Helium Micro Air Vehicle (MAV)

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Team 07

Final Report

May 6, 2016

Submitted towards partial fulfillment of the requirements for

Mechanical Engineering Design I – Fall 2015

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1 Introduction

Dr. Srinivas Kosaraju is a lecturer of Mechanical Engineering at Northern Arizona University. He is the client whom has requested the conceptual design of a Helium Micro Air Vehicle (MAV). Intended use of the design is related to purposes of surveying. The client has specified that an optimal system would have an ability to communicate in-flight data, take pictures, and cost less than 2000USD. Engineering constraints considered for this project are that a successful device should maintain a height of 100 feet, employ a navigation system, communicate in-flight data and have an ability to take photographs simultaneously during operation. Team objectives will outline our approach and identify affective parameters. A solution to the given requirements and constraints will be characterized by the optimization of these parameters. The Helium MAV team goal is to create a design that meets all requirements with greater comparable efficiency to any commercial product available in the market. This project will embody the clean energy movement of NAU by eliminating energy consumption of fossil fuels and creating a reusable electrical system.

2 Objectives

1. Weight/payload - Carried equipment should not exceed the payload of 215 cubic feet of helium, measured in kilograms.

2. Optimize Flight Time – Goal is to allow the Blimp to stay inflight for long duration to be able to survey more efficiently. Measured in seconds

3. Minimize Cost - The budget is important since there is only a limited amount of money, so minimizing the cost is essential. This is measured in USD.

4. Maximize Thrust – Must maximize the thrust so that it can counteract the drag force on the blimp to be able to propel the blimp forward and down. Trust will be measured in Newtons.

5. Easy to store - A single person must be able to lift the MAV up and be able to store it in a compact area so volume matters, and will be measured in cubic meters.

Table 1: Objectives

Objective	Measurement	Units
Reduce Weight	Mass	kg
Optimize Flight Time	Time	sec
Minimize Cost	Currency	$
Maximize Thrust	Force	N
Easy to Store	Volume	m^3

3 Materials

3.1 Propellers

The propeller selection is based upon the functionality needed; low diameter, high pitch propellers are used for a speed system. High diameter, low pitch propellers are used for a high thrust system. The blimp for this project requires a high amount of thrust to counter the lift force of the helium gas, therefore, high diameter, low pitch propellers are needed. As a result, the Dynam Carbon Fiber Propellers have been selected to perform the desired task because they can exert the required thrust. The team also chose the carbon fiber propellers because they are light weight, which is crucial in not exceeding the maximum weight capacity. Figure # below, displays the Dynam Carbon Fiber Propellers.

Figure 1: Dynam Carbon Fiber Propellers

3.2 Motors

The motors has been selected to produce a high thrust in order to counter act the drag force and the buoyancy force. To achieve such a task, a high power motor with a low KV ($\frac{Rpm}{Volt}$) value can be used to maximize the thrust. Based on these specs the LDPOWER M4114-320KV Brushless Motor (CW) was chosen which operates at 320KV and produces a power of 999W. The motor functions at two different phases, at 14.8V-22.2V which is a (4S-6S) battery. Each cell (S) is approximately 3.7V. To maximize the thrust, a 6S battery is used. Figure #, shows the motor used for this system.

Figure 2: Brushless Motor

3.3 Power Source

Two main power sources were used to power the blimp. The reason for this is because the team wanted to maximize the flight time of the system. The first battery is the Turnigy nano-tech 2000mAh 2S(7.4V)1P 20~40C, this battery is used to power the servos and it was chosen because it has a enough voltage and amperage to power the servos. Keeping in mind there is a weight limit, the battery chosen is lightweight at approximately 0.098 kg. The second battery is the MultiStar LiHV High Capacity 6S(22.8V) 5200mAh Multi-Rotor, which weighs at 0.613 kg. Comparing it to similar batteries this one is considered lightweight. This battery will power the motors and electronic speed controllers, generating up to 10.5 N of thrust per motor. Figures # and #, show the batteries used to power the electronics.

Figure 3: Nano-Tech 2.0

Figure 4: MultiStar 5.2

3.4 Servos

The servos needed must be able to withstand the weight of the motor, the L bracket carrying the motor, a propeller and be able to rotate 90 degrees. The servos' function is to be able to change the direction of the propellers which will steer the blimp to any desired direction. Sufficient torque is required to achieve such a goal, therefore, the Turnigy™ TGY-5521MDHV servos were chosen. These servos have a torque of 22kg/cm and weight approximately 0.0635 kg. Figure # below, shows the servos used.

Figure 5: Servo Motor

3.5 Quadrino

The Quadrino Nano is a flight controller with incorporated sensors. The Quadrino contains a magnetometer, pressure, GPS, accelerometer, ATMega 2560 processor and a gyroscope. The gyroscope shows the orientation of the quadrino, which will be used to see the orientation of the blimp. The accelerometer show how fast the MAV is traveling. Magnetometer show the direction, the pressure sensor is configured to show altitude, and the ATMega is the processor and is programmable. The GPS only works under an open sky so inside any enclosure will interfere with the signal. The GPS must be mounted on the outside of the enclosure to be able to work effectively.

The Quadrino came with its own firmware that is compatible with the program MultiWii, which is a program used to control multirotor aircrafts. The firmware is used to calibrate the Quadrino to function with the brushless motors and servos and also allow adjustments to the sensors. The Quadrino has 2 serial ports and 3 i2c ports along with a motor, radio and many more ports that are displayed in Figure (6). The reason for choosing the Quadrino Nano is it has integrated sensors along with a compact light weight enclosure. For the testing the Quadrino Nano was used for telemetry data only.

Figure 1 shows an outline of where the sensors and components are located on the Quadrino Nano. Figure 2 shows the real image of the Quadrino Nano in its enclosure.

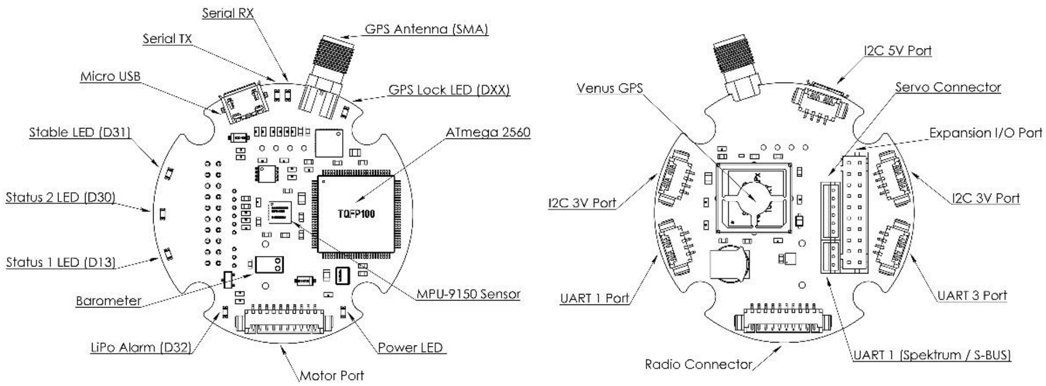

Figure 6: Quadrino Nano hardware components

Figure 7: Quadrino Nano Shell

3.6 Radio Transmitter

3DR 915 MHz radio transmitters are used for inflight communication and allow telemetry data to be sent back in real time. One transmitter connects directly to the Quadrino's serial port and the other connects to a computer acting as the ground station. The transmitter can send data back up to 500 m this can be enhanced by changing the antenna. The antenna needs to be on the outside of the enclosure so that the signal isn't disrupted. This moment the radio transmitters are set up and can send gps, altitude, acceleration, receiver and magnetometer data back.

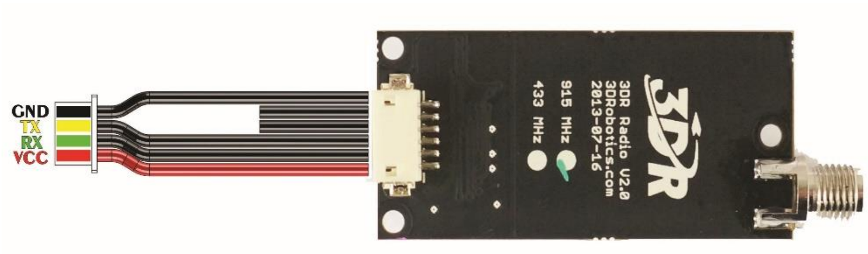

Figure 8: 3DR Radio Transmitter Wiring

Figure 9: Radio Transmitters

3.7 Receiver/ Controller

Currently using a Spektrum AR610 that communicates with a Spektrum DX6i RC transmitter to power the receiver the Quadrino's positive and ground connectors will be connected to the AUX channel. To communicate with the controller a binding process had to be done. To bind the receiver to the controller you had to attach the bind plug to the BIND channel, make sure the throttle stick is in the down position then power the receiver and turn on the controller. To save the binding process you first take out the binging plug from the receiver, unplug the power source then turn off the controller if this is not done the binding processes won't be saved. To see if the process was saved power the receiver and turn on the controller the LED will light up when the controller is turned on. The Spektrum transmitter has 9 different modes each one can be calibrated separately. When switching to different modes beware the binding process will have to be redone to communicate with the specific mode. There are 4 Channels used the Rudder, Elevator, Aileron and Throttle Channels. The Throttle and Elevator channels are used to control the thrusters while the Rudder and Aileron are used to control the servos.

Figure 10: RC Transmitter

3.8 Camera

The camera used is a lynx compatible ELP 2.1mm lens USB camera. Do to complex coding the camera could not be integrated with the Quadrino to transmit images back. The setup is made of 1 USB camera, 1 raspberry pi 2, 1 mini SD card and 1 mini 64 GB USB. The raspberry pi has 4 USB ports, 2 of these ports are used for the USB and camera. The raspberry pi also has a built in micro USB port along with a mini SD card port. The reason our team went with this microcontroller is the coding is more user friendly and has enough power to operate the camera. There will also be a 5 volt portable battery connected to the raspberry pi's micro USB port to provide power to the system.

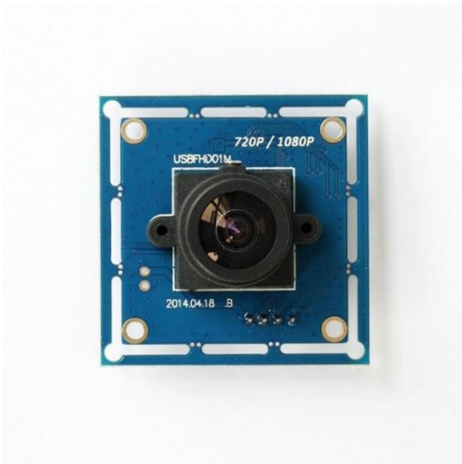

Figure 11: USB Camera

3.9 Electronic Speed Controller (ESC)

Electronic speed controllers are used to control the motors speed. A 40 amp ESC is recommended for the LD mk-4114 brushless motor. Currently going with the ZTW Spider 40 amp 3mm bullet connectors were soldered on both ends. Two wires a positive and a negative are on one end, which connects to the battery, while 3 A, B, C wires are on the opposite end that connect to motors.

A signal cable extends out of the ESC which connects to the AR610 Receiver one connects to the throttle channel and the other is connected to the Elevation channel this allows separate control of the thrusters. Since the signal cable cannot reach to the top of the enclosure so extension wires were attached. The motors will have to be rotated in opposite directions to be able to apply a downward thrust this can be done by switching the A, B, C attachment cables to C, B, A.

Figure 12: ZTW Spider 40A ESC

4 System Designs

4.1 Camera Setup

To first set up the raspberry pi the SD card must have Raspian downloaded on it. Raspian is a free program and will allow you to get the necessary video and image files for the camera to work. The directory **fswebcam** will have to be uploaded as well. This can be done directly from the raspberry pi. Then a file will be created using the configuration function to store the images. In the code you must reference the USB and tell the raspberry pi to dump the image within a file created within the USB drive.

To get the raspberry to automatically take photos, a code was created to take a certain amount of pictures every second until it reaches the required limit. Every picture the camera takes automatically sends the image to the USB drive. The USB drive then can be taken out and connected to a computer to download the images you want. Every time the raspberry pi runs it automatically overwrites the previous photos, this is done to save space. The USB is 64 gb which can store up to 36620 JPEG photos for a 5 Megapixel Camera and 3662 photos for raw uncompressed photos. When plugged in to a power supply the raspberry pi automatically runs the code, this is where the delay function is useful. The delay functions specifies when to start taking images. For example if you write **delaySeconds**(120) it will wait 120 seconds before beginning to take photos. The range function is used to specify how man images the camera will take. What I noticed from using the USB camera is the camera needs to be primed. To prime the camera the skip function is used to not store the first few frames, this will warm up the camera and allow the images to come out clearer. Time stamps and other functions can also be incorporated into the photos. The camera will be mounted onto an L bracket which is mounted on the electric box towards the bottom where the viewing is possible, while the raspberry pi is setup inside the setup mounted to the polycarbonate by bolts. Below is a schematic of the components that are connected to the Raspberry Pi

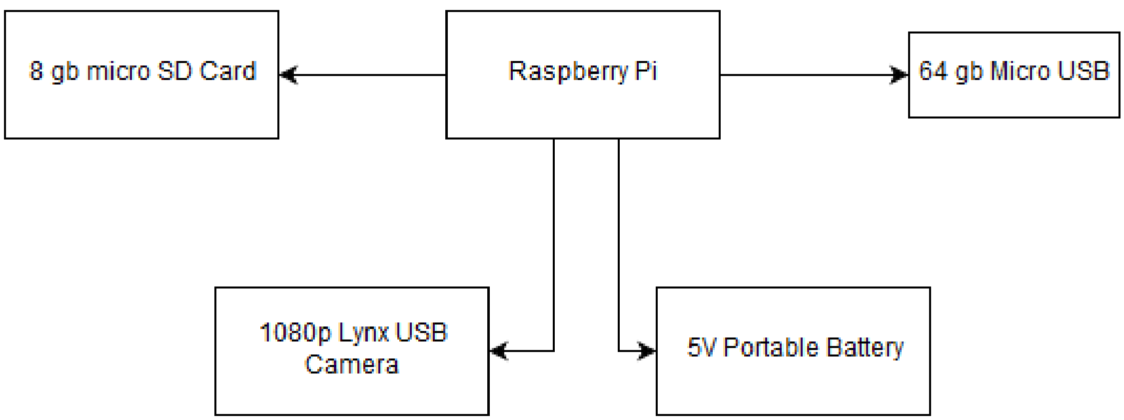

Figure 13: Camera Diagram

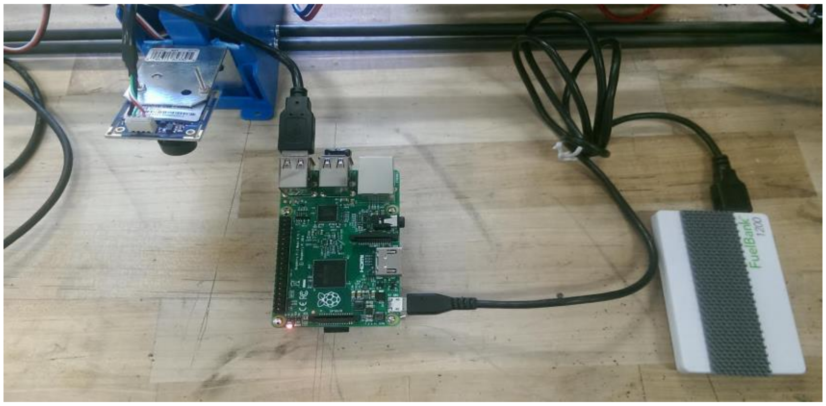

Figure 14: Camera Setup

4.2 Power Setup

There are two battery supply's one for the servos and one for the motors. The power supply is attached to a rocker switch which allows the power to be able to turn off and on without disconnecting the connectors. Power supply goes through the rocker switch and outputs to other electronics through the servo and ESC splits go to the motors and servos. A separate 5V battery powers the Quadrino Nano through a micro USB cable then the Quadrino powers both the radio transmitter and receiver. This provides a more stable voltage compared to the BEC which limits the voltage output and cause fluctuations. The BEC allow individual power sources to run off of one battery but the voltage fluctuates too much causing interference with receiving telemetry data.

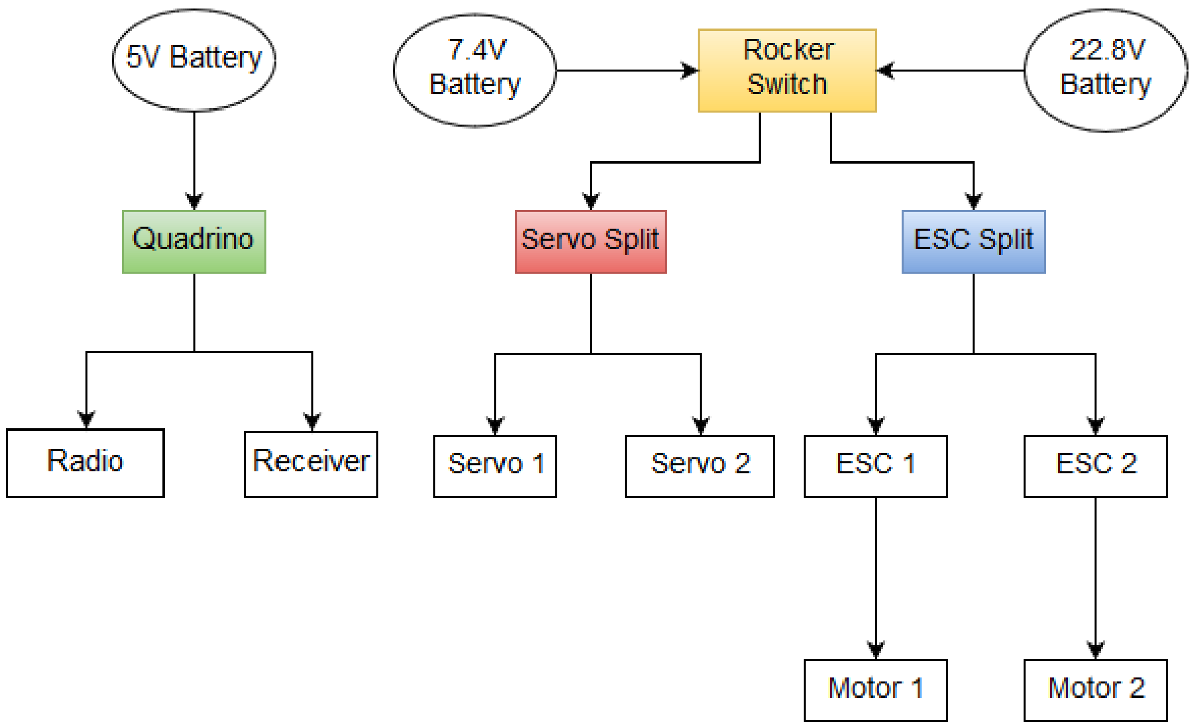

Figure 15: Power Schematic

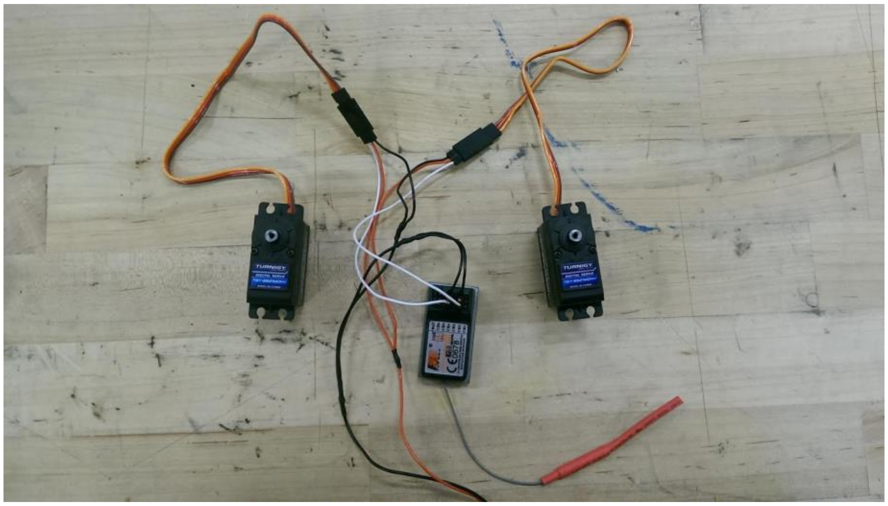

Figure 16: Servo Split connected to Receiver

4.3 Enclosure

To build a durable enclosure that will withstand the weight of all the electronic components and not shatter, the team used polycarbonate. The enclosure design consists of 2 slabs of polycarbonate, the bottom slab is rectangular shape and the top slab is an “I” shape. These 2 slabs are connected with four bolts at each corner that act like pillars and are capable of adjusting the height. The reason for this particular open enclosure design is due to the weight constraint. Velcro strips are attached on the top of the enclosure to be able to fasten it to the bottom of the blimp. The items within the enclosure have been set up to ensure there is proper weight balance when the system is attached to the blimp. The 22.8V battery is located on the bottom right corner of the enclosure and the rest of the electronics are placed on the top left portion. Figure 17 shows the electronic set up on the bottom slab of the enclosure and Figure 18 shows the enclosure design with the electronic components.

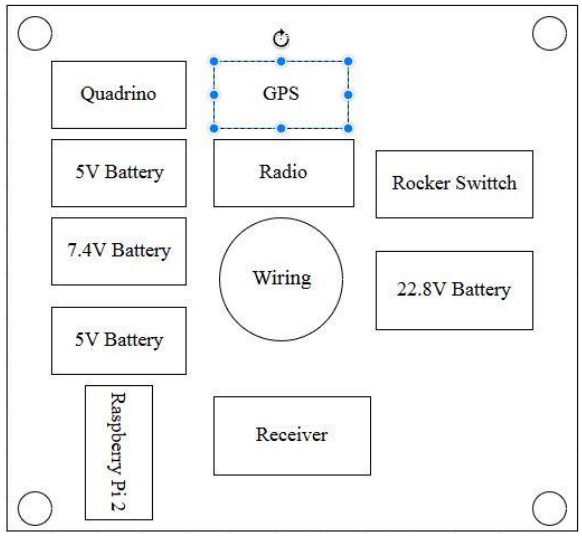

Figure 17: Enclosure Design with Electronics

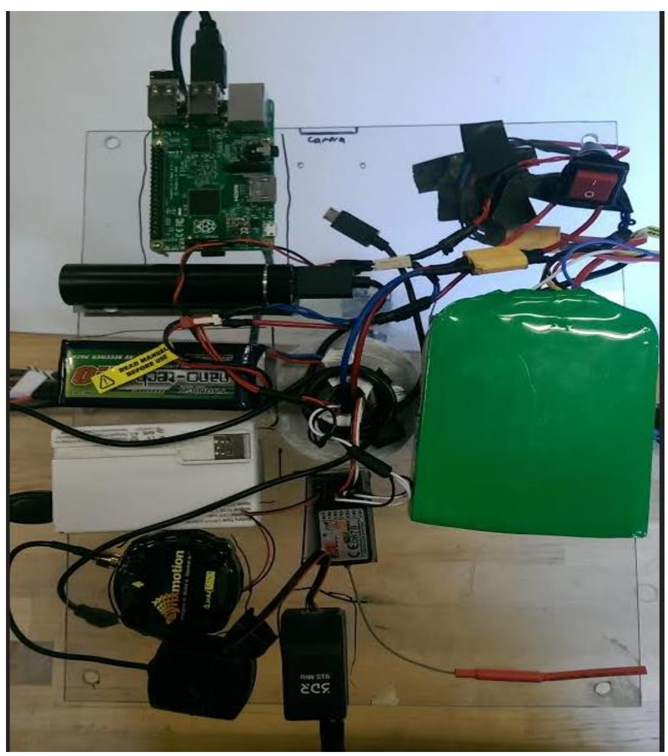

Figure 18: Components of the Enclosure

4.4 Shaft Design

Once the enclosure was designed, a hole was drilled through the middle of the bottom polycarbonate sheet to allow a shaft system to connect to it. The shaft system will be designed to hold the propellers, motors, servos, electronic speed controllers and a camera. Initially, the entire shaft design was created out of PVC, however, after building the prototype the weight reached 3.2 kg which exceeded the maximum weight that the blimp is capable of carrying. After some modifications, the final design consisted of the original PVC pipe that is connected to the bottom of the enclosure which allowed the team to run the electronic wires through the pipe. The pipe was kept as PVC because it was very durable and upon flight testing most of the forces would act upon the shaft. An electric box replaced the tee fitting and was attached to the middle shaft using flanges. Each side of the electric box has four uniformed holes to attach carbon fiber rods. The carbon fiber rods replaced the other PVC shafts because they are extremely low weight and also durable enough to withstand the weight of the propellers, motors, servos, and electronic speed controllers. Three L brackets were used, two to mount the motors on the servos and the third L bracket was used to mount the camera on the front of the electric box. The servos are attached at the ends of the carbon fiber shafts and can rotate the L brackets 90 degrees using the controller or 180 degrees mechanically. The rotation of the motors and propellers is used to steer the blimp to any desired direction. Springs were attached to spacers above each servo to decrease the stress on the servos' motors when rotating the thrusters. In order to decrease the deflection of the carbon fiber rods, ribbons were used to fortify the structure as trusses and attached to the bottom of the PVC pipe. All of these specific materials were chosen for this design because they are lightweight and resistant, which is crucial to keeping the weight under the project limit. The final weight of the modified shaft system was 2.85 kg which satisfied the carrying capacity of the blimp. The Figures 19 shows the initial shaft system design, and Figures 19 and 20 show the final shaft system design.

Figure 19: Initial Shaft Design

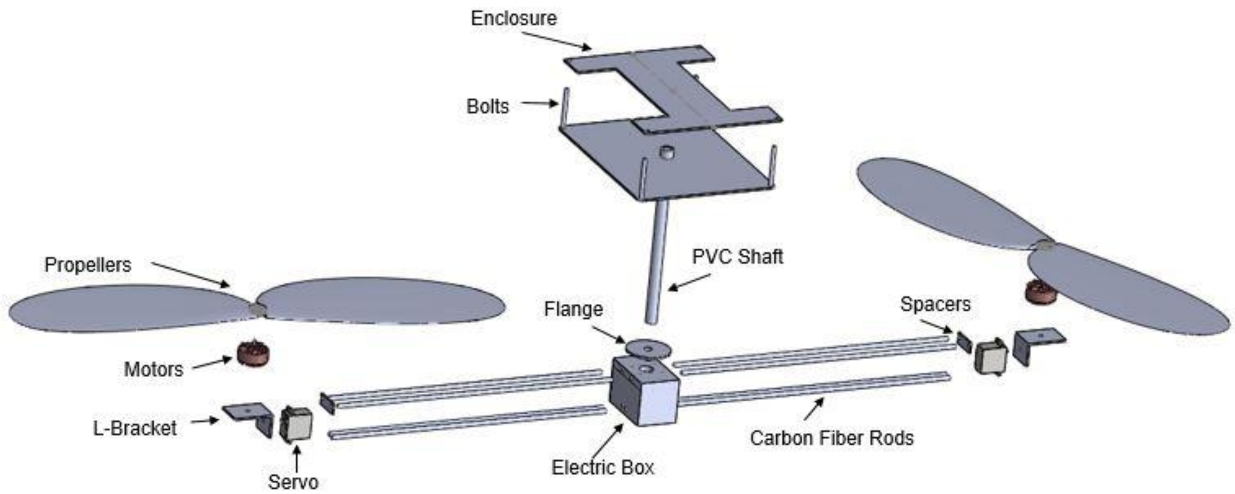

Figure 20: CAD of Final Design

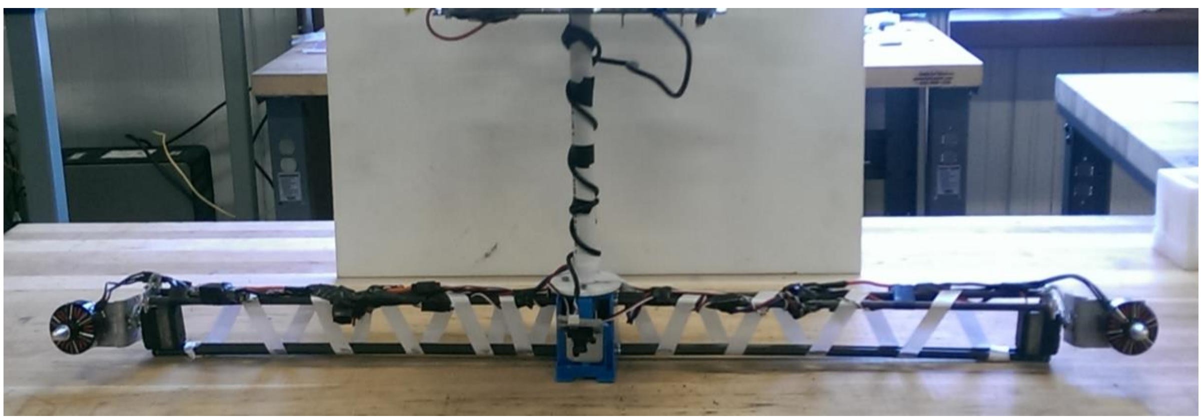

Figure 21: Final Shaft Design

5 Testing

5.1 Payload

Prior to the day of testing, Tom, a manager at the machine shop, installed the helium k-tank for the team in Building 77, Capital Assets. The regulator as well as the hose were attached to the helium tank. Tom showed the team how to use the regulator, and how to release the helium at no pressure so the team would not tear the blimp during the filling process. Once everything was prepared and there was enough cleared space for the testing, the team expanded the blimp on the ground. Afterwards, the hose was attached to the back entrance sleeve of the blimp and then tied it with a bungie cord and rubber bands, so the helium could not escape. Upon opening the valve of the tank at no pressure, the blimp took approximately fifteen minutes to fill up. During the filling process, a prototype enclosure was made and attached by tethers to the bottom of the blimp. The blimp used all of the helium in the tank which was approximately 6.14m^3, it was then noticed that the blimp would need more helium to be completely filled. However the blimp was still acceptable for testing. The team then added small weight bags to the enclosure in order to determine how much weight the blimp could carry. The end results, that the team concluded, was that the blimp could carry 3.11 kg. In order to create a SolidWorks design, the next step was to measure the dimensions of the blimp, the length of the blimp was 4.88m and the center diameter was 1.91 m. Figure # below, shows the blimp after being filled with helium.

Figure 22: Maximum Weight Test

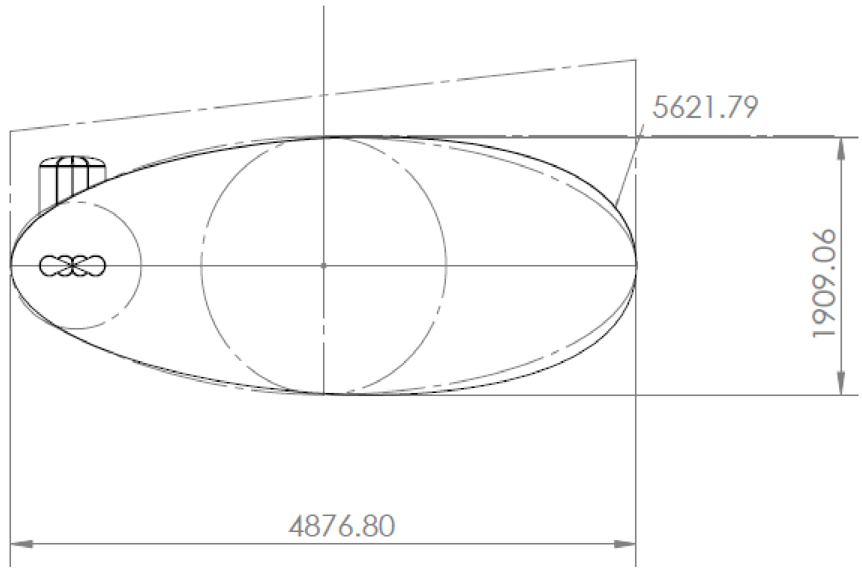

Figure 23: Dimensions of Blimp (mm)

5.2 Communications

The Quadrino was used to communicate the telemetry data of the flight. The consistency of our telemetry data was based on the accuracy of our calibrations and the frequency of the transmitter such that the signal would not be intercepted or altered by other frequencies along the path back to control. This is a few images of our communication tests, showing the GPS and telemetry data of movement of the enclosure.

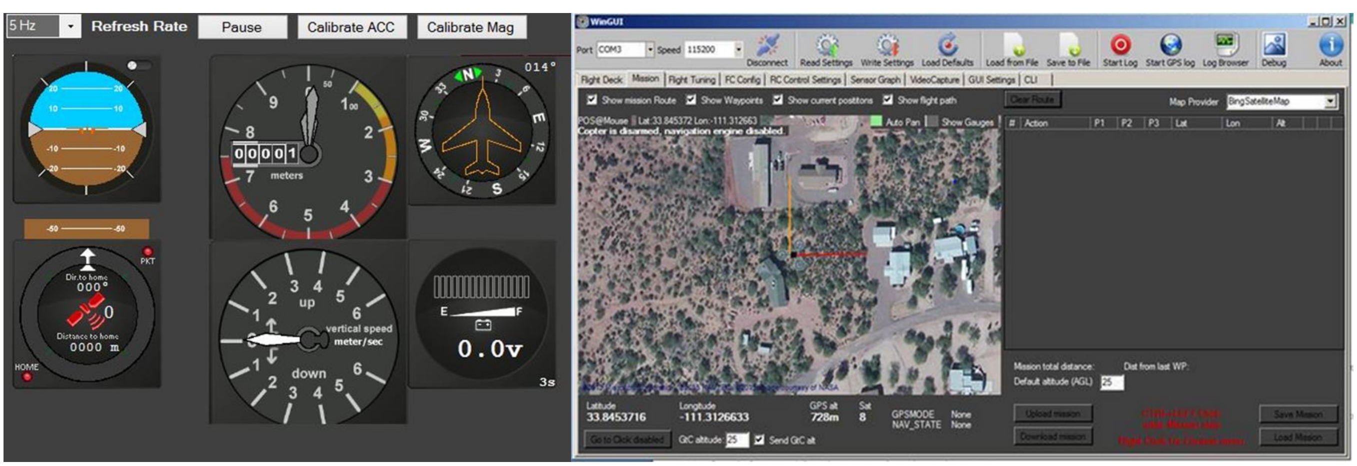

Figure 24: In Flight Telemetry and GPS Interface

5.4 Propulsion system

Testing of the propulsion system was done to ensure our motors, servos and enclosure would operate as one functional unit, with the intention of gathering data that would support our final test of the entire system.

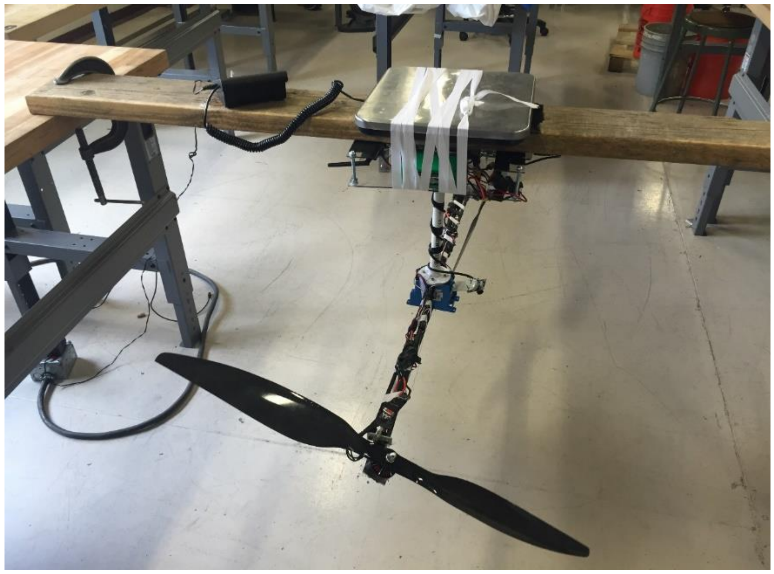

Figure 25: Propulsion System Test Setup

Measurements were obtained using an industrial grade scale, which we secured to a wooden plank at safe distances from any obstruction, taking into account the limiting dimensions which included the combined length of the hanging enclosure, shaft and propellers. Hanging the enclosure over the weight represented a realistic assumption of the attachment to the blimp. After taring the scale, the weight we obtained supported evidence of achieving our objective, which was to come under the payload capacity of the blimp. The weight of the entire system measured 2.85 kg, which is .26kg less than the payload. This data meant that we needed to counter the buoyancy of the blimp with 2.55 N to maintain equilibrium. Next, we tared the scale to the weight of the enclosure. The thrusters were then initialized and maintained at an operating capacity of less than half of maximum. Figure 26 shows the resulting force the thrusters applied to the scale.

Figure 26: Thrust test

Figure 26 shows that the propulsion system produced an equivalent of .45 kg, which is 4.41 N of thrust. This data provided evidence that we could maintain control of the blimp during flight.

6 Flight Testing and Results

6.1 Final Test

After gathering evidence of the success in operating different individual systems, the enclosure was attached to the blimp. First, Velcro was secured at the center of buoyancy to maintain a point load from our propulsion system. Rope was wound tight around the enclosure for additional support.

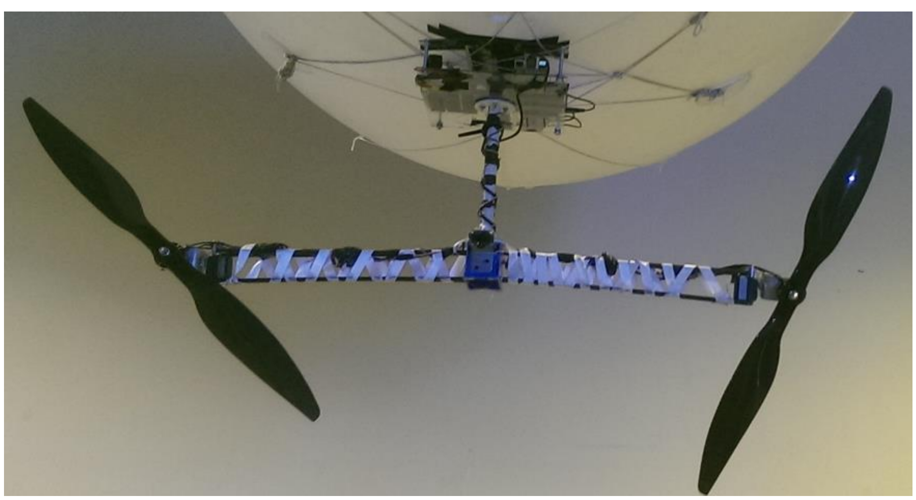

Figure 27: Secured System

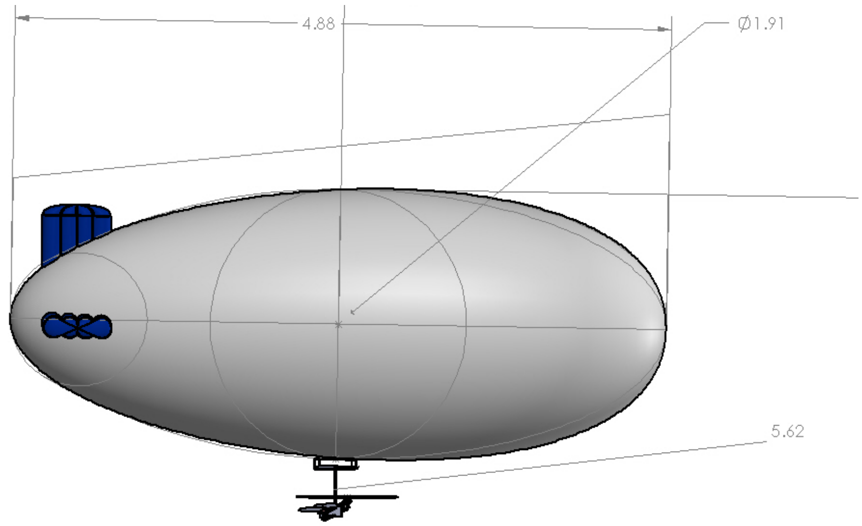

Figure 28: CAD of Final Setup (m)

Figure 30: Attachment to Blimp

Figure 29: Flight Test

Figure 31: Final Test

6.2 Results

The system performed as expected. Proof in navigation abilities were obtained by maneuvering the design. Single rotors were operated as the servo was prompted to be fully active from rest to perform 180 degree turns right and left. To descend, both rotors were active at top position of the servo. All communications were sound in operation. Figure 00 shows retrieval of the communications data during flight. Figure 00 shows an image captured by the camera at a height of 10 feet during operation.

Figure 32: In-Flight Communication

Figure 33: Image from Test Flight 10ft

7 Bill of Material (BOM)

This proposal includes the final Bill of Materials (BOM) which has a description of the parts that are divided into sections. Each section contains different items that were used on the enclosure on for the blimp. Eventually the components can be combined in the enclosure and placed in the correct way to help the blimp lift it easily without any trouble. The research process for this project requires investigation into different aspects of energy losses and movements within the blimp. There are areas of the blimp that experience greater energy and helium losses than others, and there are different variables that need to be considered. Unfortunately, the only figure missing from this list are the costs for the extra helium tanks that are needed for the future as it cannot be determined to how many trials the team will do. To receive accurate costs for the installation of the new helium tank, contractor bids would need to be collected and assessed for determination of a final budget. Determining eligibility of future design teams is necessary to ensure the correct helium tanks needed for the trials that have been designated. A large amount of the materials that have been used are recyclable and could be used again for future teams or other project for the university.

Table 2: Bill of Materials

Name	Cost ($)	Quantity (#)	Total Cost ($)	Weight (g)	Total Weight (g)
Raspberry Pi 2	42	1	42	60	60
USB Camera	45	1	45	15	15
Micro SD Card	8.05	1	8.05	1.5	1.5
Portable Battery	14.99	1	14.99	30	30
Mini USB Flash Drive 64 GB	15.99	1	15.99	22	22
Surveillance System					
Repair	100	1	100	NA	NA
Blimp	221	1	221	NA	NA
Helium	150	3	450	NA	NA
Regulator	130	1	130	100	100
Blimp/ Maintenance					
Propellers	72	1	72	230	230
LDPower Brushless Motor	56.9	2	113.8	154	308
ESC	21.99	2	43.98	62	124
MultiStar Battery 22.8 V	55.67	1	55.67	613	613
Propulsion System					
Velcro	19.98	1	19.98	61.8	61.8
Ribbons	NA	NA	NA	NA	NA
Attachment System					
Polycarbonate Glass	15	1	15		0
Bolts	NA	4	NA	30	120
PVC	0.97	1	0.97	64.21	64.21
Electric Box	0.98	1	0.98	56.7	56.7
Carbon Fiber Arrows	NA	8	NA	7.57	60.56
Aluminum Spacer	NA	NA	NA	NA	NA
Enclosure System					
Lynxmotion Quadrino Nano	149.99	1	149.99	64.22	64.22
AR610 Spectrum Receiver	39.99	1	39.99	NA	NA
Lynxmotion Quadrino Nano Advanced Wiring Kit	9.99	1	9.99	80	80
3DR 915MHz Radio Set for UAV	100	1	100	20	20
RC Transmitter	129.99	1	129.99	NA	NA
Electronic Wiring	NA	10	NA	62.4	624
Portable Battery	15.99	1	14.99	115	115
Telecommunication System					
Turnigy Servo 180 degree	28.99	3	86.97	90	180
Steering System					
Total			1881.33USD		2849.99g

8 Conclusion

The goal of this project was to reach our objectives for the purpose of creating a design that met all constraints. Several factors influenced our ability to test at the constraint altitude, but we have reached our goal in that all constraints of this project are addressed, conceptualized and implemented as a complete system that performs the duties requested by our client. The enclosure design is the compact solution for housing necessary components, which were researched for the intention of efficiency by price. All components are seated in and protected by this enclosure, which is durable beyond the thrust capacities of the navigation system. The communication abilities of our product are limited to a two mile range from control base, manually operated, and can be coded for the purpose of navigation by GPS. Estimated usage time of our design would approximate more than 1.5 hours at constant maximum usage. The total cost of the project does not exceed our budget, even as repairs, design iterations and multiple tanks of helium used for testing purposes were summed with analysis. All components of this project are reusable and will last beyond the use of future students if properly maintained.

The average cost of a competitive product that parallels the abilities of the Helium MAV concept is 1,400 USD with a maximum flight time of 28 minutes. It is firmly believed that improvements characterized by only additional coding would make this product far more proficient and customer-user friendly than current models in the market.

9 References

[1] M. Sivak, 'Air conditioning versus heating: climate control is more energy demanding in Minneapolis than in Miami', *Environ. Res. Lett.*, vol. 8, no. 1, p. 014050, 2013.

[2] A. Saari, T. Tissari, E. Valkama and O. Seppänen, 'The effect of a redesigned floor plan, occupant density and the quality of indoor climate on the cost of space, productivity and sick leave in an office building–A case study', *Building and Environment*, vol. 41, no. 12, pp. 1961-1972, 2006.

[3] Julie Hirtz, Robert Stone, Daniel McAdams, Simon Szykman, and Kristin Wood. "A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts." *Research in Engineering Design*, vol. 13, pg 65-82, March 2002.

[4] Dieter, George E & Schmidt, Linda C, Engineering Design, 4th ed., New York City, New York: McGraw-Hill, 2009, ISBN 978-0-07-283703-2.

[5] Barnes C.H. & James D.N. Shorts Aircraft since 1900. London (1989): Putnam. p. 560.ISBN 0-85177-819-4

[6] Dan, Vergano. "100 years in the air." *USA Today* n.d.: *Academic Search Complete*. Web. 23 Oct. 2015 ISSN 0734-7456

[7] F. Croce, G. B. Appetecchi, L. Persi and B. Scrosati.Nanocomposite polymer electrolytes for lithium batteries. Nature Publishing Group.Jul 30, 1998.

[9] http://www.strapworks.com/Loop

[10]:http://www.aliexpress.com/store/product/Wholesale-Outdoor-tactical-nylon-ribbon-hooks-The-fan-belts-mountaineering-buckle-the-molle-hook-and-equipment/1478383_32465660697.html

[11] http://flitetest.com/articles/propeller-static-dynamic-thrust-calculation

[12] http://kb.sandisk.com/app/answers/detail/a_id/69/~/number-of-pictures-that-can-be-stored-on-a-memory-device
[13] http://www.lynxmotion.com/p-1020-lynxmotion-quadrino-nano-flight-controller-with-gps.aspx