Midterm I

Team 8

Design an Unmanned Tilt-Rotor Aircraft for Multi-Mission Application

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ABSTRACT

Team 8 has been tasked with designing an aerial vehicle capable of completing various in air operations, ranging from waypoint navigation to payload delivery. Team 8 has decided to utilize the innovative technology of rotorcraft in conjunction with a fixed wing plane. This vehicle will use a rotorcraft for vertical take-off and landing and transition to horizontal flight for task completion. This will be achieved with the use of a tri-copter design, implementing a tilt-rotor mechanism.

1. Introduction

Every year the Seafarer Chapter of The Association for Unmanned Vehicle System International, also known as AUVSI, host a student design competition. This competition is known as the Student Unmanned Air Systems (SUAS). This year's competition will be hosted in Webster Field, Patuxent River, MD from June 15^{th} -19^{th}. This competition is intended to stimulate and foster interest in the innovative technology and encourage careers in the field.

This competition requires the students to design, manufacture, and demonstrate a system capable of completing a specified aerial operation autonomously, whilst ensuring safe application and execution of Systems Engineering principles. This competition is a college level competition, and will be supervised by multiple sources such as, government agencies, contractors, engineering firms, and universities. There are three components to this competition, the technical paper, the flight readiness review (FRR), and the flight-mission demonstration. The technical paper will be produced when the team has completed all design, verification, and fabrication; this document will describe in detail all aspects of our design process, research and results. The FRR is an oral presentation provided by the flight team at the time of competition to demonstrate readiness to compete. While the Journal Paper and Oral Presentation are collectively worth 50% of the overall grade given in the competition, the other 50% is based on the Flight-Mission Demonstration.

The Flight-Mission Demonstration is comprised of primary and secondary tasks. The scoring for these two types of tasks are divided as follows; the Primary tasks are worth 60% of the demonstration and the Secondary tasks are worth 40%. Throughout each task, there is a minimum threshold that must be met for each of its aspects. There will be no points assigned to those who do not complete the threshold. 50% of the points is awarded if the threshold is met. Each task also has an objective, which the team should aim for when competing. Completing the objectives will award 100% points for that task. To aid in the understanding of these objectives they have highlighted some terminology:

- "Shall" – indicated a requirement is a **THRESHOLD.** Failure to meet the threshold is a failure to meet the minimum criteria.
- "Should" – indicates a requirement that is an **OBJECTIVE.** Demonstrating these requirements will earn extra points, but basic mission can be achieved without meeting it.

- “May” – indicates a permissible implementation, but is not a requirement.
- “Will” – indicates actions to be taken by the competition judges or other information pertaining to the conduct of the competition.

There are two Primary task: Autonomous flight and search area. Both are each worth 50% of the original 60% of the Primary demonstration. Below are the primary and secondary tasks in detail. The first of the primary task is the Autonomous Flight Task, below you can see in Table 1 the parameters of this task. With Autonomous flight, the threshold is to have the craft to takeoff, fly, and capture waypoints, have Ground Control Station display, and land. The objective is to achieve all of that, but completely autonomously.

Table 1 - Autonomous Flight Task (Primary)

Parameter	Threshold	Objective
Takeoff	Achieve controlled takeoff. Properly transition to autonomous flight.	Achieve controlled autonomous takeoff. Properly transition to autonomous flight.
Flight	Maximum of 3 minutes manual flight. Maximum of 3 manual takeovers from autonomous flight.	Achieve controlled autonomous flight with no manual flight, except for transition from manual takeoff.
Waypoint navigation (every waypoint)	Capture waypoint in sequence with ±50 ft. accuracy, and maintain navigation ±100 ft. along the planned flight path	Capture waypoint in sequence while in autopilot control with ±50 ft. accuracy, and maintain navigation ±100 ft. along the planned flight path.
GCS display items	Accurately display “no-fly-zone boundaries” and **shall** accurately display current aircraft position with respect to the “no-fly-zone” boundary, display indicated airspeed (**KIAS**) and altitude (**feet-MSL**) to the operators and judges	
Landing	Achieve controlled landing. Properly transition from autonomous flight	Achieve controlled autonomous landing. Properly transition from autonomous flight

The next primary task is the search area task, after the vehicle has properly completed the predefined waypoint navigation, the vehicle will enter a search area and will be tasked with identifying targets, Table 2 below defines the parameters. During the Search Area task, the threshold is to classify 2 target, and localize them within 150 feet as well. The objective is to classify 5 targets, localize them within 75 feet, decode a QRC target, provide imagery of the targets, and decipher the anagram collected from the targets, all done autonomously.

Table 2 - Search Area Task (Primary)

Parameter	Threshold	Objective
Localization (each standard and QRC target)	Determine target location within 150 ft. Must be paired with at least a threshold classification	Determine target location within 75 ft. Must be paired with at least a threshold classification
Classification (each standard target)	Provide any two target characteristics, electronically.	Provide all five target characteristics, electronically.
Classification (QRC target)	Detection.	Decode the message.
Imagery (each target)	n/a	Provide cropped target image (>25% of image frame).
Autonomous Search	n/a	Aircraft in autopilot control during search
Secret Message	n/a	Decipher the message anagram collected from the targets in the search area

There are several Secondary tasks that accumulate to 40% of the points for the Demonstration. The Automatic Detection, Localization, and Classification task much like the Search Area task, but with autonomous detection (20%). The Actionable Intelligence task, much like the Search Area task, but can transmit the characteristics of the targets electronically (15%). The Off-Axis Standard Target task where the craft must provide imagery and classification of a target outside of the fly boundaries (10%). The Emergent Target Task is where the craft is must autonomously find and identify an “emergent target” when only given a last-known position (10%). The Air-Drop Task has the craft release an object onto a target and is graded on accuracy (5%). The Simulate Remote Information Center task is where the craft must autonomously download a message and upload a text file (10%). The Interoperability task is where the craft can communicate with a server and upload target details (10%). The Sense, Detect, and Avoid task is where the craft can avoid both a stationary obstacle and moving one (20%). The following Tables 3-10 are detailed layouts of these secondary tasks, this includes the parameters and their thresholds and objective.

Table 3 - Automatic, Detection, Localization, and Classification (ADLC) Task (Secondary)

Parameter	Threshold	Objective
Automatic Localization (each target, standard and QRC)	n/a	Automatically tag and identify target position within 150 ft.
Automatic Classification (each standard target)	n/a	Provide at least three of five target characteristics electronically.
Automatic Classification (each QRC target)	n/a	Automatically decode the message.
False Alarm Rate (FAR) on Classification.	n/a	Demonstrate > 50% (with only 6 detections >50% is a 67% classification rate).

Table 4 - Actionable Intelligence Task (Secondary)

Parameter	Threshold	Objective
Actionable Intelligence (any target)	Provide target location within 150 ft. and 3 characteristics electronically, while airborne during the same flight	Provide target location within 75 ft. and all 5 characteristics electronically, while airborne during the same flight.

Table 5 - Off-Axis Standard Target Task (Secondary)

Parameter	Threshold	Objective
Imagery	n/a	Provide an image of the off-axis target electronically.
Classification	Provide any two target characteristics electronically	Provide all five target characteristics electronically
Payload Autonomy	n/a	Automatic persistent tracking of the off-axis target during search

Table 6 - Emergent Target Task (Secondary)

Parameter	Threshold	Objective
In-flight re-tasking	n/a	Add last known position of the emergent target as a waypoint.
Autonomous Search	n/a	Autopilot control during search.
Target Identification	Provide an image of the emergent target, electronically.	Provide an image of the target, electronically, along with target location within 75 ft and an adequate description of the emergent target's activity, electronically.

Table 7 - Air Drop Task (Secondary)

Parameter	Threshold	Objective
Release	Manual release within constraints	Autonomous release within constraints.
Drop Accuracy	≤ 100 ft. from center.	≤ 30 ft. from center.
Bull's Eye Delivery	n/a	Hit the 5 ft. radius bull's eye.

Table 8 - Simulated Remote Information Center (SRIC) Task (Secondary)

Parameter	Threshold	Objective
Localization (each standard and QRC target)	Determine target location within 150 ft. Must be paired with at least a threshold classification	Determine target location within 75 ft. Must be paired with at least a threshold classification
Classification (each standard target)	Provide any two target characteristics, electronically.	Provide all five target characteristics, electronically.
Classification (QRC target)	Detection.	Decode the message.

Table 9 - Interoperability Task (Secondary)

Parameter	Threshold	Objective
SRIC Download task	n/a	Download the SRIC message. Download path: /team/X/download.tx
SRIC Upload task	n/a	Upload a secret text file to the same folder. Upload path: /team/X/upload.txt
Autonomous SRIC task	n/a	Automatically detect SRIC and perform download and upload tasks.

Table 10 - Sense, Detect, and Avoid (SDA) Task (Secondary)

Parameter	Threshold	Objective
Localization (each standard and QRC target)	Determine target location within 150 ft. Must be paired with at least a threshold classification	Determine target location within 75 ft. Must be paired with at least a threshold classification
Classification (each standard target)	Provide any two target characteristics, electronically.	Provide all five target characteristics, electronically.
Classification (QRC target)	Detection.	Decode the message.

In addition to the three main components, throughout the design process, the AUVSI committee requires our team to provide deliverables and communication, more details on these dates and descriptions can be found in the project planning section of this report. The AUVSI Committee also establishes rules which govern the systems constraints and requirement, more detail on this can be found in the needs assessment on this report.

In order to successfully compete in this competition our team must design an Unmanned Aerial Vehicles (UAV). UAVs are airborne crafts that are capable of remote or autonomous control, and have been and will continue to be a critical technology in applications such as reconnaissance and payload delivery. By removing a human pilot from the operation, the risk of human casualties are eliminated. When autonomous, a single UAV can take a tedious task such as searching an area and complete it efficiently. Past uses for UAVs mostly involved some war endeavor, such as use as a weapon and recon. While UAVs are still active in military missions, they have found a more commercial use in society as payload delivery, surveying, agricultural management, and emergency response/aid.

UAVs come in many different shapes and sizes, all falling under two main categories Planes and Rotorcrafts. Rotorcrafts are aircrafts with a configuration of multiple rotors that can efficiently climb vertically and hover in place. They are a common form of UAV because of their ability in vertical flight and precision. Planes provide high efficiency and are valuable for flying long distances. Both Rotorcraft and Planes are efficient at what they do, but a hybrid version of the two could be both efficient in horizontal and vertical flight. This project's design is to combine the two air systems into one to take advantage of both efficiencies. We have considered many variations of rotorcraft and plane configurations, and have decided a Tri-copter and Flying Wing would be most advantageous. The Tri-copter/Flying Wing would have a tilt rotor that rotates the front two propellers forward, creating a transition from Vertical Take-Off and Landing (VTOL) to horizontal flight. In Figure 1, below, you can find a rendering made of this hybrid design concept.

Figure 1 - Conceptual Rendering

2. Background Research

The Unmanned Aerial Vehicle (UAV) maintains its relevance by not requiring a living person to control it and/or be onboard during use. Some of the first UAV systems were not planes as what would first come to mind, but were munitions like an aerial torpedo that would blow up after a set time. The first actual unmanned aerial vehicle would be the Hewitt-Sperry Automatic Airplane, in 1918, which similar to the UAVs today use the help of sensors like the gyroscope, flight surface manipulators to stabilize itself, and the use of radio control to be piloted from tens of miles away[6]. Not all of these aircraft are used for military use around 1930 is when RC flying among civilians became popular[7]. Using the same radio controlled concept just scaled down and lacking most if not all of the stabilization anyone could pilot their own UAV. The way UAVs were used, in a military point of view, didn't change much until "The War of Attrition" in 1967 where the UAVs were used more for reconnaissance, or intelligence gathering[8], than running attack missions. After almost a hundred years several things have changed including the types of sensors available, the increased accuracy of said sensors, the application of autonomous systems to munitions, and the aerodynamic advancements of aerial vehicles themselves. The most used UAV in the 21st century is the General Atomics MQ-1 Predator which started out as a reconnaissance drone, but now is currently being outfitted with several missiles and rockets capable of destroying a bunker over 600 miles away while remaining in the air for up to fourteen hours[9].
There is another type of UAV that hasn't been discussed yet and that is the autonomous UAV. Every type of vehicle previously mentioned has either had a very simple control (a timer) or has been controlled by a user. A fully autonomous UAV acts completely on its own making its own decisions on where it needs to be, how fast it needs to get there, how to deal with obstacles or hostiles, and what to do when it arrives. This is where the majority of research in UAVs goes today like the swarming LOCUST[10] to cargo precision landing Firefly's[11].

These unmanned aerial vehicles avoid the loss of human life by relocating the pilot away from the cockpit. This also allows for these vehicles to take on more risky tasks that would otherwise be deemed too dangerous to perform.

The applications of Unmanned Aerial Vehicles are vast, encompassing Security, Search & Rescue, Monitoring, Management, Communications, and Survey purposes. UAV's are capable of aerial reconnaissance, policing, and trafficking, as well as aiding in disaster relief. Commercial uses include agricultural management and monitoring natural environments. It is estimated that 80% of UAV applications will be for farming [#], as infrared sensors can find fertile areas on a farm. Beyond agriculture UAV applications are currently extending to firefighting and media purposes, where aerial photography could be beneficial in providing overhead views not easily obtainable filming angles unobtainable from the ground all the while eliminating for eliminates the risk to pilots, as well as having a constant monitoring of forest fires. UAV’s even have applications in media and entertainment uses, as they can get

aerial views not easily obtained.

Research has been done on the advantages and disadvantages of various planes and rotorcraft vehicles. These planes and rotorcraft also included this project’s past year’s designs. From this research Team 8 has decided on the best possible components for a V-TOL system which will be discussed in a later section.

A lot more research must be done in order to compete in the AUVSI SUAS competition. One of the topics includes performing FEA analysis on the internal mount positions so Team 8 can plan according with the design of those components. Also another near future research point is the integration of the tilt rotor’s control algorithm into the firmware that is already available for V-TOL flight. The AUVSI SUAS competition requires the identification of characteristics of ground targets like what shape, color, letter, or number is being displayed. Team 8 plans on doing research into the Pixycam, which is a commercially available imaging device that has the capabilities to detect the characteristics stated previously. As well as finding servos that are both high torque and high speed, reinforcing the surface with carbon fiber, making a suitable ground station, and diving into the firmware for V-TOL flight.

Research has been done on the advantages and disadvantages of various plane and rotorcraft vehicles. Vehicles such as multi rotors, like the quadcopters, which are very maneuverable, but the continuous use of four motors means a short flight time. Fixed wing aircraft, like the traditional single prop planes, are much more efficient in horizontal flight and because of that can maintain a longer flight time. A specific design, called the Firefly Y6 by BirdsEyeView Aerobotics, is a hexacopter that can transition from multicopter to flying wing by tilting the front two set of props forward.

5. Needs Assessment

4. Customer Requirements

Our project goal being to enter the SUAS competition, we have customer requirements from multiple sources. Not only do we have to satisfy our sponsor's requirements, we also must satisfy the requirements needed for participating in the SUAS competition. It is these requirements that we will incorporate into our House of Quality in Figure 2 below.

These requirements include:

- The vehicle should be capable of vertical take-off and landing
- The vehicle should be capable of heavier than air flight
- The vehicle should have a visual feed for target acquisition
- The vehicle should have a time of flight long enough to complete competition objectives
- The vehicle should be able to operate in a safe manner at all times during operation
- The vehicle should sense, detect and avoid moving or stationary obstacles along its path
- The vehicle should be able to achieve controlled take-off and properly changeover to autonomous flight. In the same manner, transit from autonomous flight to a properly achieved controlled landing.

Competition constraints

The AUVSI organization has a guide encompassing the rules of the SUAS competition. These rules became the basis for our constraints that follow:

- The maximum takeoff gross weight of the aircraft shall be less than 55 pounds, when fueled and weighed with a calibrated scale; unless in compliance with the AMA Large Model Airplane program. (AMA Document 520-A.)
- The maximum airspeed of the UAV shall not exceed 100 KIAS.

- The UAV shall sustain flight within 100 and 750 feet. Flight of about 400 feet above ground level within three (3) miles of an airport without notifying the airport operator is not allowed
- The UAV should not interfere with operations and traffic patterns at any airport, heliport or seaplane base except where there is a mixed use agreement
- The UAV should not operate aircraft with metal-blade propellers or with gaseous boosts except for helicopters operated under the provision
- The UAV should not operate model aircraft carrying pyrotechnic devices that explode or burn, or any device which propels a projectile or drops any object that creates a hazard to persons or property
- The UAV should not operate a turbine-powered aircraft, unless in compliance with the AMA turbine regulations. (AMA Document #510-A.).
- Based on the competition flying time is 30 minutes maximum
- Aircraft should be able to operate in winds up to 15 knots, gusts up to 20 knots and surface temperatures up to 110 degrees Fahrenheit
- Aircraft must be able to navigate using GPS coordinates
- The UAV shall upload position information at a target rate of 10Hz from the first takeoff until the last landing with an average upload rate of 8Hz or more

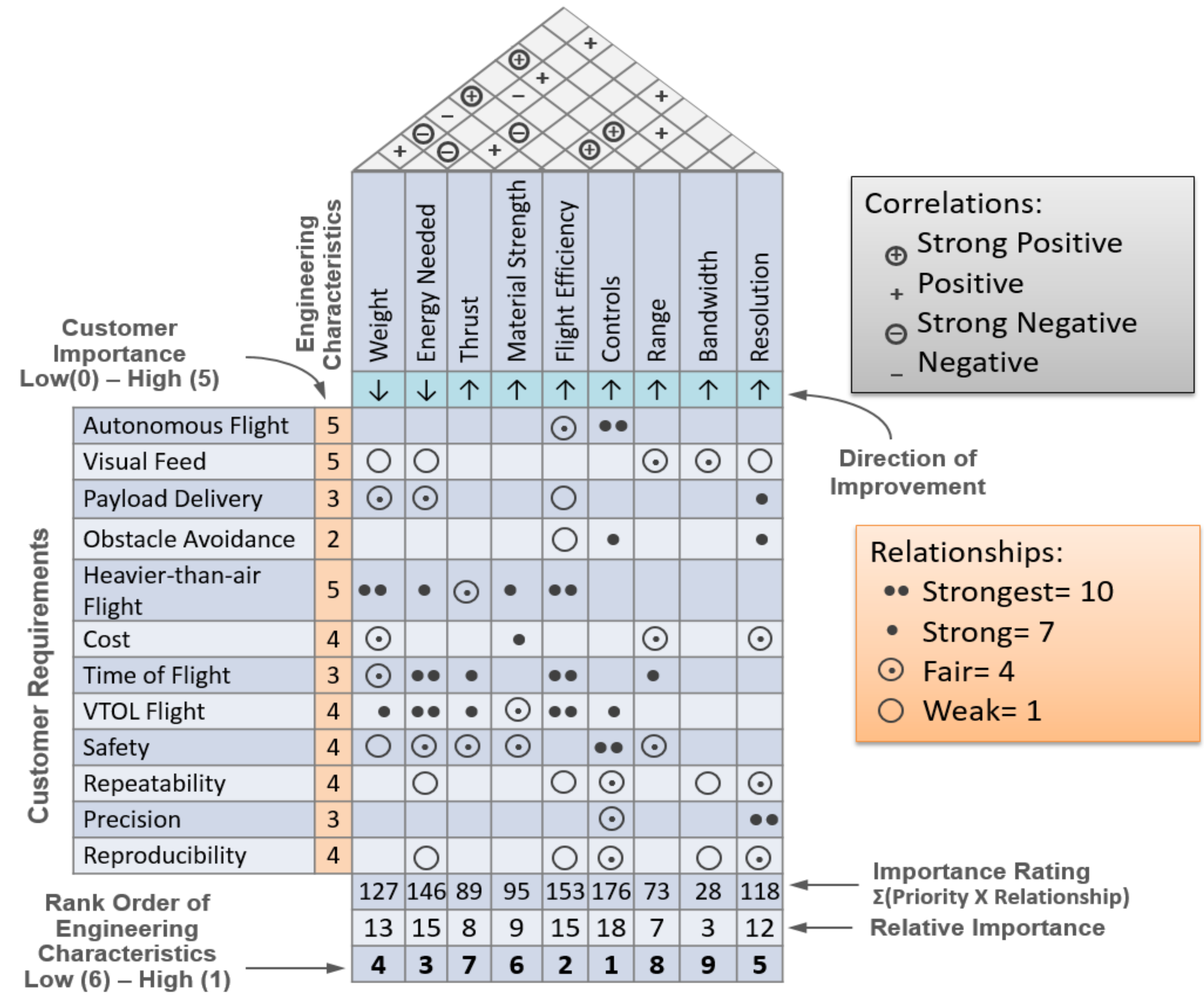

Figure 2 - House of Quality

5. Needs Statement & Goal Statement

After analyzing all the information from the AUVSI SUAS competition the needs statement generated is as follows:

> "There needs to be an autonomous aerial vehicle capable of navigating waypoints, searching autonomously, and identifying targets."

As a team of engineers the group decided that the following goal statement that they would follow is:

> "The goal is to design an autonomous aerial vehicle able to compete in the SUAS competition and capable of vertical take-off and landing."

6. Project Scope

This design should fulfill the customer requirements, as well as competition specifications. The aircraft is expected to be capable of Vertical Take-Off & Landing (VTOL) as well as autonomously navigating waypoints and search large areas for targets and determine the characteristics of target. For our tilt rotor design, the team has decided to first build a prototype that will be incorporated into the Skywalker frame. Most of the components needed for the prototype matches the components left by the older groups. Our major purchase will be the Skywalker X8 and the sensor package.

Part of the project objective is to integrate all systems including the visuals, communication system, mechatronics and as well develop a firmware that suits the UAV design. The firmware that will be used for the design is the Pixhawk with an open source. Each of these integrated systems has to meet the competition requirements. For example, the RF communication is allowed to be on Wi- Fi (2.4/5.8GHz) and on (RF) 900 MHz.

Moreover, the assembled prototype will be benchmarked by comparing it to existing designs like the Firefly Y6 and other functional UAV resource available. Characteristics like efficiency, speed, travel time and payload would be compared. This is to ensure that the design has high performance as compared to existing models. Furthermore, the design will be tested manually for takeoff and landing as well as controlling autonomously. The competition allows the use of manual and autonomous control for the aircraft.

As what is required of the UAV sensor package, it should sense, detect and interpret object target. It should be capable of avoiding obstacles in the air. With telemetry, we can receive real-time information on the condition of the aircraft. After all of the mentioned steps above has been completed, the team will analyze or determine the technical details and performance of the vehicle. Based on these results we can decide if the UAV meets the competition requirements.

As soon as all project objectives are met, we will compete against other teams at the Student Unmanned Aerial System (SUAS) Competition between June 15-19, 2016.

7. Methodology

4. Embodiment Design

After the project scope has been properly realized, it is appropriate to begin the embodiment design process. Embodiment design is a part of the design process in which the design is progressed while taking into consideration the technical and economic criteria that has been established. The main embodiment design concepts that will be focused on are brainstorming, concept generation, and hardware failure modes and effects analysis (H-FMEA).

5. Brainstorming

The initial stage in embodiment design is the brainstorming stage. In this stage, basic concepts are brought about to facilitate a creative atmosphere while also establishing a healthy foundation for the design to rise from. During the brainstorming stage, all ideas are shared from each member of the group. This allows for a culmination of diverse ideas, as each member has a unique background. While sharing and discussing ideas, four main concepts seemed to be focused on which were aptly suitable for the AUVSI competition. These four feasible SUAS concepts were a multi-rotor, a commercially available V-TOL flying wing, a continuation from a previous group's V-TOL design, or a completely new V-TOL design. These broad concepts for the flying platform will serve as the main contenders in the concept generation. The brainstorming session also yielded in the implicit project requirements. These project requirements are not stated explicitly, but rather require knowledge of how to best perform. An example of an implicit project requirement is the time of flight. The maximum flight time allowed in the competition is 45 minutes. This serves as a goal to increase the flight time as much as possible in order to achieve success in multiple primary and secondary objectives. Understanding and knowing the project requirements allows further analysis to be conducted on them. To initiate this process, a house of quality will be used.

6. House of Quality

The House of Quality (HOQ), as seen in Figure 2, is used to relate project requirements with the certain engineering characteristics. The project requirements are found on the left portion of the figure, and the engineering characteristics on the top portion. The requirements that have been determined implicitly and explicitly are given a corresponding level of customer importance. This value varies from 0 to 5, where 0 is the lowest value and 5 is the highest value. In this case, the customer importance is synonymous with the project importance, or how important each requirement is to the project. The engineering characteristics have a determined direction of improvement associated with them. For example, the design is improved if the weight decreases. Each of the engineering characteristics are related to each other through the use of the correlation matrix. The correlation matrix is found above the engineering characteristics – this is the theoretical "roof" of the House of Quality. The amount of correlation varies from Strong Positive to Strong Negative. These correlations are based upon the engineering characteristic's direction of improvement. For example, as the weight follows its direction of improvement, or decreases, the energy needed also decreases, or follows its own direction of improvement. This results in a positive correlation between the two engineering characteristics.

Now that the requirements and engineering characteristics have been properly defined, it is possible to relate them to each other. This is done through the use of the relationship matrix, which is the body of the House of Quality. Each requirement is given a level of relationship with each engineering characteristic. These relationships vary from weak (1) to strong (10). An engineering characteristic's importance rating is calculated by summing the values given through the multiplication of each customer importance value and the relationship value for the corresponding customer requirement. Take, for example, Material Strength to be the engineering characteristic of interest. The relationship value for cost is 7. This value multiplied by the customer importance of Cost, 4, yield a value of 28. This is done for all customer requirements and the values are summed to yield a total value of 95. Once all the importance ratings are calculated, they are averaged against the sum of all the importance rating. This calculation gives the Relative Importance of each engineering characteristic. The engineering characteristics are then ranked based upon how important they are in comparison with the other engineering characteristics. It can be seen from Figure 2 that the most important engineering characteristic is Controls. Knowing how these engineering characteristics rank allow insight to where emphasis needs to be placed in the design process.

7. Concept Generation

To generate a design that will address the needs made clear by the House of Quality, a concept generation method is implemented. The morphological method was chosen for the concept generation. The morphological method is useful as it breaks down the concepts or solutions that satisfy the functional parameter of the project requirement of interest. When multiple solutions are present, it allows for a realistic comparison between different designs. Table 11 illustrates the morphological chart used in the concept generation. The differing designs are labeled numerically on the table. Combining all the solutions for each design allows a whole design solution to be generated. Two core designs are illustrated in the morphological chart. For example, the design labeled with a "1" represents a completely new V-TOL design. This design would most likely be the most expensive. As a result of this, it has been given the highest cost association possible. This process is continued for the remaining functional parameters. Once all the other designs have been through concept generation, they are compared in a Pugh matrix.

Table 11 - Morphological Chart

<table>
<tr><th>Project Requirement</th><th>Functional Parameter</th><th colspan="6">Concepts or solutions that satisfy the function</th></tr>
<tr><td>Heavier-Than-Air Flight</td><td>Negatively Buoyant Aircraft</td><td>Quadcopter</td><td colspan="2">Firefly6</td><td colspan="2">Previous V-TOL Design 2</td><td>New V-TOL Design 1</td></tr>
<tr><td>Inexpensive</td><td>Cost</td><td colspan="2">$500</td><td colspan="2">$1000 2</td><td colspan="2">$1500 1</td></tr>
<tr><td>Available Payload</td><td>Carrying Capacity</td><td colspan="2">250g</td><td colspan="2">500g 1</td><td colspan="2">1000g 2</td></tr>
<tr><td>Time of Flight</td><td>Time</td><td colspan="2">10+ min.</td><td colspan="2">25+ min. 2</td><td colspan="2">40+ min. 1</td></tr>
<tr><td>Efficiency</td><td>Thrust Needed</td><td colspan="2">Low</td><td colspan="2">Medium 1</td><td colspan="2">High 2</td></tr>
</table>

The above is the Pugh matrix used to rank each design concept. The criteria was the same used in the morphological chart. As seen in the AUVSI SUAS competition videos (Citation) most of the teams use only a fixed wing aircraft with either manual takeoff (and landing) or a used a mechanical launch assist. As mentioned before, Team 8 is required to use V-TOL. Positive values indicate it is better than the datum and negative values indicate that they are worse than the datum. Using the total of each design the New V-TOL design was the one with the best score. Knowing this Team 8 decided to focus more time on the higher scoring design over the other From the Pugh matrix the design chosen was the New VTOL design using the Skywalker frame.

8. H-FMEA

The H-FMEA, located in appendices (A-1), generated focused on each major component of the New V-TOL design and looked at each way those parts could fail. Then, looking at these failure modes, the potential causes and effects are recorded and values assigned to them. These values include the Severity (S) of the failure, where one mean not harmful and ten means catastrophic. The next factor is Occurrence (O), where one means it rarely occurs and ten means it occurs frequently. The last factor is Detection (D), where one means instantly detected and ten means hard to detect. With these there values the Risk Priority Number (RPN) and Criticality (CRIT) can be calculated by multiply S, O, and D. RPN denotes which causes and failure modes should be focused on the most. CRIT focuses on the Severity and Occurrence of the failure mode. Special attention should be paid to the highest scoring RPN and CRIT failure modes. In H-FMEA for Team 8 the two highest ranking failure modes were the “Transition Bar Mounts” failing and the “Tilt Rotor Mount” skipping teeth. Where these failure modes happen can be seen in Figure 3.

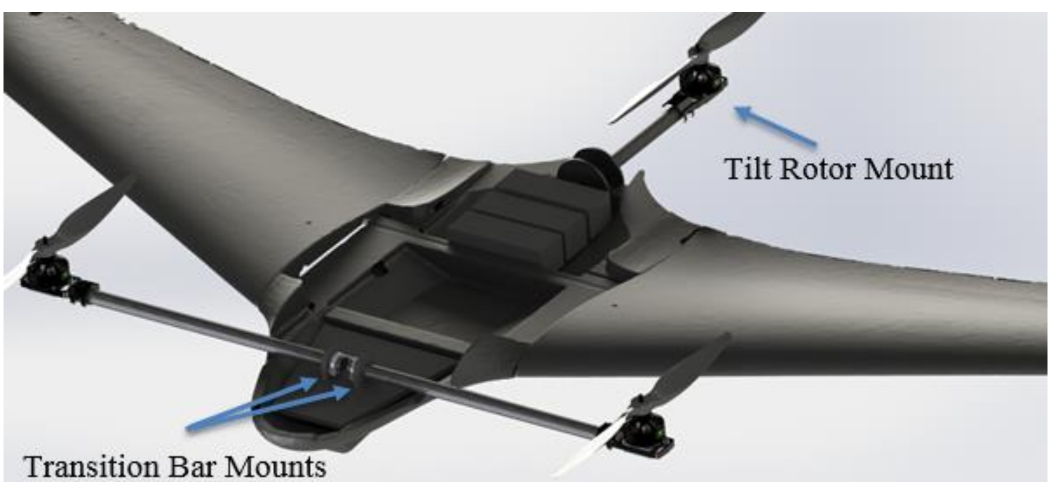

Figure 3 - Exposed Mounts

8. Potential Challenges & Risk

Based on the 2016 Seafarer Association of Unmanned Vehicle System (AUVSI) competition, the Unmanned Aerial Vehicle (UAV) poses these challenges:

- Firmware complications – Our VTOL firmware is being designed using another VTOL vehicles firmware for reference. Our vehicle will have half the motors and because of this our vehicles algorithm for flight might need to be altered which could prove to be a very time consuming process.
- Limited reference for this type of vehicle – There is not a lot of information on fixed wing aircraft capable of VTOL, especially autonomous craft.
- Autonomous flight – Creating an algorithm for VTOL transition to fixed flight, object avoidance, waypoint navigation, and target acquisition will require a lot of research.
- Imaging software / hardware – We have to create our target acquisition software from the ground up although we do have some research leads for the hardware needed.
- Competition fees – The competition fees are $1200 and our budget is $1500. We have already spent $500 on components meaning without a budget increase whether we have a completed vehicle or not, we can't go to competition.

Possible risks associated with our project include:

- Inadequate testing facilities- The competition rules include a range of environmental conditions our vehicle should be able to perform in that we can't always recreate. This could lead to performance issues at the time of competition.
- Flight testing- Whenever our vehicle performs a flight test it runs the risk of crashing.
- Loss of communication- Our vehicle uses radio frequencies to communicate with the controller meaning it is vulnerable to a loss in communication when out of range or blocked by objects such as buildings.
- Schedule delays- Our project has strict deadlines for pre-competition requirements set by the AUVSI that must be met. Failure to meet these deadlines could hinder competing in the summer 2016 competition.

9. Product Specification

With a fundamental understanding of how the matured design will be developed, it is now appropriate to begin the product specification. During the product specification, the actual parts of the design will be realized through the use of engineering practices and analysis. This method ensures that the finished product will not only function as intended, but also have an overall level of robustness towards it. The product specification will focus on the airframe design, propulsion system, and controls.

4. Airframe

The airframe is composed of two major systems, the tri-copter and the fuselage. The tri-copter frame will be created to sit inside the fuselage and provide structural support for the propulsion system. The fuselage will be a flying tailless wing, this fuselage provides both a desirable lift and payload capacity. Further analysis of these systems can be seen in the sections below. All together we are estimating the system will weigh no more than 5500g, this includes an estimate of 0.5kg payload for sensor package and payload delivery systems.

1. Airfoil/Fuselage

When determining the appropriate type of airfoil to use for this unique application, there are somewhat limited resources. Most of the well-known airfoils are those used for full scale aircraft. After a great deal of research, it was found that there are a few hobbyists that create and analyze airfoils for foam R/C aircraft. Among these airfoils, there were a couple of them which were specifically tailored towards tailless models. One of the most common of these is the EH 2.0/10. There is a commercially available flying wing model, the Skywalker X8, which accurately mimics this airfoil. This was determined by using a 3-D laser scan on the airfoil found on the internet. This data allowed a sectional view of the wing to be created. This sectional view is a close representation of the implemented airfoil. When comparing this airfoil sketch with the EH 2.0/10 airfoil, their similarity is clear. This comparison can be seen in Figure 4.

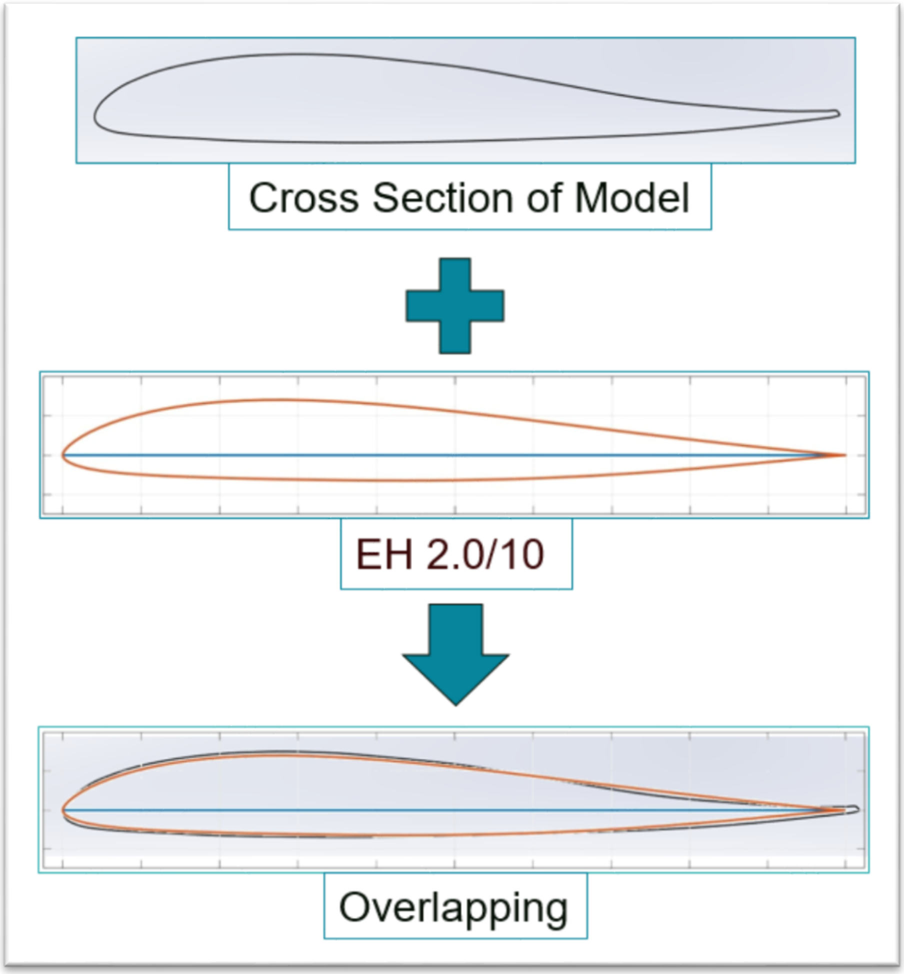

Figure 4 – Airfoil Design

This close relationship allows for an accurate analysis of the airfoil. This is a large reason why the Skywalker X8 was chosen. Further analysis on the characteristics produced by the airfoil was conducted with help from Airfoil Tools. Airfoil Tools is an online resource that provides information for a large number of airfoils. The key information provided is the coefficient of lift as the angle of attack of the airfoil increases. Figure 5 illustrates a graph of this information at a Reynold's number of 200,000.

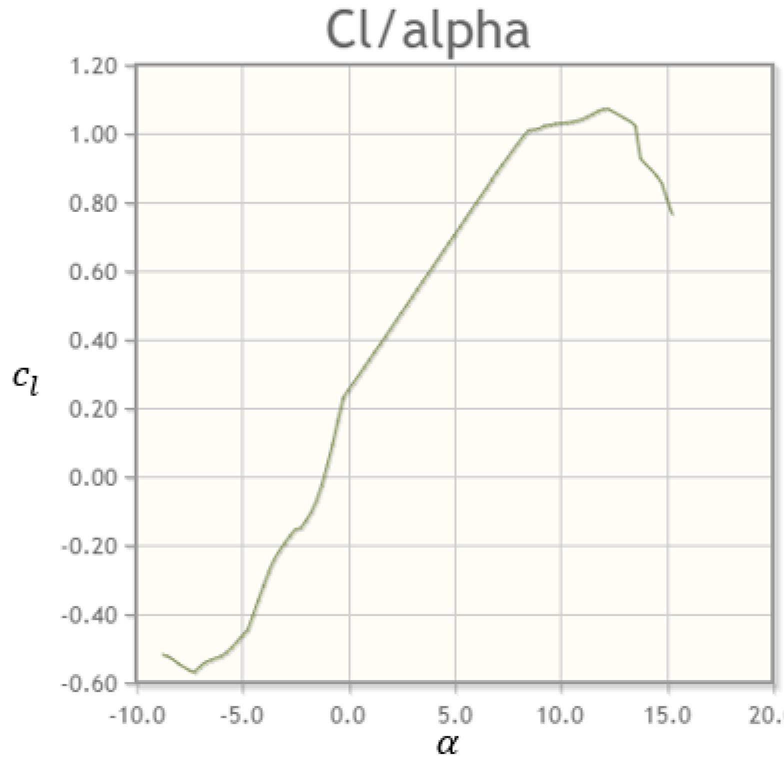

Figure 5 - Airfoil Coefficient of Lift vs. Angle of Attack

For a fixed angle of attack, it is possible to create a relationship between the amount of lift force and the velocity of the airspeed. This is done by gathering the coefficient of lift for varying Reynold's numbers. The coefficient of lift aids in determining the lift force, while the Reynold's number is used to back calculate out the velocity. Using this method a graph was made to illustrate this relationship while also serving as an approximation tool. This graph can be seen in Figure 6.

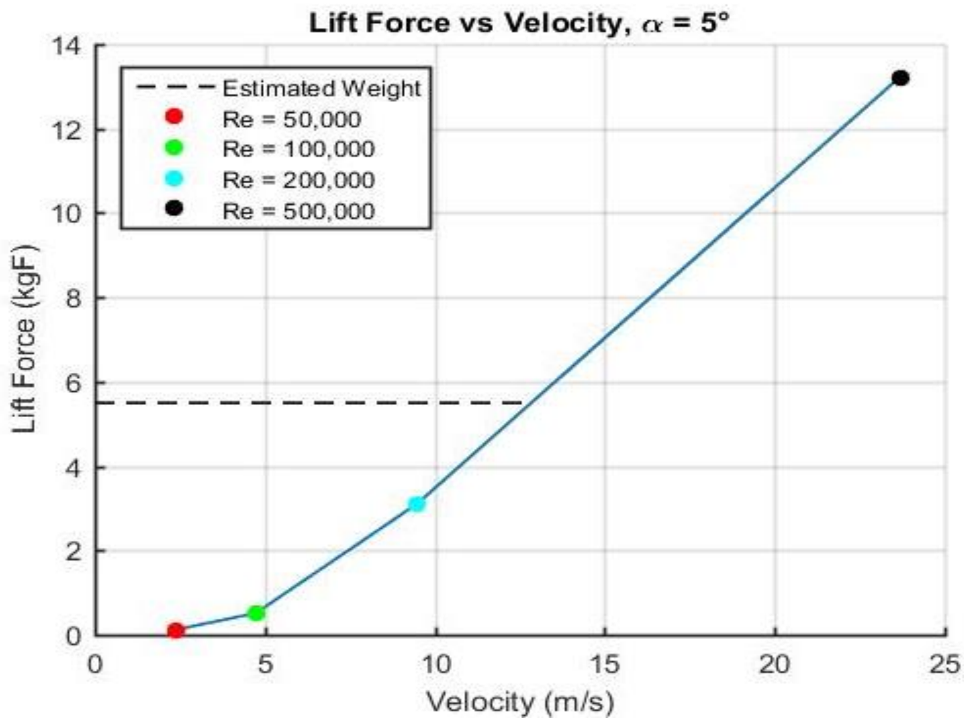

Figure 6 - Lift Force as a function of Velocity

This method can be used as an approximation tool to determine the needed velocity to lift a certain amount of weight. By entrusting the plotted points with making a basic trend, assumptions can be made. With our estimated design weighing in at 5.5 kilograms and an angle of attack of 5 degrees, it would have to be traveling approximately 12.5 m/s. When comparing this value to other R/C aircraft this is a reasonable amount, as the Firefly6 has a max speed of 18 m/s. Also taking into account the very small angle of attack used (5%), this is a worthy airfoil.

2. Tri-Copter

The tri-copter is as it sounds, a three rotor aircraft. This system will be mounted inside the fuselage, the front two motors will extend in front of the wings and the third rotor will be in the rear as seen in figure 1 above. The tri-copter frame will be integrated to stay within the fuselage, along with all other communication and propulsion components, this allows for lower drag. The tri-copter will also utilize a tilt-rotor mechanism for transition from vertical to horizontal flight. By this we mean, with the use of a servo we will tilt the two front rotors forward for horizontal flight and up for vertical flight. Since the system is a tri copter, thus an uneven amount of rotors, we will have a moment about the center due to the rotation of the rotors. To circumvent this the system will use a tilting motor mount, this allows for the change in axis of the rotor to combat the change in yaw of the aircraft.

5. Propulsion System

The propulsion system of this aircraft entails all the components that work in unison to provide thrust to the vehicle. This propulsion system is composed of three motors, three propellers, three motor controllers, and a power supply.

1. Motor

The motors we have chosen for this aircraft are the Cobra 4510-28 Brushless motors, these motors are 420kv motors. This means that these motors revolve 420 times a minute for every 1 volt supplied, which equates to roughly 155 times a second (with 22.2V battery). This is relatively slow compared to most RC propulsion systems, but nonetheless very dangerous. These motors have a maximum continuous current of 35 Amps, this value will be essential in the selection of our microcontroller. This motor allows for both 5-Cell & 6 Cell Li-Po power systems, by this we mean it is limited to using either 18.5 volt or 22.2 lithium polymer batteries. Figure 7 and Figure 8 show a top and side view of this motor, respectively.

Figure 7 - Cobra 4510/28 Top View

Figure 8 - Cobra 4510/28 Side View

2. Propeller

Another essential component of the propulsion system design is the propeller. The propeller selection defines the thrust, thrust efficiency, amp draw, and overall flight time. Knowing this we carefully selected our propellers, luckily the manufacturer of the cobra motors provide some test data of various propeller/battery combinations with our selected motor. Below you will see a detailed chart providing most of the data required to select the proper propeller.

Prop Manf.	Prop Size	Li-Po Cells	Input Voltage	Motor Amps	Input Watts	Prop RPM	Pitch Speed in MPH	Thrust Grams	Thrust Ounces	Thrust Eff. Grams/W
APC	14x5.5-MR	6	22.2	21.50	477.3	7,525	39.2	2788	98.34	5.84
APC	16x5.5-MR	6	22.2	31.29	694.6	6,915	36.0	3749	132.24	5.40
APC	18x5.5-MR	6	22.2	38.76	860.5	6,414	33.4	4468	157.60	5.19
GemFan	15x4.5-MR	6	22.2	19.73	438.0	7,638	32.5	2661	93.86	6.08
GemFan	16x4.5-MR	6	22.2	25.37	563.2	7,276	31.0	3220	113.58	5.72
RC-Timer	12x5.5-CF	6	22.2	16.44	365.0	7,874	41.0	1911	67.41	5.24
RC-Timer	13x5.5-CF	6	22.2	21.90	486.2	7,495	39.0	2417	85.26	4.97
RC-Timer	14x5.5-CF	6	22.2	29.31	650.7	7,021	36.6	2855	100.71	4.39
RC-Timer	15x5.5-CF	6	22.2	40.09	890.0	6,352	33.1	3375	119.05	3.79

The prop is to small to get good performance from the motor. (Less than 50% power)

The prop is sized right to get good power from the motor. (50 to 80% power)

The prop can be used, but full throttle should be kept to short bursts. (80 to 100% power)

The prop is too big for the motor and should not be used. (Over 100% power)

Figure 9 - Propeller Selection Chart

Based on this chart in Figure 9, we were able to select the 16" x 5.5" Propeller, It provided both a high efficiency and a desirable thrust. Though there are propeller combinations that provide higher efficiency, they do not allow for the amount of thrust we would require. When comparing this motor/propeller combination to the desired design weight we can produce some estimates on the amp draw and use of power this can be seen in Figures 10 and 11.

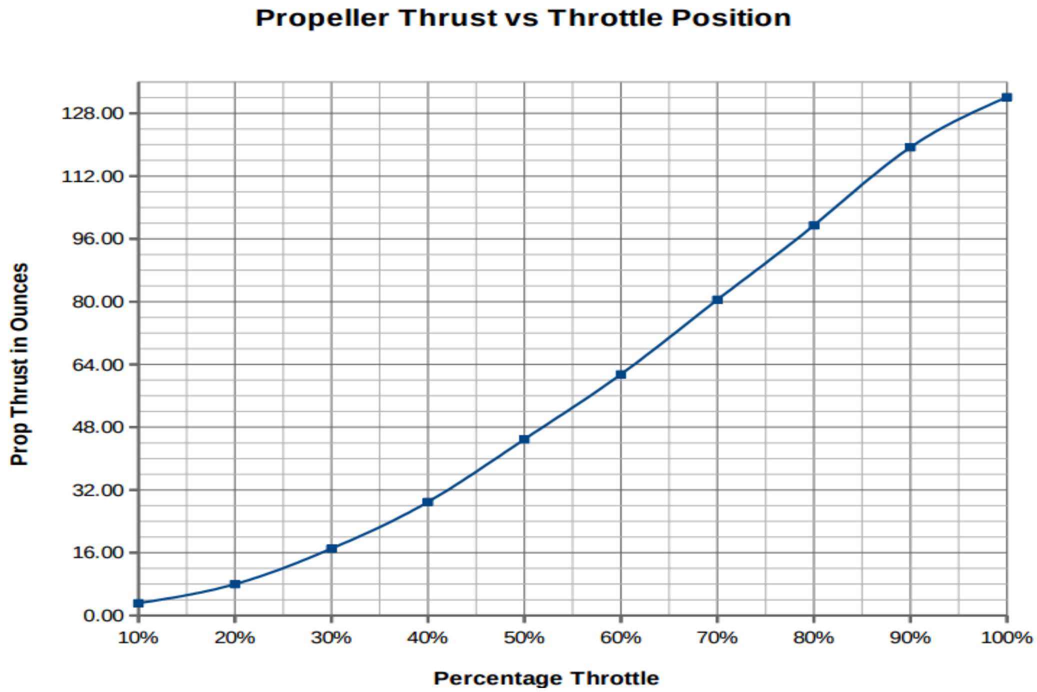

Figure 10 - Thrust vs Throttle

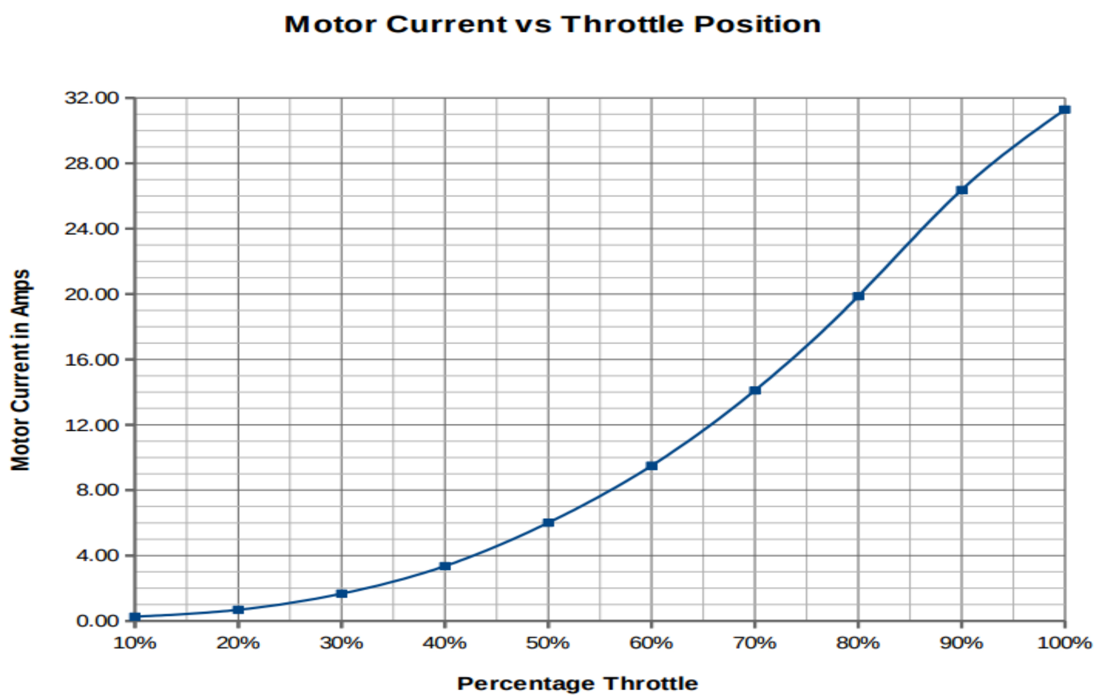

Figure 11 - Amp Draw vs. Throttle

3. Motor Controller

The next component that must be consider is the motor controller. The motor controller is the device that receives a signal from the microcontroller and the power from the power supply, and delivers the appropriate amps to the motor. In this aircraft the motor controller is referred to as an Electronic Speed Control (ESC). For this design we require an ESC that provides the Maximum continuous current draw that our motor requires, as stated before this value is 35 amps. Knowing this we have decided on a Cobra – 40 Amp ESC, this device will provide the required current without any conflict.

4. Power Supply

The last component of the propulsion system that is required is the power supply. For RC systems, the only form of power supply is Direct Current, this limits us to the use of batteries, though obvious, there are still a wide arrangements of batteries to choose from. Another constraint worth mentioning is the weight and voltage of these batteries. At the time, Lithium-Polymer (Li-Po) batteries are the only know batteries that provide the necessary voltage and weigh the least. Moving forward we must decide on a capacity of current that will be enough for our design, we have decided to use three 5000mAh Li-Po batteries for maximum flight-time. With this system we can produce roughly 9.59 minutes of flight, using 100% throttle, a weight of 5.5kg and 15,000 mAh.

$$Flight\ Time = \frac{Battery\ Capacity}{Amp\ Draw}$$

6. Controls

1. Microcontroller

The Pixhawk is an all-in-one flight controller capable of autonomous flight, and is an essential product to include in the design. While it contains the potential for any normal flight project, there exists a community of developers constantly adding and updating unique projects, in the form of open firmware. The Pixhawk is targeted towards high-end research, making it possible to achieve uncommon designs. More specifically, the Pixhawk has the hardware and firmware capable of autonomous VTOL and transition from multicopter to flying wing.

Some of the key features of the Pixhawk include a 168 MHz / 252 MIPS Cortex-M4F, which is more than sufficient for this design, and 14 PWM / Servo outputs, which can accommodate all of the servo, motor, telemetry, and peripheral connections that will be included. There are multiple forms of recovery built into the firmware so that the craft will always be flying in some form, and provides a transition from autopilot to manual. It includes all of the basic sensors required by most flight projects, such as a gyroscope, accelerometer, magnetometer, and barometer.

Firmware development stresses user-friendliness, with a large group of developers communicating and overview others' code. In fact, this firmware required for this design is already developed, and will only require files that have adjustments to variables such as motor speeds, number of motors, multicopter configuration, and flight parameters.

2. Servo

For most the mechanisms in this design, we will be utilizing servos. Servos are geared motors that allow for a range of motions between 0º and 180º, sometimes they allow for full continuous rotation, but this doesn't apply to our design. The servos in our design will provide motion to our elevons, tilt-rotor, and rear tilt mechanism. At this time we are looking further into which servo would be best for each mechanism.

10. Project Plans

As for the Project Plan, we have divided the task for into three categories; VTOL Tilt-Rotor Aircraft Design, senior design deliverable, and competition deadlines. Below is a detail description of each sub component of these categories. In the appendices you will find a Gantt chart representation of these task and the associated dates and progression algorithm.

4. Aircraft Design

For the design category we have decided to focus solely on providing an operation aircraft by the end of the semester, to make this possible we will be holding off on the ground station, sensor package, and payload delivery system until next semester. Though we are holding off on these components, we will be keeping in mind all requirements that these components have, for example: power consumption, necessary space, and associated weight.

1. Fall 2015

- **Brainstorming** – During this process we discussed various topics. Firstly, we had to discuss and decide if we would go forward with the previous year's team. We discussed the timeline, cost, pros and cons associated with changing the design. We eventually decided that a different approach wasn't ideal, but feasible.
- **Design** – Since we decided to change our design approach, we had to come together and apply our knowledge to each subsystem and decide on many factors. Some of the subsystems are the fuselage, airframe, orientation, thrust, weight, aerodynamic characteristics. These systems have been considered and some still need refinement.
- **Manufacturing** – We have begun to manufacture/fabricate a test platform for firmware implementation. This platform will eventually incorporate our final pieces, thus becoming our prototype.
- **Part Ordering** – We have already ordered some essential products for prototyping, for example, abs sheets/wood for chassis creation, props for new thrust efficiency, bearings for transitional pieces (front propulsion transition and yaw component)
- **Prototype Building** – We have begun production of the platform, this includes mount design and overall component placement.
- **Verification** – This process will be a verification of our conceptual design. We anticipate some mechanical/software discrepancies.

- **Modification** - At this time we will address what component are not fully functioning, and make the necessary modifications/adjustments needed to provide successful flight.
- **Part Order/ Manufacturing** - At this time we will address what parts we will need going forward, and purchase new component or if not available, design a substitute component.
- **Final Building** – After all iterations of building and verification process and we are happy, we will produce a refined final product.

2. Spring 2015

- **Ground Station** – We will design a ground communication system, that meets all competition requirements
- **Sensor Package** – We will finding a suitable sensor package for target detection, and adapting the vehicle for the said sensor package
- **Payload Delivery** – The payload delivery system isn't a necessity, it is a secondary task. We believe it is an easy adaptation and therefore will be planning on its implementation
- **Safety Operator flight logs** – A requirement of the competition is a 10 hour flight log on manual control of the competition vehicle, this is for safety precautions.

5. Deliverables

1. Fall 2015

- **Code of Conduct** – This deliverable was to ensure proper order within the team, for example, forms of communication, meeting times, dress code, etc.
- **Needs Assessment** – The report required us to review the competition rules and outline what was necessary going forward. Considerations of sponsor require was taking into account and a problem statement was achieved.
- **Project Plans and Product Specifications** – This document serves as our Project Plan & Product Specification at the time. These concepts will be further developed.
- **Initial Web Page Design** – We have constructed our initial website and contains all necessary pages. These pages are still in need of population, descriptions, files, and poctures.
- **Midterm Presentation I: Conceptual Design** – This will serve as our first presentation and we will bringing forward all our research, calculations, and results thus far.
- **Midterm Report I** - This document has not been created, but it will represent our finding at the time of creation for all conceptual and actual components

- **Peer Evaluation** – We have yet to discuss this, but we infer it will be a evaluation of our efforts from our peers.
- **Midterm Presentation II: Interim Design Review**
- **Peer Review**
- **Final Web Page Design**
- **Final Design Poster Presentation**
- **Final Report**

2. Spring 2016

At this time we are unaware of what will be required of us in the Spring of 2016.

6. Competition Deadlines

1. Fall 2013

- **Team Written Comments** – We prepared comments on the draft ruling of the AUVSI Competition
- **University Day/ Conference Call** – We discussed the discrepancies of the draft rulings
- **Registration** – This will ensure our position in the competition
- **Competition Conference call** – This will be a call to discuss registration, team status update, and rule update.

2. Spring 2015

- **Team Composition Table**
- **Fact Sheet/ Flight Plan**
- **Base Access Information Data/ Signed Team Roster**
- **Competition Mid-Course Call**
- **Proof of Flight Video**
- **Journal Paper Submission**
- **Competition Readiness Call**
- **Career Fair & Student Interviews**
- **Competition**

11. Conclusion

In conclusion our group has decided to develop the skywalker tri-copter design. We will be using the pixhawk microcontroller to allow our vehicle to be fully autonomous and it will incorporate tilt rotors to allow for transition from vertical rotary flight to horizontal fixed wing flight. We have yet to finalize our sensor package software and hardware but are seriously investigating the use of the pixicam. With our current design we aim to complete all objectives at the AUVSI SUAS competition in the Summer of 2016. Autonomous UAV technology is an emerging field with widespread applications both commercially and militarily, and with our project we hope to make contributions to this field of study.

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Please put all references here

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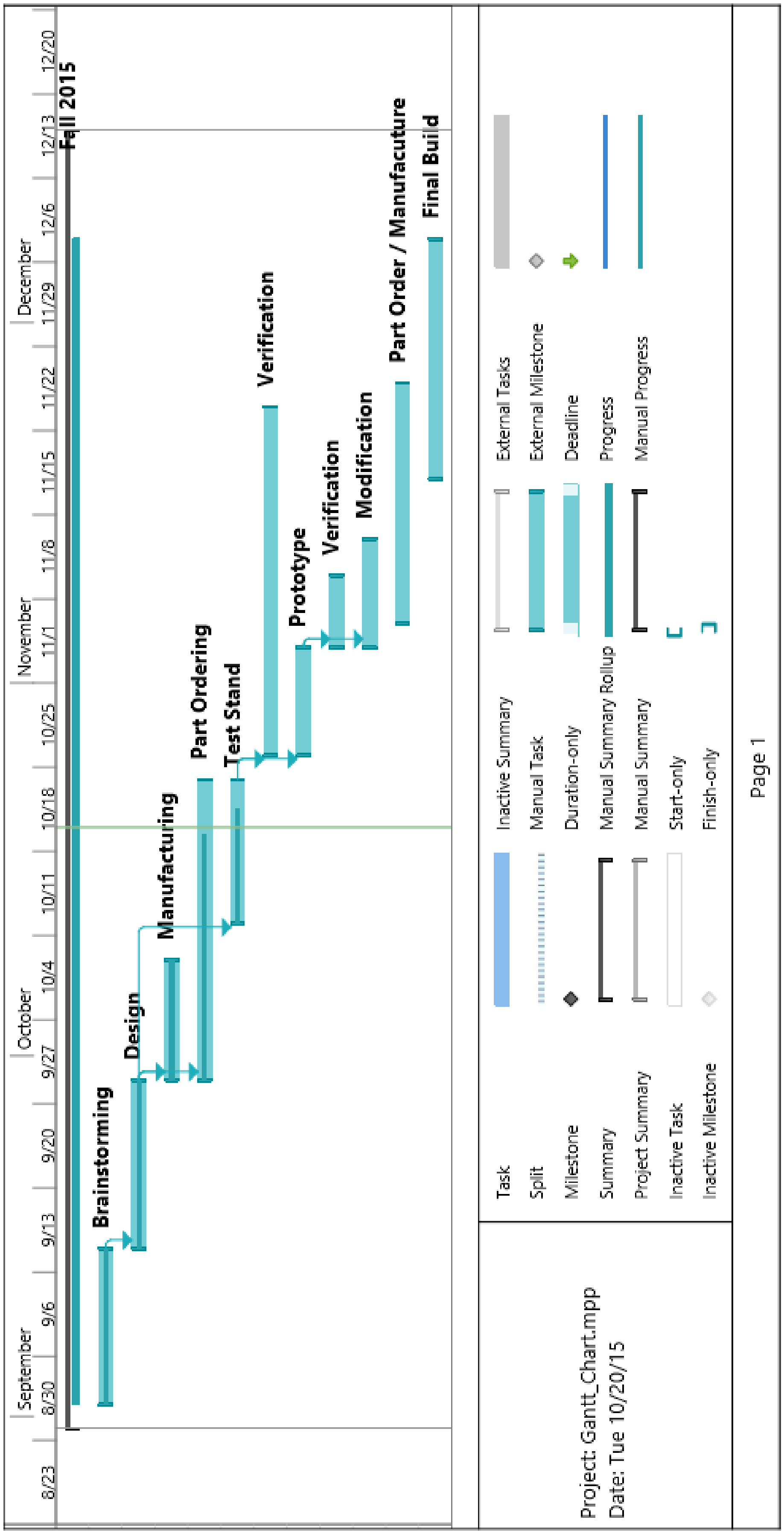
Appendix A

Hardware	Potential Failure Mode	S	Potential Cause of Failure	O	Potential Effect of Failure	Current Control	D	RPN	CRIT	Reccomended Actions
Flying Wing	Wing to body joint fracture	10	High speed vertical take off	3	Crash	Spotter	1	**30**	**30**	Reinforce connection
Transition Bar	Flexing of rods	3	High thrust from motors	7	Controller commands wrong control	Spotter	3	**63**	**21**	Reinforce bar
	Bar mounts failing	10	High thrust from motors	7	Loss of motor control	Spotter	1	**70**	**70**	Have mounts cover more area of bar
Tilt Rotor Mechanism	Gear teeth skipping	10	Soft gear material	7	Loss of zero position	Spotter	6	**420**	**70**	Use harder material for gears
Battery	Voltage below threshold	3	Flying for longer than allowed	3	Damage to battery	Low battery alarm	1	**9**	**9**	Once alarm goes off, land.
	Voltage above threshold	3	Faulty charger/user	3	Damage to battery. Possibly volatile.	Charger alarm	3	**27**	**9**	Take batteries off when fully charged
Electronic Speed Controller	Stop supplying voltage	10	Battery voltage too low	3	Motors stop running	Low battery alarm	1	**30**	**30**	Once alarm goes off, land.
	Fried ESC	10	Applied amperage above upper limit	1	Motors stop running	Using correct the ESC for chosen motor	1	**10**	**10**	N/A
Pixhawk Microcontroller	Supplies wrong control	7	Snags foreign object	1	Crash	Spotter	1	**7**	**7**	Fly in large open areas
Motors	Seized bearings	10	Deterioration of grease	1	Motors inoperable	Spotter	3	**30**	**10**	Taking care of motors


September
October
November
December
8/23
8/30
9/6
9/13
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9/27
10/4
10/11
10/18
10/25
11/1
11/8
11/15
11/22
11/29
12/6
12/13
12/20
Fall 2015
Brainstorming
Design
Manufacturing
Part Ordering
Test Stand
Verification
Prototype
Verification
Modification
Part Order / Manufacuture
Final Build
Project: Gantt_Chart.mpp
Date: Tue 10/20/15
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress
Page 1

Biography

Kade Aley

Kade Aley is a Florida State University Mechanical Engineering student graduating in May of 2016. He is a research assistant at the Florida Center for Advanced Aero Propulsion (FCAAP), where he has participated in several research projects. His passion lies within the realm of unmanned aerial vehicles, as he has constructed several small unmanned aerial systems, both for competition and for pleasure.

Patrick McGlynn

Patrick McGlynn is undergraduate student in the Mechanical Engineering program at Florida State University. Patrick is an officer of the American Society of Mechanical Engineers, and a member of Tau Beta Pi, American Institute of Aeronautics and Astronautics (AIAA), and Small Unmanned Aerial Systems at FSU. He has a passion for the innovation and development of unmanned aerial vehicles.

Jake Denman

Jake Denman is a Computer Engineer Undergraduate at Florida State University, who plans to graduate in Summer of 2016. Within his education at FSU, he developed an interest in coding languages and microprocessors. Outside of his studies, he programs for recreational purposes. He hopes to take his studies farther into a field that will provide challenge.

Kikelomo Ijagbemi

Kikelomo Ijagbemi is a senior Electrical Engineering student at Florida A&M University (FAMU). She interned at Nigerian Airspace Management Agency (NAMA), Lagos State, Nigeria. Kikelomo is interested in Space Communication. She believes solutions to the world's problems exist in nature, if only they can be discovered. She plans to further her education with a graduate study in the field of bio- engineering and pursue a career in the aerospace industry.

Christian Mård

Christian Mard is a Mechanical Engineering student at the FAMU-FSU College of Engineering, graduating in May 2016. Christian's interests lay in robotics and hardware design where he has volunteered in the Center for Intelligent Systems, Control, and Robotics (CISCOR) lab in contribution to “Motion Planning for Wheeled Robot” project. Another interest of Christian’s is in sport of table tennis where he was the FSU Sport Club president for two years and now current A-team player.

Daylan Fitzpatrick

Daylan Fitzpatrick is a mechanical engineering student from Viera, FL. He has attended Florida State University for 4 years and will graduate in May 2016. His 2015 summer break was spent interning at the Kennedy Space Center under NASA's primary contractor Jacobs Technology.