Zenodo.pdf

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04/24/2015
Revision D
Revision Log

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<th>Date</th>
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<tr>
<td>A/B</td>
<td>Conceptual and Preliminary Design Review</td>
<td>03/03/2015</td>
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<td>C</td>
<td>Critical Design Review</td>
<td>03/15/2015</td>
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1.0 - Mission Overview

1.1 Mission Statement

Project FOCUS is a part of Gateway to Space and the Edge of Space Sciences balloon flight. The mission of project FOCUS is to develop a camera pointing platform for a BalloonSat that can both passively and actively stabilize itself for maximum quality photos of predetermined locations throughout the flight.

1.2 Mission Overview

Project FOCUS was inspired by watching past students’ videos in Gateway to Space wherein the video imagery had an uncontrollable spin that made the ascent very difficult to observe. The objective of Project FOCUS is to develop a camera orienting system as discussed in the mission statement. The payload shall be able to take a video despite the rotation of the BalloonSat and turbulence encountered in flight. It shall achieve this feat by, first, separating itself from the flight string, while also working to actively dampen the effects of rotation caused by the movement of the entire balloon system, as well as friction with the air. Project FOCUS has created a variety of tests to isolate the individual systems within the BalloonSat, as well as a mission simulation test. This shall be used as both a test of the BalloonSat in mission-simulated conditions, as well as a test of the degree of successful integration within all systems inside the BalloonSat. The design of project FOCUS includes a camera that has not only lateral control, but also longitudinal control through the camera tilt system. The design will also analyze navigational data which will outline precisely where the BalloonSat has gone as well as the route it has taken. This is significant because it will provide a clear account of the whereabouts of the balloon system, thus giving a more accurate account of the video imagery.

Project FOCUS expects to prove that it is possible to create a BalloonSat that can effectively dampen the chaos produced while flying underneath a balloon, and along with that dampening effect, to achieve a stable video of three separate targets. These targets will be hard-coded into the BalloonSat to avoid having to fly a GPS which would be potentially expensive to implement. Project FOCUS expects to receive data from the flight in the form of a stable video. To determine whether or not the flight was successful, project FOCUS will compare the video to both the statements laid out in the requirements flowdown as well as video data from previous teams that have flown cameras in search for video without any attempt to dampen the environmental effects upon the BalloonSat.

Additionally, Project FOCUS could potentially serve as a benchmark to start development on a BalloonSat that could potentially be a part of the Space Grants coalition based
out of Montana State University to study the total solar eclipse in 2017 and provide the general public with a way to monitor the eclipse in real time\(^1\). Total eclipses are fairly rare, with the last one visible from the United States occurring in 1979. Since total solar eclipses are observed in some form by a large portion of the population, it is a great opportunity to increase awareness of astronomical events to the masses by allowing the public to engage in the science being conducted through the Space Grant Consortium. By developing an attitude control and camera orientation system, as well as flight testing it to test validity and gauge effectiveness, Team High Five will be able to contribute a great deal of technical experience to other schools participating in the observation of the solar eclipse. Also, project FOCUS chose to find an inexpensive way to implement a BalloonSat that is capable of taking stable video of the world from 100,000 feet above the Earth’s surface. Normally to take pictures from this altitude, there needs to be a specialized aircraft (such as the SR-71 Blackbird, reaching a maximum altitude of 85,000 feet)\(^2\) to fly in at an altitude that does not support human life. Limited by the cost of sending humans to this altitude (the cost of a single SR-71 Blackbird was an average of $34,000,000)\(^3\), there is no feasible way to reach this altitude. Instead of a person reaching this altitude, though, project FOCUS intends to reach this altitude with simply a balloon and a BalloonSat. With the knowledge received from project FOCUS, anyone can reach this altitude and conduct their own photographic flight on a budget.

During the mission, project FOCUS will collect scientific data in the form of visual video recorded via a camera mounted within the BalloonSat. This visual data will be collected in addition to sensor data from the navigation and C&DH subsystems. To begin, FOCUS will point its camera due West of the launch site in Windsor, CO, toward the Rocky Mountains. The next stage will be to obtain images of Denver, CO. Finally, FOCUS will aim the camera at the sun when sufficient altitude is reached.

These targets will provide a cohesive amount of data that can test the structural validity as well as the functionality of the system. By being able to target multiple objects, Project FOCUS will demonstrate the possibility of having a camera orientation system on future BalloonSats.

2.0 - Requirements Flow down

2.1 Introduction

The Requirements for project FOCUS shall outline a clear expectation for the mission. The requirements stem directly from the mission statement outlined above as well as the Request for Proposal. As part of the mission, the requirements will focus on what the team plans to do. The key objectives project the date of launch, the mission objective, the expectations from data analysis, as well as the RFP requirements. The requirements are pertinent to this mission because it enables the team members to be involved and aware of what the project needs to be successful. Verification of project FOCUS will be assessed by completion of all requirements.

2.2 Flowchart

Level 0 Requirements

<table>
<thead>
<tr>
<th>Level</th>
<th>Requirement</th>
<th>Origin</th>
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<tbody>
<tr>
<td>0.1</td>
<td>Project FOCUS shall be included on a high altitude balloon flight to deliver a payload to an altitude of 30 km on April 11th 2015.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td>0.2</td>
<td>Project FOCUS shall collect video imagery of specified targets.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td>0.3</td>
<td>Project FOCUS shall analyze visual, magnetic, position, and acceleration data to determine the effectiveness of system and any possible adjustments.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td>0.4</td>
<td>Project FOCUS shall meet all requirements laid out in Request for Proposal.</td>
<td>Mission Statement</td>
</tr>
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Level 1 Requirements

<table>
<thead>
<tr>
<th>Level</th>
<th>Requirement</th>
<th>Origin</th>
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<tbody>
<tr>
<td>0.1.1</td>
<td>The Balloon Sat shall be attached to a helium balloon with a flight string running through and shall reach a height of 30 km.</td>
<td>Requirement 0.1</td>
</tr>
<tr>
<td>Level</td>
<td>Requirement 0.2: Project FOCUS shall collect video imagery of specified targets.</td>
<td>Origin</td>
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<tr>
<td>0.2.1</td>
<td>The camera shall be a Canon A3400 to take video imagery of specified targets</td>
<td>Requirement 0.2</td>
</tr>
<tr>
<td>0.2.2</td>
<td>The Balloon Sat shall orient itself via the reaction wheel and servo motor to aim the camera</td>
<td>Requirement 0.2</td>
</tr>
<tr>
<td>0.2.3</td>
<td>The camera shall be able to move longitudinally via a camera tilt sensor run by a motor</td>
<td>Requirement 0.2</td>
</tr>
<tr>
<td>0.2.4</td>
<td>The Balloon Sat shall be connected to an accelerometer which shall be able to locate the Balloon Sat’s position</td>
<td>Requirement 0.2</td>
</tr>
<tr>
<td>0.2.5</td>
<td>The camera shall be equipped with an 8GB SD card in which the video recordings shall be stored</td>
<td>Requirement 0.2</td>
</tr>
<tr>
<td>0.2.6</td>
<td>The camera tilt motor and the servo shall be connected to an Arduino which shall be preprogrammed with predetermined coordinates</td>
<td>Requirement 0.2</td>
</tr>
<tr>
<td>0.2.7</td>
<td>The BalloonSat shall be powered by one 1500 mA lithium polymer battery.</td>
<td>Requirement 0.2</td>
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<tr>
<th>Level</th>
<th>Requirement 0.3: Project FOCUS shall analyze visual, magnetic, position, and acceleration data to determine the effectiveness of system and any possible adjustments.</th>
<th>Origin</th>
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<tbody>
<tr>
<td>0.3.1</td>
<td>Project FOCUS shall analyze data by collecting images off of the SD card and running it in the computer.</td>
<td>Requirement 0.3</td>
</tr>
<tr>
<td>0.3.2</td>
<td>Project FOCUS shall analyze data from the</td>
<td>Requirement 0.3</td>
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environmental sensors by graphing and analyzing the SD card onto Excel

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<tr>
<th>Requirement</th>
<th>Requirement 0.3: Project FOCUS shall analyze the accuracy of the reaction wheel and heading correction by taking data off of the magnetometer.</th>
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<td>Level</td>
<td>Requirement 0.4: Project FOCUS shall meet all requirements laid out in Request for Proposal.</td>
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<tr>
<td>0.4.1</td>
<td>Project FOCUS shall send a camera orienting system that shall be analyzed upon descent</td>
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<tr>
<td>0.4.2</td>
<td>Project FOCUS shall be a reusable system, that will be ready to work after flight</td>
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<tr>
<td>0.4.3</td>
<td>The flight tube used during Project FOCUS shall be an acrylic tube that is rigid and shall go through the center of the Balloon Sat and does not interfere with the flight string</td>
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<tr>
<td>0.4.4</td>
<td>The internal temperature inside the Balloon Sat shall be at -10°C</td>
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<tr>
<td>0.4.5</td>
<td>Total weight shall not exceed 1,300 grams</td>
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<tr>
<td>0.4.6</td>
<td>All Balloon Sats shall have visual indicators on the outside of the flight structure to confirm at launch that the payload is active and running as well as excellent internal wire management as this is the leading cause of failure.</td>
</tr>
<tr>
<td>0.4.7</td>
<td>BalloonSat shall be made of foam core</td>
</tr>
<tr>
<td><strong>3.0 - Design</strong></td>
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| **3.1 Intro** | Project FOCUS will achieve its requirements by a combination of subsystems working in concert. In order to meet launch deadlines and maximize spare time for testing, subsystems will be assembled separately according to initial design specifications. Compatibility of each subsystem will be assessed at each team meeting to avoid complications as the project
progresses. Subsystem leaders will run tests specific to their system to ensure quality and effectiveness, and will communicate with other leads to resolve uncertainties. Once all subsystems are complete they may be integrated and prepared for mission simulation tests. The requirements adhere to the current design by using an efficient easy to build design that will be functional during launch. Requirement 0.1 in the flowchart in section 2.2 requires the team to launch a payload on April 11th. For this requirement to be met the design utilizes mechanisms and resources that are simple and easily available. Using this design the payload will be ready by the requirement date. The design will also meet Requirement 0.2 which refers to the video imagery because the design is based around the camera system that will be held within the balloon sat. The different subsystems sections below will discuss in greater detail how this shall be accomplished. Using the two Arduino Uno microcontrollers provided to the team, programmed with custom code to run various subsystems Requirement 0.3 shall be met. Requirement 0.4 shall be met throughout the entirety of the design, as part of the Gateway to Space class the design shall keep mass, budget and other RFP requirements by making the design as efficient as possible, exact details of each subsystem are discussed below.

3.2 Functional Block Diagram

Within the project there are four subsystems that come together to operate the BalloonSat. System I contains the heater circuit, which will be used to actively heat the internal environment of the BalloonSat. System II contains the camera subsystem, which is responsible to collecting the bulk of the data for the BalloonSat. System III is the RFP required Arduino which will be collecting the requested environmental information and data throughout the course of the flight. System IV contains the hardware that Team High Five has implemented in order to accurately orient and aim the camera subsystem. All these subsystems come together to create the functional parts of the BalloonSat project presented by Team High Five.

As of April 11th 2015 the functional block diagram was updated to reflect the flight setup of the BalloonSat. It was unrealistic to incorporate the GPS and pressure sensor due to code storage on the Arduino Uno. In future flights a microcontroller with more memory should be used. The accelerometer was unnecessary for control and so was unused on the flight. The heater drew 1A current, which over the course of the flight would consume the entire power budget thus it was removed.
3.3 Concept of Operations

The mission will occur on April 11, 2015 at approximately 0700hrs. Prior to the launch date, all construction, programming and testing will be complete. BalloonSat will be loaded with fresh batteries and prepped for launch. On launch day, all switches will be switched on and Team High Five will use LEDs wired in parallel to indicate that all systems are receiving power. LED indicators will also be used to indicate that the SD card on Arduino I is being written to. Upon receiving power the Arduinos will start executing their pre-programmed code, as explained in Figure 3.2.1. At approximately 30km the balloon will burst and the BalloonSat will experience free fall. Data from the barometer will determine that it is the descent phase of the flight, and will cease orientation of the camera to save battery and mitigate risk of damage in a high-acceleration environment. After landing the BalloonSat will be recovered along with all data stored on the SD cards. Finally, the data and video will be analyzed and compared to the expected results.

3.4 Structure

The structure of the BalloonSat will accommodate the camera and will work with the other subsystems to not only keep an appropriate mass, but also to have an efficient amount of space within the structure that will keep the system heated and working. The box will be a cube measuring 200mm per side. These dimensions were carefully chosen to keep the minimum mass while still allowing adequate space for internal components. The structure was made by first designing a net with appropriate allocations for the mechanisms subsystem. This design was subsequently laser cut from 6 mm thick foam board. This ensures accuracy and precision when it comes to the dimensions of the box. A detailed drawing of the net is included below in Figure 3.3.1.
The structures team will work very closely with the mechanisms team to ensure that the system will have enough space to house the different mechanisms. The camera is the main component of the satellite and it is important that the motors and gears that control the lateral and longitudinal movement have enough range of movement within the box. The structure has a half cylindrical structure at the front of the box where the camera will be placed. The cylindrical component is made of foam core. This design is important as it not only saves space from the previous dome design but also gives the servo and motor more range for the camera to move in the vertical direction.

This design is efficient, however keeping the camera heated is one of the issues that will need to be overcome. Thus, the structures team is also working very closely with the thermal team as keeping the structure insulated will be very important. Since the insulation is 1 cm thick, it slightly reduces the overall space within the structure, which is a limitation that can easily be overcome by keeping a constant communication with the mechanism team.

Figure 3.4.1 Structure Net

3.5 Thermal

The thermal subsystem is responsible for the regulation of the internal temperature of the BalloonSat. Thermal will provide the BalloonSat with the provided heater module as well as insulation. These two systems will combine to meet the RFP requirement of maintaining an internal temperature of -10°C throughout the entire flight. The internal temperature is also
regulated to keep all the internal systems functioning properly. For example, the Arduinos in use during this flight have a temperature restriction of -20°C which means that in order for most of the experimental data to be logged and the BalloonSat to rotate properly, an internal temperature of -10°C must be regulated. Another component within the BalloonSat that is subject to the effects of low temperature is the camera. The minimum operating temperature of the camera is 0°C which means the temperature needs to be regulated at higher than the RFP requirement. Based upon data from previous teams, this requirement becomes a guideline as other teams did not have problems with the minimum operating temperature of the camera. This becomes a secondary priority as it has not shown signs of failure in the past.

The thermal subsystem interacts with other subsystems in the BalloonSat in one particular way. They are all connected by the fact that the thermal subsystem is responsible for the regulation of the temperature of the BalloonSat as a whole. For example, thermal will be important in ensuring that all the gaps where mechanisms are working are properly insulated, and making sure that there is still room for internal subsystems.

The biggest challenge within the thermal subsystem is figuring out how to insulate around the camera-cylinder. The way that the camera is positioned within the BalloonSat leaves very little room for insulation, thus this is a large place in which the BalloonSat will not be sheltered from the outside temperatures during flight. To overcome this obstacle, there will be a combination of 1/4” and 1/2” insulation placed within the cylinder itself, as well as providing a “back door” like hinged piece of insulation that will attempt to isolate the entire camera system from the rest of the balloon sat in order to maintain homeostasis. Another challenge insulating the reaction wheel axle. This will be overcome by creating a cone of insulation using consecutively smaller and smaller rings of insulation that will work to close the gap between the axle and the structure, but also leave enough room in between as to not cause friction while the parts are moving.

The limitations of this subsystem depend mostly on two variables. The mass of the insulation as well as the power supply to the heater circuit. The way that the heater circuit is going to limit the entire BalloonSat is through its heat output. The heater circuit cannot be as efficient as possible because of the amount of power that is necessary for it to operate at this temperature. If the heater circuit would take too much power, it would not leave enough power for the rest of the science subsystems to collect data throughout the duration of the flight. The second limitation is with regard to the thermal insulation. To be most effective, the thermal insulation would be as thick as possible. With the mass limit being a real issue, though, there needs to be limitations set on the masses of certain parts of the BalloonSat. One of these limitations is set upon the amount of thermal insulation placed within the BalloonSat because of the nature of the product, and the “return on investment” for increasing amounts of thermal insulation is not as mass-effective as adding other things to the BalloonSat.

In the end, Team High Five decided to remove the active heater system from the BalloonSat in order to preserve both mass and power. The group made this decision because the BalloonSat was over-mass and the temperature requirement of the RFP was decided to be of
lesser importance compared to the other RFP requirements, so the heater was removed. This saved the BalloonSat a total of approximately 100 grams which was enough to move the BalloonSat under the required 1300 gram mass limit. As well as preserving mass, Project FOCUS determined that over the course of the flight, the active heating circuit was drawing 1 A of current, which equates to 1500 mAh over the course of the flight. This sums to half of the total power being flown throughout the flight, which meant there was not enough power toward the end of the flight in order to provide sufficient power to the motor to drive the reaction wheel, which is the purpose of the flight. The only way to be able to fix this would be to add more power, which would mean extra batteries to the BalloonSat, but this move would increase the overall mass of the BalloonSat. Because of these two factors, it was decided to remove the active heater circuit from the BalloonSat.

3.6 Power

The current strategy in terms of power is being able to use batteries that will effectively power all subsystems as well as provide the lightest weight possible, since weight is a most significant challenge. There shall be two 1500mAh batteries connected in parallel that will run through the Arduinos, active heater, and ESC, also connected in parallel. All systems will take the full 12.6 volts from the two batteries without any additional resistors. The ESC shall power the motor by converting 12 volts in direct current to a three phase alternating current with a variable frequency. There is a large demand for power by all of the subsystems especially the motor and heater. In turn, this could lead to weight challenges if bigger batteries are needed to efficiently power the subsystems. Another limitation of the power circuit is that, aside from the ESC, the arduinos, heater, and relays are not voltage protected. This could cause those subsystems to draw voltage from the battery too low; in turn damaging the battery and causing a fire hazard inside the structure.

Before flight the power distribution arrangement was reconfigured. The thermal subsystem team decided to remove the heater and thus relieving the strain on the power system. With this in mind the Arduinos and sensors were wired separately from the motor on 7V DC
from a 2 cell 800mAh LiPo battery. The motor and relay system will be powered by a 12V DC 3 cell 1800mAh LiPo.

3.7 Navigation

The goal of the Navigation subsystem is to determine the position of the BalloonSat, and relay this data to C&DH. From there C&DH will use this data to aim the camera. To obtain this data, Navigation will use two sensors: a magnetometer for heading and a barometer for altitude.

3.7.1 The Magnetometer

The magnetometer that will be fitted to FOCUS is the SEN-10530 module from SparkFun Electronics. The magnetometer adjusts its output according to the orientation of Earth’s magnetic field, creating an electronic compass that can be used to determine where the camera is pointing. This particular sensor uses a type of communication called I²C that utilizes two inputs, a clock line and a data line. To retrieve the proper data from this device the team will use the source code “wire.h” which will return the heading of the BalloonSat in degrees. Due to the fact that the magnetometer will only point to magnetic north the program will need to add the magnetic declination of the BalloonSat’s location, which is about 9° in Windsor, Colorado. The magnetometer will be aligned with the front of the camera to ensure that the data received indicates the camera’s heading.

3.7.2 Unused Instruments

The pressure sensor will be used as FOCUS’s altimeter. This data will be used to determine the current flight stage. The first three flight phases will determine the current target. The final flight stage will stop the reaction wheel from rotating. However the communication interfered with the SD card communication, so the unit was removed from the BalloonSat before flight.

Initially a GPS receiver was used to determine the position of the BalloonSat however, due to memory limitations in the Arduino and communication interference with the SD card, this device was also removed before flight. The GPS was to calculate the distance and heading to a target, so the BalloonSat could self correct during flight.

3.7.3 Final Data

The magnetometer data shall be retrieved in every execution of the Arduino loop. The target heading and approximate tilt angle for the camera for each target will be hard coded into the Arduino’s program. Targets will be switched based on the Arduino’s time stamp.
3.8 Command and Data Handling

Command and Data Handling is responsible for many aspects of the mission, including coding the algorithms for camera orientation and storage of data. All of the C&DH will be run through the Arduino Unos and the camera’s internal system, as described below.

3.8.1 Camera

The camera will be a Canon A3400 IS digital camera. The camera is an essential part of the BalloonSat since it will be taking the video imagery of targets. The stability of the video will aid in determining the success of Project FOCUS. The video will be stored directly onto an SD card mounted inside the camera. The camera will be turned on right before flight and will record video and still images according to presets set on the camera’s SD card, provided by Gateway. The camera will be recording HD imagery (1280x720) at 5 frames per second (See Figure 3.7.1.1).

Figure 3.7.1.1 (Provided by Canon USA)

3.8.2 Arduino I

Arduino I will be the processor interpreting the baseline environmental data as stated in the Request for Proposal. This Arduino will be reading analog data from the pressure sensor, accelerometer, compass, internal thermometer and external thermometer. It will then save this data as a string of comma separated values to the SD card, interfacing through the SD card shield. The Arduino will receive 7V DC power from the power subsystem, and the thermal subsystem will keep it at a safe operating temperature.

3.8.3 Arduino II

Arduino II will be responsible for processing the functions necessary to complete the mission of orienting the camera. This includes taking in analog input from a magnetometer, accelerometer, GPS, and pressure sensor (heading, orientation, position,
and altitude respectively), writing and coding targeting algorithms utilizing the above data, and then communicating commands to the servos and motors controlling the mechanisms. The data from the various sensors will be stored on the SD card. The targeting functions will comprise the primary aspect of the code; the structure is elaborated on below:

3.8.3.1 Target Determination
Each of the predetermined targets will be hard coded in Arduino II. Each target will have a heading and a camera tilt angle associated with it in memory. Logic “if” statements will determine which target is the current target and appropriately set the current target variables.

3.8.3.2 Targeting Algorithm
Targeting is performed continuously while Arduino II is on. Upon set-up the arduino arms the motor by sending it a high, low, high signal. In the setup portion is where all variables are declared and initialized. This keeps the targeting loop’s speed high. Within the void loop() logic statements determine how much time to spend targeting and how much to spend reading the altimeter. The altimeter will be read, and the flight phase checked, once for every 5000 targeting loops. The targeting loop uses closed loop proportional and integral control.

3.8.3.2.1 Target Loop
The target loop uses proportional and integral gains to maintain the correct heading. The two most important variables used in calculation of gains are the difference value itself, and a constant multiplier that allows fine tuning. For each loop the proportional gain is equal to the difference between the current heading and the target heading times the proportional constant. For each loop the integral gain is equal to the sum of the last thirty differences times the integral constant. Once the gains have been calculated they are summed with the minimum motor signal. The addition of a minimum motor signal means greater resolution on the gain settings.

3.8.3.2.2 Tilt Function
The tilt function will send commands to the camera tilt servo. It will accept a desired angle from -30 to 30. Inside the function the desired angle will be scaled to a PWM signal and then written to the servo.
3.8.4 Limitations

There are a few limitations that must be considering the command and data handling. One is storage. The camera’s imagery algorithm is determined based on the amount of storage that will be mounted within the camera. The camera will be equipped with a 4Gb SD card. Team High Five must also consider the amount of storage mounted on the SD card shields, which each have a 2Gb capacity. Arduino II, which records more data, can store 1,791,130 data points in under 10Mb. On a 2GB card Arduino II will be able to record 3.5 billion points of data. Additionally, the rate at which the Arduino must execute the code and run the loop must be relatively high in order to maintain accuracy. Finally, with only 32kb of memory for code on the Arduino it is imperative to write efficient code. This limitation has led project FOCUS to abandon the use of the GPS and accelerometer which were originally intended for flight.

3.9 Mechanisms

Mechanisms play an important role in the FOCUS mission, specifically to orient the camera in the direction of the target. Mechanisms will provide two axes of control—lateral and vertical—referred to as yaw and pitch respectively. Yaw and pitch control will be achieved by the implementation of two systems, a reaction wheel for yaw, and a camera tilt system for pitch. Details of each system can be found below.

3.9.1 Reaction Wheel

The reaction wheel will control the angular position of the structure by conservation of angular momentum. Angular momentum is defined as the product of moment of inertia \( I \), and angular velocity \( \omega \).

\[
\tau = I \times \omega
\]

To rotate the structure torque must be applied. In the reaction wheel system this is achieved by a brushless direct current motor in contact with the drive gear of the reaction wheel. As the angular momentum of the wheel increases, the angular momentum of the structure must decrease equally due to conservation of angular momentum in a closed system. Effectively the structure will rotate opposite to the rotation of the reaction wheel. To apply this to the mission consider two situations. The first scenario is that of acquiring
a target from rest. To point the camera toward the desired heading the motor will run in the desired direction of rotation. This causes the opposite rotation in the reaction wheel and thus the same rotation in the structure. Once the desired heading is achieved the motor will apply the opposite torque to the drive gear until the structure is no longer rotating. In the second scenario the goal is to maintain a heading while external aerodynamic forces torque the structure. In this case the motor applies torque to the drive gear in the same direction as the external torque. The result is that the net torque on the structure is zero, and there is no change in angular velocity for the structure.

It is important to consider the capabilities of this system. They will determine the accuracy with which the camera can be pointed. The brushless motor specified in design has a maximum speed of 13,320 rpm at 11.1 volts. The gear reduction is $13: 200 = 0.065$ or 6.5%, meaning that under maximum voltage and no load the reaction wheel could turn at 865 rpm. Considering that this is the maximum angular velocity of the reaction wheel it is possible to find the maximum angular velocity of the structure for which the reaction wheel can compensate. In the case that the system becomes saturated with angular momentum the reaction wheel will stop and allow friction between the flight tube and the structure to dissipate the accumulated momentum.

3.8.1.1 Maximum Correction Calculations

**Definitions**

$M =$ Mass of reaction wheel

$R =$Radius of Reaction wheel

$L_R =$Maximum angular momentum of reaction wheel

$\omega_R =$Maximum angular velocity of reaction wheel

$I_R =$Moment of inertia of reaction wheel

$m =$ Mass of structure

$r =$ Effective radius of structure

$L_S =$Maximum angular momentum of structure

$\omega_S =$Maximum angular velocity of structure

$I_S =$Moment of inertia of structure

$A =$Mass allowance of BalloonSat

$m = (A - m)$

$I_R = M \times R^2$

$I_S = m \times r^2$

$L_R = (M \times R^2) \times \omega_R$

$L_S = (m \times r^2) \times \omega_S$

Let $L_{R0} = 0 = L_{S0}$

By conservation of momentum

$L_R = -L_S$

$-((A - m) \times R^2) \times \omega_R = \omega_S$

$(1 - \frac{A}{m}) \times (\frac{R}{r})^2 \times \omega_R = \omega_S$

The result of substitution of known values is a function relating maximum correctable angular velocity of the structure to the mass of the structure.
\[
\omega (m) = \left(1 - \frac{1300 g}{m_g}\right) \times \left(\frac{15_{cm}}{12_{cm}}\right)^2 \times \left(\frac{90.6_{rad}}{1_{sec}}\right)
\]

3.9.1.2 Maximum Correction Related to Mass of Structure

A reaction wheel of mass 100 g, paired with a 1200 g structure, would be able to compensate for the structure rotating at -11.8 radians per second, or -112 rpm. Because the speed control is digital and has 256 states, this particular configuration would have control accurate to 0.4375 rpm. This translates to 2.62 degrees per second.

The reaction wheel must be constructed to rotate around the center flight tube, in order to maximize its radius. The rotor will be attached to a hollow axle, through which the flight tube passes, on the exterior of the structure. On the interior side of the axle there will be a drive gear mounted. the axle will be held in place on either side of the drive gear by ball bearings, which are in turn supported by acrylic motor mount arms. The lower of the arms will mount the motor and hold it in contact with the drive gear. The motor mounts will be secured to the corner of the structure to allow for transfer of torque. The motor will be driven by a three cell Lithium Polymer battery, supplying 12 volts. This will be converted to three phase AC current by an electronic speed control, which interprets a pulse width modulation signal from Arduino II.

The reaction wheel system represents a significant load on various systems. It requires mass to be effective, so the supporting structures as well as other systems must remain as light as possible. The brushless motor will require a large amount of energy to operate during the flight. It has a maximum current draw of 17A. Energy is defined by current times time, so the motor will require 1700 mAh per hour of operation at full throttle. The rotor axle must pass through the structure which represents a challenge for the Thermal subsystem.
3.9.1.3 Design Renderings

Isometric View

Side and Front View
Reaction Wheel

275.2475 mm dia.

300.1094 mm dia.

15.875 mm dia.

14.9134 mm rad

11.9617 mm rad

82.9184 mm

60°

Motor Mounts
Camera Tilt Mechanism

Camera Tilt Photo
3.9.2 Camera Tilt Mechanism

Pitch control of the camera will be provided by a camera tilt gimbal. One wall of the structure will have a half-cylinder shape in the center. The camera will be able to rotate within this structure so that it remains insulated, as well as capable of vertical control. A small slit in the outer cylinder will allow the lens to look out from within the structure. A small shield mounted around the lens will make a close fitted seal with the outer cylinder for the length of the slit, thus retaining most warm internal air. The camera gimbal will be linked to a servo by a gear with a 15:25 gear ratio, increasing torque and reducing range of movement. This way the servo may remain unmodified and still accurately control position. The angle of the servo will be determined by a pulse width modulation signal and powered by five volt output of Arduino II.

Some limitations of the camera tilt mechanism include a slow rate of travel, because of the gear reduction ratio. Furthermore the system is limited in maximum angular displacement by the flight tube and reaction wheel axle located in the center of the structure.

3.9.3 Relay System

It is necessary to rotate the reaction wheel in two directions. In order to achieve this capability a relay system will switch two of the three phases of AC power between the ESC and the motor. The relay system is controlled by digital pin 4 of the Arduino. The high 5V signal drives a transistor that is opens a 12V positive voltage to operate the relay coils. Each of the two coils draws approx. 30 mA current. The relay contacts are
rated for 16 A current in order to handle the high current draw of the motor. Across each coil there is a parallel flyback diode to decrease response time.

3.9.4 Mechanisms Interaction with Other Subsystems
The primary interaction of the mechanism subsystem with others will be receiving electronic communication from Command and Data Handling. ArduinoII will send pulse width modulation signals to the Electronic Speed Control (ESC) and Camera Tilt Servo. These signals will control the speed of the motor, as well as the angle of the servo respectively. The Arduino will also send a binary signal to the relays to control motor direction. Mechanisms will return no data to C&DH. Secondary interactions with other subsystems are primarily physical in nature. The reaction wheel and the camera tilt servo represent flaws in the thermal integrity of the system. The reaction wheel in particular draws a lot of current and will strain the power subsystem. Any friction between the rotor and the structure will accumulate angular momentum in the structure. Angular momentum accumulation from friction can be dissipated through friction between the structure and the flight tube.

4.0 - Management

4.1 Introduction
Owen Lyke was elected to be project manager for Project FOCUS. After a brief discussion of strengths, experience and interest, each team member was assigned to lead a subsystem. Additionally, each team member was also assigned to assist the lead of a different subsystem. By having team members serve as both lead and assistant on two separate subsystems, members will have a better understanding of the system as a whole, which will make the system engineering aspect more efficient. Furthermore most subsystem work will be accomplished by the subsystem lead outside of group meeting time. Performing construction and development outside of team time will allow that time to be used for communication and clarification. At team meetings the subsystem leads will discuss any questions or concerns with the appropriate individual. Besides these positions team High Five has also elected Jacob Crouse as Project Treasurer and Tia Basak as the Schedule Manager to distribute the managerial load.
4.2 Team Structure

![Project FOCUS Organization Diagram]

4.3 Subsystem Responsibilities

4.3.1 Navigation
Lead: Alexander Swindell  Asst. Sofia Rae
The Navigation team is responsible for determining the use of the GPS and determining the algorithms necessary for finding the targets. They will work closely with the C&DH team in developing the targeting algorithms.

4.3.2 Structures
Lead: Tia Basak  Asst. Jacob Crouse
The Structures team is responsible for the actual physical structure of the BalloonSat. This includes construction and assembly, as well as working with the foam core used for the body. The Structures team will also work closely with the Mechanisms team to ensure that the mechanisms needed for camera orientation, such as the reaction wheel and camera tilt gimbal, are properly installed.

4.3.3 Mechanisms
Lead: Owen Lyke  Asst. Rishab Gangopadhyay
The Mechanisms team is responsible for developing and constructing the mechanisms for camera orientation. This includes the reaction wheel and camera tilt gimbal. The mechanisms team will also work with the motors and servos that control these systems. They will work closely with the C&DH team to ensure proper communication of commands between the Arduino and motors/servos.
4.3.4 Command and Data Handling
Lead: Rishab Gangopadhyay  Asst. Tia Basak
The C&DH team is responsible for writing the code on the Arduinos to complete mission objectives. This includes writing the algorithms for targeting the camera, code to control servos and motors, and reading in data from analog sensors, as well as storing data and images on various SD cards.

4.3.5 Thermal
Lead: Jacob Crouse  Asst. Owen Lyke
The Thermal team is responsible for using active heater systems and insulation to ensure that the BalloonSat internal temperature remains above the required -10° C. Additionally, the Thermal team will work with the Mechanisms team to ensure that all of the Arduinos, motors, servos, and camera remain at a safe operating temperature.

4.3.6 Power
Lead: Sofia Rae  Asst. Alexander Swindell
The Power team is responsible for ensuring that all systems are supplied with a sufficient amount of power throughout the entirety of the mission. This includes testing batteries and systems to investigate how battery performance is affected by the harsh environment of space, specifically below freezing temperatures.

4.4 Schedule
Team High Five will have a very tight schedule to get the optimum amount of work done in the given amount of time. The schedule outlined below is a very specified date by date outline of what needs to be done when. It will be pertinent to the teams success for each subsystem to stick to the schedule. The schedule does account for unexpected delay by ensuring that the tentative date for the completion of the project is well ahead of the actual weigh in and launch date.

<table>
<thead>
<tr>
<th>Date</th>
<th>To Do</th>
<th>Subsystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/9/15</td>
<td>· Proposal Due (8:00 AM)</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td>· Start Finalizing Design</td>
<td></td>
</tr>
<tr>
<td>2/13/15</td>
<td>· Homework 6 DUE</td>
<td>Structures</td>
</tr>
<tr>
<td></td>
<td>· Have complete Design done along with a CAD design</td>
<td>Mechanisms</td>
</tr>
<tr>
<td>2/16/15</td>
<td>· Start Building: Reaction Wheel, Sat Cube etc.</td>
<td>(All):</td>
</tr>
<tr>
<td>Date</td>
<td>Tasks</td>
<td>Notes</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>2/20/15</td>
<td>· Start Programming the Arduinos &lt;br&gt; · Work on Homework 7/8 &lt;br&gt; · Order Hardware Parts and sensors needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>2/23/15</strong> &lt;br&gt; · Work on DD Rev A/B &lt;br&gt; · Start on PDR Presentation &lt;br&gt; · Program Arduino Uno (System 1 and System 2)</td>
<td>(All) -C&amp;DH</td>
</tr>
<tr>
<td></td>
<td><strong>2/27/15</strong> &lt;br&gt; · Finish Building everything that does not need parts from outside (Sat Cube, Reaction Wheel, Arduinos programming done)</td>
<td>-Mechanisms &lt;br&gt;-Structures &lt;br&gt;-C&amp;DH</td>
</tr>
<tr>
<td></td>
<td><strong>3/2/15</strong> &lt;br&gt; · Finalize PDR Presentation &lt;br&gt; · Finalize DD REV A/B &lt;br&gt; · Max Date that Parts should arrive by &lt;br&gt; · Start Assembling the Camera Tilt Servo &lt;br&gt; · Start coordinating power source and heater elements</td>
<td>-Mechanisms &lt;br&gt;-Power &lt;br&gt;-Thermal &lt;br&gt;-Navigation</td>
</tr>
<tr>
<td></td>
<td><strong>3/3/15</strong> &lt;br&gt; · <strong>PRELIMINARY DESIGN REVIEW DUE</strong> &lt;br&gt; · <strong>DD REV A/B DUE</strong></td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td><strong>3/6/15</strong> &lt;br&gt; · Work on DD Rev C</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td><strong>3/9/15</strong> &lt;br&gt; · Start coordinating between the subsystems (Ex. Software make sure that the corresponding hardware works) &lt;br&gt; · Put heater and compass in the balloon sat And Test + All sensors</td>
<td>-Navigation &lt;br&gt;-Thermal &lt;br&gt;-C&amp;DH &lt;br&gt;-power</td>
</tr>
<tr>
<td></td>
<td><strong>3/13/15</strong> &lt;br&gt; · Finalize all of the Building: Any last minute problems must be addressed today</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td><strong>3/16/15</strong> &lt;br&gt; · <strong>ALL BUILDING FINISHED</strong></td>
<td>(ALL)</td>
</tr>
<tr>
<td></td>
<td><strong>3/19/15</strong> &lt;br&gt; · In Class Work Time: Start Testing &lt;br&gt; · Continue all Programming</td>
<td>-Structures &lt;br&gt;-Mechanism &lt;br&gt;-C&amp;DH</td>
</tr>
<tr>
<td></td>
<td><strong>3/20/15</strong> &lt;br&gt; · Work on DD Rev C &lt;br&gt; · Testing: Whip Test</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td><strong>3/30/15</strong> &lt;br&gt; · Testing: Motor Testing the Camera and Sensors</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td><strong>4/3/15</strong> &lt;br&gt; · Finalize all of the Testing</td>
<td>(All)</td>
</tr>
<tr>
<td>Date</td>
<td>Tasks</td>
<td>Assignees</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>4/6/15</td>
<td>- All testing should be finished by the end of the day</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td>- Work on LRR Presentation</td>
<td></td>
</tr>
<tr>
<td>4/7/15</td>
<td>- All Testing and everything must be ready to go</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td>- Finish DD Rev C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Finish LRR Presentation</td>
<td></td>
</tr>
<tr>
<td>4/9/15</td>
<td>- LRR PRESENTATION</td>
<td>(All)</td>
</tr>
<tr>
<td>4/10/15</td>
<td>- Final Balloon Sat Weigh in</td>
<td>(All)</td>
</tr>
<tr>
<td>4/11/15</td>
<td>- LAUNCH DAY</td>
<td>(All)</td>
</tr>
<tr>
<td>4/13/15</td>
<td>- Work on DD Rev D</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td>- Work on Presentations DUE (4/16/15—7:00AM)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Analyze Flight Data</td>
<td></td>
</tr>
<tr>
<td>4/20/15</td>
<td>- Work on Final Presentation</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td>- Work on DD Rev D</td>
<td></td>
</tr>
<tr>
<td>4/24/15</td>
<td>- Work on Final Presentation</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td>- Work on DD Rev D</td>
<td></td>
</tr>
<tr>
<td>4/25/15</td>
<td>- 1st Draft DD Rev D DUE</td>
<td>(All)</td>
</tr>
<tr>
<td>4/28/15</td>
<td>- FINAL PRESENTATION DUE</td>
<td>(ALL)</td>
</tr>
<tr>
<td>4/30/15</td>
<td>- All Hardware parts DUE</td>
<td>(All)</td>
</tr>
<tr>
<td></td>
<td>- Work on DD Rev D</td>
<td></td>
</tr>
<tr>
<td>5/5/15</td>
<td>- DD Rev D DUE</td>
<td>(All)</td>
</tr>
<tr>
<td>5/5/15</td>
<td>- Celebrate</td>
<td>(All)</td>
</tr>
</tbody>
</table>

4.4.1 Schedule Review

The team fell behind schedule after the 4/3/15 date. The schedule specified that all testing shall have been completed by the end of the day. Testing continued until the end of 4/9/15. The effect was that the buffer week was utilized for systems integration and testing, leaving little time to produce documents such as the LRR and DD Rev C as well as rushing final testing.
5.0 - Budget

5.1 Introduction

All purchases, mass, and power requirements have been organized into three separate tables. The materials budget focuses on the financial budget of the team attempting to stay under the maximum given amount. In addition to the total cost of each material, there is a table for the mass of each item. This ensures the team is conscious of the mass limitations of the BalloonSat. Because of changes in the amount of total mass flying on the balloon string, project FOCUS has been granted an additional 300 grams to create the BalloonSat. This means that project FOCUS should have a final mass of 1300 grams or under. Finally, the power budget allows the team to effectively calculate the power consumption of each electronic device. The team shall then brainstorm ways in which to power all subsystems in the most efficient way.

The scope of this project required expenses that went beyond the available budget. In the materials budget items in orange are materials that were covered by the team collectively.

5.2 Materials Budget

<table>
<thead>
<tr>
<th>Name</th>
<th>Part ID</th>
<th>Quantity</th>
<th>Total Cost ($)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude/Pressure Sensor Breakout</td>
<td>SEN-11084</td>
<td>1</td>
<td>$14.95</td>
<td>Sparkfun</td>
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<tr>
<td>Arduino Stackable Header 8-pin</td>
<td>PRT-09279</td>
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<td>$2.00</td>
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<td>Triple Axis Accelerometer</td>
<td>SEN-10955</td>
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<td>$9.95</td>
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<tr>
<td>Triple Axis Magnetometer</td>
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<td>$39.95</td>
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<tr>
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<tr>
<td>NTM 28 mm 1200kv BLDC</td>
<td>NTM2826-1200</td>
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<td>$15.97</td>
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<tr>
<td>HobbyKing 30A ESC</td>
<td>F-30A</td>
<td>1</td>
<td>$10.78</td>
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<tr>
<td>Turnigy 1500 mAh LiPo 3S Battery</td>
<td>T1500.3S.20</td>
<td>2</td>
<td>$20.10</td>
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<tr>
<td>Turnigy 380 mg Servo</td>
<td>BMS-380MG</td>
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<td>$13.95</td>
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<tr>
<td>Acrylic Parts</td>
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<td></td>
<td>$5.50</td>
<td>McGuckins</td>
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<tr>
<td>Reaction Wheel Rotor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive Gear</td>
<td>N/A</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


| Camera Tilt Gears | N/A | 4 | “” |
| Motor Mount | N/A | 1 | “” |
| PVC ½” ID | N/A | 1 | “” |
| Foam Core Parts | N/A | 5 | N/A |
| Panel 200x200 mm | N/A | 1 | “” |
| Panel w/ Cut Out | N/A | 2 | “” |
| Camera Holder | N/A | 1 | “” |
| Camera Lens Cover | N/A | 2 | “” |
| Cylinder Ends | N/A | 1 | “” |
| Cylinder Wall | N/A | 1 | “” |
| Canon A3400 Digital Camera | A3400 | 1 | N/A |
| Thrust Bearing | N/A | 1 | N/A |
| 13 Tooth Pinion Gear | N/A | 1 | N/A |
| Motor / Axle Assembly | N/A | 2 | $6.00 |
| Brass Bushings | N/A | 1 | McGuckins |
| Motor Mount Hardware | N/A | 1 | Team |
| 13 Tooth Pinion Gear 3mm ID | N/A | 1 | Team |
| Motor Switching Relay Parts | N/A | 2 | $6.50 |
| Omron G5LE-1-E-36 (Z3109-ND) | N/A | 2 | DigiKey |
| 2N3904 Transistor | N/A | 2 | ITLL Tim May |
| Flyback Diode | N/A | 2 | ITLL Tim May |
| 480 Ohm Resistor | N/A | 2 | ITLL Tim May |
| Shipping and Handling | N/A | 2 | $22 |
| Spares | HKz30A | 1 | $32.67 |
| ESC - Magic Blue Smoked | | | Assorted |
| (Allotted) | | | |
| Testing / Spares | 45 lbs | $45 |
| Dry Ice | | | King Soopers |
| Batteries | | $40 | Colpar Hobbies |
| Total | | $225.00 |

### 5.3 Mass Budget

<table>
<thead>
<tr>
<th>Name</th>
<th>Quantity</th>
<th>Total Mass (g)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude/Pressure Sensor Breakout</td>
<td>1</td>
<td>1.6 g</td>
<td>Sparkfun</td>
</tr>
<tr>
<td>Name</td>
<td>Count</td>
<td>Weight (g)</td>
<td>Supplier</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-------</td>
<td>------------</td>
<td>-------------------</td>
</tr>
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<td>Arduino Stackable Header 8-pin</td>
<td>2</td>
<td>0.04</td>
<td>Sparkfun</td>
</tr>
<tr>
<td>Arduino Stackable Header 6-pin</td>
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<td>0.03</td>
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<tr>
<td>Triple Axis Magnetometer</td>
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<td>1.6</td>
<td>Sparkfun</td>
</tr>
<tr>
<td>GPS Receiver</td>
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<td>15.2</td>
<td>Sparkfun</td>
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<td>Arduino GPS Shield</td>
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<td>14.3</td>
<td>Sparkfun</td>
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<td>54.4</td>
<td>HobbyKing</td>
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<tr>
<td>HobbyKing 30A ESC</td>
<td>1</td>
<td>32.0</td>
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</tr>
<tr>
<td>Turnigy 1500 mAh LiPo 3S Battery</td>
<td>2</td>
<td>248.0</td>
<td>HobbyKing</td>
</tr>
<tr>
<td>Turnigy 380 mg Servo</td>
<td>1</td>
<td>15.6</td>
<td>HobbyKing</td>
</tr>
<tr>
<td>Reaction Wheel Rotor</td>
<td>1</td>
<td>71.8</td>
<td>Scrap Acrylic</td>
</tr>
<tr>
<td>Drive Gear</td>
<td>1</td>
<td>20.4</td>
<td>Scrap Acrylic</td>
</tr>
<tr>
<td>Camera Tilt Gears</td>
<td>1</td>
<td>10.0</td>
<td>Scrap Acrylic</td>
</tr>
<tr>
<td>Foam Core Panel 200x200 mm</td>
<td>6</td>
<td>147.6</td>
<td>Gateway</td>
</tr>
<tr>
<td>Canon A3400 Digital Camera</td>
<td>1</td>
<td>145.0</td>
<td>Gateway</td>
</tr>
<tr>
<td>Thrust Bearing</td>
<td>1</td>
<td>18.3</td>
<td>Team</td>
</tr>
<tr>
<td>13 Tooth Pinion Gear</td>
<td>1</td>
<td>2.8</td>
<td>Team</td>
</tr>
<tr>
<td>Motor Mounting Hardware</td>
<td>1</td>
<td>11.7</td>
<td>Team</td>
</tr>
<tr>
<td>Brass Bushings</td>
<td>2</td>
<td>25.4</td>
<td>Team</td>
</tr>
<tr>
<td>Glue, Al Tape, Flight Tube</td>
<td>N/A</td>
<td>~45.0</td>
<td>Gateway</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1348 g</strong></td>
<td></td>
</tr>
</tbody>
</table>

### 5.4 Power Budget

<table>
<thead>
<tr>
<th>Name</th>
<th>Voltage</th>
<th>Current Draw</th>
<th>Estimated Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servo</td>
<td>5V</td>
<td>1 A</td>
<td>500 mAh</td>
</tr>
<tr>
<td>Arduino Uno</td>
<td>5V</td>
<td>80 mA</td>
<td>240 mAh</td>
</tr>
<tr>
<td>Component</td>
<td>Voltage</td>
<td>Current</td>
<td>Capacity</td>
</tr>
<tr>
<td>------------------</td>
<td>---------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>Active Heater</td>
<td>9V</td>
<td>300 mA</td>
<td>450 mAh</td>
</tr>
<tr>
<td>Compass</td>
<td>5V</td>
<td>500 µA</td>
<td>0.75 mAh</td>
</tr>
<tr>
<td>Pressure Sensor</td>
<td>5V</td>
<td>600 µA</td>
<td>0.90 mAh</td>
</tr>
<tr>
<td>GPS</td>
<td>5V</td>
<td>70 mA</td>
<td>105 mAh</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>5V</td>
<td>500 µA</td>
<td>0.75 mAh</td>
</tr>
<tr>
<td>Motor</td>
<td>12V</td>
<td>17 A</td>
<td>3000 mAh</td>
</tr>
<tr>
<td>Camera</td>
<td>3.6V</td>
<td>82 mA</td>
<td>123 mAh</td>
</tr>
<tr>
<td>Relays</td>
<td>12V</td>
<td>60 mA</td>
<td>180 mAh</td>
</tr>
<tr>
<td>LiPo 3s</td>
<td>12V</td>
<td>-17060 mA</td>
<td>-1800 mAh</td>
</tr>
<tr>
<td>LiPo 2s</td>
<td>7V</td>
<td>-2000 mA</td>
<td>-800 mAh</td>
</tr>
<tr>
<td>Li-Ion (Camera)</td>
<td>3.6V</td>
<td>-82 mA</td>
<td>-1100 mAh</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.0 mA</td>
<td>450.4 mAh</td>
<td></td>
</tr>
</tbody>
</table>

### 6.0 - Testing

#### 6.1 Structural Tests
- All Structural tests will be conducted with mass simulators
- Drop Test: The structure will be dropped from a height of 9 meters onto a hard surface, which will test impact survivability at 13.28 m/s (~30 mph)
- Bounce Test: The structure will be launched down a set of stairs to simulate intense shock from being dragged or bounced across the ground at high velocity.
- Whip Test: The structure will be attached to a rope through the center tube and whipped around by a team member at high velocity, and will also be subject to large magnitudes of angular acceleration. This test will simulate the high G forces that the BalloonSat will undergo after burst.

#### 6.2 Temperature Test
- The BalloonSat with all structural, electronic and mechanical components will be placed in a cooler filled with dry ice to simulate the -80°C temperatures that the BalloonSat will be subject to during flight. All systems will be running, and the stabilization system will run a simulated
flight plan, to test power consumption at temperature. The test will last for three hours to ensure that the BalloonSat will remain functional for the duration of the flight.
○ In order to verify the functioning of the stabilization system during the test, there will be a small hole cut into the surface of the top plate of the cooler, and on that hole a camera will be placed in order to monitor what is happening during the test. To ensure that this doesn’t interfere with the internal environment within the cooler, the hole will be insulated with foam.

6.3 Orientation Test
○ The BalloonSat will be suspended by the flight string and be programmed to aim at a set of 6 targets for 5 minutes each. During the test, team members will apply forces to the structure to simulate the forces of flight. This test will evaluate the functionality of the tilt and rotation mechanisms, as well as the effectiveness of the orientation algorithms.
○ After this initial orientation test, there will be a secondary test. This secondary test will consist of the same parameters as the first test, but instead of the system being stable while rotating to its 6 different targets, the system will be physically moved (both in the vertical and horizontal directions) through the duration of the test. This will test the GPS system along with the magnetometer to make sure that they will properly feed information to the camera and rotor systems to ensure proper targeting.

6.4 Camera/Servo Test
○ In order to test the individual camera/servo system, the group will conduct a test with this system isolated from the rest of the BalloonSat. With only the key functional parts to this subsystems under observations, accurate measurements and understandings will be drawn that pertain to only this subsystem. In order to conduct the test, the servo will be sent code which will cause it to rotate the camera to a list of pre-determined angles to test both the accuracy of the servo and the limitations of the camera as it is being rotated.

6.5 Mission Simulation
○ The functional test will ensure that the BalloonSat will be able to fulfill the mission with all factors simulated. The BalloonSat will be suspended by a rope in a cooler filled with dry ice and programmed to orient towards 6 directions for 20 minutes each. The BalloonSat will be pushed at random intervals by a member of the team to test the self-correction algorithms. All components will be functioning to the fullest degree. This test will ensure that all mechanical and electrical systems will work effectively in cold temperatures, that the battery load will be sufficient, and that the algorithms are programmed correctly. The goal of this simulation should be to make sure that the BalloonSat is ready for launch day.

6.6 Test Results

6.6.1 Structural Testing
To ensure the proper stability and capability of the payload Team High conducted various structural tests to verify that the Balloon Sat will be able to handle the conditions during launch. The first test that was conducted was a whip test where a team member connected the BalloonSat to a flight string and for 3-4 minutes whipped the satellite with a decent amount of force. This test was successful as there was no damage to the internal or external structure of the box. Figure 6.6.1.1 shows a team member conducting this test.

The next test that was conducted to ensure the stability of the structure was a stair test. During this test a team member went to the top of a flight of stairs and kicked the box down. There were minor dents but overall the box remained intact. The last structural test that was conducted was the drop test. The BalloonSat was dropped from a 2 story ledge, from this test, the Balloon Sat did receive some significant damage. One corner of the Balloon Sat was partially crushed and mildly deformed. From the structural testing Team High Five can conclude that the BalloonSat is strong enough to handle the impact during launch. The figure below is from the structural test after the drop test.

6.6.2 Cold Test and Mission Simulation
To understand the full capability of the BalloonSat and the camera orienting system, Team High Five conducted two mission simulation tests each having improvements taken from the previous tests to improve upon the experiment and data. The first simulation test that was conducted was fairly successful. In order to have mission simulation, the team acquired a large cooler that was able to encompass the entire satellite and have enough room for the reaction wheel to spin and orient the box. The figure below shows the cooler in which the tests were conducted.

This means that the code was running during the cold test. The repercussions that were associated with this cold test was that the cooler was too large and the temperature did not drop to -40°C as expected. Instead the temperature on the outside only dropped to about 60°F. However the inside temperature of the box did reach a maximum temperature of 120°F which gives a delta Temperature of about 60°. From this data it can be speculated that the box will remain at the RFP requirement of 10°C if the outside temperature is at -40°C. The figure below is the actual temperature data taken from the first cold test.

Data was also taken from the accelerometer and the humidity and pressure sensor. From these sensors it is clear that they are in working order and ready to fly. The pressure sensor is shown to have no change which is logical because there was no change in altitude. There is steady decrease in humidity, which also shows that the data was correctly recorded. The accelerometer data...
shows increments where there is a lot of movement and then the graph is unmoving and flat. This indicates that the camera was successful in finding the predetermined target which during the flight simulation was heading 178.45°. During the mission simulation one team member would constantly turn the box to simulate how the camera will find the target.

The battery did run out during the first cold test after 1 hour and 6 minutes. There was one lithium polymer battery running during the mission simulation. From this data the team gathered that in the next mission simulation two batteries must be tested. This will ensure that there is enough power to run during the course of the entire mission. However, the downside to this is that the structure becomes over mass and budgeting that is going to be very difficult. During the second cold test and mission simulation many things were changed to accommodate for the mistakes in the first mission simulation. Although the team was not able to chart the data, during the second cold test the amount of dry ice that was used was increased to simulate the cold temperatures. In the process, two of the lithium polymer batteries were damaged and new ones had to be acquired. During this mission simulation however the system was powered for 2 hours and 40 minutes which is a large improvement from the first simulation.

7.0 - Expected Results
Project FOCUS is expected to prove a feasible system for aiming an optical device throughout a BalloonSat flight. Upon liftoff, the stabilization system will maintain a lateral heading facing due west for the first 3,000 meters of vertical ascent. Once the BalloonSat has achieved an altitude of 3,000 meters the system will re-orient to targeting Denver, CO which will provide a test of the vertical camera tilt system. Finally at 20,000 meters the system will perform its main function by focusing on the sun.

Team High Five expects to receive accurate and stable video and images from the BalloonSat camera. Whether or not the video will be deemed accurate and stable will depend on if the video meets the precise specifications laid out in the requirement flow down. However, the results will also be clarified by analyzing the navigational data from the Arduino’s SD cards. In accordance with the FOCUS mission objectives, Team High Five will analyze the overall stability of the image, whether the correct targets are chosen, that the system successfully switches targets, and that the correct heading is maintained accurately. This analysis will be conducted with the requirement flowdown specifications in mind. Also the team expects to find that there was sufficient battery power and that the internal BalloonSat structure will remain intact. The external reaction wheel has been designed to be easily replaceable, and has not been designed to withstand the landing, mostly due to mass restrictions. The internal temperature data will show that the BalloonSat maintained an internal temperature of -10°C, as a result of both the active (active heater circuit) and passive (thermal insulation) heating systems within the BalloonSat.

It is expected that Team High Five expects the first section of footage will show the Rocky Mountains as the BalloonSat first ascends, maintaining a due west heading. This is when aerodynamic forces will be at their maximum, and will test the yaw compensation algorithms the most. Then the camera should tilt down and aim southwest toward the city of Denver. This will test the precision of the camera tilt servo. This portion of flight data will be subject to weather conditions, namely cloud cover. If there is an abundance of clouds, it may be impossible to determine where the camera is pointing. To analyze this section of the flight, it may be necessary to rely solely on the sensor and navigational data. Finally the FOCUS system will orient the camera toward the sun, which will be shown in the video data.

The course of the BalloonSat will be mapped to show how the camera tilt system and reaction wheel adjusted to changes in altitude and external forces such as the rotation of the BalloonSat due to wind, friction with the air, and motion created on the flight string by the other Balloon Sats. The sensors will record the heading and camera tilt degree. The heading should remain stable until the BalloonSat reaches the altitude where it is directed to change. The reaction wheel should also be constantly making small adjustments to maintain the current heading, therefore the magnetic heading should oscillate minimally around the target heading.

Because team High Five’s goal is to develop a working stabilization system, error analysis will be the most important part of FOCUS’s post-flight analysis. To check for errors, team High Five will model the flight path, the magnetometer data. The necessary tilt angle and orientation angle will then be calculated post-flight, and compared to the recorded servo and
reaction wheel data. The team will then take these results and determine if refinements need to be made to the FOCUS system. These adjustments could be anything from altering battery power and flow, refining the mechanical system or adjusting the targeting algorithms. Below is some example code from the magnetometer and accelerometer.

The results from the environmental sensors are expected to look similar to the mission simulation data. These will indicate if each sensor worked during the mission and provide the team with substantial data that will be analyzed after the mission. The images from the camera will also be another source for data analysis. After the launch and recovery Team High Five expects to have concrete images that will indicate whether the targeting system on the camera has worked or not.

8.0 - Launch and Recovery

8.1 Intro

It is important to outline a clear procedure to follow on launch day to ensure that quality data can be retrieved. Deviating from the procedure could result in no data retrieval at all in the case of failure to power on, misinterpreted data in the case of damaged sensors, to mission failure due to failure of critical components. Outlined below are the procedures operations that the team must adhere to during launch.
8.2 Launch Overview

On launch day, Jacob Crouse has been designated by the team to be responsible for the launch process of the BalloonSat. This responsibility entails making sure the camera is on and recording before launch, as well as ensuring that the motor for the reaction wheel is connected to the power circuit. Also, Jacob Crouse will be responsible for the verification of power throughout the BalloonSat just before launch. During recovery, the goal is to include all of Team High Five on the recovery team. To be able to achieve this, Rishab Gangopadhyay and Owen Lyke will be driving their cars to make sure that the entire team will be able to both make it to launch as well as to the recovery of the BalloonSat.

As the recovery team approaches the fallen BalloonSat, Alex Swindell will be responsible for taking pictures of the wreckage, making sure to take pictures of the BalloonSat as it has landed, as well as all six sides of the structure before any other action is performed. After this action is completed, one side of the BalloonSat will be removed and before any internal tampering is done, Alex Swindell will again be sure to document the state of the internals of the BalloonSat before any further investigating will be initiated. After the BalloonSat is recovered by Owen Lyke and all the necessary pictures have been taken to document the status of the internals and the externals of the BalloonSat, Owen Lyke will then remove the SD cards from their respective SHIELD’s, and will hold onto these SD cards until team High Five makes it back to CU in order to inspect and analyze the data from the flight. In order to view this data, the SD cards will be placed into a laptop that belongs to Team High Five, and from there, the flight data will be distributed via Google Drive to each group member in order to create backups of the data. This practice has been tested many times throughout the course of the project and has been verified to work on multiple occasions.

8.3 Launch Procedure

It is imperative to follow a specific start up sequence for the the systems aboard Project FOCUS in order to avoid damage to critical components. In order for the success of the mission and the safety of the team the following start up procedure must be followed completely and in the correct order.

8.3.1 Launch Day Checklist

<table>
<thead>
<tr>
<th>Mission Time</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-03:00:00</td>
<td>Fit all components, ensure proper connections, ensure space for camera movement.</td>
</tr>
<tr>
<td>T-01:00:00</td>
<td>Arrive at launch site</td>
</tr>
</tbody>
</table>
8.3.2 System Power Sequence

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-00:00:00</td>
<td>Launch</td>
</tr>
<tr>
<td>T-00:03:00</td>
<td>Start up systems in proper order according to below table, ensure proper function by rotating</td>
</tr>
<tr>
<td>T-00:10:00</td>
<td>Turn on camera, begin recording</td>
</tr>
<tr>
<td></td>
<td>Position upper plate and seal with glue and aluminum tape. Add flight tube and mounting hardware</td>
</tr>
<tr>
<td></td>
<td>Pass flight string through flight tube</td>
</tr>
<tr>
<td></td>
<td>Emplace cotter pin</td>
</tr>
</tbody>
</table>

**Ensure switches all in off position**
- Connect balance leads
- Connect discharge leads
- Power on heater
- Power on Arduino I
- Power on Arduino II

8.4 Account of Launch and Recovery

The launch procedure went exactly as planned. Launch started by having the payload handler (Jacob Crouse) approach the payload and oversaw its handling from T-45 minutes until launch. At T-30 minutes, Jacob Crouse received the batteries that had been charging over the last
day and connected them to their respective connectors and then placed them in their specified locations within the BalloonSat, making sure that their velcro attachments were secure before closing the structure for the last time before launch. Then, the remaining edges that had been left open to gain access to the power circuit for the placement of the batteries were taped over with aluminum tape, taking care to make sure that the tape was placed securely along the entire seam. Finally, to secure the payload into its final position along the flight string, a knot was tied on above the BalloonSat (which was previously left open to allow access into the internals of the BalloonSat). These were the last modifications to the structure of the BalloonSat before launch.

At T-10 minutes, the payload handler proceeded to pick up the BalloonSat and carried it over to the area that the balloon was to be launched. At T-3 minutes, the payload handler received a paper clip which was then pushed through a specific hole that lead from the outside of the BalloonSat to the power button to the camera. At T-30 seconds, the payload handler made sure to activate all the external switches (being sure to follow the procedure for turning on the BalloonSat and all it’s components). At launch, the BalloonSat was released from the hands of the payload handler, at which point the launch procedure was finished.

Recovery went very much like what was predicted. As the convoy arrived at the landing area, the team approached the downed flight string with caution, making sure not to disturb the landing site before the go-ahead was given. After tampering was allowed, the BalloonSat was immediately cut from the flight string and photographed from every possible angle to document its state after landing as thoroughly as possible. After this was completed, the BalloonSat was turned off to accurately estimate the state of the Lithium Polymer batteries as close to the end of flight as possible. Finally, the aluminum tape sealing the edges of one face were severed in order to access the internals of the satellite. This was to access the SD cards with all the data from flight to begin the analysis of the data as early as possible. This event concluded the recovery process of flight.

8.5 Condition of Payload Post-Launch

The external of the structure reached its final position with minor damages. The structure itself sustained negligible damage to the foam core structure, with the most significant amount of damage occurring on the foam core boom to suspend the external temperature sensor in the atmosphere. The next most damaged part of the BalloonSat structure was bottom side of the structure, which had become slightly concave due to the repeated collision with the thrust bearing, which was supporting the weight of of the BalloonSat. After this was a small triangular piece had broken off from the flight tube. Other than these three specific things, there is virtually no noticeable damage to the external structure. The same case goes for the internals for the BalloonSat, with its state being exactly the same as before launch. Everything that was velcroed in place was in its original position, with the rest of the loose equipment being glued to the internal insulation before turn-in.
9.0 - Results, Data Analysis, Failure Analysis, and Conclusions

9.1 Results and Data

The BalloonSat stored three types of data that were recovered at the landing site:

- Arduino 1: Environmental Data (See Section 9.1.1)
- Arduino 2: Orientation Mission Data (See Section 9.1.2)
- Canon A3400: Continuous Imagery (See Section 9.1.3)

9.1.1 Arduino 1: Environmental Data

9.1.1.1 Temperature

The above temperature graph shows the internal and external temperatures from launch to recovery.

The external temperature data was similar to the predicted data and closely matches known temperature values at various altitudes. The lowest temperature recorded was -58.0°C.

The internal temperature of the payload dropped to a minimum of -20.6°C. Therefore, the BalloonSat failed the RFP requirement of remaining above -10°C. This was mostly due to the fact that the heater circuit was removed in order to reduce power consumption. Another contributing factor was that the design of the BalloonSat incorporated a large viewing window in the camera housing, which likely allowed a great deal of heat to escape.
9.1.1.2 Pressure

The external pressure increased at a relatively steady rate for the first half hour. Around 35 minutes into flight the rate of pressure drop decrease, which is in agreement with known data. The minimum pressure recorded was 0.32 PSI, which corresponds to roughly 26789.04 m (87890.6 ft). After burst, the payload descended rapidly, accounting for the rapid increase in pressure.

9.1.1.3 Humidity
As the BalloonSat ascended and the temperature decreased, the relative humidity decreased. This data makes sense since lower temperatures result in decreasing humidity. As the BalloonSat descended after burst and the external temperature increased, the relative humidity rapidly increased as well.

9.1.1.4 Acceleration

The accelerometer recorded acceleration along the X and Z axis of the BalloonSat. The payload underwent up to 1 G of acceleration during launch. Between launch and burst the payload was relatively stable. At burst the payload underwent an extreme amount of acceleration. As the parachute stabilized the flight string, the magnitude of acceleration decreased with time. Finally, the payload experienced a spike in acceleration during landing, where it remained stationary until recovery.

9.1.2 Arduino 2: Experimental Data

The second Arduino was programmed to record the following data:

- Time (in milliseconds)
- Loop Count Number
- Current Heading (in Degrees)
- Target Heading (in Degrees)
- Difference Angle (The total angle between Current Heading and Target Heading)
● Relay position (on or off, as 0 or 1)
● Motor Speed

For the first five minutes of flight, all data was recorded as expected. Accurate heading data was recorded, the Target Heading, Difference Angle and Motor Speed was zero, as this was the condition to turn the targeting algorithms off. After 300,000ms, the targeting algorithms were switched on. At this point, the Arduino only recorded the relay position and motor position. Later in the flight, beginning at 719,000ms, data began recording again. However, the loop count was a negative value, and the accurate data was only recorded for 100ms. After these 100ms the data failed again. Several more periods of full data were recorded later in flight, but there was never enough to get an accurate picture of what was happening in the arduino. Below are three sets of data retrieved from Arduino 2 at different times throughout the flight.

| Time (ms), Loop, Head, Targ, TDiff, FRDirection, Speed |
|---------------|-----------------|----------------|----------------|-----------------|-----------------|
| 9419, 0, 32.98, 0.00, 0.00, 0.00, 1, 0 |
| 9458, 4, 32.98, 0.00, 0.00, 0.00, 1, 0 |
| 9496, 8, 33.31, 0.00, 0.00, 0.00, 1, 0 |
| 9533, 12, 33.31, 0.00, 0.00, 0.00, 1, 0 |
| 9567, 16, 33.43, 0.00, 0.00, 0.00, 1, 0 |
| 9600, 20, 33.43, 0.00, 0.00, 0.00, 1, 0 |
| 9634, 24, 33.27, 0.00, 0.00, 0.00, 1, 0 |
| 9668, 28, 33.27, 0.00, 0.00, 0.00, 1, 0 |
| 9700, 32, 32.93, 0.00, 0.00, 0.00, 1, 0 |
| 9743, 36, 32.93, 0.00, 0.00, 0.00, 1, 0 |
| 9777, 40, 33.05, 0.00, 0.00, 0.00, 1, 0 |
| 9810, 44, 33.05, 0.00, 0.00, 0.00, 1, 0 |
| 9844, 48, 33.22, 0.00, 0.00, 0.00, 1, 0 |
| 9879, 52, 33.22, 0.00, 0.00, 0.00, 1, 0 |
| 9916, 56, 33.30, 0.00, 0.00, 0.00, 1, 0 |
| 9954, 60, 33.30, 0.00, 0.00, 0.00, 1, 0 |
| 9994, 64, 33.38, 0.00, 0.00, 0.00, 1, 0 |
| 10028, 68, 33.38, 0.00, 0.00, 0.00, 1, 0 |
| 10062, 72, 33.38, 0.00, 0.00, 0.00, 1, 0 |
| 10097, 76, 33.86, 0.00, 0.00, 0.00, 1, 0 |
| 10135, 80, 33.86, 0.00, 0.00, 0.00, 1, 0 |
| 10172, 84, 33.79, 0.00, 0.00, 0.00, 1, 0 |
| 10206, 88, 33.79, 0.00, 0.00, 0.00, 1, 0 |

As expected, data began to record approximately one second after power up, due to SD and sensor initialization, servo arming and motor arming.
After the initial error of the SD card, there are numerous points where all data points were written, however these periods were too short and sporadic to reach any conclusions. Also, the loop count is a negative value, which is a sign of a significant error.

9.1.3 Camera Images

The Canon A3400 took a total of 500 pictures in the duration of its flight and descent. The camera was programmed to take one picture every ten seconds. The intention of the BalloonSat was to target and take pictures of first Greeley, then the mountains, and then the sun. However, the glitch in the programming only allowed pictures to be taken of Greeley and a couple hundred of the sun. In addition, there were many pictures of the earth’s horizon and
cloudy stratosphere. As shown below, the camera tilt system did a very good job of stabilizing the camera before each picture was taken.

One clear limitation of the system during flight was that the foam insulating its lens obstructed the camera’s view; making the pictures appear blurry around the edges and corners.

9.2 Post-Flight Conclusions

After compiling all data recovered from the flight, it was inconclusive as to whether or not the experiment succeeded. Our two main sources of data for the FOCUS system were camera images and magnetometer data from Arduino II. Without the magnetometer data, the only way of verifying the results was the camera images. However these images were spaced 10 seconds apart, and this separation was too large to provide an accurate result. It is difficult to tell whether or not any targeting happened, or how well the targeting system worked. Below is a sequential set of images taken from the camera, from the time the FOCUS system was programmed to target towards Greeley, CO. The images read left to right. These images represent the best sequence of targeting from the entire flight, However, these images do not prove that the balloonSat was targeting as programmed. It is important to note that since these images are 10 seconds apart, they may not show the direct camera rotation (i.e the BalloonSat could have rotated a full 360 degrees or more between images)
9.3 Failure Analysis

There are two parts of the project that did not function as expected. First the SD card on Arduino II did not accurately record data. This was due to a multiple errors in programming: The first cause was an uninitialized variable, tiltAngle. This variable was to be sent to the servo aim function, which was called at the moment of failure. However, the variable was not actually initialized to a specified value until ten minutes later, so the function was sent “garbage” data. This could act as a virtual monkey wrench in our program. After eliminating this issue (by initializing the angle to zero), the test code was run again. This time the code stopped when the loop count reached a value just of 3200. After eliminating the loop counter from the code (this variable had no practical purpose, and was only installed to keep track of data), the Arduino was able to record good data to the SD card for 90 minutes continuously.

In addition to data recording issues, the targeting system itself did not reach its goal of maintaining a target heading within 10 degrees for five minutes. Ultimately, this was due to a lack of calibration of the motor and targeting algorithms. For the final flight code, the motor control algorithms only used proportional and integral control, and these values were not properly calibrated. After flight, derivative control was added to the program to prevent overshooting. After more calibration, the balloonSat was able to find a target heading much faster. However, it was still unable to compensate for external forces acting on the structure. Particularly, the Arduino failed to stop a constant spin. This is because as the structure spun, the target angle would periodically increase and decrease, and there were no built in parameters to counter a full spin. The algorithms were only designed to point the camera in the correct direction, and not detect and stop constant rotation. An accelerometer may have helped the Arduino to compensate and predict outside forces. It could have been calibrated to detect when the structure was spinning, and sent a signal to the motor to compensate.

Another issue of motor control came from a build of friction. If the system was pointing away from the target for a long time, the system would ramp up to a higher speed. As this speed increased, the force required to stop this motion would also increase. So when the magnetometer was pointed in the right direction again, the motor would suddenly stop. This sudden stop forced the balloonSat to rotate in the opposite direction, moving away from the target. The process would then start again, as the balloonSat would point far away from the target, and the speed increased.

9.4 Post Flight Test Results

After recovery and analysis the code was fixed so that magnetometer data would be recorded and a post flight test was conducted. During the test the payload started indoors and was transitioned to outdoors. The payload was subject to external forces throughout the duration of the test to simulate the aerodynamic forces of flight. The test ran for an hour and a half to simulate the ascent and descent of the flight string. The results of the test showed that the motor was likely inactive during flight because the acceleration experienced during targeting was consistently between 0.5 and 1 g’s, but during the flight the accelerometers recorded values close
to 0 until burst. The heading data that was recorded showed that the structure did exhibit orientation during the test. Indoors the most often occurring heading angles exist between 240° and 300°, while the target heading was 270°. Outdoors there was a significant wind and the most often occurring angles were between 230° and 340°.

9.5 Conclusion

After reviewing the data from flight, making predictions as to the cause of the mission failure, and finally testing to verify what the results should have been the team is confident in saying that the targeting system was not active during flight. The initialization error in the code cause sporadic behavior of the system, which included very little if any motor control. This conclusion was reached due to analysis of the acceleration experienced when targeting in turbulent conditions, which is approximately +/- 0.5 g in the yaw direction. During the flight the recorded values of this acceleration remained very close to zero, indicating little acceleration about the flight tube. Post flight testing also concluded that the algorithms used would have likely produced an accuracy of +/- 55 deg from the target during flight.

10.0 Ready for Flight

The RFP requires that the payload is turned in in working condition and is ready to fly again. With this requirement in mind the team has inspected the payload, identified and corrected
failures, compiled information regarding the storage of the payload, and written instructions for payload activation.

10.1 Failure Correction

10.1.1 Data Recovery

Project FOCUS relied on magnetometer data stored on the SD card associated with Arduino II to provide quantitative data on the success of the mission. A variable initialization problem regarding the servo tilt angle caused data losses during flight. The CD&H team worked with Navigation to determine the cause of the failure.

10.1.2 Image Density

Images were taken every ten seconds for the duration of the flight. It was expected that these images would assist in determination of the success of the targeting systems. The frequency with which the images were taken invalidated the majority of this secondary data. When consecutive images appeared to show successful camera orientation it was possible that the payload had rotated any number of full revolutions in that ten second period. This was not a critical failure and so it is not necessary to correct before flight. Team High Five suggests using a different imaging system to record video for the duration of the flight. This would mean purchasing a high-capacity SD card as well as an action cam style camera to record video continuously for the entire duration of the flight.

10.1.3 PID Gains

Assuming that the qualitative data from the camera represents oscillation from the targeting system the team agreed that the gains must be adjusted to perform in high turbulence environments. With this in mind it is clear that overshooting the desired heading is undesirable, and so more derivative gain should be implemented to arrest movement close to the target.

10.1.4 Internal Temperature

The RFP required the payload to maintain a minimum internal temperature of -10°C. During the flight the payload’s internal temperature reached -20.266°C without an active heater system. To meet this requirement on subsequent flights an active heater system should be added. It is imperative to note that the heater was abandoned due to power system and mass concerns. The heater, when run at 12V, drew 1A. Over the course of a three hour flight and recovery the heater alone would consume the entire energy budget and destroy the LiPo cells, simultaneously creating a fire hazard. If the payload was to fly with an active heater system a low voltage cutoff circuit must be incorporated to protect the batteries. The internal temp was not
a critical failure, all systems remained operational, and so it has not been corrected for the next flight.

10.1.5 Camera Aperture

The camera aperture was designed to allow imagery outside the payload without exposing the internal environment to cold. The design that flew specified a recessed lens. Images from flight were framed by black foam insulation. To improve the quality of images on future flights it is suggested that the camera lens is positioned further out from the camera tilt mechanism. The seal with the structure could then be made at an intermediate segment of the telescoping lens, retaining the same thermal properties.

10.2 Storage

Proper Storage is necessary to ensure that the payload is ready for flight after an extended period of inactivity. Two subsystems in particular are vulnerable to improper storage.

10.2.1 Mechanisms

The mechanisms subsystem should be treated with care. Distortions in the structure can cause excessive friction between the axle and flight tube, flight tube and structure, or camera tilt tray and structure. Excessive friction could cause the targeting system to become ineffective or even completely inoperational. Furthermore the reaction wheel is constructed out of acrylic which is brittle so the payload should not be stored supporting any weight.

10.2.2 Power

The power subsystem employs lithium polymer batteries which must be treated correctly to ensure long life and proper performance. For storage a LiPo battery should be discharged to 3.8 volts per cell. This will prevent reactions from occurring within the battery rendering it useless over a long period of inactivity.

10.3 Activation

The Arduinos have been stored with flight code that has been tested and is ready to perform the mission from April 11th. If other targets are desired the flight code should be updated with new target headings and activation times, and ArduinoII (located in the corner of the structure) should have the new code uploaded and tested. After any testing and before launch the batteries should be fully charged and balanced on a proper charger. The camera battery should be charged as well. All SD cards should be cleared to make room for new data and tested to ensure that they are in working order. Batteries should be connected corresponding to color. Upon launch the external switches should be activated in the following order: Heater, ArduinoI, ArduinoII. Upon retrieval the switches should be turned off and the batteries disconnected, then charged to storage level.
11.0 - Lessons Learned

11.1 What Was Learned

Team High Five learned many lessons throughout the semester from this project and the Gateway to Space class. In terms of academics, the team learned how to apply physics equations when calculating power, momentum, etc. for the BalloonSat. These calculations included computing for angular momentum, the maximum correction of angular velocity of the BalloonSat, etc. In addition, multiple members of the team were able to apply their knowledge of computer programming to program the arduinos. The most difficult part about programming was debugging the code, and trying to fit all the code on the arduino. Space was definitely a barrier when programming the arduinos, which resulted in many revisions to compress the code. Coding was extremely time consuming and at many times frustrating.

In regards to experiencing college life, the most important lesson learned was team work. The team has spent at least ten hours a week every week, if not more, since the beginning of the semester. Emotionally the team has become much closer and understand the value of working together on a single goal.

11.2 What Would Have Been Done Differently

As a team, it has been decided that the entire mission would have been changed if the chance was given to do this again. To begin, the team would not have chosen such a difficult mission because the time crunch really affected the success of this mission. Perhaps the camera would only focus on one target and take a continuous video instead of rapid pictures. The suggestion of a GoPro was brought up when discussing what video device to use, as well as more time spent during the week on programming to ensure it works properly.

12.0 - Message to Next Semester

There are many different things to keep in mind while thinking about what you want to do in your Gateway To Space class. One of the most, if not the most, important thing in this class is to have a great team dynamic. It is important to be understanding that everyone is coming to the group with a different skill set and a different point-of-view toward every situation. Team chemistry is what determines to a certain extent how much time is going to be spent on this class. A good team dynamic will equate to work going faster and the project being done more efficiently, and the opposite will occur for a team with bad chemistry. If there is an issue in the group, work it out. Nothing productive comes from complaining to anyone else.

The next most important thing is the act of picking the project to pursue. It is very important to research the topic in question before deciding on that topic. There are a lot of little things that will come up during the course of building that will be of much heartbreak to the team and will cause a lot more work than was initially anticipated. Make sure to completely understand every aspect of a topic before it is chosen as the project to pursue. It will save a ton of
work in the long run. Also, if Chris says that the project is too much work for one team, know that he has been doing this class for a long time, and knows when someone as attempted something before and it turned out to be too much work for one team. Heed his warning.

Finally, do not procrastinate. Procrastination will cause things to pile up, and this class throws so many different papers, presentations, and home works at whoever is taking it that if procrastination to any degree is observed, there is almost no way to get out of that slump. Even without any procrastination, there is still going to be a ton of work that needs to be done and there will be long nights and all-nighters without regard to how well time has been managed.

Overall, this class requires a lot of work, and make sure that every move that is made has been thoroughly researched and understood, or else this class will become more work that was ever initially anticipated.