EML 4905 Senior Design Project

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BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Florida Space Grant Consortium FUNSAT Design Competition 100% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Gonzalo Vivanco, Giampiero Revelo, Luis Fernandez, and Henry Vazquez and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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1 Abstract

The Florida Space Grant Consortium FUNSAT Design competition gives university students in the state of Florida the opportunity to design and eventually build a working satellite. Throughout the competition the students will be faced with many factors that go into designing a satellite while also teaching them about concepts that they may have had no knowledge about. On May 8, 2014 the team's findings will then be presented to a panel of judges which will verify the design's feasibility for working and later distribute funding to those teams who have provided accurate findings for the final build. These teams will then have the opportunity to have their built satellite launched into low earth orbit.

Throughout the design and building of this satellite the team will explore the method of using solar sails as a means of propulsion which will allow the satellite to change its orbit without the need of propellant. This will equate to giving the satellite the ability to have a free range of motion when required and lengthen its service life. The satellite will incorporate common satellite communications components while also housing imaging devices so as to monitor the Earth. Testing will then be performed to ensure the integrity of the system and all of its components through the means of vibrations testing, thermal testing, and deployment testing.

2 Introduction

2.1 Problem Statement

The Florida Space Grant Consortium hosts every year the Florida University Satellite (FUNSAT) Design Competition where students from universities all across Florida are given the opportunity to design a satellite. The design restrictions that are placed on all competing teams are that the satellite must meet all requirements as stated in the CubeSat Design Specification document [2]. These restrictions however do not limit the possibilities of what our payload will consist of, therefore each satellite will have similar designs but will each have unique functions when compared to others. The competition will consist of a conceptual design phase followed by a detailed design phase [1]. After completing both phases the design must be presented on May 8, 2014 in order to obtain funding for the construction of the satellite as well as determining whether or not the satellite will be launched into low earth orbit [1].

2.2 Motivation

The motivating factor behind this project is the chance to apply all knowledge that has been obtained through several semesters of studying engineering principals. This encompasses the opportunity to work on a project that allows free reign as to the possibilities of what a satellite can do as well as being one of the top teams chosen to have their satellite built and then launched into space. More importantly, it gives us the chance to represent Florida International University in the competition while inspiring future undergraduate students to take part in such project-oriented competitions which could eventually lead to the creation of a new field of study at Florida International University.

2.3 Literature Survey

The first mathematical conception of an artificial satellite was thought of by Sir Isaac Newton through a thought experiment referred to as Newton's Cannonball [4]. He hypothesized that the force of gravity was universal and explains that the velocity of an object must be equal to the orbital velocity in order to maintain a constant orbit any faster or slower will cause its orbit to change [3]. In 1903 Konstantin Tsiolkovsky introduced insights into space travel and rocket science [5] which would later on have a role in modern rocketry and space flight. Then in 1945 an English science fiction writer by the name of Arthur C. Clarke would then introduce in detail the concept of mass communication through the use of communications satellites [4]. We can see that space travel has been an idea that humans have thought of whether it was theoretical or fictional, but all of these ideas would later lead to the first successful creation and launch of a satellite. This artificial satellite was named Sputnik I which was launched by the Soviet Union in October 4, 1975 [6].

Figure 1: Sputnik I [7]

At the onset of this achievement by a rival nation, the United States would later successfully launch a satellite of their own named the Explorer I which carried a small payload which allowed the discovery of the magnetic radiation belts around the Earth [6].

Figure 2: Explorer I [8]

This would eventually lead to the creation of National Aeronautics and Space Administration (NASA) in October 1, 1958 and the creation of and the start of the race to space [6]. The creation of a satellite was mostly limited to governments with the ability to fund such large projects, but it was in the year 1999 that professors Jordi Puig-Suari of California Polytechnic State University and Bob Twiggs of Stanford University came up with the reference design for a cube satellite known today as a CubeSat [13]. The introduction of the CubeSat would later become adopted over time by different universities, governments, and countries as an affordable alternative to launching satellites into space as compared to launching larger satellites which may require complex launching mechanisms [14]. Through these achievements it is now a common thing to hear about satellites being used for many applications that have a purpose in our daily lives such as communications, weather monitoring, and even reconnaissance. But what should be noted is that satellites will continue to be needed and the technology behind them will only further advance simply because of an idea or concept one person has in mind.

3 Project Formulation

The FUNSAT competition is a way to not only build a working satellite, but is also a means to demonstrate different iterations of what a satellite can do. In this case this project will emphasize on the use of a solar sail for propulsion. Satellites tend to have a certain life expectancy in which they function. They eventually reach that end-life and become nothing more than another piece of debris floating around earth's orbit. With the use of the solar sail not only will the satellite be able to change orbits at a controlled rate, but it can do it without having to worry about the addition of weight caused by a form of propulsion system along with its required propellant. With this concept it is desired that the project will gain recognition at the FUNSAT competition in order to have it implemented on a satellite which will then be launched into low earth orbit.

4 Conceptual design

4.1 Overview

For this competition it should be noted that the basic layout of the satellite will be relatively the same for all competitors, the only difference being that the size will vary. The satellites, called CubeSat, are categorized as 1U, 2U, and 3U where 1U is a satellite whose dimension must be 10 cm X 10 cm X 10 cm and a weigh of no more than 1.3 kg [9]. The other corresponding U's are simply the number of 1U stacked on top of each other. Figure 3 will give a better representation as to the basic design of a CubeSat.

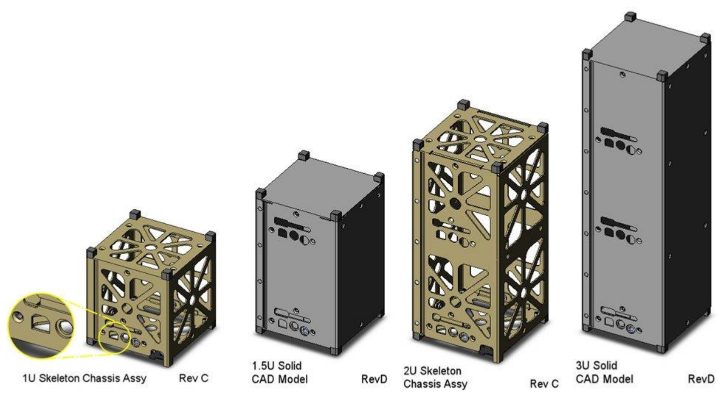


Figure 3: 1U, 1.5U, 2U, & 3U respectively [10]

4.2 Proposed Design

The initial design will consist of a 3U satellite with the dimensions as stated previously and will house the necessary payload while trying to maintain a weight of less than 4 kg. For this to be achieved, the weight of all the components inside of the specified volume as well as the support structure needs to be taken into account. The design will implement the use of a solar sail which will be housed within the satellite and will serve as a form of propulsion once deployed. The deployment system will consist of a set of four equal length supports which will be flexible enough that they can be rolled around a central hub. When this hub rotates it will allow the supports to extend fully from the center of the 3U satellite and form a rigid support structure which will allow the sections of the sail to extend.

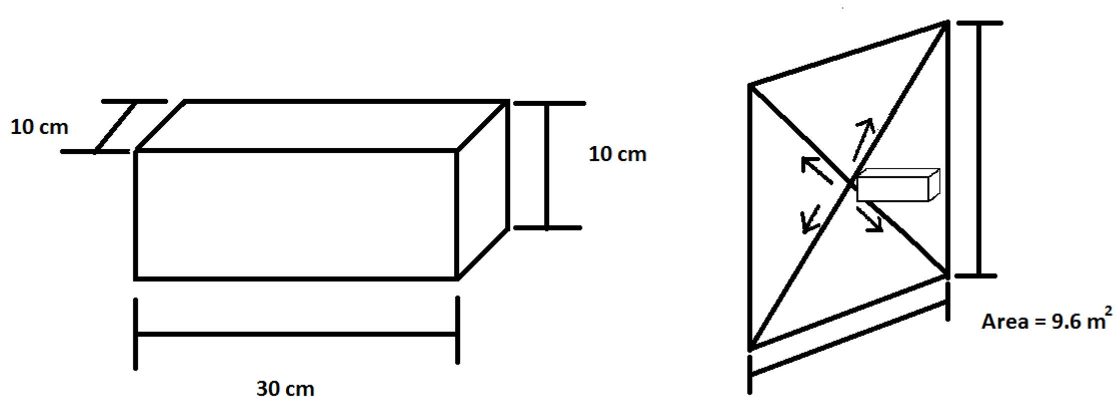


Figure 4: Un-deployed and Deployed Orientation (Not to scale)

The sail will consist of four equal triangular sections that when extended will form a symmetrical square shape. It should be noted that in order to avoid any form of tearing or cuts in the solar sail material, a specific type of fold will need to be implemented so as to avoid damage. For this design it has been determined that a frog leg fold will be implemented. It consists of folding a triangular section from the peak to the base on its self in alternating from back to front then taking both ends of the fold section and performing the same fold as shown in Figure 3. This fold allows for movement in one direction and provides three anchor points to hold the sail in place. Two of these anchor points, located at each end of the base of the triangular section, will be attached to the ends of the extendable supports while the tip of the triangle will be the third anchor. When these supports start to extend, the anchor at the tip of the triangle will provide the necessary tension to allow the supports to start stretching the sail material causing it to unfold. Once the supports are fully extended there will be enough tension in the sail material to fully expand the triangular shape and form one section of the square sail. All four triangular sections will expand simultaneously, but a specific speed of extension will need to be determined in order to avoid any unnecessary damage to the sail material.

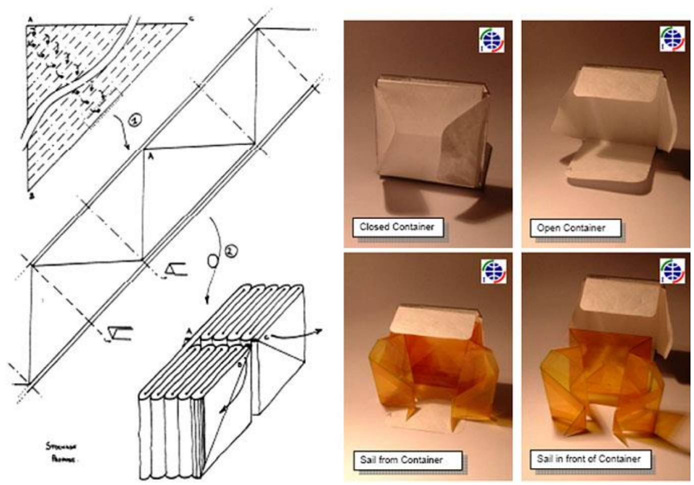


Figure 5: Frog leg folding method [11]

A square shape was chosen as it maximized the most surface area as well as aided in the simplicity of the design based on the required constraints when compared to the other orientations shown in Figure 6.

(a) (b) (c)

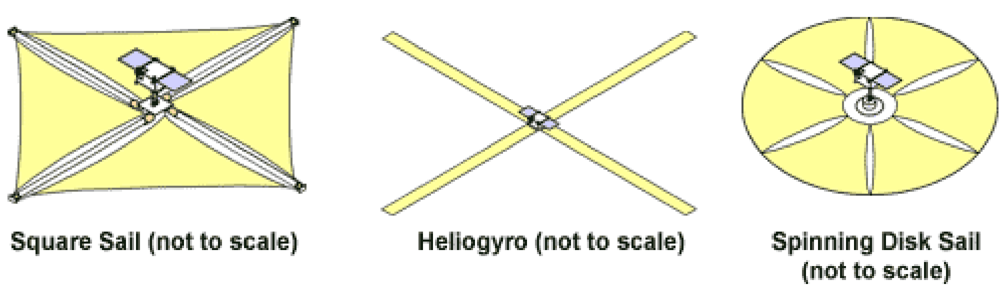


Figure 6: Sail Design Types [12]

In order for the sail to take advantage of the solar radiation, it must be light and have some reflective properties which will allow the solar radiation to reflect off of the sail surface. Materials which are most commonly used are aluminized PET film (Mylar), LaRC-CP1 polyimide, and polyimide resin (Kapton); all of which have been used in previous projects from different institutions. For the initial design it has been decided that

Kapton will be used for it has properties that make it favorable for use as well as remaining cost effective. Such properties include its high tensile strength while still having a low density as compared to other materials with equal or higher tensile strengths, as well as its thermal conductivity. By using Kapton we can be rest assured that the material will not physically change excessively due to the surrounding environment as well as have the ability of being pulled without risking tears in the material.

The satellite will also require the use of several components in order for it to function such as a power subsystem, a communications subsystem, and an attitude control subsystem. Each subsystem will each require different components to operate all of which will be housed in 1U of the 3U available space. The power subsystem of course will have one of its components on the outside of the frame which is the solar panels. This is necessary as they need to be exposed to the sun in order to provide not only power to the satellite but as well as charge the onboard batteries.

5 Project Management

The following table is an estimated plan in regards to the process of the project. This plan is preliminary at the moment and may change with time depending on any difficulties that may arise or if the project is ahead of schedule.

Table 1: Suggested Timeline for Project

	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
Project Discussion												
Research												
Initial Design												
3D Modeling & Simulations												
Final Design												
Obtain Materials												
Manufacture Prototype												
Prototype Testing												

As for the individual tasks, it has been broken down into the key sections as shown below in Table 2.

Table 2: Individual Contributions

STRUCTURAL FRAME DESIGN	SAIL SYSTEM	PROGRAMMING	MANUFACTURING
Gonzalo Vivanco	Giampiero Revelo	Henry Vazquez	Luis Fernandez

Each section dives into a series of subcategories in which multiple members had work put in, however the main sections were covered as listed.

6 Analytical Analysis

The solar sail takes advantage of the solar radiation pressure which can calculated based on the amount of power of electromagnetic radiation per unit area is incident on a surface. This means that depending on the angle that the solar radiation is initially moving towards the solar sail, the sail will experience a certain amount of radiation pressure [2]. The force that the solar sail will experience due to the solar radiation pressure can be calculated as,

$$F = F_o \cos^2 \alpha \tag{1}$$

F = Force applied onto the sail

F_o = Force of the solar radiation

α = angle of the net force to the perpendicular force

This force of course can only be obtained by determining the force of the solar radiation pressure per square meter of sail which is,

$$F_o = 2PA \tag{2}$$

F_o = Force of the solar radiation

2P = Solar radiation pressure at 1AU

A = Area of the sail

As well as taking into consideration the angle α which is the angle of the net force to the perpendicular force. The angle will dictate the amount of force exerted on the sale as well as the direction in which it will move in. The value of 2P is considered to be the solar radiation pressure experienced at 1 AU from the sun which in this case happens to be near the area of the Earth.

$$2P \text{ at } 1AU = 9.073\ \mu N/m^2 \tag{3}$$

This calculation of course pertains to an ideal solar sail meaning little to no imperfections and assuming 100% reflection. From this it is then possible to calculate the acceleration of the satellite which is based on the force exerted on the sail mass ratio.

$$a = F/m \tag{4}$$

a = Acceleration

F = Force exerted on the sail

m = Mass of the satellite

It should be noted that these equations are taking into account that it is within a 1 AU distance, meaning that as long as the satellite does not cross a significant threshold which will cause a significant change greater than 1 AU.

7 Major Components

A satellite can be as complex or as simple as the designer wants, but it all depends on the required objective and desired function one wishes to have in said satellite. In the case of this project, a solar sail will be employed which will require special devices in order to allow it to work. These components are described in the next sections.

7.1 Solar Sail

The solar sail is composed of a thin plastic material with a reflective coating which allows the solar radiation to reflect off the surface and imparting the momentum of its particles to the sail resulting in motion. A square shaped design was chosen as it provided a large enough area and aided in its simplicity.

7.2 Solar Sail Deployment Mechanism

The deployment mechanism of the solar sail is a critical subsystem which usually has a high risk associated with it. The mechanism of the solar sail consists of two main sections. The first is concerned with boom storage and deployment and the second is the storage of the sail. The booms will be rolled around a spindle at the center of the bottom plate and a motor will have the function of deploying the booms out to space. The booms will be attached in the corner to the sail and they will be pulling the sail out of their compartments. Once the deployment is complete the satellite is ready to change its orbit.

7.2.1 Booms

The booms have to occupy a small volume during stowage which is confined to a 10 cm x 10 cm base area and leave a reasonable amount of space for the folded sail. This is on top of the fact that they have to extend to about 2.9 meters in length. The diameter the booms roll around, along with the inner hub, is 90 mm, so it will fit perfectly in the satellite. In Figure 7 the dimension sign of the boom are illustrated along with an isometric view.

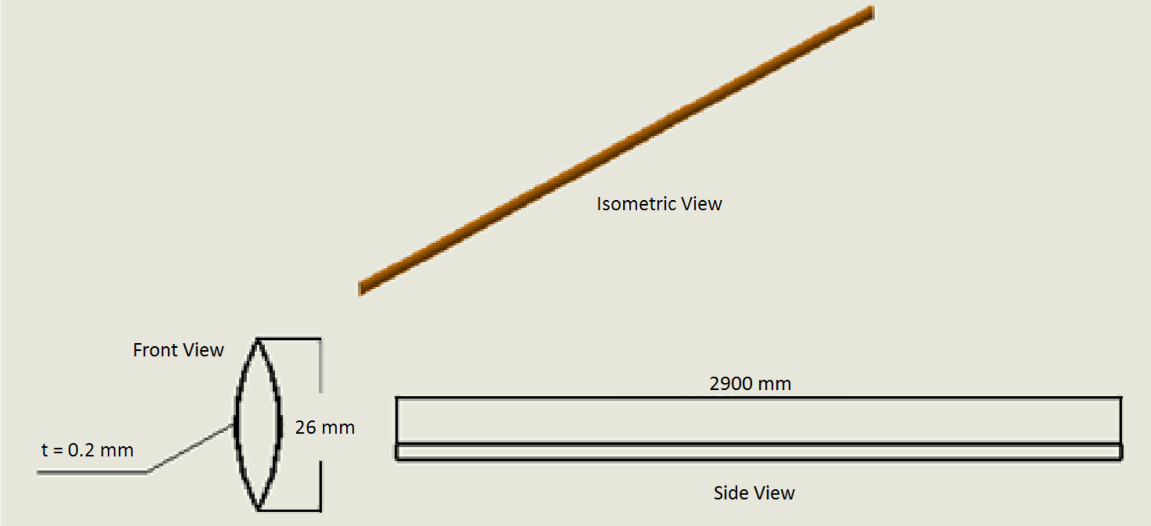


Figure 7: Boom Dimensions

The CubeSail booms are made of tape-spring blades, similar to the ones used in tape measures. Due to its flexible nature, a long blade is able to roll back out and hold its straight shape. These blade show a very good stiffness when held curve down. Some tape measures are claimed to stand horizontally up to four meters. This kind of bending stiffness is more than sufficient in a very low gravity environment to extend the sail film and make it taught while enduring the solar radiation pressure. However when the blades are flipped upside down they quickly buckle under gravity and bend under the smallest of forces.

To strengthen the blade, two of the blades are attached to each other front to front. This solves the buckling problem and increases the stiffness of the booms. It should be noted that the ends of the booms will attached to the ends of the sail.

7.2.2 Motor

To control the deployment, a DC electric motor is added to the system. This motor drives the booms out of the mechanism at a slow speed to avoid damage to the sail. The motor will be located above the sail compartments and is going to be fixed to the plate with two screws, leaving enough space in the satellite for the other components. The solar sail compartment will have a hole in the middle to connect the motor to the spindle; the hole is bigger than the shaft diameter in order to avoid friction between both surfaces. The weight and dimensions of the engine are the most important aspects that were taken into account to choose the model. The model chosen is the HiTec HS-645MG servo motor because it will fit perfectly inside the satellite and with 8.0 to 10.0 kg/cm^2 is able to move the metal component of the system.

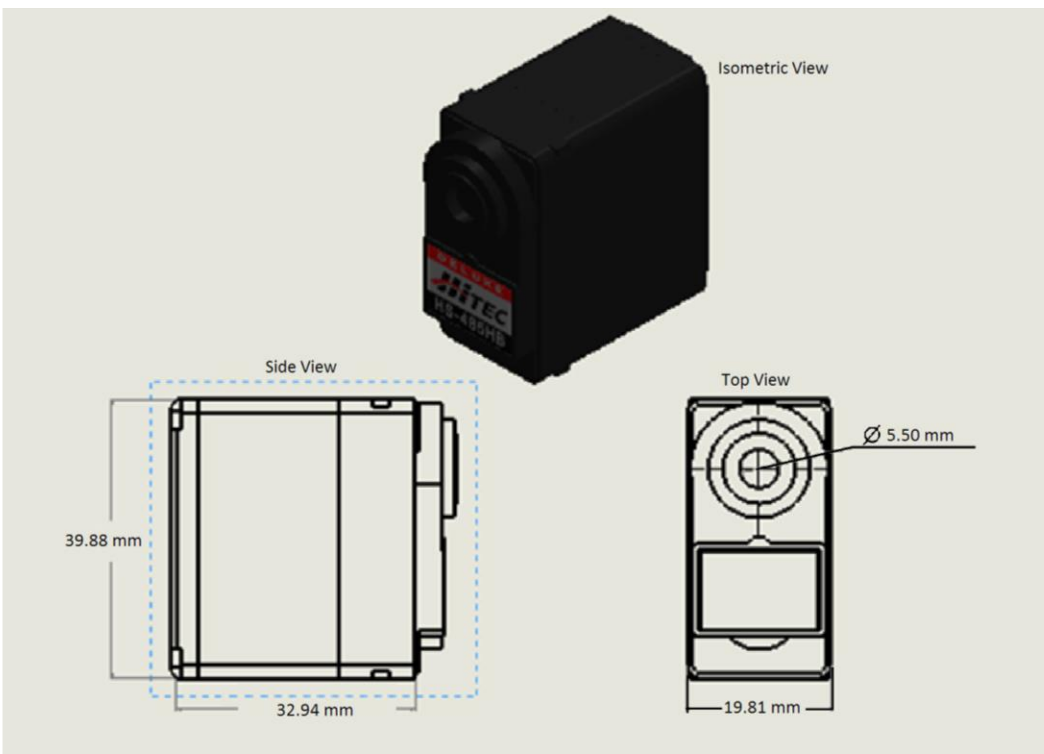


Figure 8: Servo Motor Dimensions

7.2.3 Spindle

The spindle consists of two parts, both made of aluminum. This material was chosen because it is resistant to corrosion and maintains a light weight while having high strength properties. The outer hub is where the booms are going to be rolled around. The inner hub is going to hold the booms and it will be connected to the shaft motor to rotate the whole spindle. The diameter of the spindle, 26 mm, will allow enough space for the booms. Once the tapes have wrapped around the spindle, we can measure the total diameter to be 90 mm.

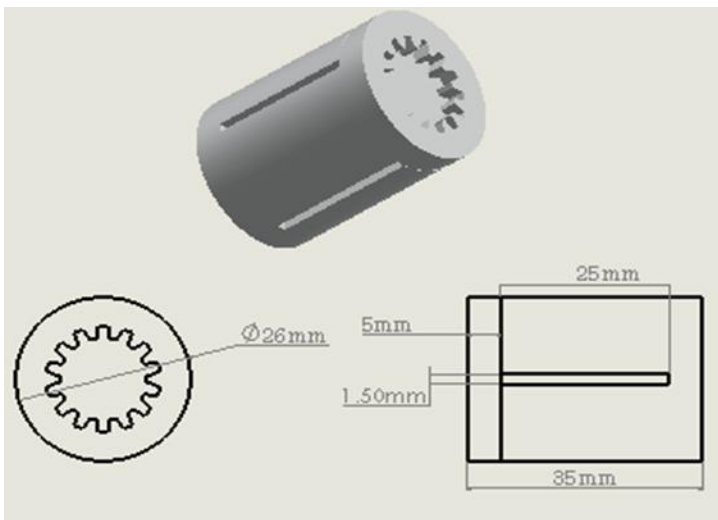


Figure 9: Spindle Dimensions

7.2.4 Sail Compartment

The sail compartment function is to store the solar sail until deployment. It will also be made of aluminum like many of the other parts. The center of the compartment will have a center hole to let the motor shaft through; the diameter of the hole is going to be bigger than the shaft to avoid friction. A small gap between the center and wall was designed to decrease the weight. This was possible because the area needed for the solar sale once it is folded is just 20 mm^2.

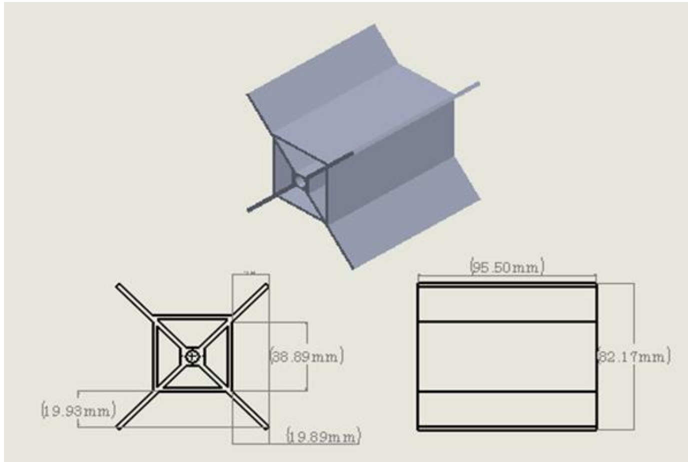


Figure 10: Sail Compartment Dimensions

7.3 Power Subsystem

The purpose of the power sub system is to provide uninterrupted and adequate power to on-board electronics in sunlight as well as in eclipse. The power subsystem is designated to supply power to the Attitude Determination and Control System (ADCS), communication system, and payload as well as the temperature sensors in the satellite.

7.3.1 Solar Cells

We have selected 29.5% NeXT Triple Junction solar cells in the design of our 3U satellite because they are very accessible and highly efficient. The efficiency of the cells in our design is very important due to the limited surface area available on the satellite. The triple junction cells are composed of a germanium substrate and a GalnP2, GaAs, and Germanium solar cell. XTJ solar cells produce 135-mW/cm^2. In Figure 11, a spec sheet listing the performance of the cells can be seen. The system will be set up to accommodate 4 cells per vertical wall to yield a total of 16.

Typical Electrical Parameters

(AM0 (135.3 mW/cm²) 28°C, Bare Cell)

Jsc= 17.76 mA/cm²
Jmp= 17.02 mA/cm²
$Jload_{min\ avg}$= 17.14 mA/cm²
Voc= 2.633 V
Vmp= 2.348 V
Vload= 2.310 V
Cff= 0.85
Effload= 29.3%
Effmp= 29.5%

Radiation Degradation

(Fluence 1MeV Electrons/cm²)

Parameters	$1x10^{14}$	$5x10^{14}$	$1x10^{15}$
Imp/Imp_0	1.00	0.99	0.95
Vmp/Vmp_0	0.94	0.91	0.89
Pmp/Pmp_0	0.95	0.90	0.85

Thermal Properties

Solar Absorptance= 0.90 (5 mil CMG/AR, 0.88 for bare cell)
Emittance (Normal)= 0.85 (Ceria Doped Microsheet)

Weight

84 mg/ cm² (Bare) @ 140 μm (5.5 mil) Ge wafer thickness

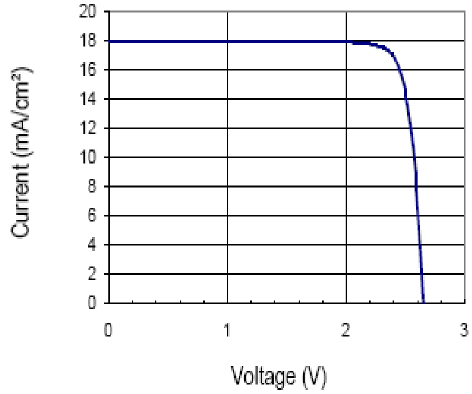
Temperature Coefficients *(15°C - 75°C)*

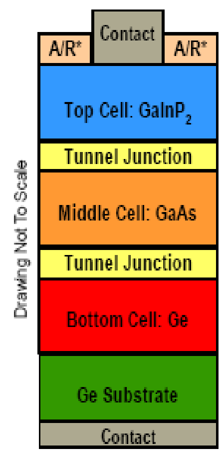
(Fluence 1MeV Electrons/cm²)

Parameters	BOL	$5x10^{14}$	$1x10^{15}$
Jmp (μA/cm²/°C)	6.6	10.0	13.2
Jsc (μA/cm²/°C)	11.6	10.9	11.9
Vmp (mV/°C)	-6.5	-6.8	-6.9
Voc (mV/°C)	-5.8	-6.5	-6.6

Typical IV Characteristic

AM0 (135.3 mW/cm²) 28°C, Bare Cell





*A/R: Anti-Reflective Coating

The information contained on this sheet is for reference only. Specifications subject to change without notice. Revised 5/20/2010

Figure 11: Solar Cell Spec Sheet

7.3.2 Battery

Batteries are essentially needed to supply power at times when there is no direct solar radiation to the satellite's solar cells. It is also of great necessity in situations when there is a greater power need than can be obtained from the solar cells. Such batteries should be able to operate in high and low temperature conditions and they need to be compact and lightweight to comply with the NASA restrictions. In our design, we have selected Lithium-Polymer batteries.

7.4 Communications

Communication subsystem is one of the important subsystems for the satellite operation. The main goal of the communication subsystem is to establish a communication link between the satellite and the Earth ground station. Telemetry and command are the two forms of communication between a satellite and the Earth ground station. In telemetry communication, satellite transmits to the ground station regarding its attitude and station. Similarly, in the command communication information is transmitted to the satellite. These two types of commutations require an antenna, RF transceiver, TNC (Terminal Node Controller), PIC microcontroller, GPS and a Beagle Bone.

7.4.1 Beagle Bone

The Beagle Bone is a small computer that provides the satellite information through the serial port connected to PIC microcontroller. The Beagle Bone provides the control subsystems to other subsystems.

7.4.2 TNC & RF Transceiver

TNC is responsible for assembling data (bits) from the microcontroller into packets before sending to the RF transceiver. Similarly the RF transceiver dissembles the packets into bits before sending to the microcontroller. The TNC has two full duplex serial ports; one is for the GPS and the other for the RF transceiver.

7.4.3 Antennas

Antennas are essential for radio communications. They provide the ability to send wirelessly all satellite functions and receive any and all commands from ground control. The antenna will be constructed from steel tape which is usually found in measuring tape.

7.5 Attitude Control

The sensors, which are mainly used in the attitude control subsystem, are a Razor 9-degrees of freedom sensor and a Sun sensor. The Razor 9-degrees of freedom, consists of a gyroscope, accelerometer and magnetometer with an ATmega328 host controller. These sensors can provide the feedback signals necessary for the attitude control of the CubeSat and are interfaced with the Beagle Bone via a serial interface port. A magnetic torque driven by a H-bridge generates control torque required to rotate the satellite. The Beagle bone through the general-purpose digital output pins provides the control signals to the H-bridge. We can also manage to control the orientation of the satellite through the use of torque coils. Magnetic torque coils can be chosen for the attitude control for their low weight, low power, small size and relative ease of use.

7.5.1 Gyroscopes

Gyroscopes are devices that sense rotation in three-dimensional space without reliance on the observation of external objects. They will be included in order to obtain satellite orientation as well as use the information provided by the gyroscope to adjust orientation.

7.5.2 Magnetometer

A Magnetometer is a device that senses magnetic field strength and, when used in a three-axis triad, magnetic field direction. This device will allow the satellite orientation to be changed whether automatically based on the information provided by the gyroscope and accelerometer or manually from a ground station by using user input.

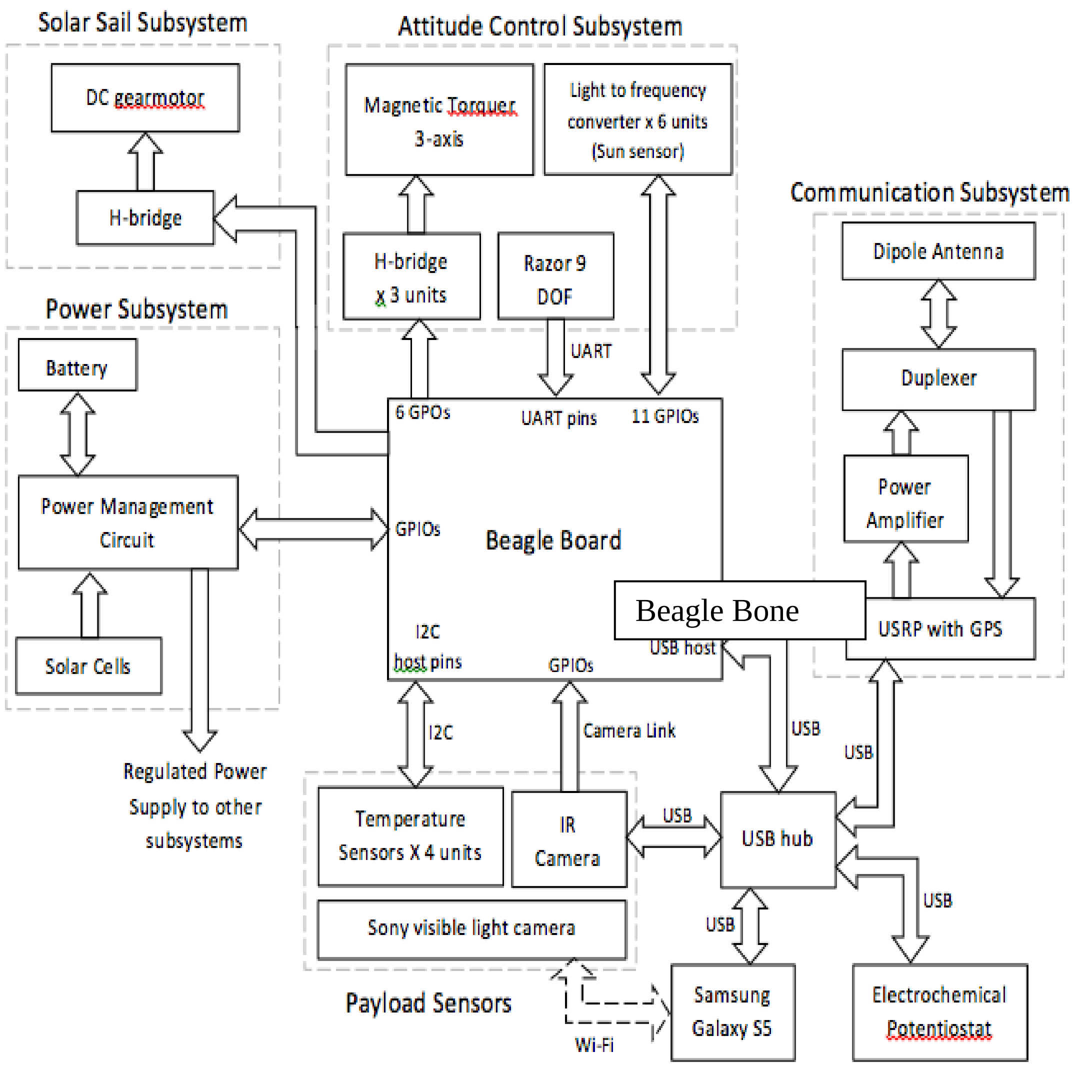


Figure 12: System Diagram

8 Structural Design

The structural design of our CubeSat structure has been designed in such a way that it meets the constraints of a 3U satellite. Our chassis will consist of four separate walls of aluminum 6061-T6511 grade that are welded to four external rails. This material has been chosen because of its favorable properties, light weightiness and machinability. Referring to outside resources that show experiments similar to ours also helped us reinforce our reason for choosing this material. Considerations for using the aerospace standard aluminum 7075 T-6 material were made, but after conducting a cost analysis, it was decided that the material vs. cost was more in favor of the aluminum 6061 T-6 grade.

DIMENSION (IN)	PART	PRICE/PLATE(SHEET)	WEBSITE	QTY REQ.		SUM	
3/8" X 1/2" X 18"	**RAIL**	$2.01	SPEEDYMETALS.COM	4		$8.04	
3.31" X 3.31" X .05"(CUSTOM CUT)	**BOTTOM/TOP PLATE**	$0.88	ONLINEMETALS.COM	4		$3.52	
4" x 0.05" x 14"(CUSTOM)	**CHASSIS**	$4.48	SPEEDYMETALS.COM	4		$17.92	
12" X 18" X .05"(SHEET)	**L BRACKET**	$0.96	ONLINEMETALS.COM	1		$0.96	
12" X 18" X .05"(SHEET)	**TOP PLATE L BRACKET**	$0.96	ONLINEMETALS.COM	1		$0.96	
					SUM	$31.40	**6061**
		$23.13	SPEEDYMETALS.COM	4		$92.52	
		$1.31	ONLINEMETALS.COM	4		$5.24	
		$5.94	FUTUREALLOYS.NET	4		$23.76	
		$1.44	ONLINEMETALS.COM	1		$1.44	
		$1.44	ONLINEMETALS.COM	1		$1.44	
					SUM	$124.40	**7075**

Figure 13: Material Cost Comparison

When developing our structure, we have to keep in mind that there is a possibility of having external forces, such as those experienced from a rocket, acting on our system and for that reason four rails have been added to absorb these external forces. These rails are specifically created for the forces acting on our system including those of the other satellites that we take under assumption to be placed on top of our structure. This is due to the fact that it is common to have other satellite launched at the same time as it is not cost effective to send one satellite that cost less than the cost of launching a satellite. We must make sure that the structural integrity of our proposed system will be able to withstand these forces while maintaining a lightweight design so that it does not prematurely collapse before deployment from the rocket once in space. Sections of the chassis have removed material so as to accommodate a light weight design. We must keep in mind that our entire system including electronics cannot exceed the 4 kg limit of weight.

For our current progress, a static analysis was conducted using Solidworks Simulation. Our current design has not been fully assembled so we cannot assume that the results obtained now will reflect those of the finalized structure because we will have different downward force values due to a lack of internal components. When the satellites are stacked within the rocket, they are assembled in stacks of 9U high. Since we cannot simulate the components that we are lacking just yet, we will assume an extra 3U satellite is going to be stacked on top of our system. To determine the force acting on each rail we follow the equation as follows:

$$F_R = F_f \, m_{3U} / n \tag{5}$$

F_R = Force on each rail

m_{3U} = Mass of 3U Satellite

F_f = Force experienced during flight

n = number of rails

For our case it will be a max of 4 kg multiplied by the three sets of satellites. We take this result and multiply it once again by the launch force of 14 g to yield a result of 412.02 N.

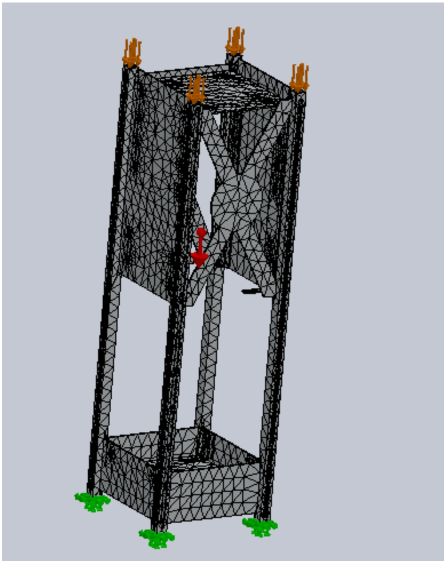


Figure 14: Frame undergoing simulated force

Using the Solidworks program, we can see in Figure 12 the properties of the chassis which include but are not limited to mass and volume:

Mass properties of version 10 c.o.g.
Configuration: Default
Coordinate system: -- default --

Mass = 383.12 grams

Volume = 141896.91 cubic millimeters

Surface area = 241685.56 square millimeters

Center of mass: (millimeters)
X = 0.38
Y = 183.02
Z = 0.00

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)
Taken at the center of mass.

Ix = (0.00, 1.00, 0.00)	Px = 1091898.93
Iy = (-0.00, -0.00, 1.00)	Py = 5315494.11
Iz = (1.00, -0.00, 0.00)	Pz = 5417723.35

Moments of inertia: (grams * square millimeters)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 5417709.53	Lxy = 7731.76	Lxz = -0.03
Lyx = 7731.76	Lyy = 1091913.59	Lyz = 1878.57
Lzx = -0.03	Lzy = 1878.57	Lzz = 5315493.27

Moments of inertia: (grams * square millimeters)
Taken at the output coordinate system.

Ixx = 18250811.53	Ixy = 34140.37	Ixz = -0.03
Iyx = 34140.37	Iyy = 1091967.93	Iyz = 1878.69
Izx = -0.03	Izy = 1878.69	Izz = 18148649.61

Figure 15: Proprietary information of structure

It is good to take note that the slots in the rails and the material reduction in the side panels played a significant factor in our weight from our previous design which weighed in at 520 g. The positioning of each slot was specifically placed so as to not reduce the integrity of the overall structure.

9 Cost Analysis

The cost of the satellite hasn't fully been taken into consideration. The current cost is based on current materials that have been taken into account for the solar sail. The following table also does not take into consideration the cost of machining of the components.

Table 3: Cost of Components and Materials

Components	**Cost ($)**
Booms	15.90
Spindle	4.17
Sail Compartment	35.00
Plate Bottom	0.88
Plate Top	0.88
Sail Compartment Plate	0.92
Motor	31.49
Rail	2.01
Bottom/Top Plate	0.88
Chassis	4.48
L Brackets	0.96
Top Plate L Brackets	0.96
Total	98.53

Table 3 consists of total hours worked along with salary earned based on an hourly rate of $15 per hour. This of course will change with time depending on the amount of time needed for the project.

Table 4: Hours and Salary

Name	Hours	Salary ($)
Gonzalo Vivanco	60	900
Luis Fernandez	60	900
Giampiero Revelo	60	900
Henry Vazquez	60	900
	Total	3600

10 Prototype

The construction of the prototype will take into account several components. It will follow closely with the proposed design. In the event of a design change all changes will be taken into account. Table 4 provides a visual representation of the proposed cost of the components.

Table 5: Material Cost Analysis

Components	**Cost ($)**
Booms	15.9
Spindle	4.17
Sail Compartment	35.0
Plate Bottom	0.88
Plate Top	0.88
Sail Compartment Plate	0.92
Motor	31.49
Rail	2.01
Bottom/Top Plate	0.88
Chassis	4.48
L Brackets	0.96
Top Plate L Brackets	0.96
Solar Sail Material	648.10
Total	746.63

10.1 Weight Reduction

To reduce weight in the structure we made some slots in the structure rails. First we drill ten holes along the rails with a 5mm drill bit, in order to create space for the mill bit to remove the material.

Figure 16: Drilling

After making the holes and before starting the milling process we have to calculate the RPM for the milling speed. For that we use the following equation

$$RPM = (3.82 * SFM) \qquad (6)$$

For the SFM value we use the Speed and Feed Chart in our case is Aluminum, consequently the SFM value is 300, as a result the safe cutter speed is about 1150 RPM. While we were doing the milling we applied coolant on the cutter to decrease its temperature and prevent it from breaking. The total time to do all the slots was about three hours per rail with a total of twelve working hours. Comparing to the original weight, the reduction was about 2 lbs which is a very significant value since we are trying to keep the whole satellite weight under 12 lbs, Figure 17 show the final product.

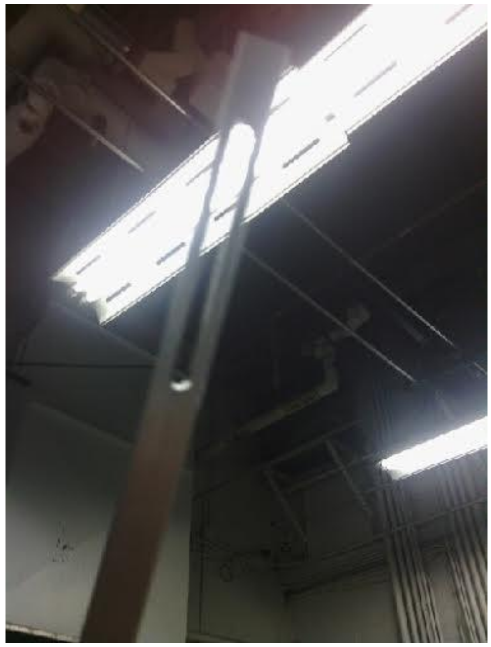


Figure 17: Slot

10.2 Frame Construction

The construction of the prototype begins with the foundation of the chassis which will provide structural rigidity as well as a location for all the electrical components to be stored. In order to save on cost, the structure will be built in-house; the first step was to take the four main square rods and machine them in a manner in which to reduce weight. This was done by first cutting the rods to the required dimension and then machining 2 inch slots through the square rods ensuring even spacing while maintaining structural rigidity. Once all rods were finished cutting the side panels to size was performed using a band saw as seen in Figure 18.

Figure 18: Cutting of side panels

After completing the cuts the panels needed to have a straight clean edge free from any burr’s and sharp edges to allow for save handling as well as prepare the aluminum for welding which can be seen in Figure 19.


Figure 19: De-burring process

The process was then moved to building of the structure. This was done through the process of aluminum brazing which is a form of welding aluminum. This is done by heating the base metal to the point that it is becoming malleable. Once it reaches that point filler metal, in this case aluminum welding rod, is added which can be seen in Figure 20.


Figure 20: Joining of support rod and panel

The welding of the aluminum panel to the support rod became a bit difficult due to the lack of experience as well as the inability to control the heat distribution of the thin panel with the thicker rod. After some practice with the propane torch, it was possible for the panel to join with the support rod as well as obtain an evenly distributed weld.


Figure 21: First completed weld

Since the structure will take the shape of a rectangular box two more panels need to be attached while the forth will be left off in order to provide access to the compartment. This will allow for the placement of the internal components. Figure 22 demonstrates the addition of another panel forming the first corner.

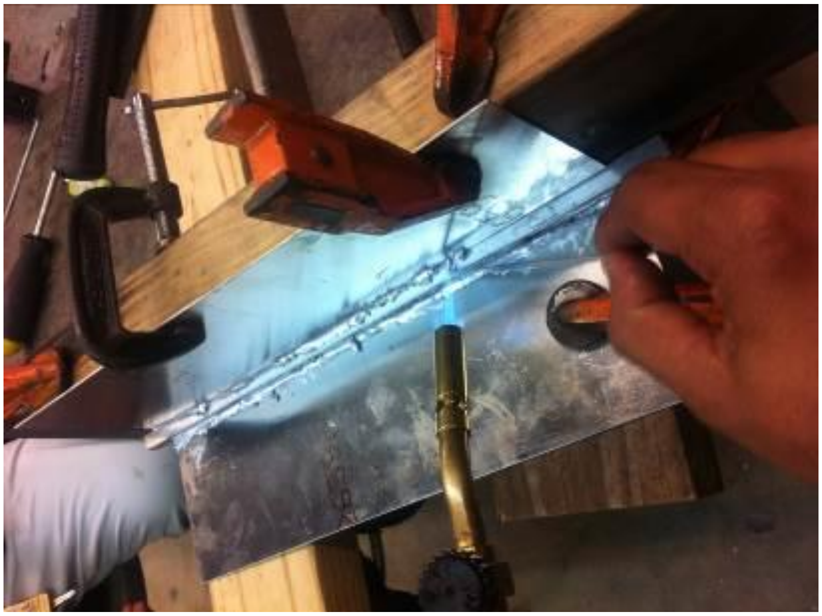


Figure 22: Formation of first corner of frame

An issue arose while forming the corner of the frame; since the weld requires heating of the structural rod and the panel. It was possible to weld the next panel to the rod but it was not known that the previous weld would lose its integrity.

Figure 23: Weakening of the weld

By looking at Figure 23, it can be seen that the previous weld that was added to the first panel and rod started to become undone when welding the second panel. This was most likely due to the fact that once the rod was heated, it affected the welds that were performed beforehand to re-melt. At the moment, the integrity of the complete weld hasn't been compromised and still shows signs of rigidity, but a second pass of the welds will need to be done in order to ensure complete welding of the panels to the support rod.

11 Modifications and Updates

Over the course of this project several changes were implemented that affected the CubeSat significantly. These changes had to be implemented due to the main issue of funding. Major systems will be affected that involve new components that will be explained momentarily, electrical systems, launching parameters, and payload.

11.1 Payload and Constraints

As mentioned in the previous sections of the document, the intent of building the CubeSat was, with the help of NASA, to launch it at a given altitude so that it travels in orbit to collect data. Unfortunately, NASA did not approve our design for the launch therefore our funding was immediately cut short. This did not discourage the group however. The intent is still to launch it into the atmosphere but at a much lower altitude. For this reason, several factors must be taken into account along with some that can be neglected.

Working in collaboration with some outside sources, it was established that wind would not be a big factor that would have to be considered in the new concept. A lot of restraints were set forth to build this CubeSat to meet the design requirements of the NASA competition however most of these can now be neglected because it is no longer under NASA's guidelines. It is still high priority to keep a low cost and low weight design but, unfortunately, the smaller, lightweight components cost significantly more so some exceptions must be made. With the changing of, for example, the sail deployment system, more weight will be added. This, in turn, balances out because the housing compartment for the sail is being removed because the system will be open to the air at the bottom of the CubeSat. This will increase the overall dimensions but this is no issue because the CubeSat will now be traveling via balloon launch.

A company in California known as Global-Western launches unique balloons for various unique projects. It was determined that the goal to launch our CubeSat was still attainable. This company informed us that they could launch our CubeSat at an altitude of 50,000 feet for a price of $500 if launched from their site. This is the route that we plan to take however due to time limitations for the project; we will continue this as part of an effort to develop a new course of study or perhaps a club for FIU for next semester.

The new payload will consist of simply monitoring temperature and taking pictures with camera that is to be used. Working with the meteorology department, they informed us that wind would not be a significant force to account for so its considered negligible.

11.2 Structural Design

The current structure of the CubeSat has changed from the original design; the deployment system has moved from the inside of the CubeSat to a 4.5” extension that is now on top of the structure as shown in Figure 29. The new deployment system houses two worm gears which are attached to the outer extension plates of the structures with four flange bearings, and one worm driver which is placed in between the two worm gears and is attached directly to the stepper motor by way of a coupler. Figures 24, 25, 26, 27, and 28 show the designs of the structure along with the deployment system

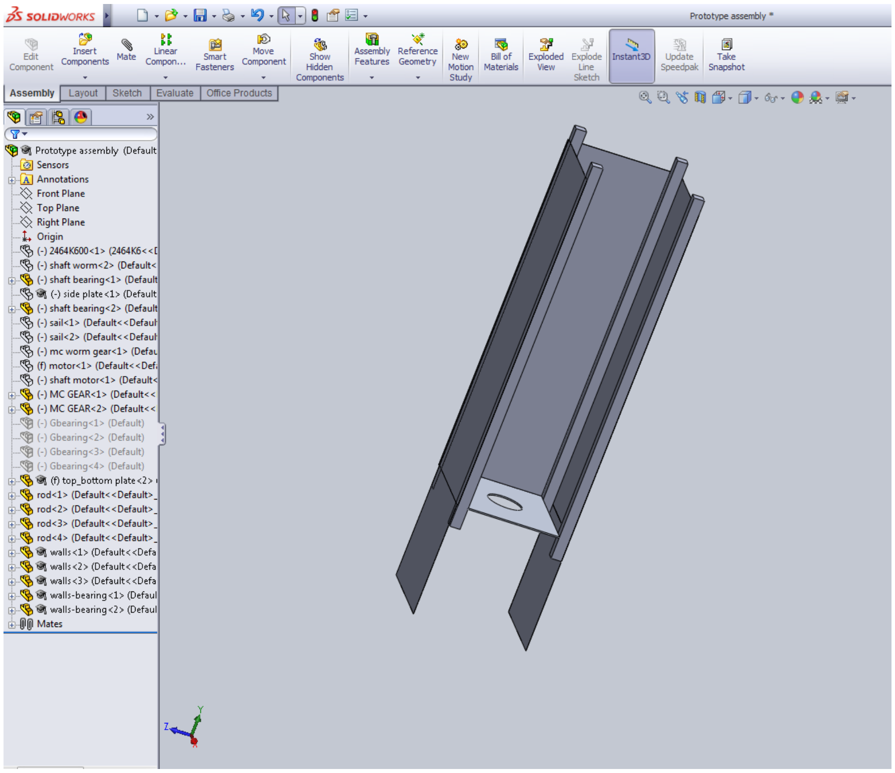


Figure 24: Frame Design

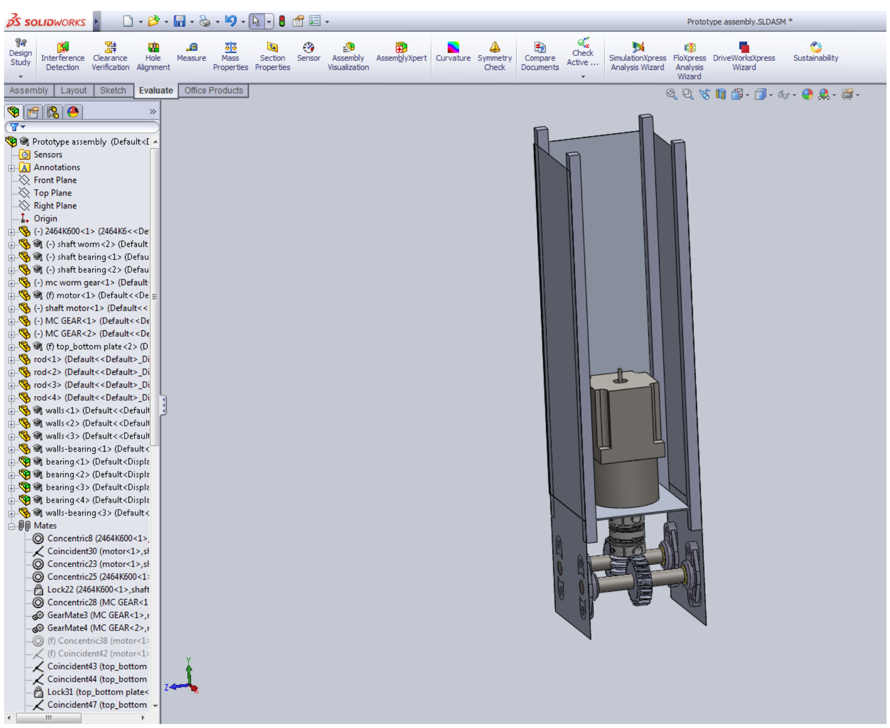


Figure 25: Stepper Motor with Deployment System

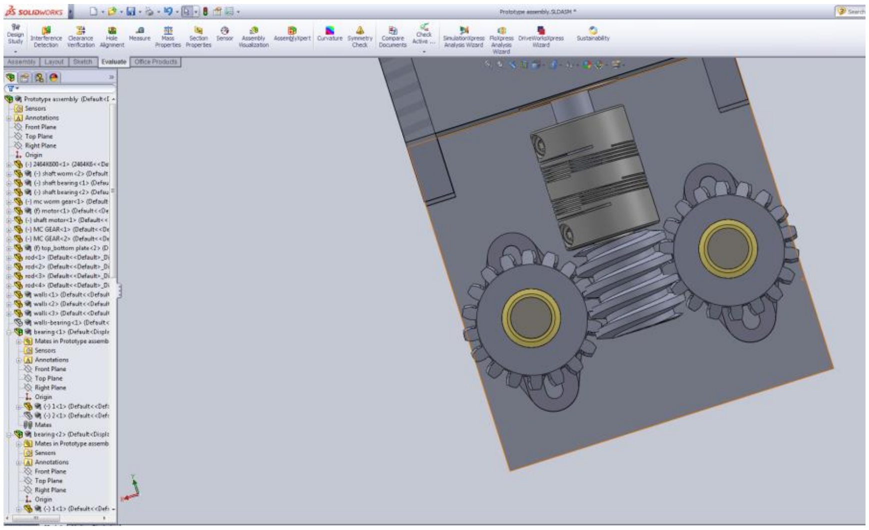


Figure 26: Up Close Design of Deployment System

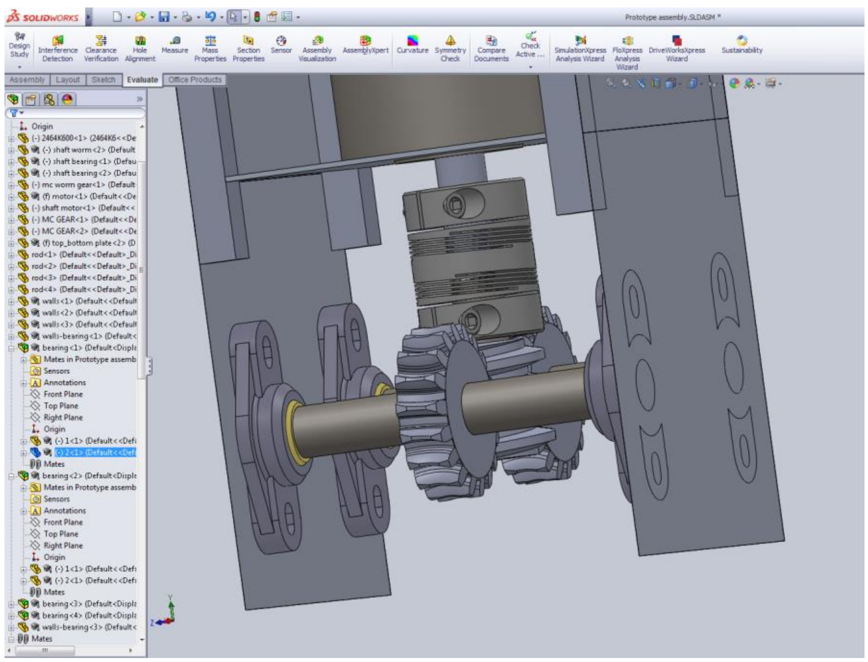


Figure 27: Up Close Design of Deployment System Including Bearings

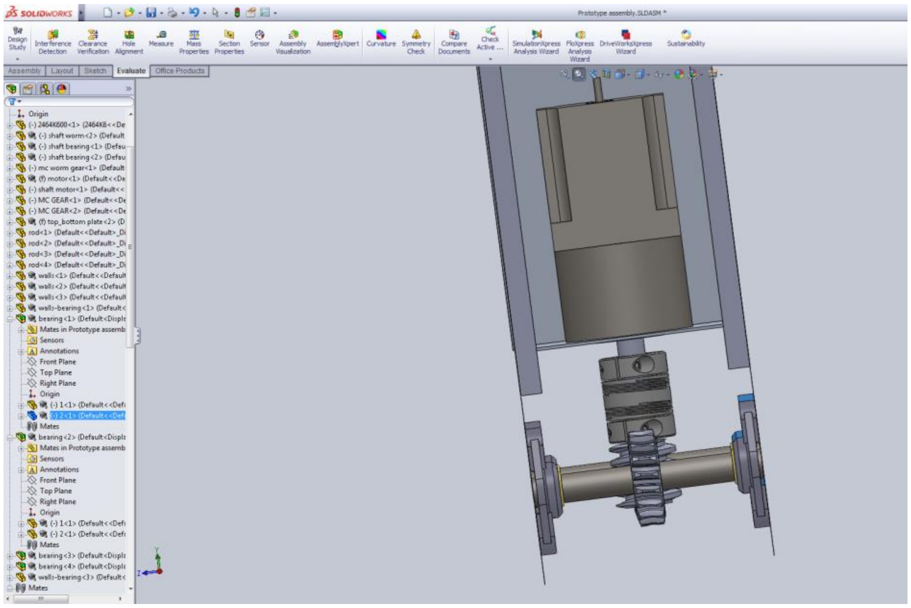


Figure 28: Side View of Deployment Design

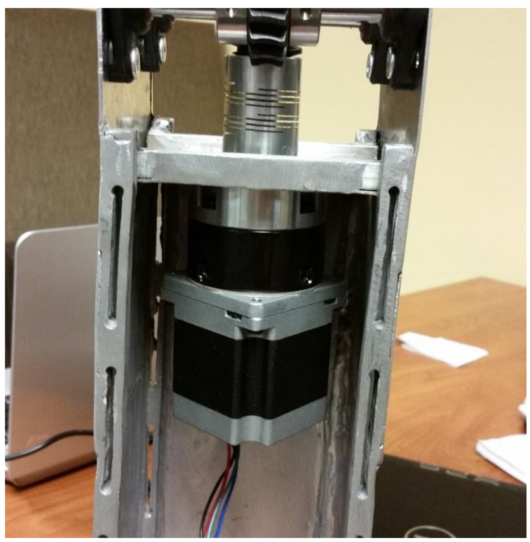


Figure 29: CubeSat Structure with Deployment System

The sailing material will no longer be housed within the CubeSat and instead will be in an un-deployed state outside of the structure but still be attached to the aluminum rods that are shown in Figure 25; it should be noted that the support rods have not yet been welded during the generation of this report. When welded, the support rods will be parallel to the horizontal plane which will result in the sail to be fully deployed.

Figure 30: Deployment system with Attached Support Rods

Figure 26 shows that in the location of the proposed sail storage compartment, the stepper motor has taken its place in order to drive the worm driver and worm gears and the rest of the structure will hold all remaining components.

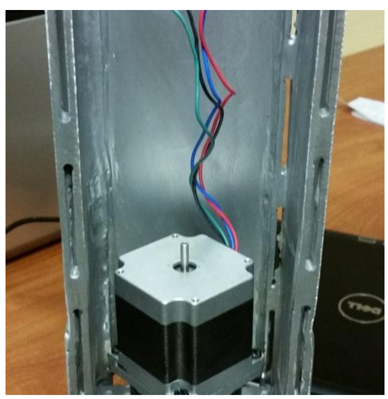


Figure 31: Stepper Motor Location

11.3 Solar Sail Design and Analysis

The solar sail design received a complete overhaul due to the fact that the method of launching would no longer be implemented as originally designed. The purpose of the sail is still to modify the position of the satellite but will now use wind force for this to happen. Simple angular adjustments to the sail will allow the CubeSat to be moved in a different orientation. Because the method of launch has been changed to a balloon launch that will be provided for by the company, Global Western, only slight changes in position can be achieved. The material was also changed due to the fact that it no longer has to be reflective. The property we are more focused on now is the strength and durability during changing winds. The sail chosen is from Grafix Duralar and is suitable for our design. A simple test resembling that of flying a kite would determine if the sail material would tear. Various trials were conducted on different days to try and exhibit varying wind forces and to see if the sail would not tear. During days of harsh winds, it proved that the material would not tear and thus would be used for our design.

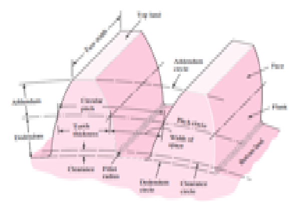
The deployment system will open two rods to drive the satellite using the wind force. The motor used to drive the gears was determined by using the conventional lifting equation.

$$L = Cl \frac{\rho V^2}{2} A \tag{7}$$

$$\text{Lift} = \text{coefficient} \times \frac{\text{density} \times \text{velocity squared}}{\text{two}} \times \text{wing area}$$

Coefficient Cl contains all the complex dependencies and is usually determined experimentally.

After having performing the gear analysis, the worm gear was purchased to comply with the AGMA standards. Force analysis was also performed to determine the forces acting in the bearings. Once having calculated the radial and axial forces acting in the bearing, it was purchased a set of four flange bearing that withhold the amount of force according to the calculations shown.



Gear Analysis					
		Worm		Worm gear	
Given					
RPM TRANSMITTED		375			
Torque (lbs-ft)		3.83			
HP [hp]		0.27			
axial pitch [in]/ linear pitch	Px	0.2618		0.262	Worm pitch diameter selection to optimized the horsepower
transverse circular pitch [in]	Pt			0.262	0.65568695 <=dw<= 1.15709462
Pitch diameter [in]	d	1		3.33333	
Pitch diameter [mm]	d	25.4		84.666582	
face width [in]		1.125		0.5	
pitch		12		12	
Pressure angle	degree	14.5		14.5	
# worm threads and teeth	N	1		40	
Calculatated					
helix angle	Ψ	85.74			
module [mm]	m	25.400		2.117	
circular pitch [in]	p	0.262	#	0.262	
circular pitch [mm]	p	79.796		6.650	
Pitch diameter [in]	d	1		3.33333	
Axial Pitch [in]	Px	0.2618	@	0.262	Px = F
Transverse Pitch [in]	Pt			0.262	
Center distance [in]	C	2.166665		2.166665	C = (dw + dg)/2
Lead [in]	L	0.261799388	#	0.262	L = px * Nw
Lead angle [degrees]		4.76		4.76	Lead angle = tan-1 (L/pi * dw)
Pitch line velocity (ft/min)	V	98.17477042		8.181222687	V = (pi*d*n)/12
Speed of the gear (rpm)	n	375		9.375	
ratio	40				

$$P = \frac{N}{d}$$

$$m = \frac{d}{N}$$

$$p = \frac{\pi d}{N} = \pi m$$

$$pP = \pi$$

where P = diametral pitch, teeth per inch
N = number of teeth
d = pitch diameter, in
m = module, mm
d = pitch diameter, mm
p = circular pitch

Figure 32: Gear and Bearing Analysis

11.4 Component Changes

The reason for these changes in parts had a lot to do with the programming challenges that were faced during the testing phase of the project. For this reason, the main controller that integrates everything together will be the Beagle Bone Black. In previous reports, it was specified that a beagle board was to be used as the primary programming unit. This, however, proved to be inefficient because of the lack of help such as online tutorials that were available. This new Beagle Bone operates on Linux software and is much easier to program with several online references on how to program the new components. It operates with Python programming libraries that enable the user to input codes after calling out the desired library and responds rather quickly to commands.

For the sailing system, the motor that was going to be used needed to be changed. It was necessary that the new motor have the capability of being able to connect to the Beagle Bone Black. In order to pick the appropriate sized motor for our project it was necessary to first calculate how much torque is needed to turn the solar sails booms. It was also necessary to determine the size of the sail that was needed to move the 10kg mass of the entire satellite. Figure 28 represents the maximum wind speed that our satellite will face during its travel, which is found to be 18 ft/s.

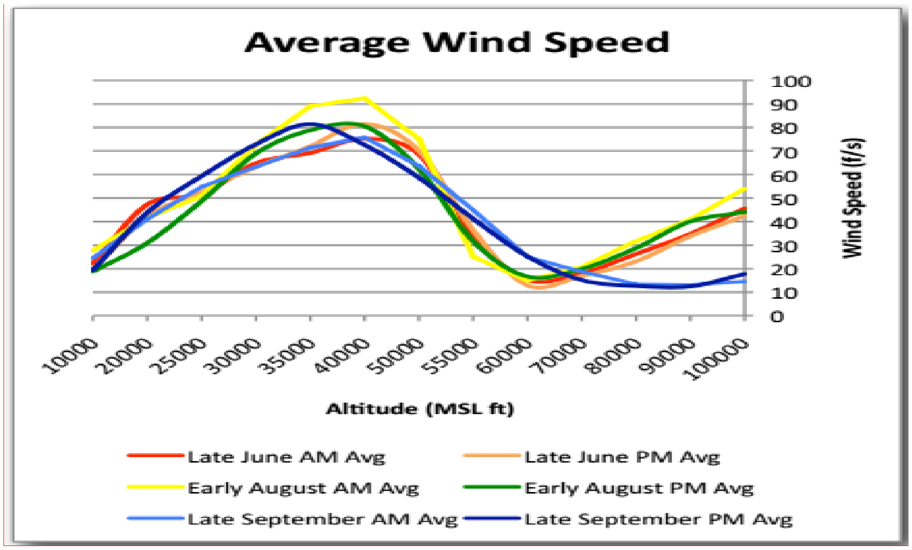


Figure 33: Wind Speed vs Altitude

Once the total mass of the CubeSat has been obtained and the expected wind speed based on the altitude the pressure caused by the wind needs to be calculated.

$$\text{Pressure} = D_c * \rho_a * V_w^2 \tag{8}$$

D_C = Drag Coefficient

ρ_a = Air Density

V_w^2 = Wind Speed

Then we calculate the area of our sail need it to move the satellite.

$$A = F/P \tag{9}$$

A = Area

F = Force

P = Pressure

With the values obtained from equations seven and eight the torque required for our motor can be calculated. Since the sail is divided into two equal sections the torque required is doubled.

$$T = 2 * F * r \tag{10}$$

T = Torque

F = Force

r = radius

Table 6: Motor Calculation

Name	Value	Units
Mass	11.02	lb
Force	11.027	lbs
Air Density	$4.42*10^{-5}$	lb/in^3
Wind Speed	1080.12	in/s
Drag Coefficient	0.5	N/A
Pressure of the wind	0.0669	PSI
Area	164.95	in^2
Radius	1.35	in
Torque	29.66	In-lbs

Based off the performed calculations the chosen motor would have to have a max torque of 30 in-lbs with a max rpm of 375 in order to drive the sailing system. When looking for a motor with similar specs it was decided that a stepping motor with a torque of 46 in-lbs would be more than sufficient for our needs while also overcoming any additional forces caused by air pressure on the non-deployed sail.

The voltage required would also be compatible with the power supply requirements of the system. Another component that was changed was the temperature sensor. The model switched to was the TMP36 sensor. This was mainly due to an incompatibility issue with the sensor that was intended for use. There was a special adapter that was needed to integrate the old sensor to the Beagle Bone that could not be ordered in time. Nearing the time of launch, the new adapter will be available in which only a minor change to coding should get it working. For now, the sensor used is to display that functionality of room temperature readings proving that the system can be integrated with the sensor and establish temperature readings.

In addition to the changes in components, some components were also removed because since the application was to be different in terms of travel (balloon launch), they would no longer be needed. The PIC microcontroller would no longer be required because the Beagle Bone Black acts as the central control unit through which everything is interfaced. The magnetorquer and magnetometer as individual components are also going to be removed because the CubeSat will not be able to be fully rotated because of the attachment to the balloon. However, the Razor 9 D.O.F IMU that is being used as an incorporated sensor that provides the magnetometer. As for the solar panels, attachments for the panels to the CubeSat are still being manufactured and will unfortunately not be ready by the end of this semester so for the scope of the project they will not be included.

The next major change incorporated the sail material itself. Kapton was the original material intended to be used in the sail. This was chosen because of its material properties and highly reflective surface. However, because of the change in altitude, the energy from the sun will no longer provide a change in direction for the CubeSat once it hits the sail. A replacement sail from Grafix Duralar will be used. A simple test where we used the sail and made it into a type of kite to test against wind resistance proved that this material would not tear in harsh wind conditions. It is relatively cheap and conforms to ASTM D4236 certification. It is also light weight and only .005 inches thick.

12 Component Lists

For a clear representation of the parts used, Tables 7, 8, and 9 show the variety of components used as well as a breakdown of the cost.

Table 7: Sailing System Components

SOLAR SAIL SYSTEM		
STEPPER MOTOR		NEMA-23 BIPOLAR STEPPER WITH 4.25:1 GEARBOX
SHAFT		STEEL DRIVE SHAFT (1/2" OD, 24" LENGTH)
COUPLING		ALUMINUM HELICAL FLEXIBLE SHAFT COUPLING(38MM LENGTH,30MM OD)
WORM GEAR		14-1/2 DEGREE PRESSURE ANGLE WORM GEAR(12 PITCH, 18 TEETH,1.5" PITCH DIAMETER)
WORM		STEEL WORM,12 PITCH WITH 1/8" x 1/16" KEYWAY FOR 14-1/2 DEGREE
BEARING		IGUBAL FLANGE BEARING EFOI

Table 8: List of Electronic Components

ELECTRONICS		
TEMP. SENSOR		TMP-36 TEMPERATURE SENSOR
AMPLIFIER		WIDEBAND LINEAR AMPLIFIER 45 MHz – 1000 MHz 2 W OEM
DUPLEXER		RFS 633-6A-1 406-450 MHz MOBILE DUPLEXER | TESSCO
INTERFACE BOARD		BEAGLE BONE BLACK
SOLAR PANEL		6V 5.6W ADAFRUIT SOLAR PANEL(MONOCRUSTALINE CELL
POWER CONNECTOR		PJ-035D DIGIKEY POWER CONNECTOR
CHARGER		USB / DC / SOLAR LITHIUM ION/ POLYMER ADAFRUIT CHARGER
BATTERY		ADAFRUIT LITHIUM ION BATTERY PACK - 3.7V 6600mAh
USRP		PROVIDED BY DR. ISMAIL GUVENC (ELEC./COMP. ENG. DEPT.)
CAMERA		LOGITECH C525 8MP 720P CAMERA
RAZOR IMU		SPARKFUN 9 DEGRESS OF FREEDOM IMU
MINI USB HUB		5 PORT MINI USB HUB

Table 9: Project Expenses

GONZALO		**HENRY**		**GP**		**LUIS**		**DR. TANSEL**	
ITEM	PRICE	ITEM	PRICE	ITEM	PRICE	ITEM	PRICE	ITEM	PRICE
				RAZOR	79.04				
SHEETMETAL	114	Beaglebone	57	MOTOR	82.45	Beaglebore	130	AMPLIFIER	300
TORCH	17	Lithium Battery	123	COUPLING	65.99	Mill bit	110	DUPLEXER	400
TEMP. SENSOR	46	Solar Lithium charger	22	SHAFT	15.34	welding	80	XXX	XXX
ROUTER	23	Aluminum Welding Rods	25	BEARINGS	29.44	Amplifier	80		
SOLAR PANELS	215	Measuring tape	6	SPLIT SHAFT					
		Stepper Driver	34.95	COLLAR (6X)	75				
TOTAL	415	Break away headers	13	**TOTAL**	347.26	**TOTAL**	400	**TOTAL**	700
		screw terminals	16.7						
		tmp 36 Sensor	1.95						
		beaglebone charger	32.09						
		webcam	21.39						
		homedepot screws	6.32						
		TOTAL	359.4						

13 Testing

Certain testing will need to be implemented in order to determine the integrity and function of the satellite components, solar sail, and solar sail deployment system. These include but are not limited to:

Test 1. Vibration Testing: Will provide information as to whether or not vibrations, which can be experienced during launch, will affect the deployment system, packaging of the solar sail or other components. This can be achieved by subjecting the entire satellite to low and high levels of vibration. A device which induces variable vibrations will need to be sourced in order to conduct this test.

Test 2. Thermal Testing: Will determine the characteristic behaviors of the Kapton material under different operating temperatures as well as to test the performance of the deployment system under varying temperature. Subjecting the satellite to varying temperature as experienced at 800 km above sea level in initial state as well as fully deployed state. An apparatus which can provide varying degrees of temperature as well as providing visual temperature readings will need to be sourced in order to perform this test. This test is no longer applicable due to altitude change.

Test 3. Solar Sail Deployment Testing: Allows the testing of the deployment system as well as provide insight on how the sail will deploy. Will determine if any obstructions are present which can cause damage to the sail. Can be conducted during thermal testing to determine reaction to varying temperatures.

13.1 Component Testing

Due to the time constraints on the project, the previously mentioned structure tests are to be continued at a later time out of the time frame of the class project. The testing that was performed was mainly on the electronics to see if connections could be interfaced properly to the Beagle Bone. For this reason, the components currently being used are not necessarily going to reflect the ones that will be on the CubeSat at launch. Starting with the camera, the materials required are: camera, 1 x energy cell charger 5 V 3.6 A, 1 x USB to usb mini, 1 x micro SD card. We then continue with the Beagle Bone setup process.

Figure 34: Camera Connection

In order to establish any form of communication between the beagle bone black and the host computer a program called PuTTY as seen in Figure 35.

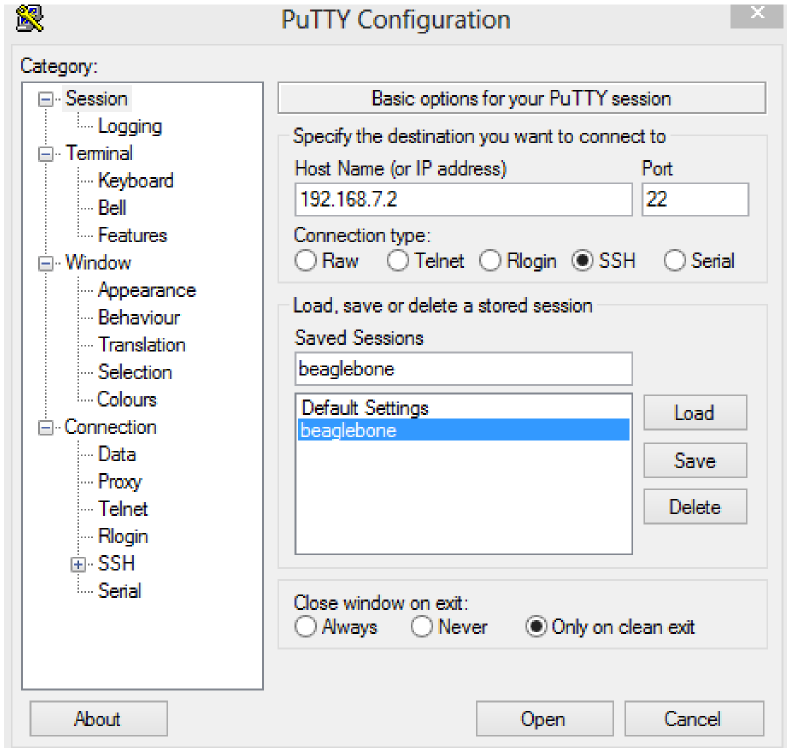


Figure 35: Putty Configuration

The user will then have to login as a root user by typing "root" and pressing enter.

Figure 36:Putty Initial Screen

Once logged in as root the window will show itself as shown in Figure 37.

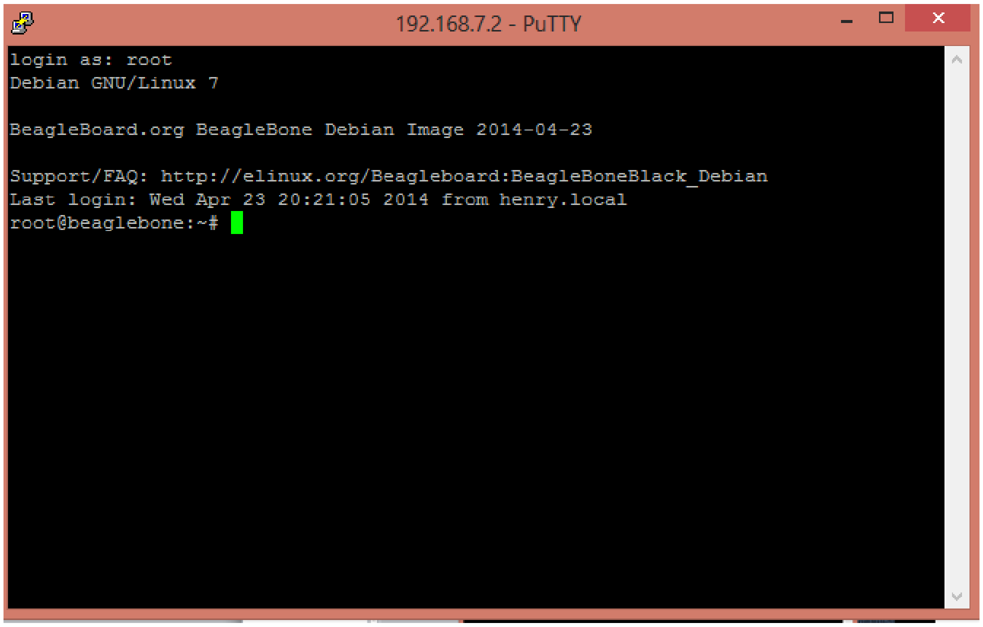


Figure 37: Loaded Login Screen

A desktop emulating program will need to be run in order to interface with the graphical processor of the beagle bone black. This is done by first running a program on the terminal for the beagle bone black known as x11vnc and a program on the host computer called VNC viewer [15]. For testing purposes a non-secure connection is established for testing purposes only. In order to ensure that the x11vnc program runs properly the following commands must be performed:

1. su debian, Press Enter
2. x11vnc -display :0 -forever, Press Enter

Once the program x11vnc is run a screen update is noted as shown in Figure 38.

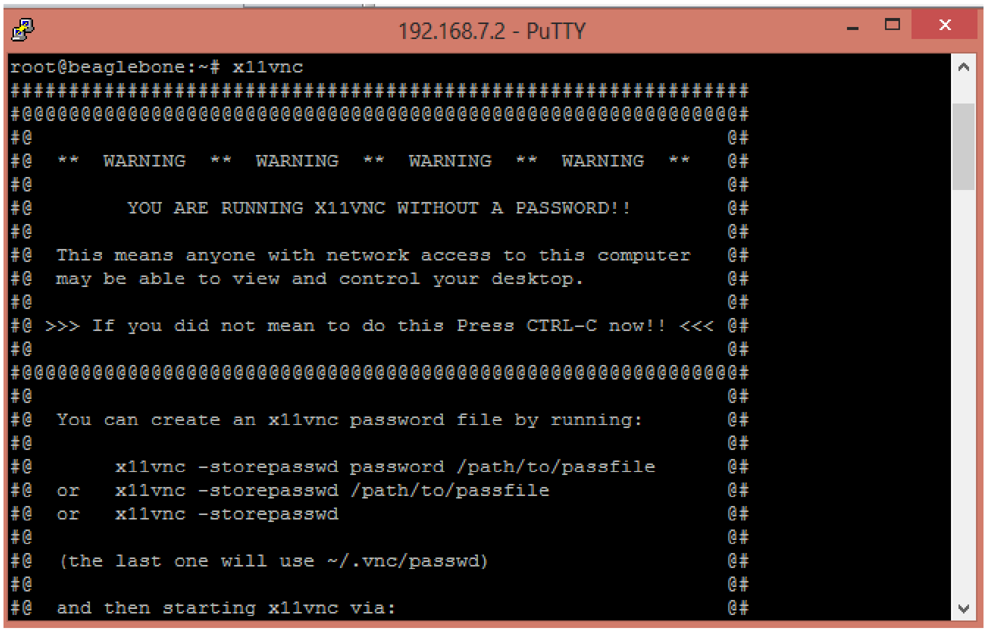


Figure 38: Initial Command Prompt

Once this is performed on the beagle bone black terminal, then the VNC viewer program must be run on the host computer.

Figure 39: VNC Viewer

A new window will open, as seen in Figure 40, once the VNC viewer program is opened requesting a VNC server location, which in this case is the network address for the beagle bone black.

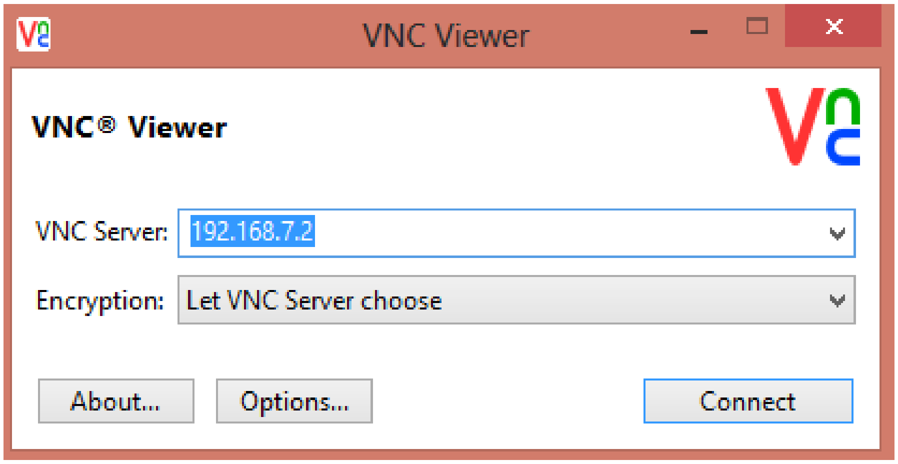


Figure 40: VNC Login

When the connection is made a new prompt will bring to attention the fact that the following connection is a non-secure one. For future connections it is important to later establish a form of encryption which will prevent any unwanted access. But for testing purposes this will be ignored for the time being. An example of the prompt is seen in Figure 41.

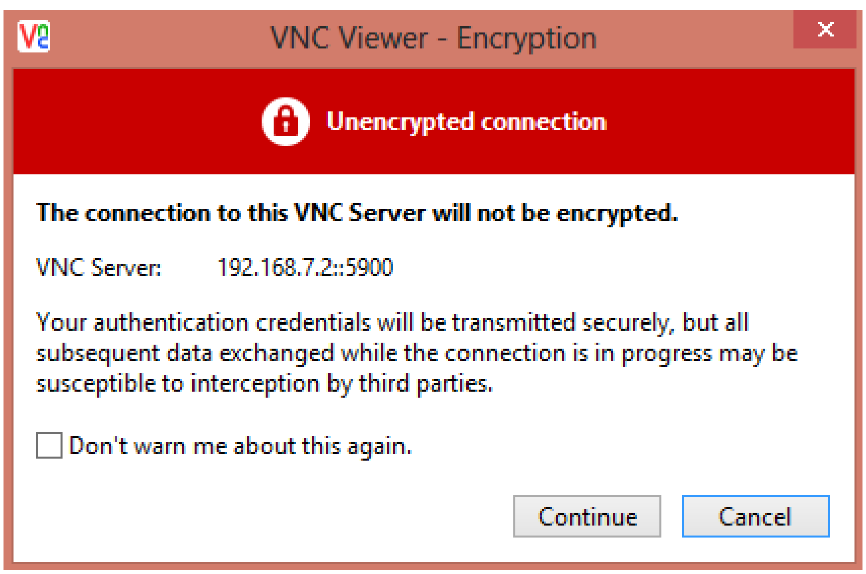


Figure 41: VNC Connection Prompt

For the image and video capture a program called Guvcview will be run on the beagle bone black, it is important to know that this will need to be downloaded and installed through the PuTTY terminal. Once installed the beagle bone black will then have the possibility to interface with the webcam. A window with multiple user inputs will appear, after opening the Guvcviewer, along with a viewing window as seen in Figure 42.

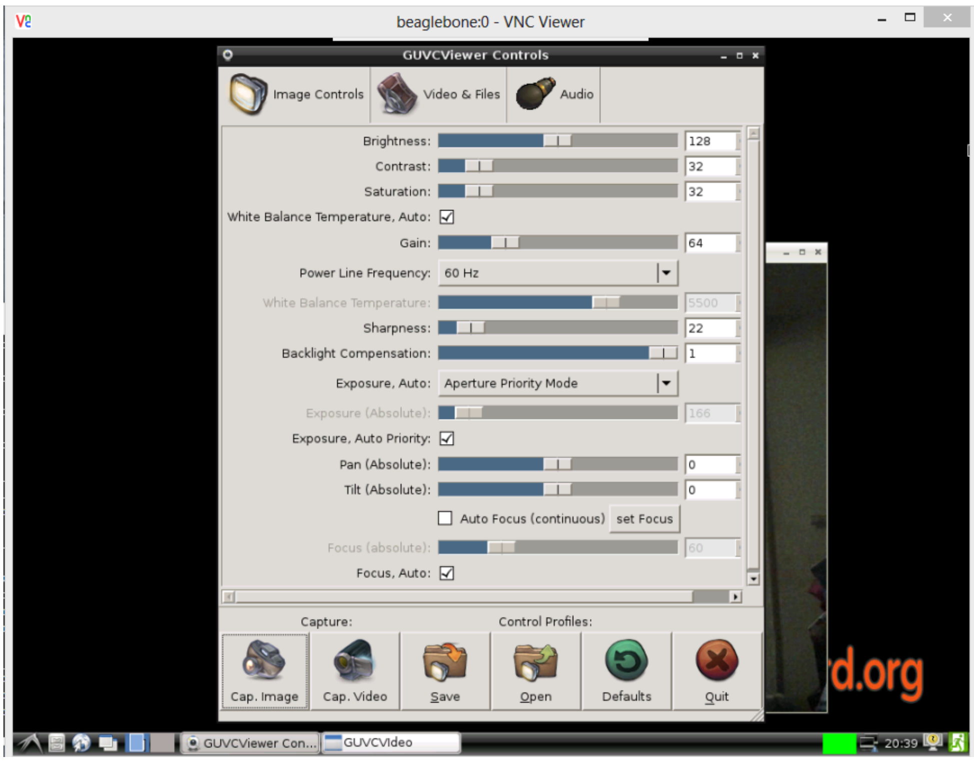


Figure 42: VNC Viewer Menu

The viewing window will appear but when opened it was noticed that there was a significant amount of lag between the object being viewed and what is being viewed by on the viewing window. This is mainly due to the fact that the resolution, which was set at 800 x 600, required more processing power to interpret hence increasing the amount of time between each frame.

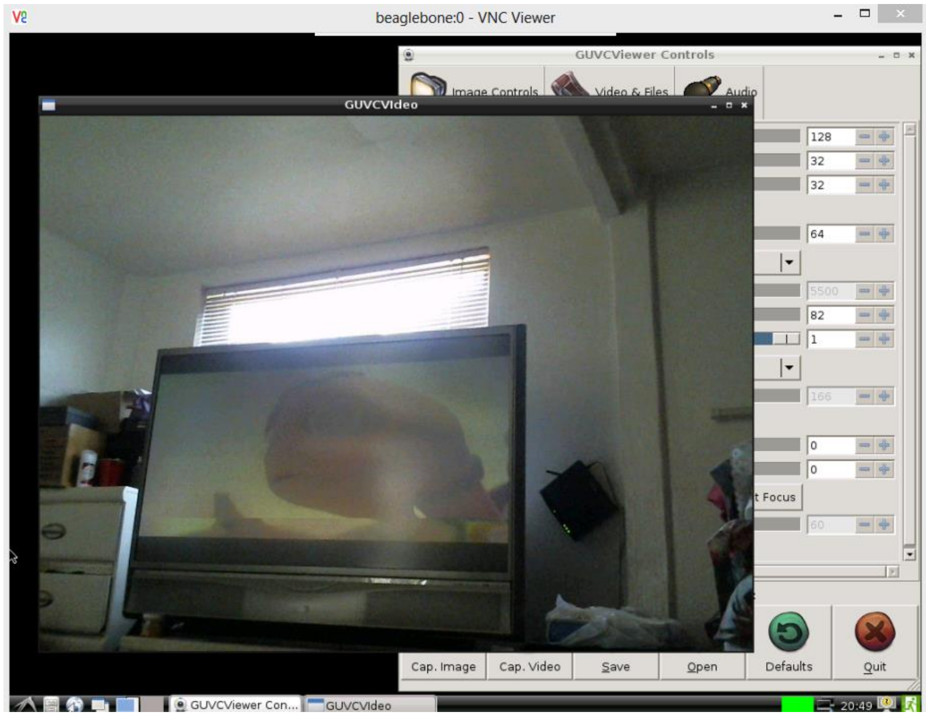


Figure 43: Image Output Screen

By reducing the resolution, the lag is reduced significantly but the size of the window that one can see is also reduced as seen in Figure 44.

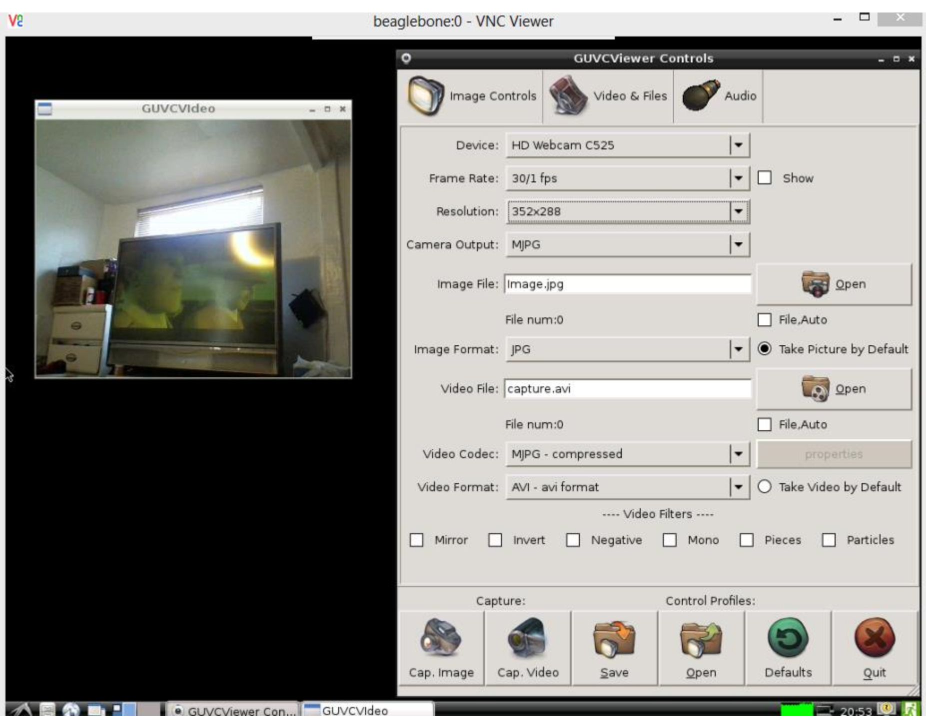


Figure 44 : Video Viewer

By using the guvcviewer interface we have the option of capturing images by simply pressing the capture image button. Once performed the image is saved onto the debian main file as seen in Figure 45.

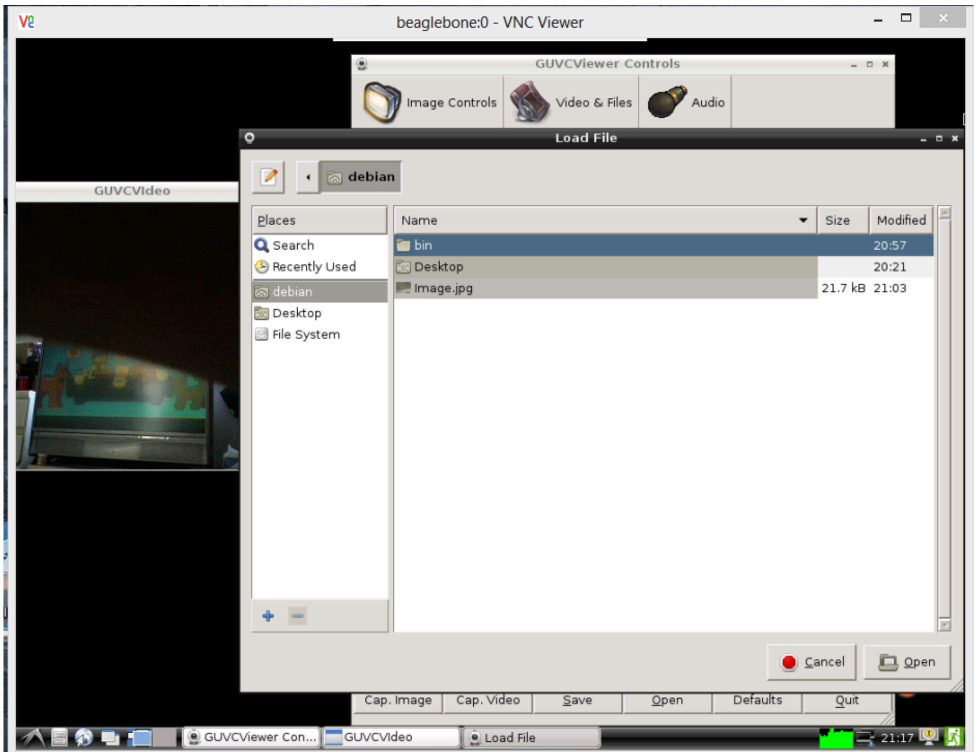


Figure 45 : File Exporting Window

In order to record video that same process is performed as in capturing an image but instead the Cap. Video button is pressed to begin recording and pressed a second time to stop recording. A file of the video is then saved to the debian file in .avi format as seen in Figure 46.

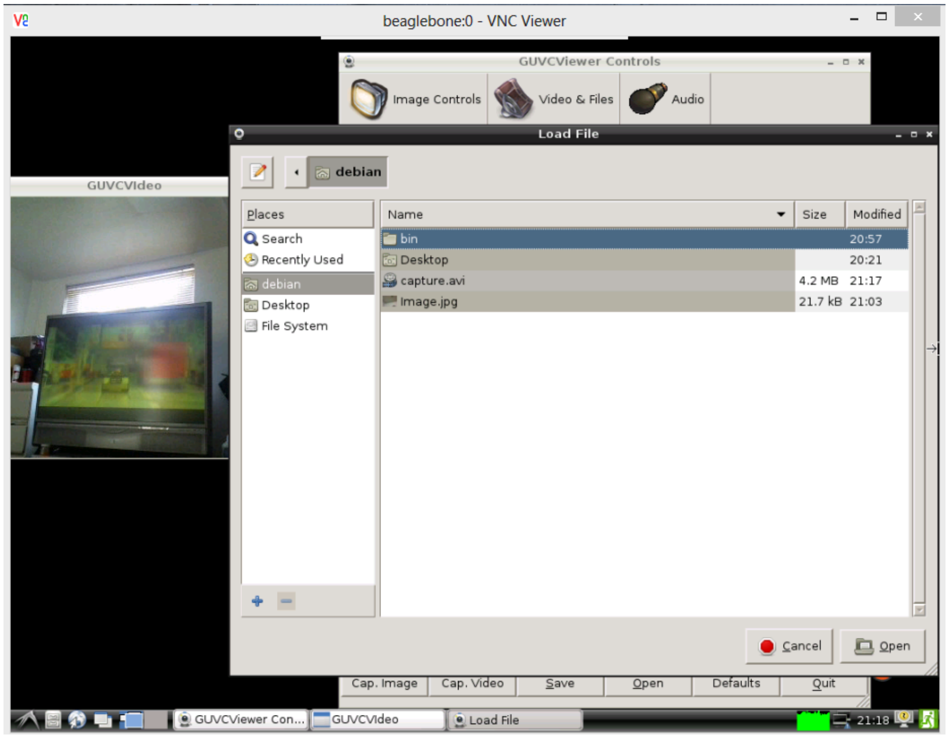


Figure 46 : Guvcview Save Screen

Now it should be noted that when the beagle bone loses power all saved images and video to the debian file are deleted. Therefore in order to prevent any loss of data due to a power loss or a reset of the beagle bone the location of the saved images is saved to an onboard micro-sd card. This is done by using the same gucv view interface and change the save location for both the pictures and videos.

Next, we can see how the temperature sensor is setup using the Python libraries and how the user interfaces is setup. The required items are as follows: one TMP36 sensor, three jumper wires, one breadboard, and one Beagle Bone Black [14]. Once a connection with the beagle bone black is established we run the program under python as shown in Figure 47.

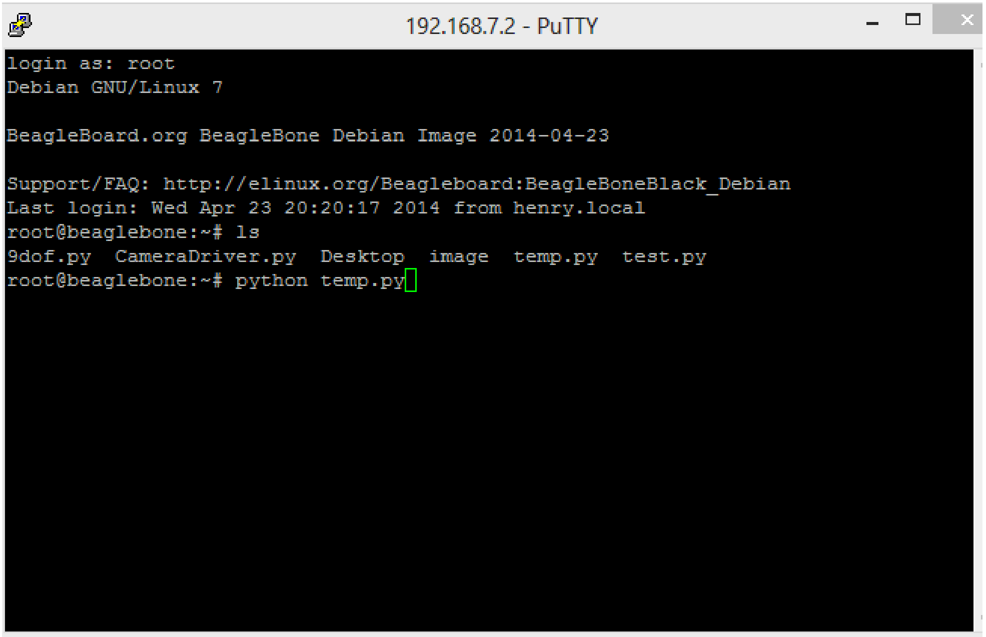


Figure 47: Python Library Callout

The data output for the Beagle Bone black is set at 1 sec interval for demonstration purposes but can be modified if needed as seen in Figure 48.

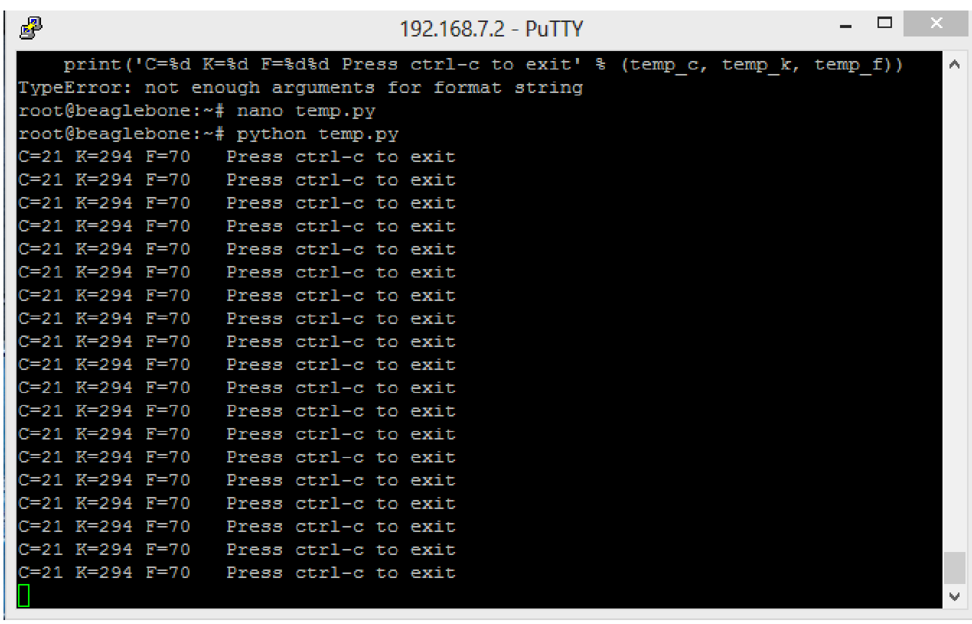
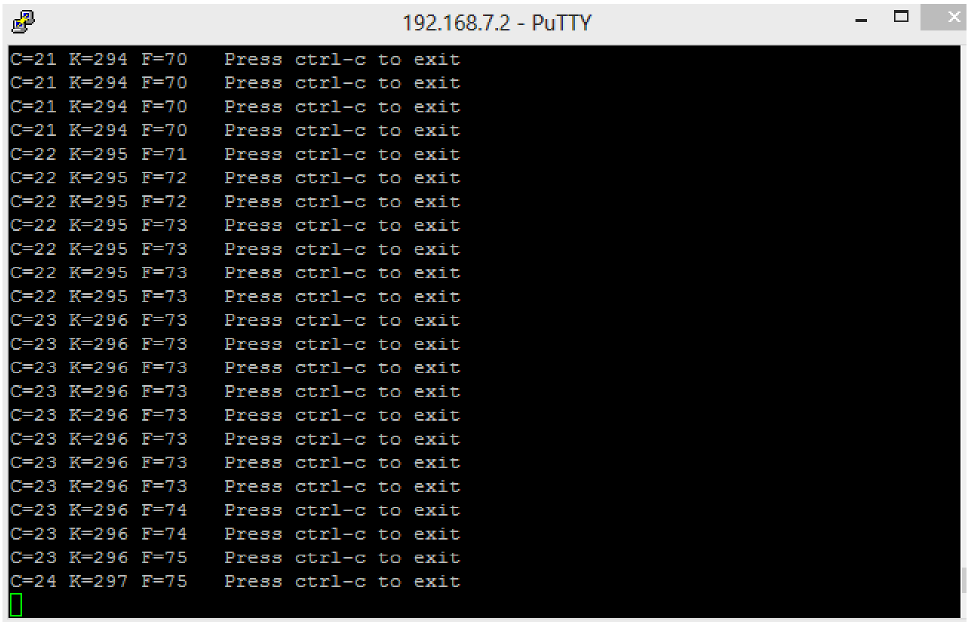


Figure 48 : Temperature Readings

When inducing a temperature change it can be seen that the values change as shown Figure 49, as well as include information as to how to end the program.



```
192.168.7.2 - PuTTY
C=21 K=294 F=70   Press ctrl-c to exit
C=21 K=294 F=70   Press ctrl-c to exit
C=21 K=294 F=70   Press ctrl-c to exit
C=21 K=294 F=70   Press ctrl-c to exit
C=22 K=295 F=71   Press ctrl-c to exit
C=22 K=295 F=72   Press ctrl-c to exit
C=22 K=295 F=72   Press ctrl-c to exit
C=22 K=295 F=73   Press ctrl-c to exit
C=22 K=295 F=73   Press ctrl-c to exit
C=22 K=295 F=73   Press ctrl-c to exit
C=22 K=295 F=73   Press ctrl-c to exit
C=23 K=296 F=73   Press ctrl-c to exit
C=23 K=296 F=73   Press ctrl-c to exit
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C=23 K=296 F=73   Press ctrl-c to exit
C=23 K=296 F=73   Press ctrl-c to exit
C=23 K=296 F=73   Press ctrl-c to exit
C=23 K=296 F=73   Press ctrl-c to exit
C=23 K=296 F=74   Press ctrl-c to exit
C=23 K=296 F=74   Press ctrl-c to exit
C=23 K=296 F=75   Press ctrl-c to exit
C=24 K=297 F=75   Press ctrl-c to exit
```
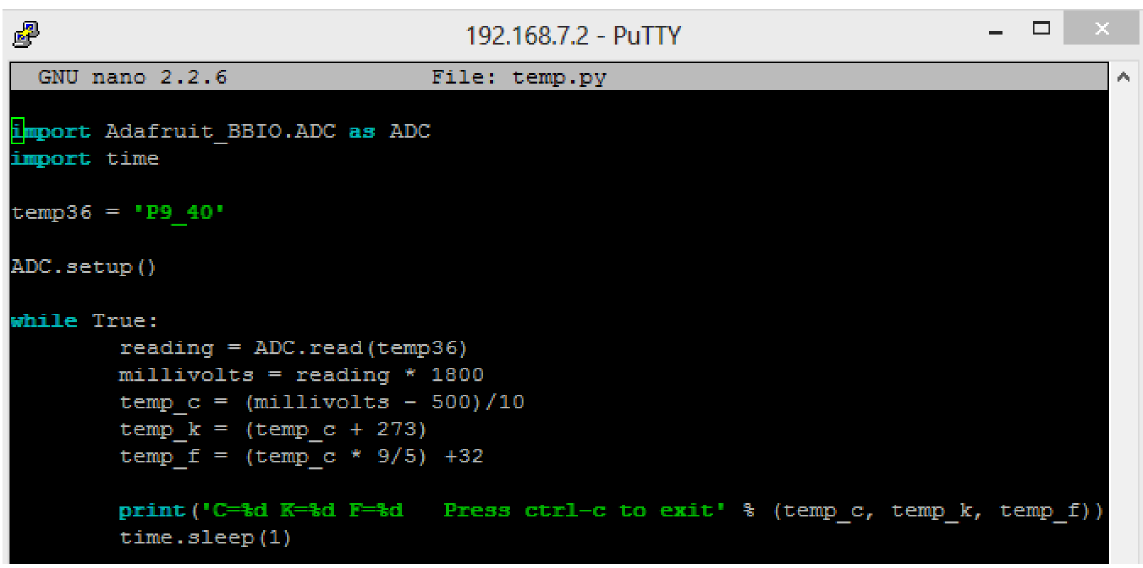

Figure 49:Temperature Readings cont'd

Figure 450 represents the code used in the programming of the TMP36 sensor.



```
192.168.7.2 - PuTTY
  GNU nano 2.2.6                File: temp.py

import Adafruit_BBIO.ADC as ADC
import time

temp36 = 'P9_40'

ADC.setup()

while True:
        reading = ADC.read(temp36)
        millivolts = reading * 1800
        temp_c = (millivolts - 500)/10
        temp_k = (temp_c + 273)
        temp_f = (temp_c * 9/5) +32

        print('C=%d K=%d F=%d   Press ctrl-c to exit' % (temp_c, temp_k, temp_f))
        time.sleep(1)
```

Figure 50 : TMP36 Coding

The next device tested is the 9 Degrees of Freedom (9DOF) razor by spark fun. It is a device that incorporates three different sensors which are an ITG-3200 (MEMS triple-axis gyroscope), an ADXL345 (triple-axis accelerometer), and a HMC5883L (triple-axis magnetometer); these sensors would provide data on the orientation, g-force, and direction of the

CubeSat. In Figure 51 we have the 9DOF Razor attached to a bread board which in turn is connected to respective pins on the Beagle Bone black.

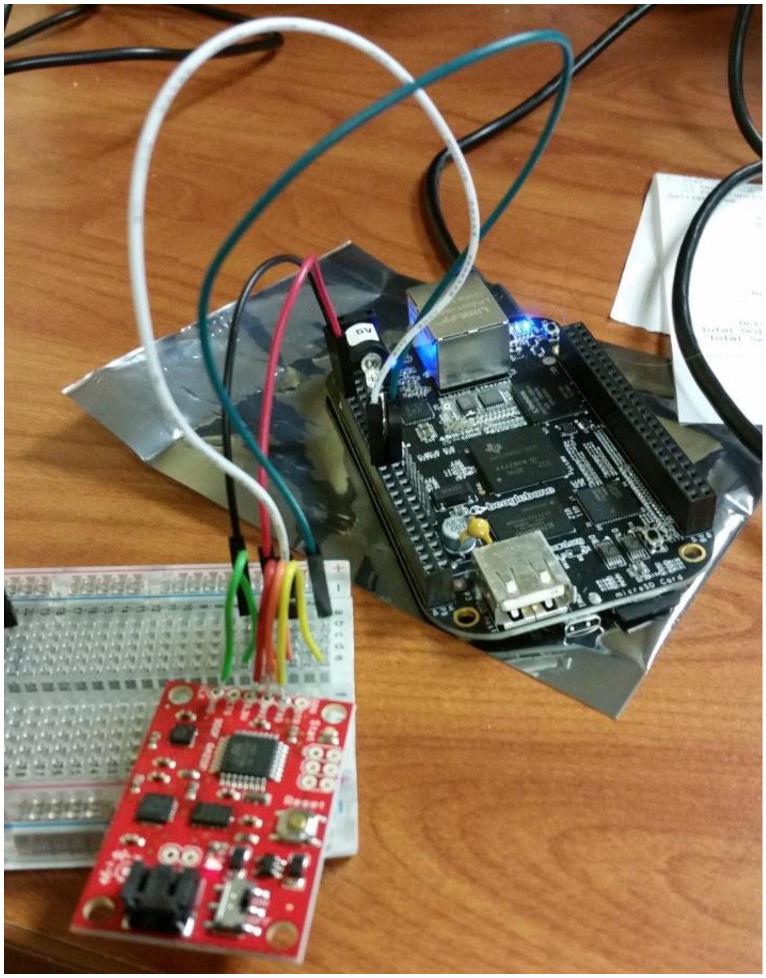
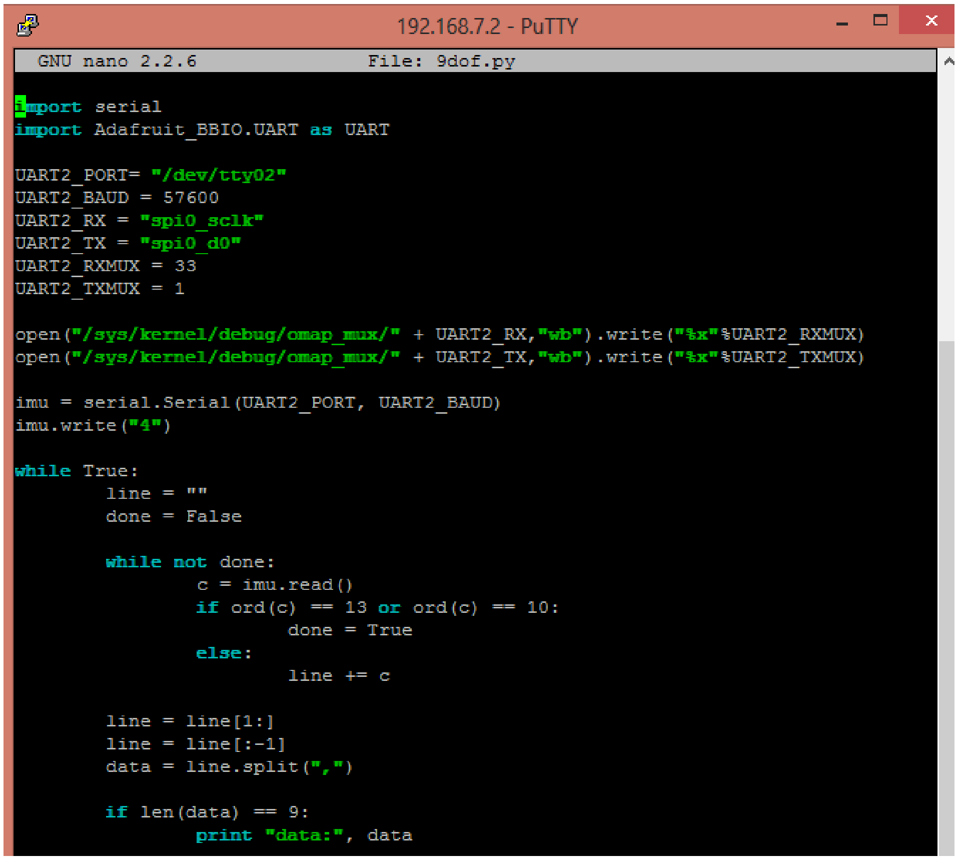


Figure 51: 9 Degrees of Freedom (9DOF) Razor connected to Beagle Bone Black

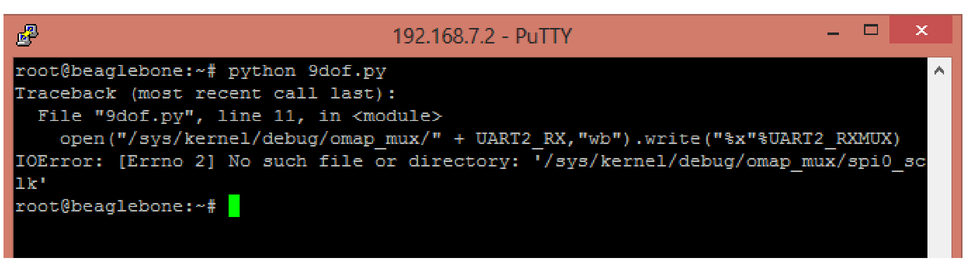
The four wires which are connected are one for 3.3 V input, one to ground, and the remaining two are the data transmitting and receiving wires which are all connected to the Beagle Bone's respective ports. In Figure 52, the following code shows the setup of the pins along with their file directories, while also importing libraries which are required to allow the program to run.



```
192.168.7.2 - PuTTY
GNU nano 2.2.6                File: 9dof.py

import serial
import Adafruit_BBIO.UART as UART

UART2_PORT= "/dev/tty02"
UART2_BAUD = 57600
UART2_RX = "spi0_sclk"
UART2_TX = "spi0_d0"
UART2_RXMUX = 33
UART2_TXMUX = 1

open("/sys/kernel/debug/omap_mux/" + UART2_RX,"wb").write("%x"%UART2_RXMUX)
open("/sys/kernel/debug/omap_mux/" + UART2_TX,"wb").write("%x"%UART2_TXMUX)

imu = serial.Serial(UART2_PORT, UART2_BAUD)
imu.write("4")

while True:
        line = ""
        done = False

        while not done:
                c = imu.read()
                if ord(c) == 13 or ord(c) == 10:
                        done = True
                else:
                        line += c

        line = line[1:]
        line = line[:-1]
        data = line.split(",")

        if len(data) == 9:
                print "data:", data
```

Figure 52: 9DOF programming code

When testing the program the code would be compiles under python and generate values for all nine parameters being measured. But we came across an issue when compiling the code which was the absence of a specific file that contained the information for initiating the Beagle Bone Black's I/O pins as shown.



```
192.168.7.2 - PuTTY
root@beaglebone:~# python 9dof.py
Traceback (most recent call last):
  File "9dof.py", line 11, in <module>
    open("/sys/kernel/debug/omap_mux/" + UART2_RX,"wb").write("%x"%UART2_RXMUX)
IOError: [Errno 2] No such file or directory: '/sys/kernel/debug/omap_mux/spi0_sc
lk'
root@beaglebone:~#
```

Figure 53: Compiled 9DOF code error

After doing some research it was determined that the most recent revision of the beagle bone black lacked the necessary files. The newest revision, which is revision C4, used device trees which would allow the user to set and initiate the pins they wish to use manually rather than automatically activating them. An attempt was made to perform the individual activation of the desired pins but lack of information, experience in programming, and time made it difficult to solve the problem.

14 Complications and Solutions

There are a few deviations from the original solar cells concept. After having contact the solar cells provider, www.spectrolab.com, to get an estimate, it was concluded that the 29.5% NeXT Triple Junction solar cells were significantly overpriced. A minimum purchase order of 5,000 US dollars was required to buy the solar cells. Due to the significant price for the solar cells and the minimum sponsorship in the development of the project, it was recommended to find a different way to provide energy to the satellite. An alternative solar cell was selected for the project. Although the selected solar cells did not have the same properties as the 29.5% NeXT Triple Junction solar cells, it was selected because of its accessibility and design to provide energy to the prototype. However, because of the delay in manufacturing the solar panels will not be mounted at this time. For the scope of the class it will only be mentioned as to what is planned for the initial launch of the final design of the CubeSat.

A new design for the solar sail deployment system was proposed since there are no resources to launch the satellite into space and balloon launching is an alternative. The new solar sail deployment system has been described in the previous sections.

The temperature sensor was another issue that was encountered. The sizing for the original temperature sensors contact points was too small to make a connection between controllers. This is the reason to change to the other analog temperature sensor. The intent of the change was just to show that we had a valid program which could be implemented and modified so as to record temperature at different time intervals. At the time of launch however, the original temperature sensors will be used in conjunction with mini adapters. This is basically a plug and play system where you can actually drop the temperature sensor into the adapter housing and it already has wiring pins built in so that you can attach the leads from the adapter to the Beagle Bone.

15 Conclusions

Over the course of the project, several deviations from the original design were made. Among them were features changed to payload, structural design, sail deployment design and overall function of the CubeSat. It was worth noting that even though the funding and resources were not received from NASA, other alternatives were sought out to get the CubeSat up in the air. The method of balloon launch was by far our best option. With this method, we could conduct our test at an altitude of approximately 50,000 feet for an inexpensive cost when compared to that of a rocket launch.

The structure received some major revisions as well. The sail compartment system was completely eliminated. This is due to the fact the the sail deployment mechanism will now be open to the atmosphere and located at the very bottom of the CubeSat. Two of the sidewalls had been extended to act as a mounting surface for the flanges added. This caused the overall dimensions to change as well as the weight of the structure.

The sailing system received a complete overhaul. It would now be driven by a worm gear and a different stepper motor. The gear system operates in a way that causes the booms to rotate outwards so as to expand the sail. After conducting an analysis on the gears and bearings used, it was determined through AGMA standards that our system would indeed work with the bearings and gears chosen for the design.

Unfortunately, the project was not completed as fully intended with the components that would have like to have been implemented. The budget was a significant aspect into why certain parts were bought. Issues arose also with one of the part suppliers that we ordered. An order was placed for the amplifier where confirmation was received through email and verbally that the order was received and item shipped however the part never arrived. Communication is still in progress with the vendor to get the part priority shipped for the project.

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