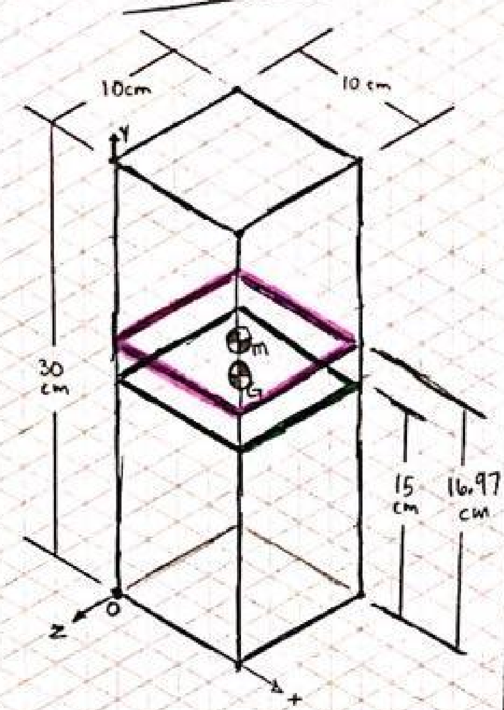


10.3 Appendix of the Orbital Elements



10.4 Appendix on Center of Mass Calculations

Cubesat



if
Point O = origin
with x, Y, z axes

Geometric Center

• Half of length, width, and height

• Geometric center located @ (5, 15, -5) cm

Mass Center

• using Table 16 masses

• found using following assumptions:

→ subsystems have a uniform mass (generally true)

→ situated in structure as seen below

$$Y_{com} = \frac{\Sigma y_i m_i}{\Sigma m_i}$$

$$Y_{com} = \frac{Y_1 M_1 + Y_2 M_2 + Y_3 M_3 + Y_4 M_4 + Y_5 M_5 + Y_6 M_6}{m_1 + m_2 + M_3 + m_4 + m_5 + m_6}$$

$Y_1 = 8$ cm $Y_3 = 21.5$ cm $Y_5 = 26.5$ cm

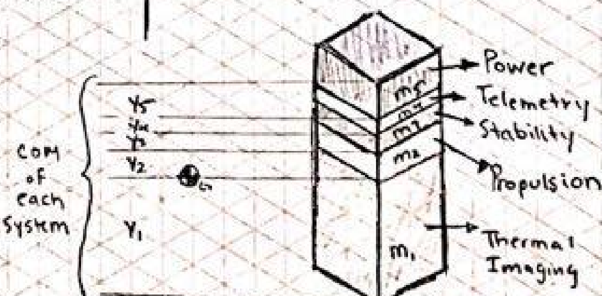
$Y_2 = 18$ cm $Y_4 = 23.5$ cm

* plug in values

$$Y_{com} = \frac{61.227}{3.608}$$

$$\boxed{Y_{com} = 16.9698 \text{ cm}}$$

labeled on Diagram (



m_6 → Structure acts at

10.5 Tables of the Decision Matrix

		1	2	3	4	
Criterion:	Criterion:	Mass (Kg)	Size (U)	S.I. (S)	Power (W)	n
1.0000	Mass (Kg)	1.0000	0.1667	2.0000	0.3333	0.285714
2.0000	Size (U)	4.0000	1.0000	0.0833	2.0000	0.564706
3.0000	S.I. (S)	0.5000	12.0000	1.0000	6.0000	0.025641
4.0000	Power (W)	2.0000	0.5000	6.0000	1.0000	0.210526

	1	2	3
Systems:	Halo Micro Hall	EPSS C1	VACCO ArgoMoon
Mass (Kg)	0.6000	1.2000	1.5000
Size (U)	0.4000	1.3000	1.3000
S.I. (S)	700.0000	213.0000	250.0000
Power (W)	75.0000	9.6000	20.0000

Table 1	Mass (Kg)	Size (U)	S.I. (S)	Power (W)	n
Mass (Kg)	0.1333	0.0122	0.2202	0.0357	0.133333
Size (U)	0.5333	0.0732	0.0092	0.2143	0.533333
S.I. (S)	0.0667	0.8780	0.1101	0.6429	0.066667
Power (W)	0.2667	0.0366	0.6606	0.1071	0.266667

CR-1	1	2	3
1	1.0000	0.5000	0.4000
2	2.0000	1.0000	0.8000
3	2.5000	1.2500	1.0000

n	1	2	3	p
1	0.181818	0.181818	0.181818182	0.181818
2	0.363636	0.363636	0.363636364	0.363636
3	0.454545	0.454545	0.454545455	0.454545

CR-2	1.0000	2.0000	3.0000
1.0000	1.0000	0.3077	0.3077
2.0000	3.2500	1.0000	1.0000
3.0000	3.2500	1.0000	1.0000

CR-3	1.0000	2.0000	3.0000
1.0000	1.0000	3.2864	2.8000
2.0000	0.3043	1.0000	0.8520
3.0000	0.3571	1.1737	1.0000

CR-4	1.0000	2.0000	3.0000
1.0000	1.0000	7.8125	3.7500
2.0000	0.1280	1.0000	0.4800
3.0000	0.2667	2.0833	1.0000

n	1	2	3	p
1	0.133333	0.133333	0.133333	0.133333
2	0.433333	0.433333	0.433333	0.433333
3	0.433333	0.433333	0.433333	0.433333

n	1	2	3	p
1	0.601892	0.601892	0.601892	0.601892
2	0.183147	0.183147	0.183147	0.183147
3	0.214961	0.214961	0.214961	0.214961

n	1	2	3	p
1	0.717017	0.717017	0.717017	0.717017
2	0.091778	0.091778	0.091778	0.091778
3	0.191205	0.191205	0.191205	0.191205

p values	1	2	3	4
OBJ-1	0.181818	0.133333	0.60189166	0.717017
OBJ-2	0.363636	0.433333	0.183147034	0.091778
OBJ-3	0.454545	0.433333	0.214961307	0.191205

n	1	2	3	4	w
1	0.133333333	0.0121951	0.220183	0.035714	0.100357
2	0.533333333	0.0731707	0.009174	0.214286	0.207491
3	0.066666667	0.8780488	0.110092	0.642857	0.424416
4	0.266666667	0.0365854	0.66055	0.107143	0.267736

Om				
OBJ-1	0.493336			
OBJ-2	0.228709			
OBJ-3	0.277955			