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PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

UNMANNED AERIAL VEHICLE
Final Report

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ETHICS STATEMENT AND SIGNATURES

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

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ABSTRACT

The focal object of the competition is to create and operate an unmanned aerial vehicle that is capable of autonomous target reconnaissance, navigation, takeoff and landing operations. The judges will score the participants based on their system's performance composed of three sections: a final journal paper, oral presentation, and a flight demonstration. It is a performance-based competition where multiple government agencies and corporate partners will be in attendance. As part of the senior design project, we will be designing the platform and integrating the required components for programming. Along with the assembly, programmed navigation, flight control and image recognition algorithms are needed to identify the targets and complete the proposed mission objectives. Both a prototype and final model where designed and tested for performance capabilities during competition. Through numerous testing regimes, mechanical improvements & various techniques, a final model was optimized to perform at a standard high enough to compete in the AUVSI Seafarer competition.

1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

Design an autonomous and unmanned aerial platform capable of control and target acquisition. The designed aerial platform should be capable of achieving these objectives at a standard high enough to compete in the UAS AUVSI Seafarer competition. Complete design of the system as well as system integration will be the focus of the project. It is believed that the requirements for the UAS AUVSI Seafarer competition can be directly related to a Senior Design Project. The majority of engineering knowledge obtained throughout undergraduate studies will be tested throughout the project. It is extremely important that both competition objectives and senior design requirements overlap to satisfy both entities.

1.2 MOTIVATION

The inspiration for the proposed project arose from a variety of reasons. The first major reason for choosing such a project is the ability the project has to involve each team member. It is believed that designing the platform and target recognition program will adequately fulfill the requirement. The most important aspect is to make sure all three team members utilize the four years of undergraduate studies in mechanical engineering. System integration will be the key focus of the project as the only designed parts will be the structure of the system.

Florida International University is an up and coming University. Over the years, it has become well known over the community as well as the country. The University is seeing improvements each day and is expanding at a rapid pace. Entering the AUVSI Seafarer competition allows for the opportunity to showcase the Mechanical Engineering Department at Florida International University. During this competition, many companies will be in attendance and the most motivating aspect of this project is the chance to win and promote the University.

1.3 LITERATURE SURVEY

The project literature survey began by looking at previous teams who had competed in the competition in earlier years. Speaking with the ex-competitors and faculty familiar with the matter presented a broad overview of what the competition involves. A brief survey of teams from other universities, which are available upon request from the AUVSI representatives, also provided insight on the overall scope of the competition and the aspects contained.

Further investigation encompassed reading material, which was closely related with the subject of unmanned platform operations. According to Valavanis autonomy is single most difficult mechanism to incorporate into any system [1]. In this text, the complex art of autonomous flight techniques are discussed and depicted in diverse forms to offer intuitive methods for programing and incorporating these techniques to aerial platforms.

Figure 1: Previous AUVSI Seafarer Competitor equipped with autonomous systems [4]

Additional review consisted of mostly physical and mechanical properties associated with flight. After considering all the possible conceptual design ideas and history of success in the competition, an overwhelming appeal towards helicopters formed. Studying texts such as *Bamwel's Helicopter Dynamics*, literature on flight mechanics of vertical lift platforms provided an insightful view of the subject. A brief section of the text discussed the integration of computer chips to achieve autonomous flight and the differences between each of the mechanics. This offered an immense benefit for our project as it described detailed information on how to convert the mind behind the pilot of the platform to a computer chip, which uses algorithms to replicate the complex process of flying a helicopter.

In contrast to mechanical and aviatronic research regarding UAS, a separate survey was prepared on practical image recognition techniques worth pursuing for the purpose of our project. Image recognition has repeatedly shown its importance over the last ten years or so. Not only is it a vividly researched area of image analysis, pattern recognition and more precisely

Biometrics, but also it has become an important part of our everyday lives since the introduction of military drones and other Unmanned Systems [6] [7] [8] [9].

From a practical implementation point of view, an important, yet often neglected part of any image recognition system is the image compression. In almost every imaginable scenario, image compression seems unavoidable. Just to name a few:

- Image is taken by some imaging device on site and needs to be transmitted to a distant server for verification/identification;
- Image is to be stored on a low-capacity chip to be used for verification/identification (an image is needed and not just some extracted features for different algorithms to be able to perform recognition)
- Thousands (or more) images are to be stored on a server as a set of images of known shapes or variants to be used in comparisons when used for verifying/identifying.

All of the described scenarios would benefit by using compressed images. Having compressed images would reduce the storage space requirements and transmission requirements. Compression was recognized as an important issue and is an actively researched area in other biometric approaches as well. Most recent efforts have been made in iris recognition and fingerprint recognition [10] [11]. Apart from trying to deploy standard compression methods in recognition, researchers even develop special purpose compression algorithms, e.g. a recent low bit-rate compression of images [12]. From this research a number

1.4 COMPETITION GUIDELINES

The AUVSI Seafarer competition is a very prestigious UAS event hosted at the Naval Air Station Patuxent River's Webster Field in Maryland. Every year they host over 30 teams from across the world but mostly Engineering & Aeronautic University Institution in the US. Such a competition has a large list of very strict rules and formulation. A full list & description of competition guidelines can be found in Appendix A, however for the purpose of conciseness a brief description of the most important parameters kept in mind while designing and testing the UAS can be seen below as stated on the AUVSI Request for Proposal 2013 [13].

Table 1: Threshold vs. Objective

Key Performance Parameters Parameter	Threshold	Objective
Autonomy	During waypoint navigation and area search.	All phases of flight, including takeoff and landing
Imagery See paragraph 3.5.2.3 for target characteristics	Identify any two target characteristics (shape, background color, orientation, alphanumeric, and alphanumeric color)	Identify all five target characteristics
Imaging Autonomy	Identify targets with 50% false alarms or more including a "man in the loop" for verifications	Identify all targets autonomously with less than 25% false alarm return rate
Target Location	Determine target location ddd.mm.ssss within 250 ft	Determine target location within 50 ft
Mission time(1)	Less than 40 minutes total Imagery/location/identification provided at mission conclusion	20 minutes Imagery/location/identification provided in real time
Operational Availability (AO)	Complete 50% of missions within original tasking window (no more than one time out)(2)	Complete 100% of missions within original tasking window (no time outs used)
In-flight re-tasking	Add a fly to way point	Adjust search area

Note 1: Time is measured from judges permitting activation of transmitters to the aircraft being shut down and providing the judges the completed mission report & associated imagery. There is a separate requirement for 40 min set up time.

Note2: Due to limited competition time, time outs may not be possible and teams that cannot complete their mission within the original tasking window may not be given another mission window. No team will receive more than two opportunities to fly (one time out)

Key Performance Parameters are the most important requirements. KPPs make up the vast majority of the scoring possible for the mission performance portion of the competition. Failure to meet any threshold will be heavily penalized. Performance beyond the threshold up to the objective will receive some bonus points.

- "Shall" indicates a requirement that is a threshold (mandatory). Failure to meet this requirement will result in no points being awarded in this area.
- "Should" indicates a requirement that is an objective. Demonstrating these requirements will earn extra points, but the basic mission can be achieved without meeting it.
- "May" indicates a permissible implementation, but is not a requirement
- "Will" indicates actions to be

4.1. Safety Flight operations of any type involve some level of risk to personnel and property. It is the responsibility all personnel involved in flight operations to identify, evaluate and mitigate risks to the maximum extent possible. Systems that do not meet the requirements listed below will not be permitted to fly.

4.1.1. The Maximum takeoff gross weight of the air vehicle shall be less than 55 lbs.

4.1.2. The system shall provide sufficient information to the judges to ensure that it is operating within the no-fly/altitude boundaries on a continuous basis.

4.1.3. The air vehicle shall be capable of manual override by the safety pilot during any phase of flight.

4.1.4. The air vehicle shall automatically return home or terminate flight after loss of transmit signal of more than 30 sec.

4.1.5. The air vehicle shall automatically terminate flight after loss of signal of more than3 minutes.

4.1.6. The return home system, if installed, should be capable of activation by the safety pilot.

4.1.7. The flight termination system shall be capable of activation by the safety pilot.

4.1.10. The maximum airspeed of the air vehicle shall not exceed 100 KIAS.

4.1.13. Physical inspection of vehicle to insure structural integrity, including: 4.1.13.1. Verify all components adequately secured to vehicle. Verify all fasteners tight and have either safety wire, locktite (fluid) or nylock nuts.

4.1.13.2. Verify propeller structural and attachment integrity.

4.1.13.3. Visual inspection of all electronic wiring to assure adequate wire gauges and connectors in use. Teams shall notify inspector of expected maximum current draw for the propulsion system.

4.1.13.4. Radio range checks, motor off and motor on.

4.1.13.5. Verify all controls move in the proper sense.

4.1.13.6. Check general integrity of the payload system.

4.1.13.7. Verification of Academy of Model Aeronautics (AMA) Fail-safe mode operation covered by manual override and pilot commanded flight termination.

6. Performance Metrics

6.1. The major graded items/events are:

6.1.1. Final Journal Paper

6.1.2. Oral Presentation

6.1.3. Flight Demonstration

6.2. Each item/event will be measured in four respects:

6.2.1. Autonomy. – The degree to which the system can operate without human intervention will be evaluated as part of the judges' discretionary score.

6.2.2. Systems Engineering. A methodical approach to deriving performance requirements, allocating functionality to subsystems, system design, adjustments made due to test & evaluation.

6.2.3. Mission Accomplishment. The ability to meet the top-level system requirements that enable mission accomplishment.

6.2.4. Safety. A system safety approach that identifies risk to mission performance, material safety and personnel safety, then implements mitigation strategies to reduce those risks.

2.0 PROJECT FORMULATION

2.1 PROJECT OBJECTIVES

The primary objective of this project is to investigate and construct a system for aerial vehicles that will allow for autonomous operation and target recognition. Case study and mentor guided research into existing methods will be examined and improved upon to conform to realistic objective, platform, and budget constraints. Implementation of those methods will be done upon optimizing computer and programming language combinations in order to improve system efficiency. The system will then be outfitted with cameras and sensors in order to identify and track objects of interest using GPS technology.

The competition clearly establishes a distinction between competition objectives and thresholds. As part of our senior design our team aims to achieve all thresholds and all competition objectives. If competition objectives are only partially concluded, the team would still have a 6 month period to finalize any issues pertaining to the objectives for competing.

The largest area of objectives is encompassed in the Flight Demonstration portion of the competition guidelines, Section C 3.5. Takeoff shall take place within one of the two designated Takeoff/Landing areas depending on current wind direction. The area will be approximately 100 feet wide with no height obstacles. After takeoff the UAS shall maintained steady controlled flight at altitudes between 100-750 feet. Takeoff under manual control is permitted and considered under threshold; extra credit will be provided for autonomous takeoff/landing and considered under objective.

Way-point Navigation, Section 3.5.2 requires the use of GPS coordinated to navigate the UAS autonomously through a mission profile designated by the judges. An en-route search will be required to fly specific altitudes while identifying several targets along the route when the vehicles is required to be at 500, 250, 200 feet with a n MSL 100 foot tolerances. All en-route waypoint shall be achieved in order to meet threshold. To meet objectives for this section all phases of flight included previously stated takeoff/landing.

A Simulated Remote Information Center (SRIC) will be implemented into the mission profile to allow the UAS to connect through a Wi-Fi signal to access a Windows 7 Computer on a ground station to retrieve a text file with contents ready to be received by the judges. Prior to the takeoff, the position of an SRIC will be provided. The SRIC portion is no part of threshold but will be part of the team's objectives as extra credit and awards are given to team able to carry out this portion of the mission profile

Total mission time is fairly flexible within the competition, however due to the nature of our UAS, it is an essential objective that will need to be met and tested within certain accuracy to be able to compete at a high standard. Threshold for the competition is under 30 minutes total flight time including all mission profiles. Objective is 20 minutes in total flight times, therefore the objective for our team is to have minimum 30 minutes of flight time while performing test mission similar to competition in less than 25 minutes.

3.0 CONCEPTUAL DESIGNS

Every team entering the competition is free to choose an aerial platform that will perform the specified tasks. The team went through careful research and investigation of three main platforms; helicopter, fixed wing airplane, and multi-rotor copter. Among these three platforms are considerable advantages and disadvantages that must be taken into account before choosing the optimal platform. Helicopters and multi rotor copters have similar advantages as they are allowed to take off and land virtually anywhere. Both platforms can hover in one place and can move in any axis from a point with great maneuverability. Each style can carry a small payload if necessary but travel slowly, with the multi rotor travelling a bit faster. Planes on the other hand can travel large distances at a faster rate. Planes have the ability to be designed simpler and repair costs are considerably less than multi rotor platforms.

Figure 2: Conceptual Design – Plane [2]

While all three platforms show tremendous upside, each has its own fair share of disadvantages. Multi rotor platforms require rigorous programming along with tedious calibration of the motors. The weight of multi rotor platforms must be distributed evenly as to avoid over compensating a motor. A major setback for multi rotor platform is in flight issues; if a motor decides to give out, the aerial vehicle will shortly come to a fall. Planes alike the multi rotor platforms must have the weight distributed evenly. They also have the disadvantage at take-off and landing as they require plenty of space to perform both tasks. Overall, the plane requires a great deal of space to fly in to avoid any crashes. Lastly, the helicopter has the most complex design among the three platforms. This complexity is usually prone to failure, if not properly designed. A helicopter requires more maintenance than the other two platforms.

Figure 3: Conceptual Design – Multi Rotor [2]

4.0 PROPOSED DESIGNS

4.1 INITIAL PROPOSED DESIGN

Carefully considering all advantages and disadvantages of all three platforms, it was decided to carry out the project with the design of a helicopter. For the task at hand, the helicopter offers the best possible results. Take-off and landing are important factors in the competition due to the time constraints placed. The team believes using a helicopter will avoid take-off issues and save much needed time. While planes do cover ground better than helicopters, the helicopter has the ability to fly slow and also hover in one location. This alone makes the helicopter the most intriguing as the design must perform target recognition. The ability to hover and simultaneously scan the area for targets is a great advantage. The last factor in terms of capability is the maneuverability in any axis. The ability to change direction quickly and decisively will prove a strong point in the design. The multi rotor platform was an intriguing option as it provides similar benefits as the helicopter. The main issue is the simplicity in the design. The helicopter not only provides a platform to compete but also challenges the team in making a complex design.

Figure 4: Proposed Design – Helicopter [3]

4.2 FINAL PROPOSED DESIGN

When considering the initial design for both the competition and senior design requirements, a helicopter delivers better results for the competition but was not feasible in the time frame allotted. Therefore, it was decided to carry forth the project by designing and fabricating a Multi Rotor platform. This option provides similar flight characteristics to the initial design but has some limitations in the power system. With limitations in the power system, the main objective is to control the weight of the system without suffering mechanical strength and stability. This will be done by properly researching materials best suited for the system while also accounting for the cost. Along with managing the weight, the primary engineering done will be system integration. The competition requires a variety of goals to be accomplished and it must be done with a couple components. How to integrate all the components to avoid interference and maximize efficiency while simultaneously manage the payload will be the goal and focus of the design.

Figure 5: Final Proposed Design – Multi-Rotor [3]

5.0 PROGRESSIVE FUTHER RESEARCH

5.1 MULTI-ROTOR MECHANICS

Due to the fact that our design changed through the course of the proposal stages, further research was conducted to better understand that mechanics of multi-rotor systems. A quad-rotor helicopter is a helicopter which has four equally spaced rotors, arranged at the corners of a square frame. The need for a swash plate mechanism used on helicopters is eliminated due to the four independent rotors. Electronic assistance is needed to control the quad copter and even then it is still a challenge. The platform has six degrees of freedom (three translational and three rotational) with only four independent inputs. In order to achieve six degrees of freedom, rotational and translational motions are coupled. The resulting dynamics are nonlinear, especially after accounting for the aerodynamic effects. Finally, rotor vehicles have very little friction to prevent their motion, so they must provide their own damping in order to stop moving and remain stable. All of these factors create interesting control problems. Before any further theory, the nomenclature for direction of motion will be exactly like any other aircraft. Referring to figure 5, the orientation of the quad copter is determined by roll, pitch, and yaw.

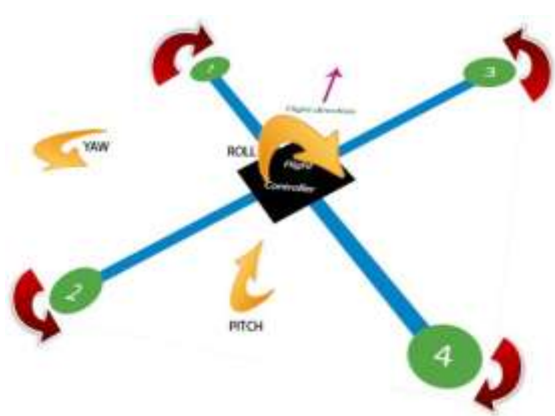

Figure 6: Roll, Pitch, Yaw Diagram

Each rotor produces both a force in the vertical direction formally known as thrust, and a torque about its center of rotation. A drag force is also created opposite to the vehicle's direction of motion. When all rotors are spinning at the same angular velocity, there is a net aerodynamic torque about the yaw axis and it is exactly zero. In order to accomplish this, we start by calling the first rotor R1, and the rotor directly across from it R3. The other two rotors are called R2 and R4. Rotors R1 and R3 must be spinning in the same angular velocity. This creates a torque that must be counter balanced. Rotors R2 and R4 must also spin in the same direction but opposite angular velocity of R1 and R3. Figure 6 shows how each rotor is configured to spin in order to achieve a balanced platform.

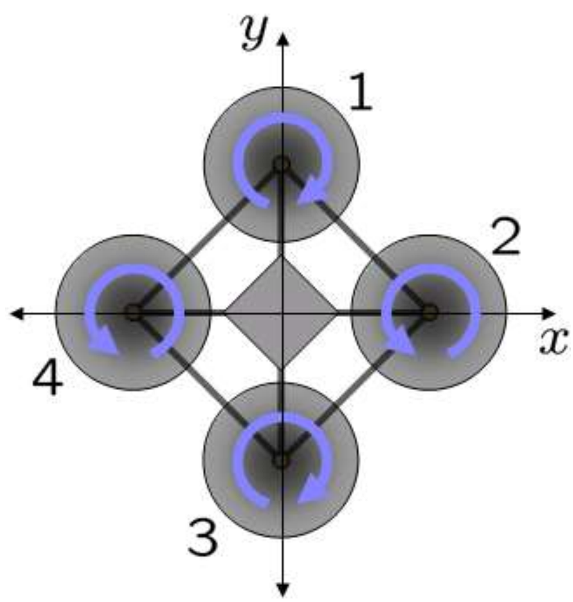

Figure 7: Quad rotor Torque Diagram

Case 1: Loitering

Rotor platforms have the unique ability to loiter (hover) in an area. Depending on the application, it poses advantages and disadvantages. In order to achieve this type of position, the thrust force must be equal to the weight of the platform. It is important to note that four inputs create thrust thus the total thrust created must be equal to the weight of the platform. Loitering is vulnerable to gust of winds and any variable force against the platform.

Case 2: Take-off & Landing

Rotor platforms do not need a takeoff strip to startup. With the required space, rotor platforms have the advantage to take off from any desired location. The thrust force must be greater than the weight of the platform in order to move in the vertical direction. Today's technology offers light motors with great thrust capabilities. Therefore, an operator must be mindful of the thrust to weight ratio as quad copters are designed to be light in weight to optimize flight time. A recommended thrust to weight ratio for take-off is 1.05 to allow adequate response time and optimum control. The same can be said for landing as you do not want to come crashing down at a high velocity. Thrust to weight ratio again is important as you want to descend slowly to the ground before cutting off power to the motors. To descend, it is recommended to start at a high altitude in case something goes wrong and to monitor your thrust to weight ratio at 0.95.

Case 3: Roll, Pitch, Yaw

Roll, pitch, and yaw dictate the maneuverability of the quad copter. All three require a manipulation of the torques induced by the rotors. Roll and pitch are essentially the same type of motion just at different orientations. Roll controls movement from left to right, while pitch controls forward and backward. A quad rotor adjusts its pitch or roll by applying more thrust to one rotor and less thrust to its diametrically opposite rotor. It is also possible to adjust roll and pitch by applying more thrust to two rotors that are next to each other while the other two offer less thrust. One cannot simply just add thrust to one or two rotors as that will create an imbalance of thrust and not only roll or pitch the platform, but also propel it upward. Therefore, it is imperative to reduce thrust in other rotors. To adjust yaw, rotors rotating in the same direction must increase thrust output or vice versa.

6.0 PROTOTYPE DESIGN

6.1 SRUCTURAL DESGIN

A multi rotor system structure is composed of two main parts; the center console and the legs connecting the motors. The center console provides the operator to store major electrical components and necessary flight tools. The legs are equidistant and are sized depending on the size of the center console and propeller size. Three designs were considered for the structural design, all designs required using ¾ inch square aluminum bars. The first design proposed was a cross configuration using two identical 32 inch bars with material removed in the middle so that they would fit together closely. To ensure rigidity, both bars would be welded together at the joints.

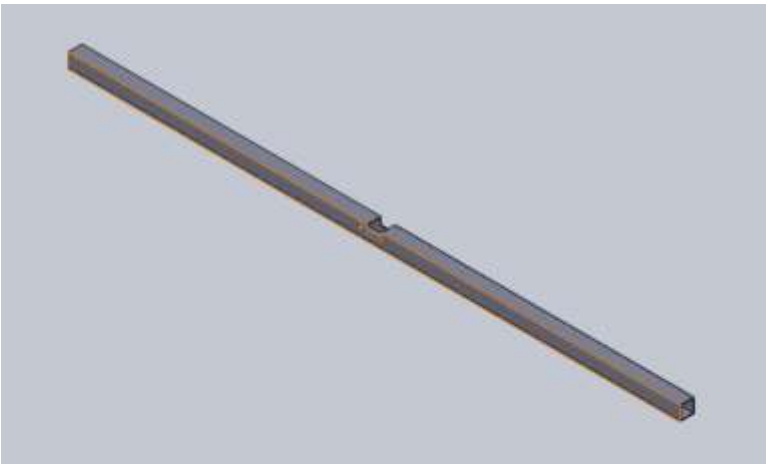

Figure 8: Aluminum Bar - Welded

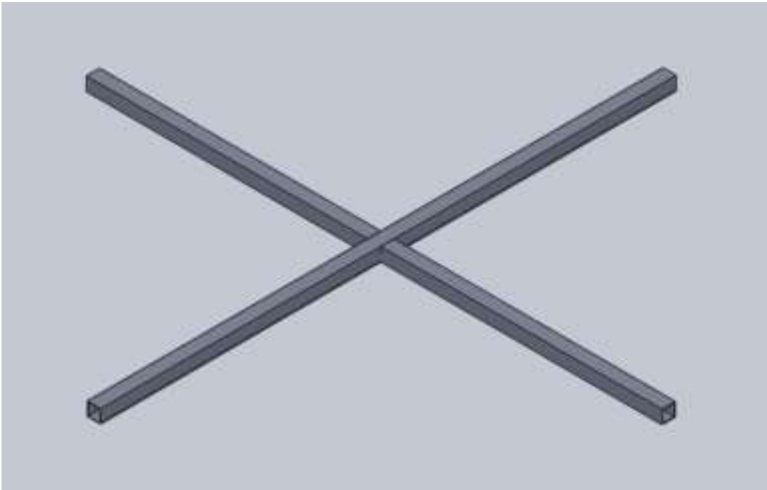

Figure 9: Aluminum Bars – Joined by Welding

The second proposed design for the legs uses one 32 inch bar and two 15 3/8 inch bars also connected in a cross configuration.

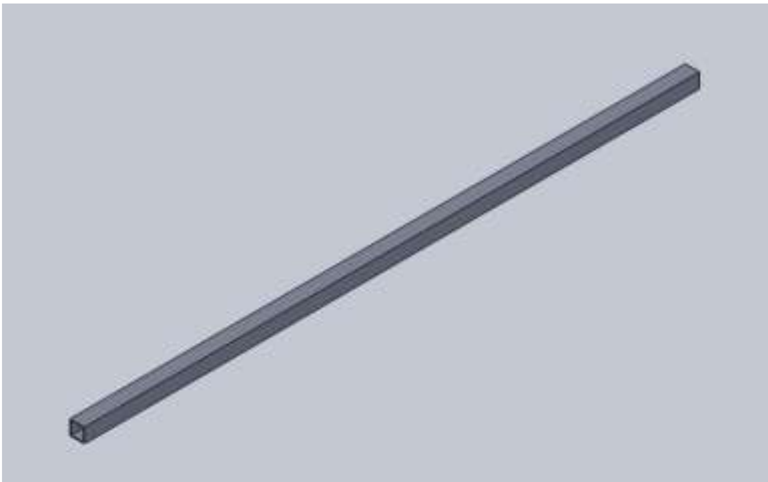

Figure 10: 32 inch Aluminum Bar

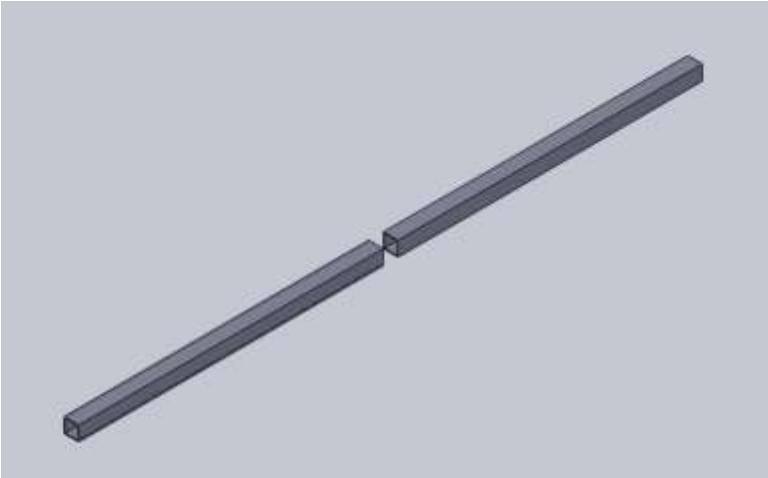

Figure 11: 15 3/8 inch Aluminum Bars

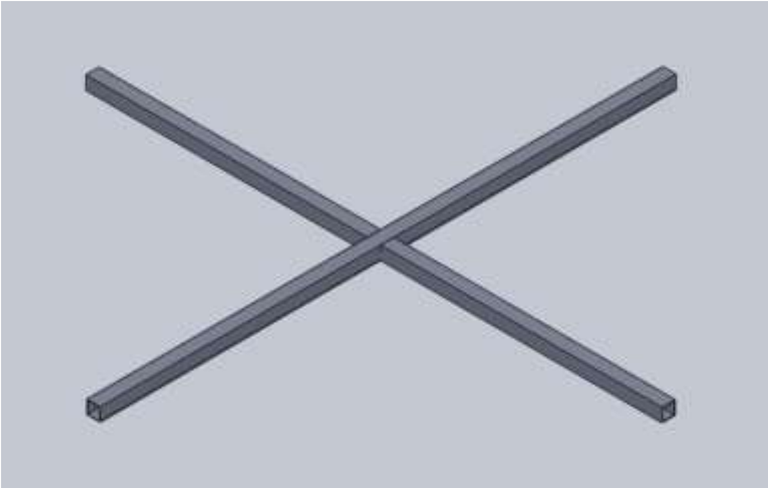

Figure 12: Aluminum Bars – Joined by screws

The last design consists of four 16 inch bars that are evenly spaced in the center. This configuration offers the ability to pass electrical wiring through the center of the platform and offers a reduction in weight.

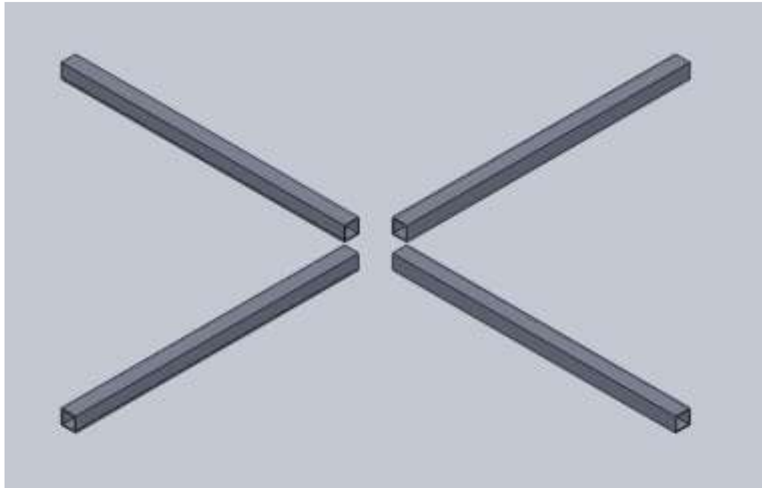

Figure 13: Four 16 inch Aluminum Bars

The latter was used for the prototype as it offered the most advantages to start the project. Weight management is one important factor in this design as it will directly influence flight time. Any proposed design that can limit weight but can still offer durability is a design worth using. Using square bars has an advantage as it offers easy installation of other components. Two acrylic plates identical in size but different cut layouts are used. All acrylic parts cut were cut with a laser printer. This resource offered precise cuts to size and cut down manual manufacturing time. Three different geometries were considered to use as the body and the connection of the four legs.

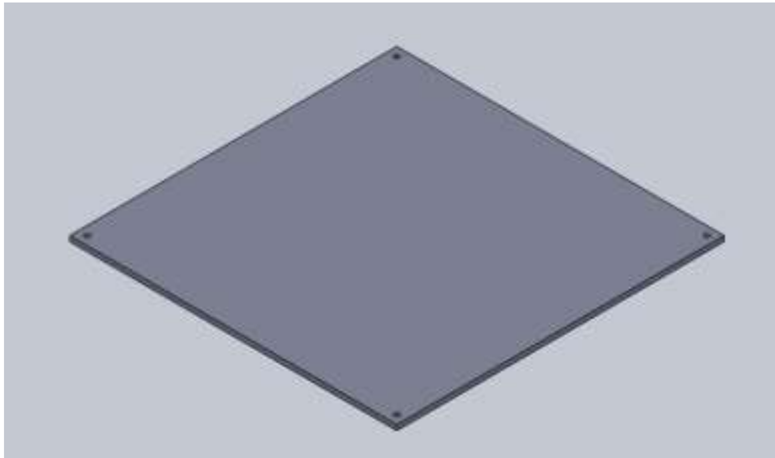

Figure 14: Square Plate – Fixed at the Corners

The square plate fixed at the corners offers the ability to use all the available space while holding a strong support. It is vulnerable to cracks near the fixtures and the corners as vibrations will primary result from the motors.

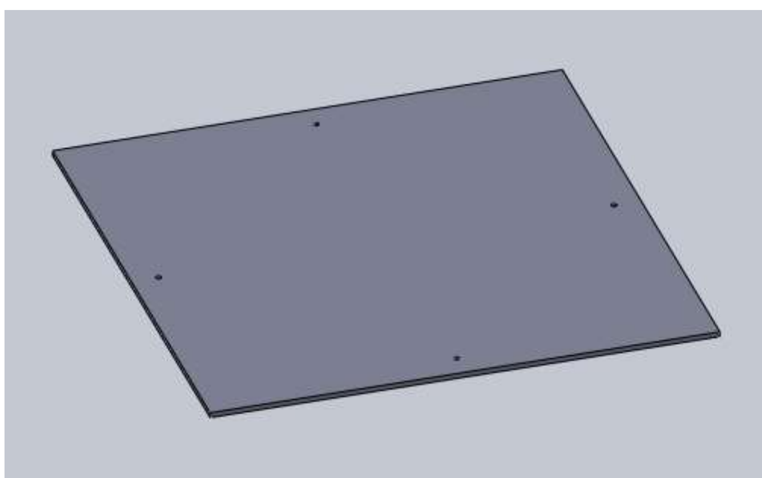

Figure 15: Square Plate – Fixed at the sides

The square plate fixed at the sides avoids the chances of cracking. The main issue with this is the inability to add any load at the corners. Adding equipment at the corners will cause bending through the middle of the plates where vibrations are present.

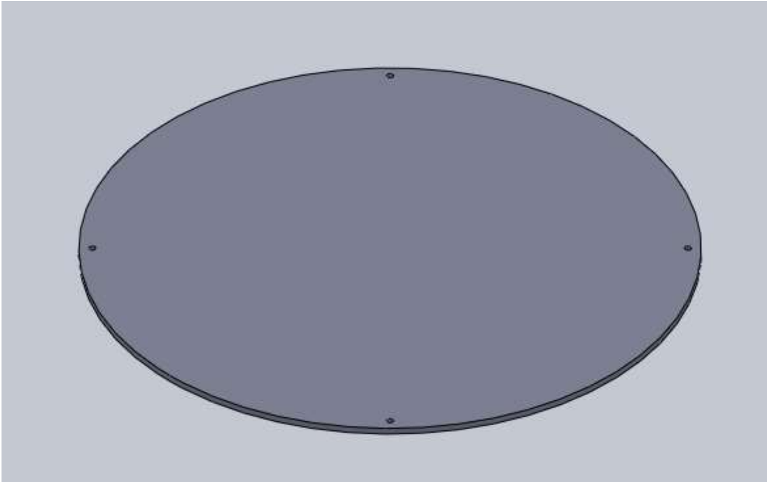

Figure 16: Circular Plate – Fixed evenly

The circular plate offers less area which directly affects the weight of the system. This resulting reduction of area offers less space to work with for additional components. Stress concentrations at the fixtures are dampened with the resulting curvature of the plate.

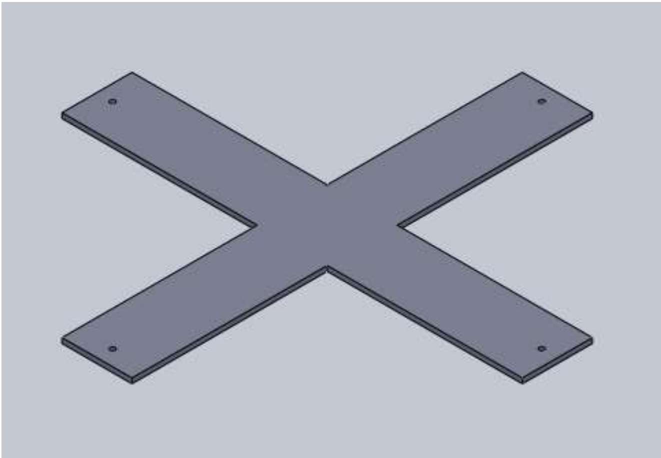

Figure 17: X Configuration – Fixed at the ends

The last system structure considered is the x-configuration. This setup reduces weight drastically as the plate width is 1.5 inches. The downfall is the lack of available space to install other valuable components.

Motor mounts of all sizes and configurations were considered for the system. All mounts designed must be level with the aluminum bars, fixed in such a way to avoid interference with the motors, and fixed to the bars to ensure system function and safety of personnel. Materials that were considered in the design were plastic, acrylic, rubber, and carbon fiber. All motor mounts must be designed with the same hole configurations as the motors themselves have a specific screw alignment.

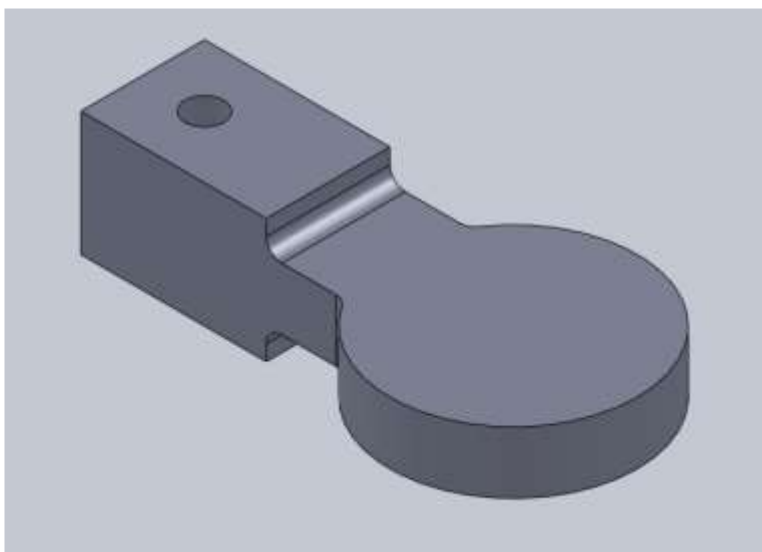

Figure 18: Motor Mount – Fixed within Bar

The first motor mount considered is designed from a 3D plastic printer. The mount has a square body to be inserted into the hollow aluminum bars. The motors would sit atop the circular platform and be the farthest component from the center of the system. A major drawback is the excessive use of material and clearance issues. In order for this design to function properly, the clearance would have to be an extremely tight fit to avoid any wiggle room of the part. Since the 3D printer operates using heated plastic, the parts tend to shrink a considerable amount once cooled.

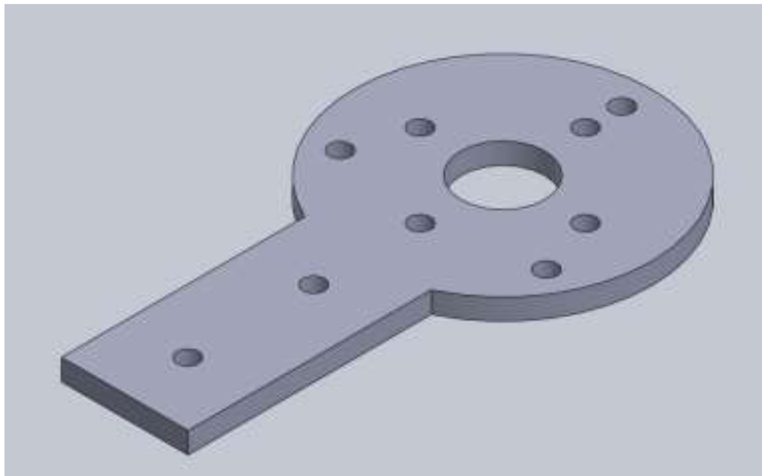

Figure 19: Motor Mount – Hanging off the edge

The second motor mount considered also hangs off the edge of the aluminum bar. Fixed at two points on the square end while the motor is mounted using the screws it came with. The setup leaves the mounts and the motors extremely vulnerable. Any kind of crash that platform takes, the mounts are directly exposed and take the impact. The motors are the driving force of the system so keeping them relatively safe is a must. Acrylic was used for this type of mount.

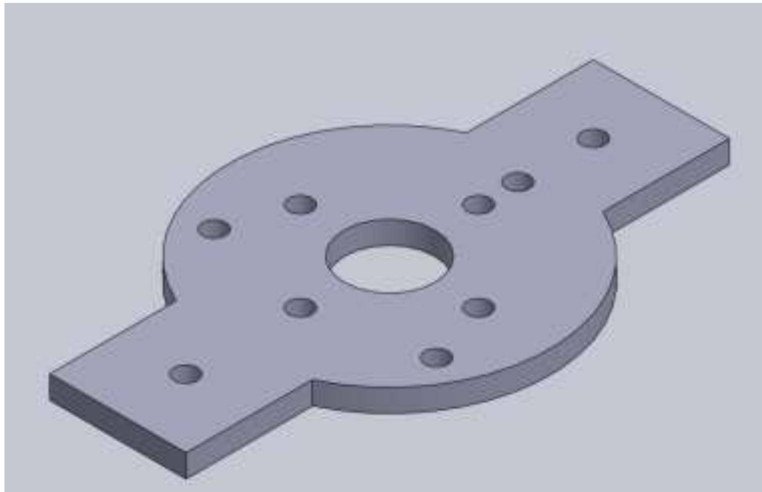

Figure 20: Motor Mount – Fixed on top of Aluminum Bar

The last motor mount proposed is fixed on top of the aluminum bars. It was decided to use the four screw configuration closer to the center hole. Four screws are driven through the aluminum rods and are secured with a washer and nut. The other two screws are fastened on the outside holes that just grab the acrylic to the motors. The center hole is an important feature to note as it allows the motor to spin freely. Without the center hole, the acrylic interferes with the motor and friction is created. This motor mount allows any impacts to be taken by the aluminum rods. It is easier to replace propellers than to replace four electrical motors.

6.2 MANUFACTURING

Manufacturing for the prototype was decided to be kept as simple and inexpensive as possible, while also having ease of replacing major parts and components. With this criteria the frame and center console were designed and manufactured from parts found in local stores at inexpensive prices and ease of access. The center console is made from 1/8” thick Plexiglas and was cut via a laser cutter courtesy of FIU’s architecture department. The 3D CAD design can be imported to the laser cutter and an outline cut is made of the material inside. A closer view of the cutting process can be seen in figures 21 & 22.

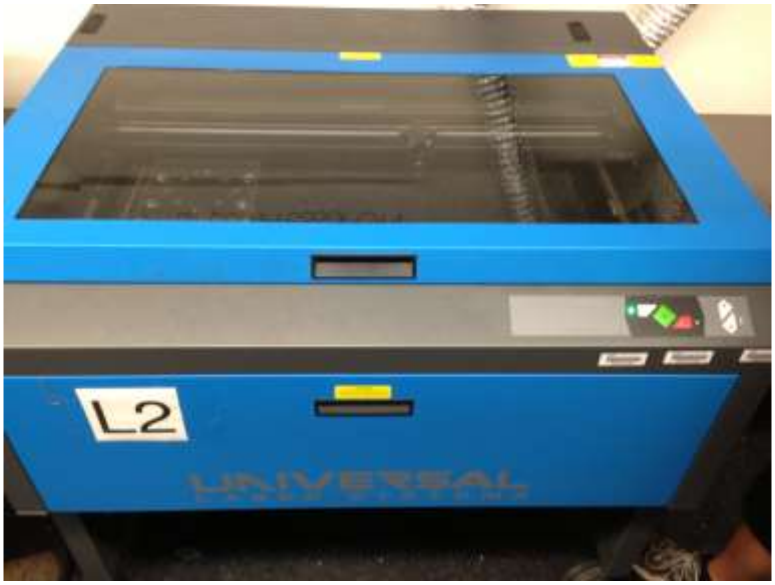

Figure 21: Laser Printer

Figure 22: Laser Printer – In service

The frame which connects the motors to the center console consists of 4 legs. For these, 3/4" aluminum bars were cut (16 inch lengths) with an electric saw and drilled to the specs of the center console via drill press accessible to the team in the Mechatronics Lab. A photograph of one of the team members drilling the necessary holes and features can be seen in figure 23.

Figure 23: Manufacturing – Mechatronics Laboratory

6.3 MAJOR COMPONENTS

Major components for this project include mostly the hardware required for the construction of the UAV platform. Basic material and flight components include the frame structure, engine, rotor mechanics, etc. Additionally key electrical components along with image recognition devices must also be integrated to this list.

- Propulsion

The Turnigy Multistar 480Kv Multi-Rotor out-runners were selected for prototype testing and use for data collection. They are specifically designed from the ground up for multi-rotor use. Featuring high-end 45SH magnets, high quality bearings, 22 poles, custom motor mount make these motors a great choice for the design. Below are specifications for the motors:

- KV (RPM/V): 480
- Lipo cells: 6s
- Max Surge Watts (W): 680
- Working current: 22 amps
- Max. Current(6s): 31 amps
- No Load Current: 1.2 amps
- Internal Resistance: 0.062 ohm
- Number of Poles: 22
- Dimensions: 47.5 x 33 mm
- Shaft: 6 mm
- Prop: 14 x 4-15 x 5
- Weight: 154g

Propellers come in different sizes that optimize performance based on the application. Carbon fiber blades were selected as the major component but a complete thrust & efficiency analysis will be shown later in this report with the specified propellers below:

- 12x4.5 Slow Flyer Propellers
- 14x4.7 Carbon Fiber Propellers 1pc Standard/1pc RH Rotation
- 15x5.5 Electric Carbon Fiber Propellers
- APC 16x5.5 MR Propellers
- APC 15x4 Electric Propellers

Several thrust tests can be performed to analyze propeller & motor combination for power draw and efficiency. Different combinations will yield different results and such can be analyzed only through physical tests using a thrust apparatus and a power measurement to analyze and compare results to find optimal efficiency while still maintaining the level of power required by the aircraft. Numerous tests coupled with different combinations of propellers and motors are planned to establish the best components to achieve objectives can be found in section 13.0 Prototype Testing.

- Fuel

Lithium Polymer batteries were selected to produce less voltage sag and a higher discharge rate than a similar density lithium polymer battery. The Turnigy nanotech 6s 8000mAh are the highest end batteries available on the market and suit our needs. Below are the specifications for the batteries:

- Capacity: 8000mAh
- Voltage: 6S1P / 6 Cell / 22.2V
- Discharge: 25C Constant / 50C Burst
- Weight: 1105g (including wire, plug & case)
- Dimensions: 195x50x55mm
- Balance Plug: JST-XH
- Discharge Plug: 5mm bullet-connector

- Power Distribution

Immediately subsequent to the battery, a power harness which splits into 4 separate terminals supplies power to each Electronic Speed Controllers (ESC). The ESC's offer the communication between the on board flight controller and the four motors. The ESC's come with bullet connectors for east installation and convenience, stripping the wire is not required. The throttle response is very smooth and also a linear relationship. The specifications for the ESC's are as follows:

  - Constant Current: 45A
  - Input Voltage: 2-6 cells Lipoly
  - BEC: Yes (Switching)
  - Output: 5.5V/6A
  - PWM: 8 KHz
  - Max RPM: 240,000rpm for 2 Poles Brushless Motor
  - PCB Size: 50mm x 30mm
  - Weight: 58g

- Computation/Autopilot

The APM 2.5 (ArduPilot Mega 2.5) is the open source autopilot system used for the autonomous control. It allows for any aerial platform to operate autonomously; capable of performing programmed GPS missions with waypoints. The APM includes a 3-axis gyro, accelerometer, magnetometer, and barometer. The software provided comes with built in settings depending on the aerial platform chosen. Features included for the APM 2.5 are as follows:

- High quality auto level and auto altitude control – fly level and straight
- No programming required
- Unlimited GPS waypoints in the Mission Planner
- Loiter at any position using its GPS and altitude sensors
- Return to launch. Set home to any location and flip a switch to have the platform fly back automatically
- Do all mission planning via a two-way wireless connection option? Waypoints, mode changing, even changing the gains of every control parameter can be done from your laptop, even while the copter is in the air
- Automatic takeoff and landing

- Imaging & Recognition

Figure 24: Turnigy Micro FPV Camera 700TVL

For the image recognition system, the Turnigy FPV full color camera was chosen for its small form factor and low power consumption. At just under 35 grams and with a current draw of 150 mA the camera will minimally affect the performance of the quad copter. It is capable of outputting a resolution of 976x494 pixels per inch.

The camera features automatic white balancing with a 3.6 mm lens. Multiple lenses with different focal lengths are to be tested for barrel distortion and sharpness. Focal length is important for camera systems since they describe how much of a scene the camera is able to capture. A shorter focal length will feature a narrow field of view with higher magnification while a longer focal length will feature a broader field of view with lower magnification. These considerations must be examined so that the image recognition software is able to identify the objectives correctly. Having a narrow field of view will output a fast moving image however the image will be sharper. While having a sharper image aids in the image recognition the camera will have to pan and tilt more frequently in order to scan the entire landscape for objectives. The opposite is true for longer focal length lenses. A wider field of view will offer a slower speed at which the objects pass through the screen which aids in detection however the images will appear less sharp which may interfere with image recognition program's ability to detect the objects. Lenses are cheap and will be tested to see which offers the best performance.

Video will be transmitted to the base station via a video transmitter mounted on the quad copter and video receiver connected to a video capture card on the base station computer.

Figure 25: Boscam 5.8G 500mW 8 Channel AV Transmitter

The transmitter is a Boscam 5.8 GHz 8 channel audio and video transmitter popular with hobbyist. The transmitter features a supply current of 500mA operating at 5.8 GHz at a weight of 66 grams.

A transmitter with a frequency range of 5.8 GHz was chosen for its reliability and superior reception capabilities. Higher frequency transmitters offer better reception and longer transmission in open, unobstructed fields where line of sight to the transmitter is maintained. The use of lower frequency transmitters is often recommended where tall buildings, tress, or other obstacles impede transmission. This is because lower frequency transmissions are transmitted easier through objects however with the popularity of lower frequencies being used from anything from remote controllers to telemetry transmitters and other wireless data, a higher frequency was chosen to minimize interference.

Figure 26 - Boscam RC805 5.8Ghz 8 Channel AV Receiver

The receiver is a Boscam RC805 5.8 GHz 8 channel receiver. This base station receiver with antenna will be capable of receiving a video feed for up to an estimated 4 kilometers when keeping direct line of sight. It will output through a composite video feed into a USB video capture card where it will be used by the image recognition software.

- Telemetry & Transmission

Telemetry communication with the UAS will be vital for mission testing and meeting critical competition objectives. To achieve this communication, the 3DRobotics & 3DR Radio was used to link the ArduPilot and a ground station. Some of the attractive features of this particular system are:

- Very small size
- Light weight (under 4 grams without antenna)
- Available in 900MHz (Very Long Rang with minimal interference)

- Receiver sensitivity to -121 dBm
- Transmit power up to 20dBm (100mW)
- Transparent serial link
- Air data rates up to 250kbps
- MAVLink protocol framing and status reporting
- Frequency hopping spread spectrum (FHSS)
- Adaptive time division multiplexing (TDM)
- Support for LBT and AFA
- Configurable duty cycle
- Built in error correcting code (can correct up to 25% data bit errors)
- Demonstrated range of several kilometers with a small Omni antenna
- Can be used with a bi-directional amplifier for even more range
- Open source firmware
- AT commands for radio configuration
- RT commands for remote radio configuration
- Adaptive flow control when used with APM
- Based on HM-TRP radio modules, with Si1000 051 micro-controller and Si4432 radio module

It is clear this system has many benefits worth using while having the most important asset of being 100% compatible with our autopilot system (ArduPilot). A list of different transmitter Gains compared to power allocated can be seen in table 1.

Table 2: Telemetry Transmitter Gains vs. Power

Power (dBm)	Power (mW)
1	1.3
2	1.6
5	3.2
8	6.3
11	12.5
14	25
17	50
20	100

7.0 COST ANALYSIS

7.1 PROTOTYPE COST

Table 3 shows a rough estimate of the components used to build and setup a working prototype. Expectations for the prototype were mainly to achieve flight autonomously while using a guided system to follow pre-determined waypoint navigation using GPS. Additionally a telemetry system was implemented to allow in-flight input to the UAS, which is part of the competitions pre-flight checks. The prototype in this case is far more expensive than the actual final design since majority of the cost is in startup components. Almost 90% of the components carry over to the final design with the major difference being the cost of the structure. What is failed to be described is the unexpected cost due to part failure, and damage from crashes. The actual cost exceeds what is list below since the project went through a series of troubleshooting events.

Apart from component costs, material & manufacturing cost can be added but tend to be negligible in comparison. The prototype was designed to be inexpensively replaced if any components were to break or fail during tests. The entire frame on its own cost a total of $40.00 using aluminum square bars purchased at a local hardware shop and a 1/8 in thick Plexiglas sheet purchased at a local arts & craft shop. With the help and use of university resources such as the laser cutting center at the College of Architecture, the prototype was manufactures and built in a small time frame with easy to swap out replacements prepared for any mishaps.

Table 3: Major Components List – Prototype

Description	Price
Turnigy Multistar 480Kv Multi-Rotor Outrunners	$163.96
Turnigy nano-tech 8000mAh 6S Lipo Batteries	$204.48
12x4.5 Slow Flyer Propellers	$25.28
Turnigy Multistar 45 Amp Brushless ESC	$73.68
5.5mm ESC Power Breakout System	$3.85
Ardupilot APM 2.5	$240.95
Imaging Device - (Camera, Lens , Transmitter)	$500.00
Image Recognition Software	$150.00
Off-Platform Computing Devices	$150.00
Telemetry System	$199.99
Aluminum Rods	$19.99
Nuts, Screws, Bolts, Washers	$10.99
Tie Wraps	$5.99
Landing Gear	$9.99
Receiver	$9.99
Radio Transmitter	$59.99
Total	$1,834.13

7.2 FINAL MODEL COST

The final design cost has a complete focus on structure cost. All components used in the prototype design were optimized for better performance. Aluminum rods were swapped out with carbon fiber tubes which offer a lighter and stronger frame. Motor mounts and the sandwich plates also saw an upgrade as well by moving to carbon fiber sheets. Due to the use of better materials specifically carbon fiber, typical manufacturing techniques could not be used. Carbon fiber cannot simply be machined with a mill as it would destroy the fibers and in turn result in a weaker part. Manufacturing had to be outsourced to Mr. Richard Zicarelli; the Florida International University machinist.

Table 4: Final Design Cost

Description	Price
Carbon Fiber Rods (8)	$150.00
Carbon Fiber Sheet (2 ft x 2 ft)	$110.00
Lexan Plastic	$24.99
Manufacturing Cost	$125.00
Motor Mounts	$0.00
Total	$384.99

8.0 PROTOTYPE SYSTEM DESCRIPTION

8.1 MECHANICS, AVIATRONICS & COMPONENTS

Following the prototype design, a fully functional, autonomously capable prototype of the unmanned aerial system was developed and manufactured for testing and data collection. Figure 27 shows the prototype fully equipped and flight ready.

Figure 27: Prototype

A closer look at all the onboard components that work together with the flight computer and autopilot (Ardupilot) can be seen in figure 28

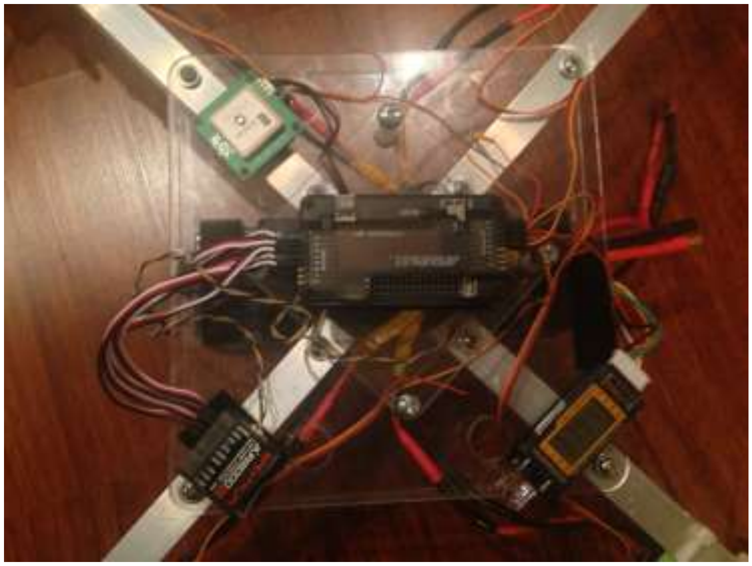

Figure 28: Prototype – Center Console Overview

Onboard the prototype has a total of 4 Major working components. The processor, GPS module, receiver and battery monitor/alarm.

Figure 29: ArduPilot

The autopilot works on 8V Switching BEC regulator provided by one of the ESC as seen on the output side of figure 29. The input side is connected to all the channels of the receiver in order of

Throttle, Aileron, Rudder, Elevator, and Auxiliary. For test flights and autonomous flights only these 5 channels are needed.

Figure 30: ArduPilot Receiver

The input side is connected to the 2.4 GHz 8 channel receiver made by spectrum which is coupled with a similar DX8 transmitter shown in figure 31

Figure 31: Radio Transmitter

On the output side are 4 Turnigy Multistar 45 Amp Opto ESC's connected to the frame via zip ties for ease of removal or replacement if needed.

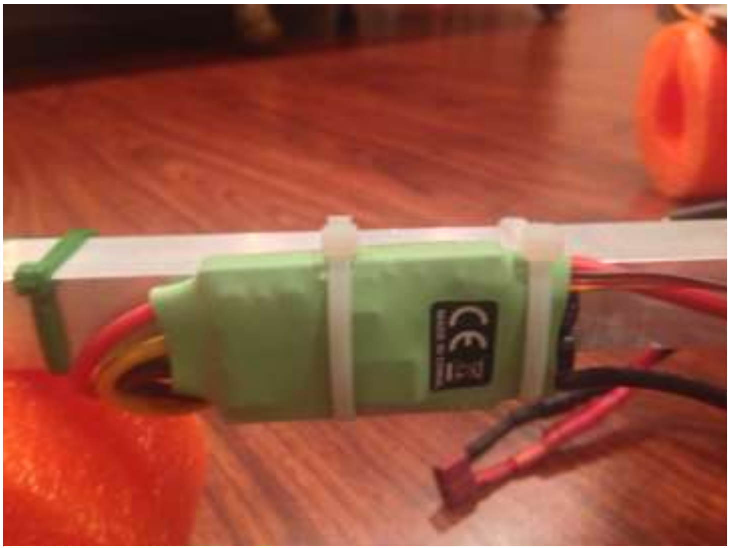

Figure 32: Electronic Speed Controller

On the final end of the ESC's can be found the propulsion units (Turnigy Multistar 480Kv Multi-Rotor Outrunners) made specifically for multi-rotor use and capable of a payload much greater than our designed carrying capacity.

Figure 33: Turnigy Multistar Motor

Attached to these motors are different sets of propellers which offer different static thrust and different amp draws from the batteries. Further Propulsion tests are needed to select the most efficient and effective propeller, however for the purpose of our prototype, 12x4.5 Slow Flyer & 14x4.7 Carbon Fiber Propellers were used for testing and can be seen in figures 34 & 35 respectively.

Figure 34: Propellers – Plastic

Figure 35: Propellers – Carbon Fiber

A design change which occurred during prototype testing occurred with respect to landing gear. Initially 4 aluminum sheets were bent and installed to the bottom of the frame using the same hardware connecting the Plexiglas plates together. This however was a very sturdy and stiff system which caused hard landing and unexpected behavior when testing. Therefore a new landing gear system using foam cylinders were installed which produced much softer and predictable results when landing the aircraft. A side by side comparison of the initial and retrofit landing gear systems can be seen in figure 36 with a more detail view in figure 37.

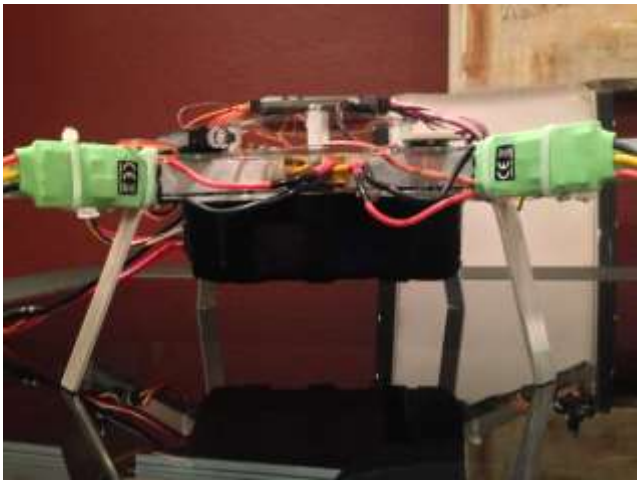

Figure 36: Prototype – Side View

Figure 37: Prototype – with Landing Gear

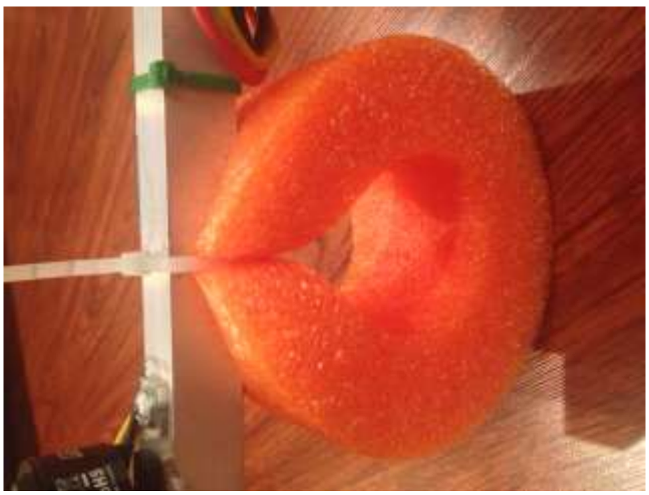

Figure 38: Landing Gear

Components and accessories including in the prototype system include GPS receivers, Battery Alarm, Power Harness, Battery carriage and Battery charging system all of which can be seen in the respective figures below.

Figure 39: GPS

Figure 40: Cell-meter

Figure 41: Battery Charger

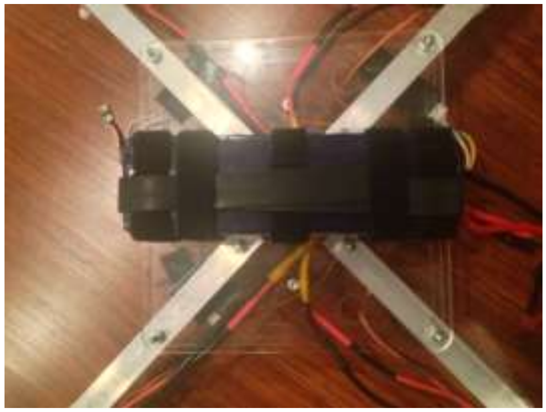

Figure 42: Battery

8.2 IMAGE RECOGNITION

At the heart of the image recognition software is JAVA based open source programming language which helps facilitate creating code incorporating advanced programming concepts into an easy to understand visual context. With an emphasis in visual design, computer vision algorithms are easier to implement.

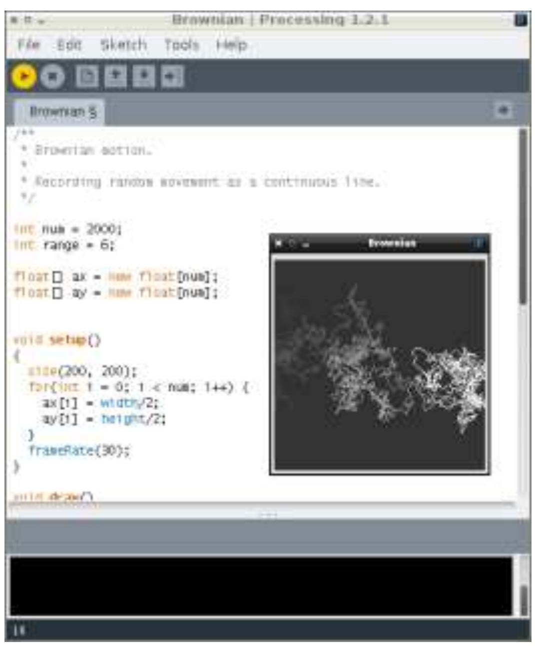

Figure 43: Code

Simplifying the process in which code is written, Processing includes a minimalistic IDE. Setup and execution is more intuitive with Processing IDE, which eliminates complicated setup when compared to Visual Studio, MATLAB, and even the popular ECLIPSE development environments.

The program works by importing a video feed from the USB video capture module and running algorithms to detect a predefined set of parameters within the feed. Such parameters include shape, letter and number, and color detection. To increase accuracy, certain colors will be filtered out.

The program will first determine if there are any shapes. This is done by edge detection. Edge detection is the process of detecting objects within an image by analyzing the differences RGB values between neighboring pixels. If a large enough difference is detected, an edge is found. Comparing the resulting edges to a predefined list of shapes will output a shape designation for the object. Once the shape is detected, the letter or number will be detected in a similar fashion. Color information will be extracted from the video and will be included in the detection log along with shape, letter, and number information.

Orientation, location, and distance detection from the aircraft will require additional sensor input from the autopilot. Information such as GPS coordinates is used to locate the quad copter. Knowing the altitude of flight and the degree of inclination of the camera, the distance from the aircraft can be calculated. Once distance and direction is found, it is converted to latitude and longitude coordinates and included into the detection log.

9.0 TESTING

9.1 PLAN FOR TESTS ON PROTOTYPE

Plans for prototype testing include testing individual components of the drone as they are completed and then tested again once the platform has been assembled. The image recognition system is scheduled to be completed by end of October. Objectives for completion include target acquisition, color and shape identification as orientation of the target from various angles. The method of testing will be to show shapes of different colors to the system and a tabulated result will be output with the image data. A Wi-Fi transmitter will be then incorporated to transmit the signal back to a base computer. Finally monitoring the output for proper operation will test the autopilot and GPS equipment. The helicopter drone will not be operational however the system must still be tested to verify that the board is sending and receiving proper signals and that it is actuating the servos correctly.

The mechanical portion is scheduled for completion for the beginning of August. The helicopter will be tested at first with radio control to verify the mechanical components. It will be deemed successful if the helicopter is able to operate under normal conditions.

Integration of the computer and navigation equipment will follow and is scheduled to be completed by the end of August. This includes the installation of the computer, navigation and camera equipment. Image recognition and target acquisition will be initially tested by manually flying the helicopter. The helicopter will fly over targets as described in the competition rulebook. The success of the system will be achieved when it is able to correctly identify the targets while operating at competition conditions. The next step in testing will be done on how the computer and auto navigation is able to autonomously control the helicopter. Successful integration of the autopilot will be achieved when the system is able to navigate a set of GPS waypoints and return back to base. At this time transmitting diagnostic information to the base computer in order to monitor reliability will test the Wi-Fi equipment.

Once the individual systems have been successfully integrated the drone will have to perform the same exercises as described in the rulebook. The testing of the drone will be a success if at a minimum the drone is able to follow a pre-determined flight course, identify the targets and return back to base autonomously.

9.2 STABILITY

Once the aerial platform has been built and is ready for manual flight hours, it is imperative to perform stability tests. A stable platform will allow for optimum flight efficiency and will reduce the likelihood of sudden in-flight errors. Assuming manufacturing and assembly of the platform went smoothly (symmetric platform), manual tuning is required using the APM 2.5. Pitch and roll values in the MAVlink Mission planner software must be adjusted. During the first flight, the platform was coming off the ground but was wobbling uncontrollably. Each time parameters are adjusted, the platform must be connected to the ground station. This is tedious and requires a great amount of time while avoiding complications. In order to avoid crashes, a jig was manufactured to maintain the platform fixed in the x and y planes while allowing a bit of freedom in the z direction. With this apparatus, it is possible to stabilize the platform while avoiding any in flight errors. The jig offered a great way to test stability but it did not allow pure in flight characteristics. A telemetry kit was established to communicate with the platform wirelessly to adjust parameters on the go. This proved to be an essential way to change flight parameters. To fully test the platform's stability, a different system was used. Four ropes at a length of three feet were tied to each landing gear and restrained with a cinderblock on the ground. This testing system allowed the platform to elevate a few feet while travelling in the roll and pitch directions. The telemetry kit made changing roll and pitch values extremely efficient.

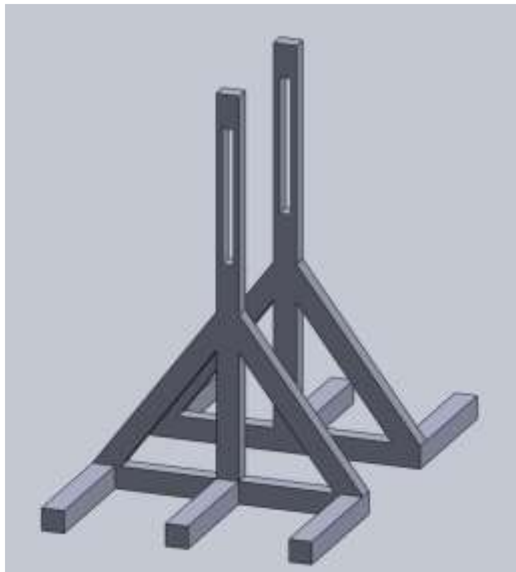

Figure 44: Jig Apparatus

There are many gains that can be tuned in APM 2.5 to get optimal performance, but the most critical is the Rate Roll and Pitch P values. This tuning alone will likely get it flying reasonably well at least in Stabilize mode which is important for testing. The initial PID settings used to fly the prototype can be seen below.

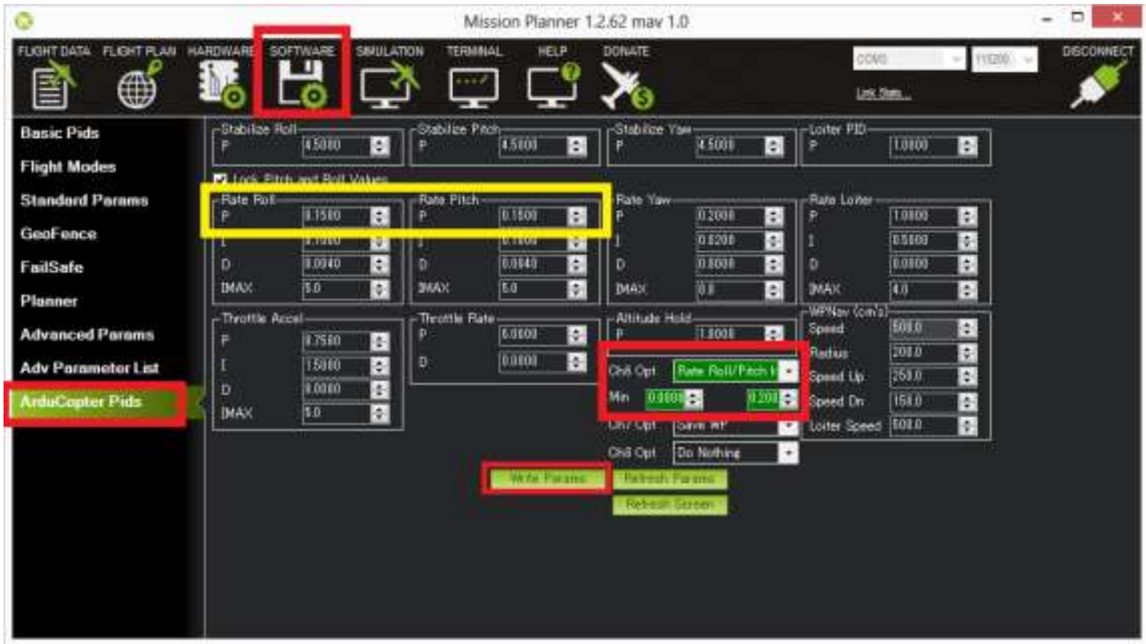

Figure 45: Initial PID Parameters

These values seem to be fairly stable whole taking off manually with nothing but applying throttle to the aircraft. The throttle in (from transmitter) and throttle out (actual throttle to motors) can be seen in the flight logs graphs stored in the APM below.

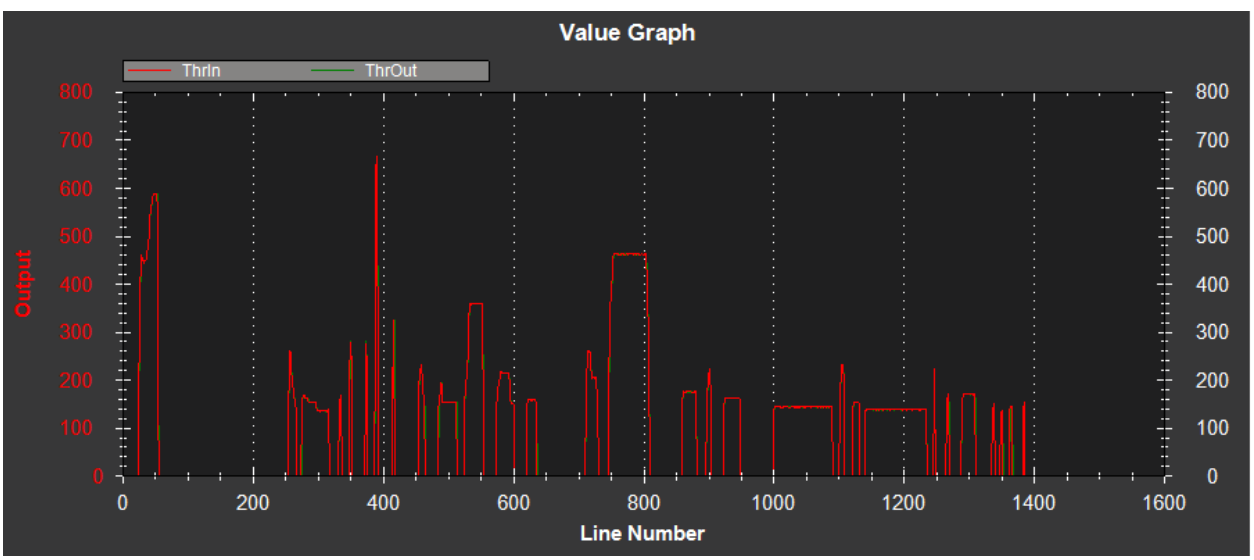

Figure 46: Throttle Curves

The throttle values seemed to be within quite similar magnitudes to one another with throttle out (green) slightly delayed a few milliseconds which is normal can accounting for processing time. . However, there was quite a heavy amount of drift of the copter without using any roll and pitch inputs and in very slight windy conditions.

One thing noticed while testing is that the copter hovered above the ground while the input throttle value was about 25% of the maximum which can be a problem as you have little down switch room to land smoothly. This is a phenomena caused by having an over-powered aircraft which was expected due to having only one battery and excluding many components that while be extra payload for the actual model. To fix this issue a Throttle-Mid value can be set for the hover throttle value can be set to the middle transmitter position. All in all, the prototype performed very stable while hovering and doing complex maneuvers which led us to continue with the final model and incorporate all of our knowledge and experiences to produce an even more stable aircraft than the tested prototype.

9.3 FLIGHT MODES

- Stabilize Mode

Stabilize mode is the primary operating mode for flying APM and can be considered its manual flight mode. Stabilize automatically levels the multi-copter and maintains the current heading, while allowing the pilot full control over the throttle. Stabilize is good for general flying and FPV. The autopilot must always initially be set to stabilize mode in order to be able to arm the ESCs before takeoff. It is very important to be able to easily and rapidly switch back to stabilize mode from any other mode in order to regain control from any unexpected or undesirable flight behavior. This mode was used to manually test for stability and flight performance of the aircraft with the prototype model, this mode was tested and confirmed to be reliable under any condition.

- Altitude Hold (ALT HOLD) Mode

When altitude hold mode is selected, the throttle is automatically controlled to maintain the current altitude. Except for automatic altitude maintenance, alt hold mode operates the same as in stabilize mode. The accelerometer-based “inertial compensation” is also used to maintain altitude. This results in faster compensation and more accurate altitude maintenance, but it also requires vibration damping for your flight controller mounting. The flight controller uses a barometer which measures air pressure as the primary means for determining altitude (“Pressure Altitude”) and if the air pressure is changing in your flight area, the copter will follow the air pressure change rather than actual altitude. This mode was rarely used as it not a critical part of the objectives we had set for competition.

- Loiter Mode

When switched on, loiter mode automatically attempts to maintain the current location, heading and altitude. Wind and sensors will affect the effectiveness of maintaining position; the stronger the wind the greater the location deviation.

In loiter; the copter’s location can be manually adjusted with the control sticks.

- Horizontal location can be adjusted with the Roll and Pitch control stick.
- The Heading can be reset with the Yaw control stick.

- Altitude can also be adjusted with the Throttle control stick.

Since Loiter mode attempts to maintain position, it relies on the GPS which must be on and indicating that it is locked before takeoff.

Loiter is not an important mode for competition but it is a useful tool when experiencing conditions such as strong winds and can be used a “soft-failsafe” to counteract any sudden situations for stability.

- Return to Launch (RTL) Mode

When RTL mode is selected, the copter will return to the home location. By default the copter will first rise to at least 15m before returning home, or it will maintain the current altitude if it is higher.

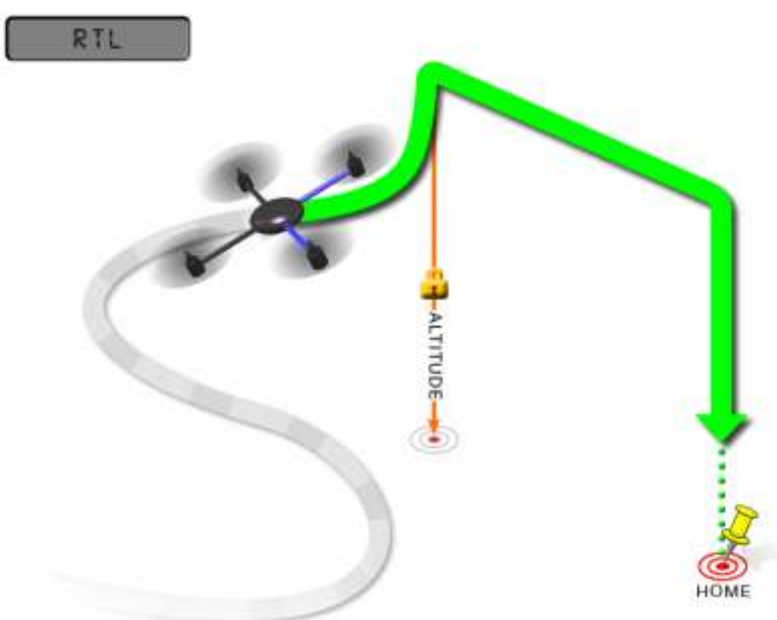

Figure 47: Return to Launch Path

RTL is a GPS-dependent move, so it is essential that GPS lock is acquired before attempting to use this mode. RTL will command the copter to return to the home position, meaning that it will return to the location where it was armed. Therefore, the home position is always supposed to be your copter's actual GPS takeoff location, unobstructed and away from people. If the GPS is locked and the aircraft is armed, the home position is the location the copter was in when it was armed. This means if you execute an RTL mode, it will return to the location where it was armed. This mode was tested while tethered and performed with great precision landing autonomously within 2 feet of the takeoff position. Return to launch will always be enabled as our primary failsafe in case of any problems or issues encountered in-flight.

- Auto Mode

Auto mode allows the copter to follow internal mission scripting to control its actions. Mission scripts can be a set of waypoints or very complex actions such as, takeoff, spin X times, take a picture, etc.

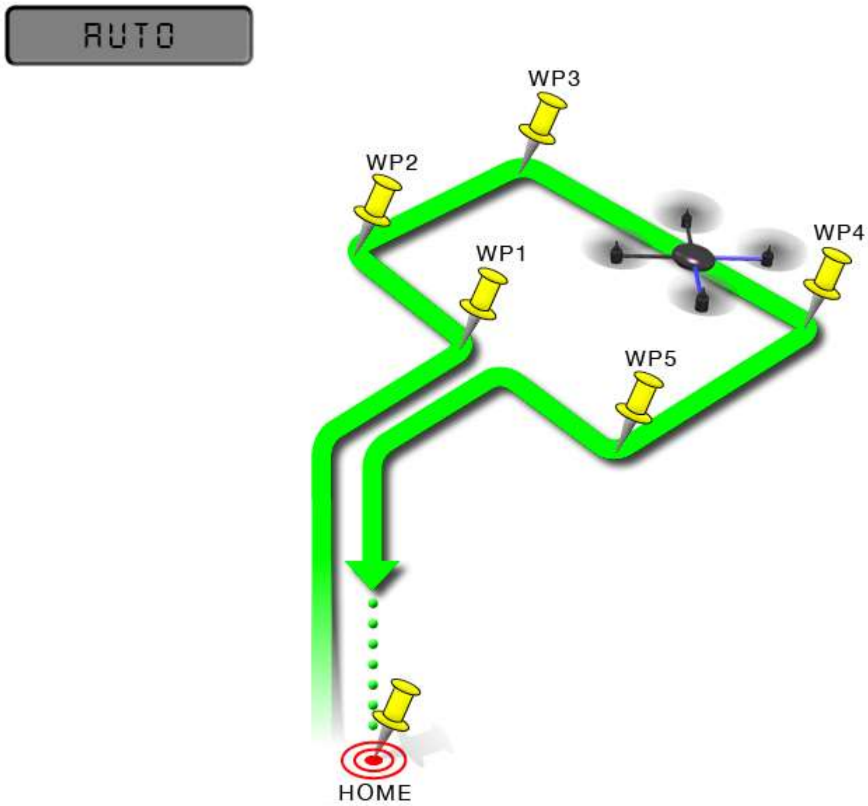

Figure 48: Auto Waypoint Navigation

Since mission scripts depend on the GPS for location information, auto mode is GPS dependent and it is necessary to allow the GPS to achieve lock before arming and taking off. Always ensure that the LEDs on the autopilot and GPS module indicate that GPS lock has been acquired. There are two ways to enter auto mode: in the air or on the ground.

If using auto mode to takeoff from the ground, a special safety prevents the execution of the mission script until the aircraft is both armed and the throttle is raised for the first time. This is to prevent the copter from taking off on its own by accidentally flipping the mode switch. When using auto mode to takeoff from the ground, the most recent ALT HOLD throttle value is used as a baseline for throttle control. Once the copter has taken off it will proceed to the first target altitude and to begin following the mission script. Switching to auto mode when the aircraft is already in the air will cause it to go to your first target altitude and to begin following the current mission script.

Auto-mode is the most important flight mode pertaining to our project and competition objectives. The competition objectives require autonomous waypoint navigations and search. For waypoint navigations a set of coordinated can easily be input into the Mission Planner to plan a mission and follow the profile. The area search is a bit more complicated, it requires an external sub-routine within the auto mode called “Auto Grid”.

Auto grid basically lets Mission Planner create a mission for you, which is useful for function like mapping missions, where the aircraft should just go back and forth in a “lawnmower” pattern over an area to collect photographs. A basic polygon is created to setup boundaries for the search. A user-defined number of vertical and horizontal sections can be created to adjust the density of the search area. This will be a perfect feature to use for the search area given in the competition section. However this mode is the most complex as it rests on the hand of the computer to make decisions and fly on its own. While testing this mode the team experienced many problems, some which have still not been identified and are still under revision and require further work and tuning.

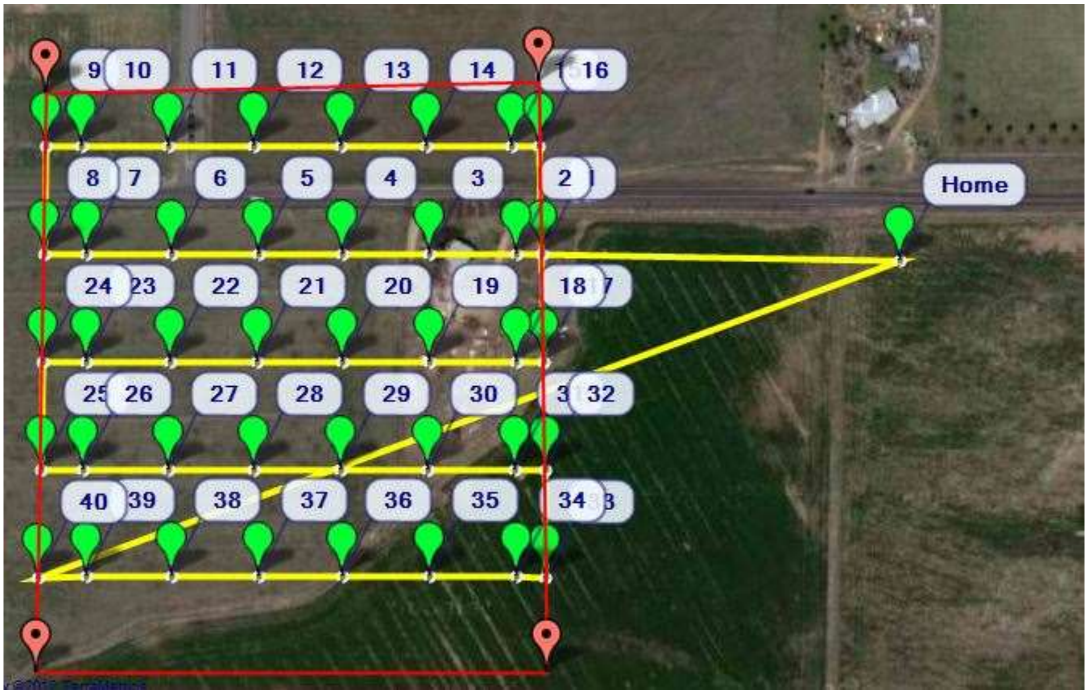

Figure 49: Auto-Grid Waypoint Search Path

9.4 FAILSAFES

➢ Throttle Failsafe

The throttle failsafe will trigger if:

- The aircraft goes out of radio range.
- Transmitter is turned off.
- The onboard receiver loses power.

The trigger physically makes the channel 3 signal wire from the receiver to the APM's input become disconnected. The PPM encoder is a small chip on the APM boards whose sole function is to read the radio signals from the receiver and send them to the APM's main CPU.

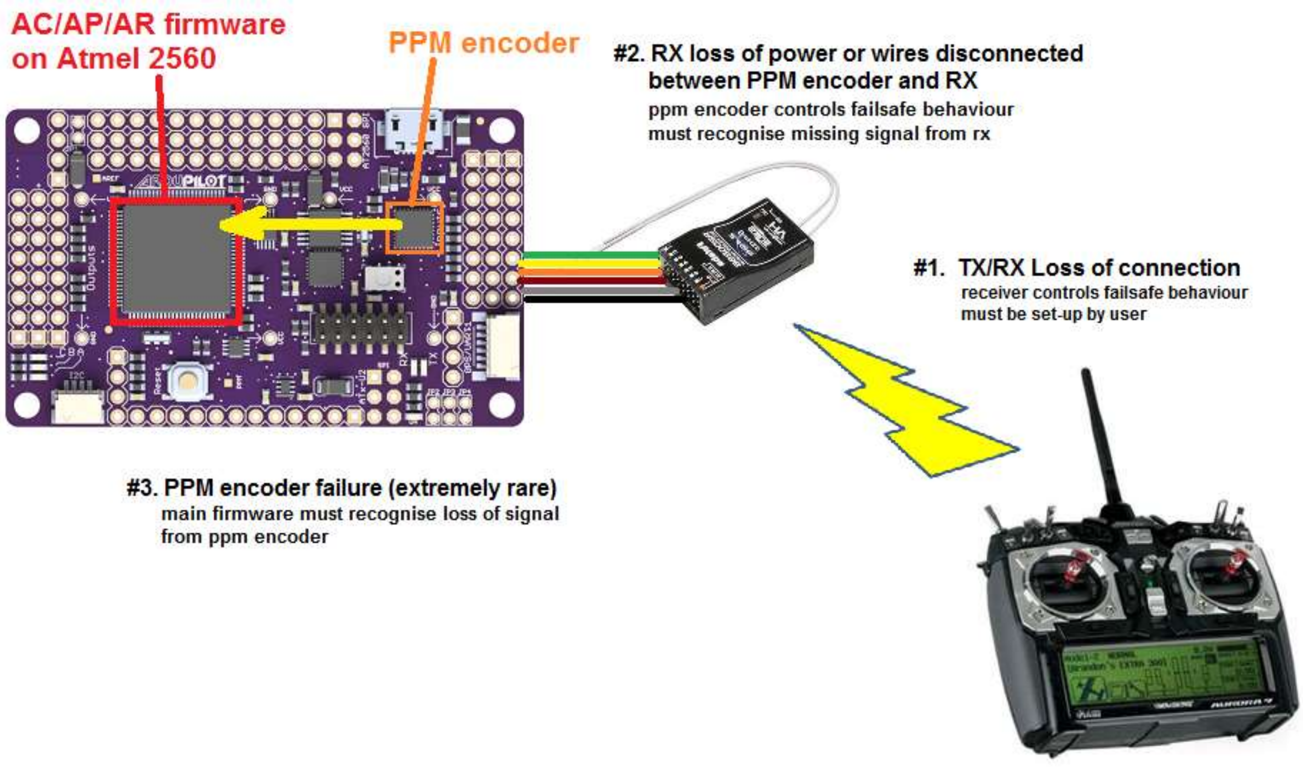

Figure 50: Schematic of Connection Failsafe

When a throttle failsafe is triggered one of the following will happen:

- Disarm motors – if aircraft is in stabilize and input throttle is zero.
- RTL (Return to Launch) – if GPS has lock and are at least 2 meters from your home position
- LAND – if there is no GPS lock or are within 2 meters of home when the failsafe triggers
- Continue with the mission – if aircraft is in AUTO mode
- If the failsafe clears, the copter will remain in its current flight mode. It will not automatically return to the flight mode that was active before the failsafe was triggered. This means that if, for example, it is flying in stabilize mode when the failsafe is

triggered, and this causes the flight mode to change to RTL or LAND, then change the flight mode switch to another position and then back again to Stabilize to re-gain control of the aircraft.

To test our connection failsafe we recorded the minimum throttle value the transmitter broadcasts and the throttle value it broadcasts when the connection is cut (Radio is off or too far away). For our system these two values are 1102 and 965 respectively. With this information we can set our throttle failsafe with some number between these two values to ensure if the connection is lost, the failsafe will trigger. We decided to us a value closer to the loss connection value to account for deviations in the lowest throttle value while the radio is on.

Figure 51: Connection Loss setup

- Low Voltage

Currently our system does not have a direct low voltage failsafe integrated to the controller. Instead, a light-weight low voltage meter is connected to the balance plug of the LiPo battery to read the voltage from all cells in the batteries and is user-programmed to set off an audible alarm of up to 2000ft when the voltage on any of the cells becomes too low or the difference between the cells is too high which can also cause issues pertaining to power distribution. This system, while primitive, is very effective and was tested to work with high precision and good reliability.

- Geo Fence

The APM 2.5 includes a simple cylinder shaped fence centered on home that will attempt to stop the aircraft from flying too far away by initiating a RTL command. The maximum circular distance and altitude and the vehicle behavior when the fence is breached are all user-defined parameters.

Figure 52: Fence Radius and Height Schematic

If the vehicle strays outside these borders it will switch into RTL or LAND (depending on user settings). At the moment the fence is breached a backup fence is erected 20m further out (or up). If the copter breaches this backup fence (for example if the vehicle is not set up correctly or the operator takes control but is unable to bring the copter back towards home) the copter will be switched into RTL again (and another backup fence an additional 20m further out will be created). If the copter eventually flies 100m outside the configured fence distance, the vehicle will switch into LAND mode. The idea being that it's clearly impossible to get the copter home so best to just bring it down. The pilot can still retake control of course with the flight mode switches. Like with the earlier fences, another fence is erected 20m out which will again switch the copter to LAND if it continues away from home. All of the mentioned fail-safes where tested in a controlled environment and have all returned positive results in the lab and on the field.

9.4 SRIC COMMUNICATION

An integral part of the competition is to be able to wireless communicate with a competition Simulated Remote Information Center (SRIC) through the aircraft. The goal is to connect to a Windows 7 computer setup with a router and directional antenna to retrieve a text file and read the contents to the judges. To be absolutely certain this can achieve this in competition, an exact replica of the SRIC station was purchased and tested with our own equipment.

Firstly a testing SRIC station was setup to mirror that of the competition, which is provided in the rules as follows with an picture of the setup in the figure below.

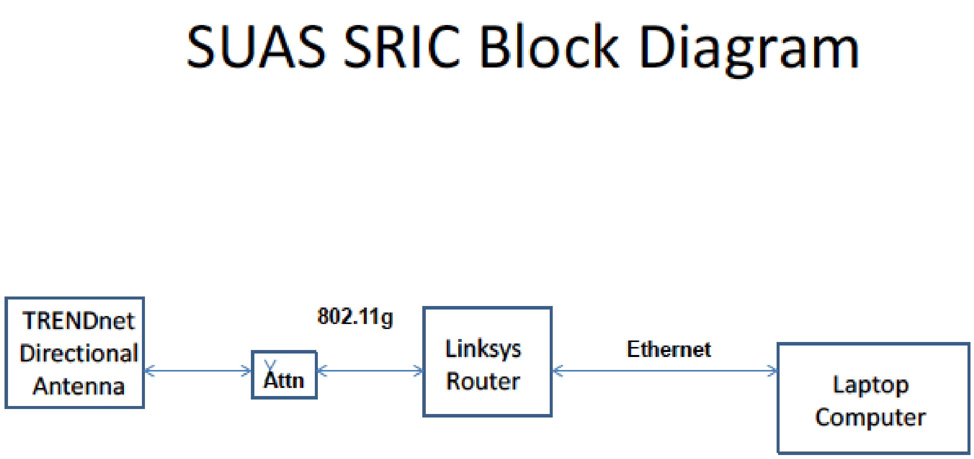

Figure 53: SUAS SRIC Block Diagram

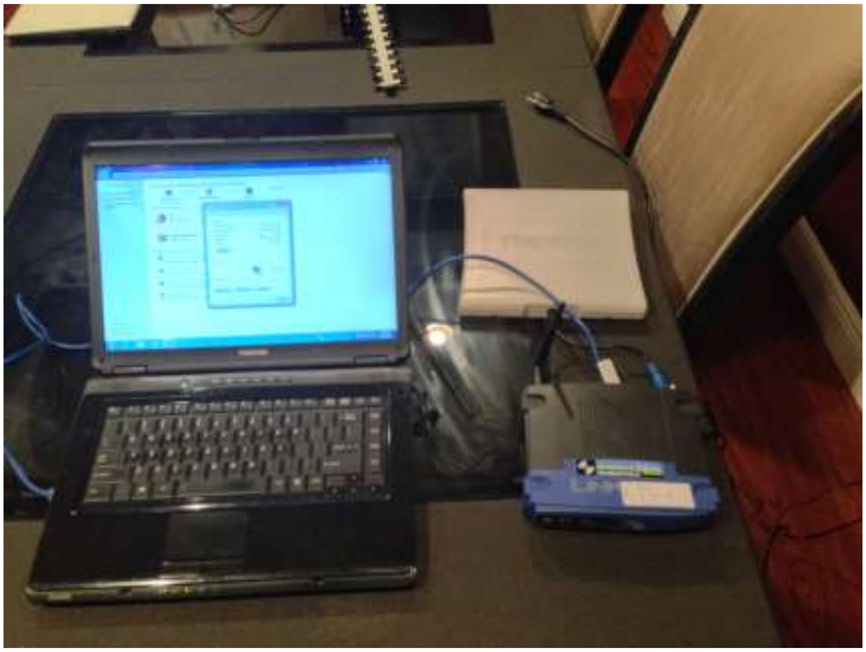

Figure 54: Simulated SRIC

On our side we setup a Ground Control Station (GCS) with the components we will use during competition. This setup comprises of a Windows 8 computer linked to a WRT54GL router and a 24 dBi Omni-directional Antenna. –

Figure 55: Simulated SRIC

This communication was tested many time and proved to work with great accuracy and a file was always able to be read from the SRIC to the GCS if system password is known, which will be given during competition.

The next step was to separate the two-access point to a distance where they could not communicate and then add a universal repeater that will be onboard the aircraft to extend the signal from the SRIC to the Ground Station and be able to connect to the access pint through the aircraft. This was done on the field using generators as power supply and a range of 3000 ft was found to be enough distance to loose connection. A schematic of the scenario can be seen below with all the components and systems listed respectively.

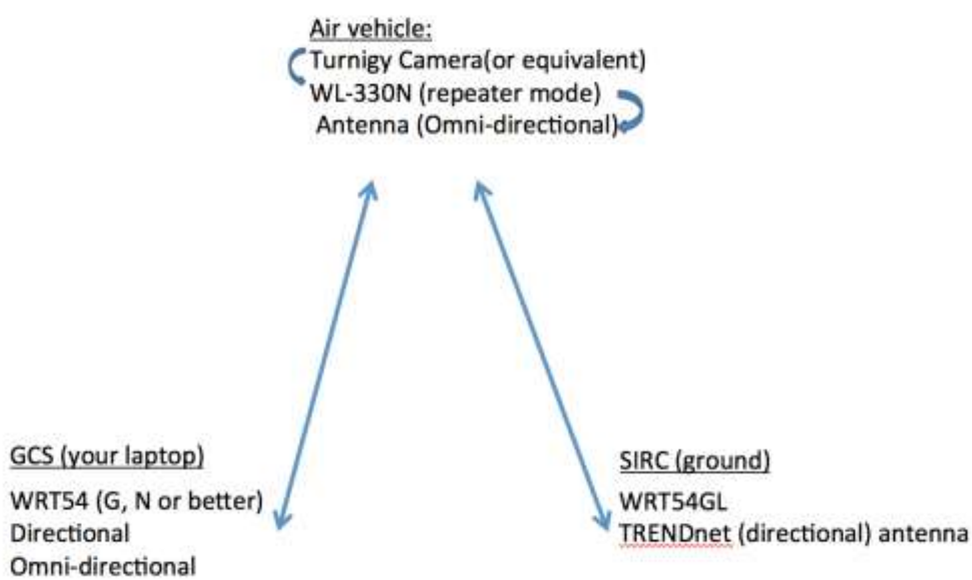

Figure 56: SRIC Communication

The repeater was proven to work and connection was again reestablished. The last step was to now move as far away as possible while using the repeater on the aircraft and determine the largest distance away from the SRIC that a connection still holds. The test confirmed that a distance of over 7500 ft can be held with a reliable connection from the SRIC to the GCS with the repeater near the SRIC stations which would be the case during competition. This was excellent in terms of distance considering that the allowable flying area is at most around 1 mile (5280) diameter which gives use more than enough range to be able to connect with a reliable wireless connection and retrieve the message and earn extra objective points for this part of the mission

9.5 IMAGE RECOGNITION

Upon further development of the system it was evident that the autonomous image recognition aspect of the design would have to be put on hold in order to develop the rest of the imaging and data systems. Difficulties with hardware interfaces made it difficult to interface the video feed from the video input device into the code. A man in the loop system was selected as the backup course of action. In this configurations an operator will be monitoring the video stream and manually identify the characteristics of the targets during flight. Software issues also plagued the program such as issues of undecipherable errors during compiling and the inability of getting reliable and consistent readings in environments outside the laboratory. Difficulties with the algorithm as written could not distinguish between objects in the foreground and background. The program lacked the robustness to deal with the objectives of the competition. It was the determination of the group that as it stood the efforts into achieving the goal of autonomous image recognition was better off being spent on other aspects of the project.

10.0 IN-FLIGHT ISSUES

10.1 MECHANICAL FAILURES

There are various forms of mechanical failures that can be encountered flying a multi-rotor platform. Among them is ESC failure, motor dysfunction, propeller improperly installed or slides off, and structure failure. The motors and ESC's are critical components as failure of either one can influence a crash. If a motor fails, it does not directly mean that the ESC failed to power it. On the contrary if an ESC fails, the motor will be immediately affected and will stop its function.

Before each flight, there is a checklist of things that must be done to ensure proper flight mechanics and safety. It is imperative to check all screws, nuts, washers and propellers for tightness. Failing to do this can result in moving parts on the platform or parts coming off the plane. Velcro straps must be checked each time as they carry the power provided to the system.

The last in flight mechanical issue is a structure issue. Materials selected must be able to withstand the payload carried by the platform along with the torques that is induced by the motors. Both aluminum and carbon fibers are formidable options for the booms. The plates in the center of the platform must also be rigid as the platform tends to cave in once all the components have been installed to the platform.

Throughout the case study and in flight testing, the platform described in this report has avoided all mechanical failures. It is important to note the AUVSI competition requires the platform to operate free of mechanical vibrations to ensure the safety of others during the competition. All mechanical failures can be verified using the mission planner logs that are recorded for each armed flight.

10.2 VIBRATIONS

Vibrations can have a dramatic effect on flight performance and efficiency. It can damage components and also free any fixtures, screws and nuts. High vibrations can also have an effect on the APM's accelerometer based altitude and horizontal position. It is important to study vibrations in all three planes: x, y and z. The goal of any vibration issue is to limit the amount of vibrations being caused as it is physically impossible to completely avoid it. A dampening system can be used along with rubber grommets and washers.

10.3 COMPASS INTERFERENCE

There are a lot of components on board that are essential to the system's performance. The majority of these components can also have a negative impact on the system. Interference is a phenomenon that goes unnoticed the majority of the time as it cannot be physically interpreted. All electrical devices can cause some sort of interference. The motors are the leading cause of interference as each motor creates a magnetic field. It is important to space the motors away from the center console depending on the size and power of the motor. Interference can throw off the compass heading which can lead to the platform travelling in the wrong direction.

10.4 GPS GLITCHES

In autopilot modes which features loiter, return to lunch, and auto mode; position errors from the GPS can arrive and cause disastrous outcomes. These errors are known as GPS glitches and can be diagnosed with the flying logs. These glitches can be caused at random and do not have a straight forward source other than decrease in satellite visibility. Glitches can cause the platform to think it is suddenly in the wrong position. With this wrong thinking comes aggressive flying to correct what the computer believes to be a location error. During testing, a GPS glitch was encountered and lead to the symptoms described above. There were two different instances where the platform showed signs of GPS glitches. The first error lead to a rapid climb that exceeded 30 feet. Due to the constraints installed in the initial parameters, the platform returned to lunch at a steady pace until it returned to the ground. Without the fence parameter, the platform could have been lost. Shortly after, the second of what is believed to be a GPS glitch occurred. The platform once again gained altitude quickly and started heading east at the same pace until it suddenly came crashing down. The platform structure was lost but all major components stayed operational. GPS glitches are a common phenomenon that is unavoidable and unpredictable. Users must be aware of satellite visibility in the testing area and must be sure to provide forms of restrains to limit abrupt flying.

10.5 POWER PROBLEMS

Power problems can arise from a couple different areas of the platform. The first and most obvious is loss of power from the power source. In this case, three batteries are used on board to provide power to the entire system. Two batteries are strictly used to power the flight of the platform while the other smaller battery is used to supply power to the repeater and camera. It is possible to fly with only one battery but flight time is greatly affected. Failure of the two bigger batteries can cause an immediate crash of the platform while the smaller battery is not as critical. The smaller battery is critical when it comes to competition purposes and thus it is not completely disregarded. To avoid any battery failure, a voltmeter which is directly connected to the larger batteries is installed on the main structure. If the voltage goes below a certain set-point that is set by the user, an alarm will go off to signal the operator it is time to land. Another form of power problems can be issues in making a complete connection with the components. All bullet connectors must be properly installed and covered with heat shrink to avoid any outside contact that might obscure the current. All wires must be checked before all flights to ensure proper connection and to check for slits/openings through the wires. The last form is power restricted to the motors. The computer will do everything in its power to correct itself in-flight if a motor loses power. It will try to provide power to three motors to compensate for the missing motor. This scenario must be avoided as it is a risk to both personnel and the life of the platform. All operators must take extra precautions and use safe pre-flight inspections to avoid any power problems.

11.0 FINAL DESIGN

11.1 OVERVIEW

The importance of the final design is to make considerable improvements in any or most aspects of the design. The structure of the design is the only aspect of the system to optimize, as the major components do not change from prototype to final design. When considering the parameters to be changed; material selection, design, weight of the system and cost were all considered. The prototype featured a combination of aluminum and acrylic body. The aluminum bars were not cut exactly to size as manual manufacturing techniques were used. The acrylic parts came specified to size as a laser printer was used to make exact cuts. In any design, when two parts do not perfectly match, deficiencies will arise. Therefore, it was decided to carefully design all the parts for the final design and to use automated manufacturing processes. This allowed for precise cuts of parts and also the ability to cut multiple parts the same way.

The first aspect of the design that was considered was the legs of the quad copter. Aluminum is already a reliable material with great material properties that provide light but and durability from crashes. The only material worth considering in the design was carbon fiber. The issue with carbon fiber is the inability to find a manufacturer who will sell the parts at a reasonable price. 'Clearwater composites' is a carbon fiber manufacturer in Minnesota. The quote to obtain eight pieces of carbon fiber tubing at ¾ inch in diameter and 16 inches in length came to be $74.99. The cost of the aluminum bars came out to be 14.99. This yields a considerable difference in terms of cost. The opportunity cost is clearly found in the weight and material strength properties. Below is a table that compares aluminum to carbon fiber in terms of material strength, weight and cost. Both bars measure 16 inches with a ¾ inch equivalent diameter.

Table 5: Aluminum vs. Carbon Fiber

Material	Aluminum	Carbon Fiber
Cross Section	Square	Circular
Strength	69 [GPa]	150 [GPa]
Weight	125.4	55.5
Cost	$14.99	$74.99

Analyzing the above data, changing the material has some major advantages and disadvantages.

Table 6: Aluminum vs. Carbon Fiber Analysis

% Increase/Decrease
217.39% increase in strength
55.74% decrease in weight
500% increase in cost

By moving forward with carbon fiber, the increase in material strength has more than doubled making the legs less vulnerable to sudden failures and/or crashes. This is especially important when getting into critical heights when flying. Although crashes may damage nearby parts, the structure can be recycled and used for multiple flights. The main objective in changing the material was achieved and that is weight reduction. Switching to carbon fiber yields a cut in weight by more than half. This is specifically important for flight time. As the weight of the structure is increased, as does the payload which helps the motors run more effectively. With these great improvements comes a heavy burden in the cost department. In order to achieve these values, the cost to switch from aluminum to carbon fiber is five times for expensive. As an engineer, one must decide whether to improve quality with the burden of cost or to cut costs by making a less appealing product.

Once the legs were chosen to be circular, motor mounts had to be designed and manufactured. Due to the carbon fiber tubing, clamps had to be assembled instead of mounting the motors directly with screws. After carefully considering all possible designs, ‘vibration isolation motor mounts’ were chosen to give the best outcome in terms of vibration dampening and effectiveness.

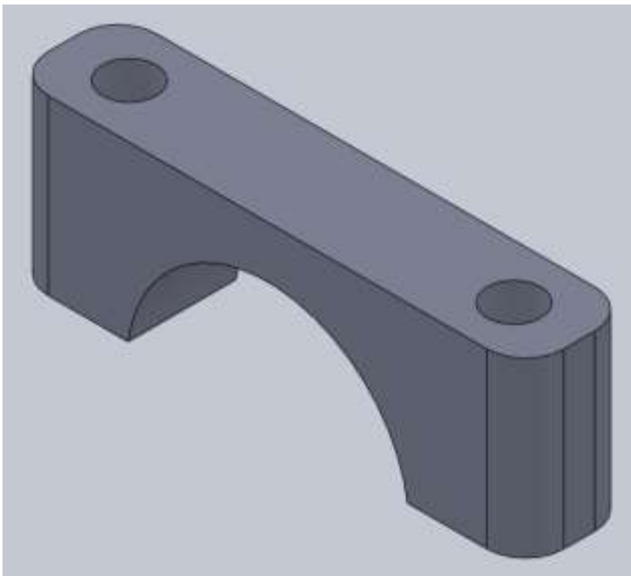

Figure 57: Isolation Motor Mounts

The motor mounts were manufactured using a three dimensional printer. The printer takes strands of hot plastic that is eventually cooled to form the part of interest. Four of these were used to attach the motors to the legs while another four were used to attach to the center of the structure. To dampen the effects of vibration, rubber O-rings are placed around the circular tube and clamped down. The prototype did not have a means to dampen the effects of vibrations. While the plastic parts as an assembly weigh in at 13.3 grams and the acrylic comes in at 4.9

grams, the trade-off is in the ability to avoid vibrations. All isolation mounts were manufactured at the Florida International University computer science laboratory free of charge.

The final structural change is the center pieces. Designed and manufactured from carbon fiber courtesy of Professor Richard Zicarelli. The design and layout of the center pieces do not see many changes except an increase in size for the final design. The increase in size allows for more room to work with but also a comfortable area for component integration. The prototype plates weighed a combined 269.4 grams while the new carbon fiber final design plates weigh in at 253.2 grams. A 6% decrease in weight, which for many may not mean too much but if it yields an extra minute in flight time it is a successful change.

The final system change is the selection of propellers. Three different propellers were actively used to find the best possible outcome in terms of stability and flight time.

Table 7: Propeller weight comparison

Propeller	Weight
Red Plastic	12.8 [g]
Gray Plastic	48.3 [g]
Carbon Fiber	19.6 [g]

The table above shows three different weights for three different materials. It was found that the gray plastic was the heaviest prop and did not provide control or stability to the system. Red plastic offered the lightest prop from the three and a cost effective part if damages occurred. The carbon fiber, which was chosen for the final design was slightly heavier than the red plastic but offered better stability and improved flight time. It is important to note reduction in weight does not always prove to be the best possible option.

The resulting platform that will be used to compete in the upcoming year of 2014 is completely designed from top to bottom. It uses only carbon fiber and plastic with a couple screws and bolts to complete the structure.

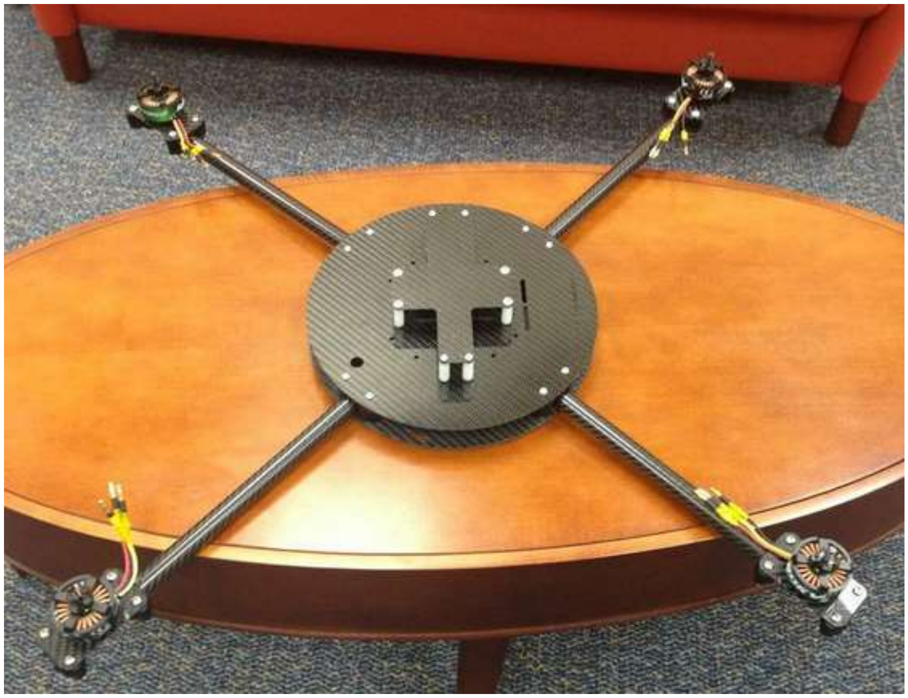

Figure 58: Final Structural Design

The purpose of creating a prototype and a final design was to achieve better results from one structure to the next. The primary goal was to reduce the weight of the structure. The prototype came in at 790.6 grams while the final design cut down to 470.8 grams. A 40% decrease in weight yields a safer, more reliable and efficient system. The total cost of the final design is $168.75.

11.2 MECHANICAL & FLIGHT IMPROVEMENTS

Focusing on the mechanical improvements of the final design compared to the prototype would draw attention to vibrations. A common issue experienced with the prototype was the excess vibrations especially in the direction of flight (z-direction). These vibrations not only affect mechanical properties of all the framework and components but more importantly affect flight. The computer wants to keep the copter in perfectly level flight, small oscillations will cause excess corrections to fight these vibrational tendencies which waste computing power and motor power. Reducing these vibrations was one of our biggest goals in improvements and by adding a new way to connect all the components and separating any hard parts with rubber O-rings to dampen vibrations. This indeed helped with vibrations in all degrees of freedom but most prominently in the z-direction, which was our biggest concern. Figures 55 & 56 show a comparison between vibrations of the prototype and final model respectively. Using the on-board accelerometer, reading were made of all 3 translations degrees of motions and there vibration oscillations while hovering

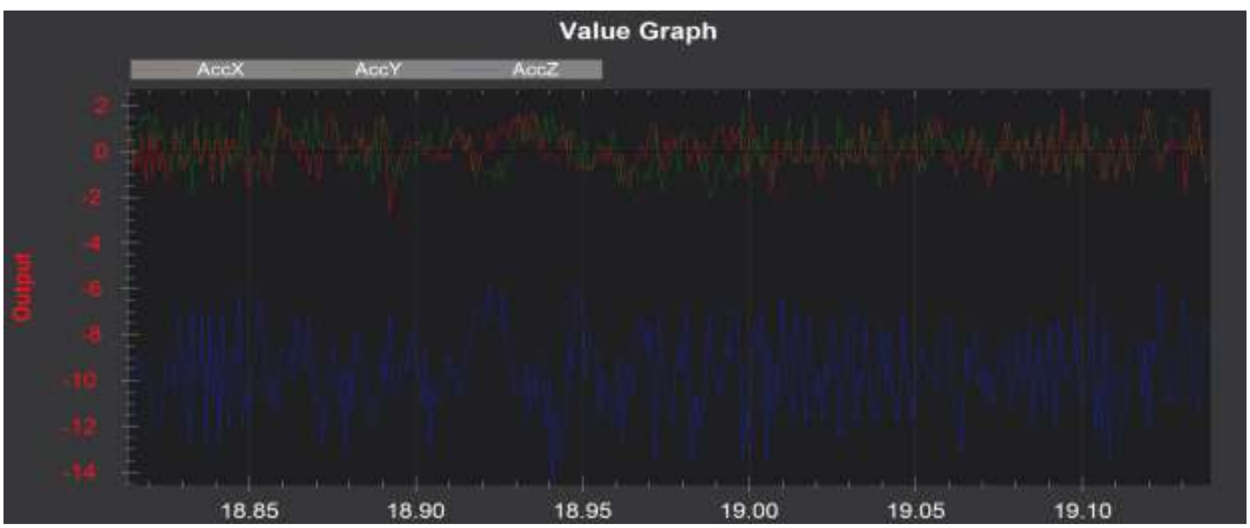

Figure 59: Prototype Accelerometer Vibrational readings

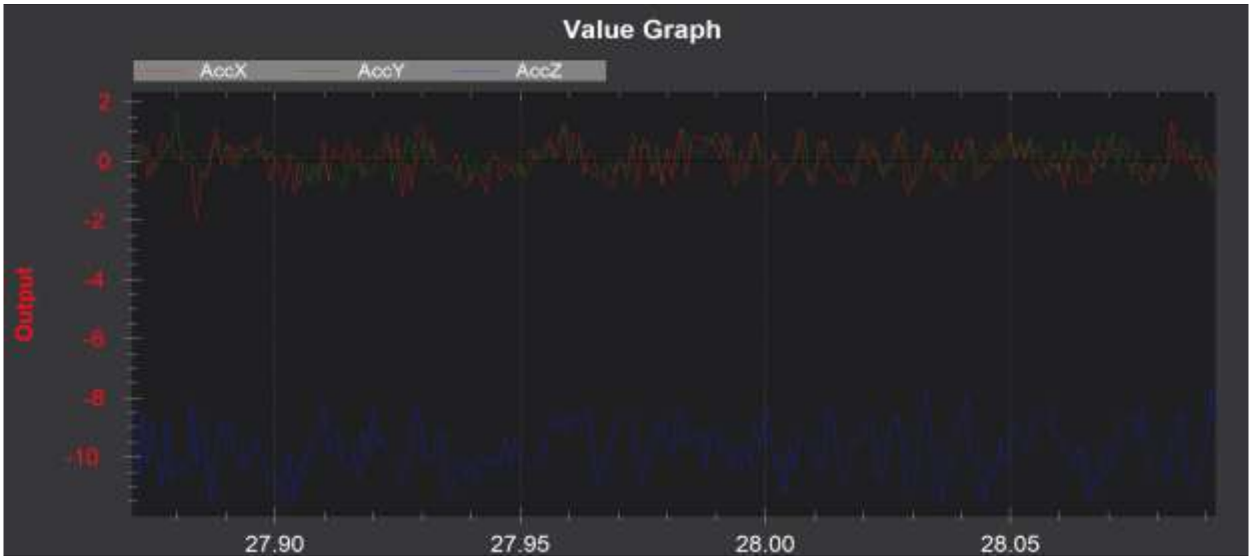

Figure 60: Fence Radius and Height Schematic

It is clear that a huge improvement in the z-direction was made just by the introduction of the rubber components to apply damping. In the x & y directions (green & red graphs) not much vibration occurs, thus an improvement is difficult to measure. However in the z-direction (blue graph) there was a peak-to-peak value of around 8 units on the prototype, which diminished to around 4 units on the model, which is an incredible 100% decrease in directional vibrations. Along with the reduction of vibrations was also a reduction of frequency, which meant the computer had fewer corrections to do at any given time. This provided a more stable and more efficient aircraft.

Naturally, flight improvement will follow any significant mechanical improvement. The added stability and efficiency provided an incredible increase in total flight time. Being one of our biggest objectives, flight time is of upmost importance and any improvement is significant. The prototype model was able to achieve 25 minutes of flight time on one battery pack. With all the improvement in weight, stability and adding of another battery pack, the final model was able to achieve a total flight time of 42 minutes. Realizing that the total flight time needed for competition is only 30 minutes; this result gives confidence in our aircraft to fly for a long enough duration to compete in the AUVSI Seafarer at a high level.

Along with improvements, noticeable addition where made to the system. Most noticeably the addition of another battery pack which may add to the total weight of the system will also double the capacity of the power on board by connecting both batteries in parallel. A picture of the bottom side of the aircraft showing the double battery configuration can be seen in figure 57.

Figure 61: Dual Battery Pack Configuration

Another feature worth motioning is the added video transmission system with an FPV camera and transmitter both powered on-board with a 2s Lipoly battery pack and transmitting clean video feed at 5.2 Ghz. Images of both can be seen in figures 58 & 59.

Figure 62: Boscam 5.2Ghz Transmitter

Figure 63: Turnigy FPV High Resolutions camera

12.0 PROJECT MANAGEMENT

12.1 BREAKDOWN OF WORK/PLANS INTO SPECIFIC TASKS

Research and design is the preliminary step in any goal oriented task. All team members must take the time to review previous journal papers done by former students. All team members must also read and know the rules of the competition to avoid surprises in the future. The next step is to propose multiple design alternatives and choose the best one to fit the project criteria. Modeling of the system will be done using Solid works program to understand the system visually. Once the team has decided on the conceptual design, a prototype must be manufactured to run important tests. While simultaneously manufacturing the prototype, all team members must practice flying using a flight simulator and a radio controller. As the team gets the platform flying, multiple tests must be run to ensure safety, durability, and efficiency. The design of the final system will be carried out with the information given by the prototype testing. While manufacturing the final product, image recognition will be the next facet of the project. Sustained testing and development will be carried out to better understand the system and work through any issues. The competition will be held in the summer of 2014 where the project timeline will officially end.

12.2 BREAKDOWN OF RESPONSABILITIES

Additionally, a breakdown of responsibilities among team members includes 3 main components. Alejandro Diaz will be mainly responsible for the development of the Image recognition software and electrical components associated with it. Luis Ramos will be in charge of flight mechanics and controls of the platform including the autopilot for autonomous use. Lastly Daniel Reyes will be responsible for the design and construction of the structure to house all the components. As a team project, all team members will assist in respective ways according to each member's specific expertise.

12.3 TIMELINE

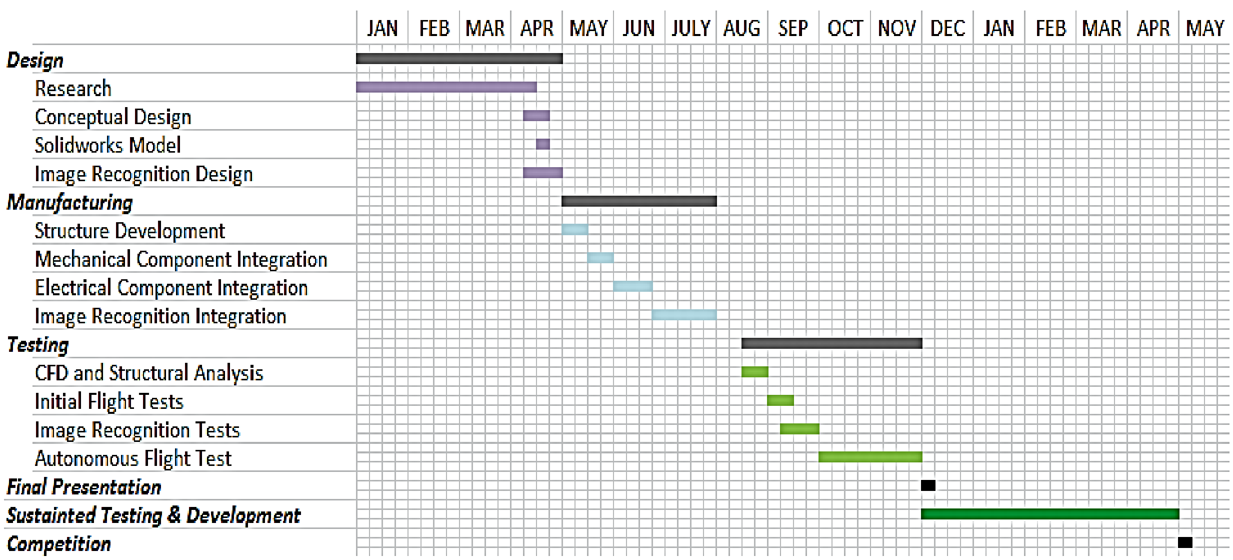

Figure 64: Overview of Project Timeline

The projected timeline illustrated in Figure 5 shows an overview of key tasks needed for a successful completion of the project before final senior design presentation and competition due dates. For this proposed timeline, the total number of man-hours needed from our group is an approximate 10 hours a week. Taking into consideration other responsibilities from each of the team members will account for approximately 350 total hours before senior design presentation and 400 hours before competition day.

13.0 CONCLUSION

In conclusion to the project, all of the goals set forth for senior design were met and exceed at a high standard of engineering. Our team was able to design, manufacture and test a system capable of competing at a high enough standard in the AUVSI Seafarer competition to be recognized by the UAV community. Although not all goals for competition have been met, our team recognized that competition is six months apart from senior design and we have all the intentions to continue working on the system to make it as efficient and capable as possible. We are confident that with further work and testing we can perform at a level higher than FIU has been able to achieve in the past and hopefully spark more interest in the field of UAV's and aviation technology in the department.

Our system is able to currently meet all threshold values for the competition and be able to perform with a lot of the objective values, which earn extra points and will be used to perform to the best of the system's capability. As a group we have learned much and have added a lot of value to our project by adding a new way to compete in this competition using multi-rotors and by proving that flight time can be achieved at a high standard as our results show over 40 minutes on a custom built system with readily available components. This increase in flight time capabilities will allow us to take full advantage of the multi-rotors hovering and navigation capabilities to outperform fixed winged aircraft and make for an excellent competitor in this prestigious competition. As a group, we are very excited to continue working on our system and compete in the coming year to showcase our system and hopefully return victorious.

14.0 REFERENCES

[1] Bramwell, A. R. S., George T. Done, and David Balmford. Bramwell's helicopter dynamics. Reston, VA Jordan Hill, Oxford, UK: American Institute of Aeronautics and Astronautics Butterworth-Heinemann, 2001.

[2] McCormick, Barnes W. Aerodynamics, aeronautics, and flight mechanics. New York: Wiley, 1995. Print.

[3] Valavanis, K. Advances in unmanned aerial vehicles state of the art and the road to autonomy. Dordrecht: Springer, 2007.

[4] AUVSI Seafarer Reference Manual. AUVSI Corp. Maryland, MD 2011.

[5] Helicopter rotor mechanics – Wikipedia < http://en.wikipedia.org/wiki/Helicopter_rotor>

[6] Zhao W., Chellappa R., Rosenfeld A., Phillips P.J., Image Recognition: A Literature Survey, *ACM Computing Surveys*, Vol. 35, Issue 4, December 2003, pp. 399-458

[7] Delac K., Grgic M., A Survey of Biometric Recognition Methods, Proc. of the 46th International Symposium Electronics in Marine, ELMAR-2004, Radar, Croatia, 16-18 June 2004, pp. 184-193

[8] Li S.Z., Jain A.K., ed., Handbook of Image Recognition, Springer, New York, USA, 2005

[9] Delac, K., Grgic, M., Grgic, S., Towards Face Recognition in JPEG2000 Compressed Domain, Proc. of the 14th International Workshop on Systems, Signals and Image Processing (IWSSIP) and 6th EURASIP Conference focused on Speech & Image

Processing, Multimedia Communications and Services (EC-SIPMCS), Maribor, Slovenia, 27-30 June 2007, pp. 155-159

[10] Rakshit, S., Monro, D.M., An Evaluation of Image Sampling and Compression for Human Iris Recognition, IEEE Trans. on Information Forensics and Security, Vol. 2, No. 3, 2007, pp. 605-612

[11] Funk, W., Arnold, M., Busch, C., Munde, A., Evaluation of Image Compression Algorithms for Fingerprint and Face Recognition Systems, Proc. from the Sixth Annual IEEE Systems, Man and Cybernetics (SMC) Information Assurance Workshop, 2005, pp. 72-78

[12] Elad, M., Goldenberg, R., Kimmel, R., Low Bit-Rate Compression of Images, IEEE Trans. on Image Processing, Vol. 16, No. 9, 2007, pp. 2379-2383

[13] Brannan, J. 2013 AUVSI SUAS Seafarer Competition RFP <http://www.auvsi-seafarer.org/documents/2013Documents/SUAS2013CompetitionRulesFinalV5Updated2012-10-31.pdf>

15.0 APPENDICES

APPENDIX A – AUVSI SEAFARER COMPETITION GUIDELINES

2013 Undergraduate Student Unmanned Aerial Systems Competition
Association for Unmanned Vehicle Systems International Final
Request for Proposal (update 31 October 2012) v5.0

SECTION DESCRIPTION

A - CONCEPT OF OPERATIONS

C - STATEMENT OF WORK FOR SEAFARER CHAPTER OF THE ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS INTERNATIONAL STUDENT UNMANNED AERIAL SYSTEM COMPETITION (DESCRIPTION AND SPECIFICATIONS)

I - COMPETITION CLAUSES

J - LIST OF ATTACHMENTS

L - INSTRUCTIONS, CONDITIONS, AND NOTICES TO COMPETITORS

M - EVALUATION FACTORS FOR AWARD

SECTION A CONCEPT OF OPERATIONS

An earthquake has impacted a small island nation in the Caribbean. Several boatloads of pirates who have been operating in the area have landed and are attempting to take advantage of the ensuing chaos. The overwhelmed local government has put out a call for help and the US Marines have responded. Their tasking includes humanitarian relief and security. Your unmanned aerial system (UAS) is supporting their mission with intelligence, surveillance and reconnaissance (ISR). In order to support them, your UAS must comply with Special Instructions (SPINS) for departure and arrival procedures, and then remain within assigned airspace. It will be tasked to search an area for items of interest, and may be tasked to conduct point reconnaissance if requested. Additionally, the UAS may be tasked to relay data from a third party Simulated Remote Information Center (SRIC). Immediate ISR tasking may be requested outside currently assigned airspace, causing the UAS operators to request deviations.

SECTION C STATEMENT OF WORK FOR SEAFARER CHAPTER OF THE ASSOCIATION OF UNMANNED VEHICLE SYSTEMS INTERNATIONAL STUDENT UNMANNED AERIAL SYSTEM COMPETITION (DESCRIPTIONS AND SPECIFICATIONS)

1. Introduction

1.1. This statement of work (SOW) defines the tasks to be performed by the competitor in performing all aspects of the Student Unmanned Aerial System (SUAS) competition.

1.2. The Seafarer Chapter of the Association for Unmanned Vehicle Systems International (AUVSI) continues the Student Unmanned Aerial System (UAS) Competition aimed at stimulating and fostering interest in unmanned systems, technologies and careers. The focus is on engaging students in systems engineering a total solution to a challenging mission, requiring the design, fabrication and demonstration of a system capable of completing a specific autonomous aerial operation.

1.3. Student teams will be judged based on their system performance, and top teams will earn prize money. Opportunities for interaction with top UAS designers, engineers, scientists and leadership will be provided.

1.4. The principal thrusts of the competition are the safe application and execution of Systems Engineering to develop autonomous operation in successful mission accomplishment.

1.5. The major graded items/events are: 1.5.1. Final Journal Paper

1.5.2. Oral Presentation /Flight Readiness Review

1.5.3. Flight Demonstration

2. Scope. This is a Performance-Based competition. Multiple government agencies, prime contractors, engineering firms and Universities are observing and judging this competition. Contestants may be awarded prizes for major graded items/event, overall performance or individual aspects of a graded item/event.

3. Requirements. The Statement of Work for this competition is laid out in paragraph format in line item number order to facilitate tracking and task identification. Technical support tasks, documentation and products should be provided in accordance with the Statement of Work.

3.1. System Design & Development (SDD). There are no graded events during SDD – this SOW task is entirely to aid the competitor to understand the requirements and the systems engineering process. Each team will establish its own Plan of Action and Milestones (POA&M) to complete SDD within the time available before the graded Flight Demonstration.

3.2. Fact Sheet. Six weeks prior to the competition (May9, 2013) a one-page fact sheet providing basic descriptions of the air vehicle and systems shall be submitted to AUVSISeafarer Chapter. It shall include frequencies used for air vehicle control (manual or autonomous) and payload control/imagery receipt, fuel and/or battery type and air vehicle dimensions including gross weight, launchers, vehicles, and other large equipment that the team will bring to the competition and which equipment will be taken to the airfield. A specific format for the fact sheet will be posted at the competition web site.

3.3. Journal Paper. Each team shall electronically submit a journal paper that describes the design of their entry and the rationale behind their design choices. The acceptable means of electronic submittal is posting in the team's folder on the competition SharePoint site. The paper shall include an abstract, description of the systems engineering approach, descriptions of the UAS design, test and evaluation results (including payload and navigation system performance), and safety considerations/approach. Systems engineering includes mission/requirements analysis, design rationale, and expected performance. Design descriptions are required for the air vehicle, ground control station, data link, payload, mission planning, data processing and method of autonomy and target types supported by autonomous cueing/recognition (if utilized).Specific attention shall be paid to safety criteria. The journal paper shall include a photo of the UAS air vehicle. The journal paper (including proof of flight video or statement) must be received by AUVSI Seafarer Chapter no later than May30, 2013.

3.4. Oral Presentation. The Oral Presentation will not be a restatement of the Journal Paper. Instead, it will take the shape of a Flight Readiness Review (FRR) during which the competitors will present the judges with

3.4.1. System Safety Overview

3.4.2. Results of developmental test (DT)/Evidence of likely Mission Accomplishment

3.4.3. Pre-Mission Brief

3.4.4. A static display describing the elements above

3.4.5. Only systems presented in the FRR, inspected by safety inspectors, and included in the preflight brief will be permitted to fly.

3.5. Flight Demonstration.

3.5.1. Takeoff - Takeoff shall take place within one of two designated Takeoff/Landing areas, depending on wind direction. This area will be paved asphalt surface, roughly100 ft wide, with no height obstacles. Systems utilizing launchers and/or not performing wheeled landing may utilize the grass immediately adjacent to the runway; however, grass area will note prepared. Takeoff from moving vehicles is prohibited. Launchers will be inspected by competition safety inspectors before they are allowed for use in the competition. After takeoff, the air vehicle shall maintain steady, controlled flight at altitudes above 100 feet and under 750 ft MSL (Note: airfield elevation is approximately 10 ft MSL). Takeoff under manual control with transition to autonomous flight is permitted. Extra credit and a cash award will be provided for autonomous Takeoff.

3.5.2. Waypoint Navigation – Air vehicles shall autonomously overfly selected waypoints and remain inside assigned airspace, and avoid no-fly zones. Teams will fly a predetermined course that includes changes in altitude and in heading, to the search area.

3.5.2.1. Waypoints - GPS coordinates (ddd.mm.ssss) and altitudes will be announced the day prior to the flight competition. However, because of the dynamic nature of modern warfare, it is possible that additional waypoint(s) and/or search area adjustment(s) will be required.

3.5.2.2. Enroute Search – Air vehicles will be required to fly specific altitudes while identifying several targets along the predefined entry route. One of the targets will be directly along the route when the vehicle is required to be at 500 ft MSL (± 50 ft). Another target will be up to 250 ft from the center of the flight path while the vehicle is required to be at 200 ft MSL (± 50 ft). The team will be given the position of the off-center target. UAS shall not vary from the flight paths (± 100 ft tolerance) briefed during the mission planning in order to obtain an image of the target; flight path deviations shall not be permitted as to avoid being shot down by hostile or friendly forces. Enroute way points shall be achieved in order.

3.5.2.3. Targets - Targets will be constructed of plywood of a given size, basic geometric shape, and color. For an example, see figure 1. Each target will be a different shape and a unique color; a different color alphanumeric will be painted on each target. There are an unknown number of targets in the area. The additional target will be more reflective of a realistic surveillance target. The minimum dimension of the targets (length or width) will be 2 feet, and the maximum dimension will be 8 feet. Alphanumeric will be sized to fit within the overall dimensions of the target varying between 50-90% of the length/width of the target and between 2-6 inches in thickness, and will vary in color and contrast. The alphanumeric of the targets can be arranged to spell a “secret” message. Any team that can spell the message will receive bonus points and a cash prize.

3.5.3. Area Search - once transitioning into the predefined search area via the entry/exit route, the air vehicle shall autonomously search for specific targets of interest. Air vehicles may search the area at any altitude between 100 and 750 ft MSL. Targets will be distributed throughout the search area. Competitors shall record the characteristics (location, shape, color, orientation, alpha, alpha color) of all observed targets on a target data sheet (and/or in electronic form) and provide this data to the judges at completion of the mission. 3.5.3.1. While executing the search mission, the team will be provided with a new search area (within the existing no fly zone boundaries) allowing you to locate “pop-up” targets. The “pop-up” target will be in the form of a human engaged in an activity of interest.

3.5.3.2. There will be a minimum of 200 ft margin between the search area and the no fly zone boundary.

3.5.4. Landing - Landing shall be performed completely within the designated takeoff/landing area. Transition to manual control is permitted for landing. Extra credit and a cash award will be provided for autonomous landing. Control in landing will be graded. Mission completion is when the air vehicle motion ceases, engine is shutdown, and the target data sheet and imagery have been provided to the judges.

3.5.5. Total Mission Time - Total mission time is the time from declaration of mission start from the judges and permission to turn on transmitters until the vehicle has safely landed, transmitters are shut off, and target data sheet (or spread sheet) is handed to the judges. Accuracy of results and time required to submit results will be measured. Missions completed between 20 and 40 minutes will receive some bonus points for each minute less than 40 minutes (must land vehicle, crashed and/or terminations do not earn bonus points); however, no additional points will be awarded for mission times less than 20 minutes. Significant points will be deducted for each minute over 40 minutes mission time, up to 60 minutes total where it is mandatory to turn in results. It should also be noted that each team will be given 40 minutes time to set up equipment prior to the beginning of the mission. After 40 minutes, the judges may declare mission start, regardless of the team's readiness to launch the mission. If 40 minutes has elapsed and the air vehicle has not achieved flight, the mission will be terminated.

3.5.6. "Real time" actionable intelligence. Extra credit will be given for providing complete and accurate information (actionable intelligence) during flight within the search area: once that information is provided, it cannot be modified later. Intelligence is actionable only if all six target characteristics (shape, background color, alphanumeric, alphanumeric color, orientation, and location) provided at that time and recorded on the target data sheet is correct. This will not be considered to be "real time" intelligence unless designated as such. Credit for "real time" actionable intelligence will only be given for one target.

3.5.7. Simulated Remote Information Center (SRIC). Prior to the takeoff, the position of

An SRIC will be provided. Extra credit and a cash award will be given if the appropriate data is relayed from the SRIC to the ground station via the air vehicle.

SECTION I COMPETITION CLAUSES

1. PROOF OF FLIGHT. Based on experience from the 2005 competition, we now require validation that team air vehicles have flown prior to arrival at Webster Field. A video that shows your air vehicle in flight or a statement signed by a faculty member of your university or school that verifies your system has successfully flown at least once shall be submitted with the journal paper. The proof of flight video or statement will identify the facility (or facilities) used for system integration and flight test.

2. OFFICIAL RULES, SUBMISSIONS, AND FEES

2.1. The official source for all information concerning rules, interpretations, and information updates for the Seafarer Chapter of AUVSI 2013 Student UAS Competition is the World Wide Web home page at: http://www.auvsi-seafarer.org.

2.2. An application form is available on the website. A completed form with entry fee is due to AUVSI Seafarer Chapter no later than January 15, 2013. Entry fee and application form shall be mailed to:

James Curry 21487 Great Mills Road, Suite a Lexington Park, Maryland 20653

2.3. The submission shall be in English and is not considered official until the entry fee of five hundred U.S. dollars ($500 Check or Money Order) has been received by AUVSI Seafarer Chapter. If a team decides to withdraw from the competition, they must inform the Seafarer Chapter (via email or post a document titled "Withdrawal" in the team's SharePoint folder on the competition web site) no later than 30 May 2013 at which time the registration fee will be refunded. After this date, no refunds or credits to future competitions will be granted. As the competition format cannot handle an unlimited number of entries, the organizers reserve the right to limit the total number of entries that are allowed to compete by declaring the competition closed to new entries before the due date above. Flight Competition/Mission phase may be further limited based upon results of journal paper, static display/oral brief and safety inspection. As with all official information, this announcement (should it be necessary) will appear on the official website.

2.4. Full-time undergraduate or high school students including no more than one graduate student shall compose the team. If a faculty advisor, non-student or AUVSI Staff is used as the air vehicle pilot they are not counted as team members. Members from industry, government agencies, or universities (in the case of faculty or additional graduate students) may advise the team; however, they may not directly contribute in the creation of the design, test, paper or oral presentation. The faculty member/advisor will sign a statement that the team consists of no more than one graduate student and submit it with the team list discussed in Section C, paragraph 5.2.1. No more than ten people from each school will be covered by competition expenses (food, shirts, etc.). Faculty/advisors are limited to participation as a safety pilot during the competition.

Students shall present data analysis, etc. Participants shall be enrolled at their schools for at least 12 credit hours or more per quarter/semester

During winter 2012 and/or spring 2013 to be considered "students” unless cleared by the Competition Director (winter 2012/ spring 2013 graduating seniors are not considered as graduate students for this competition).

2.5. The student members of a joint team shall make significant contributions to the development of their entry. Only the student component of each team is eligible for the cash awards. One student member of the team shall be designated as the "team captain." Only the team captain will speak for the team during the competition run. Teams registering to compete shall indicate on their application form the name of the individual or organization to whom prize checks will be made payable.

3. TIMELINE:

Date	**Item**
September 13, 2012	Draft Request for Proposals Released (Competition rules simulating a performance specification and statement of objectives).
September 29, 2012	Deadline for comments or questions. Post questions to team’s SharePoint folder on the competition web site.
October 2, 2012	University Day (4:00 PM, EDT, phone conference with competition judges. Call in

	instructions posted on website. http://www.auvsi-seafarer.org/news-events/UniversityDay.aspx
October 23, 2012	Request for Proposal Released (Final competition rules).
January 15, 2013	Completed entry form and registration fee received by AUVSI Seafarer Chapter.

SECTION J LIST OF ATTACHMENTS

Attachment 1 Flight Readiness Review Criteria

Attachment 2 Electronic Data Format

Attachment 3 Student Unmanned Aerial Systems Competition Network Connection Interface Control Document

Attachment 1

Flight Readiness Review (FRR)

The FRR is a multi-disciplined technical review to ensure that the subsystem or system under review is ready to proceed into formal test. The FRR assesses test objectives, test methods and procedures, scope of tests, and safety. The FRR verifies the traceability of planned tests to program requirements and user needs. The FRR determines the completeness of test procedures. The FRR assesses the system under review for development maturity, effectiveness, and risk to determine readiness to proceed to flight testing.

The FRR should answer the following questions:

- Will the planned flight test verify all directly traceable requirements?

- is the configuration of the system under test sufficiently mature, defined, and representative to accomplish planned test objectives and or support defined program objectives?
- Have all planned preliminary, informal, functional, unit level, subsystem, system, and qualification tests been conducted, and are the results satisfactory?
- Have all applicable flight/system limitations been defined and agreed to?
- is the planned test properly resourced (people, test article or articles, facilities, data systems, support equipment, logistics, etc.)?
- Have the crew members been trained properly?
- has discrepancy identification and reporting system been defined and agreed to?
- Have Go/No-Go criteria been agreed to?
- what is the fall-back plan should a technical issue or potential showstopper arise during testing?
- Has a final reporting process been defined and agreed to?
- What is the expected result and how can/do the test results affect the program?
- What are the risks associated with the tests and how are they being mitigated?

FRR success criteria:

A. Identified risk level is acceptable.

B. The judgment that previous component, subsystem, and system test results form a satisfactory basis for proceeding into planned tests.

Test and evaluation is critical to evaluating the system. The FRR ensures that the testing

Electronic Data Format

Name the file using the initials of your school or team as a text file (.txt).

9 fields, tab delimited, new target on each line

Field 1: Target Number, two digits, starting at 01 and increment by one for each additional target. Target number is assigned by team. Example: 01, 02, 03, etc.

Field 2: Latitude in the following format, first character N or S, two digit degrees (use leading zeros if necessary), followed by space, two digit minutes, followed by space, two digit seconds followed by decimal point and up to 3 digits (thousandths of a second) Example N30 35 34.123

Field 3: Longitude in the following format, first character E or W, three digit degrees (use leading zeros if necessary), followed by space, two digit minutes, followed by space, tow digit seconds followed by decimal point and up to 3 digits (thousandths of a second) Example W075 48 47.123

Field 4: Target orientation, up to two characters: N, NE, E, SE, S, SW, W, NW

Field 5: Target shape, list geometric shape as appropriate: Example, rectangle, square, triangle

Field 6: Target color, as appropriate. Example: Red, Orange, Yellow, etc.

Field 7: Alphanumeric, as appropriate Example: A, b, 2, &

Field 8: Alphanumeric color, as appropriate Example: Red, Orange, Yellow, etc.

Field 9: Name of jpeg file with image of target

Example for two targets

01 N30 35 34.123 W075 48 47.123 N rectangle red A orange target1.jpg

02 S34 00 12.345 E002 01 12.345 SE square orange 4 yellow target2.jpg

Attachment 3

Student Unmanned Aerial Systems Competition

Network Connection

Interface Control Document

SUAS Simulated Remote Information Center (SRIC)

1.1 Scope

This document provides or references the data definitions required for transfer of data from the Simulated Remote Information Center (SRIC) to the competing team's UAS. These definitions encompass the data link and message interfaces.

1.2 Equipment Definition

The SRIC will comprise of a laptop computer running Microsoft Windows 7, a Linksys Model WRT54GL Wireless Broadband Router, a 10 dB attenuator, and a TRENDnet Model TEW-A014D High-gain directional antenna.

3.0 INTERFACE DESCRIPTIONS

3.1 Logon Procedures

1. The antenna location and the wireless network name will be provided on the day before the competition (practice day).
2. The router IP address, net mask, and static IP Address, network passphrase, and folder name will be provided by the SUAS judge at the start of setup on the taxiway.

3. Students will be allowed to test the network connection during the practice day.

4. The student teams shall use Wired Equivalent Privacy (WEP) encryption when accessing SRIC.

5. When flying in the specified area, connect to the network. The router will be located on wireless channel 1 at 2.412 GHz.

6. Enter the provided network passphrase.

7. Dynamic Host Configuration Protocol (DHCP) will be enabled. If dynamic IP is not used, a static IP address will be provided.

8. After network connection is confirmed, enter the provided IP address. An example is below: FTP://192.168.1.110/auvsi/team1.

9. Open the folder and read the included text file to receive the code phrase. This folder will be read only.

10. Provide the code phrase to the SUAS judges.