AUVSI Design Competition

Midterm I Report

Figure 1. Arcturus UAV Jump[1]

Team 8
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Abstract

This report represents the research and design selection of Team 8's 2015 Senior Design Project. Team 8 has completed a plethora of research and overcome multiple new obstacles to reach this point. One underlying hardship is the communication with the students located in Brazil, taking part in the FIPSE study abroad program. While working through and learning how to effectively operate as an international team, Team 8 has refocused and changed their previous goals and objectives. The new direction the team will be taking is identifying and building the most optimal aircraft for future success at the AUVSI SUAS Competition. Team 8 has performed significant research into which aircraft will be best for the competition and has developed three plausible designs. Taking into account the constraints and tasks of this competition, Team 8 has come to the conclusion that a Vertical Takeoff and Landing (VTOL) aircraft, specifically Team 8's Design #3, will be the best option going forward. Team 8's new goal is to have the new design built and capable of both horizontal and vertical flight by the end of the academic year. To accomplish this, the team must work effectively to finish the mechanical and electrical design, construct the final design, and program and test the aircraft's flight.

1 Introduction

The objective of this project is to design the optimal Unmanned Aerial Vehicle (UAV) for the 2015 Association for Unmanned Vehicle Systems International (AUVSI) Student Unmanned Aerial Systems (SUAS) Competition. In addition to technical experience, this project will provide students with the opportunity to work internationally with group members abroad. Two members of this team are involved in the Fund for the Improvement of Postsecondary Education (FIPSE) study abroad program, currently living in Itajuba, Brazil. The international team allows its members to better their teamwork and communications skills in preparation for real-world engineering challenges.

In addition to the obstacles created by the international collaboration, the group also has many challenges to overcome in the SUAS competition. One of the most important tasks is autonomous takeoff and landing. Therefore, the team is considering the idea of designing a hybrid aircraft. The aircraft will take off and land like a multi-rotor aircraft, but fly like an airplane. These features would provide the aircraft with the best chance of completing the autonomous takeoff and landing segment of the competition. In addition, the aircraft would consume less power if it were to fly like a traditional plane. As a result, the vehicle would have a longer flight time and greater velocity compared to a traditional multi-rotor aircraft. The team has conducted research on the hybrid aircraft and its adaptability with the various mission objectives of the 2015 AUVSI SUAS competition. This aircraft would be able to complete the autonomous vertical takeoff and landing easier than any fixed wing aircraft, because it does not need a runway to takeoff or land. It can take-off and land in an area that is just larger than its overall dimensions. There are several types of aircraft that would be successful at the AUVSI SUAS competition, each having their own advantages and disadvantages. By analyzing different aircraft, a decision can be made as to which would be most beneficial for various tasks.

2 Project Definition

2.1 Background research

The development of unmanned aircraft system has had a pronounced impact on society. Most modern day UAVs are fixed-winged or multi-rotor aircraft. Each type of aircraft have their disadvantages and advantages. Primarily, fixed wing aircrafts have longer flight time and higher velocities than multi-rotor aircraft. The longer flight time is a result of the aircraft having to power only one motor and the lift is achieved by the shape of the wings, rather than the constant vertical thrust needed in a multi-rotor. In addition, fixed winged aircraft achieve higher velocities due to the lift being handled by the wings, and motor applying only horizontal thrust. Meanwhile, multi-rotor aircraft are more agile compared to fixed-wing aircraft because they don’t need constant velocity to generate lift and can change direction instantaneously.

Waypoint_navigation is another important aspect of the 2015 SUAS competition. The aircrafts in the competition have to travel to specific coordinates in a predefined sequence. The aircraft will be given a score that is dependent on quickly and precisely it can complete each event. Precision is measured by how much the aircraft does not deviate from each waypoint. Deviations that are more than 15m from the waypoint location and altitude will result in point deduction. A fixed winged aircraft can reach these waypoints faster than a multi-rotor aircraft. Unfortunately, it does not have agility of multi-rotor aircraft. For instance, if two waypoints are in proximity of each other, the multi-rotor vehicle has a better chance of reaching them successfully because it can accelerate and decelerate quicker than a fixed-wing aircraft. The fixed-winged aircraft does not have that luxury.

Each type of vehicle have its disadvantage and advantages. The majority of the competition mission could be accomplished with a multi-rotor aircraft. Unfortunately, it would take a great deal of effort to have a multi-rotor aircraft fly for the 40 minutes allotted by the competition. Multi-rotor aircrafts consume a considerable amount of energy compared to a fixed winged aircraft. Therefore, Team 8 is looking forward to the potential benefits of building a hybrid VTOL aircraft.

Team 8 has conducted a great deal of research about hybrid designs, which interface aspects of both a fixed wing and multi-rotor aircraft. The hybrid multi-rotor designed by Latitude Engineering has been described as the best fit for the 2015 competition. It would permit team 8 to perform simpler automated takeoff and landing. “The Hybrid Quadrotor (HQ) is an innovative airframe technology that the combines the Vertical Takeoff and Landing (VTOL) capabilities of a quadrotor and the efficiency, speed, and range of a normal fixed-wing aircraft”.[2] The aircraft would have the capability of a fixed wing aircraft and a multi-rotor aircraft. Therefore, it could complete the aforementioned mission objectives without any major design limitations.

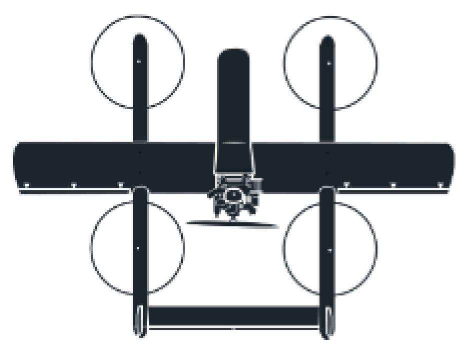

Figure 2. Latitude Engineering HQ

2.2 Need Statement

The objective of this project is to build, design, modify, and program an autonomous aerial vehicle. Dr. Shih and Florida State University have sponsored Team 8 to compete in the 2015 SUAS Competition hosted by AUVSI. The aircraft will be designed to comply with competition rules and complete various mission requirements. The mission of the SUAS competition is to "stimulate and foster interest in unmanned system technologies and careers".[3] Unmanned aerial vehicles are still a growing concept, and much research and development can be added to improve existing systems.

"There needs to be further advancement in the design and control of autonomous aerial vehicles."

2.3 Goal Statement & Objectives

In order to advance the design and control of autonomous aerial vehicles, Team 8 will be designing and building an aircraft of their own. The aircraft will be built to meet the constraints of the 2015 AUVSI SUAS Competition. **"The goal of this project is work effectively as an international team to create the best possible aircraft for future success at the 2015 AUVSI SUAS Competition."** We hope to create the ideal aircraft by completing the following objectives:

- The aircraft should meet all AUVSI SUAS design specifications
- The aircraft should be capable of VTOL
- The aircraft should sustain flight for 40 minutes of total flight
- The aircraft should be capable of autonomous navigation

The previous objectives must all be reached in order to create the ideal platform for the competition. With the size and complexity of modifying the aircraft, Team 8 is aiming to greatly advance the ongoing project. The underlying drive is to see FSU/FAMU Seniors compete and have great success in future competitions.

2.4 Constraints

In every project, there are some limitations that team members must overcome. Primarily, time places a restriction on how and when the design can be built. The team also has finite funds that it can spend on acquiring the resources needed to implement the design for the competition.

- *Physical system limitation*- The aircraft cannot weigh more than 25kg. at any time. Also, 25% of the different sections of the aircraft must be brightly colored.[3]
- *Environmental constraints*- The vehicle should be capable of flying in winds up to 7 m/s and gusts up to 10 m/s. The system should operate in temperatures up to 38 degrees Celsius for a maximum of 12 hours.[3]

- *Mission constraints*- Aircraft must fly between a 30 m. and 230m. Mean Sea Level (MSL).The Aircraft must have a reliable manual override system. The vehicle must be able to fly between 20 and 40 minutes.[3]
- *Budget*- Total expenses on the design must be less than $ 1500.

3 Design and Analysis

3.1Functional Analysis

3.1.1 Electrical Functional Analysis

There will be numerous components that will be required in reference to the hybrid design concept that will be used to achieve the overall construction of this year's plane. From the electrical standpoint, which involves the components inside the hybrid aircraft, design begins with the flight controller. Based on the type of flight controller that is selected for this design, it will allow for stabilization, flight in autonomous mode, and even allow for programmable waypoints which are essential to the AUVSI competition. Researching flight controllers, the Ardupilot Mega 2.5+ seems ideal for the task at hand as it can "turn any fixed, rotary wing or multi rotor vehicle into a fully autonomous vehicle, capable of performing programmed GPS missions with waypoints".[4] The GPS system is also included in the flight controller. The Ardupilot is ideal for this project because it includes both a GPS system and autonomous flight ability. To go along with this, Team 8 would not need to purchase this flight controller because they have inherited it from previous year's teams.

Moving on from the flight controller, the next required part that is needed for hybrid plane would be the motors, propellers, and electronic speed controllers (ESC's). These three parts are essential to provide flight to the overall aircraft. The motors provide the power to rotate the propellers which produce thrust needed to lift the aircraft. The ESC allows for the flight controller to control the speed of each motor in order to establish flight, speed, and direction. Utilizing a "4 in 1 ESC instead of individual ESC's allows for the reduction of electromagnetic field and neater installation".[5]

After the components that are necessary to provide flight to the aircraft, the radio transmitter and receiver is then required to control movement of the plane manually. The receiver which is mounted on the plane takes in the signal from the transmitter allowing control over the aircraft. The transmitter, normally functioning at 2.4GHz, sends the signal to the receiver, and based on the number of channels on the transmitter, it can control various functions on the aircraft from the landing gear to the overall flight control.

The last required component from an electrical standpoint is the battery selection. The battery used for flight is going to need to provide enough flight time to complete the required objectives based on power consumption of the aircraft. Based on the weight of the components, frame, and flight time needed, the appropriate size of the battery can be determined.

3.1.2 Mechanical Functional Analysis

For the goals of the project there are several specifications that need to be met. These include:

- The ability to lift up to 7 kg of weight
- Ability to store and release payload
- Ability to maintain stable and autonomous flight
- Ability to fly long enough to complete mission objectives (min. 40 minutes)
- Ability for autonomous camera target detection
- Low vibrations
- Autonomous takeoff and landing

The most suited vehicle that can accomplish these specifications is one that has the stability and flight time of a fixed wing aircraft but has the ease of takeoff and landing of a multi-rotor. Therefore, a VTOL aircraft using an existing fixed wing aircraft and a customized multi-rotor attachment is best for the competition. When designing the hybrid VTOL aircraft it is necessary to combine both the function of a multi-rotor and that of a fixed wing aircraft. For the VTOL portion of our mission the aircraft will function as a multi-rotor. The flying weight of our aircraft is approximately 4082 g. The weight of a multi-rotor including the frame and all components is about 2411g. The total combined weight of the hybrid will be approximately 6493g.

When in forward flight conditions the amount of lift needed to carry the plane is minimal. It is at this stage that thrust is of the most importance due to the need to overcome the increased drag and weight added to the frame by the quad copter attachment. When taking off and landing the total thrust from the four motors is approximately 7200g. This is enough thrust to lift the entire aircraft and support it in hover for short durations. The thrust to weight ratio is approximately 1.1. Given the above thrust to weight ratios for forward flight and vertical flight, it is concluded that theoretically the vehicle should be able to maintain flight. The discharge rate for the vertical component will 104A, based off a 5200 mAh battery.[6] Based on the current draw from the four motors, the flight time was calculated to be 11 minutes. This will suffice as the vertical component will only be used briefly during takeoff and landing.

Table 1: Fixed Wing Specs

Flying Weight	4082g
Wingspan	239cm
Wing Area	3960 cm^2
Length	163cm
Motor	.46 Brushless Outrunner
RPM/Voltage	600
Weight	215g

Table 2: Quad rotor Specs

Flying Weight	2411g
Thrust	7200g
Thrust ratio	2.99
Wingspan	650mm
Motor	MN4010 475
RPM/Voltage	283
Weight	112g
Prop	16x5.4" Carbon Fiber

Table 3: Hybrid Specs

Flying Weight	6493g
Thrust ratio (vertical)	1.1

3.2 Design Concepts

Latitude Engineering has released a hybrid UAV which exhibits characteristics of both a plane and multi-rotor.[2] Team 8 has decided this is the ideal aircraft for the SUAS design competition. The aircraft can fly as a traditional fixed wing, as well as hover like a multi-rotor. Team 8 has inherited a Senior Telemaster fixed wing plane, which was used in last year's project. This aircraft could be retrofitted with a multi-rotor frame in order to have the benefits of both designs. The resulting aircraft would be optimal for the competition. For this, three designs have been proposed:

Design 1:

Design 1, Figure 3, is much like the Latitude Engineering prototype which has two beams running parallel to the plane; upon which are mounted four vertical thrust motors. The beams are fit to the plane by running a horizontal rod through the rear wing which sticks out on both sides so that one end of each the tube can be connected to either side of the rear wing. The opposite end of each tube will be connected by another set of rods that are in a vertical orientation and connect by drilling straight down through the wings to place a vertical rod at a distance from the center that is greater than half that of the total tubes length. The distance between the front and back motors should be equal to the distance between the motors on both sides of the craft, as to create a square between all the motors. This simplifies the calculations needed for programming the quad rotor aspect of the UAV.

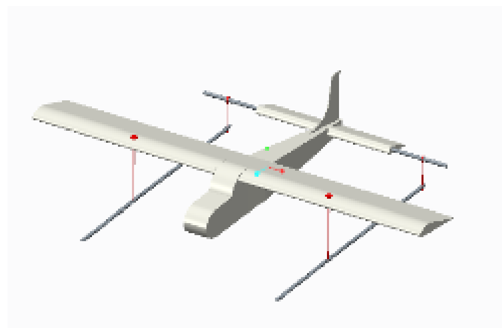

Figure 3. Design 1

The front rods hang down far enough so that when the UAV is tilted and moving forward, as a quad rotor would be, the plane's orientation is such as it would be when taking off. The idea being that lift under the wings can begin to be generated the same way as when the craft is taking off. While tilted, the front rotor would be on and would help accelerate the craft until enough speed is generated for the lift under the wing to support the UAV's weight, so that the 4 vertical motors can turn off. These motors are fixed to the tube in a vertical manner as to only generate lift when the vehicle is in hover.

The positives of the design are that it requires little modification to the integrity of the plane. Also, it is lightweight, aerodynamic, and only has a limited number of parts. The design however does require holes to be drilled into the plane's wings which could lead to weakening the wings overall strength. It also is not favorable to drill into the wings because they are structurally weak due their construction and material. The wings are necessary to horizontal flight and any damage can result in a prompt failure of the aircraft.

Design 2:

Design 2, Figure 4, also has four vertical motors and props so that a functioning multi-rotor can be achieved. The frame is fixed to the plane by way of drilling into the base of the existing fixed wing. The diamond should be shaped so that the motors can be set a fixed distance apart, in a square pattern, as to create symmetry about the center of mass of the design. The blunt side of the diamond is toward the front of the plane and the point edge is toward the tail as to reduce drag. The blunt side would act as a plate traveling through the air therefore most of the drag effects of this frame would come from skin friction.

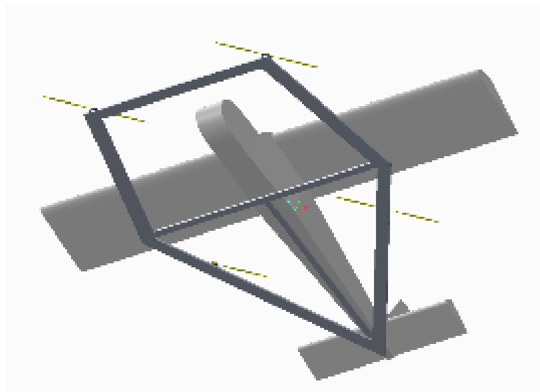

Figure 4. Design 2

The positives of this frame are that it can help the plane to ride on the air but this is also its drawback in that the added surface area may create substantial skin friction, which would increase drag. Also as the aircraft is using the four vertical propellers to lift off, the increased surface area would create additional forces for the vertical props to overcome.

Design 3:

Design 3, Figure 5, has many characteristics that are similar to that of Design 1 and Latitude Engineering's plane. This design consist of four adjustable push rods, two arm braces, a base plate, three rails, two rail guides, and the four vertical engines and props. Unlike the other designs this design does not call for any drilling to be done to the body of the fixed wing. This is favorable in that the fixed wing does not need to be modified. The frame is fixed to the plane by way of the four adjustable push rods which allow the frame to be fixed to more than one fixed wing frame. The base of the frame can be centered up under the planes center of gravity by using the adjustable push rods. When the base of the frame is in a desired position the rods are tightened and the frame is fixed into its position.

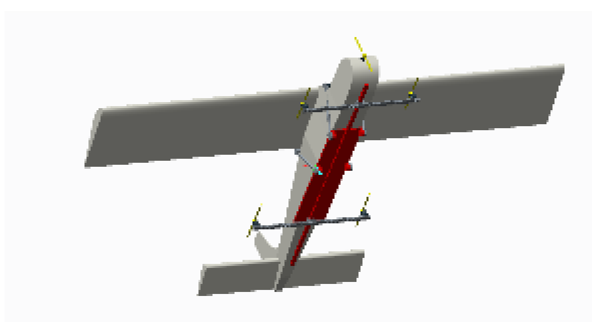

Figure 5. Design 3

To create a cushioning effect and minimize any damage that could occur by tightening the push rods, a pad will be placed on top of the base and around the bracing rods, which run over the top of the plane and are connect to the adjustable push rods on both ends. The brace/pad combos have one paired with the front rods and the other paired with the rear rods. A rail runs down the center of the frames base, which means it also runs down the center of the plane from its nose to tail. This rail is used to fit two other perpendicular rails to the frame by using a rail clamp. The clamp and rail combination allows for a variety of positions to be obtained. This is desirable in that it allows for many propeller sizes to be fit to the plane, as well as addition motors and propellers if needed.

This design has an advantage over the other designs because it does not require anything to be done to the body of the fixed wing craft. Since the fixed wing can already fly, enough lift can be generated under the wings and the wings can support the fixed wings weight. With the additional weight added to the vehicle, a larger front propeller or a stronger motor may be needed to generate enough forward thrust to create lift for takeoff.

3.3 Evaluation of designs

3.3.1 Criteria & Method

When considering the design of the ideal aircraft, many criteria were taken into account. Some of these are directly related to the constraints of the project, such as cost, time, and system weight. The others are related to the performance of the aircraft. The strength of the VTOL system must be high to withstand the lift forces and the opposing weight forces of the aircraft. This is similar with the stability and vibration resistance of the design. The system must be stable enough to achieve vertical takeoff and landing, without excessive vibrations that disrupt flight. The aerodynamics of the aircraft will also be affected by the VTOL system. It is important that the aircraft can still effectively fly after transitioning from vertical to horizontal flight. Finally, the difficulty of the design must also be taken into account. If the design requires great expertise, or is extremely complicated, it is possible that it will not be completed. All of these factors are important to consider. Below, the designs are ranked in relation to the criteria described.

Table 4: Design Decision Matrix

Component	Weight	Design 1	Design 2	Design 3
Cost	10	4	4	7
Build Time	8	4	4	6
Weight	8	7	6	5
Difficulty	5	4	4	6
Strength	5	4	7	7
Aerodynamics	5	6	4	4
Vibration Damping	5	4	4	6
Variability	3	4	4	8
	Total Score	230	227	297

3.3.2 Selection of Optimum Design

After collaboration, Team 8 was able to assign values to each design for each important criteria. It was found that Design 3 ranked the highest based on all the factors. This is mainly due to the cost, build time, strength and variability. Design 3 scored very high values in these sections because of its simplicity. There would be no physical modification to the existing plane needed to add the VTOL system. This avoids problems with attaching components to the fragile wings, which we cannot afford to damage. The system should be fairly strong as well, lifting the aircraft from its most reinforced section. Another advantage of Design 3 is its variability across aircraft. The design is fully adjustable, allowing its attachment to different aircraft. This is a benefit that will help future teams and possibly hobbyists.

4 Methodology

The flowchart below lays out the plans for team 8 to complete the design they have selected. By following this processes, Team 8 should be able to effectively design and build a complex aircraft that would excel in the AUVSI competition.

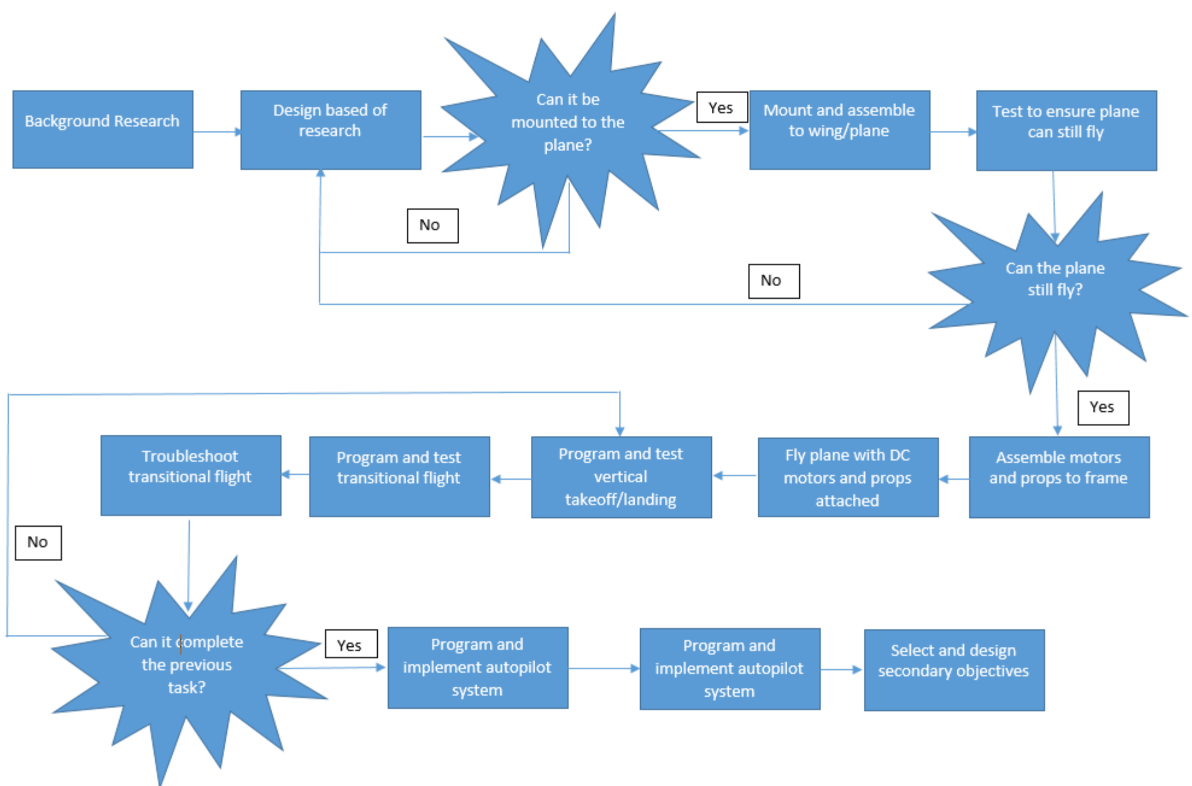

Figure 6. Team 8 Flowchart

As one can see, there will be an extensive amount of programming needed for this vehicle. The three main parts that will need programing are the vertical takeoff/landing, transitional flight, and autonomous navigation. This is also not taking into account the secondary objectives that can be done for the competition. Team 8 will strive to complete each of these goal, but could greatly benefit from the addition of a computer science major during the spring semester. .

4.1 Schedule

To reach all of the goals Team 8 has set, Gantt charts for the next 4 semester have been made to ensure Team 8 and the team that follow Team 8 will be able to successfully complete the design. These Gantt charts for each semester are shown in the appendix.

4.2 Resource Allocation

Table 5:Tasks for David Hegg

Task	Type	Time Frame
MIcrocontrollers	Calculation and Research	10 hours
Inventory of Parts	Inventory	5 hours
Stabilization Research	Research	5 hours

Table 6: Tasks for Jermaine Dickey

Task	Type	Time Frame
Frame Design	CAD	10 hours
Material Selection	Research and Purchase	2 hours
Drawings and Dimensions	Research	8 hours

Table 7: Tasks for Will Di Scipio

Task	Type	Time Frame
Thrust Calculations	Calculations	8 hours
Stabilization Research	Research	6 hours

Frame Cost Projection	Calculation and Research	3 hours

Table 8: Tasks for Tavarius Slaughter

Task	Type	Time Frame
Autopilot Research	Research and Purchasing	4 hours
Radio Controller Selection	Purchase and Research	6 hours
Project Budget Projection	Research and Calculation	8 hours

Table 9: Tasks for Gavarni Leonce

Task	Type	Time Frame
Power Supply Design	CAD and Research	10 hours
Inventory Electrical Components	Inventory	5 hours
Wiring/Schematics	Purchasing and Research	2 weeks

Table 10: Tasks for Chris Bergljung

Task	Type	Time Frame
Stabilization Research	Research	8 hours
Force/Moment Calculation	Calculations	8 hours
Center of Gravity Calculation	Calculations	8 hours

Table 11: Tasks for John Murnane

Task	Type	Time Frame
DC Motor	Research	4 hours

Rotor Selections	Research and Purchasing	4 hours
Stabilization Controls	Research	8 hours
Web Design	Maintenance	6 hours

5 Conclusion

The AUVSI SUAS Competition presents an opportunity for engineering students to expand their knowledge and challenge themselves by building a fully autonomous UAV. The challenge is an exceptionally large task, often taking years of work and collaboration to successfully complete. Team 8 aims to continue advancing the FSU/FAMU college of engineering senior design team toward reaching the competition. Last year, the team was able to build an aircraft capable of semi-autonomous flight, and a vision system capable of some target identification. The team had a difficult time automating the takeoff and landing of the aircraft. Because of these issues, Team 8 had decided to design and retrofit the existing Senior Telemaster plane for VTOL. The team will aim to integrate the automated vertical takeoff and landing with the existing platform and automation from last year. The resulting aircraft will be an ideal aircraft for the competition, with characteristics of multi-rotor aircraft and fixed wing aircraft. Team 8 decided that Design 3; a fully adjustable, exoskeleton-style attachment, would best fit the situation. This allows attachment of the multi-rotor without physical modification of the flight-proven plane. To accomplish this goal, all team members must work and communicate effectively; even with two members working abroad as part of the FIPSE program. The team must finalize the mechanical and electrical designs, construct the system, and program the aircraft for both vertical and horizontal flight. Upon the completion of the project, Team 8 hopes to have a functional VTOL aircraft that fits within the 2015 AUVSI SUAS Competition specifications. This project will put the future teams in a great position to succeed in subsequent competitions.

6 References

1. "Arcturus UAV Home Page." *Arcturus UAV Home Page*. Web. 31 Oct. 2014.
2. "Hybrid Quadrotor Technology." *Hybid Quadrotor*. Web. 31 Oct. 2014.
3. "2015 AUVSI SUAS Rules Rev 0.9 DRAFT." *AUVSI Seafarer Chapter.* Web. 31 Oct. 2014.
4. "APM 2.5 Set." - *3DRobotics Inc*. Web. 31 Oct. 2014.
5. "What I Need for Arducopter UAV."*Arduino Based Arducopter UAV, the Open Source Multi-rotor*. Web. 31 Oct. 2014.
6. "Multistar High Capacity 3S 5200mAh Multi-Rotor Lipo Pack." *HobbyKing Store*. HobbyKing, n.d. Web. 31 Oct. 2014.

6 Appendix

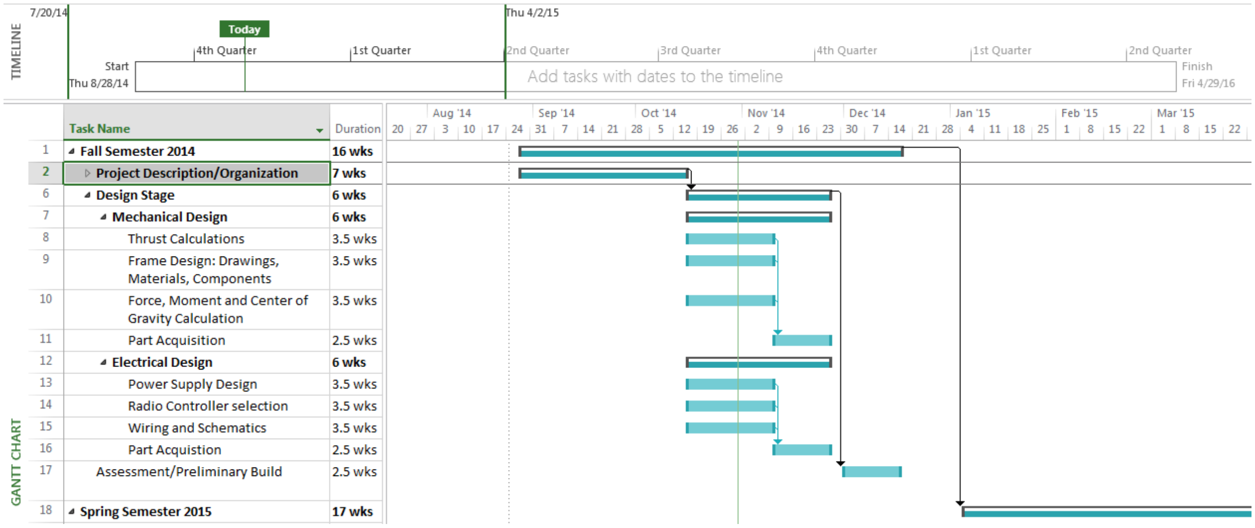

Figure 7. Fall 2014 Gantt Chart

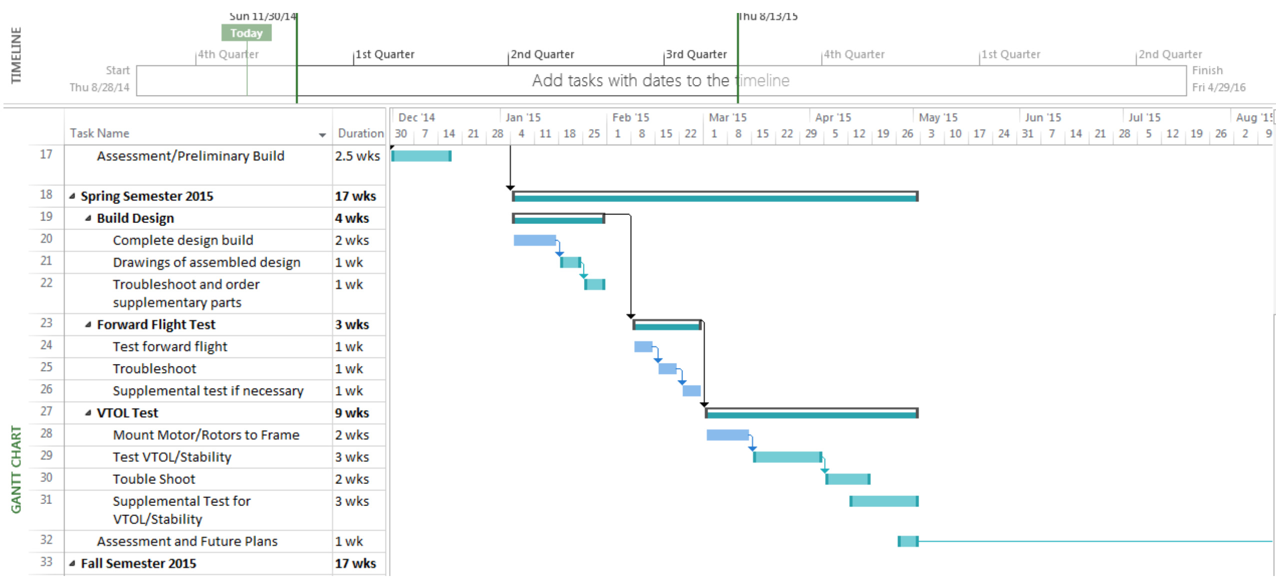

Figure 8. Spring 2015 Gantt Chart

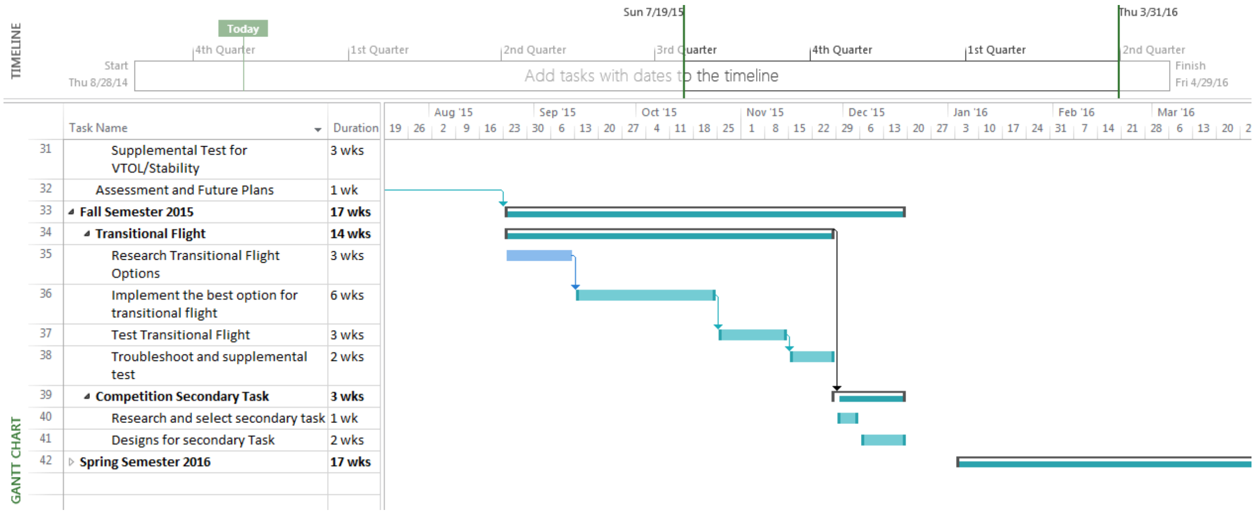

Figure 9. Fall 2015 Gantt Chart

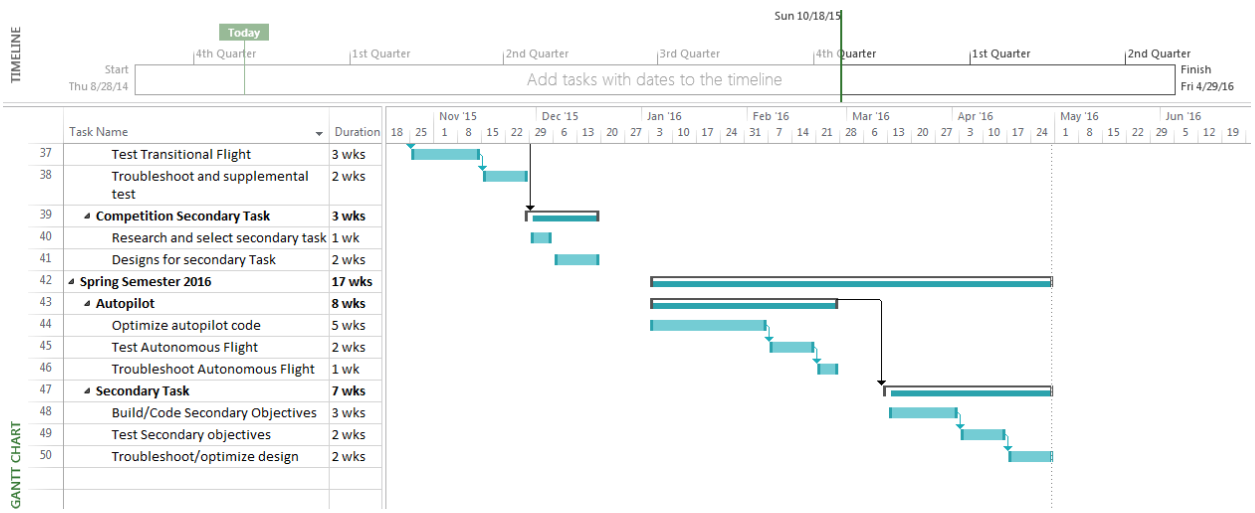

Figure 10. Spring 2016 Gantt Chart

Calculations:

Current Draw

Battery Capacity= B_c = 5200 mAh

Peak Discharge= P_d = 20C

$$Discharge = B_c * P_d = 104000mA = 104\ A$$

Max current that can be drawn from a 5200 mAh battery.

Flight Time

Current Drawn from 4 motors= C_d = 28 A

Battery Capacity= B_c = 5200 mAh

$$Flight\ time = \frac{B_c}{1000 * C_d} * (60) = 11.1\ min$$