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Icarus : aerial recording system

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ENTITLED

ICARUS: AERIAL RECORDING SYSTEM

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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IN
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ICARUS
AERIAL RECORDING SYSTEM

Development and analysis of an aerial camera system that is adaptable to any situation

Santa Clara University, 2012–2013

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ICARUS
AERIAL RECORDING SYSTEM

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Abstract

The goal of Project ICARUS is to create an aerial videography system that is easy to set up, inexpensive, portable, and highly adaptable to any situation. This is accomplished by using a balloon mounted camera rig that is grounded by a number of winches. This system is able to obtain a higher altitude than similar systems and is much more cost effective because the system can be applied to a number of circumstances such as sporting events, disaster relief, wildlife videography, and aerial monitoring, to name a few. The ICARUS system allows the user to control the position of an aerial camera as well as its orientation in three dimensional space using minimal infrastructure. This system features a control system that allows the user to specify an input in cartesian space as well as a live view from the aerial camera.

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1 Introduction

The Project ICARUS team has created an aerial, balloon-hoisted camera system connected to a modular system of up to four computer controlled winches that is easy to set up, inexpensive, portable, and adaptable. The goal of the project was to create a new type of aerial recording device that could be adapted to numerous situations.

1.1 Background

There are many situations that could benefit from having a stable and constant aerial view, such as sporting events, disaster relief, concerts, wildlife videography, aerial monitoring, and others. In many of these cases, those involved don't have sufficient funds to construct the infrastructure required to create an aerial view. The Project ICARUS team has constructed a balloon-suspended aerial camera system, which allows a constant aerial view. In order to expand the availability of this product, it was designed to be inexpensive, easy to use, and portable.

Our primary target applications are sports-related events where the video would assist coaches with strategy, overall athletic performance, and player safety. This system will allow lower level athletic programs, with minimal funding and experience, the ability to record and improve their athletes. For example, this aerial view will help to educate players about how to tackle properly, and how to run their football routes. It also gives coaches the ability to look over full field footage of previous games so that they can critique and help players improve their technique.

Ideally, this system can be used for both indoor and outdoor venues and will be adaptable for use with any sport. This adaptability would allow a high school to buy only one of these products and use it for all of their teams to help improve overall athletic performance.

Since this system is easily adaptable and simple to set up, it can be used for other, non-athletic, applications. One such application that this system can apply to is disaster relief situations. After major disasters such as earthquakes, tsunamis, hurricanes, or landslides occur, disaster relief groups rush to help the victims as quickly as they can. With the rapid deployment capabilities provided by this camera system, relief teams would be able to get a bird's eye view of the situation within several minutes of arrival. This view can help first responders to better evaluate where to look for survivors and direct their attentions so they can save as many lives as possible.

Complex alternative systems such as helicopters, airplanes, and aerial drones are incapable of maneuvering in small enclosed areas, are expensive to maintain, and are time-constrained by fuel reserves. Simpler systems, such as a pole mounted camera are used by many organizations to film a steady aerial vantage point; however, these systems are limited by the expense of the infrastructure and to a single vantage point.

To create this inexpensive and portable solution, many off-the-shelf parts were incorporated. These products needed to be inexpensive to minimize the total cost of the system, while also being durable to withstand many different environments. Some of the products that were sourced commercially off the shelf included components for the winches, small microcontrollers, and a durable inexpensive camera. When all of these components were combined with a control system, a higher quality aerial viewing apparatus was achieved, compared to current systems on the market. The total cost of this system has been calculated to be produced for under \$1000 to enable as many organizations as possible to afford the system.

1.2 Literature Review

As part of our initial research, we reviewed several journals and textbooks with related information to the design of our project. When developing the preliminary idea of how to attach the camera, tethers and balloon to one another, with the grounded winches we referred to the article "Determination and Stability Analysis of Equilibrium Configurations of Objects Suspended From Multiple Aerial Robots" by Qimi Jiang which discusses an inverted system (Jiang). Upon completing this preliminary design we realized this article was also relevant to an alternative design which we considered implementing in future revolutions.

One of the main concerns we had when beginning our project was the stability of the camera footage. In order to develop improved footage we referred to the article "Real-Time Image Stabilization Using Fuzzy Logic" by Anthony De Sam Lazaro and Joseph Tucker as well as the article "Image-Based Pointing and Tracking for Inertially Stabilized Airborne Camera Platform" by Z. Hurak. Here it was discussed how to improve the camera platform stability of an airborne system through the use of an image tracking system. This allowed the camera platform to continually readjust its positioning due to external disturbance. Ultimately, such an image tracking system would help the stability of the final image and should be explored.

Furthermore, there exist numerous sources on balloon dynamics. A few of such sources are referenced which provided necessary equations for use in evaluated the lift of a balloon as well as the force of wind on such a balloon. Similarly, in our analysis of the current state of the helium marketplace, many sources were used to provide statistical and market data, such as the United States Geological Survey mineral commodities survey (USGS).

There are no existing systems that satisfy all of the requirements for a time independent aerial system. However, some products do exist that attempt to provide an aerial view for specific functions (Appendix F). Furthermore, a similar system was researched prior to this project as part of a previous senior design project at Santa Clara University (SkyWorks) that focused on disaster relief functions.

There are several current camera systems on the market today. There are two main competitors to the ICARUS system: home video recorders and professional camera equipment. These systems have several flaws, which limit their usability. In general, the high end systems are incredibly expensive, and are arduous to move or set up. Some of these systems rely on expensive and heavy infrastructure to be set up, such as the SkyCam or the EagleCam system (Appendix F).

On the other side of the spectrum, there are home video devices that vary in price and are much cheaper, however, they are limited in their usability. One common alternative is a pole mounted camera. These vary in cost and capability but are limited in the mounting height by the size of the infrastructure. Furthermore, these systems are constrained to a single location above the viewing surface (Appendix F).

The previous senior design work consisted of a very similar system with a balloon supported camera, and a winch to hoist it in the air. The original project served as reference for the kinematics, design and control system. Furthermore, the issues that this initial team faced and dealt with provided a basis for the preliminary design and all subsequent designs for the ICARUS system (SkyWorks). However, the SkyWorks system was rather large and bulky and was primarily intended to be used by researchers or well funded disaster response teams.

1.3 Project Statement

Project ICARUS designed, manufactured and tested a balloon hoisted, tethered, aerial videography system with full position and orientation user control for live filming and recording. First, an analysis was conducted to determine the expected wind disturbance loads on the balloon as well as the expected tensile load in the tether. A camera mount has been designed to control the position and orientation of the camera in a mass efficient way. A winch subassembly was designed and constructed which received commands wirelessly and adjusted the length of the tethers. Finally, a control system has been developed, including the underlying communication protocols and software, to precisely control the position of the camera.

2 System-Level Design

In order to design the whole system, first the requirements and needs of the intended customers were characterized as a way of benchmarking the success of the final design. Once these requirements were in place, a system-level design was created involving modular winches connected to a lightweight camera mount with winches. When deployed outdoors, a balloon hoisted the camera system into the air providing an affordable, long duration, movable aerial viewpoint for filming and recording.

2.1 Customer Needs and Requirements

As part of the initial market analysis of the needs of customers for this type of system, interviews with potential customers and marketers were conducted. It was found that stable video recording, ease of use, adaptability, and affordability were the most relevant requirements that the customers required. The interviews conducted included an NCAA soccer coach, a representative of the Santa Clara Fire Department, and a representative of Nike Research Laboratories:

- Jerry Smith
  - White male, Age: 50-60
  - Santa Clara's Women's soccer coach for the last 25 years
  - Has won a national Championship with Santa Clara
- Representative for the Santa Clara County Fire Department
  - Asian American
  - Age: 25-35
- Jeff Ota
  - Asian American
  - Age: 30-40
  - Research and Development Lead for Nike
  - Worked in Robotics Systems Lab at Santa Clara University

The needs of the representatives were compiled into a customer needs matrix and used to determine the specifications of our design (Table 1).

By using Table 1, it was easy to see what items were most relevant for this project. The most important part of our project, which determined a variety of other components,

Table 1: Customer Needs Matrix

Use	Needs	Speed of Winches	Number of Winches	Weight	Camera Quality	Battery Life	Adaptability
Sports Filming	Stability of Video	+	+	+	+		
	Ease of Use		−	−		+	+
	Safe			−			
	Instant Playback						+
	Ability to record long games				−	+	
	Inexpensive		−	−	−	−	−
	Wireless Transmission of Video						+
Disaster Relief	Easy/fast to set up		−	−			+
	Secure Video						
	Wireless Transmission of Video						
Manufacture	Easy to make	−	−				
	Off the shelf parts						
	Scalability						
	Inexpensive	−	−		−	−	
	Positive Relation: +						
	Negative Relation: −						

would be the number of winches we use. To maximize the systems efficiency for each user, a different number of winches can be used, varying in ease and affordability per customer. This modularity required that the system have the ability to work with multiple variations, as well as multiple winches.

Another aspect of the project that affected a lot of the needs was the weight. When the system is heavy, it has a larger moment of inertia, which makes it harder to move and therefore more stable. However, this was the only benefit of having a heavy system. Though a helium balloon could support this system, the heavier the system is, the more helium is needed to lift the camera mount. Because of political and environmental issues beyond our control, helium is extremely expensive so minimizing the amount of helium used is important. The safety of the system is also directly related to the weight of the final product. A heavier system can be more harmful if it falls out of the sky and hit someone or something.

From the customer needs survey and other definitions of our project, a preliminary design specification was completed, Appendix A. In this design specification, performance criteria for the final project were specified. From this report, some of the more important specifications are the winch speed, 1-5 meters per second, the initial price, $1000, the recurring price per deployment, $50-100, and the degrees of freedom, 5. Having a modular number of winches allows for more affordable systems with up to 5 degrees of freedom while having a lightweight camera mount reduces the need for a large balloon saving cost per deployment.

Ultimately, the most important needs are stable video recording, ease of use, adaptability, and affordability. From the interviews, these were the most frequently requested needs and preferences. However, from the design specifications, Appendix A, we could clearly see that the weight of the camera mount and number of winches were the most important design concerns to accommodate the customer needs.

2.2 System Sketch

The initial overall design of the ICARUS system is shown below (Figure 1) and comprises a higher tier version of the design with three winches. However, the overall concept is similar for all tiers in that components can be added or removed in a modular format with only the basic control system changing (Appendix E). The design starts with a large 1-2 meter diameter balloon that is connected by a swivel to a camera mount system. The camera mount is comprised of a ring connected to the winches and balloon and a rotating center mount that also controls the angle of the video camera. A battery powered on-board microcontroller communicates to the user on the ground. The camera is an off the shelf GoPro Hero 2 that communicates by wireless internet to a users tablet or smartphone. Finally, winch cables connect the balloon system to the modular winches. These winches communicate to the users control system on the computer and control the amount of tether released.

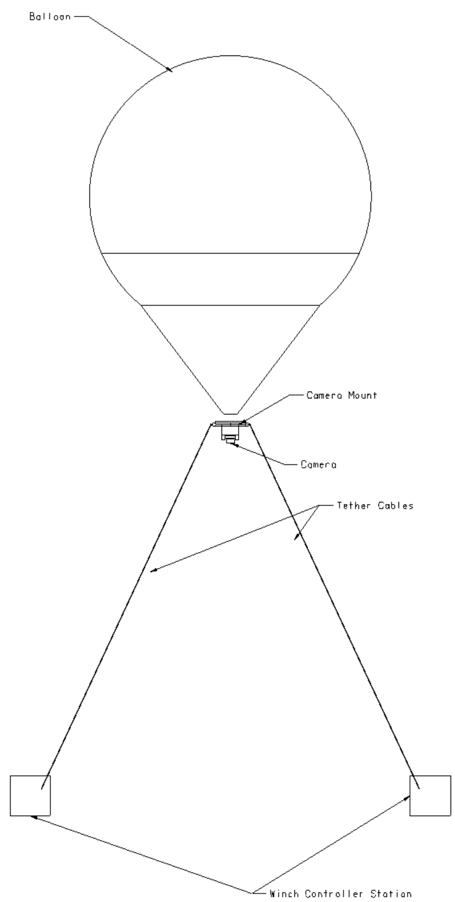


Figure 1: Initial system sketch of the ICARUS system using two winches

2.3 Benchmarking

The final design of the ICARUS system needs to be benchmarked to evaluate the success of the project. Unfortunately, there were no similar products on the market or in existence to compare to the ICARUS design; however, each subsystem could be compared to existing similar systems. These subsystems include available electronic pull winches and security camera frames. For more information, please refer to the Project Design Specifications (Appendix A).

For the camera mount subsystem, the most important design considerations were weight, field of view and battery life. Existing systems were not as weight optimized and were not battery powered. Our system is designed to operate up to 4 hours and weigh less than 2 kg. More detailed information is given in the Camera Mount design, section 5. For the winch subsystems, most existing systems were either too slow with much higher torque, like the referenced all terrain vehicle winch, or did not provide enough torque to line. Our design goal is to operate each winch at up to 5 meters per second speed. More detailed information is given in the Winch design, section 6.

2.4 System-Level Requirements Issues and Tradeoffs

As a result of the customer analysis and the Decision Matrix (Appendix B), the requirements and the Project Design Specifications (Appendix A) for the entire system were developed. These included a general emphasis on keeping the weight down while maintaining ease of setup and operation, and battery life. Furthermore, stability of the video and durability of the whole system were important, whereas the speed and accuracy of the system were least important. For more detailed requirements, please refer to Appendix A and B.

As has been stated elsewhere, the biggest trade-off was in the weight of the camera mount, as an increase in weight allowed for higher durability, and better control and actuation, but also causes an increase in the size of the balloon, which results in larger upfront and recurring cost. Other key issues were the sizing of the winch subsystem so that it is large enough to contain all necessary hardware, controllers and battery, and heavy enough to be stable in inclement weather as the balloon pulls on the winch while still maintaining portability, and ease of setup.

2.5 System Block Diagram

In order to visualize the overall system, a system block diagram was created (Figure 2). In this diagram, the winches are shown in the blue box, the camera system is in the green box, and the user is shown as the yellow circle. Within each of these subsystems, the components are broken down and the various connections are shown. These connections include physical, control, video, and electrical. The subsystems consist of the winch, camera mount, tether, and balloon subsystem. The winch subsystem consists of the reel, motor, motor controller, microcontroller, and communication devices and serves as mobile command stations. The tethers connect the camera mount to the winches. The camera mount is the platform on which the camera is attached. The balloon is attached to the camera mount from above while the tethers attach to the camera mount from below. Each of these subsystem's will be developed more in later chapters.

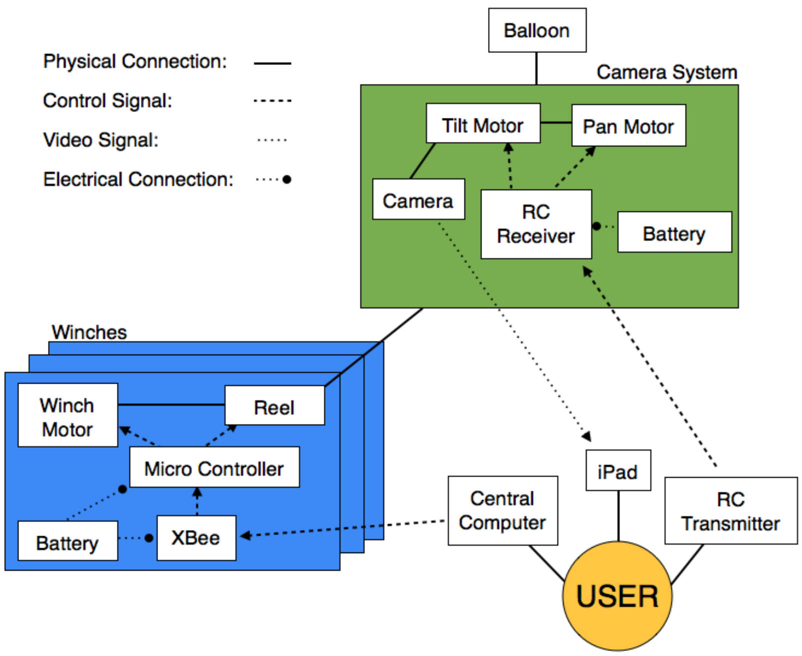


Figure 2: System block diagram of project Icarus showing the physical, control, video, and electrical connections between the different subsystems.

The user, using the central computer and RC transmitter, sends control signals to the XBee and RC receiver respectively. The XBee communicates with the microcontroller which sends control signals to the winch motor. The winch motor is physically connected to the reel which is in-turn physically connected to the camera system. As mentioned earlier, the RC transmitter sends control signals to the RC receiver. These signals are then translated into commands which are sent to the pan and tilt motors. These are connected to the camera which sends a live video feed back to the iOS or Android device. The camera system is physically connected to the balloon.

2.6 Team and Project Management

2.6.1 Project Challenges and Constraints

This project had numerous challenges and constraints. These challenges were both self imposed and physically imposed. The major challenge against this project was the cost of helium. This led to constraints on the mass of the camera mount system. As mentioned in the customer needs analysis, affordability was a major necessity. These requirements directly required that the minimum amount of helium be used. This minimization required that the camera mount be as light as possible while still including the desired functionality.

Another challenge was converting power from our motor to the reel. The motor couldn't easily be connected to the reel because the reel was store bought, and because the motor had a square shaft. To solve this connection issue, an adapter was created which, when combined with a round to square shaft coupler, converts the rotational energy of the motor to the reel. This solution will be discussed in Section 6.4 of this paper.

2.6.2 Budget

The main issue that pertained to the budget was the rising cost of helium. Each time we fill our balloon, it cost 300 dollars or more. Furthermore, balloons tend to lose one percent of the helium per day inflated, resulting in a varying recurring cost. In addition, purchasing off the shelf components tends to increase the cost of the prototype system, when compared to the estimated cost to produce components that are designed specifically for the system. For instance, each winch subsystem is estimated to cost around 200 dollars when prototyped for this project, but over 800 dollars if purchased off the shelf. For more details, please see Appendix C.

2.6.3 Timeline

There were numerous deadlines for Project ICARUS, the majority of which were expected to be met by the team. However, the first deadline to finish a preliminary tier 1 prototype by the end of November was not met. This was due to an unexpected amount of work in the preparation of papers for classes and exams during the interval of time devoted to the prototype. Nevertheless, prototypes were completed towards the end of the winter academic quarter and the final design was constructed within the first couple weeks of the academic spring quarter. Though this delay did push back the testing period, there was still enough time to properly test the system and obtain video footage of various sports.

2.6.4 Design Process

The teams design process was based on principles learned in the Advanced Design course series. It started with a design problem that was defined either at the start of the process. The solution to this problem was brainstormed in a group setting and proceeded to an engineering calculation-based analysis. If the solution did not pass the analysis, it was either modified based on the results or the group returned to the brainstorming stage and designed a new solution. Once the design passed the engineering analysis, it was brought to applicable advisors: the faculty advisor and/or industry representatives. Once the overall design was completed, testing began and design flaws were noted. This results in an analysis of the prototype, which led to the brainstorming of the next prototype version until the final design was completed.

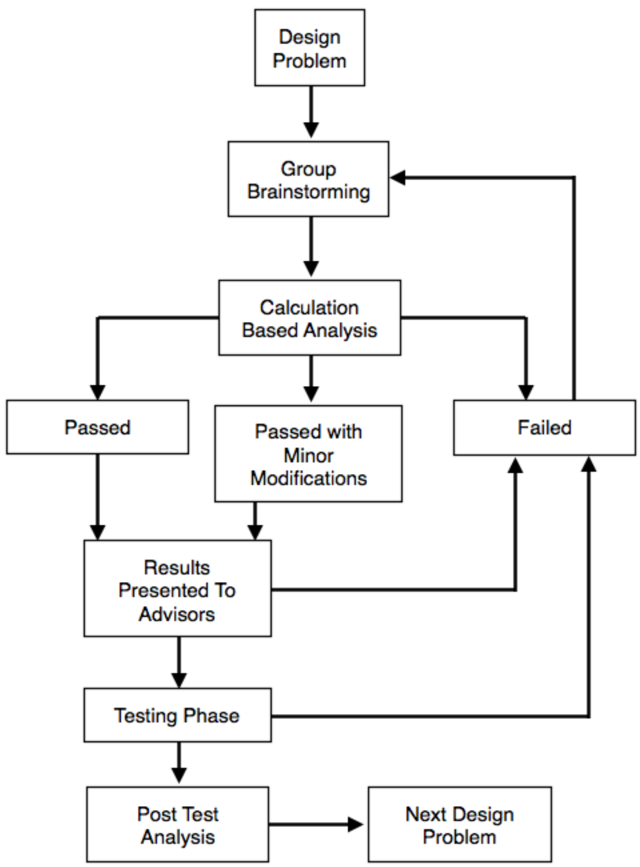


Figure 3: Design process diagram that outlines the methodology the team used to approach and solve problems.

2.6.5 Risk Mitigation

As the designers, our goal was to make the system as safe as possible and to account for unexpected accidents as best as possible. Though we can tell people what the intended purposes of this system are, that is not going to prevent someone from taking the system and using it in a manner that is not intended. Because we cannot control how the system is used, the responsibility lies with the user to operate the system safely. If we, the designers, had the responsibility to prevent people from using this system in an unintended manner, the only solution would be to not make the system at all. Therefore, our responsibility is to make sure that safe operating procedures are clearly communicated to the end user and to reduce the risk from misuse when possible.

Furthermore, while operating the prototypes, the team must ensure the safety of those who are in the vicinity of the system. Though unexpected events do transpire, the team should do everything in it's power to ensure that all calculations are done properly and that measures are taken to account for these unexpected events as best as possible. While there is always a chance that our system could fall out of the sky, it is very unlikely. Our product has a very good camera attached to it, which enables us to film farther away from the action. This distance from the field of play, will make it safer for anyone around it. The camera itself is put into a shock and waterproof case, which will prevent it from being destroyed if a pop up storm comes and destroys the balloon supporting the camera rig. To prevent athletes and observers from running into the tethers, certain measures need to be taken. These include designating an area where people shouldnt be walking, and ensuring that the tethers are easily visible by attaching flags, ribbons, or colored sleeves.

2.6.6 Team Management Organization

When considering the design of the ICARUS aerial camera system, special attention was given both to how the team members interact with one another, and how the team interacts with the organizations involved in the project.

The team is regulated through an inherent series of checks and balances. Because our team worked as a group, it was possible to check and make sure that corners werent being cut and that credit was given where it was due. Likewise, both our advisor and our project sponsor had oversight over our project. Their role was to give us advice and lead us in the appropriate direction. While the team makes all final decisions as a group, the advice of our advisors was weighted very heavily. Furthermore, organizations that provide us with money had requirements which needed to be completed with quality and punctuality by the team members. These organizations provide a different, less involved, type of oversight. Their requirements were based on presenting the project to potential future engineering students of Santa Clara University and thus didn't directly affect the design, but did affect the timeline, as we needed to have a prototype we could showcase. Finally, the School of

Engineering and the University provided our team with an ethical framework and guidelines for completing our project. Each of these groups helped insure that requirements were met and the desired quality standard was maintained.

In order to make sure that each team member was pulling his or her own weight, the hours were tallied that each person spends working on certain sub-projects that lead to the final goal. If someone was not contributing enough to the project, they were confronted and expected to put in additional time and contribute more on the next task. Any other internal conflicts have been dealt with by mediation within the group and if necessary with our advisor. Furthermore, there was not a singular team leader in charge, so the group did it's own policing, motivating and organizing.

3 Balloon

Before we could design the overall system, we first had to characterize the behavior of the advertising balloon and tension in the tethers. We began our analysis by examining the balloon and determining the lift of the balloon and wind drag force. The balloon is the most crucial part of our project, for without it we would not be able to run our system outdoors.

3.1 Role and Requirements

The role of the balloon is to lift the camera subsystem into the air above the playing field. This required a large enough balloon to provide a large enough buoyant force to counter the weight of the camera subsystem. The balloon would be connected directly to the camera mount system, which would in turn be attached to the grounded winches. Any wind disturbance on the balloon would affect the stability of the camera mount and increase the tether tension. Thus, while a larger balloon provides more lift increasing stability, it is also more affected by winds. Therefore, the balloon must provide enough lift to hoist the camera subsystem without being too large. A balance must be found between the two requirements. It was also a requirement that the balloon be easily handled and durable enough to withstand normal and repeated use.

3.2 Summary of Options and Tradeoffs

A few different options were examined for providing the lift required for our system. We examined using weather balloons, hot air balloons and advertising balloons. The weather balloons, while being very lightweight and therefore more efficient at providing lift, were too thin for use in this project and would require very delicate handling to not puncture the balloon. The hot air balloons are the next best option for they are easily obtainable, relatively cheap and provide enough lift. The advantage to hot air balloons is that they do not require any helium, which is very expensive to use. However, hot air balloons require either massive power sources or chemical ignition sources and are therefore too dangerous to use in this capacity where ease of user experience is desired.

After comparing these options, the team chose to use large latex advertising balloons. These are cheap and easily obtainable and can even be purchased with custom design which would be useful for advertising purposes as described in the business plan in Section 9. Furthermore, these balloons are durable enough to withstand repeated use without rupturing. While the use of helium is expensive, these balloons are safer than the hot air balloons and can be filled by any user that has access to party stores and helium suppliers. Furthermore, as an inert gas, helium is very safe to handle. Ultimately, advertising balloons were a perfect match for this project as they were designed for similar uses.

3.3 Lift Analysis

In order to find the overall lift of the balloon, we took the average lift force of one cubic foot of helium and calculated how many cubic feet we would need in order to lift the weight of the camera mount and tethers. One cubic meter of helium lifts approximately 1.004 kg. Using this measurement, we could calculate the overall size of the balloon required but we also needed to know the total weight of the camera subsystem. Since we had not designed the camera subsystem yet, we would need a recursive process where we start by overestimating the lift and reevaluate after we have our preliminary designs. We decided to evaluate two separate balloons, a 1.8 meter and a 1.2 meter diameter balloon. Using the volume of a perfect sphere the lift of each was calculated to be a maximum of 2.3 kg and 0.67 kg respectively. This was about 5% higher than the lift specified by the manufacture, or roughly 22 Newtons and 6.5 Newtons. As a reference, future design on the camera platform structure results in a mass budget of 757 grams which can be seen in the Camera Mount design, section 5.

3.4 Wind Force Analysis

An important factor when considering the tether tension was the wind force. Not only would wind disturbance reduce the stability of the footage, but also increase the tensile load in the tether. This load needs to be determined by an analysis of the wind force on the balloon. We conducted an analysis using the known diameters of our chosen balloon and varying the wind speed. Using equations from the NASA website article Drag of a Sphere" we were able to calculate the expected force on the balloon. In Equation 1, ρ is the air density, C_d is the drag coefficient of the balloon, v is the airspeed, and A is the cross sectional area of the balloon. From experiments from the same NASA article, the drag coefficient of a round sphere is 0.47. This is a very large drag coefficient for a spherical object, but we chose to use a larger than expected value to over design the tethers, effectively applying a factor of safety.

$$F_d = \frac{1}{2}\rho C_d v^2 A \tag{1}$$

Equation 1 shows the change in drag force as wind velocity changes for two separate balloon sizes. As can be seen, the larger balloon is obviously more affected by the wind force. At a wind speed of 12 meters per second the maximum tensile force in the tether approaches 120 Newtons. This is well beyond the maximum wind speed as laid out in the preliminary design specifications in A and by using a larger than anticipated wind speed we are increasing our factor of safety in the design.

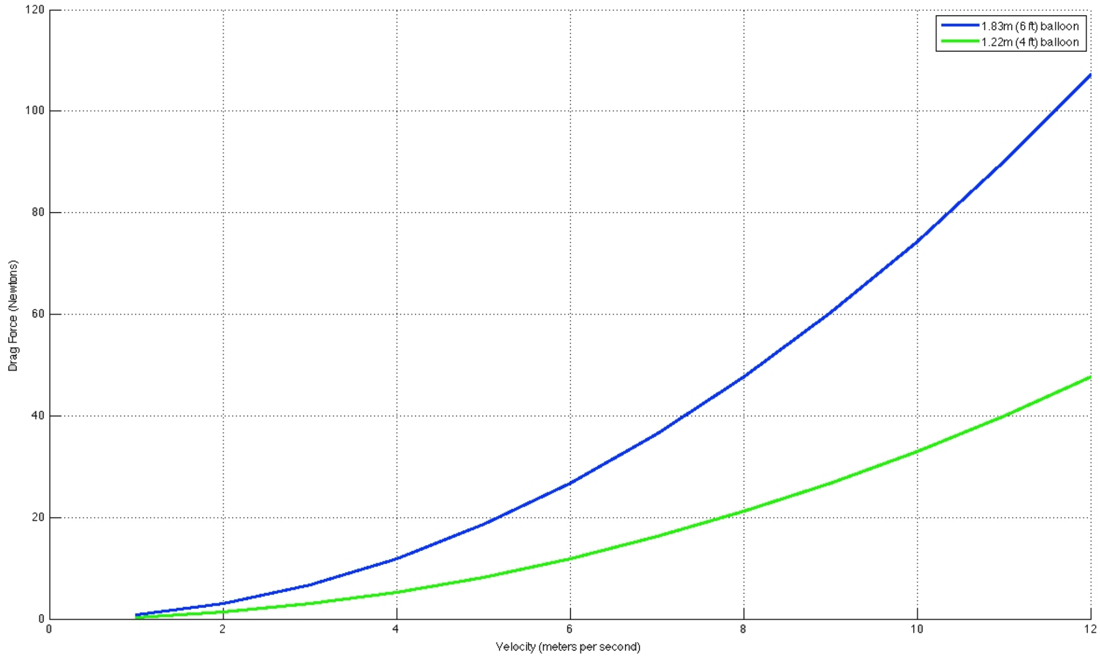


Figure 4: Wind force acting on a 4 foot and 6 foot balloon

Using this analysis, the wind force on the different sizes of the balloons was calculated. This allows the disturbance on the system to be characterized. Both of these analyses allows us to anticipate the lift and drag force on the balloons that were obtained. Using the results of this analysis and the maximum force of 120 newtons, the maximum tension in the tether line was analyzed.

4 Tether

After the selection of a balloon had been made and the expected disturbance loads due to winds on the balloon characterized, the design and selection of an appropriate tether was analyzed. The safety and structural integrity of the system relies upon the tether selection even though it is one of the simpler design elements. Thus, it was very important to select a proper material for the tether that would ensure safe, reliable and strong system integration.

4.1 Role and Requirements

The primary role of the tether is to connect each winch independently to the camera mount and balloon subsystem. Furthermore, a number of requirements are levied on the tether selection. First, it must have a tensile strength greater than the expected tensile load on the tether in order to ensure the structural integrity of the overall system. The weight and cost of a standard length should also be minimized to improve the system performance and economics. Furthermore, in order to reduce the load on the camera mount, the tether line passes through the camera mount structure to connect straight to the balloon, which means the tether must be malleable enough to be easily worked with. The safety, visibility and malleability should all be maximized to increase the usability and safety of the system, while the diameter of the line should be minimized to increase the length of line on each spool without decreasing safety. All of these requirements were factored into the summary of options and tradeoffs. However, before we could examine each option, we needed to characterize the maximum tension in the line.

4.2 Tension Analysis

The maximum tensile load expected in the line is directly related to the lift of the balloon, the mass of the camera mount and tethers, and the wind load on the balloon. However, the camera mount mass and the tether mass is not considered in this analysis because both of these forces oppose the balloons lift force and neglecting these forces actually increases the expected load on the tether lines. By only examining the lift and drag on the balloon, our calculations produced a higher expected tensile load than reality which increases the factor of safety for our design. It was also determined that analyzing the single winch system will result in the maximum tensile force. This is due to the fact that the drag force on the balloon affects the tension calculation the most and, at high winds, the balloon will drift and introduce slack into the leeward lines, effectively resulting in the single winch system.

The calculation simplifies to the square root of the sum of squares of the drag force and the lift force (Equation 2). However, since the lift force is, at it's max, 20 Newtons which is 18.6% of the max drag force, 107 Newtons, the lift force effect on the max tension is very limited. Ultimately, at a wind speed of 12 meters per second, larger than the design limit, and with a large 1.8 meter balloon, a max tensile force of 109 Newtons acts on the tether. This tensile force will be much larger than what will be experienced, because of assumptions of a single winch system, weightless tethers and camera mount, and excessive winds. Designing higher than this max tension will introduce extra safety margins.

$$T_{max} = \sqrt{F_d^2 + F_t^2} \tag{2}$$

4.3 Summary of Options and Tradeoffs

A thorough research of options resulted in the analysis focusing on three possibilities: Fishing Line, Paracord and Arborline. The team chose fishing line because of it's weight and cost per meter, smaller diameter and tensile strength of over 400%, the max tensile strength expected (Table 2). Paracord and Arborline both were strong enough to work for this project but were either too expensive or weighed too much for this particular application. However, fishing line, as a dense, white and thin material, is more dangerous to bystanders and harder to see. Ultimately, these issues were less important for a prototype system that required a more affordable solution.

Table 2: Summary of Tether options and tradeoffs. Fishing line is chosen for it's lower cost and weight per meter.

	Fishing Line	**Paracord**	**Arborline (Dynaglide)**
Tensile strength	130 - 450 N	2450 N	4450 N
Weight per m	<1.71 g/m	6.574 g/m	3.0 g/m
Diameter	0.58 - 0.89 mm	3.175 mm	2mm
Safety	Medium	High	High
Visibility	Low	High	High
Malleability	Low	High	High
Cost per 100'	$6.67	$10.95	$19.50

5 Camera Mount Design

5.1 Camera Mount Overview

The camera mount system needs to be modular so that it can be upgraded (or downgraded) for the customers specific needs. The basic frame consists of a circular plastic ring with mounting holes for various winches. The ring contains mounting positions for the pan and tilt servos as well as the associated circuitry. The circular shape is advantageous because it allows for easy panning of the camera. Furthermore, the circular design should provide some measure of protection to the electronic components that communicate with the computer and control the servos. Alternative designs were considered but they did not allow the ease of panning that the circle provided.

5.2 Role and Requirements of Camera Mount

The camera mount system is a very important component because it provides the basis for controlling the camera orientation. The most important aspect of the camera mount is that it has to be lightweight. Because the balloon can only lift a very small amount before size becomes a major factor, the camera system has to be as light as possible. At the same time however, the system has to be sturdy enough to provide a stable base for the camera. Unstable video footage is unusable and is a major concern for most of the customers. The camera mount is required to be durable against impacts, provide stable video, be efficient in weight and contain enough battery power to provide video footage for an extended period of time: four hours minimum (Appendix A).

5.3 Summary of Options and Tradeoffs

With the tier-based system, the camera rig has the capability to have different parts added as necessary, thus providing a number of options to the customer. If customers require a basic system, they can purchase a lower tier system. If they later decide that they want more functionality, they can purchase the components necessary to upgrade their system.

The biggest tradeoff that had to be made was the stability of the camera rig versus the weight of the system. By adding more weight, the systems could be very stable, however, that would have meant that the balloon would have to be very large to lift the weight. A large balloon will cost more to purchase and fill with helium. Another tradeoff is in the control of the camera pan and tilt. As the control of the system increases, the camera will have improved stability, however, this will increase the weight of the overall system and necessary complexity of the control system. Ultimately, a tradeoff between size and complexity of the camera mount was to design a system that provides the necessary control and stability without the need for an expensive balloon. Our design utilizes a laser cut platform, servos and brackets to provide mounting locations for the camera, control electronics and tethers while minimizing the weight of the system.

5.4 Platform

5.4.1 Design Iterations

As the system was designed in Solidworks, there was no need to simplify the structure of the camera mount. We created it how we wanted it to actually look. Because we laser cut the platform, however, we were constrained by that process. We couldnt add certain elements because the laser cutter couldnt do them. These features include filleted edges or changes in thickness. Adding these features would add extra work and thus extra cost towards the final system, so designing a camera mount that could be cut from acrylic and be ready for deployment was ideal.

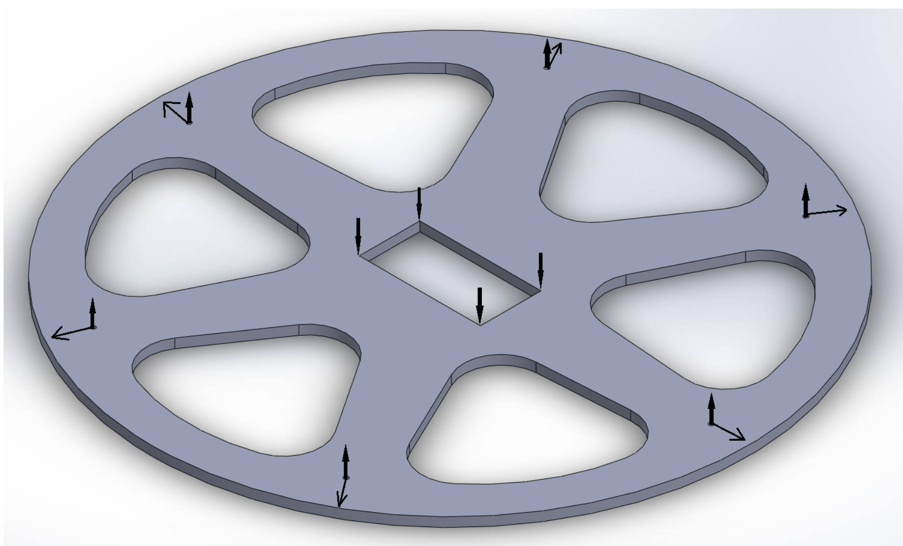


Figure 5: The forces acting on various parts of the camera platform for a three winch system are shown. The direction of the arrow indicates the direction of the force

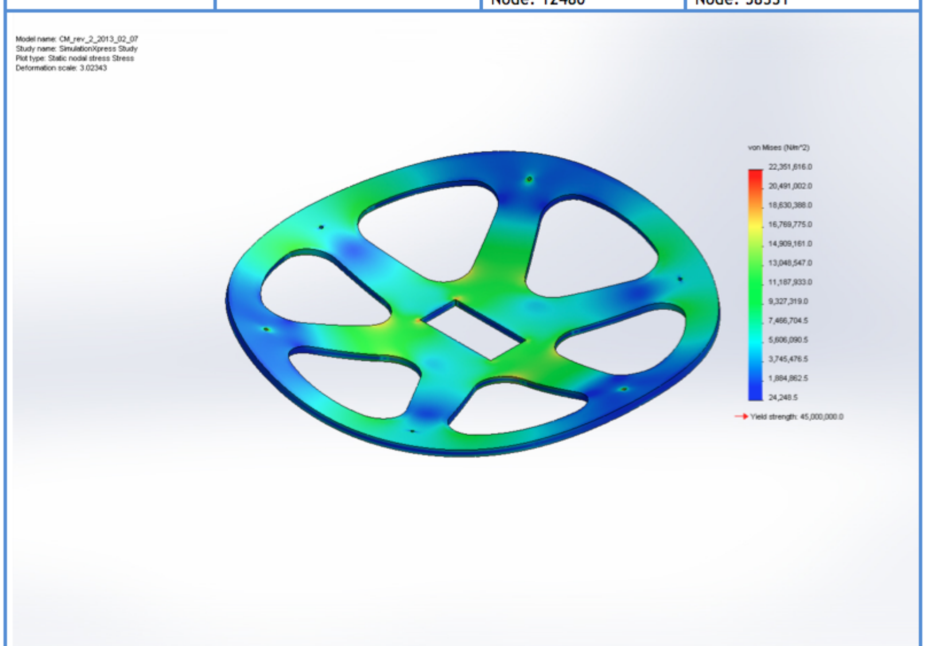
Once the initial requirements for the platform were established, we decided on a circular frame, which would provide needed stability. This design would also be easily upgraded and adaptable to multiple different customer needs. With a circular fame, one to three winches could be connected and the platform would still be able to maintain a parallel angle to the viewing surface. Once the geometry of the platform was decided, the overall diameter was analyzed. With a smaller diameter for the platform, the weight of the camera system would be reduced. Initially we used a ten-inch diameter frame. This design was then tested using a finite element analysis and we concluded that a smaller frame would not only improve the overall strength of the platform, but also reduce the total weight. From here we reduced the diameter to eight inches and used a quarter inch thick, medium high impact acrylic. The final design of the platform can be seen in Figure 5 with the appropriate forces acting on it.

Downward forces around the square represent the mounting of the pan and tilt bracket and the camera. The upward forces represent the tensile force from the tether connected to the balloon. The horizontal forces pointing towards the edges are the tensile forces from the tethers connecting to the winch.

5.4.2 Finite Element Analysis

In order to quantify the strength and durability of the platform we performed a finite element analysis on the three-dimensional CAD model. When performing the Finite Element Analysis in Solidworks, the criteria used to determine failure was the von Mises stress criteria. Developed between 1865 and 1913 this criteria states that yielding of the material (acrylic) begins when the second stress invariant values reaches a critical point. This theory assumes that prior to failure (yielding), the material is elastic (von Mises). Figure 6 shows the stress distribution on the camera platform.

Name	Type	Min	Max
Stress	VON: von Mises Stress	24248.5 N/m^2 Node: 12480	2.23516e+007 N/m^2 Node: 58331



CM_rev_2_2013_02_07-SimulationXpress Study-Stress-Stress

Figure 6: Von Mises stress report for the camera platform.

This FEM analysis simulated the forces and deformation our final product would endure by taking into consideration the diameter, thickness, material, forces due to the balloon, camera and winches, as well as cut-outs in the frame. By simulating the stresses acting on the frame, we were able to see where the highest stress would occur and potentially lead to failure. We initially anticipated that the acrylic would crack or undergo permanent deformation due to the applied loads. The loads we applied to the model included tension from the tethers pulling on the acrylic and from the weight of the camera itself pulling down in the center of the camera mount. This included the effect of wind applied on the balloon which increased the tension in the tether lines. The results from the analysis can be seen in Figure 6. These results demonstrate that the overall design of the platform would undergo minimal deformation due to the applied loads and provide a stable overall platform.

5.4.3 Manufacturing

Manufacturing of this part would be fairly simple. Since the material used was a quarter inch thick medium high impact acrylic, the platform would be laser cut to the specified dimensions. The CAD drawing would allow an exact replica every time by providing the appropriate dimensions to the laser cutter.

5.5 Pan and Tilt Bracket

5.5.1 Design

The design for the pan and tilt brackets, which adjust the view of the camera, was modeled after smaller components purchased from online retailers. Since we used larger servos, an updated version of the initial product was needed. This basic design consisted of square U shaped brackets made of steel. These ends were bent to 90-degree angles and were inverted and attached to one another, by using a pin on one side of each bracket. A completed view of the brackets can be in Figure 7. While 360 degree rotation was desired, the servos only provided 60 degrees of rotation for the pan and tilt.

5.5.2 Manufacturing

Minimal manufacturing was necessary for the brackets, since a basic steel sheet metal was used. This was then cut to the appropriate dimensions, and bent into shape. Prior to bending the bracket into shape, the four holes necessary to attach the servos were drilled using a drill press. These three steps require basic machinery and simple procedures allowing ease of manufacturability.

Figure 7: Pan and tilt brackets used to maneuver the camera.

5.6 Electrical Design

The camera mount electronic design is a simple combination of off-the-shelf components. As discussed, the goal of the camera mount is to provide proper orientation for the camera. To accomplish this proper orientation, hobby servos were used. These require power to be provided between 4 and 6 volts and a data signal to tell the servo the angle desired. In order to provide data and power, a hobby RC receiver and battery are used. The battery provides approximately 6 volts when fully charged. A 5 channel RC transmitter, designed for use with hobby radio controlled aircraft, is used to provide the signal from the user to the camera mount. The onboard radio receiver takes this signal and sends it on to the servos. The battery is a multiple cell Nickel-Metal Hydride battery that provides 1 amp hour of charge.

5.7 Communication and Control

Communication is accomplished, as mentioned, with hobby-class radio transmitters and receivers. This system provides excellent reliability and range. Unfortunately, this system is limited to direct user control with a hand-held remote control. Currently, the system features no stabilization onboard the camera mount as it is outfitted with simple hobby electronics.

Future work would include utilizing a microcontroller, compass and gyros to determine the orientation of the camera mount and provide accurate control and disturbance rejection to the pan and tilt servos. These improvements would greatly improve performance and is a design goal for future systems.

5.8 Camera

5.8.1 Summary of Options

Multiple different camera options were considered. The most practical, however, was the GoPro due to it's weight, overall reduced size and filming capabilities. Alternative cameras considered were larger in size and weight. For our target audience of athletic teams, the GoPro provided clear, and detailed footage of high enough quality to provide feedback to the teams. The footage from the GoPro was clear and stable enough to allow the teams to improve their technique and usable for any desired purpose.

- Angle View:
  - Angle of View: 170 wide angle available in all modes
  - Angle of View: 127 medium angle in 1080p, 720P, or WVGA mode
  - Angle of View: 90 narrow angle in 1080p or 720P mode
- Video HD Video Resolution Modes:
  - 1080p = 1920x1080 pixels (16:9), 30 fps
  - 960p = 1280x960 pixels (4:3), 30 fps or 48 fps
  - 720p = 1280x720 pixels (16:9), 30 fps or 60 fps
  - WVGA = 848x480 pixels (16:9), 60 fps or 120 fps
  - Light Sensitivity: Professional low-light sensitivity (¿0.84 V/lux-sec)
- Storage
  - Memory: SD card (SDHC), up to 32GB capacity (not included)
  - Average Recording Times (using 32GB SD card):
    - 1080p (30 fps): 4h
    - 960p (30 fps): 5.5h
    - 720p (60 fps): 4h
    - 720p (30 fps): 6h
    - WVGA (120 fps): 4.5h

- Power & Battery
  - Battery Type: Rechargeable 1100 mAh lithium-ion
  - Battery Life: Approximately 2.5 hours [1080-60FPS 30minutes]
- Size and Weight
  - Dimensions (H x W x D): 1.6" x 2.4" x 1.2" (42mm x 60mm x 30mm)
  - Weight: 3.3 oz (94g) including battery / 5.9 oz (167g) including housing

5.8.2 User Interface

The current camera system uses a separate user interface from the winch system. This consists of a RC transmitter, which adjusts the viewing angle of the camera and the GoPro iOS or Android application which receives the video feed in real time. Ideally, for a future project both the live footage and control would be integrated into a single user interface such as a smart device application that can be used directly from a smartphone or iPad. This combination of interfaces would simplify our product and improve it's ease of use. Our final design prototype does not include this integration and requires two separate systems to properly control the camera footage.

5.9 Integration

The overall camera mount subsystem consists of the platform, two servos, metal brackets, battery pack, RC receiver, and GoPro. The platform contains a rectangular cutout in the center of the platform where the first servo slides in and is attached by two screws. The first bracket is then connected to the top of this servo with two additional small screws. This bracket-servo connection provides the tilt function for the camera. The second bracket is then attached on the inside of this bracket by being epoxied to the inner frame. This servo is then screwed onto the side of the second bracket. The two brackets are then joined on the opposite side from the servo connection using a pin. On the underside of this second bracket the GoPro would be connected using the given sticky clip provided. This clip would be snapped onto the bracket, and then the adhesive peel would be removed, attaching the GoPro. The electrical component to the Camera mount system would consist of the wiring from the two servos and a small battery pack. The battery pack would be velcroed to the top of the platform on one side of the cut out rectangle, securing it in place. The cable from the battery would be inserted into the electrical box along with the two additional cables from the servos. This box would also be velcroed to the top of the platform on the other side of the rectangular cut out. Figure **??** is provided as a reference to help visualize the integration of each component.

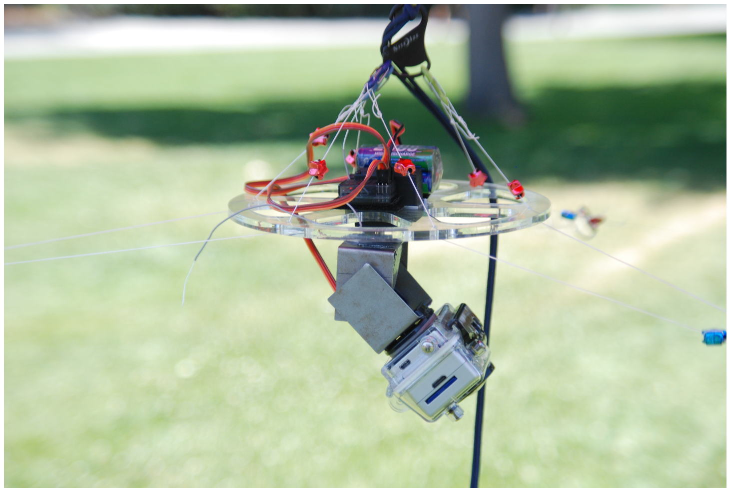


Figure 8: Integrated Camera Mount

In Table 3, one can see the mass budget for the final camera mount prototype. The largest weight penalty for this subsystem was the GoPro camera and the servos and brackets. Each of these weighed close to 200 grams. Overall, the whole system weighs 757 grams which is under the maximum lift from the balloon as can be seen from the balloon analysis, section 2.6.6.

Table 3: Camera Mount Mass Budget

Component	**Mass (KG)**
GoPro with Case and Wi-Fi Backpack	0.206
Balloon Tether	0.047
Battery	0.121
RC Receiver	0.008
Pan/Tilt Motors and Brackets	0.207
Acrylic Frame	0.135
Miscellaneous	0.033
Total	0.757

6 Winch Design

6.1 Winch Overview

To create an inexpensive, portable aerial viewing device, a camera station hoisted by a balloon is connected to a modular number of winches, which alter the height and position of the camera. These winches are controlled by an application at a ground station. To set up this product, users would decide to use either one, two, three or four winches. By using a single winch, one would only have vertical control. Two winches would allow two dimensional planar control. Three winches would enable the final degree of freedom, allowing the camera to move to any position within the bounds of the winches. Finally, the use of four winches would provide more stability compared to the three winches.

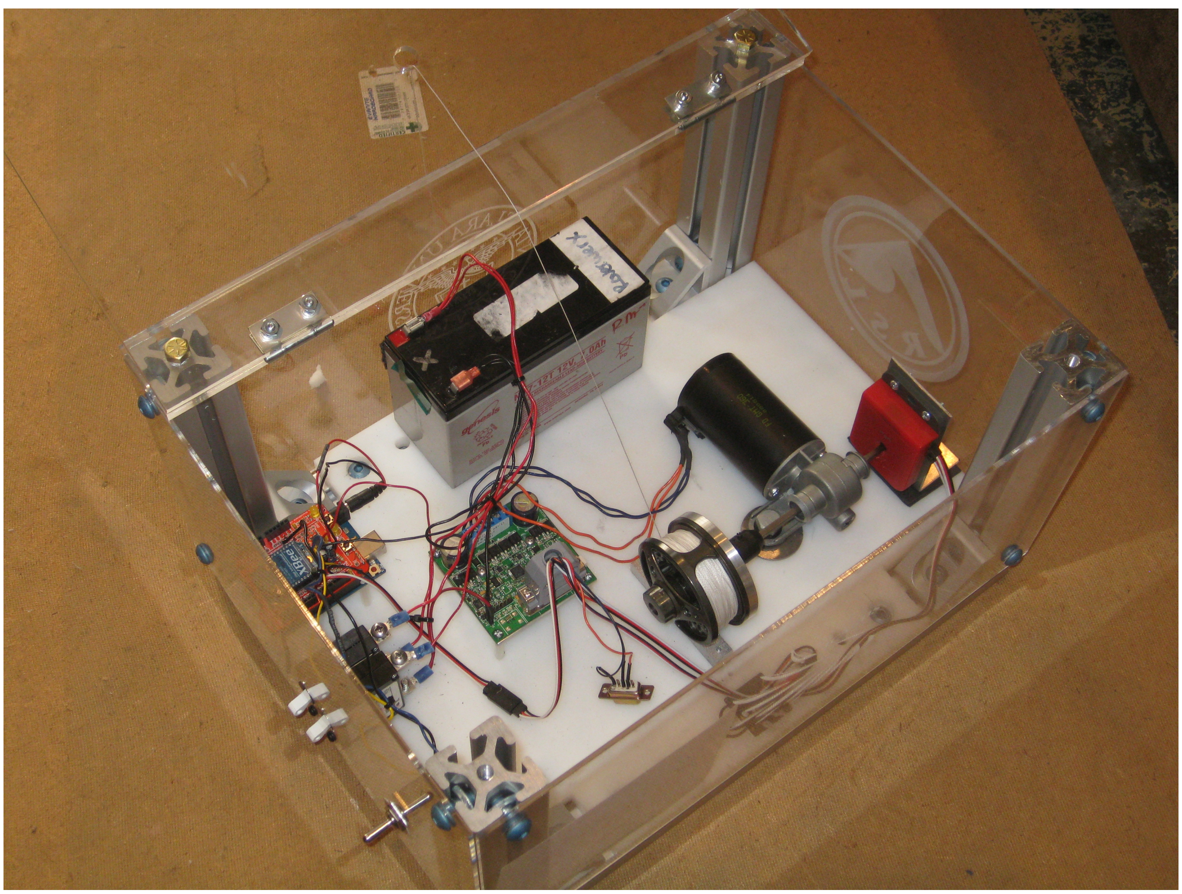


Figure 9: Final construction of the winch with the lid open. The motor, reel, and electronics can be seen.

6.2 Role and Requirements of Winch

The role of the winch is very important because it prevents the balloon from flying off. Furthermore, with multiple winches, the camera can be moved from one location to another. This is important for maintaining a close proximity to the action. The housing of the winch also plays a key role in protecting the electronics, reel and motor from damage. Because of the proximity of the winch boxes to the field of play, the housing needs to be strong enough to withstand impacts from sporting equipment and environmental conditions.

The winches have a number of requirements that they must meet. First, the winches have to be heavy enough that they wont be lifted off the ground by wind gusting on the balloon. At the same time however, the cabling connected to the balloon has to be as light as possible. With every winch that is added, the weight of the cabling that is attached to the camera system increases. On the other hand, the cabling also has to be strong enough to prevent a gust of wind from jerking the balloon up and snapping the cables, resulting in a loss of the camera system. A final requirement is that the winches have a quick enough reaction time in order to keep up with the action.

Although commercial products could be adapted to this specific role, the winch subsystem was designed and prototyped by the senior design team to fit the needs of the overall system. This design was subject to numerous requirements and needs. A tradeoff between these requirements determined the overall design of the subsystem and is discussed in the following section.

6.3 Summary of Options and Tradeoffs

No purchasable products exist that fulfill all of the requirements of the system. Those that do exist provide a couple of the necessary requirements but fail to provide all. For instance, available electric winches provide good stability and durability, but fail to be quick enough for this products requirements. Alternatively, motorized fishing reels provide a speedy response but fail to provide stability or durability. Likewise, none of the purchasable products can be controlled from a computer base station. The best option for the system is a prototype specially designed and constructed for the ICARUS system.

The primary tradeoff on the winch design is between increasing the weight, and therefore the stability and durability of the design, versus maintaining the portability of the winch. The winch is required to be heavy enough to ensure that the system is grounded and wont fly away. However, the winch also needs to be small enough to be easily moved by a single person. Another tradeoff is the need for speed and power in the tether response versus the longevity and battery life of the winch. As our system increases in power, the response time improves. However this power increase causes the battery life of the overall system to degrade. A similar tradeoff for the winch design involves the overall size of the winch because, as the winch size increases, the necessary battery size increases which improves the power and response of the system but degrades the portability or mobility of the system.

6.4 Hardware Design

6.4.1 Parts and Assembly Selection and Design

The backbone of the winch is the half inch thick high density polyethylene (HDPE) plate that all the components were mounted to. This was chosen because it is inexpensive, workable, and structurally solid. Through the design process, it was possible to modify the existing bases as the design changed because of the ease with which they could be cut, drilled and tapped. The uprights of the winch were constructed from aluminum T-Slot extrusions. These proved to be a great choice because they not only provided structural rigidity but allowed for easy mounting of components through the use of slide in nuts. With these, it was possible to easily attach the acrylic siding and the HDPE plate. The final winch boxes had a footprint of 12 x 16 inches and were 8.5 inches tall with a final weight of 25 lbm. This allowed them to be easily carried while still having enough mass so as to not be carried off in a strong gust of wind. Furthermore, through filming various sports, it was determined that the structure was strong enough to hold up to typical impacts from sporting equipment.

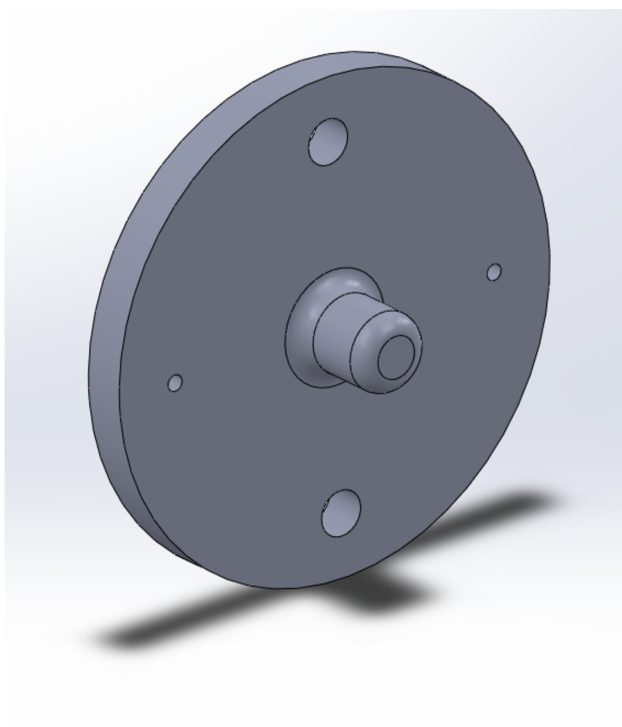


Figure 10: Aluminium reel adapter to convert rotation from the motor to the reel.

As mentioned previously, a major challenge was converting power from the motor to the reel. The adapter that was designed was lathed from three inch diameter aluminum stock. The part drawing can be seen in Figure 10. To put a square hole in the end of this adapter would have been expensive so a coupler was found which converted from a round shaft to a square shaft. The adapter itself has two holes which match up with holes in the reel. Through these holes, pins are connected which drive the rotation of the reel.

The motor itself was a 500 RPM, 12 VDC motor, that was purchased from an online surplus dealer. This motor gave plenty of speed while being inexpensive to purchase ($13.99). Similar motors in that speed range were much more expensive. The motor had a $\frac{5}{32}$" (4mm) thru-shaft and while this shaft size was easy and inexpensive to purchase, part of it needed to be ground down so that it would fit into the encoder which has a thru-shaft size of $\frac{1}{8}$". The shaft can be seen in Appendix I, Figure 32.

The reel itself is connected to the base through a simple metal bar. This bar is constructed from aluminum and serves a dual purpose. It connects the reel to the base and raises the reel up to an appropriate height so that the shaft from the motor to the reel is horizontal and not at an angle. If there was an angle in the shaft, a wobble would develop that could result in either the reel or the motor breaking.

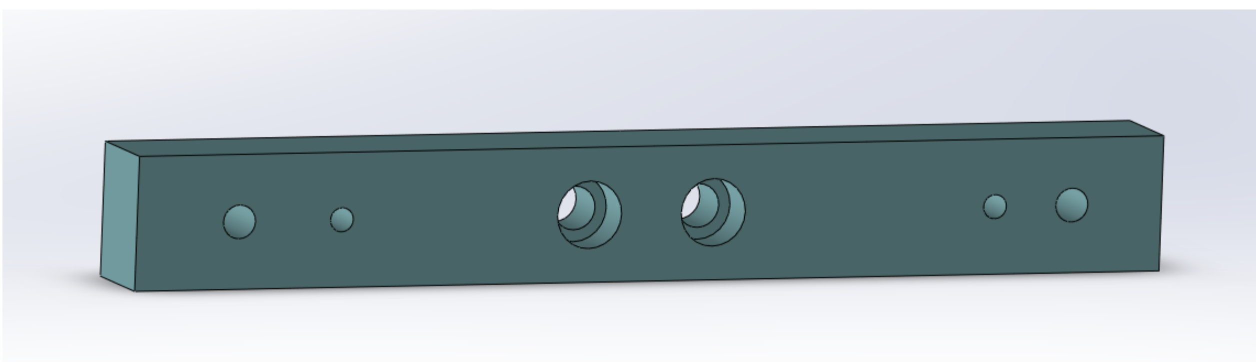


Figure 11: CAD file of the reel mount

Another major component of the system is the encoder. This counts how many rotations the motor makes and can be translated into tether lengths. To hold the encoder in place, a simple L bracket was made that the encoder is screwed to. This encoder was made from steel sheet metal. The steel sheet metal created a solid structure that held the encoder in place without flexing too much while the shaft rotates.

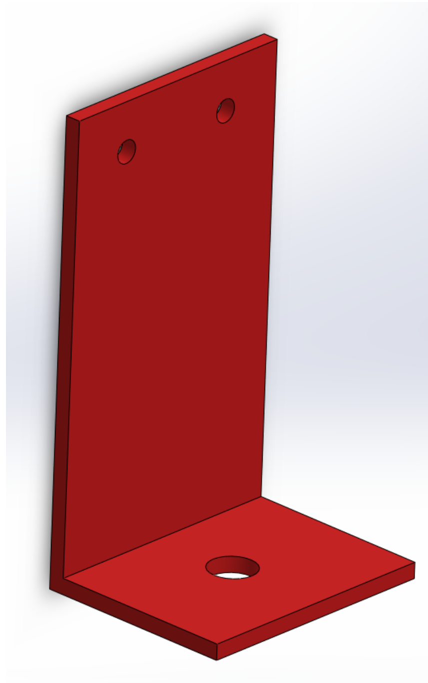


Figure 12: L Shaped Encoder Bracket

6.4.2 Manufacturing

The winch was initially designed so that it could be built from off the shelf parts. However, through the design and construction phase of the project, this became less of a reality. Because of the prototyping nature of the design, the winch needed to be made large to accommodate different components and easily modifiable so that components could be added or removed as needed.

The construction of the winch was carried out in the Santa Clara University machine shop. The major machines used to construct the parts include the lathe, mill, drill press and band saw. Future developments in the manufacturing process would include the use of a off the shelf box. This would eliminate the need for constructing one however simple modifications would still need to be performed on the box for attaching components. The reel adapter would be sent out to a machine shop for manufacturing as well as the reel mounting block. The only necessary assembly would be the putting all of the components together to build the winches.

Manufacturing of the winch is relatively simple. First the T-slot extrusions are fitted with the slide in nuts.The 16” extrusions each get 4 nuts in the same slot. The 8” extrusions have one nut each. The 16” extrusions are then connected to the 8” extrusions by a triangle bracket, part number W17, and screws W32. The HDPE base is then attached via the same screws (W32) to the 16” extrusions.

Next the reel is attached to the reel mount. The reel and reel mount is then attached to the base by 2, 4-40 x 1” screws (W34). The coupler attaches to the reel adapter and a rubber mallet is used to ensure the coupler is fully in place. The coupler and the adapter are then placed into a mill and the hole is drilled for a pin to be driven through. The reel adapter is attached to the reel by 2, 4-40 x $\frac{1}{2}$” flat head screws (W30). The motor is now attached to the base by 2, $\frac{3}{8}$ x 1.5” bolts. The drive shaft can now be connected through the motor to the coupler and the reel adapter. The encoder, which is attached to the encoder bracket by 2, 6-32 x $\frac{1}{2}$” screws, is then attached to the open end of the shaft.

The next components to be attached are the electronic circuit boards. First, nylon standoffs are mounted to the base. The motor controller and Arduino board are attached to the standoffs by 4-40 screws. The prototype board and Xbee are attached onto the Arduino board. These components are developed in more detail in the following section. Finally, the acrylic siding is attached by the screws and nuts to the 8” extrusions. Then the wiring is completed as per the wiring diagram in Appendix M.

6.5 Electrical Design

The electrical design of the winch subsystem centers on providing power to each individual component and allowing each component to communicate. Each winch contains three main components: an XBee radio transmitter and receiver, an Arduino microcontroller and a Roboteq SDC1130 motor controller. All components need to receive power from the same battery, however, the motor draws enough current to damage the control circuitry. To avoid this damage, two separate power lines are used with individual breakers to ensure the safety of the overall system. The power and communication interactions can be seen in the simple electrical block diagram (Figure 13).

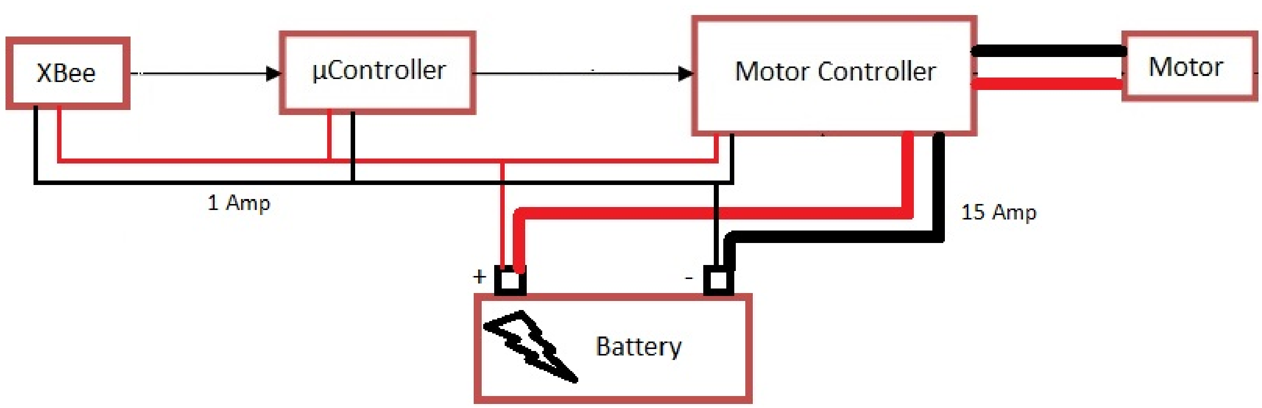


Figure 13: A simple electrical block diagram showing how a single 12 volt battery powers the isolated motor and the three electrical components: motor controller, micro controller and radio. It also shows how each component communicates.

Furthermore, the 12 volt rated battery is known to fluctuate above 12 and as high as 15 volts. Since the Arduino microcontroller is rated to less than 12 volts, the control circuitry must be regulated. To achieve this, a 9 volt regulator is used before the Arduino and after the motor controller to drop the voltage to acceptable levels with 100 micro farad capacitors from power to ground to eliminate any fluctuations. This protects the Arduino and XBee from voltage spikes and fluctuations. Power is transmitted from a single 12 volt source through two separate breakers to limit the current to within the limits of the system. The motor draws from a 15 amp line that is isolated from the control circuitry on a 1 amp line and the sealed lead-acid battery provides 7 amp hours of charge.

To improve the setup process, expedite testing and provide a fail safe mode of operation, a manual switch is added to the exterior of the winch structure which allows the user to reel in and out the tether line at will. A single pull double throw switch is connected to the interrupt pins 2 and 3 on the Arduino. To reduce false readings, the switch is connected with 10 micro Farad capacitors to ground and 10 kilo ohm resistors to power. A low value on the interrupt pins triggers a secondary script to run interrupting the main script and reeling in or out the tether line. This introduces an offset which does not return to zero when the switch is no longer held.

To connect to the motor controller, a 15 pin connector is provided with the appropriate pins labeled on the data sheet. Connected to this are encoder data, power, and ground lines, the Arduino communication line, and a 9 pin connector for computer debugging. While only one quadrature encoder is used per winch, each encoder has two separate sensors to function properly. Both of these sensors requires a power and ground as well as a data line which alternates between low and high to provide the speed and direction of travel. The TTL serial communication lines allow the Arduino to transmit commands to the motor controller and receive information. These are connected to the microcontroller pins 12 and 13 and operate on software serial protocols. Finally, the 9 pin connector allows the user to debug issues with the motor controller.

The electrical design is shown in detail in the wiring diagram in Appendix M.

The team thought the best method of implementing these electrical designs and circuits was to use a prototyping board and solder the components together. This was accomplished with a prototyping board Arduino shield purchased from the online retailer Sparkfun. The XBee transmitter shield was soldered to the board to enable a sturdy, permanent location to insert the wireless transmitter. Next, the voltage regulator was soldered to the board. Finally, the switch circuitry was wired to the board and the input and output lines soldered to the appropriate pins. Using this prototyping board, a consistent, reliable and durable electrical setup was achieved.

6.6 Control System Design

The design of the control system utilized a system-wide open loop control system and the on-board motor controllers closed loop proportional integral derivative (PID) controller. Figure 14 shows the control system block diagram and describes the flow of information from the user down to each individual winch. The user interacts with the system through a joystick which allows the user to specify a specific velocity and direction to move the balloon in three dimensional space. This velocity is then turned into a series of discrete positions in the x, y and z coordinate frame which is taken as an input to our open loop control system. The signal is converted by mathematical operations into each desired tether length and constrained to the physical working space limited by physics. These winch lengths are compiled into a command packet and sent to each winch.

Each winch receives the same command packet and can decipher which message is for each particular winch. Seen in the lower portion of Figure 14 is the winch subsystem. This command packet is received by the XBee radio and read by the Arduino microcontroller. The Arduino takes the packet, parses the command with its address and then sends the data to the motor controller. The motor controller is hooked up to the motor as well as the encoder which allows the motor controller to perform a PID closed loop control at the winch by accepting the desired location from the Arduino and achieving that position with the encoder information. This section will discuss our implementation of this control system design.

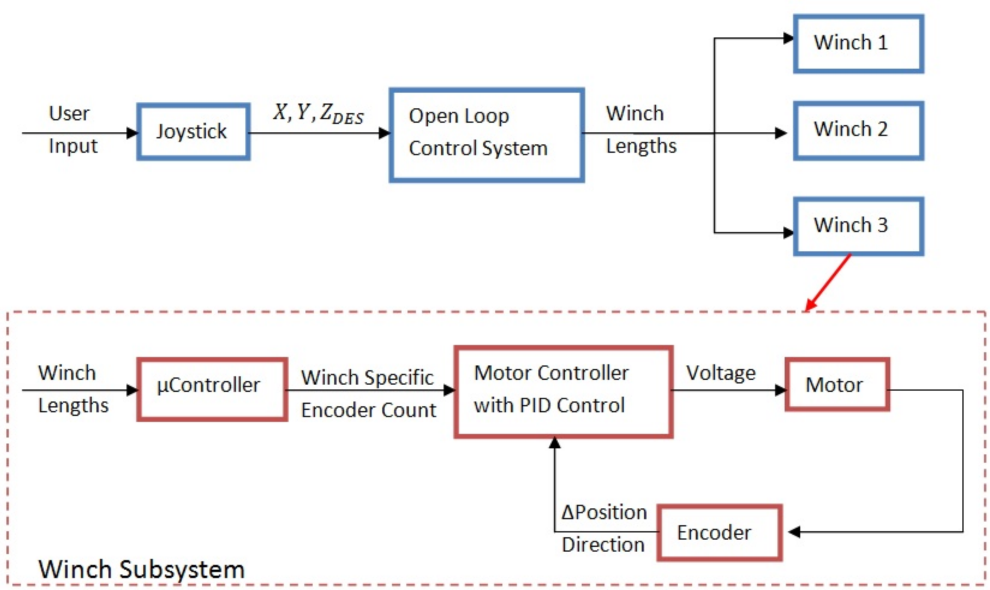


Figure 14: The winch control system block diagram showing the flow of information from the user input to each winchs motor output. An open loop control system determines commands sent to each winch while a motor controller utilizes a closed loop PID controller to acquire the desired position.

6.6.1 Mathematical Computations

There are two different computations that need to be conducted with this control system. The first computation that Matlab conducts calculates the position of the camera subsystem with respect to the axes. The origin of the workspace is located at the first winch. The X axis is defined as the line between the first and second winch. The Z axis is a vertical line from the first winch and positive towards the sky. The y axis is therefore defined as per the right hand rule. The third winch is placed in the negative y and positive x direction. (Figure 15)

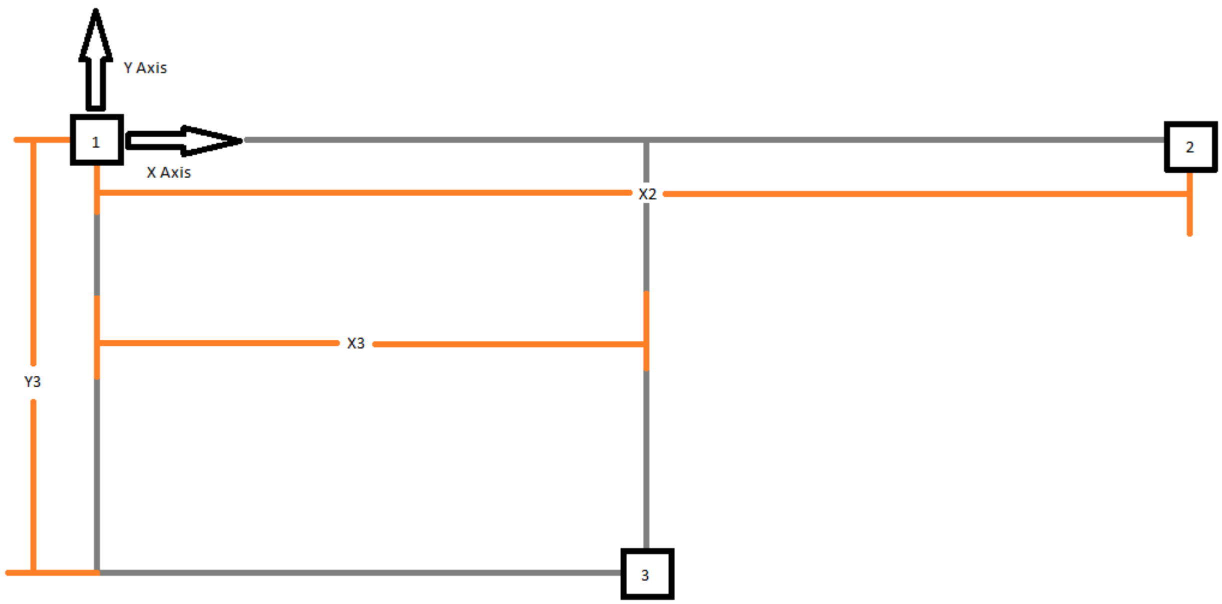


Figure 15: The winch subsystem workspace; the orange lines mark the distances between the winches.

With the defined axis, the position of the camera subsystem is determined from user input into the control system, however, the camera position must be maintained within the allowable workspace. It is physically impossible for the camera system to leave the allowable workspace defined as a triangular area with the vertices located at the winch positions (Figure 16). The control system bounds work by actively forcing the camera away from the edges of the workspace. The bounds are only applied when the camera is within a specified distance from the edges.

The first few bound equations affect the Y position of the camera mount. The first bound equation acts on the edge, defined as the line Y equal to zero, and is defined as the sum of Y and a safety distance (SD) then divided by the safety distance. This is then negated (Equation 3). The second bound equation acts on edge 2, between winch 1 and winch 3. M_a is the slope of the line defined as the Y position divided by the X position of the third winch

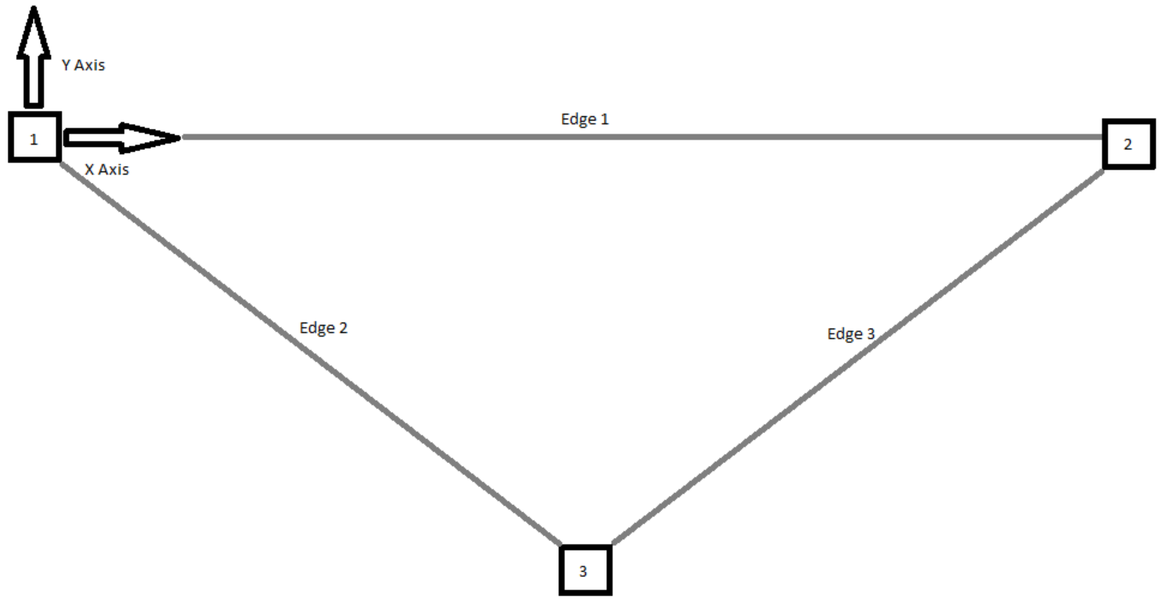


Figure 16: The allowable workspace; this shows the region that the camera is bounded to.

(Equation 4). This bound equation is more complicated and given in Equation 5. The final bound equation acts on edge 3, between winch 2 and 3. M_b is the slope of the line defined as the Y position of winch 3 divided by the difference in X position between the third and second winch (Equation 6). This equation is just as complicated as the second and is shown in Equation 7. These equations compare the current Y position of the camera system with the location of the line.

$$\frac{Y_C + SD}{SD} \tag{3}$$

$$M_a = \frac{Y_3}{X_3} \tag{4}$$

$$\left(\frac{|Y_C - M_A X_C|}{\sqrt{M_A^2 + SD}} \right)^{-1} \tag{5}$$

$$M_b = \frac{Y_3}{X_3 - X_2} \tag{6}$$

$$\left(\frac{Y_C - M_B X_C + M_B X_2}{\sqrt{M_B^2 + SD}}\right)^{-1} \tag{7}$$

The Y bounds are sufficient to constrain the system within the allowable workspace within the X-Y plane and as such, bounds on the X position of the camera are redundant. The final bound equations affect the vertical distance of the camera. The first such bound equation constrains the system to the maximum allowable height as defined by the user (Equation 8). The second constrains the camera to above a minimum allowable height (Equation 9). The final equation constrains the camera to within the maximum tether length, MTL (Equation 10).

$$\frac{H - SD - Z_C}{H - Z_C} \tag{8}$$

$$\frac{SD - Z_C}{SD} \tag{9}$$

$$\frac{MTL - SD - TL_W}{MTL - SD} \tag{10}$$

The second function of our Matlab control system is to compute each individual winch tether length. These lengths are then sent as a command to each winchs microcontroller. To compute these lengths, the positions of the winches and the camera subsystem are used with a version of the Pythagorean theorem. This computation is done for each winch as shown in Equations 3 through 6

$$D_w = \sqrt{(X_C - X_W)^2 + (Y_C - Y_W)^2 + (Z_C - Z_W)^2} \tag{11}$$

6.6.2 One Winch Design

The one winch control system was the easiest one to create because it only used one degree of freedom. This means that the system can only be controlled in 1 direction at a time. This translates to the camera mount to only be able to go up or down. Shown in Figure 17 is our implementation of this control system in Simulink. This implementation is simpler than our other control systems because it only includes an integrator with the included saturation limits acting as bounds.

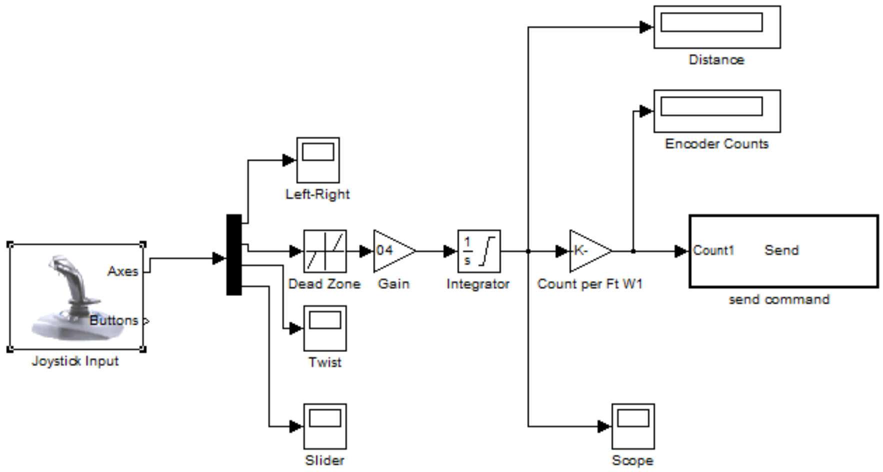


Figure 17: One Winch Control Model

6.6.3 Two Winch Design

The two winch control system allows for movement in two degrees of freedom adding complexity. This means that the camera can only go two different directions, up and towards or away from the winch. Our implementation of this control system includes bound calculations and the Pythagorean computations (Figure 18). This is more complex than the one winch design control system. Detailed figures of the subsystems are included in Appendix J.

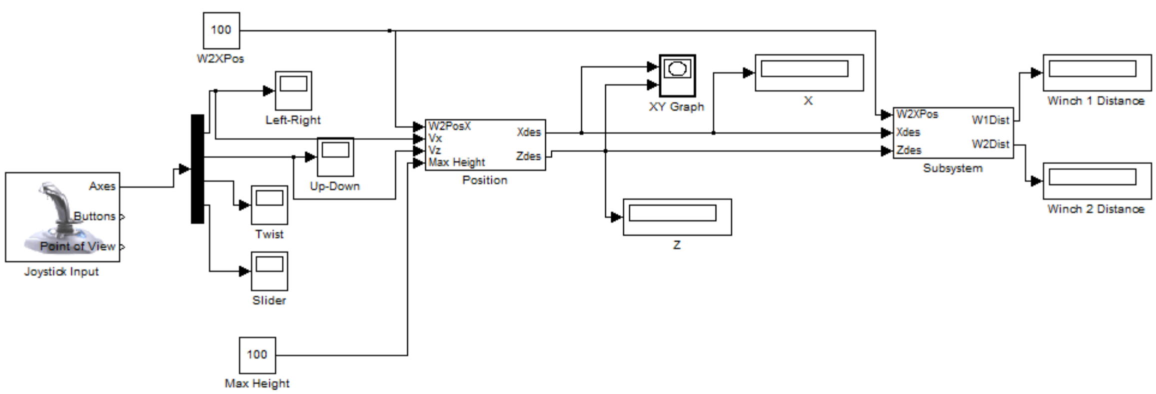


Figure 18: Two Winch Control Model

6.6.4 Three Winch Design

The three winch control system features a full three degrees of freedom and much more complexity in design (Figure 19). The computations are conducted as per section 6.6.1

and result in a completely constrained and appropriate system. In each of these control system designs, gains are included to adjust how quickly the system moves with respect to the user input. Finally, Matlab functions are used to communicate within the Windows OS framework and the Matlab program through the wireless radios. Detailed figures of the subsystems are included in Appendix J.

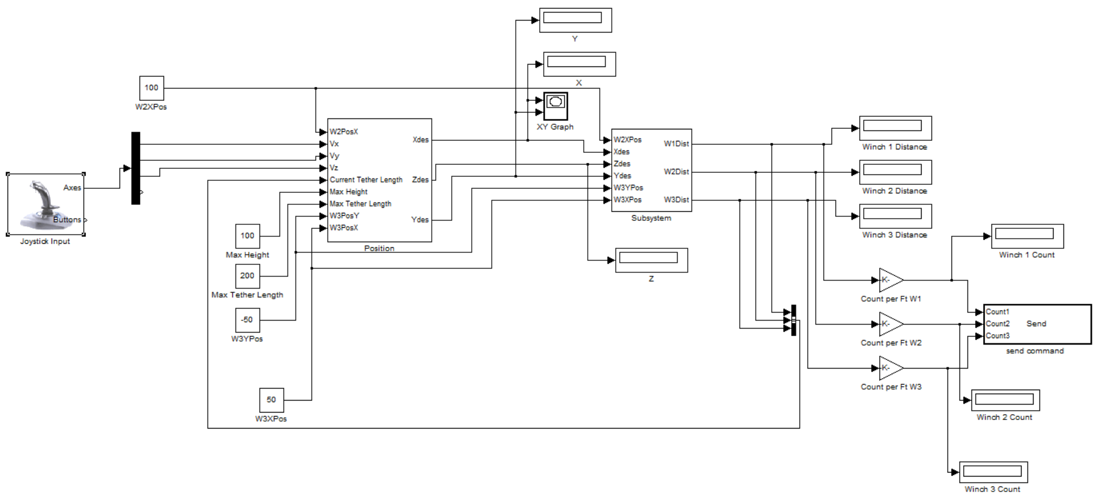


Figure 19: Three Winch Control Model

6.6.5 Communication Integration

Communication for the winch subsystem relies upon code and protocols developed by Mike Vlahos and Chase Traficanti as part of their work in the Robotic Systems Laboratory at Santa Clara University. The code provided was modified to work with this project. The goal was to be able to transmit data information from the central computer with the user interface to each individual winch. It was also desired, as a secondary requirement, to have the ability for the computer to receive information back from each winch.

The main challenge was integrating the protocols developed with the hardware acquired. After some trial and error, the team settled on using series one XBee radios. Each of these radios was programmed with a distinct address but listened to a single transmitter programmed in broadcast mode. This meant that the same message sent from the computer would be received by any number of winches. This allows for modularity in the project and theoretically allows any number of winches to be used.

However, this modularity increases the complexity of the commands sent. Since each winch receives the exact same command, differentiation and addressing had to occur in the actual packet received. Therefore, each command is compiled by the computer into a command packet which contains addresses and data for each individual winch that is operating in the experiment.

The computer compiling occurs by utilizing functions in Matlab. A Simulink function is created which writes a vector of addresses for the winches and a vector of the data. The data exists as a set encoder count, however, the function takes the encoder count and places a P" character in front as a means of letting the Arduino know that it is receiving a position command. This function is easily scaled to the appropriate number of winches. The function then sends these vectors to the compiling functions developed for Matlab. These functions take the vectors and assemble packets that contain two signs as delineators of a new message, the send address, the computers address, the most significant bit, the least significant bit and finally the appropriate message (Equation 12). This compiling is done for each winch and then formed together into a single message packet.

$$\{@@\}\{z\}\{A\}\{0x00\}\{5\}\{......MESSAGE...HERE.....\} \tag{12}$$

This compiled packet is then sent to the XBee through a Windows program called Data Turbine which acts like a digital pipe connection between a communication port and the Matlab program running our scripts. The XBees communicate as described previously allowing for each winch to receive the command packets. Matlab code has been completed which would allow for the receiving of data from the winch microcontrollers, however, it has not been implemented into the control system. This receive script functions as the reverse of the send commands with similar protocol and results.

Once the command is broadcast, the XBee radios on the winches pick up the commands and send them to each Arduino microcontroller. In the Arduino code, to be discussed in a future section, the message must be decompiled. Previous work from Mike Vlahos was implemented on this project. This code works in the background of the Arduino. After setting the XBee to listen to the appropriate channel and telling it what its specific address is, Mikes code can process the message and deliver the exact message needed to each winch. This is found to perform best at a data rate of 19,200 bits per second and a very short delay between searching for a message. Furthermore, Mikes code will scan for corrupted packages and corrupted length bytes and dispose of those bad commands which helps protect the code from entering impossible loops. Mikes code also allows for transmitting from the micro controller but these were not implemented at the current status of the project.

Overall, communication links between the computer and the winches have been developed out of previous work completed as part of the Robotic Systems Laboratory. This works well and provides protection against lost packets, corrupted data and other inconsistencies while including a modular design and send/receive protocol. The final communication protocol fulfills all of the projects design requirements and sets up the project for improved capabilities in the future.

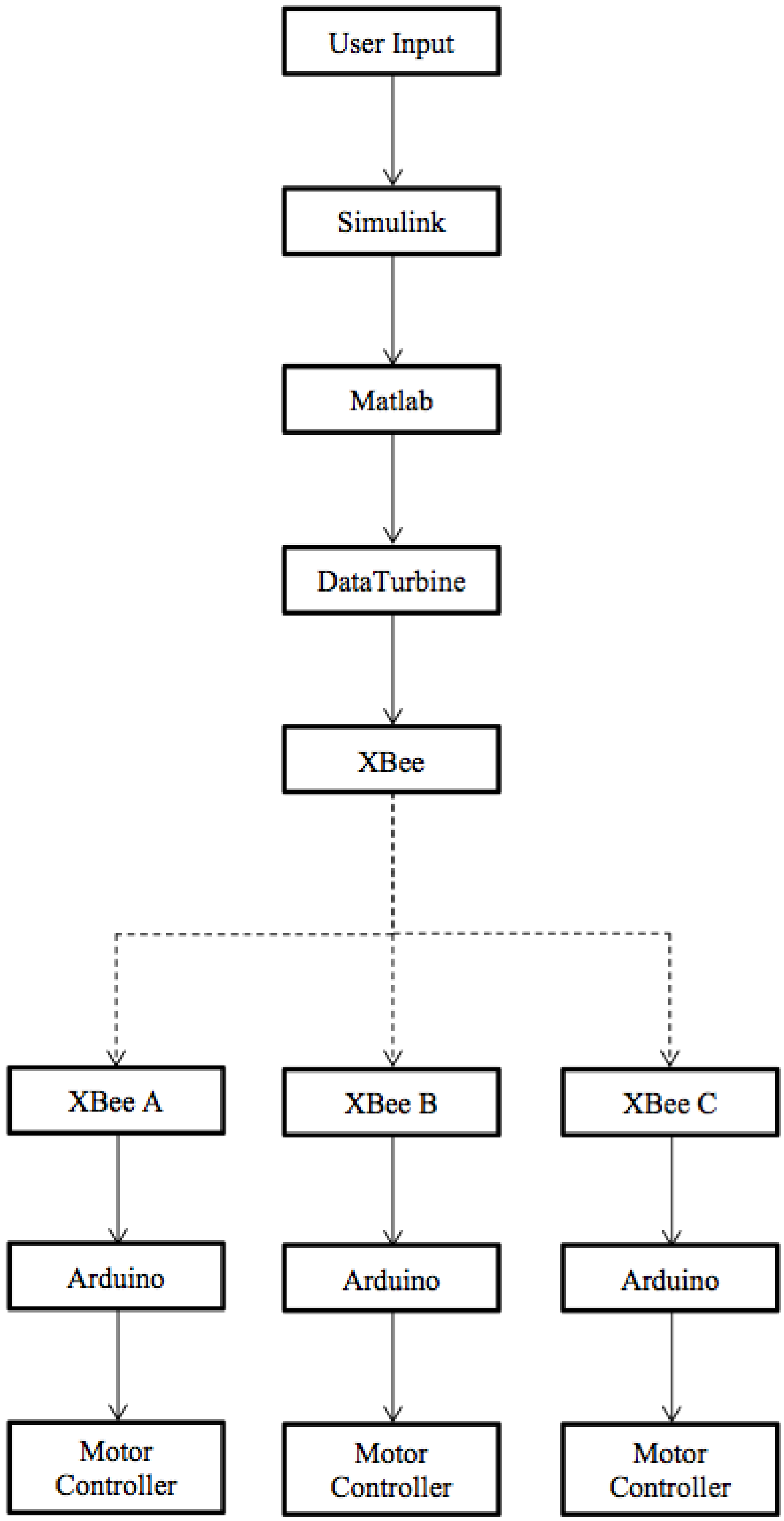
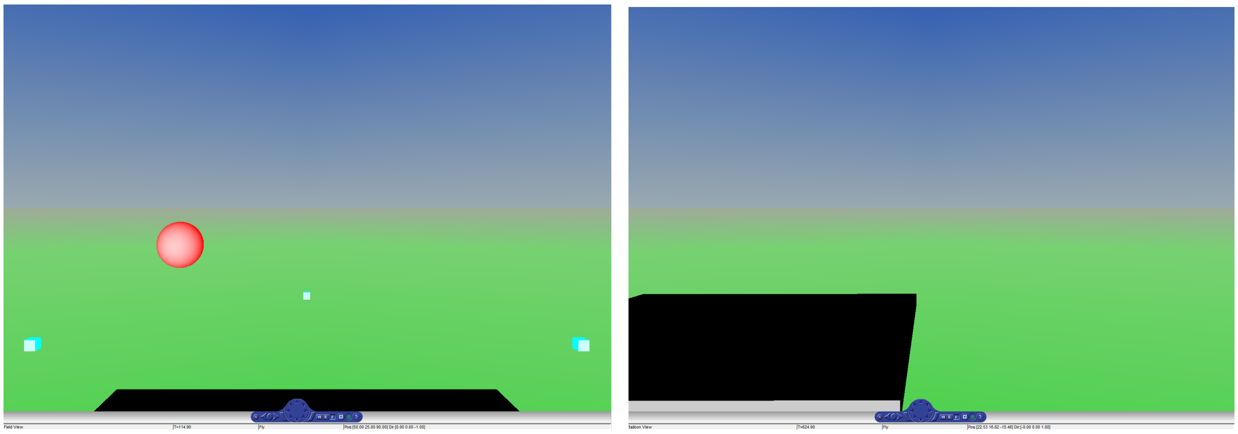


Figure 20: Communication architecture of the overall system.



(a) VR Field View (b) VR Balloon View

Figure 21: Virtual reality model showing the balloon view and field view

6.6.6 Virtual Reality Model

A virtual reality model was used to help decide what gains the control system should use. This model was created using Matlabs virtual reality toolbox which comes with the student version of Matlab. The model required two things for it to work, the first one being a defined sim world where all of the pieces of the simulation are defined. The second thing that is required is the position of the winches as well as the position of the balloon. Since our control system was continuously generating the current position of the camera mount we were able to run the simulation at the same time as the control system. Shown in Figure 21a is a snapshot of the field view of the system in action. This is a view from the field looking at the system as it is operated. Shown in Figure 21b is a snapshot of the view from the position of the camera and simulates what the user would see with their smart device during operation.

6.7 Microcontroller Software

For our project, we used an Arduino microcontroller which uses a programming language very similar to C. These microcontrollers only have a limited amount of space for programs, so anything written to the Arduino has to be short and concise. With that in mind we tried to figure out the best way for our microcontroller to work with the least amount of code written. To do this, we first had to establish all the jobs the microcontroller had to do. These jobs included passing the message received from the computer as well as making it possible to manually move the winchs position. For those two jobs to be completed, two steps needed to be accomplished on the microcontroller. The first job that we worked on was communication with the computer, which we decided was going to be through an XBee. We decided that we were going the use the communication protocol which was created by Santa Claras Robotic System Lab (RSL). This system, created by Mike Vlahos and Chase Traficanti, uses two main parts, an Arduino library called RSLPacket as well as a Matlab script. These two pieces work together to create the communication link between the computer and the microcontroller. Once the message was received by the microcontroller it is processed and converted into a message that the motor controller can understand. This message is then sent to the motor controller and the winch will go to the desired position. The second job we worked on was the manual movement of the winch. This manual input was done using a single pole double throw toggle switch which was connected to the interrupt pins of the Arduino microcontroller board. These pins are connected to the Arduino so that, if the signal changes, the program that is running is interrupted. This is used because the manual winch movement is a safety feature and we wanted to make sure that the program would always listen to the input from the switch.

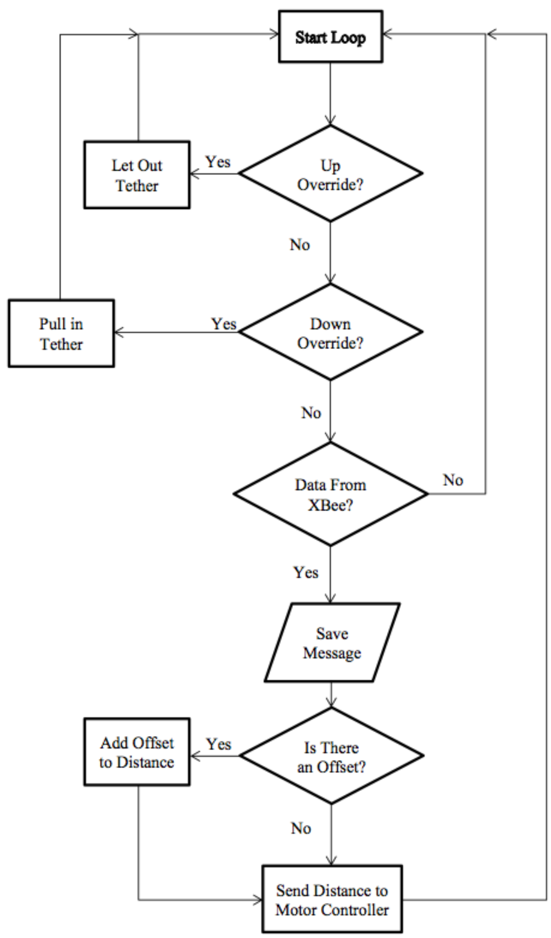


Figure 22: Arduino code flowchart outlining the microcontroller system.

6.8 Subsystem Integration

Integrating all of these components and subsystems within the winch system requires a complex organization of parts, plans and protocols. This is complicated further by the need for multiple winches and modular hardware and software.

The hardware integration includes all of the physical components: motor, structure, acrylic siding, plastic plate, reel and adapters, encoders, microcontroller, motor controller and all of the various connectors. The drive train is integrated with the structure by bolting the motor to the plastic plate and screwing the reel mount to the same plate. Next, the electronics are mounted using plastic standoffs at appropriate spacing distances. The electronics use various size wires, zip ties and plastic square organizers to maintain a clean layout facilitating maintenance, debugging and installation. Some wire connections use servo connectors to enable quick disconnects while the motor wires are screwed directly into the motor controller. Other wires are soldered into place and are not removable. The sides are finally bolted to the metal structure to prevent injury to bystanders or damage to the fragile electronics or moving parts.

The software for each winch is loaded individually before integration. The XBee and motor controller are programmed at a central computer and do not need to be reprogrammed. The Arduino is also programmed at a central computer and uploaded with unique code for each winch in order to differentiate addresses. Both the Arduino and Roboteq motor controller allow for reprogramming in the field with a USB cable or a RS232 serial cable respectively. Control of the winches can be both manual with the exterior switch or system scale control with the included control system. This higher order of control requires a laptop or computer to be integrated with Matlab, Data Turbine and XBee software and loaded with the created control system. This allows the computer to talk to any number of winches that are deployed.

Full integration has been achieved and streamlined to make setup of the system as quick and straightforward as possible. Setting up the three winch system can be done with as few as two people and within fifteen minutes. A future design goal would be to improve the control system software to reduce setup time to less than ten minutes. The current design fulfills the preliminary design specifications and has resulted in a completely integrated winch subsystem.

7 System Integration and Analysis

System integration characterizes how each detailed subsystem interacts with each other as well as the user. Two main subsystems have been developed: a modular, repeated winch, and the camera mount. A further three subsystems were designed, analyzed and used in the balloon, tethers, and user interface.

In order to fully understand how the subsystems interact, one must examine the System Block Diagram from Figure 23, reproduced below, which describes the electrical, physical and control signals between the components and the user. This will be referenced in the following sections discussing each type of integration.

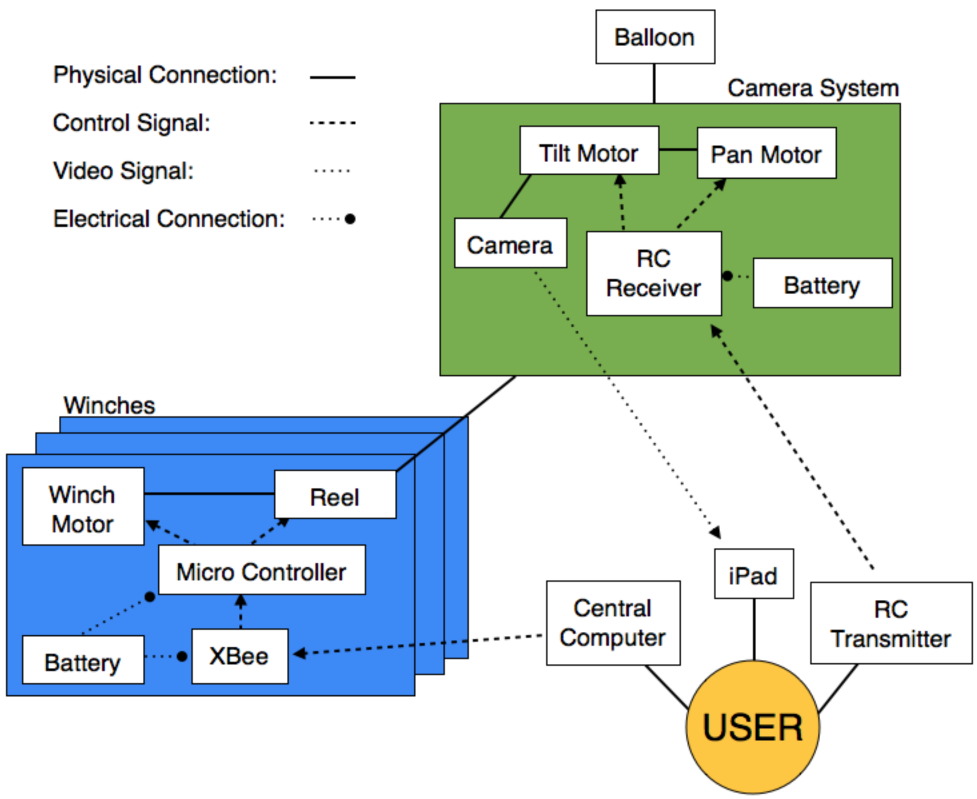


Figure 23: System block diagram of project Icarus showing the physical, control, video, and electrical connections between the different subsystems.

This image portrays the analysis of the system describes the detailed testing and experiments implemented to establish the performance of the overall system and determine if the end design met the preliminary design specifications (Appendix A). The experimental protocol is discussed in detail and the results of the experiments are given in relation to our design specifications.

7.1 Physical Integration

The physical integration has been discussed at length previously, including how each component of each subsystem is physically attached as well as how the tether subsystem is used to connect each subsystem. A separate tether of approximately 100 yards is tied to and wrapped around, each of the winchs reels. The free end of each tether is connected to a small one inch long S-hook with clip ends. This allows the winch to easily clip into the camera mount.

The camera mount needs to be physically attached to the balloon and tethers. First, the balloon is inflated and sealed off with zip ties. The open end of the balloon is folded over back on itself creating a loop. A short length of paracord is fed into this loop and down and then a series of heavy duty zip ties are used to seal off the balloon. The paracord is then fed through a swivel joint and tied into a loop. This allows the balloon to rotate from wind disturbances without affecting the camera mount stability.

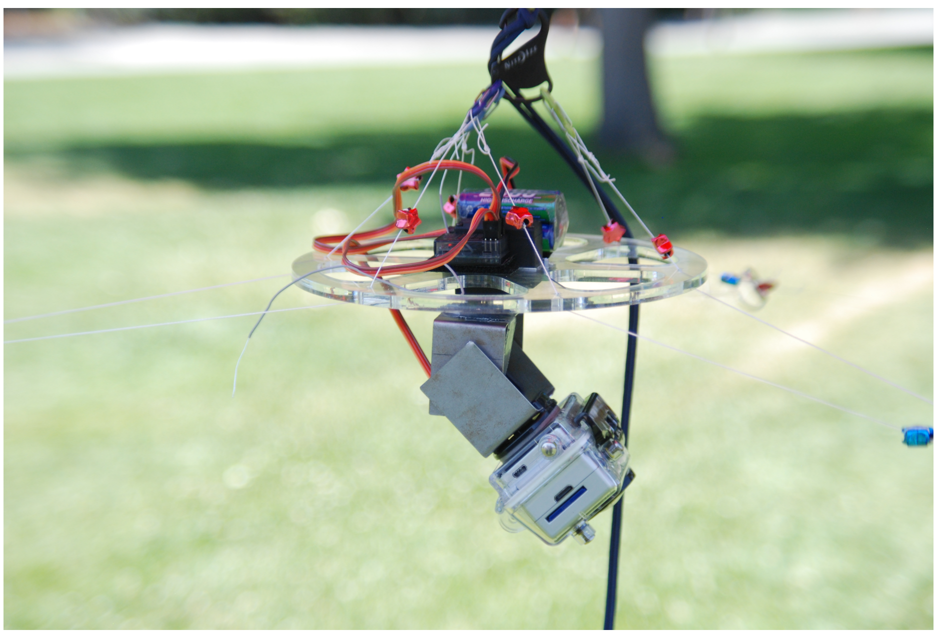


Figure 24: An image showing how the camera mount is integrated with the tether lines and balloon. The swivel mount can be seen connecting to the tethers which also connect by metal rings to the winch lines.

Next, six short, fifteen inch, lengths of tether line are cut and fed through the holes in the camera mount structure. These are tied off in the middle with small plastic beads allowing the camera mount to rest upon a platform maintaining appropriate spacing of the tether lines. On the bottom portion of this camera mount, small metallic rings are tied to the ends of the short tether lines. These metallic rings allow for any number of winches to easily connect to the camera mount by clipping the S-hooks to the metal rings. When using three winches, two rings are hooked to each winch while three rings hook to each winch when using only two winches. The other side of the short tether lines are connected to more S-hooks which then connect to the swivel mount. This can be seen visually in Figure 24 which shows how the camera mount is integrated to the tether and balloon. This integrating method allows the tension in the tether to pass through the camera mount without placing any undesirable stress on the structure..

Successfully integrating all of the subsystems will result in safe operation and flight. However, to increase redundancy, a safety line is typically connected to the swivel mount and dropped down to the operator to ensure that should an accident or failure occur, the system will not be lost.

7.2 Computer and User Integration

The user interacts with the Icarus system through three distinct user interfaces. An iOS or Android device receives the video signal from the camera. A hobby RC Transmitter controls the orientation of the camera while a central computer controls the position of the balloon. This central computer needs to be a running a Windows operating system with a hardware Joystick and Matlab, Simulink, Data Turbine and XBee software to function correctly. It is advisable to use a laptop or netbook to allow for a mobile control station. The control system and communication protocols allow the user to directly control the velocity of the camera mount in 3d space with the connected joystick. Currently, this computer control system requires the user to start multiple applications, designate numerous specifications and run multiple instances and control systems. This is not a user friendly system and requires knowledge of the system before attempting to start it up. Future work would condense the operating programs into a single program and develop scripts to reduce the number of specifications required on startup.

The radio control transmitter features five independent channels of control. For this project, only two channels are used which control the pan and the tilt of the camera. The throttle" channel is used to control the tilt of the camera and can be left in a single position. This allows the operator to select an appropriate observation angle. Next, the aileron" channel controls the pan which the operator uses to direct the camera to the left and right of the center. Currently, this system is completely independent of the other user interfaces. Future work would include modifying the subsystem to allow the computer to also control this subsystem enabling all of the control of the camera, position and orientation, to occur on one centralized user interface. It is possible to purchase parts that would allow the current hardware to accomplish this design goal, which may offer a future solution for greater integration. As it is, the operator can control the orientation of the camera through approximately 90 degrees of pan and tilt.

Finally, the user receives a live stream of the video from the onboard GoPro Hero 2 camera via an application running on iOS or Android devices. The camera subsystem and smart phone and tablet applications, are all proprietary products from the GoPro company.

The camera connects through a secure wifi connection and transmits video with a 3 second delay. Battery life is expected to last up to 3 hours but has been experimentally found to be closer to 2.5 hours. The smart device application allows the continual monitoring of video as well the control of when to record video to the onboard SD card. Any recorded videos can be access at the conclusion of the test by removing this memory card and downloading the videos to the computer. Future design iterations would include the newer Hero 3 camera from GoPro and larger battery backpacks.

An ultimate design goal, not included as a requirement in this prototype, would be to condense all of the current interfaces into a single user application. This application would be run on a laptop or alternatively on any smart device and would control all of the winches as well as the camera mount while simultaneously delivering a live video stream to the user. This type of user interface is beyond the capabilities of the current system and not included in this prototype. A future design team would be required to design and develop this application.

7.3 Electrical and Control Integration

The specifics of the integration of each electrical component are discussed in detail in each subsystem chapter. Each subsystem includes a battery, 12 volt for the winches and 6 volt for the camera mount. These batteries need to be easily removed from the structures in order to charge over night in between testing. Furthermore, the computer station requires either a laptop with included battery supply or a connection to a wall outlet for power.

Control signals are also discussed in depth in the winch and the camera mount subsystem chapters. As can be seen in the system block diagram, control is provided from an RC transmitter and central computer, both of which must be supplied with appropriate power. This signal is broadcast to the winches and the camera mount where it is converted into electrical signals to provide the desired movement. Integration of this control scheme requires the user to have access to a computer with a windows operating system, Matlab software and a RC transmitter.

7.4 Experimental Protocol

An experimental protocol has been developed to characterize the performance of the system and evaluate how close the final design performs to preliminary design specifications. The team chose to focus on the most important of the design specifications and evaluated those that were capable of being measured with the equipment on hand as part of the Robotic Systems Laboratory. Many experiments were then performed.

The first experiment measures the maximum force that the winch would be able to impart on the tether line. This is accomplished by running a single winchs tether line around a pulley on the ceiling. Using this configuration, weight is added to the tether line and the winch is commanded to manually reel in or out. When the motor can no longer move the weight is taken as the max tensile force the motor can impart on the tether line. Using a scale with up to 5 gram resolution and small weights, a 5 gram accuracy is achieved.

The next test is aimed to characterize the performance of the control system. In order to do this experiment, the winches are set up in an indoor building with pulleys attached to the roof. This acts as an inverse of the designed system. An ultra wide band positioning system with RFID tags is used to measure the position of the camera mount. To characterize the control system behavior, the camera mount is told to move at a steady rate along the X axis and the error in the X, Y, and Z axes is graphed over time. The error is measured with an accuracy of $\pm$ 5 cm at a rate of 25 hertz.

To measure the total set up and take down time, the team uses a stopwatch on one of the deployments of the system to measure how much time is required at an accuracy of $\pm$ 10 seconds. To measure the internal temperature, a thermometer is placed inside the winch and measurements are manually taken as the system is operating in the sun with resolution of 1C. Similarly, the humidity within the winch is measured in a similar fashion. Both the humidity and temperature measurements are important for the integrity of the electronics and reliability of the system.

Camera battery life is expected to vary between cameras and with camera age, but measurements taken over the course of an experimental deployment approximate the expected maximum deployment time. This measurement is taken using a stopwatch and while the resolution is on the order of milliseconds, the questionable repeatability means that an accuracy of up to 5 minutes is expected. Similarly, the camera wifi range is estimated by direct measuring of the distance with a long measuring device but will vary with environmental conditions. Measured with a resolution of 1 inch, this measurement will also fluctuate and so is represented with an accuracy of 1 foot.

7.5 Performance Evaluation

Unfortunately, due to limited time and other team responsibilities, the system was unable to be evaluated as per the experimental protocol at a high level analysis. However, a few specific tests were completed that helps to characterize some of the lower level subsystem specifications. For the winch subsystem, this included measuring the speed of the system to respond to inputs and the error in the output compared to the input.

The camera mount system was analyzed by measuring the angle of pan and tilt. These were found to be 60 degrees with an uncertainty of about 5 degrees. Furthermore, the tether line was loaded to failure to ensure the performance was as advertised. When performing this test, the tether line was found to be capable of loads up to 489 Newtons with an uncertainty of 40 Newtons.

To measure the speed, a single winch was told to move for five seconds. After the movement, the distance it traveled was measured. This was averaged and divided by the experiment time which resulted in 1.23 meters per second winch velocity. To measure the error, three tests were run where the winch was commanded to a set length and the actual length was measured. This resulted in an average error of 1.2% (Table 4).

Table 4: Test results showing error between commanded distance and measured distance.

	Test 1	Test 2	Test 3
Commanded Distance (m)	6.61	6.38	6.35
Measured Distance (m)	6.71	6.48	6.39
Error %	1.5	1.5	0.6

The system was deployed a few times by the team and so, while unable to provide analytical performance data, subjective observations allow the team to pinpoint areas of improvement and success. The system was observed to be very dependent upon a completely inflated balloon which greatly improved the stability of the video feed. It was also observed that quick panning movements of the camera caused wobble in the camera mount resulting in unstable footage. It was also observed that wind greatly affected the system and care should be taken to only deploy in favorable weather.

The team agreed that the setup of the system was overly complicated and not easy enough for our target audience. However, the camera system was generally capable of providing consistently high quality video and for a duration that matched our needs. Overall, there were no issues with battery life, mechanical construction, control system operation or user interfaces and our testing resulted in footage that was both usable and of a desirable quality (Figure 25).

Figure 25: An image taken during testing of the system.

8 Costing Analysis

The cost of this project can be separated into the three main systems. The balloon, camera structure, and base station subsystems, each have their own costing issues that need to be evaluated to ensure that the final product cost will be as low as possible. Our goal is to ensure that the manufacturing cost of a one winch controlled camera system will be under $1000.

The first part of Project ICARUS to be examined is the base station. This system includes a winch, controller, communication device, and tether. The winches that were considered included spools connected to motors, as well as electric fishing reels. Both of these solutions cost a maximum of $100, so to ensure enough money is allocated, 1.5 times the maximum cost was set aside from the budget. The controller and communication device are completely dependent on each other. An Arduino controller is the frontrunner among the potential micro controllers of this system. Arduino's can range from $20 to $50, however, since very little control is needed, controllers from the lower end of the price spectrum are considered. These controllers are inexpensive and easy to use, and can use anything from USB to Bluetooth to communicate. A battery is also needed to power this entire system. Batteries range from $25 to $50 depending on the total energy consumption of the system.

Table 5: Prototype Winch Cost Analysis

Component Description	**Cost per Part**
Battery	$23.11
Spool	$16.03
Motor	$20.03
Motor-Spool Conection	$20.76
Arduino	$41.45
XBee	$67.92
Encoder	$12.65
Structure Frame	$50.00
Structure Casing	$24.34
Motor Controller	$129.72
Breakers	$36.10
Hardware	$25.64

The second part of Project ICARUS to be examined is the camera station. This is comprised of the structure, camera, pan and tilt mechanism, and controller. The structure is made of plastic, allowing the system to be lightweight and inexpensive. The camera chosen was a GoPro, which is lightweight, durable, waterproof, and records video in high definition. The pan and tilt mechanism and the controller is a very simple design, which uses two servos connected to the camera to give it two degrees of freedom. This can be velcroed to an RC controller which can communicate the desired positioning to each servo. The two servos and controller system are frequently used in model airplanes, making it extremely easy to find and inexpensive to purchase a complete set, for around $50.

Table 6: Prototype Camera Station Cost Analysis

Component Description	Cost per Part
Frame	$25.00
GoPro	$300.00
GoPro Mount	$11.49
Servo	$22.93
Servo Bracket (pan/tilt)	$12.95
Battery	$16.10
Battery Mount	$1.95
RC Receiver	$29.99

The final aspect that needs to be examined is the balloon system. This system provides lift for every component connected to it and is essential for the success of the project. This system consists of the balloon exterior and the contained helium. The balloon needs to be durable and large, which makes advertising balloons a perfect fit for the ICARUS system. These balloons have a cost range of $20-$100. To ensure enough funds were allocated 150% of the max cost was used as an estimate of the cost of the balloon. Also helium needs be taken into consideration for it provides all of the lift for the system. Helium is not only the only recurring cost of the system, but it is also the most expensive part. Due to increased demand and supply shortage, the cost of helium is continuing to increase. This means that it can cost up to $300 to fill up the balloon per use. Overall, about half of the budget was set aside for purchasing helium. The final thing to consider for the base station is the tether, which is used to connect the winch to the camera mount. The tether material choice came down to paracord or fishing line. These options are extremely light, strong, and inexpensive, costing under $10 per 100 ft. Also to be considered is the cost of the user station. This cost includes the cost of an Xbee receiver, a laptop and iOS or Android device. Laptops can range between $250 to $2000 and iOS and Android devices generally cost around $300 to $400. Considering that most individuals have a laptop and smartphone device already, these costs are potentially negligible as customers would be able to use their own devices.

Table 7: Prototype Balloon, Tether, and User Station Cost Analysis

	Component Description	Cost per Part
Balloon	6' Balloon	$28.95
	Helium	$300.00
Tether	100 lb Test Fishing Line	$65.18
	Laptop	$479.99
User Station	XBee Receiver	$37.95
	iPad (Optional)	$399.00

After analyzing the cost for each subsystem, it was found that the final price to manufacture a one winch controlled camera system would cost approximately $1750. The final prototyping cost was much larger than expected however with the consideration that this is a prototype, the actual cost to manufacturing should be less expensive.

8.1 Prototype Costs vs Budget

Prototyping is an inherently costly process because of the constantly changing design and occasionally extraneous equipment. The budget therefore needed to be sufficiently large so that it could withstand the cost of prototyping. With this in mind, an extra 1.5x was added onto the estimated budget so that there would be sufficient funding. Now that the project is built, the budget for future development should be much easier to narrow down to a more accurate representation of the actual cost to build the system.

8.2 Manufacturing Costs

Manufacturing cost is broken into three categories: material costs, labor costs, and manufacturing overhead. The first category, material cost, is the cost of the raw materials used for manufacturing the product. For the winch, this would include the acrylic that the siding is made from, the HDPE for the base, aluminum for the reel adapter and mount, aluminum for the T-slot extrusions, and steel for the encoder bracket. For the camera mount, the material cost would be the price of the acrylic sheet that the camera platform was cut from. The cost for the tether would be dependent on the unit length cost of fishing line.

Labor costs are calculated by multiplying the amount of time required to complete a job by the wage which the employee performing the work is paid. Assuming the parts that were manufactured for this project are sent out to machine shops to be made, the amount of time spent on construction would be about two to three hours per winch per person. Assuming a wage of approximately \$50, this would result in a labor cost of approximately \$100 to \$150 per winch per worker. If the parts were manufactured in house, the labor time would increase dramatically to approximately 30 hours. This would result in a labor cost of \$600. To minimize the labor costs, the parts would be sent out to a machine shop where they could be made in bulk. Furthermore, the parts could be simplified from the prototype design. This would reduce the amount of labor required to manufacture the winches down to around \$200

The labor cost for the camera mount is much less. Because the platform is cut from a laser cutter, the required time spent working on the platform is minimal. This time would be approximately one hour and at a wage of \$50, the labor cost would be approximately \$50.

Another cost that must also be considered is the manufacturing cost of the electrical components. During the prototyping stage several different controllers and boards were used in combination with each other. However, during manufacturing, one board would be designed and produced. This would lower the cost of all the electrical components, from the

Arduino to the XBee, a drastic amount. There would be an initial, one time, setup cost of approximately $325 that includes programming and stenciling. Each board would cost approximately $80 to $100 depending on the size and complexity of the board. Bulk orders would result in a reduced overall price for the boards.

The final category, manufacturing overhead, is the manufacturing costs that can not be directly traced to the product that is being sold. Examples of this include, property taxes, electricity, maintenance of equipment, and insurance. Because of the nature of these costs, it is difficult to estimate what they would be at this time.

Ultimately, if this system was to be made into a product and manufactured using the above assumptions the cost of the manufacturing would be around $1000. This includes, for each winch, an estimated $100 per electrical board, $30 for each structure, $60 for the drive train components, $50 for miscellaneous components and $100 dollars for labor time for a total cost per winch of $340. The camera mount would cost roughly the same as the prototype, around $150 without the camera. This means the cost to produce the simplest system, without a camera, would be $490, or $790 with the GoPro camera. For the full system with three winches, the total cost would be $1170 without the camera or $1470 with the camera.

9 Business Plan

9.1 Executive Summary

This report will discuss the business plan behind the commercialization of the Project ICARUS system. The core product is an aerial camera recording system that was designed as an inexpensive dynamic video capture solution. This product will be used to offer both a video capture service and online video distribution of premium and unique sports coverage. The markets for this product include a fast growing action sports market including the world fasted growing sport, skateboarding. Other markets include high school and club sport teams. The goal of this endeavor is to create a financially viable option for interesting aerial sports coverage to all those teams and customers that may want it. We also hope to create a platform to display and share the amazing capabilities of the ICARUS System through online video production and distribution. Competition exist in this endeavor. Existing technologies such as the camera-pole system and the Skycam system provide competition to the ICARUS system, however they also provide an insight into the opportunity this new system has to succeed. The ICARUS system hold distinct strengths and advantages to all of it's competition. The online Market presents tremendous competition through new and established video providers, but also presents tremendous opportunity. We plan to leverage both the growing market in action sports and online video as well as an existing relationship with Nike to create a strong marketing campaign. Both a fee based service and free online video content will be offered with potential profits in both revenue streams. Within a year the company hope to have substantially grown with a stable revenue stream.

9.2 ICARUS System and Service

Project ICARUS has developed a balloon hoisted camera system that is tethered to the ground by computer controlled winches. This enables the camera system to stay airborne for many hours while obtain aerial vantage points. The system can be controlled in all three spatial dimensions while simultaneously controlling the orientation of the camera. The system utilizes large helium filled balloons to lift the camera into the air in a safe and controlled manner. We will utilize this system to offer a video capture service that is affordable and unique to growing sports market. Additionally we will offer new online video content captured by the ICARUS system.

9.3 Company Goals

Our goal is to provide premium high quality video content and recording services in a new inexpensive and captivating way. We will accomplish this through the use of a new aerial computer operated camera system. With this system the video capture will come from a innovative and interesting point of view at a price point that will open new markets to our endeavor. Aerial cameras have thus been confined to use solely at the professional and upper tier collegiate levels. WE plan to make aerial video coverage universally commercially viable.

9.4 Introduction and Background

The product is a service that will provide an aerial view of sporting event and competitions. Additionally we will distribute the content captured online for viewing and sharing thus exploring a secondary revenue stream. This service will be a new opportunity for growing and emerging sports markets. The skateboard industry is currently the fastest growing industry in the action sports sector. With growing participation and a similar growth in revenues skateboarding represents a great example of the type of market our product can flourish in. Additionally both high school and club sports represent sizable markets for our product. The business plan is two pronged in regards to the video capture service available for hire and the video content distribution online. currently many smaller scale sporting events and sports teams record footage either from a ground based camera or utilize tall stationary cameras mounted on poles. Our system of recording advances the capability of pole-mounted camera and is more akin to the professional Skycam system. While Skycam represent a similar technology it is not a direct competitor to our product as we will operate in a different market. The technology behind our system was designed and engineered by James Cochran, James, Audrey, Nicholas Xydes. Business plan development was headed up by Chris Mora. Christopher Kits, professor of mechanical engineering at Santa Clara University, acted as a design consultant and Jeffrey Ota, Nike, acted as a market consultant.

9.5 Potential Markets

With the two pronged business plan we have developed their exist two channels by which potential markets can be examined

The video capture service provides the clearest defined markets. The primary markets we are to focus on here are the action sports markets and the club/high school sports market. Additional markets may be evaluated and penetrated as they become viable and apparent.

The video content distribution service will be primarily focused on online distribution. The market exists through the monetization of the online video content created and posted.

9.5.1 Sports Market

The action sports market is rapidly growing globally. The fastest growing sport in the united states in skateboarding with it doubling in size of participants over the past 10 year. It has over 12 million active participants that are increasing their spending on the sport. Likewise large sports companies such as nike are looking to skateboarding as a primary candidate for increased market growth and opportunity in the near future. The retail skateboarding industry is nearly a $5 billion a year market that is growing with few signs of slowing down. Additional action sports that have seen increased popularity and market growth recently are snowboarding and bmx biking, however to a lesser extent.

The high school and club sports market are currently the primary users of the competitive technology of the camera-pole system. The opportunity exists to have teams in this realm migrate from that system to the ICARUS system.

9.5.2 Online Video Market

The online video market has seen huge expansion in the last decade. Online video content in increasing in quality and quantity. The proliferation of premium online video content has ballooned video views online to around 1.2 billion videos per day. By the year 2016 online video watchers are expected to double to a size of 1.5 billion. The primary avenue for online users to access video is through youtube. More than 1 billion unique users visit YouTube each month, spending more than 4 billion hours watching videos. 2 billion video views per week are monetized on YouTube with youtube paying between $2 and $5 per 1000 video views to the content creators. Monetization of digital video accounted for over $12 billion in payments. Top youtube channels currently can generate over $500,000 a year based solely on their online content, with estimates for the highest content creator as high as $6 million per year. Large companies have places a new emphasis on the creation of online video content, devoting large amounts of resources to it. Studios such as Maker, and Machinima are solely devoted to the creation and facilitation of youtube videos.

9.6 Competition

The competition in the markets previously mentioned varies greatly. For the video capture service channel, the competition is significantly less than for the online video content distribution channel. Competitor for the former are simply grounded and pole mounted video capture provided by the teams or event organized themselves. A formal company or service does not exist to provide aerial video coverage for these teams and events. Thus our service will immediately offer a new type of product in an underserved market. The video content distribution channel is full of competitors. Here competition comes from the wealth of online video content that competes for views which is the primary generator of revenue in the market. All these levels of competition will be examined. Additionally Skycam is a similar product, however not a direct competitor. It will be examined as well as it provides some valuable parallels to understanding the potential of an aerial video system.

9.6.1 Camera pole system

The camera pole system is usually a one time purchase expense for high school and college teams. This is a very large expense for teams costing between $4,500 and $6,000 per unit. The system offers a single static aerial vantage point that is difficult to change once established. The cost of the icarus system is substantially lower initially at under $1,500. The recurring helium cost is a variable cost that the pole system does not incur. The icarus system offers a dynamic viewing angle that is easily adjustable through the computer operated winch system.

9.6.2 Online Competition Environment

The online video market is extremely competitive with millions of youtube channels producing billions of online videos. The primary action sports channels include Red Bull Channel, Network A, Alli Sports, and Ride Channel. These channels combine for over 3 million subscribers, totaling more that 689 million overall video views. Current online video users have a vast amount of content available to them and will quickly migrate from one video to another. Online video content must be immediately enticing the the user. Users will decide to continue watching an online video within the first 5 second of viewing.

9.6.3 Skycam

Skycam is a proprietary technology that is currently utilized by major national sporting events. Similarly to the ICARUS system it provides a dynamic aerial vantage point for sports recording. The current Skycam only is cost effective for large multi-million dollar events and franchises such as the NFL and the X Games. However, the success of the Skycam in these events demonstrates that a cost effective system is viable in sports video recording.

9.7 Marketing Strategy

With the influx of major companies to the action sports market we plan to work with Nike to maximize our network of connections and best capitalize on the opportunity of the current market growth. Nike has recently placed a stronger marketing emphasis on skateboarding and through our meetings with Jeff Ota have developed a working relationship with the company. In the immediate future we plan to amass a collection of video data to create a example of the capabilities of the service we offer. We have begun this process with video of soccer and lacrosse and plan to continue with skateboarding, basketball, and other sports. Furthermore, we plan to employ a guerrilla marketing strategy at local skate parks and at all events and location where the system is in use. This will promote the online video distribution channel. We will directly access potential consumers of the online content and funnel site visits and views to our online youtube platform. We will also seek support from Nike for the promotion and marketing of this platform. Finally we will utilize personalized sales pitches to gain access to larger events such as high school and club sports games and local sports tournaments and camps. We will create these pitches as the events become available.

9.8 Cost, Pricing and Revenue Creation

The two pronged service offered will follow two unique pricing models with different revenue generation strategies. The video capture service will consist of a general rental fee charged to the hiring client. The online video distribution service will be offered for free online to users through youtube. All content online will be monetized through the inclusion of advertisement.

The initial cost of the system has been \$1,500. This will be the primary camera used to capture all the video content. Additional systems may be built with off the shelf parts and a reduced cost. All additional systems are estimated to cost below \$1,000. Further costs include video editing software to facilitate the creation of the online video content. This will cost between \$300 and \$400. All other cost will be cost of reserving recording locations and potential wages for staff needed. These costs will be variable and determined as events are planned.

The service will be offered on a hourly rental priced model. It will required at least two engineers on site to assemble and operate the system. All video distribution rights to content recorded will be retained by the company although we will offer dual content rights as well. The cost of the on-site engineers and the helium cost will require a fixed fee of \$200 for the cost of helium and and additional \$75-\$100 per hour charge for labor and on-site staff. Online video content will be provided for free and accessible to all clients. Monetization of these videos will provide \$2 for each 1000 views.

The revenue stream at first will be driven by the booking of clients for the video capture service. As more events are booked and the marketing of the online video content is increased it will become a major contributor to the revenue stream. Within a year it is a goal book enough clients and to drive enough traffic to reduce the pricing of the service and build at least five new video systems allowing the company to increase the amount of clients it can book and increase the rate at which video content is captures, placed online, monetized and generating revenue. Additional revenue may be generated from the sale of advertising space on the balloon itself during it's deployment and events.

9.9 SWOT Analysis

The SWOT (Strength, Weakness, Opportunity, Threat) analysis, lists the strengths and weakness of the product as well as opportunities available to product and threats against the product.

- Strengths
  - Extremely inexpensive compared to systems of similar functionality
  - Dynamic aerial view of video content
  - Small proactive team able to adjust to market changes quickly
- Weaknesses
  - Recurring cost of helium and balloon re-inflation
- Opportunities
  - Rapidly expanding action sports market especially skateboarding
  - Increased popularity of online video content
  - Networking connection and marketing expertise through Nike partnership
- Threats
  - Fluctuation of online video views
  - Competition of attention online with high amount of video content

10 Engineering Constraints

10.1 Ethics

The ethics of the final product have been carefully and thoroughly examined to be sure the system does not break the ethical guidelines set by the team, the advisor, the sponsors, the school, or the legal framework of the United States of America. In order to ensure this, consideration was given to how the product was designed and used.

Testing and filming took place in a public, legal and approved location. Prior to filming, participants were informed of the experimental nature of the activity as well as the inherent dangers and then signed a liability and consent forms. Filming on campus occurred with consent from the appropriate faculty while filming off campus involved acquiring approval from the local government.

Video footage, as well as a majority of the general data, calculations and data analysis was recorded and publicized through the university library to demonstrate our progress not only to our advisors, but as well to those who have invested in our product. This allows us to work with those around us and gain feedback to better improve our product throughout and after the design and manufacturing phase. The physical and control system design of our product will be proprietary information and as such, will only be shared with our advisor and sponsor.

The intellectual property of our system is shared by the group members, our advisor Dr. Kitts, and the representative from our sponsor directly involved with the project. Furthermore, all proprietary documents are protected using a secure database hosted by Google and can only be accessed by individuals given express permission. Finally, because the school of engineering provides funding, the school is also entitled to a share of the intellectual property developed as a result of this research.

10.2 Manufacturability

The goal of Project ICARUS is to create a product that, with the help of Nike and other supporters, can help all coaches with the teaching, preparation, and execution of their sports. If that goal is to be achieved, then there will be thousands of ICARUS systems created for this purpose. If the final product is not manufacturable, then each system will be extremely labor intensive, which makes them expensive to make. To make this product as accessible to as many people as possible, it needs to have a final price of under $1000. This price is infeasible if each system is to be made by hand, which means that one goal of Team ICARUS is to create a design that is completely manufacturable. To achieve this all pieces of the system either have to be off the shelf parts, or be extremely easy to make and replicate.

All the pieces also need to be easily assembled so that many of these can be assembled in a short amount of time.

10.3 Economic

The goal of Project ICARUS is to create an affordable solution to organizations, or individuals who require a constant aerial viewpoint. Therefore, the economic issues of the project revolve around maintaining the inexpensive cost of the system without infringing on the ethical limits of the project. In order to keep the cost below $1000, the system must have a simple design that factors in ease of manufacturability of the system. However, the overall durability and reliability of the design can not be compromised, which could result in a more dangerous system.

10.4 Health and Safety

As mentioned previously, the final system must be very safe. The camera mount and assembly should weigh less than 1 kg and so if the balloon were to catastrophically fail, the drag on the balloon would cause the system to fall at a very slow terminal velocity. This would limit the damage caused by failure of the balloon support. Furthermore, risk exists in the tether line coming into contact with bystanders. Therefore, a system to maintain a safe distance from each winch location will be employed such as cones and caution tape demarking a danger area. The health and safety of all involved in the operation and innocent bystanders is a paramount concern in the design of the system.

10.5 Social

The Project ICARUS team aims to provide a product solution that will be used by a number of different categories of users. The end goal of the project is to improve these users ability to perform their tasks. For instance, athletes will be able to have immediate and effective video feedback of their performances enabling them to improve their technique. Meanwhile, disaster relief agencies will use this product to enable a quicker and more efficient response. Both of these customer groups will use this product to improve the safety of those involved.

11 Environmental Impact

With the wide adoption of any new system, a potential exists to cause damage to environmental or social systems. It is the job of the engineers and project managers behind such projects, like the team behind this project, to analyze and limit any potential impacts. In order to ensure that our project is ethically responsible in this regard, we conducted an analysis on the impact that wide adoption and use of our system would cause on the helium stock on earth as well as the helium marketplace. Overall, we found that even when assuming wildly optimistic adoption and usage rates, this project would result in less than a 1.5% increase in the helium market and would not affect worldwide supplies at any measurable level.

11.1 History and Background of Helium Production

Helium is the second most common element in the entire universe making up 24% of the mass of normal matter. However, even though it is so common in the universe it is exceedingly rare on earth and is a nonrenewable resource. Because it is a lighter than air gas, and exists in liquid form at only 0.95 K, helium released into the atmosphere rises in elevation until the suns gravity pulls it away from earth. Therefore, any helium used on earth is lost to space.

Helium was first discovered in the 19th century but not attained until an oil drilling operation in 1903 produced a gas sample that wouldnt burn. This was later confirmed to contain 1.84% helium and, most importantly, proved that helium could be found in relatively concentrated quantities under the American Great Plains. Due to it's lighter than air properties, the United States military set up helium plants with the goal of supplying barrage balloons and later zeppelins with nonflammable gas. By the 1950s, the United States government was one of the only producers of helium in the world and expanded it's use to create coolant for rocket fuel.

In the Helium Acts Amendments of 1960, the U.S. Bureau of Mines arranged for five private plants to recover helium from natural gas and built a pipeline from Kansas to connect those plants with the governments Texas gas field. By the 1990s, more plants had opened around the world and the U.S. helium reserve had purchased a billion cubic meters of the gas from private sources running up $1.4 billion in debt.

This debt prompted Congress to phase out the reserve in 1996 with the Helium Privatization Act of 1996 which directs the U.S. Department of the Interior to start selling the reserve to non-governmental sources. By 2012, this reserve accounts for 30% of the worlds helium production and is expected to run out by 2018.

In the year 2012, 2.13 billion cubic feet of helium was withdrawn from the national helium reserve while 2.25 billion cubic feet of helium was produced at refineries. Including international production, the total helium usage surpassed 5.2 billion cubic feet. All of the available helium was purchased resulting in a continuing helium shortage. As per the U.S.G.S. the shortage of helium and allocations are expected to continue in 2013 and may become greater as the storage reservoir production declines" (USGS 73). Over the next 3 to 5 years the helium shortage is expected to worsen, however, new helium refineries in Wyoming, Qatar, Russia and elsewhere are expected to begin coming online in the next decade and should shorten the effects of the helium shortage. In fact, helium reserves across the world total more than 7.5 trillion cubic feet and should last for more than a hundred years at expected demands.

Furthermore, according to the USGS, less than 13% of helium produced is used for lighter than air lifting purposes while 32% is used for cryogenic applications, 18% for pressurizing, 18% for controlled atmospheres, 13% for welding cover gas, 4% for leak detection, and 2% for breathing mixtures. Therefore, balloon use accounts for a very small proportion of the overall market.

Helium is extracted as a byproduct of the natural gas refinement process. Helium is the result of radioactive materials like uranium and thorium emitting alpha particles which combine upon impacting adjacent rocks into helium. Situations where natural gas is trapped below the surface are similarly capable of trapping helium. Thus, helium is most concentrated in nature where natural gas is found.

11.2 Assumptions and Important Information

As has been experimentally determined through the testing of the system, each deployment of the balloon requires at least 75 cubic feet of helium to properly lift the camera mount during operations. According to MaxPreps.com there are 16,047 high school football teams in the United States. Furthermore, most high school football seasons run for a 10 game regular season with a 5 week playoff system. While actual athletic programs and schedules vary widely across the nation, for this analysis any program with access to the system will also use it for other outdoor sporting events like mens and womens soccer and lacrosse.

For this analysis, an optimistic market penetration of 20% of high school football teams will use the system and fill the balloon entirely for each game. An average of 6 football home games a year and 20 other sporting events will be assumed for a total of 26 deployments per year which results in the system being used for half of the weekends in a year.

11.3 Analysis Results

First, the total number of events per year that our system would record is calculated from the given assumptions to be 83,200 events (Table 8). This is for a very optimistic market penetration rate as well as a very high usage rate.

Table 8: Optimistic Market Assumptions and Calculated Total Events per Year

Total High School Programs	Market Penetration	Market Size (Programs)	Games per Year per Program	Total Events per Year per Program	Total Events per Year
16047	20%	3200	6	26	83200

Next the total amount of helium consumed is found to be 6.24 million cubic feet by multiplying the total events by the expected usage of 75 cubic feet per deployment. This represents an increase of 0.12% of the overall market and a consumption increase of 1.7% of balloon grade helium. These results indicate that a large market penetration results in a small overall change in market share.

For thoroughness, a larger market size should be considered. An even larger market is assumed to be more than 20 thousand systems sold to high schools, outdoor events, disaster response, extreme sports parks and researchers. These systems would never need to be filled up more than once per week for a total of 52 fillings. Using these assumptions and the same analysis it is estimated that a saturated market would result in a 1.5% increase in helium consumption.

Table 9: Saturated Market Assumptions and Calculated Total Events per Year

Total Systems in Use	Total Events per Year per System	Total Events per Year	Helium per Event	Total Helium Consumption per Year	Market Size Increase
20000	52	1040000	75 cu ft	78 million cu ft	1.5%

Furthermore, an increase in market size would also speed up the overall consumption rate of worldwide helium stock. However, the most optimistic analysis results in an increase of helium demand from 5.2 to 5.28 billion cubic feet. At the current rate of 5.2 billion cubic feet, the worldwide helium stock should last 1440 years. The increase to 5.3 billion cubic feet would shorten this to 1410 years.

While helium remains for the immediate future in a supply shortage, the long term future for helium is much brighter. Worldwide stocks should remain relatively stable for centuries to come once helium production catches up with demand. Ultimately, any helium consumption increase due to the adoption of the ICARUS system will result in no adverse environmental effects due to increased use of a nonrenewable resource, nor will the adoption result in adverse social effects due to the increase in helium demand. This is due to the already large demand for helium and the even larger helium stock worldwide.

12 Summary

Project ICARUS designed, manufactured and tested a balloon hoisted, tethered, aerial filming platform with full user control over the position and orientation for live filming and recording. Many tasks were accomplished to meet this objective. A winch subsystem was designed which received and processed commands to reel in and out a tether line. This design included an electrical and mechanical design as well as an embedded Arduino program and three winches were constructed. A camera mount subsystem was constructed and evaluated which controlled the orientation of the camera with servos. Finally, a control system was developed which converted the user input into the desired lengths of the winch tethers and broadcast this information wireless to each winch. At the conclusion of this design process, a complete system with three dimensional position control and pan and tilt orientation control of the camera has been developed. It has been successfully deployed five times and video has been captured of athletic events in action to demonstrate the usability of the system.

12.1 Project Summary

The Project Icarus team has developed, over the course of the last year, a balloon-hoisted, controlled camera system for aerial filming. The project started by evaluating the environmental effects and disturbances on the large balloons used for lifting the camera. Once these affects were characterized and understood, the tether lines that hold the balloon and camera subsystems in the desired location were analyzed. The maximum tension in the line was found to be around 110 Newtons. Using the results of these analyses, camera mount and winch subsystems were designed, analyzed, developed, manufactured, and tested.

The camera mount subsystem was designed to provide a stable platform which could control the orientation of the camera. First, the structure was designed to be a simple laser cut acrylic plate which would provide necessary spacing for the tether lines and a mount for the hardware and electronics. This was analyzed using Solidworks finite element analysis software and optimized to provide the most durable structure under the anticipated loads. Next, a pan and tilt mechanism was designed to allow the control of the orientation of the camera. This implements a couple of simple to manufacture steel sheet metal brackets and metal geared servo motors. A hobby RC transmitter and receiver are used to control the camera orientation. The operator uses two small joysticks to control the tilt and pan, which is then converted to pulse width modulation and sent to the servos. The control is a very simple, manual operation while future plans include computer integration and stabilization. Likewise, the camera mount electronics are derived from hobby radio controlled aircraft.

To develop the winch subsystem, complex mechanical, electrical, structural and control subsystems were engineered and optimized. The structural frame and case were developed to provide a strong platform or which to mount the hardware and electronics while providing protection against the environment and bystanders. This was also designed to enable easy modification for prototyping and debugging purposing by providing a large opening top and clear sides for visibility.

A drive train was designed and manufactured to transfer power from the motor to an off the shelf fishing reel. A special adapter was used to convert from a square shaft, necessary due to the motor square opening, to the round reel. Two parts were milled and lathed. The first was a circular reel adapter that bolted to the reel and was pinned to a square to round coupler. The second was a square reel mount that lifted the reel to the appropriate height and secured it to the platform. Finally, a quadrature encoder was mounted to the end of the drive train with a sheet metal mount.

The electronics of the winch were developed around the open source Arduino microcontroller and an off the shelf motor controller from the company Roboteq. A single 12 volt battery provides power to the systems on two separate lines for the control circuitry and the isolated motor. Communication to the computer is provided by an XBee wireless module. The microcontroller analyzes the messages and instructs the motor controller how far to turn the motor. The motor controller applies a PID closed loop control scheme to the position using the attached encoder.

An open loop control system has been developed to enable the operator to control multiple winches at the same time. Mathematical operations are performed to convert a Cartesian desired position of the balloon within the winches into each separate winch lengths. This is then communicated to the winches using a modified version of the Robotic Systems Laboratory communication protocol. Matlab running in a Windows operating system is used for this control system and a virtual reality model has been created to evaluate the performance of the model. Constraints are placed on the operating space of the balloon to ensure the safe and stable operation.

The entire system has been integrated together and experiments have been performed. Over the course of multiple deployments issues with the control system, communication protocol and mechanical connections were evaluated and solved. Preliminary experiments were conducted indoors as a method of confirming the safe operation of the control system and winches in a controlled environment without disturbances. The system performed as expected and met the preliminary design specifications. Following the indoor tests, the balloon was inflated and outdoor tests were performed. First, testing was conducted in isolated and sectioned off areas. When the team was happy with the performance, athletic events were filmed including soccer, Frisbee and extreme sports.

Project Icarus successfully created a new device for aerial videography. The system is capable of five degrees of freedom control and safe operation. The preliminary design specifications were either met or exceeded and nearly all design requirements were met.

12.2 Lessons Learned

There are several lessons that we have learn over this last year working on this project. The first group of lessons that we learned was all about the balloon. First we learned that the balloon was affected by the wind much more than we had anticipated. Soon after learning this, though, we found that the stability of the balloon could be improved by adding more helium to it. We also found that the balloon was losing close to 10 to 15% of it's helium per day, which was much faster than we had originally calculated. Once our issues with our balloon was solved and we were able to use some tests, we found that the XBee communication was not receiving several messages when the winch, was moved more than 50 feet away. After examining the winches we found that there was interference created by the motor controller, the motor and the Arduino which was drowning out the signal being received by the XBee. To fix this issue an antenna was attached to the XBee and extended outside of the box away from the devices creating the interference.

12.3 Future Work

While Project Icarus has successfully met the design criteria specified at the start of the year, there are still some design aspects that could be improved. Future work to be performed includes iterating the design of both the winch and the camera mount, improving the user interface, improving manufacturability, procuring patents to protect this intellectual property, starting and operating a service business model and developing an unorthodox business models.

From the accumulated experience of testing the initial prototypes, specific issues have been identified that would be improved with future design iterations. A priority for future design work on the winch subsystem is to weather proof the winch box. Currently, the system is minimally protected from rain or dew on the ground. Future design iterations would be sure to enclose the electronics is a moisture proof case. Furthermore, if this system is to be developed into a product, future design iterations must be made with increased manufacturability. The structure should be cheap and easy to procure while the parts should be simple to assemble.

The camera mount should follow a similar iterative design process in the future. This would include enhancing stability and control. The next design iteration would include mounting the camera on a pendulum as a means of damping wind disturbances. Furthermore, future design iterations would include a microcontroller onboard the camera mount and numerous sensors to enable stabilization. These would include a compass, gyroscope, tilt sensor and possibly an accelerometer for enhanced and controlled orientation. Furthermore, future designs would integrate the control of the camera mount into the same computer controller as the winch subsystem.

Future iterations of this control system would attempt to improve the usability and set up process. This would include a self-calibrating script which would reduce the need for calculations of winch locations in the field. It is also desired that the control system not be tied to the Matlab program and instead use a custom application which integrates the communication currently tied to proprietary programs. More advanced control should be explored by using inverse Jacobian which would enable more advanced velocity, position and path following control schemes. Advanced control schemes would also implement a tracking system that would allow real time knowledge of the location of the camera mount and enable the control system to implement closed loop PID control on the camera mount position. The camera mount and winch subsystems should also be integrated into the same control system simplifying the operation.

The user interface for the current prototype involves three different subsystems. Future prototypes would integrate each of these into a single user interface. This is envisioned as a single application that integrates the control of the winch subsystem, camera mount orientation and receives the video feed from the camera. In the long term, a product should have the capability of using this application on a computer or laptop operating system, like Mac OS and Windows OS, or a smart device operating system such as Android or iOS. A computer programmer would be required to implement these user interface design improvements into a final product.

Project Icarus aspires to create a new start up business beyond the scope of this prototype and capstone project. To accomplish this, business plans have been created that explore both service and product business strategies. In the immediate future, patents should be sought to protect the intellectual property rights of the team. Any start up business derived from this project would start by offering the service of aerial filming to outdoor events and games. The goal of this new business venture is to provide a new type of aerial filming to the marketplace.

13 Conclusion

Project Icarus has successfully developed, from the ground up, a new type of aerial filming device that meets the need for a portable and affordable aerial viewing system. The disruption due to environmental conditions, like wind, was characterized and used to determine the maximum loads on the tethers. Computer controlled winches and a remote controlled camera mount were designed, developed, analyzed, constructed and tested. A unique control system was developed to control any number of winches with included modularity. Deployments of the system were conducted to evaluate the feasibility and durability of each of the subsystems. Multiple business plans were developed that deal with different types of service and a production businesses. Future plans include development iterations of the overall system and developing new ways to monetize the efforts of the team into a new business venture. To conclude, Project Icarus has nearly met all design criteria while exceeding the preliminary design specifications for the project. Project Icarus has successfully developed a brand new aerial filming device.

References

Journals:

De Sam Lazaro, Anthony, and Joseph Tucker. "Real-Time Image Stabilization Using Fuzzy Logic." ASME Conference Proceedings 1 (2002): 153-57. Print.

Comments – An article about image stabilization. Could be an issue with our system so using computer algorithms to cancel noise could be a useful in the future.

Hodgson, A. (2007). BLIMP-CAM": Aerial Video Observations of Marine Animals. Marine Technology Society Journal, 41(2), 39-43.

Comments This article is very important because it talks about filming something while being suspended in the air. We are also doing this, except instead of filming marine animals we are filming sports games.

Hurak, Z., & Rezac, M. (2012). Image-Based Pointing and Tracking for Inertially Stabilized Airborne Camera Platform. IEEE Transactions On Control Systems Technology, 20(5), 1146-1159.

Comments –This article could help give our team ideas about how to keep our camera system stable during the filming of the sports games. Provides information for camera movement stabilization on an aerial platform

Jiang, Qimi, and Vijay Kumar. "Determination and Stability Analysis of Equilibrium Configurations of Objects Suspended From Multiple Aerial Robots." Journal of Mechanisms and Robotics 4.2 (2012): 1-21. Print.

Comments – A system with similar, but inverted, dynamics. Should be useful for the mathematics and determination behind our system.

Rendn-Mancha, J., Crdenas, A., & Garca, M. A. (2010). Robot Positioning Using Camera-Space Manipulation With a Linear Camera Model.IEEE Transactions On Robotics, 26(4), 726-733.

Comments – Our ultimate goal is to control the system in camera-space" and this article will help to define how the matrix math behind those calculations is developed.

U.S. Geological Survey, and U.S. Department of the Interior. "Helium." Mineral Commodities Summary 2013 2013th ser. (2013): 73-75. Print.

Books:

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Comments Our senior design will also be using an unmanned aerial vehicle and a camera. This article could talk about some problems that could be encountered.

Agnew, Michael Seamus. Cluster Space Control of a 2-robot Aerial System. N.p.: n.p., 2009. Print.

Comments – Aerial robotic control system

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Helium Acts Amendments of 1960, 86-777 (1960). Print.

Helium Privatization Act of 1996, 104-273 (1996). Print.

Thesis:

Illowsky, Matthew, Michael Rosshirt, Isaac George, and Senthil Chidambaram. SkyWorks: Disaster Response Eye in the Sky. Thesis. Santa Clara University, School of Engineering, 2008. N.p.: n.p.,n.d. Print.

Comments – Good quality information about the need and capabilities of aerial response to disaster situations.Very good information for the disaster response aspect of our system.

People

Dolci, Robert: Chief of NASA Disaster Assistance and Rescue Team (DART), Robert.J.Dolci@nasa.gov.

Comments– Contact at NASA Ames Research Center, chief of a dedicated disaster response team. Ideal for the ethical portion of our project.

Ota, Jeff: Nike Research Laboratories, jeffrey.ota@nike.com

Comments– Sponsor for the project, giving us guidelines and direction for the project. Helping to define project definition.

Smith, Jerry: Santa Clara University Athletics, JSmith@scu.edu.

Comments – Excellent source for coaches opinion on sports related uses of our project. Willing to assist us by getting opportunities to test.

Web:

”2012-2013 Sports Season Dates.” LHSAA. N.p., n.d. Web. 15 May 2013. http://lhsaa.org/sports/season-dates/2012-2013/.

”Drag of a Sphere.” Drag of a Sphere. National Aeronautics and Space Administration, n.d. Web. 07 June 2013. http://www.grc.nasa.gov/WWW/k-12/airplane/dragsphere.html.

Garvey, Maura D. ”Tight Supply Reins in the Worldwide Helium Market.” CryoGas International October.2011 (2011): 31-32. Web.

”High School Sports - MaxPreps.” MaxPreps.com. N.p., n.d. Web. 15 May 2013. http://www.maxpreps.com.

Jim Plutt, Anagram. ”Helium Market Dynamics & Availability Outlook.” Speech. www.theballooncouncil.org. The Balloon Council, 13 Sept. 2012. Web. 14 May 2013. http://www.theballooncouncil.org/pdf/TBC_Helium_Webinar_091312.pdf.

Appendix

A Project Design Specification

Date: 11/06/12

Datum Descriptions:

- Winch Datum: 12 VDC Lifting Winch #2647T33
- Camera Datum: Go Pro Hero 2

Revision: 2

Table 10: Customer Needs Matrix

Elements / Requirements		Parameters	
	Units	Datum	Target - Range
Weight of Camera and Structure	Kg	-	Up to 1kg
Camera DoF	Degrees	-	180 Tilt x 360 Pan
Camera Wifi Range	Meters	180	180
Camera Battery Life	Hours	3	4 to 6
Diameter of Balloon	Meter	-	2 to 3.5
Resolution	MP	720-1080p	1080p
Frames per Second	Fps	30-60	30-60
Winch Speed	m/s	0.1	1 to 5
Winch Weight (per winch)	Kg	50	20 to 40
Cable Length (per winch)	Meters	16	75-100
Max Wind Speed	Meters/Second	-	6
Pointing Accuracy	Degrees	-	$\pm$ 5
Temperature Range	C°	-	0-30
Water Proofing - Camera	Meters	60	60 Depth
Water Resistance - Winch	Minutes	0	30 (rainy environment)
Initial Price	Dollars	-	1000
Cost per Deployment	Dollars	-	50-100
Cost to Manufacture	Dollars	-	900
Set up Time	Minutes	-	15
Take Down Time	Minutes	-	15
Transportation/Storage Size	Cubic Meters	-	1 (Balloon Deflated)
Impact Resistance	Newtons	-	300
Maximum Operating FAA Height	Meters	-	150
Winch Drum Size	Meters	0.15	0.1-0.15
Winch Total Size	Cubic Meters	-	0.025-0.25

B Decision Matrix

Table 11: Decision Matrix

Design Project =	ICARUS								
	TARGET or	DESIGN IDEAS							
CRITERIA	FACTOR	1 = Baseline		two		three		four	
Time – Design	1	1		2		1		0.5	
Time – Build	1	1		2		1		0.5	
Time – Test	1	1		1		1		1	
Time Score	10		10		16.67		10.00		6.67
Cost – Prototype	1	$ 1.00		$ 0.50		$ 1.00		$ 0.75	
Cost – Production	1	$ 1.00		$ 0.50		$ 0.75		$ 0.50	
Cost Score	10		10		5.00		8.75		6.25
Weight	5	3	15	5	25	4	20	4	20
Speed	2	3	6	1	2	2	4	3	6
Accuracy	1	3	3	1	1	2	2	3	3
Ease of Set up	4	3	12	4	16	3	12	2	8
Battery Life	4	3	12	4	16	3	12	2	8
Stability	3	3	9	2	6	3	9	4	12
Durability	3	3	9	2	6	3	9	4	12
	TOTAL		66.0		70.3		69.3		76.1
	RANK								
	% MAX		86.7%		92.4%		91.0%		100.0%
	MAX	76.1							

NOTE: User fills in Purple areas, gold areas are calculated or fixed

Light blue areas filled from prioritizing matrix

BASELINE = Skyworks (Disaster Relief Camera System - 2008)

Design Idea Descriptions

two	Tier 1A
three	Tier 2B
four	Tier 3C

C Budget

Table 12: Budget

Project Icarus	**Parts List**						
Subsystem	**Component Description**	**Cost/part**	**QTY**	**Total Cost**	**Purchase Price**	**Estimated Purchase Price**	**Comments**
Winch							
	Battery	$23.11	3	$69.33	$0.00		Donated by RSL
	Spool	$16.03	3	$48.09	$48.09		
	Motor	$20.03	3	$60.09	$60.09		
	Motor-Spool Connection	$20.76	3	$62.29	$62.29		
	Arduino	$41.45	3	$124.34	$124.34		Arduino and Shields
	XBee	$67.92	3	$203.75	$203.75		
	Encoder	$12.65	3	$37.96	$50.61		Bought 4 of them
	Structure Frame	$50.00	3	$150.00	$24.63		Most of it was donated by the RSL
	Structure Casing	$24.34	3	$73.01	$53.01		
	Motor Controller	$129.72	3	$389.16	$389.16		
	Breakers	$36.10	3	$108.30	$108.30		
	Hardware	$25.64	3	$76.93	$76.93		
	Winch Assembly						
	Sub System Totals	**$467.75**	**3**	**$1,403.25**	**$1,201.20**	**$0.00**	
Camera Mount V2							
	Frame	$25.00	1	$25.00	$0.00		Donated by RSL
	GoPro	$300.00	1	$300.00	$0.00		Donated by Nike
	GoPro Mount	$11.49	1	$11.49	$0.00		
	(Servos)	$22.93	2	$45.85	$45.85		
	Servo Bracket (pan/tilt)	$12.95	1	$12.95	$12.95		
	Battery	$16.10	1	$16.10	$0.00	$16.10	
	Battery Mount	$1.95	1	$1.95	$0.00	$1.95	

Subsystem	Component Description	Cost/part	QTY	Total Cost	Purchase Price	Estimated Purchase Price	Comments
Camera Mount V2	RC Receiver	$29.99	1	$29.99	$0.00		Donated by RSL
	Mount Assembly						
	Sub System Totals	**$420.41**	**1**	**$443.33**	**$58.80**	**$18.05**	
CM V3 Additions							
	Arduino	$29.95	1	$29.95	$0.00	$29.95	
	XBee	$37.95	1	$37.95	$0.00	$37.95	
	Compass	$34.95	1	$34.95	$0.00	$34.95	
	Modified Frame	-	-				
	Sub System Totals	**$102.85**	**1**	**$102.85**	**$0.00**	**$102.85**	
Balloon							
	4' Balloon	$32.85	1	$32.85	$32.85		
	6' Balloon	$28.95	1	$28.95	$28.95		
	Helium	$1,000.00	1	$1,000.00	$0.00	$1,000.00	
Tether							
	100 lb Test Fishing Line	$65.18	1	$65.18	$65.18		
User Station							
	Laptop	-	-	-	$0.00		Using student's Laptops
	XBee Receiver	$37.95	1	$37.95	$37.95		
	iPad (Optional)	$399.00	1	$399.00	$0.00		Using student's iPad
	Joystick	$25.00	1	$25.00	$0.00		Donated by RSL
	User Assembly						
	Sub System Totals	**$1,588.93**	**1**	**$1,588.93**	**$164.93**	**$1,000.00**	
Unused Items							
	Different Motors	$67.09	1	$67.09	$67.09		
	H-Bridge	$59.90	1	$59.90	$59.90		
	Couplers	$85.51	1	$85.51	$85.51		
	Sub System Totals	**$212.50**		**$212.50**	**$212.50**	**$0.00**	
	System Total:	**$2,792.43**		**$3,750.86**	**$1,637.43**	**$1,120.90**	
	Total Funding				**$2,000**		
	Left over Money				$362.57		

D Gantt Chart

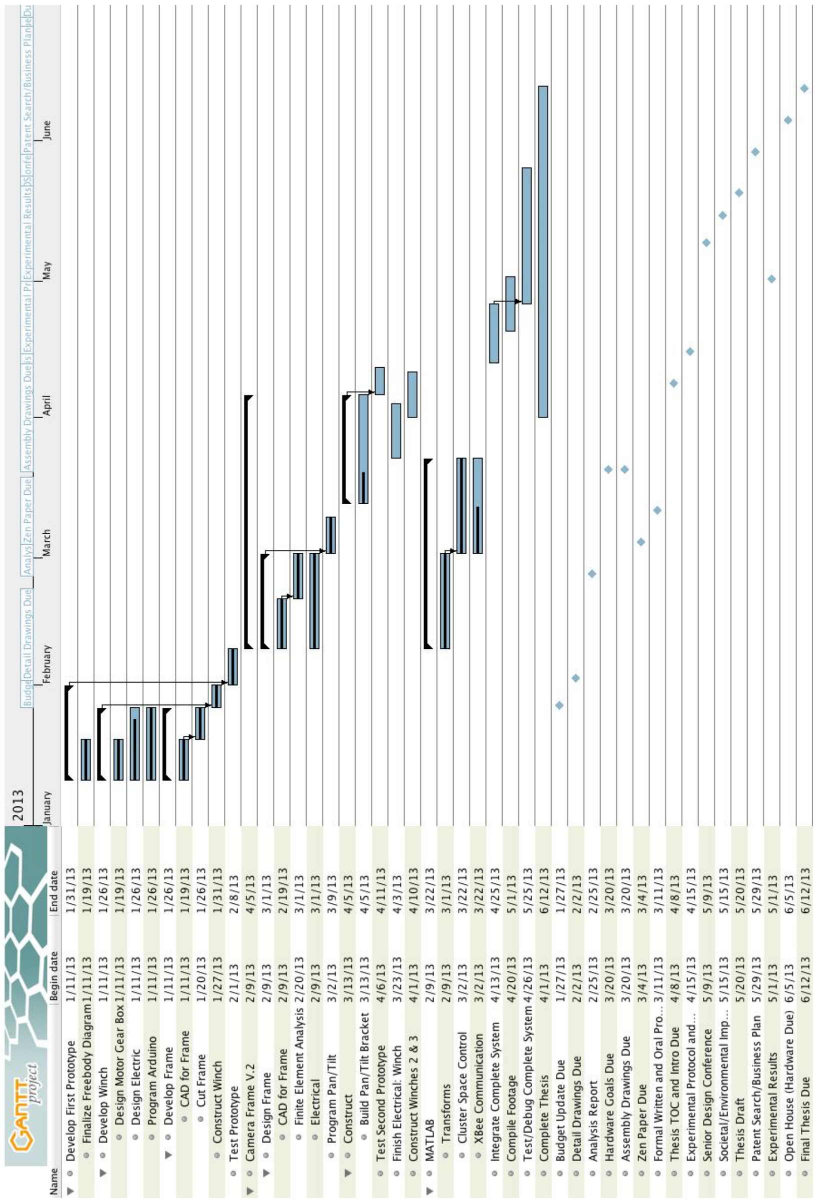


Figure 26: Gantt Chart

E Tiers

Table 13: System Tiers

Tier	**1a**	**1b**	
	1DOF	1DOF	
	Manual Winch control	1 winch position control	
	uncontrolled camera	uncontrolled camera	
Tier	**2a**	**2b**	**2c**
	2DOF	2DOF	2DOF
	2 Winch position Control	2 Winch position Control	2 Winch PID Control
	uncontrolled camera	RC Control camera	Computer Control camera
	Wired winch connection	Wireless winch connection	Computer Control Winch
			Wireless winch connection
Tier	**3a**	**3b**	**3c - End of Year**
	3DOF	3DOF	3DOF
	3 or 4 Winches Position	3 or 4 Winches Position	3 or 4 Winches PID
	Uncontrolled Camera	RC Control Camera	Computer Control Camera
	Wireless winch Connection	Wireless winch Connection	Computer Control Winch
			Wireless winch connection

F Summary of Similar Products

Table 14: Product Competition

Similar Products	Manufacturer	Price	Sale Volume	Ease of Use
SkyCam	SkyCam	Not Available	Not for General Use	Difficult
Cineflex HD aerial camera system	Helivision	Not Available	Not for General Use	Difficult, Requires Helicopter
EagleCam Raven, Sky-Hawk	EagleCam	Not Available	No Data Available	Easy
Home Video	Varied	\$50-\$300	30 Million/Year	Easy

G Parts List

Table 15: Parts List

Subsystem	Component Description	Part Number
Winch		
	Battery Internal	W01N
	Reel	W02
	500 RPM Motor	W03
	Drive Shaft Adapter	W04
	Drive Shaft Coupler	W10
	Drive Shaft Shaft	W11
	Drive Shaft Coupler/Adapter Pin 1/8"	W22
	Drive Shaft Drive Pins	W23
	Arduino	W05
	XBee	W06
	16in Extrusion	W07
	8in Extrusion	W16
	Motor Controller	W08
	15A Breakers	W09
	1A Breaker	W12
	Reel Mount	W13
	Winch Base	W15
	Small Triangle Bracket	W17
	Front/Back Cover	W18
	Right Cover	W19
	Left Cover	W20
	Top Cover Large	W21
	Top Cover Small	W24
	Encoder	W25
	Encoder Bracket	W26
	Nylon 4-40 x 1" M/F Standoffs	W27
	Aluminium 4-40 x 1" M/F Standoffs	W28
	4-40 x 1/4" Pan Head	W29
	4-40 x 1/2" Flat Head	W30

Subsystem	Component Description	Part Number
	T-Slot Nut	W31
	1/4” x 3/4” Pan Head	W32
	6-32 x 1/2” Pan Head	W33
	4-40 x 1” Pan Head	W34
	3/8” x 1.5” Bolt	W35
	3/8” Nut	W36
	Hinges	W37
	8-32” x 1/2” Pan Head	W38
	#8 Nuts	W39
	Arduino Shield	W40
	Xbee Shield	W41
	Serial converter	W42
	4-40 x 1/2” Pan Head	W44
	Winch Assembly	WA1
	Drive Shaft Assembly	WA2
	Structure Assembly	WA3
Camera Mount V2		
	Frame	C201B
	GoPro	C202
	GoPro Mount	C203
	Servos	C204
	Servo Mounts	C205
	Battery	C206
	Battery Mount	C207
	RC Receiver	C208
	Mount Assembly	CA201
Balloon		
	6’ Balloon	B02
Tether		
	100 lb Test Fishing Line	T01
User Station		
	Laptop	U01
	XBee Receiver	U02
	iPad (Optional)	U03
	Joystick	U04

H Detailed Assembly Drawings

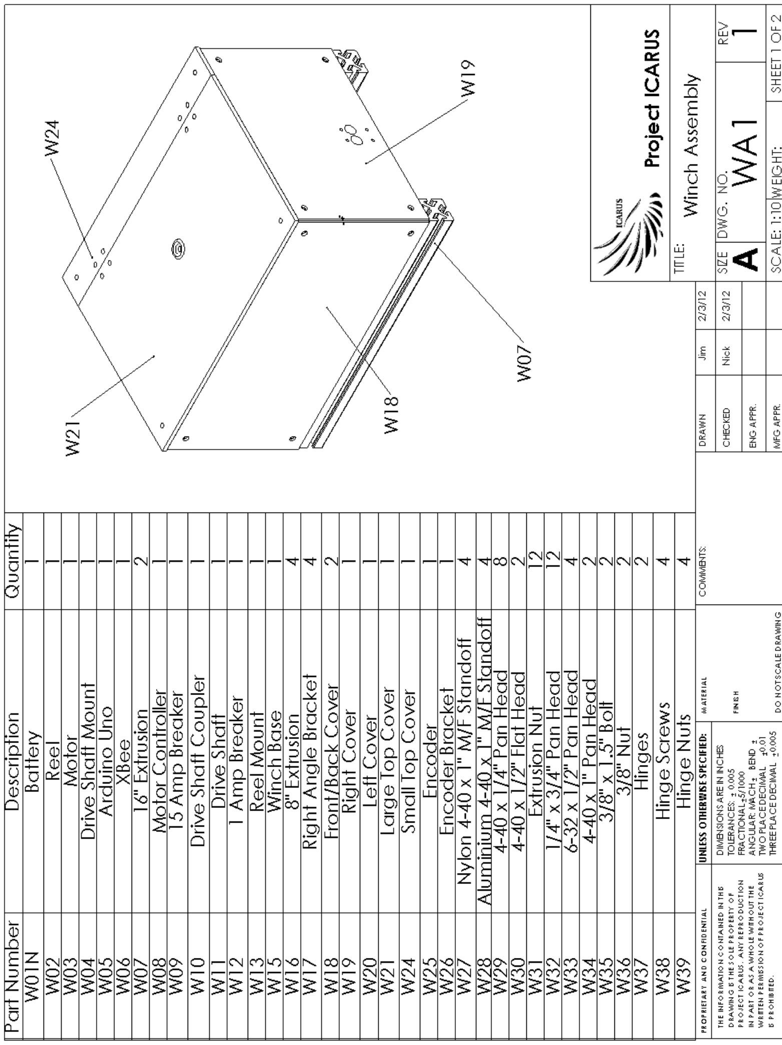
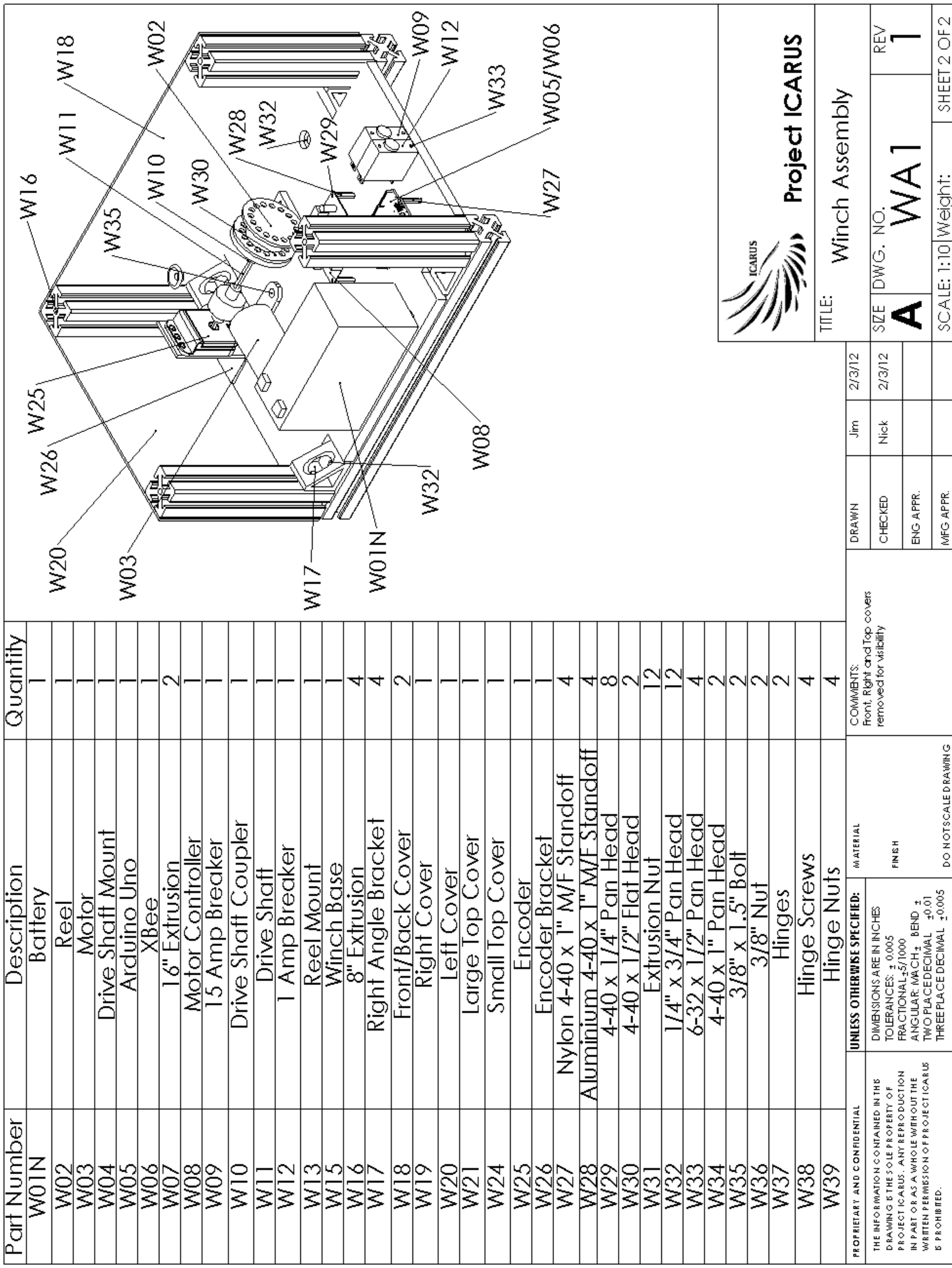


Figure 27: Winch assembly with covers on



Part Number	Description	Quantity
W01N	Battery	1
W02	Reel	1
W03	Motor	1
W04	Drive Shaft Mount	1
W05	Arduino Uno	1
W06	XBee	1
W07	16" Extrusion	2
W08	Motor Controller	1
W09	15 Amp Breaker	1
W10	Drive Shaft Coupler	1
W11	Drive Shaft	1
W12	1 Amp Breaker	1
W13	Reel Mount	1
W15	Winch Base	1
W16	8" Extrusion	4
W17	Right Angle Bracket	4
W18	Front/Back Cover	2
W19	Right Cover	1
W20	Left Cover	1
W21	Large Top Cover	1
W24	Small Top Cover	1
W25	Encoder	1
W26	Encoder Bracket	1
W27	Nylon 4-40 x 1" M/F Standoff	4
W28	Aluminium 4-40 x 1" M/F Standoff	4
W29	4-40 x 1/4" Pan Head	8
W30	4-40 x 1/2" Flat Head	2
W31	Extrusion Nut	12
W32	1/4" x 3/4" Pan Head	12
W33	6-32 x 1/2" Pan Head	4
W34	4-40 x 1" Pan Head	2
W35	3/8" x 1.5" Bolt	2
W36	3/8" Nut	2
W37	Hinges	2
W38	Hinge Screws	4
W39	Hinge Nuts	4

Figure 28: Winch assembly with covers off

I Detailed Parts Drawings

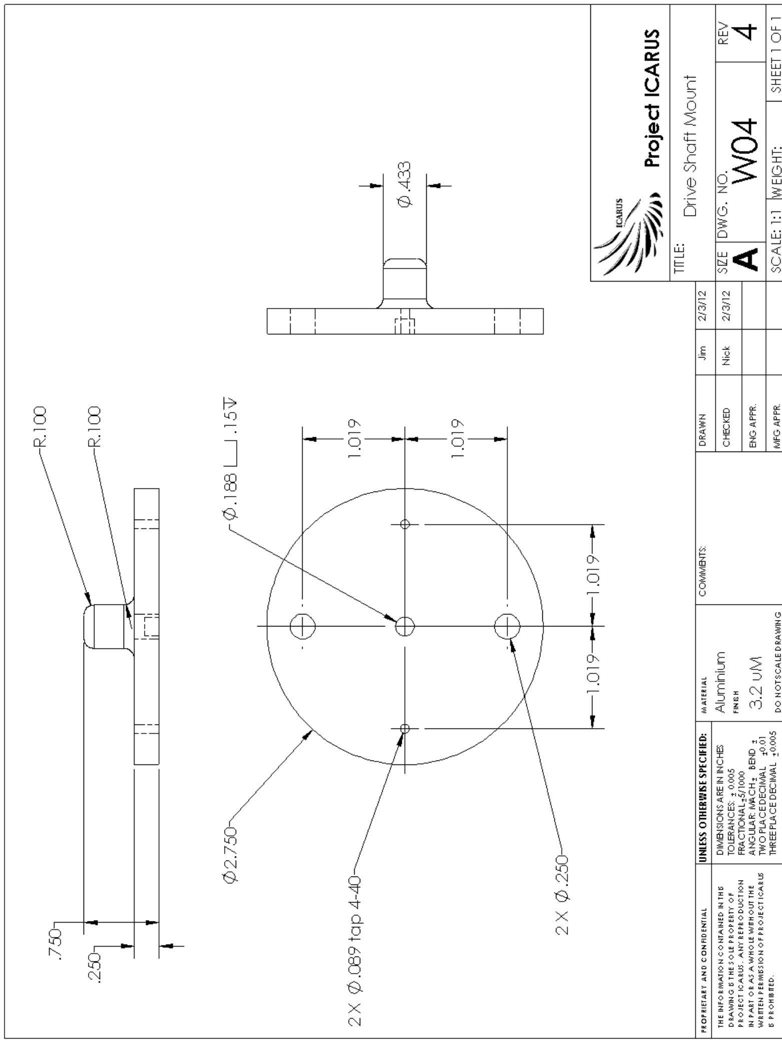


Figure 29: Reel Adapter

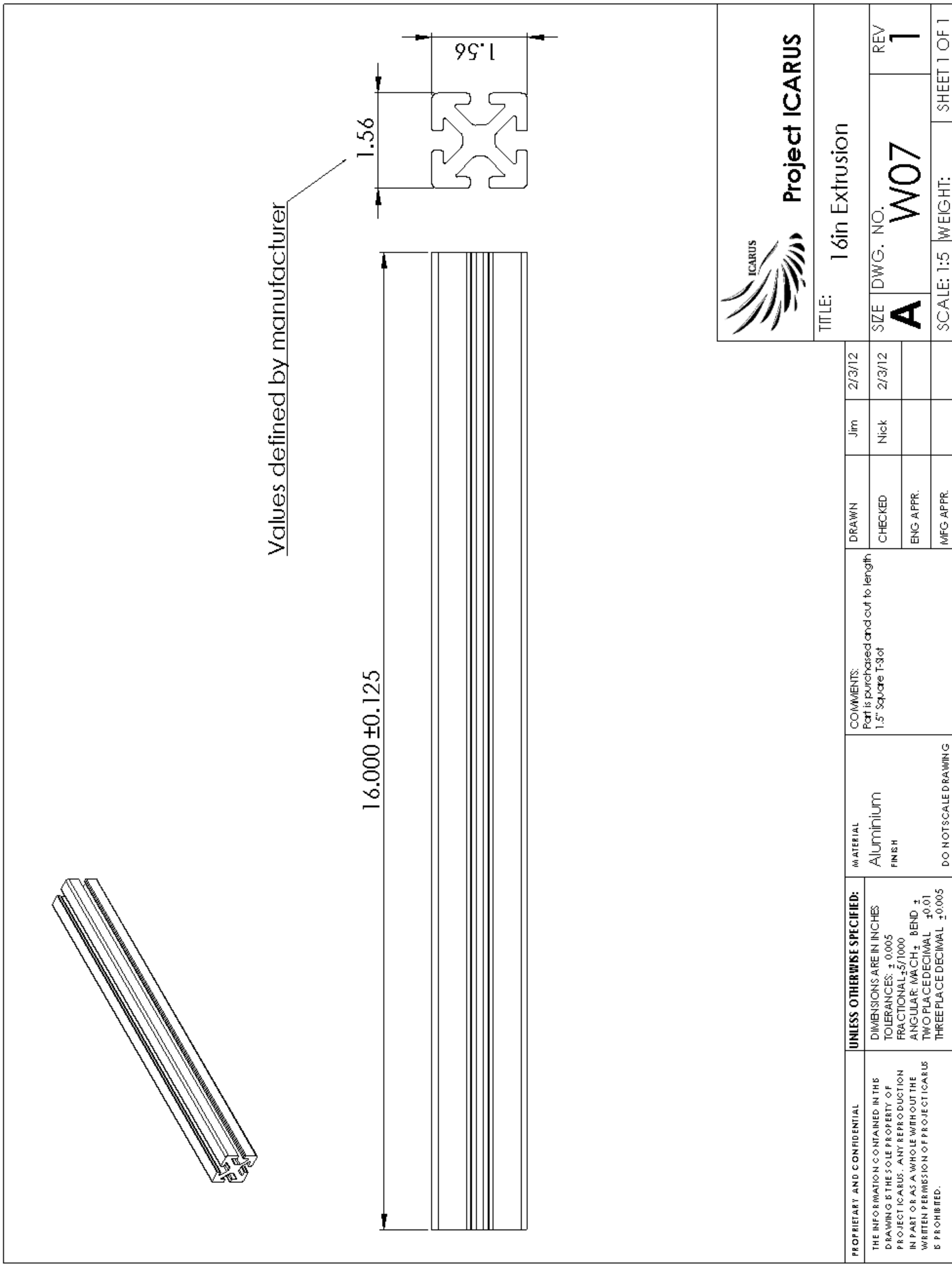


Figure 30: 16 inch Extrusion

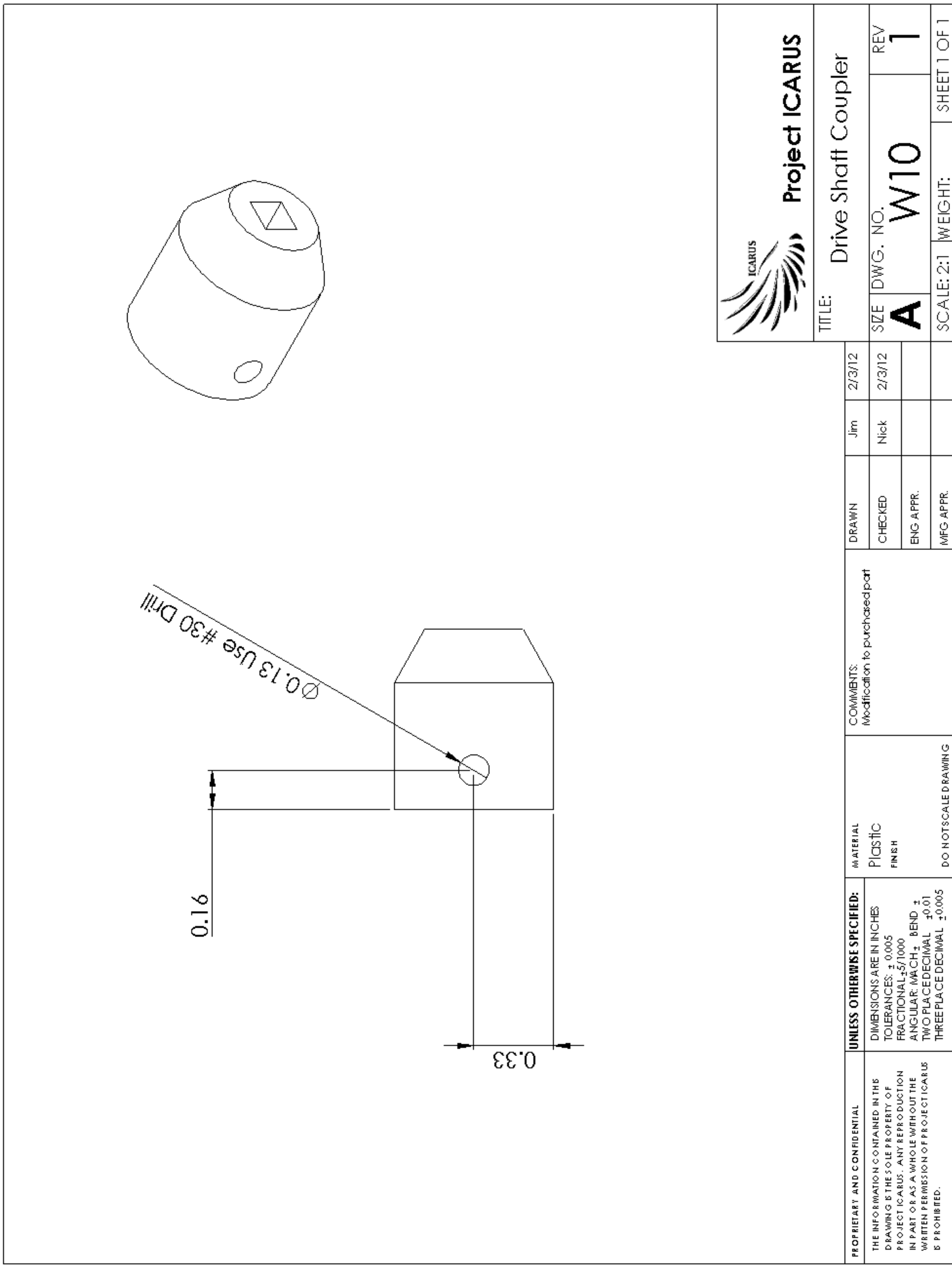


Figure 31: Drive Shaft Coupler

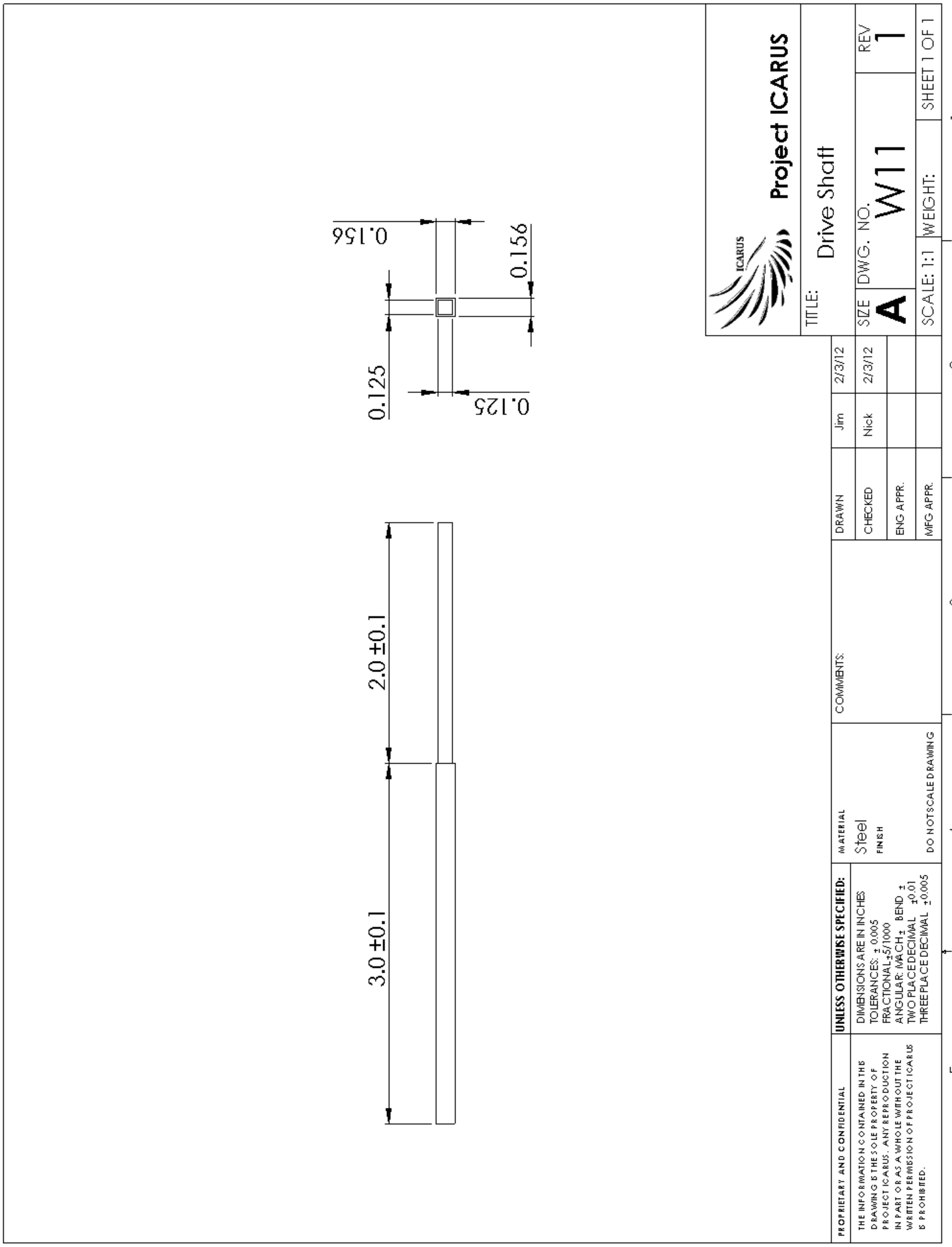


Figure 32: Drive Shaft

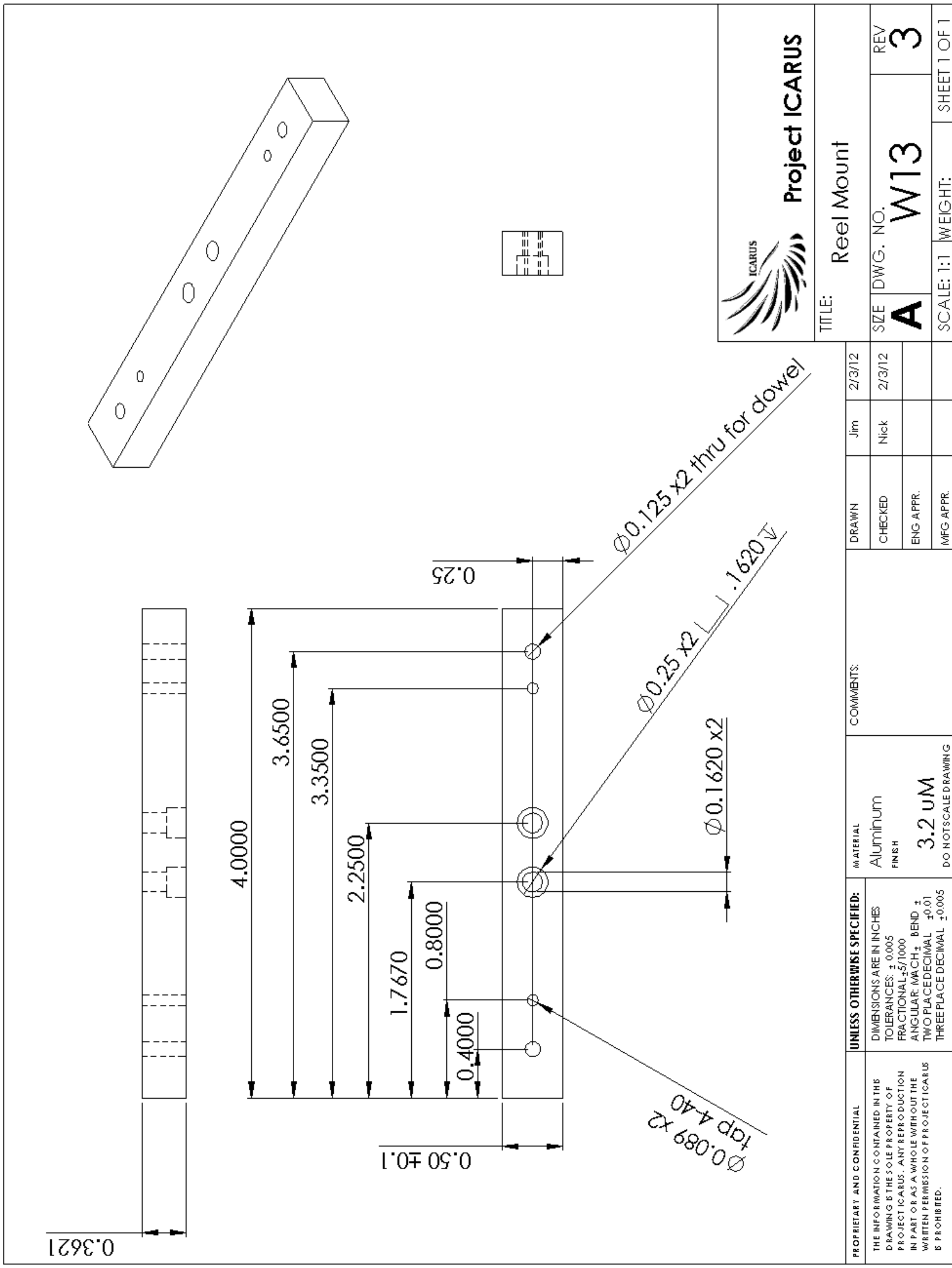


Figure 33: Aluminium Reel Mounting Block

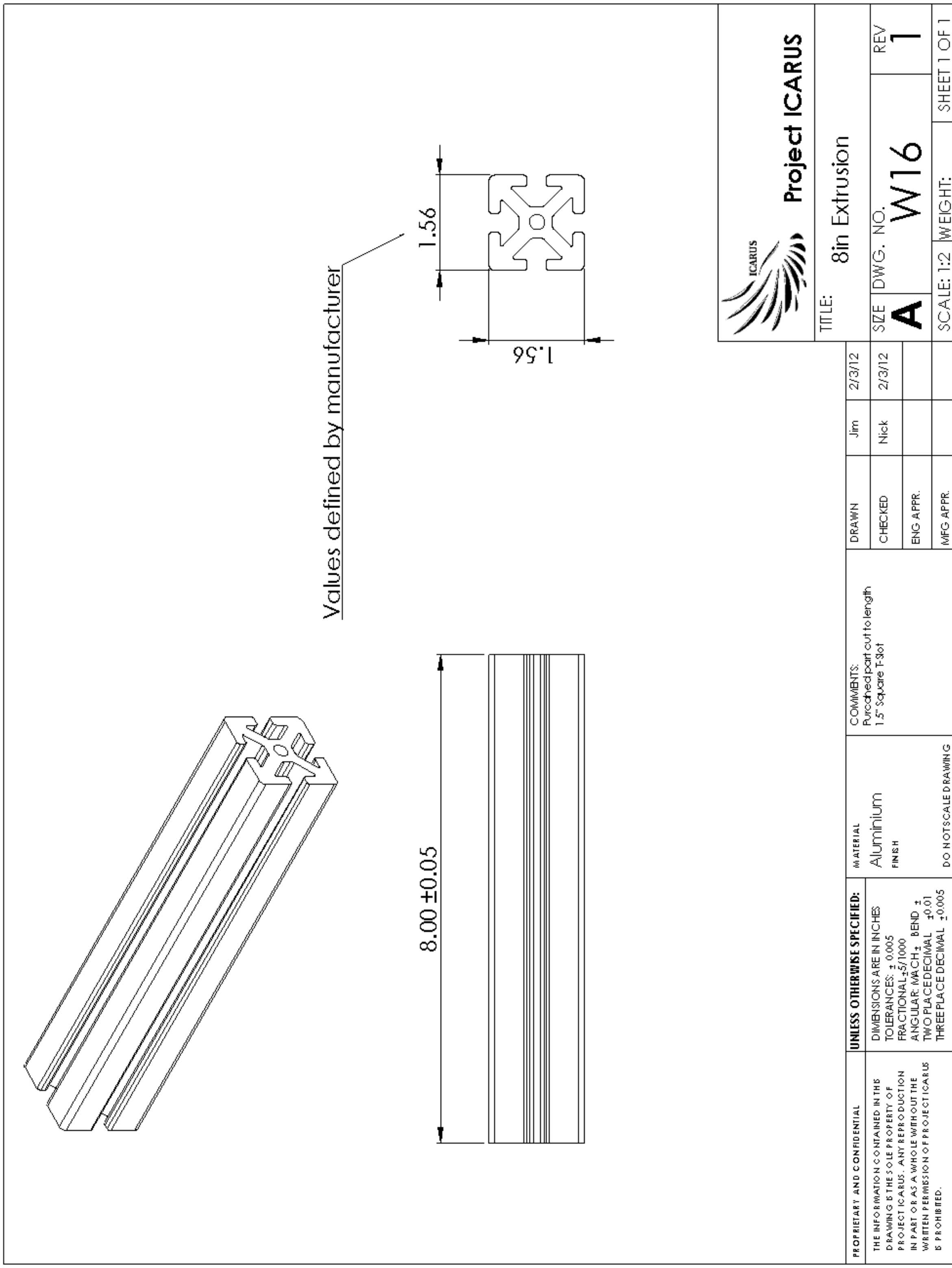


Figure 34: 8 inch Extrusion

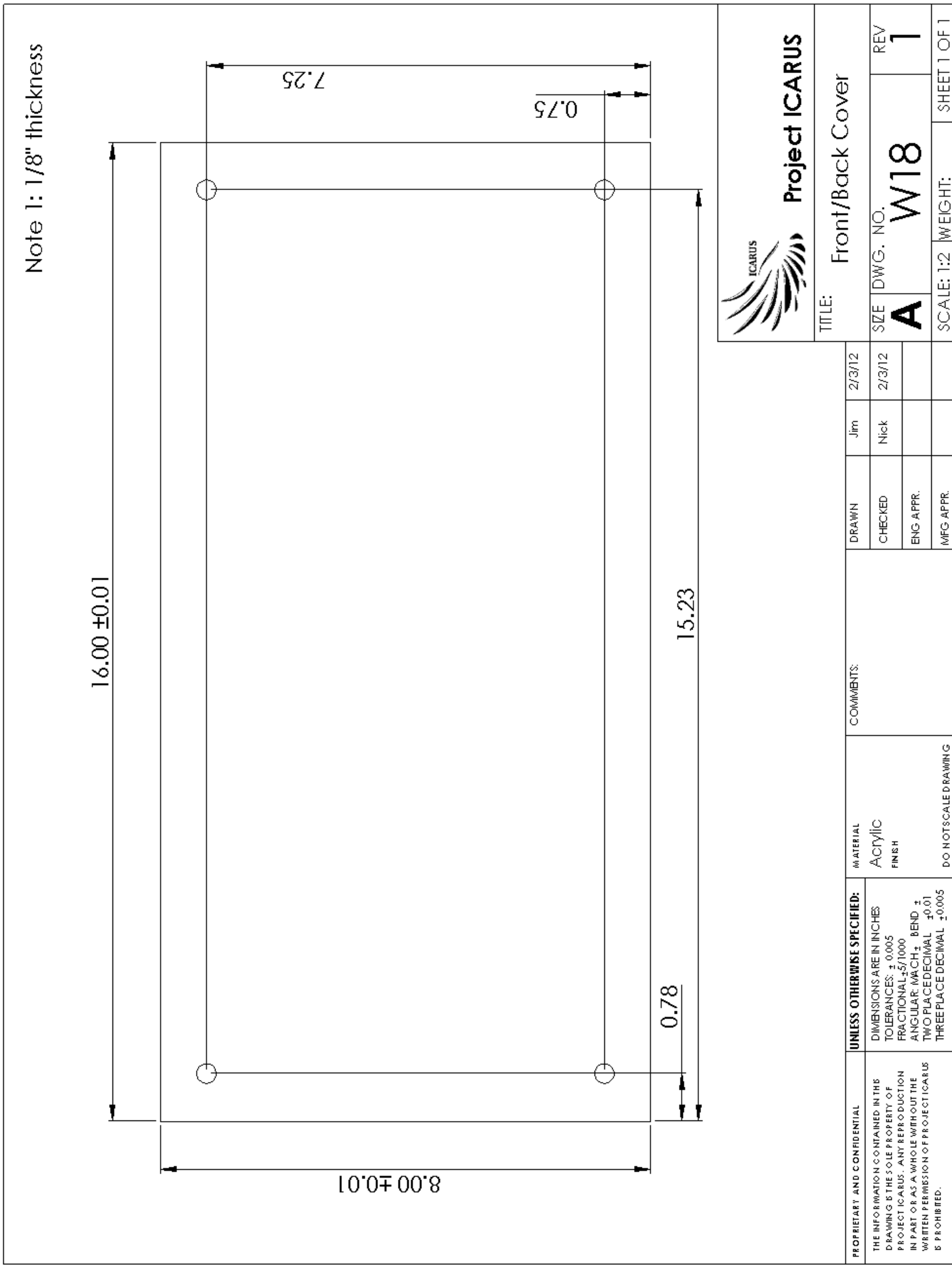


Figure 35: Front and Back Cover

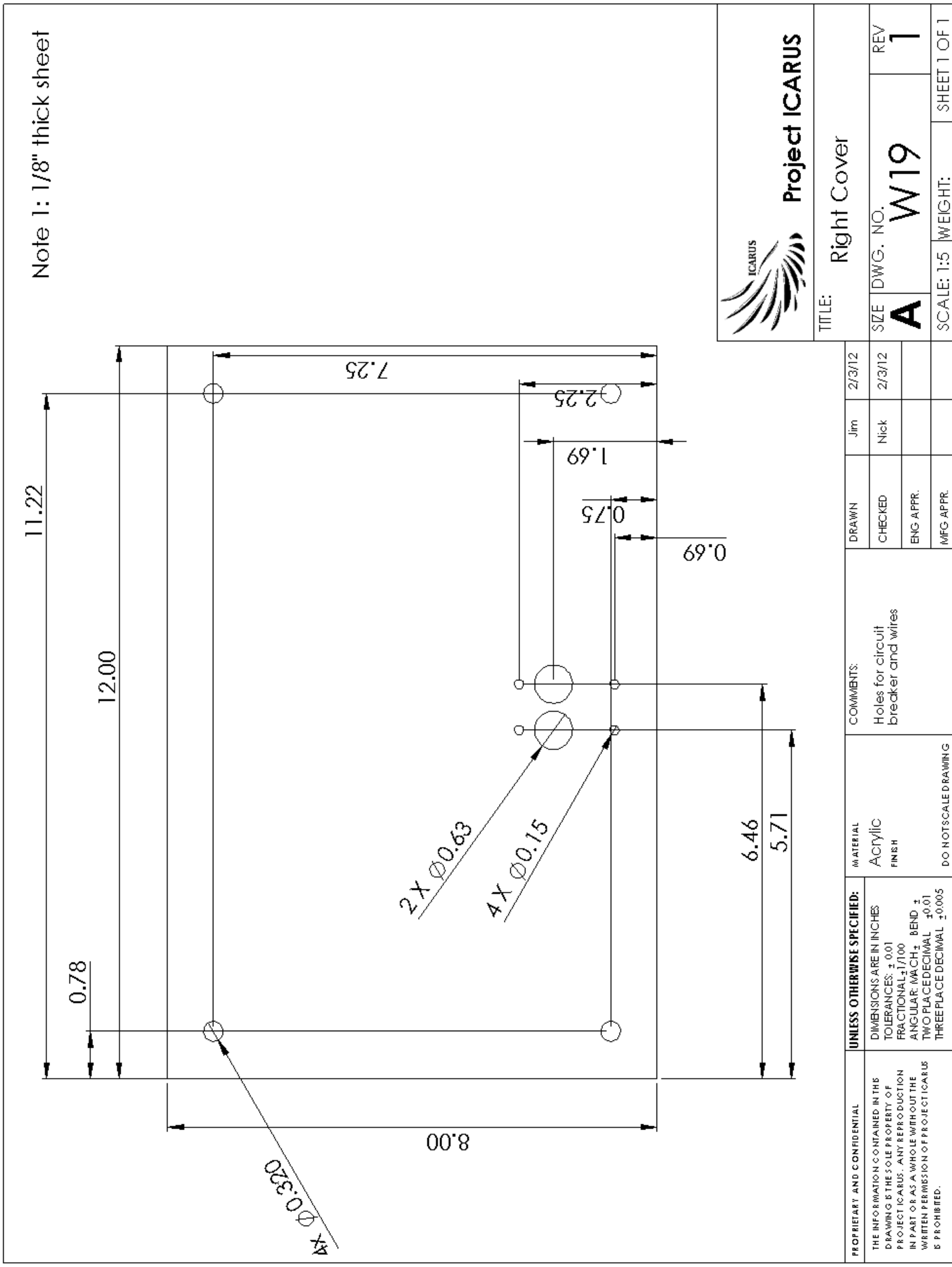


Figure 36: Right Side Cover

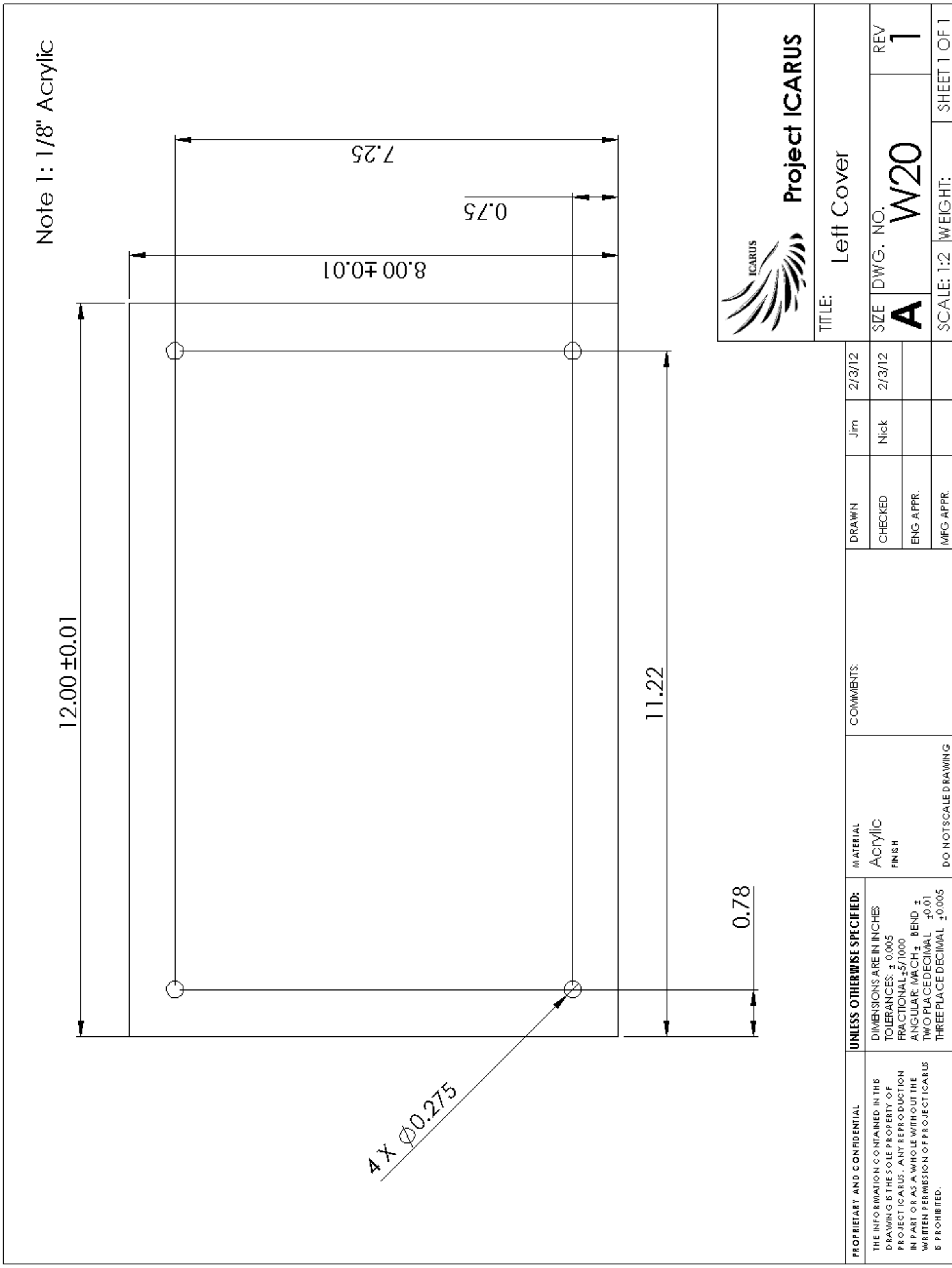


Figure 37: Left Side Cover

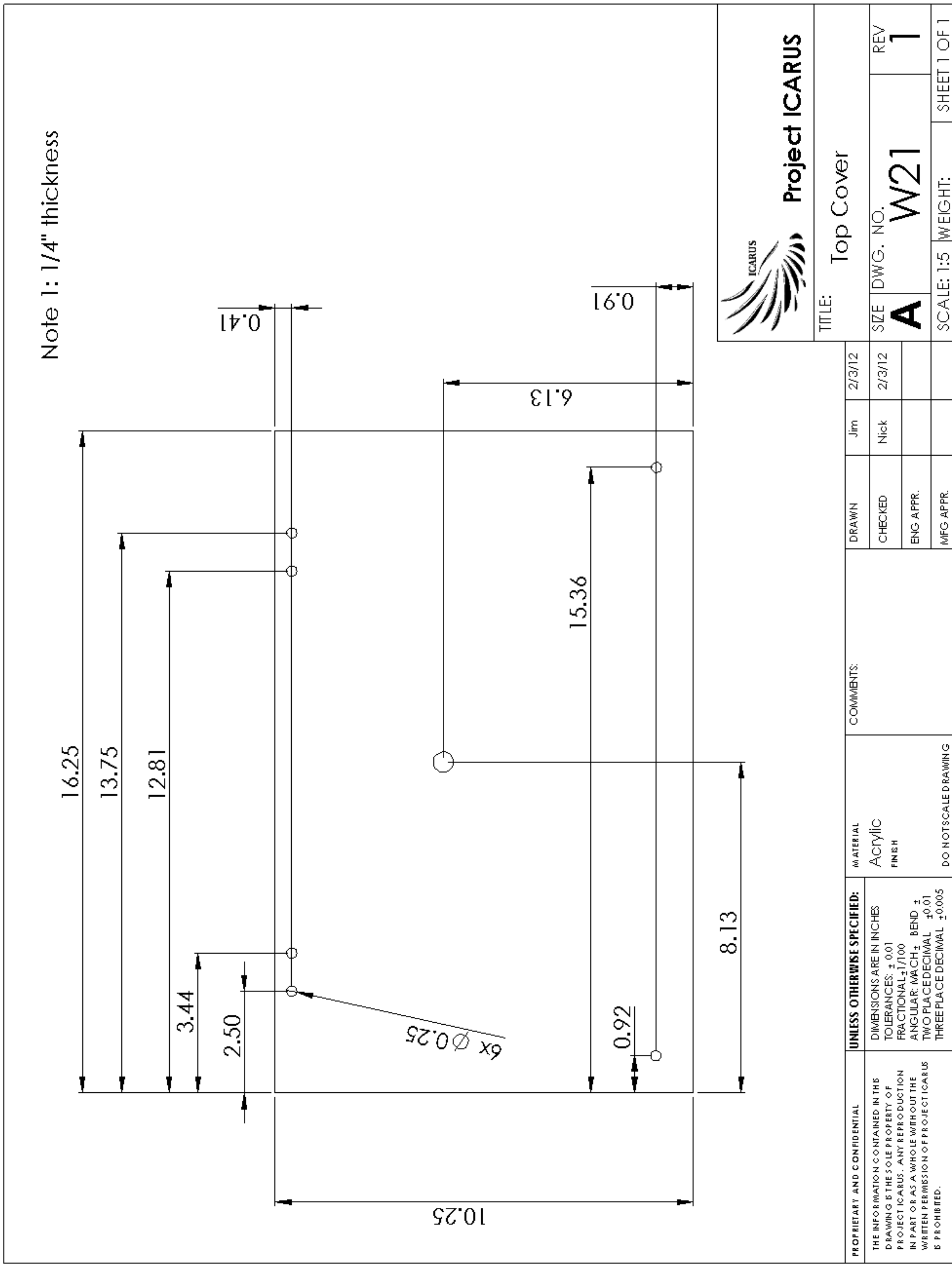


Figure 38: Large Top Cover

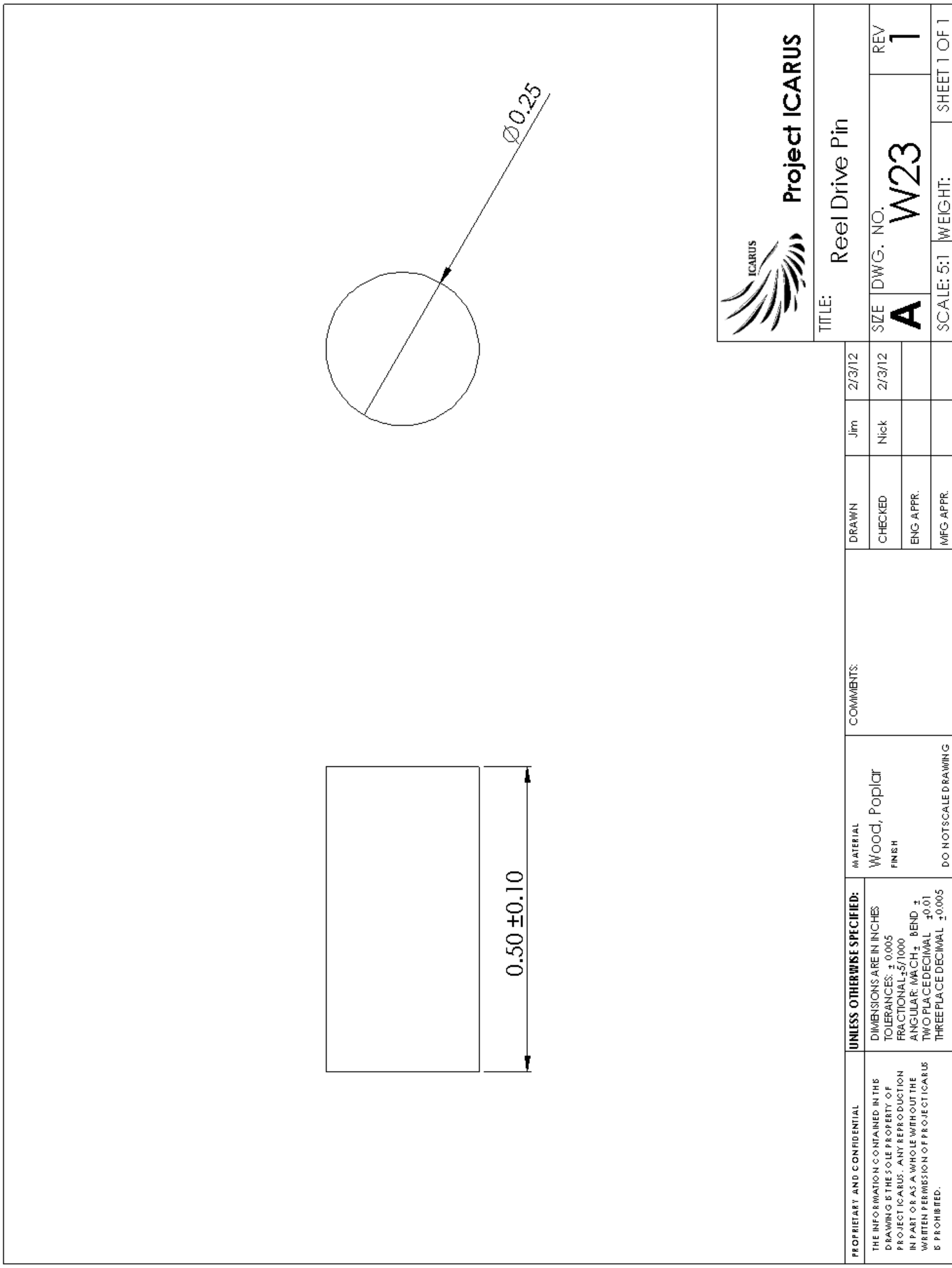


Figure 39: Reel Drive Pin

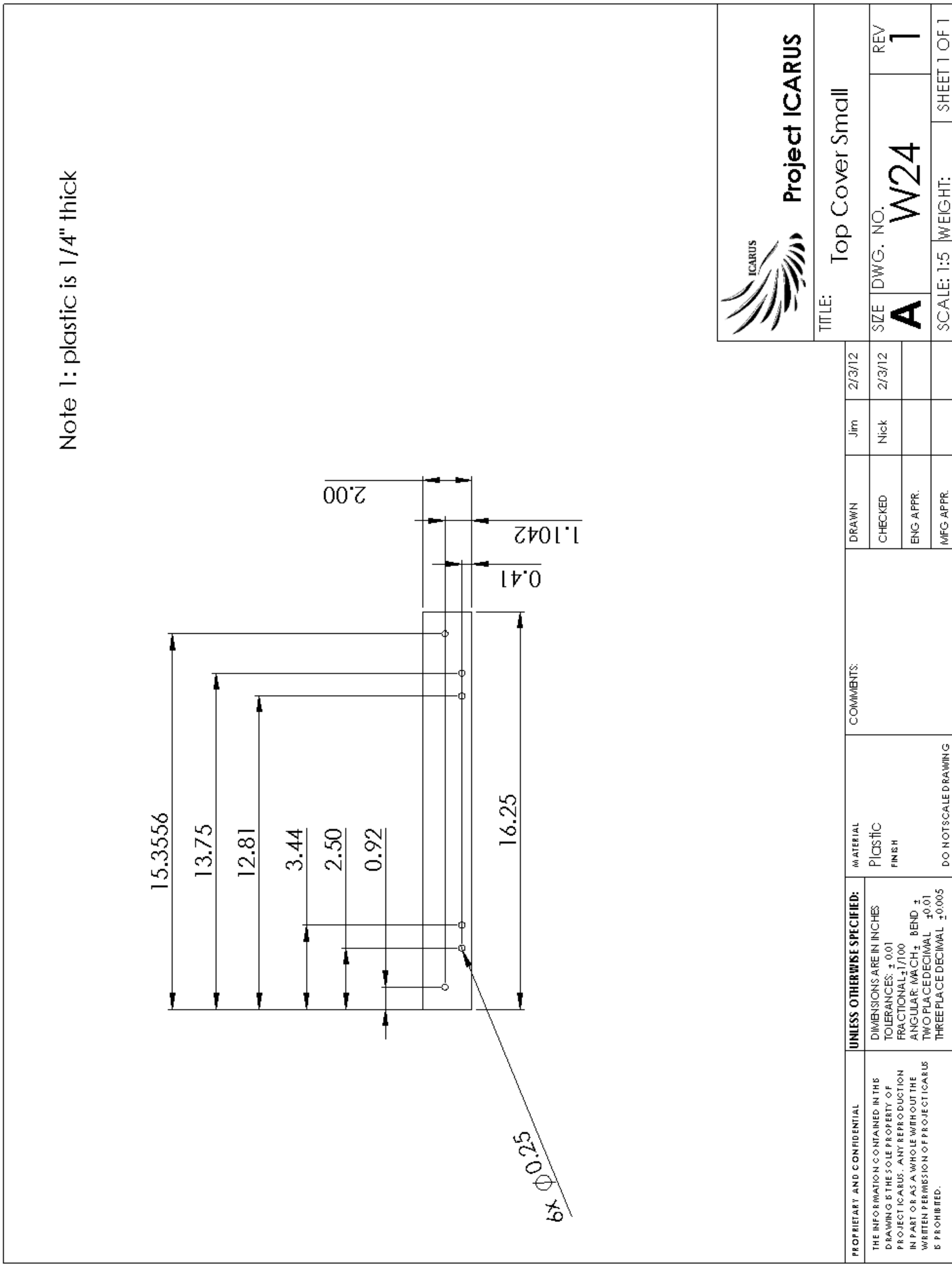


Figure 40: Small Top Cover

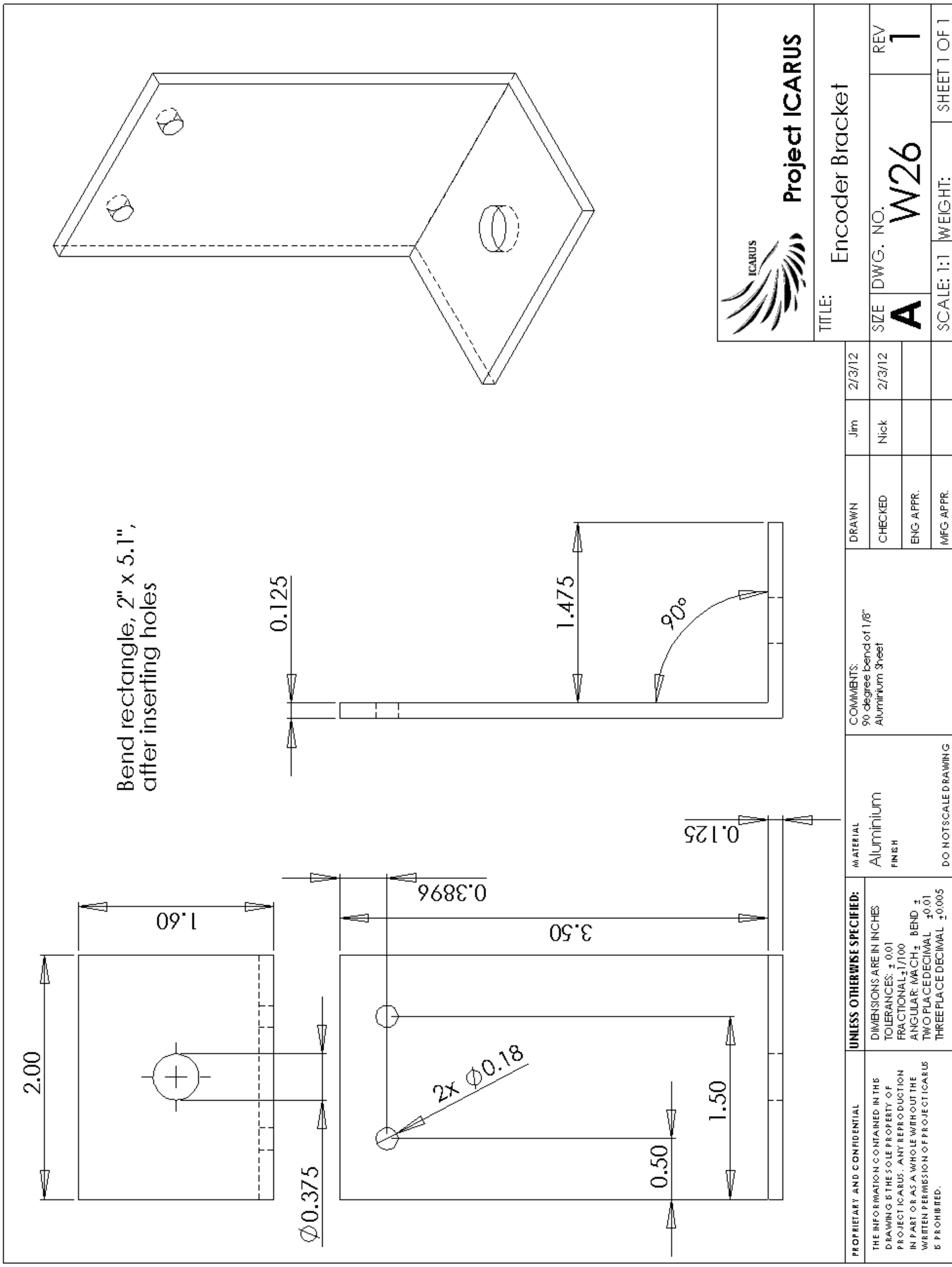


Figure 41: Encoder Bracket

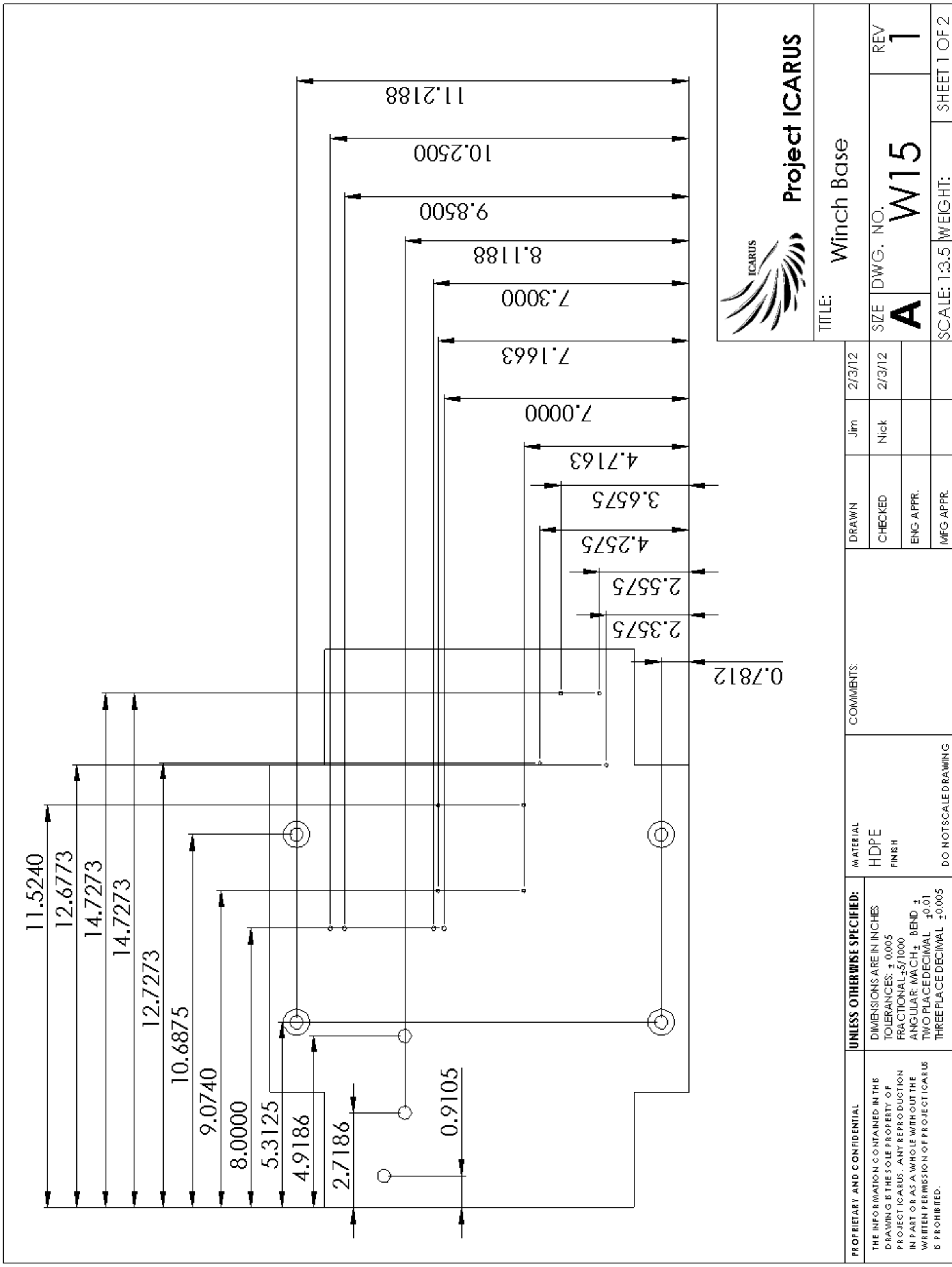


Figure 42: Winch Base Hole Placement

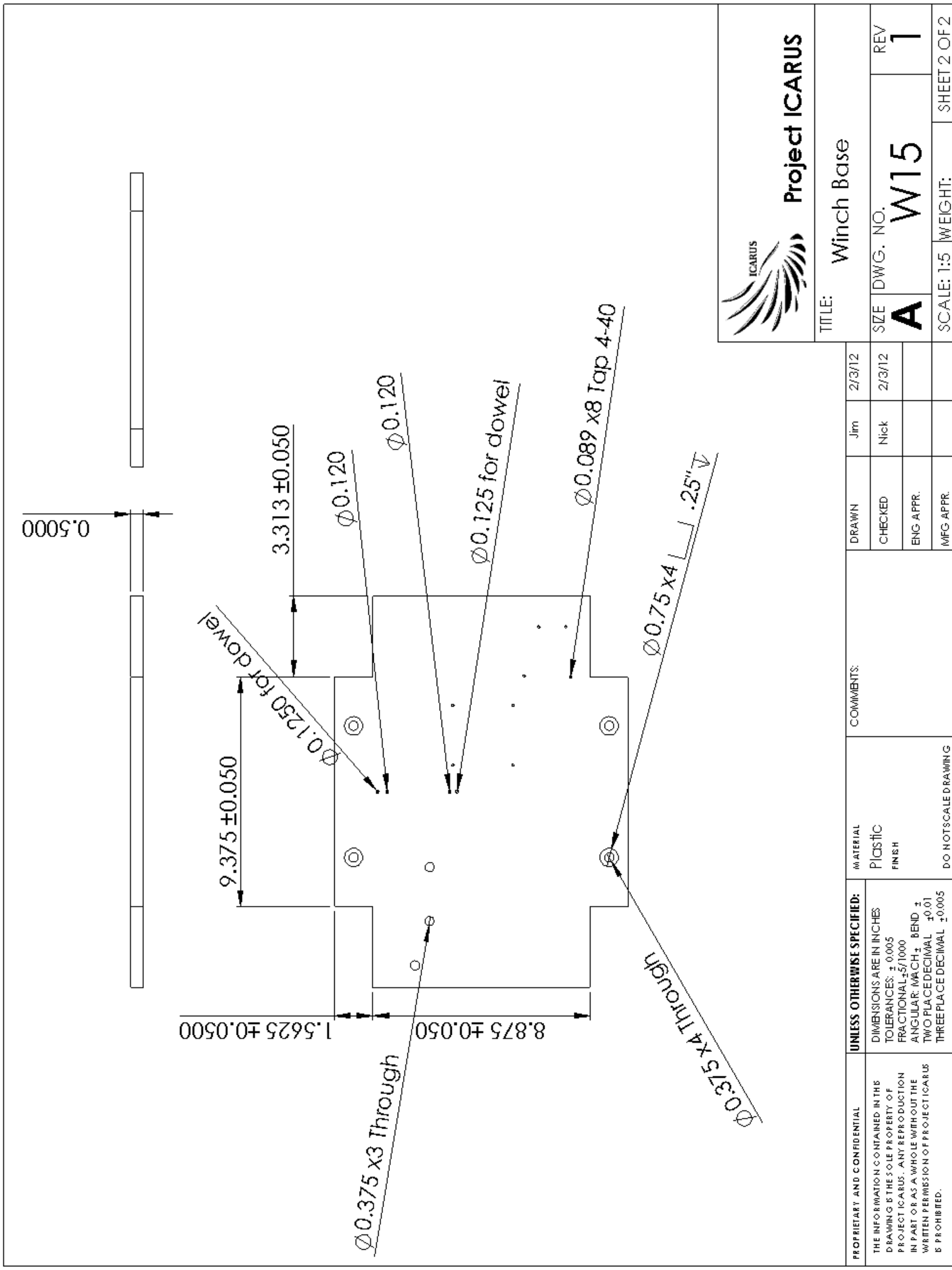


Figure 43: Winch Base Dimensions

J Simulink Files

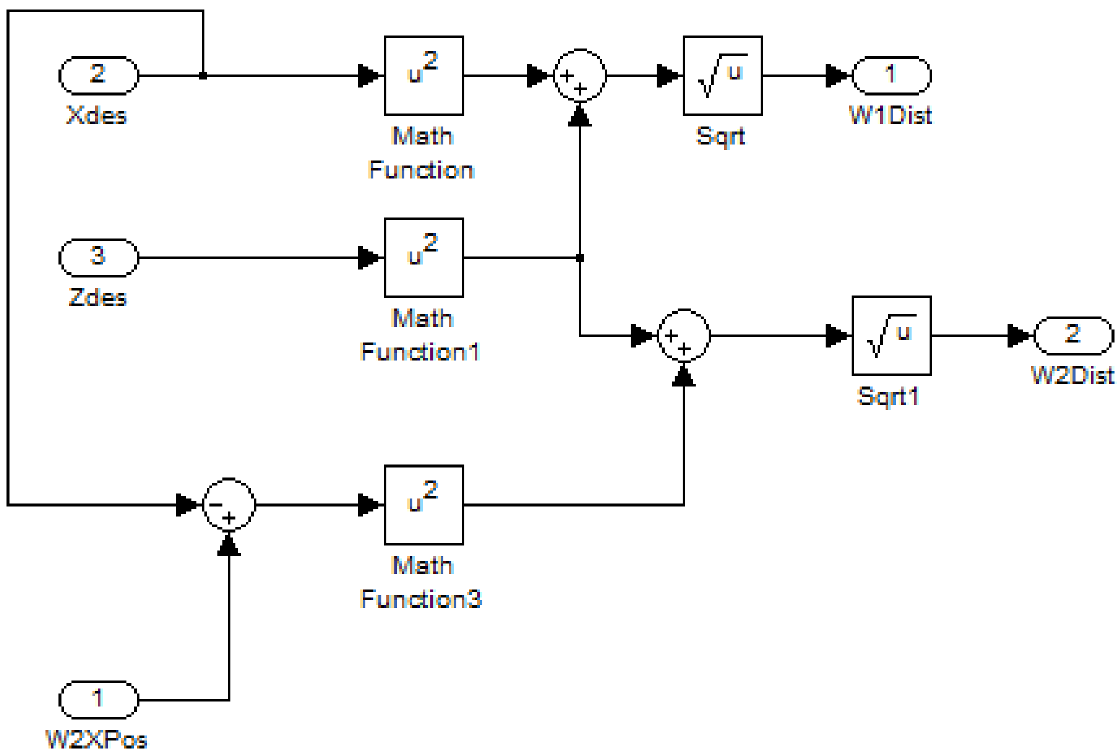


Figure 44: Two Winch Position Subsystem

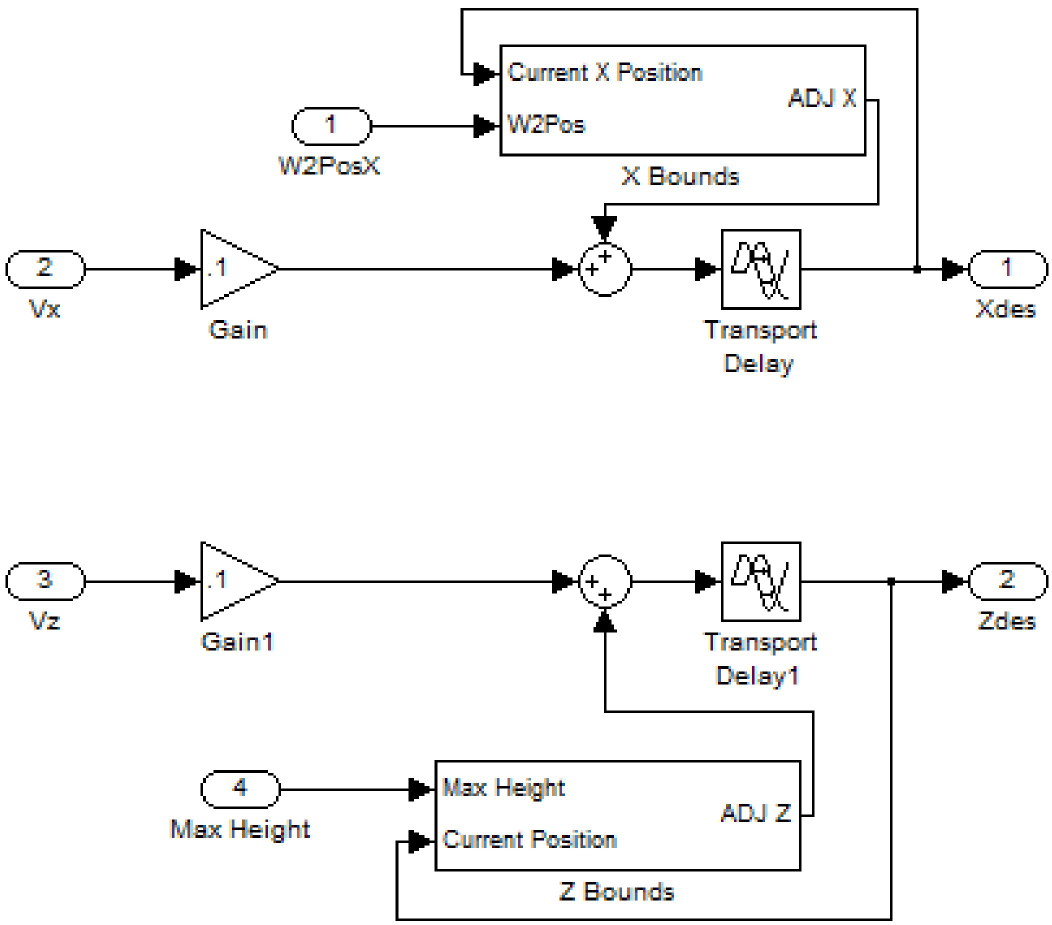


Figure 45: Two Winch Bounds Subsystem

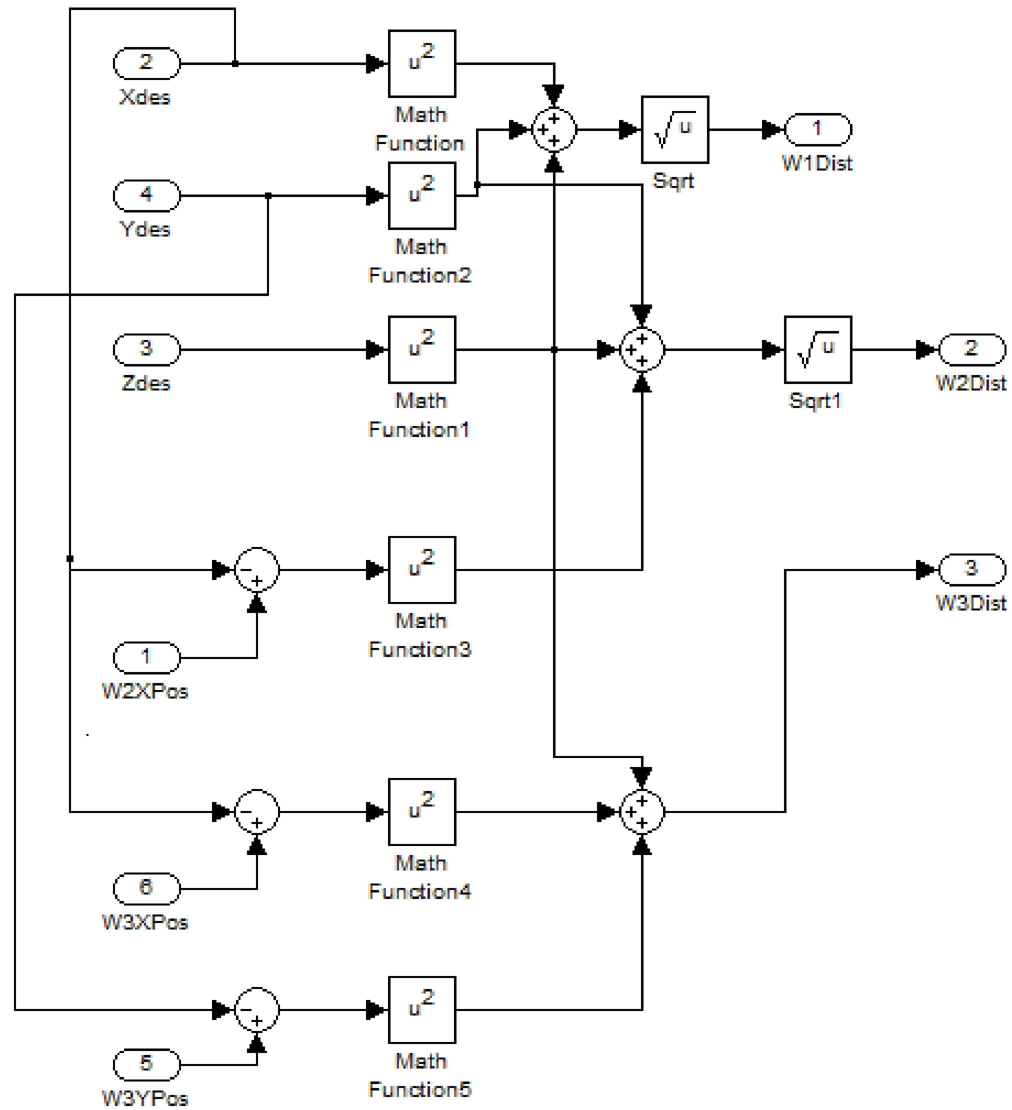


Figure 46: Three Winch Position Subsystem

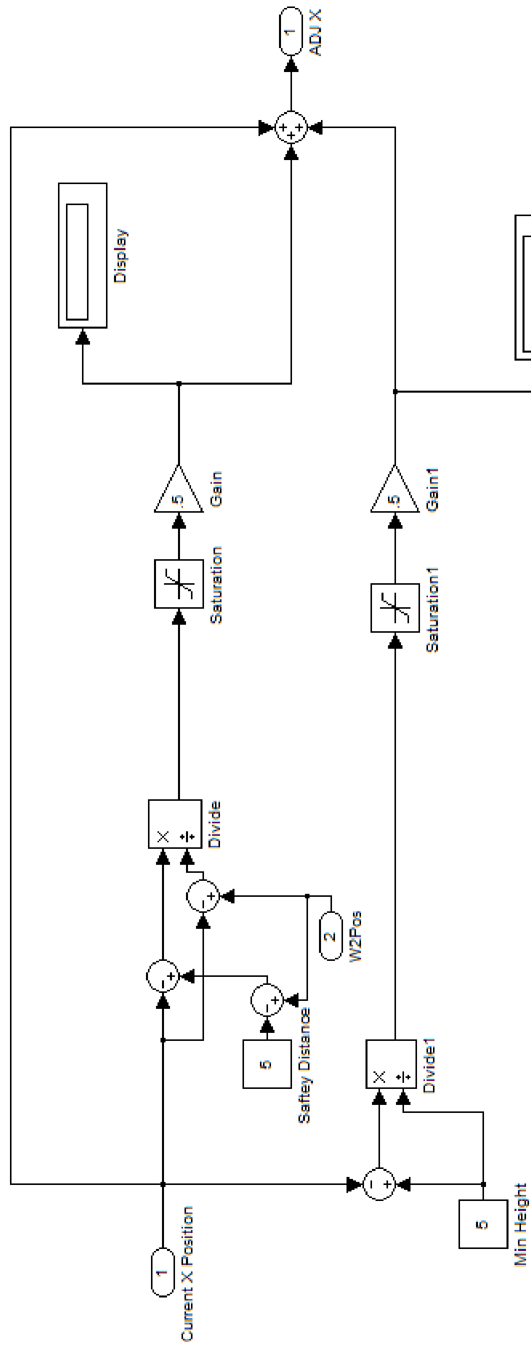


Figure 47: Three Winch X Position Subsystem

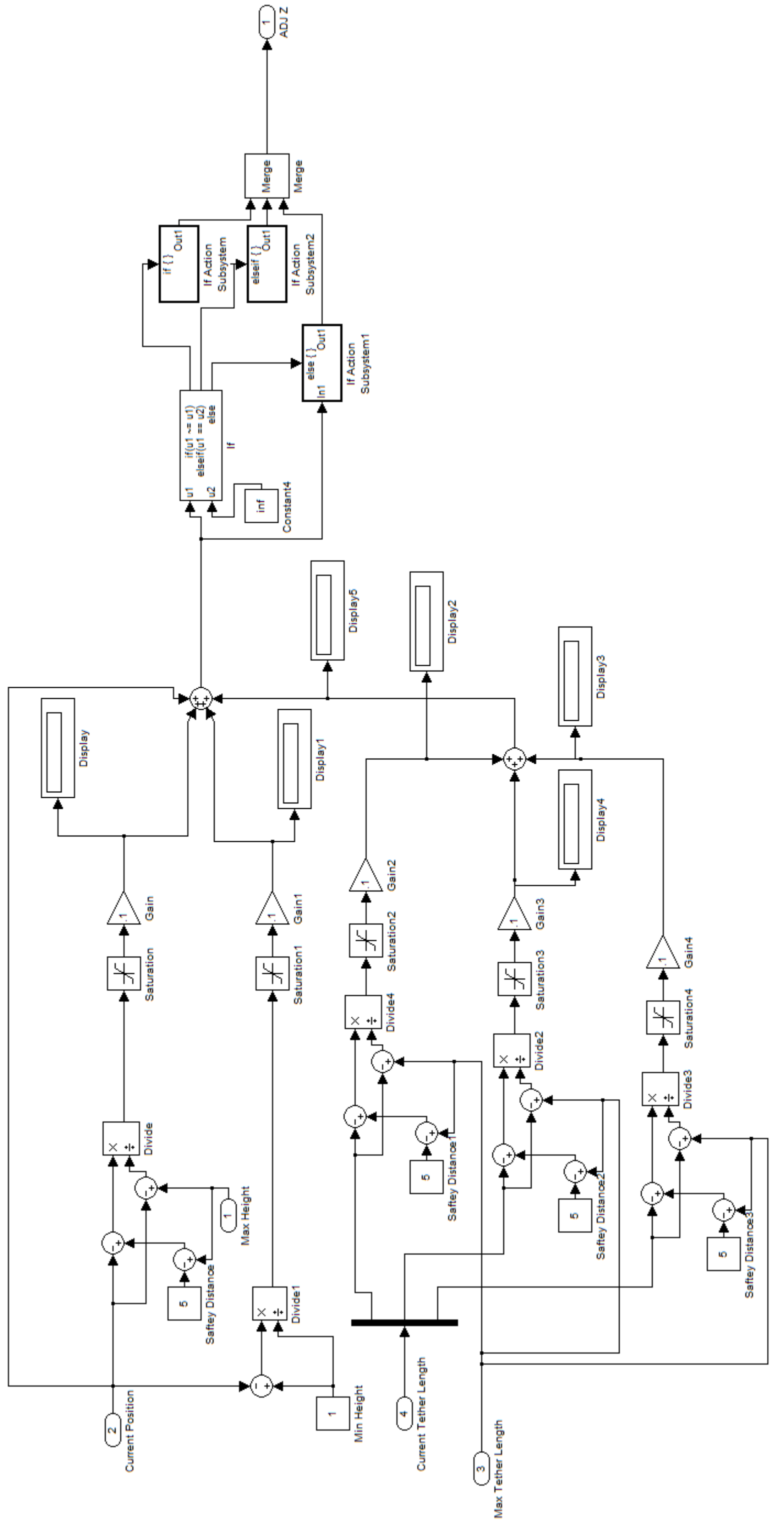


Figure 48: Three Winch Z Position Subsystem

K Arduino Code

```
#include <SoftwareSerial.h>
#include "RSLpacket.h"
//Version 3 makes it so once the winch reaches it destination, it no
//longer listens to commands that send far away
SoftwareSerial MotorCom(7, 8); // RX, TX
SoftwareSerial XBCom(5, 4); // RX, TX
//set up xbee serial adress and comm port
RSLpacket rslHw(XBCom, 'a'); //this arduino is adress 'a' or 61 in HEX
char comand[20];
char message[20];
char encCnt[20];
int count = 0;
long dist;
long pos = 0;
int offset = 0;
int numLength = 5;
int time1 = 0;
int time2 = 0;
char newmessage[5];
boolean Startup = 1;
void setup(void)
```

```
{
  Serial.begin(115200);  //This is for Debuging the code if need be

 // set the data rate for the SoftwareSerial port

 //The Motor Controller needs a baud rate of 115200

 MotorCom.begin(115200);

 MotorCom.println("!C 1 0");

 XBCom.begin(19200);

 XBCom.listen();

 attachInterrupt(0, forceUp, LOW);

 attachInterrupt(1, forceDown, LOW);

 pinMode(4,INPUT_PULLUP);

 XBCom.flush();
}

void sendComand()

{
 dist = 0;

   for (int i = 0; i < numLength; i++)

   {

     if(message[i] != '@')

     {

       dist = dist * 10 + (message[i] - '0'); //This converts the string to

     }                                // a number which then can be sent to
                                      // the motor controller
     else

     {
```

```
        loop();
      }
    }
    dist = dist + offset;
    if((dist - pos) > 1000)
    {
      if(Startup = 1)
      {
        sprintf(comand, "!PR 1 1000");
        MotorCom.println(comand);
//        Serial.println(comand);
        pos = pos + 1000;
        delay(500);
        XBCom.flush();
      }
    }
    else if((dist - pos) < -1000)
    {
      if(Startup = 1)
      {
        sprintf(comand, "!PR 1 -1000");
        MotorCom.println(comand);
```

```
//      Serial.println(comand);
       pos = pos - 1000;
       delay(500);
       XBCom.flush();
     }
   }
   else
   {
     sprintf(comand, "!P 1 %lu",dist);
     MotorCom.println(comand);
//      Serial.println(comand);
     pos = dist;
     Startup = 0;
   }
   Serial.println(pos);
}
void readEnc()
{
 count = 0;
 count = dist + offset;
 sprintf(encCnt, "C%6d",count);
//  Serial.println(encCnt);
 rslHw.sendMessage(0x7A,encCnt,7);
```

```
}
void loop() // run over and over
{
delay(5);
//  Serial.println(rslHw.available());
if (rslHw.available()>0 )
  {
  //try to read a message
    rslHw.getMessage();
  if(rslHw.ReadFail==1)
     {
         while((rslHw.ReadFail==1) && (rslHw.available()) ){
         rslHw.getMessage();}
//          Serial.println("read fail 1");
     }
  if(rslHw.ReadFail==0)
  {
//    Serial.println(rslHw.message);
   time1 = millis();
   if ((time1-time2)>5000)
   {
     Startup = 1;
```

```
    time2 = time1;

  }

  for(int n=0; n<(rslHw.mLen-1); n++)

    {

      message[n] = rslHw.message[n+1];

    }

   if(rslHw.message[0] == 'P')

  {

    sendComand();

  }

  else if(rslHw.message[0] == 'C')

  {

    readEnc();

  }

   //Speak only when spoken to.

   //rslHw.sendMessage(0x7A,"Hello World",length);   //send message to
                                                    //computer address "z"


   //Serial.println("Replied with 'Hello World'.");

 }

}

}

void forceUp()

{
```

```
 MotorCom.listen();
 MotorCom.println("!PR 1 1");
 offset = offset + 1;
 pos = pos + 1;
 XBCom.listen();
 XBCom.flush();
}
void forceDown()
{
 MotorCom.listen();
 MotorCom.println("!PR 1 -1");
 offset = offset - 1;
 pos = pos - 1;
 XBCom.listen();
 XBCom.flush();
}
```

L Matlab Script

Send Command

```
function Send(Count1,Count2,Count3)

%send to the arduino as motor commands

eml.extrinsic('senddata')

eml.extrinsic('int2str')

eml.extrinsic('sprintf')

eml.extrinsic('strcat')

c1 = int32(Count1);

c2 = int32(Count2);

c3 = int32(Count3);

Message1 = strcat('P', sprintf('%05d',c1));

Message2 = strcat('P', sprintf('%05d',c2));

Message3 = strcat('P', sprintf('%05d',c3));

%Message1 = ['P' int2str(Count1)];

%Message2 = ['P' int2str(Count2)];

%Message3 = ['P' int2str(Count3)];

SendAdress =['a'; 'b'; 'c'];

SendMessage = [Message1;

              Message2;

              Message3];

senddata(SendAdress,SendMessage);
```

RemoteNodeConn

```
%This function initializes a connection to remote node server. It needs to
%be called for each instance of remote node server that is running.
%**************************************************************************
%Note: Be sure to name instances of remote node server carefully so as to
%avoid confusion.
%**************************************************************************
%Author: Chase Traficanti
%Date  : March 29, 2013
%Modified by: Nick Xydes & Jimmy Erskine
%**************************************************************************

function RemoteNodeConn(dtip,dtport,functionname,channelname,outName,appname)
% create the MatlabController object
conn = controller(dtip,dtport,appname);
% register the callback function
registerfunction(conn,functionname,channelname);
% start the controller
addcommandchannel(conn,outName);
start(conn);
% put the MatlabControler object on the workspace
assignin('base',appname,conn);
end
```

Senddata

```
%This funciton is called by the simulink model when a command needs to be
%sent. Senddata uses the function CompilePacket to format the data into a
%format that can be read by the RSL Packet library.
%***************************************************************************
%Note: This function ensures that a data packet is only sent out every .6
%seconds since Remote Node Server can only send data at a maximum rate of 2
%Hertz
%***************************************************************************
%Note:Senddata takes in a SendAddress vector and SendMessage
%     vector of this format:
%
%      Sendaddress =   [(Robot1 address)] SendMessage = [(Robot1 message)]
%                      [(Robot2 address)]               [(Robot2 message)]
%                      [       :        ]               [       :        ]
%                      [(Robotn address)]               [(Robotn message)]
%***************************************************************************
%Author: Chase Traficanti and Michael Vlahos
%Date  : March 30, 2013
%Modified by: Nick Xydes & Jimmy Erskine
%***************************************************************************

function senddata (Sendaddress,SendMessage)
```

```
    packet=[]; %Create a varable called packet that will contain the command
                      %message

    for n=1:length(Sendaddress) %Create the command string by using
                  %CompilePacket to format commands in the proper protocal

        packet= [packet CompilePacket( Sendaddress(n),SendMessage(n,:) )];

    end

    RemoteNode = evalin('base','RemoteNode'); %take the variable node1 and
                                          % oldtime from the base workspace

    oldtime = evalin('base','oldtime');

    newtime = clock; %save the current time to clock



    if(etime(newtime,oldtime)>.33)%if .6 seconds has passed since the last
                              %message was sent, send another message

        assignin('base','oldtime',clock);

        sendcommand(RemoteNode,0,packet);

    end

end
```

Initialize

```
%This function is called before the simulink model is started. It's purpose

%is to initialize the connections to Remote Node Server and to initialize

%some variables.

%*************************************************************************

%Author: Chase Traficanti

%Date  : March 29,2013

%Modified by: Nick Xydes & Jimmy Erskine

%*************************************************************************

function initialize()

   RemoteNodeConn('localhost','3333','ArduinoCallback','*/data','command',
           'RemoteNode') %This creates the connection to Remote Node Server

   assignin('base','oldtime',clock) %This initializes the time which is a
                                    %logic variable used in sneddata

   message = [97,0,0,0 %Initialize the variable that incomming data is saved to

              98,0,0,0];

   assignin('base','message',message) %save this variable to the base workspace

end
```

CompilePacket

```
%This function formates a given message and adress into a proper RSL

%packet.

%**********************************************************************

%Note: For more information on packet protocall and communication sytems,

%see the Readme document that is provided with the Communication library

%files.

%**********************************************************************

%Authors: Chase Traficanti and Michael Vlahos

%Date   : march 29, 2013

%Modified by: Nick Xydes & Jimmy Erskine

%**********************************************************************

function packet = CompilePacket(SendAdress,SendMessage)

   CompAdress = 122; % The computer is given adress 122 or "z"

   bytes = typecast(int16(length(SendMessage)),'uint8'); % This determines
                          % what the length of the message is in hex bytes

   LSB = bytes(1);

   MSB = bytes(2);

   packet = uint8([64,64,SendAdress,CompAdress,MSB,LSB,SendMessage]);
           % Create a properly formatted packet

end
```

Close

```
%This function is evaluated when the simulink model is stopped. It's
%purpose is to  command to all of the robots to stop moving.
%***************************************************************************
%Author: Chase Traficanti
%Date  : March 29,2013
%Modified by: Nick Xydes & Jimmy Erskine
%***************************************************************************

function close (v)
   node1 = evalin('base','node1');
   assignin('base','oldtime',clock);
   message=[0,0,0];


   senddata(97,message);
   senddata(98,message);
end
```

ReadMessage

```
%This function takes the data that matlab reads from Remote Node Server,
%checks to see if the data packet is a full packet intended for the
%computer and then returns the packet information and who the packet was
%sent from.
%**********************************************************************
%Note: For more information on packet protocall and communication sytems,
%see the Readme document that is provided with the Communication library
%files.
%**********************************************************************
%NOTE: ReadMessage returns a From vector and message vector of this format:
%
%      From =   [(Robot1 address)] message = [(Robot1 message)]
%               [(Robot2 address)]           [(Robot2 message)]
%               [       :        ]           [       :        ]
%               [(Robotn Address)]           [(Robotn message)]
%**********************************************************************
%Authors: Chase Traficanti and Michael Vlahos
%Date   : March 29, 2013
%Modified by: Nick Xydes & Jimmy Erskine
%**********************************************************************

function [from,packet] = ReadMessage(bytearray)
```

```
   packetsfound=1;

   for j=1:length(bytearray)

       if ((bytearray(j)==64))&&(bytearray(j+1)==64) %check to see if the
                                  %message has a proper header

           if(bytearray(j+2)==122) %check to see if the message if for
                                  %simulink

               from(packetsfound,:)=double(bytearray(j+3)); %save the from
                                    %byte to the from vector

               MSB = bytearray(j+4); %save the Most Significant Byte of the
                                   %message length parameter

               LSB = bytearray(j+5); %save the Least Significant Byte of the
                                   %message length parameter

               len = typecast(uint8([LSB MSB]),'uint16'); %This takes the two
                           %length bytes and saves them into a single variable

               for i=1:len %Save all the message bytes to the packet vector

                   packet(packetsfound,i) = char(bytearray((j+5)+i));

               end

           end

           packetsfound=packetsfound+1; %increase the number of packets
                                        %found by one

       end

   end

end
```

M Wiring Diagram

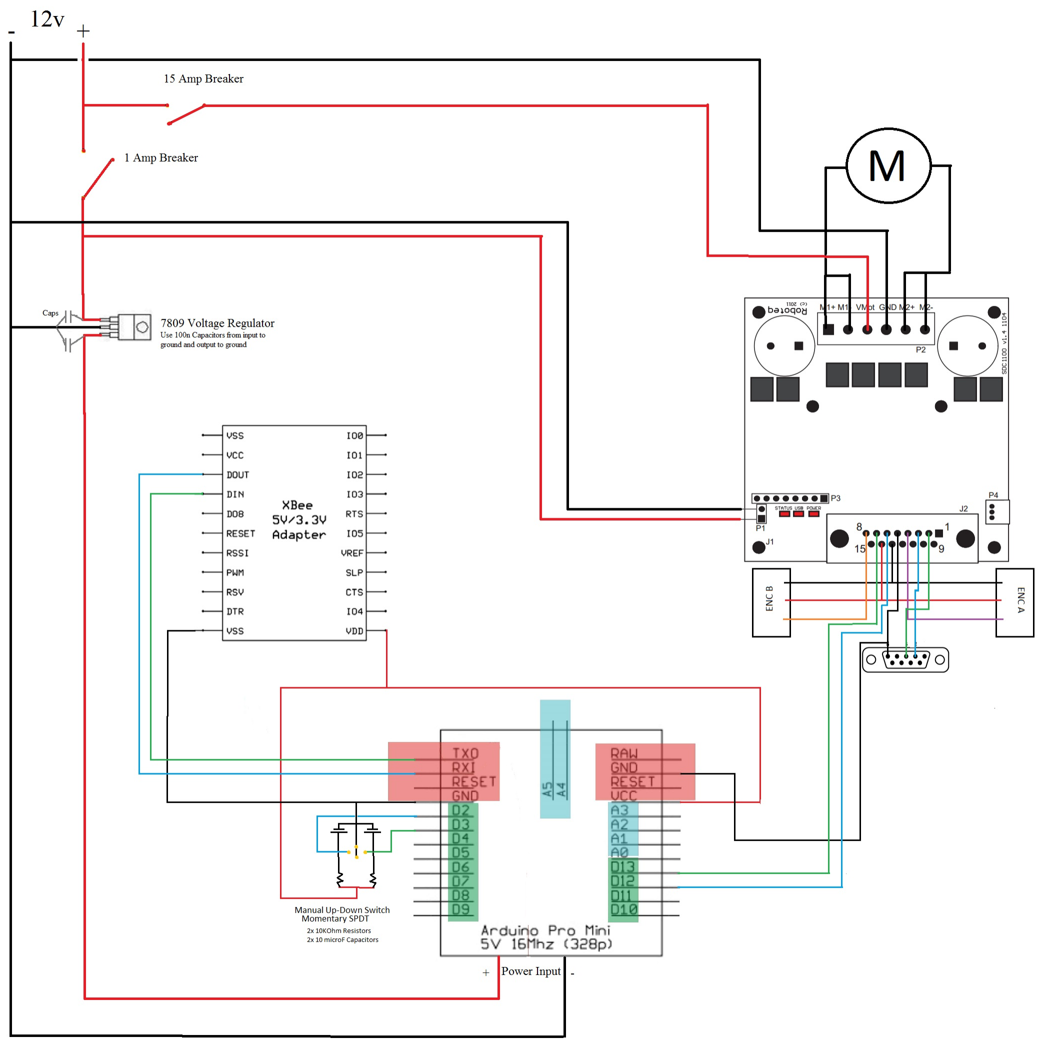
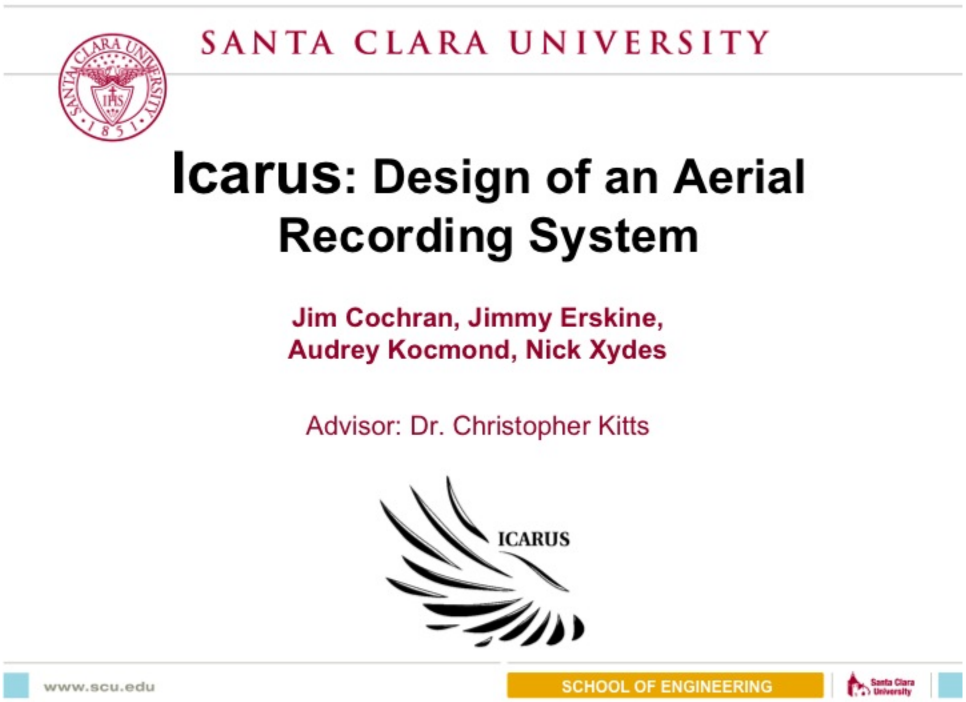


Figure 49: Wiring Diagram

N Design Conference Slides



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The Icarus System

The Inspiration: Skycam

Source: http://www.eetimes.com/

Our Design: Icarus System

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The System in Action

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Presentation Outline

- Ethical Considerations and Motivations
- Customer Needs
- Subsystem Designs
- Results
- Future Plans
- Conclusion

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Ethical Considerations and Motivations

Safety

- Athlete's safety
- Videographer's safety

Benefit to Society

- Equal opportunity for athletic teams
- Disaster relief for first responders
- Research opportunities for scientists

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Customer Needs

Potential User Groups:

- Small to medium sized athletic departments
- Disaster response
- Wildlife recording and monitoring
- Marine monitoring
- Outdoor venue and events

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Customer Needs

Interviews Conducted:

- Jeff Ota, Nike Research Labs – Manufacturing
- Jerry Smith, Santa Clara University – Women's Soccer Coach
- Fire Department Representative, Santa Clara Fire Department

Sports Filming	Disaster Relief	Manufacture
Ease of Use	Easy/fast to set up	Easy to make
Stability of Video	Secure Video	Off the shelf parts
Wireless Transmission of Video	Wireless Transmission of Video	Scalability
Inexpensive		Inexpensive
Ability to record long games		
Instant Playback		
Safe		

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System Design Tiers

Tier	1a	1b	
	1DOF	1DOF	
	Manual Winch control	1 winch position control	
	uncontrolled camera	uncontrolled camera	
Tier	2a	2b	2c
	2DOF	2DOF	2DOF
	2 Winch position Control	2 Winch position Control	2 Winch PID Control
	uncontrolled camera	RC Control camera	Computer Control camera
	Wired winch connection	Wireless winch connection	Computer Control Winch
			Wireless winch connection
Tier	3a	3b	3c - End of Year
	3DOF	3DOF	3DOF
	3 or 4 Winches Position	3 or 4 Winches Position	3 or 4 Winches PID
	Uncontrolled Camera	RC Control Camera	Computer Control Camera
	Wireless winch Connection	Wireless winch Connection	Computer Control Winch
			Wireless winch connection

* Highlighted Cells Completed as of May 8th

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System Design Requirements

- Mass of the Camera System: Under 1 kg
- Winch Mass: 10 – 30 kg
- Battery Life: 4 to 6 Hours
- Max Cost: Under $1000 per system
- Recurring Cost: Up to $100 per deployment
- Setup/Takedown Time: Under 15 minutes
- Max Operating Height: 150 meters (FAA Regulated)

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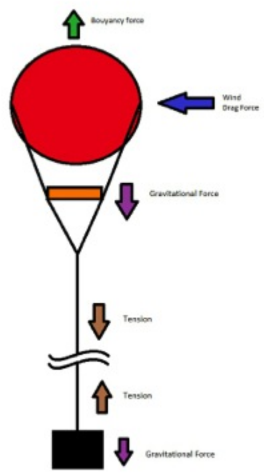
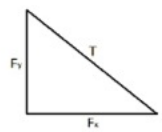
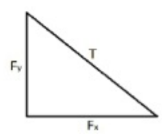
Design Overview





$$\sum F_x = F_d$$
$$\sum F_y = F_b - F_g$$
$$T = \sqrt{F_x^2 + F_y^2}$$



$$\sum F_x = 0$$
$$\sum F_y = F_g$$
$$T = \sqrt{F_x^2 + F_y^2} = F_g = mg$$

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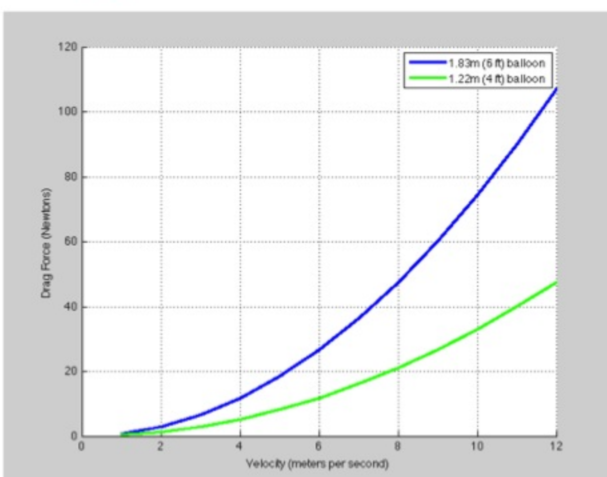
Design: Balloon



$$F_{drag} = \frac{1}{2}\rho C_d V^2 A$$

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Design: Cabling

- Lightweight
- Strong
- Inexpensive

	Fishing Line	Paracord	Arborline (dynaglide)
Tensile strength	130 - 450 N	2450 N	4450 N
Weight per m	< 1.71 g/m	6.574 g/m	3.0 g/m
Diameter	0.58 - 0.89 mm	3.175 mm	2mm
Safety	Medium	High	High
Visibility	Low	High	High
Malleability	Low	High	High
Cost per 100'	$6.67	$10.95	$19.5

100 lb = 444 N

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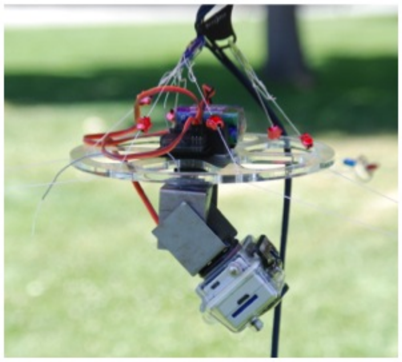
Design: Camera Mount

- Modular
  - Upgradeable
  - Adaptable to Multiple Winches
- Circular Plastic Frame
  - Allow Pan/Tilt
  - Ease of Connection
- Lightweight
- Durable/Strength
- Weatherproof



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Design: Camera Mount Mass Budget

Component	Weight (grams)
Acrylic Frame	135
Pan/Tilt Motors and Brackets	207
GoPro with Case and Wi-Fi Backpack	206
Battery	121
Balloon Tether	47.0
RC Receiver	8.00
Miscellaneous	33.0
Total	757 (< 1000 g)

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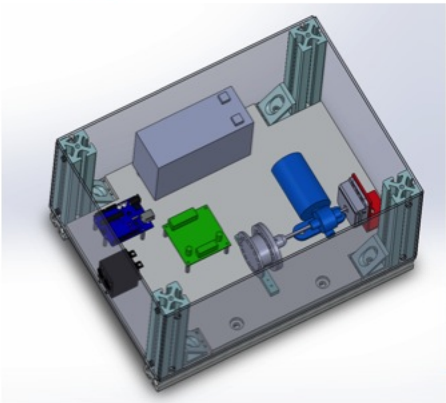
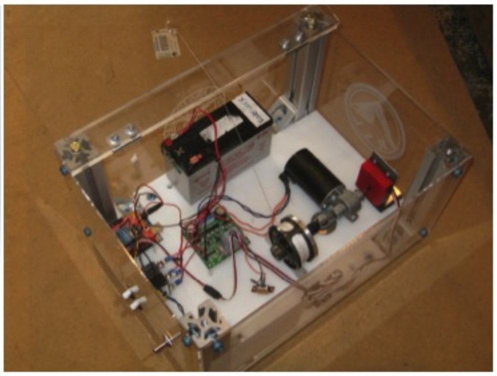
Design: Winches





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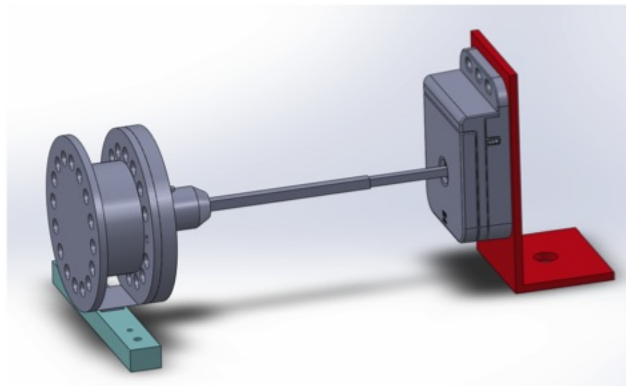
Design: Winches

- Drivetrain
  - Reel
  - Reel Adapter
  - Square Shaft Adapter
  - Square Shaft



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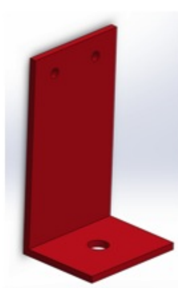
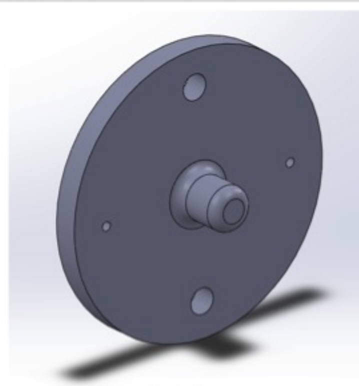
Design: Winches



Encoder Mount



Reel Adapter

Reel Mount

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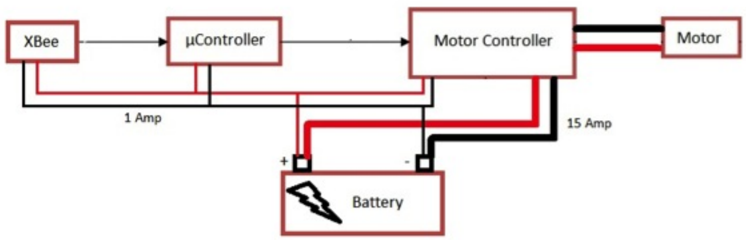
Design: Winches

- Electrical Design Includes
  - Arduino Microcontroller
  - Xbee
  - Roboteq Motor Controller
  - Voltage Regulator
  - 1 and 15 Amp Breakers



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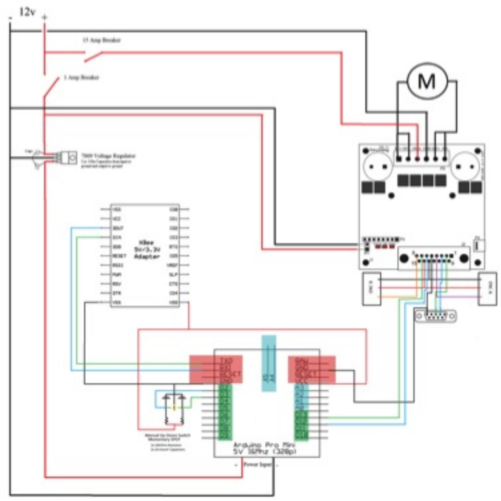
Design: Winches

- Electrical Design Includes
  - Arduino Microcontroller
  - Xbee
  - Roboteq Motor Controller
  - Voltage Regulator
  - 1 and 15 Amp Breakers



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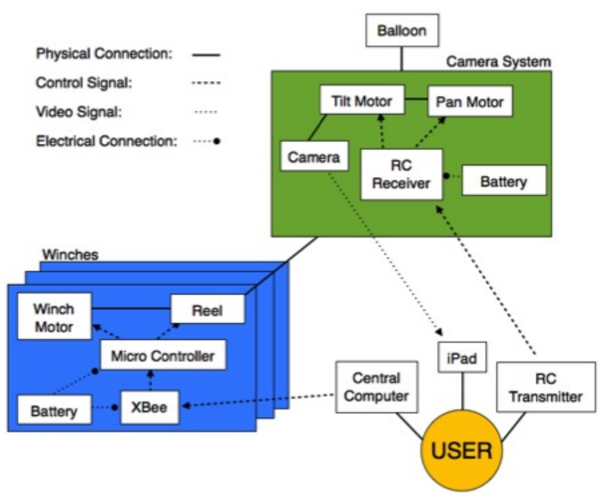
Design: Communication



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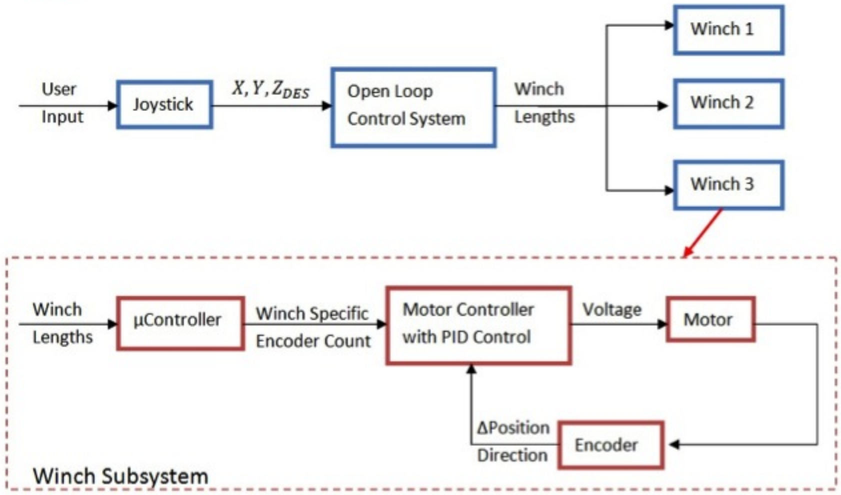
Design: Control Block Diagram



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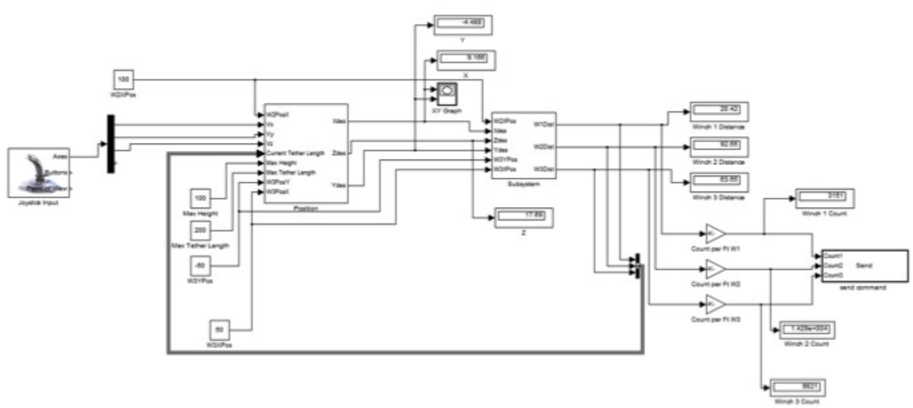
Design: Control System



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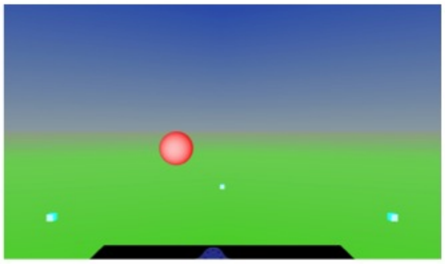
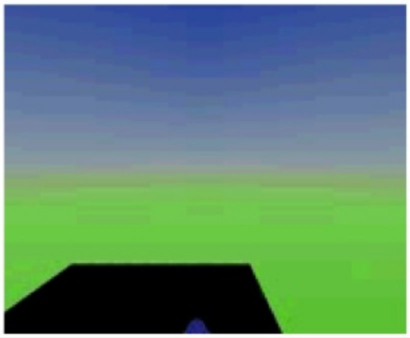
Design: Simulation



View from Field

View from Balloon



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Final System Specifications

Requirement	Specified	Actual
Camera Mass	< 1 kg	.757 kg
Winch Mass	10 – 30 kg	10 kg
Battery Life	4 – 6 Hours	~ 4 Hours
Cost of System	< $1000	~ $1500
Recurring Cost	< $100	~ $300
Set Up/ Take Down Time	< 15 min	~ 15 min

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Problems Encountered

- Balloon issues
  - Full balloon required to maintain stability
  - Severely affected by wind
  - Loses helium more rapidly than anticipated
- Xbee dropped communication
- Camera mount stability

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Future Plans

- Future Design Iterations
  - Computer Controlled Camera Mount with Stabilization
  - Weather Proofing
  - User Interface Application Development
  - Increased Manufacturability
  - Improve Controller
- Currently working with Santa Clara University business student Chris Mora to develop business models for both service and production

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Conclusion

- The ICARUS project was developed from the ground up to meet the need for a more portable and affordable aerial viewing system
- This project is unique because it is relatable to a wide range of customers from high school athletics to scientific researchers

ICARUS

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