Final Report

Team 8

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

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Table of Contents

Table of Figures

Table of Tables

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 fixed wing 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, hosts 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 specified aerial operations 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, and Table 2 below defines the parameters. During the Search Area task, the threshold is to classify two targets, and localize them within 150 feet as well. The objective is to classify five 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, 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 produce an aircraft viable for 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, without wings, and 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. This group has considered many variations of rotorcraft and plane configurations, and has 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, one 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 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 up to 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, from the gyroscopes, anyone could pilot their own UAV. The way UAVs were used, in a military point of view, did not 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 has not 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 being extended to firefighting and media purposes. In aerial surveillance a UAV can provide points of views that would usually require the use of a manned helicopter where it could look for survivors or watch where forest fires are moving.

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 looking at the past team’s designs and their pitfalls 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 position. With this force analysis Team 8 can design their mounts with factors of safety to make a secure joint. 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 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 their wings provide the more of the lifting force than the motors have to. A specific design, called the Firefly Y6 by BirdsEyeView Aerobotics, is a hexacopter that can transition from multi-rotor to flying wing by tilting the front two set of props forward.

3. Needs Assessment

3.1 Customer Requirements

Team 8's project goal being to enter the SUAS competition, they have customer requirements from multiple sources. Not only do they have to satisfy our sponsor's requirements, they also must satisfy the requirements needed for participating in the SUAS competition. It is these requirements that they will incorporate into our House of Quality in Figure 2.

These requirements include:

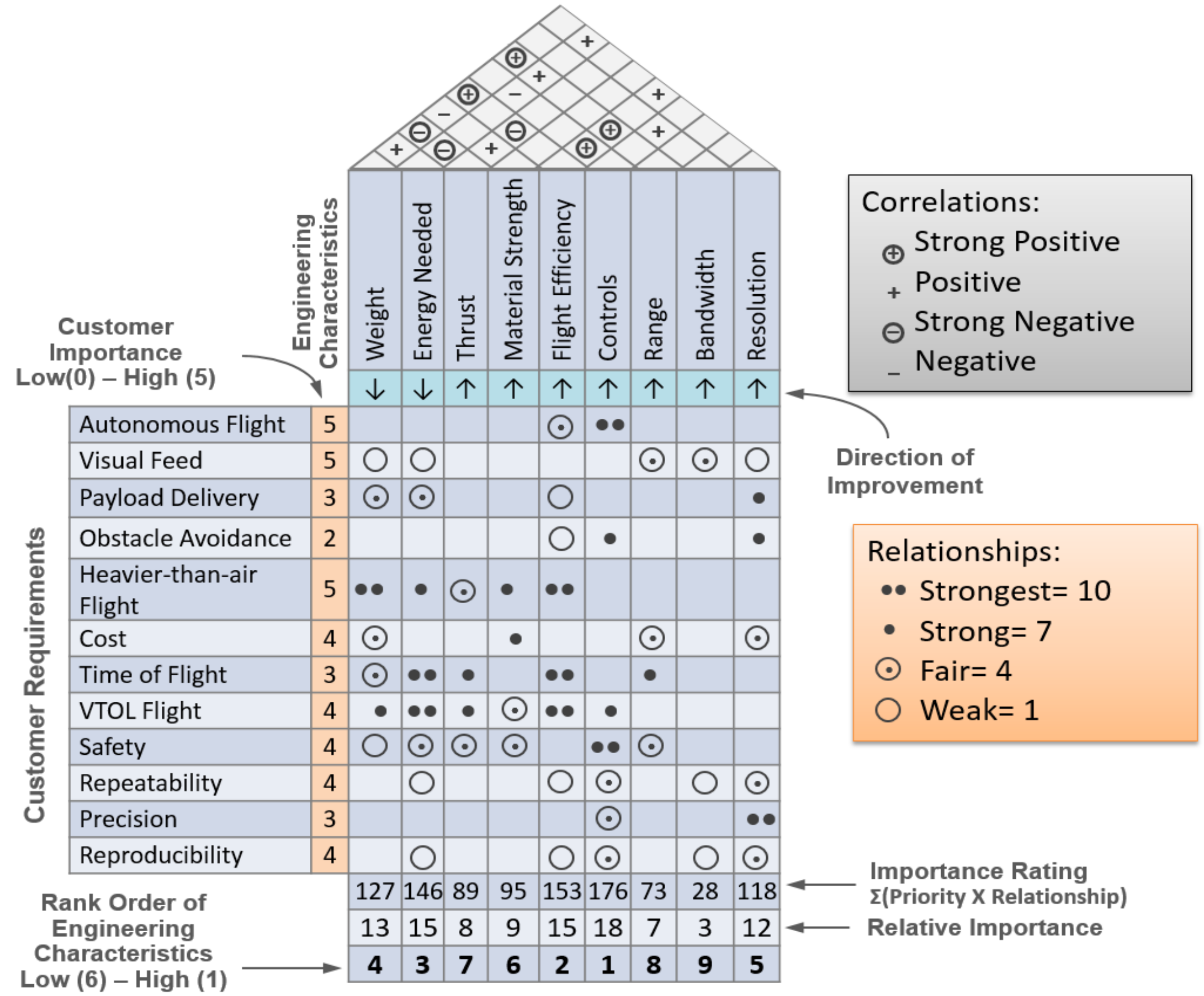
- The vehicle should be capable of vertical take-off and landing
- The vehicle should be capable of heavier than air flight
- The vehicle should have a visual feed for target acquisition
- The vehicle should have a time of flight long enough to complete competition objectives
- The vehicle should be 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

3.2 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



Customer Requirements	Customer Importance	Weight	Energy Needed	Thrust	Material Strength	Flight Efficiency	Controls	Range	Bandwidth	Resolution
		↓	↓	↑	↑	↑	↑	↑	↑	↑
Autonomous Flight	5					⊙	●●			
Visual Feed	5	○	○					⊙	⊙	○
Payload Delivery	3	⊙	⊙			○				●
Obstacle Avoidance	2					○	●			●
Heavier-than-air Flight	5	●●	●	⊙	●	●●				
Cost	4	⊙			●			⊙		⊙
Time of Flight	3	⊙	●●	●		●●		●		
VTOL Flight	4	●	●●	●	⊙	●●	●			
Safety	4	○	⊙	⊙	⊙		●●	⊙		
Repeatability	4		○			○	⊙		○	⊙
Precision	3						⊙			●●
Reproducibility	4		○			○	⊙		○	⊙
		127	146	89	95	153	176	73	28	118
		13	15	8	9	15	18	7	3	12
		4	**3**	**7**	**6**	**2**	**1**	**8**	**9**	**5**

Figure 2 - House of Quality

3.3 Needs Statement & Goal Statement

After analyzing all the information from the AUVSI SUAS competition and general observations of the unmanned aerial vehicle industry, the needs statement generated is as follows:

> "There needs to be a solution to minimize human danger and improve overall quality of human life, in the aerospace industry."

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 unmanned aerial vehicle able to meet competition parameter while emphasizing safety."

4. 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/communicate the characteristics of said target. For Team 8 tilt rotor design, the team has decided to first build a prototype that will be incorporated into the Skywalker frame. Most of the components Team 8 is using come from the previous groups because they are still good components and in working condition. Our major purchases will be the Skywalker X8 and the sensor package.

A crucial part of the project objective is to integrate all the systems. This includes the sensing, communication, mechatronic systems. Also, a firmware must be developed that suits the UAV design. Each of these integrated systems has to meet the competition requirements. For example, the RF communication is allowed to be on 2.4/5.8GHz (Wi-Fi) and 900 MHz.

Moreover, the assembled prototype will be benchmarked by comparing it to existing designs like the Firefly Y6 and other functional UAV resources available. Characteristics like efficiency, speed, travel time, and payload will 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 being controlled autonomously. The competition allows the use of manual control for the aircraft during takeoff and landing and gives bonus points for doing it autonomously.

As for what is required of the UAV sensor package, it should sense, detect, and avoid object targets. It should also be capable of avoiding obstacles in the air. With telemetry, Team 8 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 and determine the technical details and performance of the vehicle.

The Student Unmanned Aerial System (SUAS) Competition will be held June 15-19, 2016. Unfortunately, Team 8 will not be attending this competition. The registration closed a month earlier than initially posted due to an “unforeseen amount of participation”. This advance in the registration deadline severed our opportunities to compete, network, and represent the FAMU-

FSU College of Engineering at the AUVSI sponsored event. However, Team 8 remains eager to attend other potential events in which the aforementioned opportunities apply.

5. Methodology

5.1 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).

5.2 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.

5.3 House of Quality

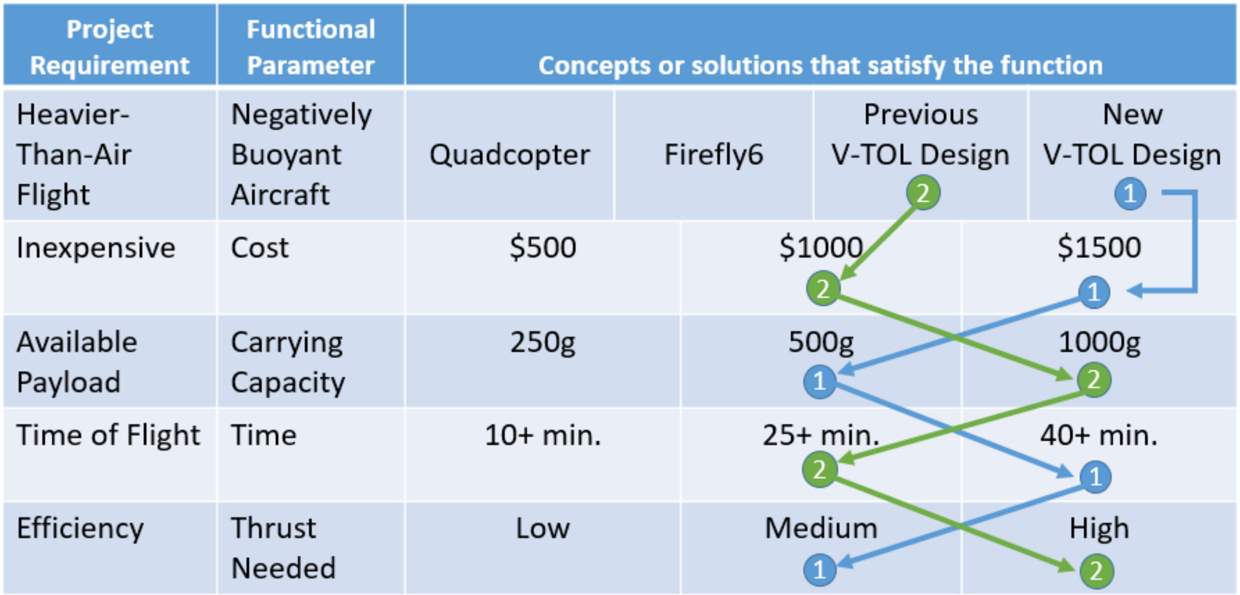
The House of Quality (HOQ), as seen in Figure 2, is used to relate project requirements with the certain engineering characteristics. The project requirements are found on the left portion of the figure, and the engineering characteristics on the top portion. The requirements that have been determined 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.

5.4 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="4">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>Firefly6</td><td>Previous V-TOL Design ②</td><td>New V-TOL Design ①</td></tr>
<tr><td>Inexpensive</td><td>Cost</td><td>$500</td><td colspan="2">$1000 ②</td><td>$1500 ①</td></tr>
<tr><td>Available Payload</td><td>Carrying Capacity</td><td>250g</td><td colspan="2">500g ①</td><td>1000g ②</td></tr>
<tr><td>Time of Flight</td><td>Time</td><td>10+ min.</td><td colspan="2">25+ min. ②</td><td>40+ min. ①</td></tr>
<tr><td>Efficiency</td><td>Thrust Needed</td><td>Low</td><td colspan="2">Medium ①</td><td>High ②</td></tr>
</table>

Table 12 - Pugh Matrix

	Baseline	Alternatives		
Criteria	**Previous VTOL Design**	**Quadcopter**	**FireFLY6**	**New VTOL Design**
Heavier-Than-Air-Flight	0	1	1	1
Cost	0	-1	-1	0
Available Payload	0	1	0	1
Time of Flight	0	-1	1	1
Efficiency	0	-1	1	1
Total	**0**	**-1**	**2**	**4**

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, most of the teams use only a fixed wing aircraft with either manual takeoff (and landing) or 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.

5.5 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.

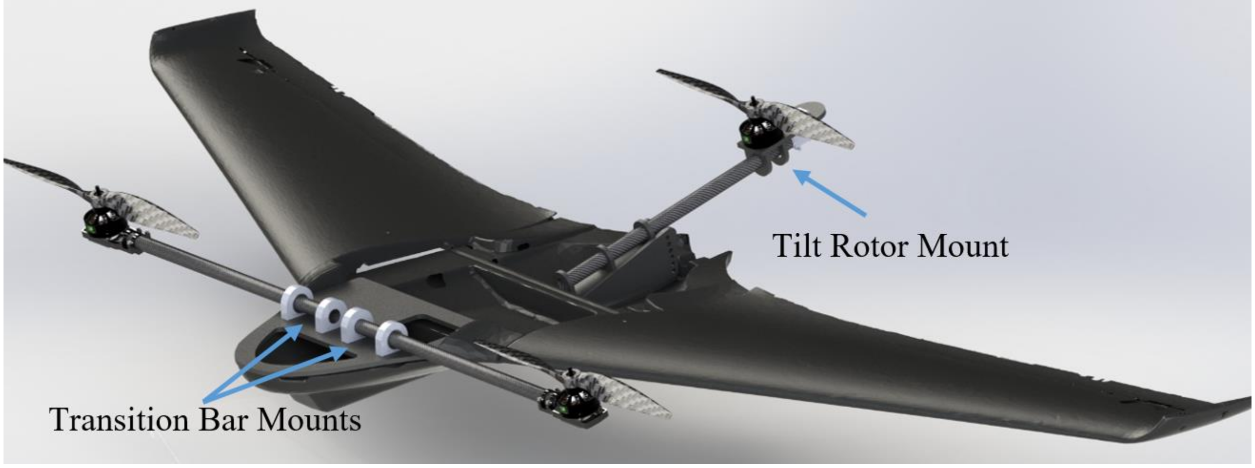


Figure 3 - Exposed Mounts

5.6 Computational Fluid Dynamics

Analysis on 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 4 illustrates a graph of this information at a Reynold’s number of 200,000.

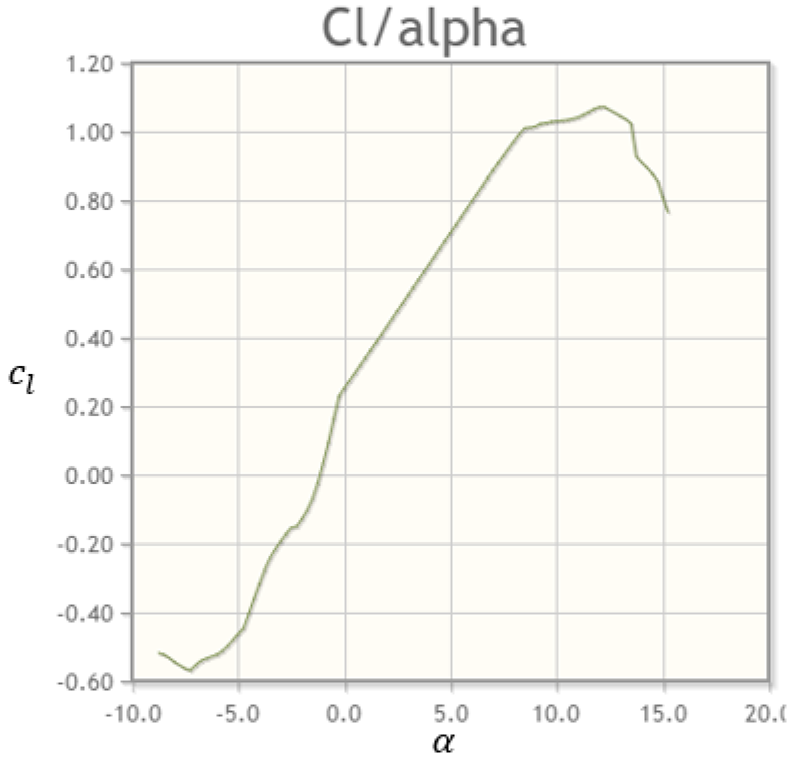


Figure 4 - Airfoil Coefficient of Lift vs. Angle of Attack

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 5.

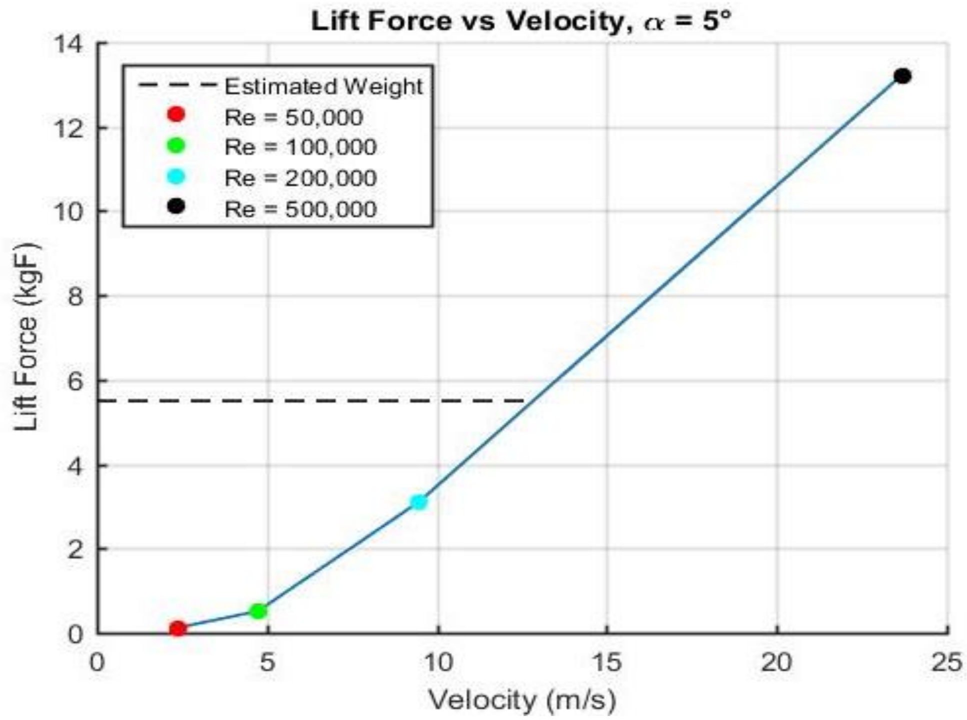


Figure 5 - Lift Force as a function of Velocity

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 to achieve sufficient lift. 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.

However, more aerodynamic analysis must be done on the aircraft as a whole. To do this, a program called XLFR5 was implemented. This free software is able to take any type of airfoil and create a simple, three dimensional winged model from it. Parameters were changed to create a model similar to that of the Skywalker X8. Due to the limited nature of this software, the model cannot be an exact replica of the Skywalker X8. The modeled body of the aircraft lacks detail and the winglets are not creatable. The program is then capable of taking this model and performing several different types of analysis on it. The analysis which is of most importance for this verification is the "Fixed Lift" analysis. In this analysis, the minimum velocity needed to provide sufficient lift is determined. This is, of course, dependent upon the angle of attack of the model.

This analysis allows the weight of the aircraft, as well as its center of gravity, to be adjusted. Figure 6 illustrates the product of this analysis.

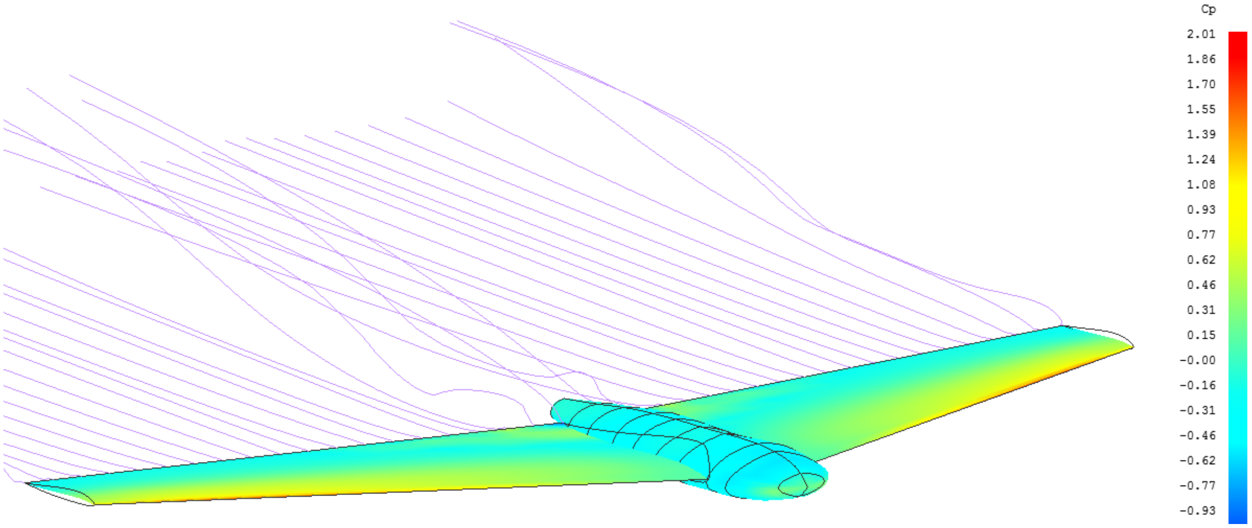


Figure 6 - XLFR5 Fixed Lift Analysis

As it can be seen from Figure 6, the model is somewhat rudimentary in respect to the Skywalker X8. However, it accurately models the airfoil that is being used, as well as the overall shape and weight of the design. The body of the model is much less aerodynamic than the body of the Skywalker X8. For the model to be able to support its target weight, it must be traveling about 19 m/s. This theoretical value is deemed to be a decent amount higher than the actual needed velocity. This is due to the crude modeling of the body as well as the omission of the winglets. The winglets are a valuable design aspect, as they reduce the size of the wing tip vortices which are a major contributor to drag.

5.7 Finite Element Analysis

Further analysis was conducted on the front mount assembly for verification of structural integrity. The analysis conducted was Von Mises Analysis, which is a computational form of finite element analysis that determines whether a component will yield due to complex loading. It calculates the Von Mises Stress and compares it to the yield stress of each material. The Von Mises stress is achieved by correlating strain energy density and materials hyperplastic properties. It is important to mention this is not an ideal process, it is an empirical process with inherent errors and deviations. Below is an illustration of our Von Mises Stress analysis, Figure 7.

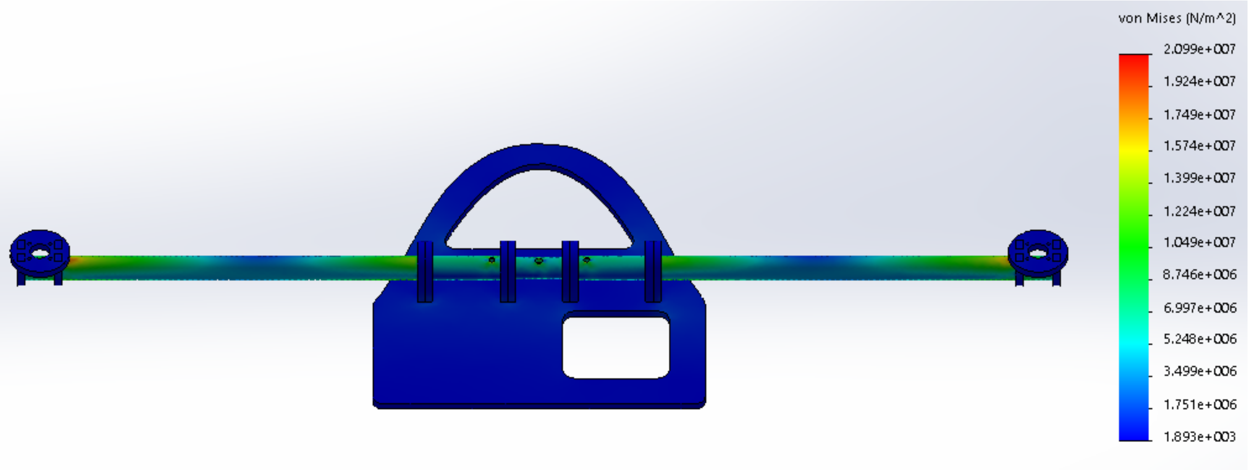


Figure 7 - Front Plate Von Mises Stress Analysis

Here we used a simplistic model of the front assembly, were the components are treated as both bonded and non-penetrating connections. From this illustration, as it can be seen the structure has not failed and is still intact. The front mounts and bearing joints have held along with the motor mounts. It can also be seen that the carbon fiber and aluminum coupler have maintain integrity, with some associated stresses.

6. Risk & Safety Assessment

6.1 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 – They have to create our target acquisition software from the ground up although they do have some research leads for the hardware needed.

Possible risks associated with our project include:

- Inadequate testing facilities- Competition rules include a range of environmental conditions our vehicle should be able to perform in that Team 8 cannot always recreate. This could lead to performance issues at the time of competition.
- Flight testing- Whenever the vehicle performs a flight test it runs the risk of crashing.
- Loss of communication- The 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.

6.2 Environmental and Safety Issues and Ethics

Lithium-ion polymer, or LiPo, batteries have been used for their power density, light weight, and flat design. LiPo batteries are used in applications ranging from powering radio controlled vehicles to powering cellular devices. Lithium-ion batteries are also known to be serious safety hazard for users if they not charged/discharged or not stored properly. This is mainly due to their tendency to overheat and sometimes catch fire. The occurrence is rare, but is still an occurrence and should be taken seriously. In a public release from the FAA, there has been 158 recorded incidents of LiPo batteries catching fire in luggage and cargo from 1991 to 2015 [12]. Most of these incidents were the result of poor storage of these batteries. A main failure point with LiPo batteries is over charging them. Charging a LiPo battery beyond its capacity causes slight vaporization of the electrolyte inside. This vaporization causes the pack to expand might tear its packaging [13]. To prevent incidents with these Lithium-ion polymer batteries this group has and will continue to be present during the charging of any and all batteries they are using, make use of piezo buzzers on aircraft to detect when the battery has reached its lower limit of charge, and store these batteries in the proper LiPo bags when not in use.

Most of the components that were designed by this group have been manufactured by use of a laser cutter. The material used in the design process is Acrylonitrile-Butadiene-Styrene, or ABS. It is readily available, light weight, and easy to cut with a laser cutter. Using a laser cutter on any kind of plastic can emit volatile organic compounds (VOCs), or in this case cyanide gas [14]. This is why the laser cutter is combined with a filtration system. This allows for a one way flow of air through the laser cutter keeping the VOCs out of the air around the users.

Creating their own unmanned aerial vehicle Team 8 must abide by the rules and regulation set forth by the Federal Aviation Administration (FAA). Under just the operations of a hobbyist flyer one must abide to the following rules [15]:

- Fly below 400 feet and remain clear of surrounding obstacles
- Keep the aircraft within visual line of sight at all times
- Remain well clear of and do not interfere with manned aircraft operations
- Don't fly within 5 miles of an airport unless you contact the airport and control tower before flying
- Don't fly near people or stadiums
- Don't fly an aircraft that weighs more than 55 lbs
- Don't be careless or reckless with your unmanned aircraft – you could be fined for endangering people or other aircraft

More specifically, the citation provided includes what exactly is and is not allowed to fly without permission from the FAA.

With the possibility of damages to people or property with an autonomous air vehicle, Team 8 is trying to procure a license with the Academy of Model Aeronautics (AMA). This membership with the AMA under the Special Rule for Model Aircraft law allows UAVs to be unregulated [16] and allowing for the AMA to insure members up to $2.5 million in liability fees as well as $25,000 in medical fees and $1,000 in fire and theft coverage [17]. This coverage is provided only while following their National Model Aircraft Safety Code [18]. Following these rules will also allow for safe test flights with the group's aircraft.

7. 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.

7.1 Airframe

The airframe is composed of two major systems, the tri-copter and the fuselage. The tri-copter frame will be integrated 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 Team 8 is estimating the system will weigh no more than 5500g, this includes an estimate of 0.5kg payload for sensor package and payload delivery systems.

7.1.1 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 researchers and hobbyists that create and analyze airfoils for foam R/C aircraft. Among these airfoils, there were a few 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 8.

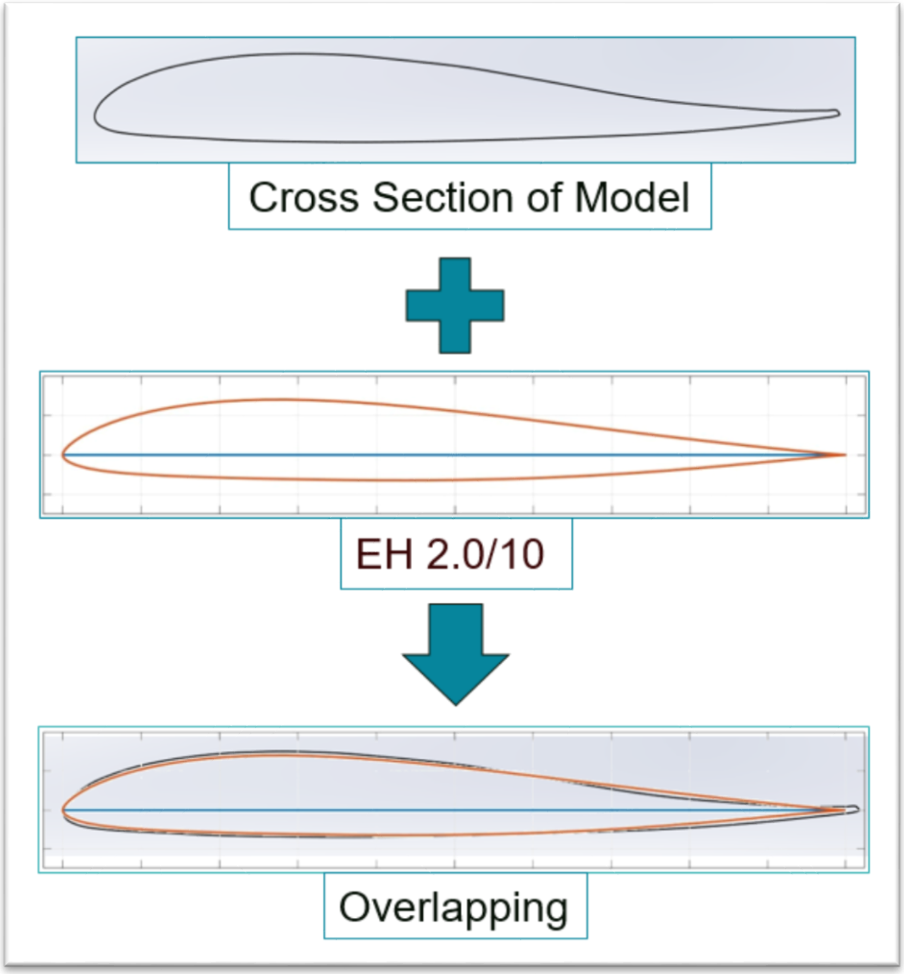


Figure 8 – Airfoil Design

This close relationship allows for an accurate analysis of the airfoil. This is a large reason why the Skywalker X8 was chosen. Analysis on the characteristics produced by the airfoil can be found in section 5.6 Computational Fluid Dynamics.

7.1.2 Tricopter

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. The tri-copter frame will be integrated within the fuselage, along with all other communication and propulsion components. This allows for lower drag as most of the components are embedded in the flying wing. The tri-copter will also utilize a tilt-rotor mechanism for transition from vertical to horizontal flight. This will be done with the use of a servo that 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, they 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.

7.2 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.

7.2.1 Motor

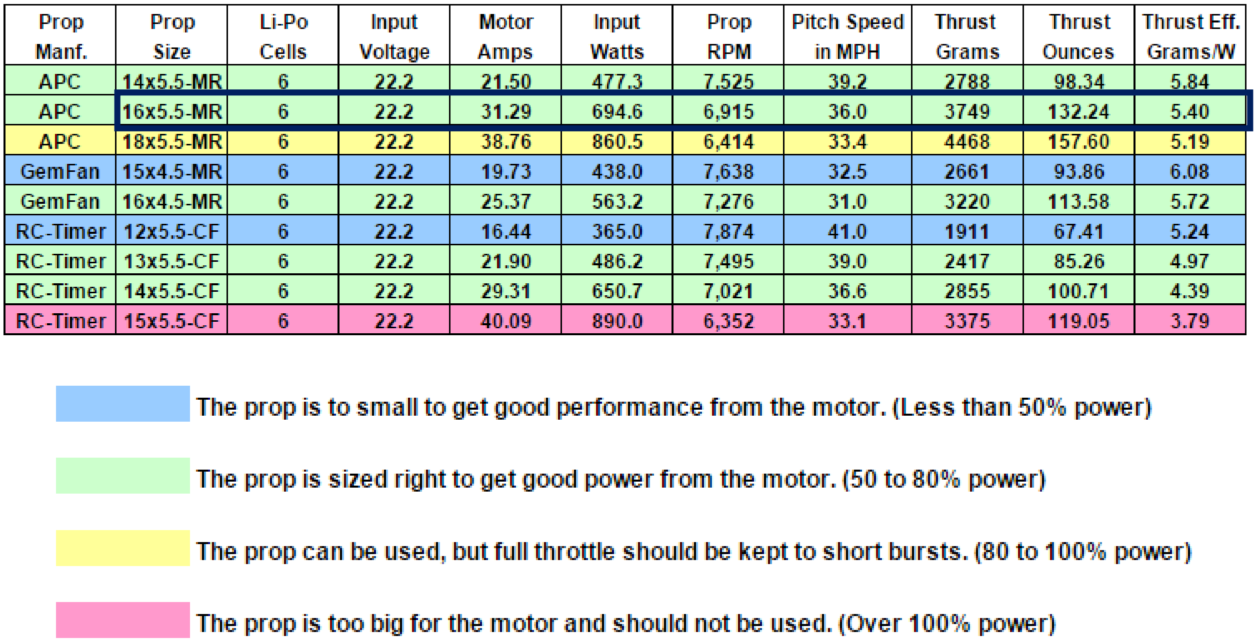
The motors Team 8 has chosen for this aircraft are the Cobra 4510/28 Brushless motors, these motors are 420kv motors. This means that these motors revolve 420 times a minute for every 1 volt supplied, which equates to roughly 155 times a second (with 22.2V battery). This is relatively slow compared to 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 motor controller. This motor allows for both 5-Cell & 6 Cell LiPo power systems, by this they mean it is limited to using either 18.5 volt or 22.2 lithium polymer batteries. Figure 9 and Figure 10 show the top and side view of this motor, respectively.

Figure 9 - Cobra 4510/28 Top View

Figure 10 - Cobra 4510/28 Side View

7.2.2 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 Team 8 carefully selected their propellers, luckily the manufacturer of the cobra motors provide some test data of various propeller/battery combinations with our selected motor. A detailed chart providing most of the data required to select the proper propeller is shown in Figure 11.



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 11 - Propeller Selection Chart

Based on this Chart Team 8 were able to select the 16” x 5.5” Propeller, as it provides 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 they would require. When comparing this motor/propeller combination to the desired design weight they can produce some estimates on the amount of thrust available as well as the amount of current drawn. These relationships can be seen in Figures 12 and 13, respectively.

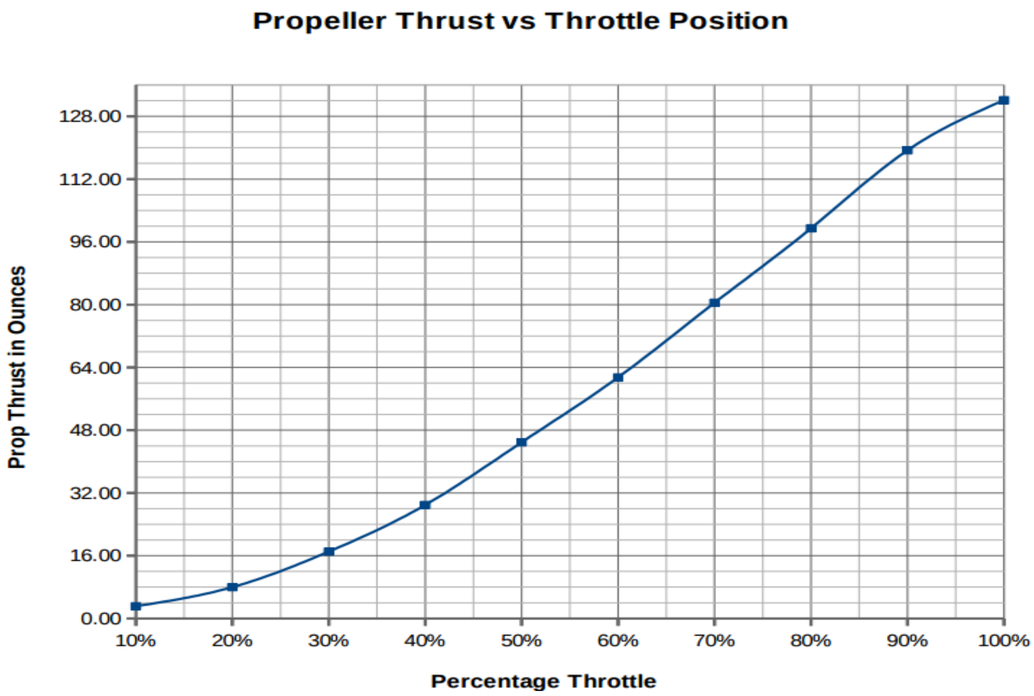


Figure 12 - Thrust vs Throttle

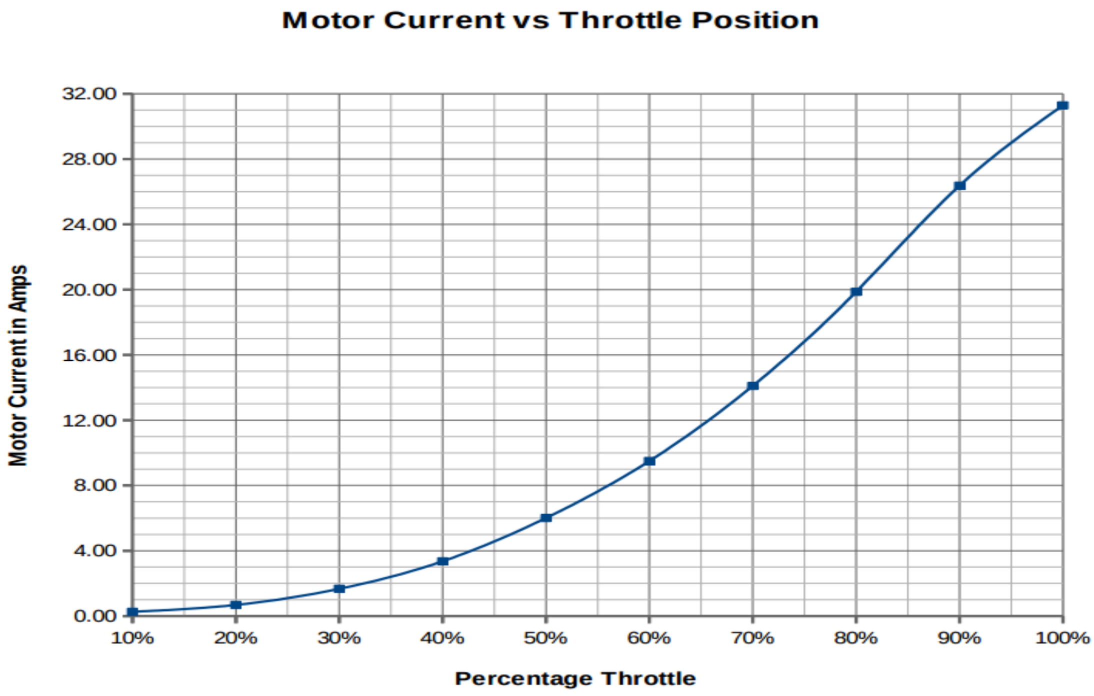


Figure 13 - Amp Draw vs. Throttle

7.2.3 Motor Controller

The next component that must be considered 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 current to the motor. In this aircraft, the motor controller is referred to as an Electronic Speed Control (ESC). For this design Team 8 requires an ESC that provides the Maximum continuous current draw that our motor requires, as stated before this value is 35 Amps. Knowing this Team 8 has decided on a Cobra 40 Amp ESC. This device will provide the required current without any conflict.

7.2.4 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 (LiPo) batteries are the only know batteries that provide the necessary voltage and weigh the least. Moving forward, Team 8 must decide on a capacity of current that will be enough for our design, Team 8 has decided to use three 5000mAh LiPo batteries for maximum flight-time. With this system can produce roughly 9.59 minutes of flight, using 100% throttle, a weight of 5.5kg and 15,000 mAh.

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

7.3 Controls

The controller, and the components attached to control surfaces, allow(s) for the aircraft to achieve stable flight in vertical and horizontal modes.

7.3.1 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 multi-rotor 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, multi-rotor configuration, and flight parameters.

7.3.2 Firmware

Using the Pixhawk microcontroller, most of the VTOL firmware required for this design has already been created by the PX4 community. Being that the source code of the firmware is already supplied, the only aspect left to alter are the parameters that this specific design will require. The parameters were based on the Firefly Y6 parameters, which is what our design is inspired from. Such parameters include the number of motors the craft has, the type of VTOL the aircraft implements, the transition speed of the tilt bar, and the default values for the motors. The firmware also includes mixers, which can initialize and alter the behavior of the components connected to the main and auxiliary ports, specifically the motors and servos. So far, all of the firmware can be tested except for the transition into flying wing mode, as the craft requires a specific airspeed. Also, the parameters are not perfect and need to be tuned. This can be done in a mode built into the microcontroller called Auto-tune, where the craft autonomously and quickly changes attitude, analyzes its reaction, and adjusts the specific parameters that will make for smoother control.

7.3.3 Servo

The tri-copter tilt rotor design has few moving parts which, with the exception of the motors and propellers, are all controlled using 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 does not apply to our design. Specifically, our design relies on servos to operate the aircraft's elevons, front tilt bar, and tail tilt platform. The aircraft's two elevons, which are used to control a flying wings pitch and roll, each use one servo. Once receiving a signal from the controller, the servo rotates pulling or pushing a servo arm attached to the elevon causing the elevon to either tilt up or down. This servo to servo arm connection is also used for the front tilt bar, and allows the tilt bar to rotate up to 90 degrees for transition from rotor flight to fixed wing flight, this is illustrated in Figure 14. The aircraft's tail tilt platform uses a servo to rotate the platform around a carbon fiber tube. This tail assembly is crucial in controlling the aircraft's yaw during rotary flight. Without this servo the aircraft would be susceptible to uncontrollable spinning due to its odd amount of propellers.

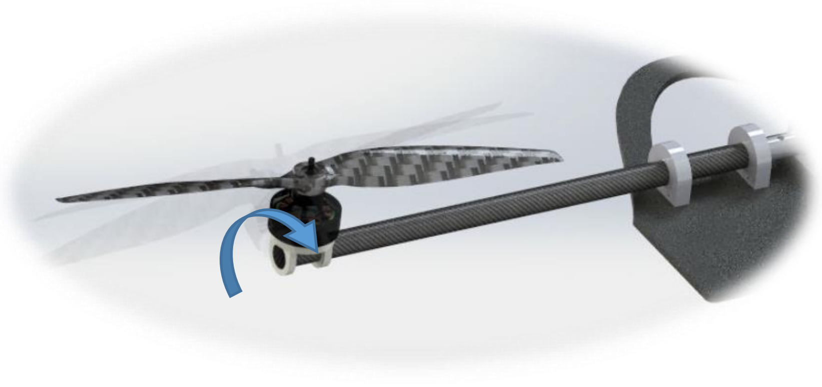


Figure 14 - Front Tilt Motion

All the servos in our design were ensured to be digital allowing for them to react faster to outside stimulus for instance wind resistance during flight. This is important in helping the aircrafts microcontroller maintain stability in a constantly changing environment. Each Hitec HS-5625MG servo produces 131 oz-inches of torque, which is well in excess of the minimum torque required of 59.902 oz-inches, from the elevens, when the aircraft flies at 50 miles per hour. The minimum torque required for the elevons was found by calculating the drag on the elevons surface. While the tail tilt platform only requires 33.845 oz-inches and the front tilt bar requires 87.091 oz-inches both use the Hitec HS-5645MG servo, which produces 168 oz-inches of torque. The minimum torque required for the front tilt bar and tail tilt platform were calculated using the weight of the parts in reference to the axis of rotation. These calculations can be found in the appendix.

7.3.4 Obstacle Avoidance

LIDAR-Lite v2 as seen in Figure 15, is a compact high performance optical distance measurement sensor is considered ideal for the unmanned vehicle. It has a reliable and powerful proximity sensor that communicates via a standard Inter-integrated Circuit (I2C) or Pulse Width Modulation (PWM) interface, which makes it interfaceable with the firmware, Pixhawk. Based on competition requirements, the Lidar-Lite will be used for optical avoidance as it senses within a range of up to 40 meters. The system consists of three key functionalities: A Signal Processing Core (SPC) which is a System-on-Chip solution encapsulating all the required functions in support of our proprietary range finding system architecture. An optical transmitter and receiver tied to the SPC emit and receives an optical signal pattern generated by the SPC. Power Conditioning and I2C signal filtering and buffering.

Lidar-Lite, pictured in Figure 15, is small in size, light-weight, has low power consumption, and dynamic configurability along with I2C communications and addressing – this means that it becomes practical to install multiple sensors on a project with minimal weight and power penalties. The beam swath of the LIDAR-Lite as delivered is 0.5°. This narrow beam provides long-range performance and also enables better target selectivity as compared to an ultrasonic sensor.

Figure 15 - A Lidar-Lite distance measuring sensor

Furthermore, with the implementation of a high performance signal processing architecture, LIDAR-Lite v2 can operate at measurement speeds of up to 500 readings per second, its I2C communications operates at 100 Kbits/s or 400 Kbits/s and data can be delivered faster. LIDAR-Lite v2 features a single stripe laser transmitter, a surface mount PIN with 3° Field Of View and a 14mm optics receiver. In order to have a 360° Field of View, we have plans of adapting a rotating mechanism to the sensor. The downside to the LIDAR Lite is that when the sensor is operated without its optics or housing, this can result in direct exposure to laser radiation and the risk of permanent eye damage when directly exposed to the emitter.

The downside to the LIDAR Lite is that when the sensor is operated without its optics or housing, this can result in direct exposure to laser radiation and the risk of permanent eye damage. Direct eye contact can be avoided by not staring directly at the emitter.

7.3.5 Target Identification

For the primary objective of searching an area for targets with multiple characteristics, the Pixycam has been considered and researched. It is a fast vision sensor that is compatible with many microprocessors, but mostly with an Arduino. It is capable of learning new objects based off of their colors by simply holding the object up to the Pixycam. The Pixycam is currently capable of locating objects by color, but it would also need to find the objects shape and symbol. It has an open source hardware, so there exists libraries and methods to find other characteristics of the targets. One of the main challenges with this sensor is having it communicate with the flight controller and have return the target characteristics.

8. Final Design

With the Methodology and Product Specification concept solidified, the next task was to implement them and create the final design. This task neared completion towards the end of the first semester. The final design can be seen in Figure XXX. It can be seen that the integral design as a whole allows for a sleek, nonintrusive profile. Some aspects of the design, however, are better designed in a modular fashion, such as the payload area within the landing gear. As pictured, a GoPro mounted on a 2-axis gimbal was implemented to gain valuable testing footage.

Figure 16 - Final Design

This creation would not be feasible without the practice of sound engineering techniques. Such techniques are to be discussed within the next section.

8.1 Design for Manufacturability, Reliability, and Economics

When formulating an appropriate design approach, one must take into account the real world implications that will affect the overall design. These implications include manufacturability, reliability, and economics. These aspects will now be discussed at length.

8.1.1 Design for Manufacturability

Before generating parts for the final design, a test rig was created. This test rig was the multirotor component of the aircraft, which essentially is a tri-copter. The vertical component from last year's design was scrapped to create a tri-copter prototype modeled after the design that would be integrated into final airframe. This early design also used the same yaw control mount design discussed later. It was easier to assemble due to the material being a combination of wood, aluminum, and carbon fiber. Adhering one piece to another was as simple as applying a screw.

The first step of building this aircraft was to embed the elevon servos into the wing and laying ribbon wire for possible future electronic additions. The wings were then fully assembled, adding the winglets and rods, then attached to the fuselage itself. After the main airframe is assembled, the next step is to integrate the multirotor component to the airframe.

The first component designed was the front motor mounts that attached the motors to the front two carbon fiber rods that protrude out of the aircraft. The motor mounts are three ABS plastic puzzle pieces that have holes matching the dimensions of the motor and rod.

The next piece of design work was the front mount that was to be the semi-rigid connection of the motors to the frame. This mount was designed with two ports to access or implement future electronics. The joints that hold the carbon fiber rods also encase two different kinds of bearings. The center two joints fully encase a ball bearing and the outer two hold a sleeve bearing. Two large access ports were adding for future sensor implementation.

The next main component to be designed was the rear motor mount, which consisted of two sub components. The first being the mount that connects the carbon fiber rod to the foam and the other connecting the rear motor to the arm, which was a specialized design. The first part is mounted to the foam using adhesive as well as being punched through the foam using a board on the other side. That rear mount also has the ability to adjust in angle for transitional flight so the aircraft maintains a neutral angle of attack during transition. The second part in this rear mount design is the yaw control mount. This piece is rigidly attached to a servo which spins about the rod, sitting on a ball bearing, to control the yaw of the aircraft.

It is important to note that all these mounts were made from ABS plastic using the laser cutter in the CISCOR/STRIDe lab workshop. There was no need for this group to use the machine shop, because they could generate all their parts themselves.

The main design, manufacture, and assembly of the aircraft did not take up as much time as anticipated. The parts that took the longest were certain additions that were unaccounted for in the original design, such as the landing gear. Since horizontal flight needed to be tested, the aircraft needed to be able to land horizontally as well, which can only safely be done using traditional landing gear. These were meant to be temporary, but figuring out where and how to mount them to foam took longer than expected.

One thing that could have improved the design was not using ABS for the large parts, like the front and rear mounts. This could have reduced overall weight, which is crucial.

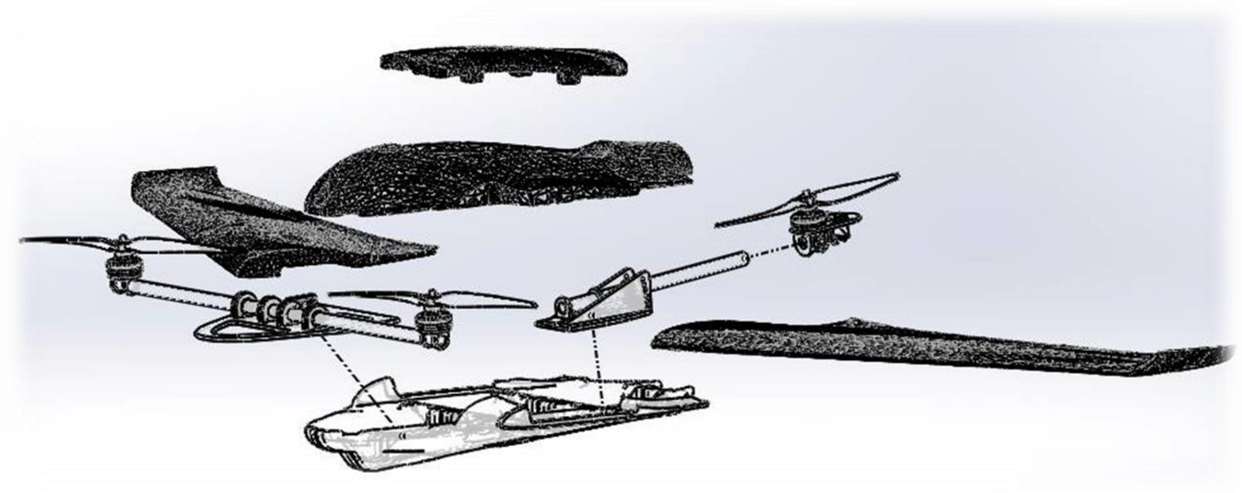


Figure 17 - Full Assembly (Exploded view)

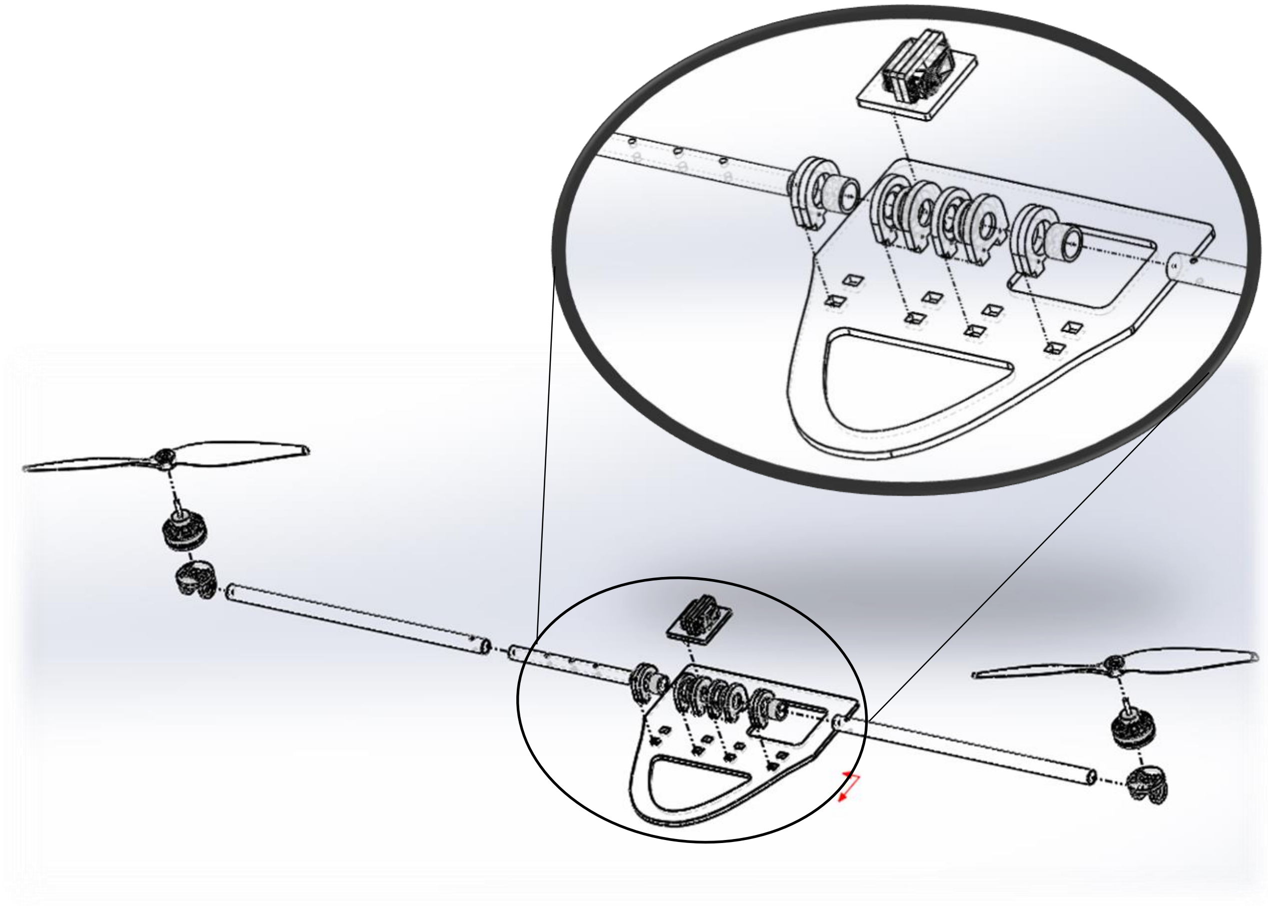


Figure 18 - Front Plate (Exploded view)

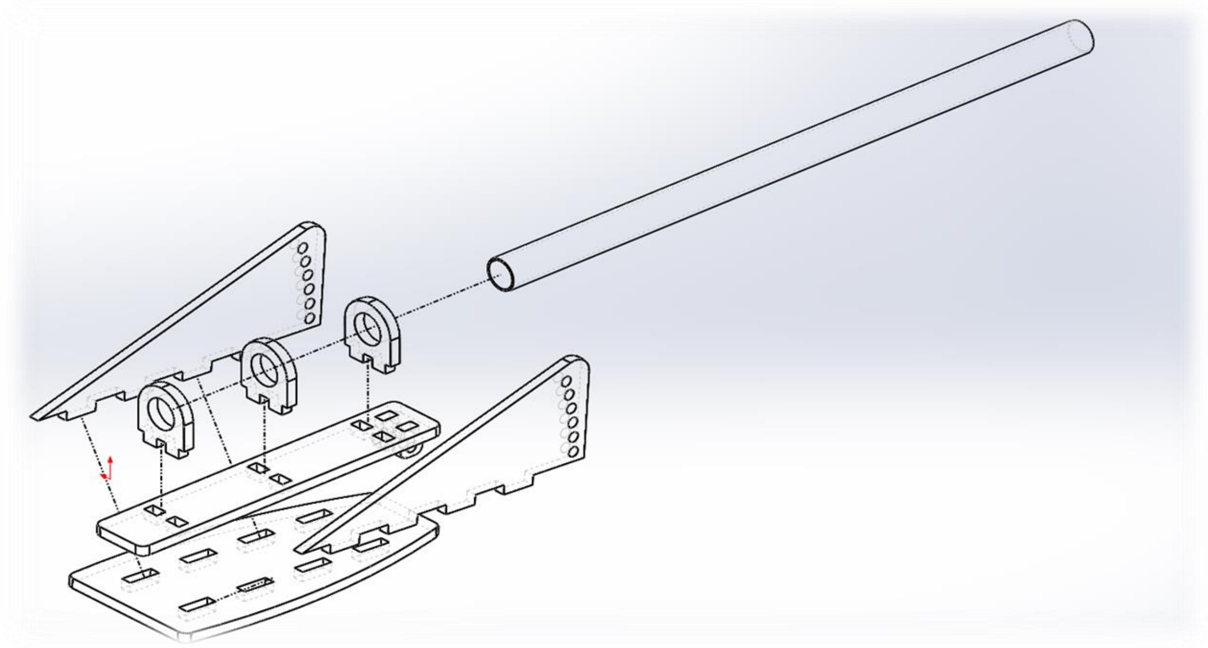


Figure 19 - Rear Mount (Exploded view)

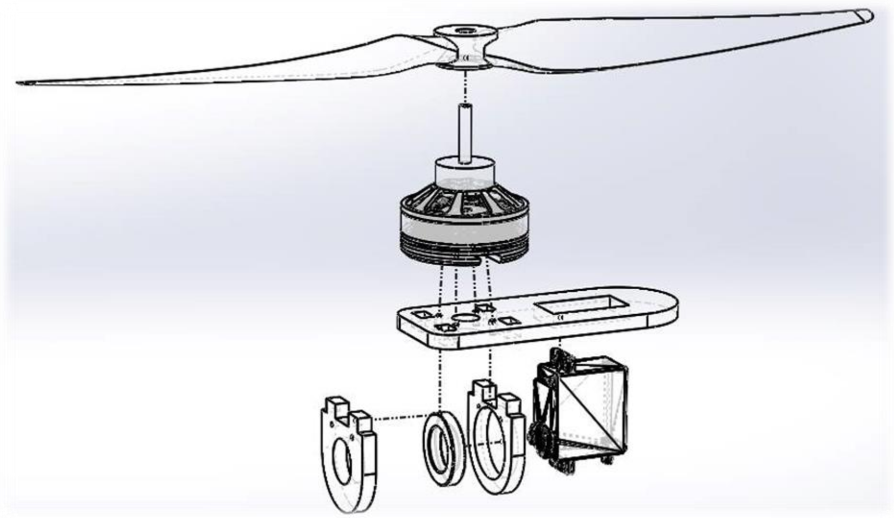


Figure 20 - Yaw Motor Mount (Exploded view)

8.1.2 Design for Reliability

The prototype performed exceptionally well when it was used for the first time. Some parameters needed to be tuned in order to achieve better stability and flight, but this condition is universal within the realm of unmanned aerial vehicles. When considering the reliability over a range of uses, it is important to note the project's applicable scope. Keeping this in mind, this is not a product that will be used 10,000 or even 1,000 times. A more realistic expectation is a couple hundred missions. Some of the most important parts within our craft boast a large amount of reliability. The motors, for example, are brushless electric motors. Being brushless, they have less contacting parts when in motion, which increases the motors life expectancy. They also do not have the combustible complexities associated with liquid fuel motors. With the design, it would not have any issue meeting the desired reliability standard, given it is controlled by an experienced R/C pilot.

The main reliability concerns that are relevant within this project is the proper upkeep and storage of the Lithium Polymer batteries. These batteries are flammable and can ignite if punctured. They are to be stored in an approved LiPo pouch at a voltage of 3.85 volts per cell. If the batteries become puffy or damaged, they should be replaced immediately. This is the main concern when evaluating the reliability of the aircraft.

Planning for reliable flight with this design, computational fluid dynamics were performed on a representation of the aircraft. This was done through a program called XFOIL. The program allowed certain characteristics such as wind speed and coefficient of lift to be determined based upon the constraining parameters. From the determined airfoil, the relationship between the coefficient of lift and angle of attack was able to be determined and can be found in Figure 5. The calculations were based on an angle of attack of 5° and yielded an appropriate amount of lift at 12.5 m/s. From this, a visual representation of the pressure distribution was created for the craft when traveling at 12.5 m/s. Figure 6 shows this visualization. Along with analyzing the aerodynamic characteristics of the aircraft, an H-FMEA was conducted on the proposed design which can be found in Appendix A-1.

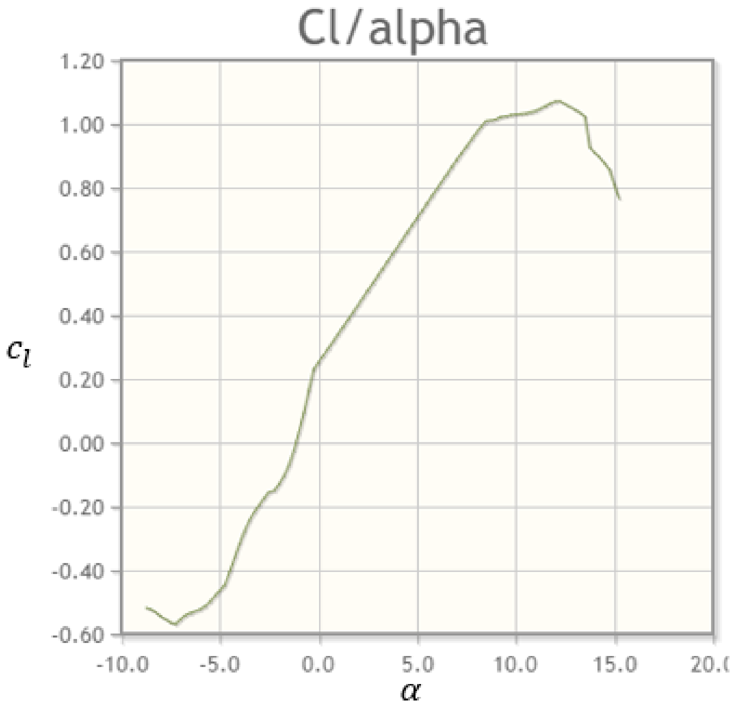


Figure 21 - Coefficient of Lift vs. Angle of Attack

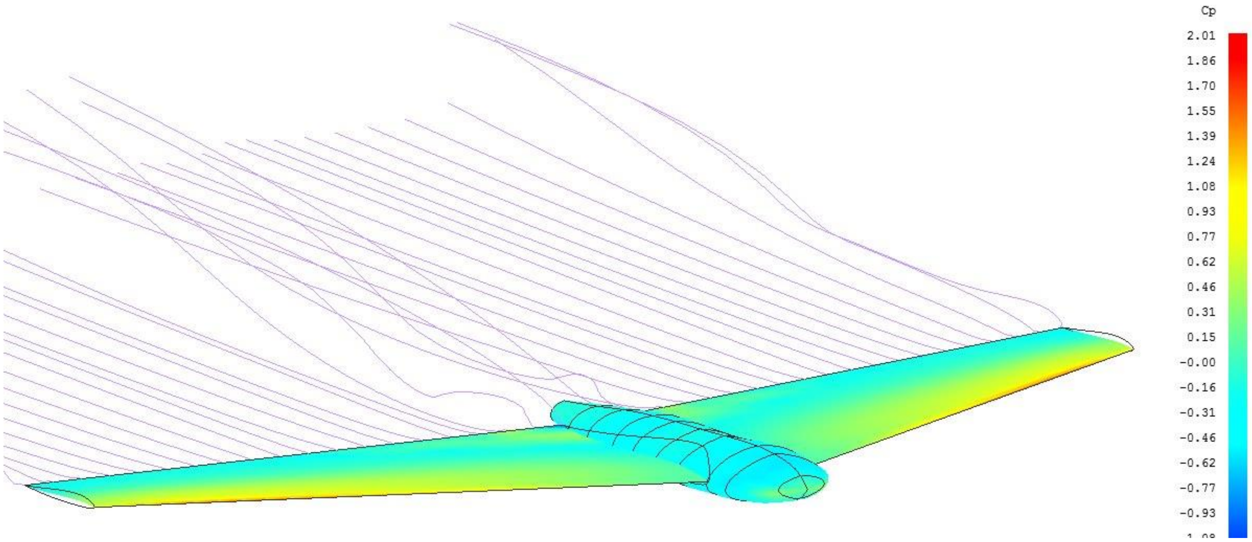


Figure 22 - Pressure Distribution on Aircraft

8.1.3 Design for Economics

The entire project currently cost $781.55 for a completed aircraft and spare Skywalker fuselage.

Located below is cost breakdown for the project and its components.

Table 13 - Cost Breakdown

Part	**Quantity**	**Cost**	**Part Total Cost**
HS-5625 Servos	2	39.99	79.98
HS-5245 Mini Servos	2	39.99	79.98
Skywalker Fuselage	2	216	432
ABS Sheet	1	18.42	18.42
Steel Needle Roller Bearing	2	6.86	13.72
Metric Steel Ball Bearings	2	13.25	26.5
Propeller Quick Detach	1	9.99	9.99
Carbon Fiber Propeller	1	57.99	57.99
Hitec Servo Hub	2	3.99	7.98
1/2 in OD Ball Bearing	1	1.99	1.99
Metric Steel Ball Bearings - Double Shielded	1	13.43	13.43
Timing Belt	1	13.68	13.68
Aluminum Tube	1	5.81	5.81
Black Epoxy	1	20.08	20.08

The team’s budget was $1500 and as previously stated the total money spent was $781.55 leaving $718.45 in the team’s budget. While Team 8 has a very unique aircraft, there are others which resemble it. The most similar RC aircraft on the market to this vehicle is the Birds Eye View Aerobotics FireFLY6. This aircraft can be seen in Figure 23.

Figure 23 - FireFLY6 Aircraft

This aircraft is also capable of transition between vertical and horizontal flight while being both manually and autonomously controllable. The cost differences between the two aircraft are very distinct. The FireFLY6 cost $500 while not including many key components already figured into the project cost. These missing components include the Pixhawk microcontroller, motors, electronic speed controllers, propellers, batteries, and 7 channel radio/receiver. The Pixhawk microcontroller alone cost in excess of $200, and when fully assembled this commercial craft would cost at least $1300 with all its components. It’s important to note that the total project cost includes an extra fuselage, which would reduce the total cost by $216, far below the FireFLY6. In addition to costing less, the design would boasts higher payload ability and more autonomous capabilities at no extra cost. Team 8’s financial decisions can be seen in Figures 24 and 25. A cost comparison between Team 8’s design and the FireFLY6 can be seen in Figure 26.

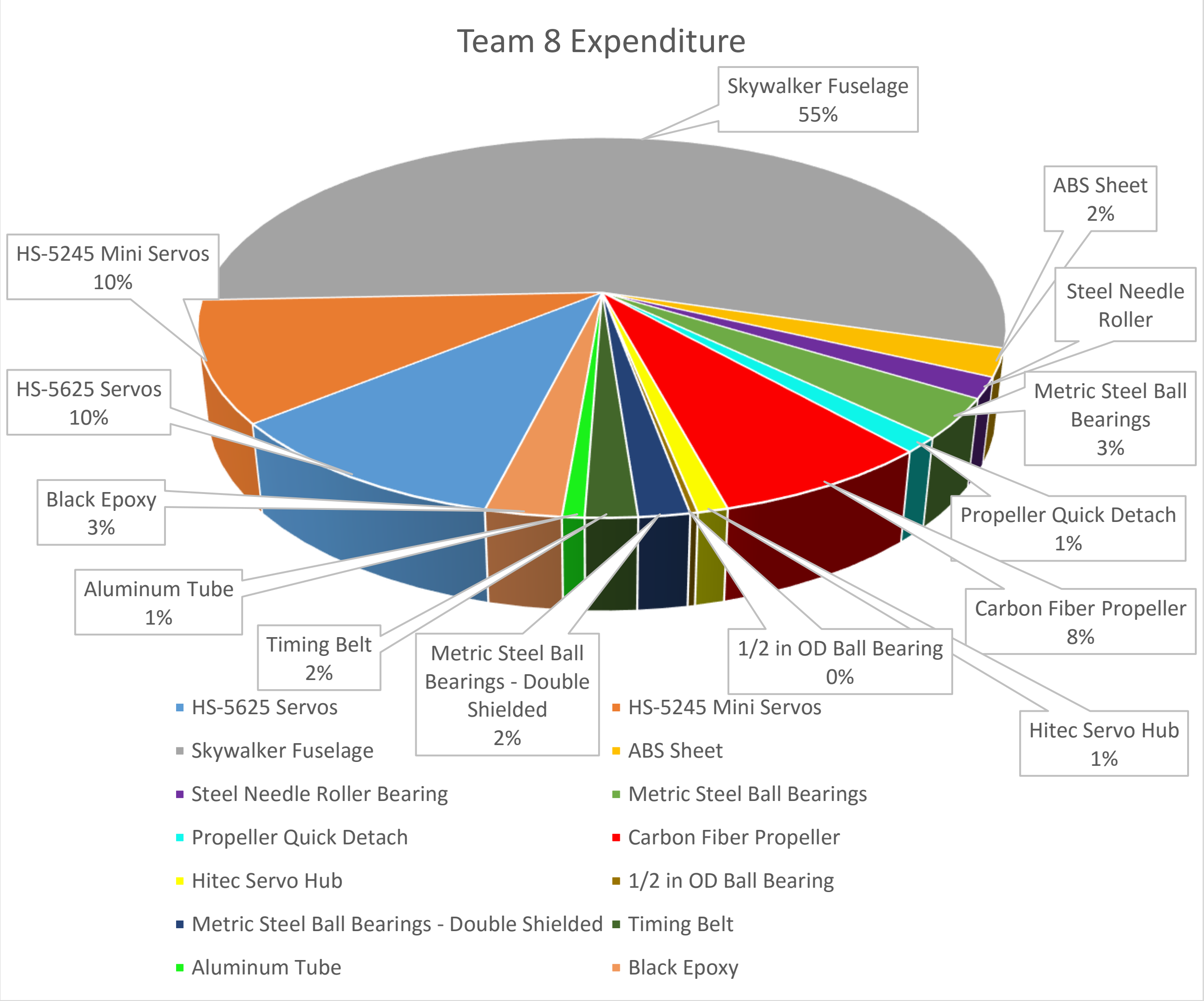


Figure 24 - Team 8 Expenditure

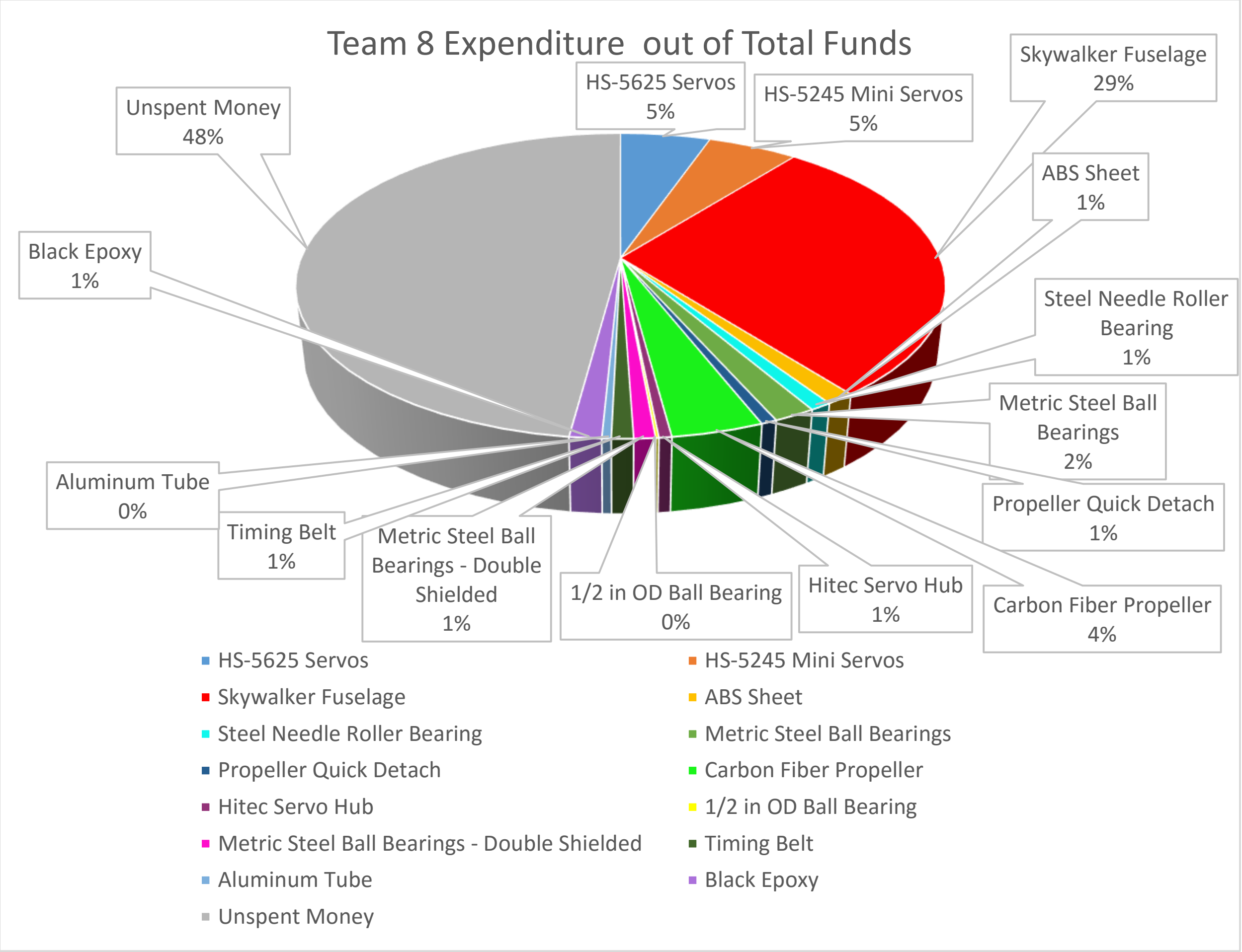


Figure 25 - Team 8 Expenditure out of Total Funds

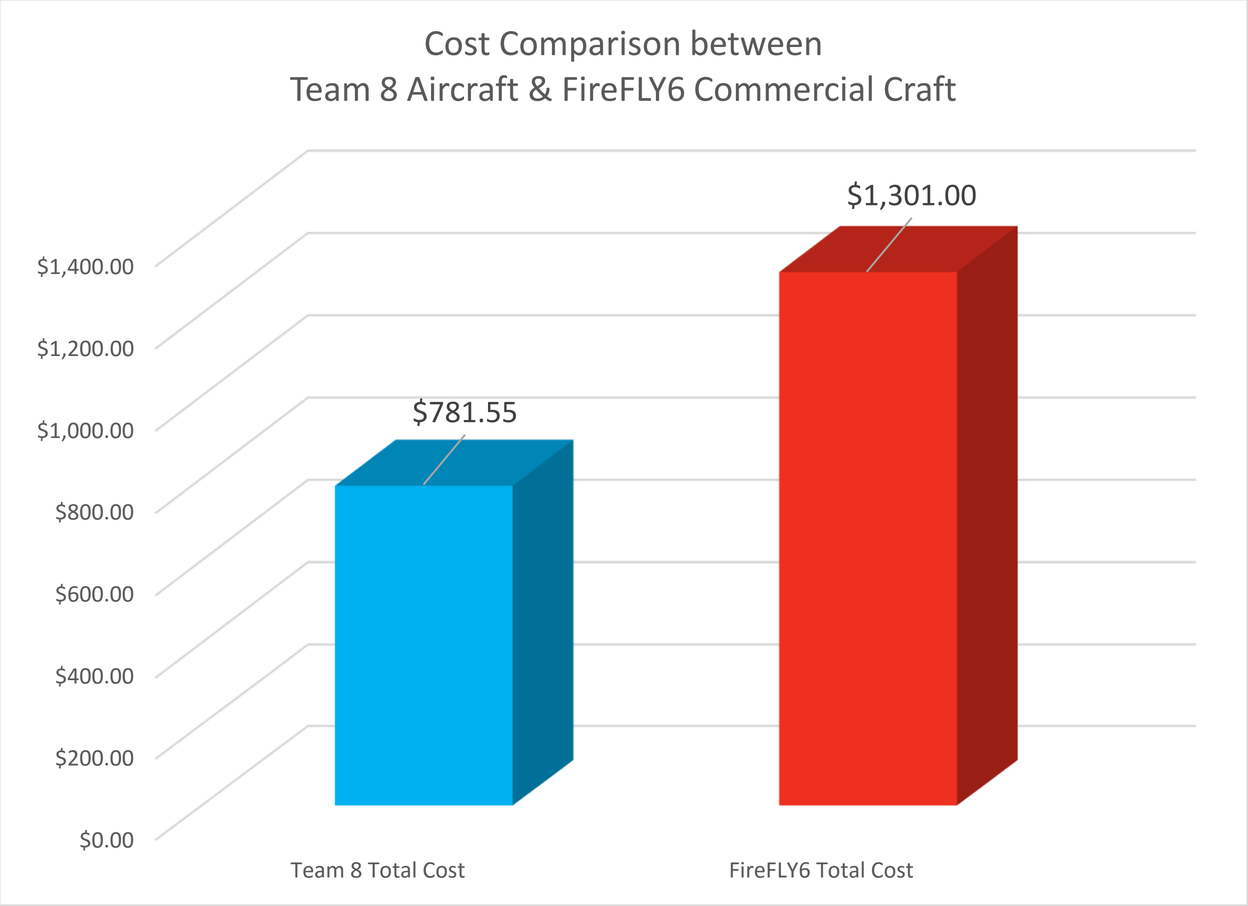


Figure 26 - Team 8 Aircraft vs FireFLY6 Cost

8.2 Operation Instructions

AIRCRAFT OPERATION

To operate the aircraft, install the firmware on an operating system. This is available at http://dev.px4.io/starting-building.html. Aircraft operation is composed of three parts: Pre-flight operation, flight operation, and post-flight operation.

Warning: Take the following precaution before executing the operation instructions.

i) All propellers should be detached until aircraft is ready for flight.
ii) Batteries should be unplugged until aircraft is ready for flight.
iii) Ensure flight area is clear of obstacles.
iv) Never fly close to people and in case of emergency, avoid crashing into people or objects.

A. PRE-FLIGHT INSTRUCTION

i) Perform an inspection on the aircraft frame. Check the wings to ensure they are firmly attached.
ii) Ensure the three motors are not loose. Spin the motors and tilt the front bar to ensure they rotate and tilt freely. Tilt the rear mount so that the motor points upwards.
iii) The Pixhawk and all other components within the frame should be firmly positioned in the aircraft. Check for damages in the wiring.
iv) If there are no damages, ensure all wires from servos and motors are correctly plugged to the right ports on the Pixhawk.
v) Test the functionality the ailerons and elevators by using the transmitter. If they don't respond, check the connections.
vi) Activate the aircraft through QGroundControl or the transmitter. Link the Pixhawk to QGroundControl through the MAV link or 3DR Telemetry kit.
vii) The firmware should be installed on the aircraft so that onboard sensors like GPS, barometer, gyroscope, and magnetometer can be calibrated. If they have yet to be calibrated, follow the instructions on QGroundControl to do so (this includes moving the craft around in various positions, so have a wide area to work with).
viii) If parts have been moved around, ensure the plane still has a stable center of gravity.
ix) Arm the aircraft by pressing the red button located near the wing. It can be armed wirelessly with the Mission Planner software. Then, hold the throttle in the down-left corner to fully arm the craft. After this, the aircraft is ready for vertical takeoff.

B. IN-FLIGHT INSTRUCTIONS

The aircraft can be flown autonomously, manually or both. This aircraft can also perform vertical and horizontal takeoff and landing, though it is recommended that it only take off vertically. With vertical takeoff, also known as tri-copter mode, the motors on the front bar are pointed upwards and rotate in opposite directions to counter each other's moment. The back motor rotates in the direction of one of the front motors.

The immediate lift off of the ground might seem unstable, but will balance out when it has reached an adequate height. Make sure to climb to a safe height before a transition, to avoid collision with any low objects. When the craft is high enough, it can be transitioned into the Transition Phase by rotating the AUX3 knob (located on the top right of the transmitter). This will cause the front bar to tilt forward and create horizontal thrust.

When the aircraft has gathered enough speed, which can be sensed by the airspeed sensor, the aircraft transitions to the horizontal flight mode. This should disengage the motors the back motor and active the elevons.

To land the aircraft, the flight mode needs to be changed back to vertical flight by rotating the same knob in the reverse direction. The back motor should reactivate and the front bar returns to its upward state. Landing should be done slowly to prevent damaging the plane.

i) Manual

In manual flight mode, the plane is controlled by the transmitter (remote control). An experienced R/C pilot should be at the control if this mode is to be used. The pilot should ensure a stable flight path while navigating the aircraft. The time of flight should be recorded as the batteries will only supply around 15 to 35 minutes (depending on the mode of the aircraft). Keep an eye on the battery percentage, as the user will have to manually land the plane before it runs out of power. Someone should be monitoring QGroundControl when the aircraft is airborne, and this operator should observe the battery charge, camera feed, GPS coordinate, orientation, etc.

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ii) Autonomous

In autonomous flight mode, the aircraft is no longer controlled remotely. It moves towards its first waypoint regardless of its current position. When Auto is engaged, the pilot loses control of the throttle and elevators (pitch), and Pixhawk will be engaged. The microcontroller will take the aircraft to the preprogrammed waypoints. With the connected 3DR telemetry radio, the operator at the ground station can remotely instruct the Pixhawk to fly in a particular direction.

C. POST FLIGHT MODE

i) After the aircraft is disarmed, disconnect the batteries to avoid powering the motors. Caution should be taken to ensure the propellers are not engaged, this can be injurious.
ii) After the power is disconnected, the propellers may be removed from the three motors.
iii) Electrical components such as the APM and 3DR telemetry kit should be unplugged.
iv) Transport carefully to a safe place to minimize damage.
v) Do not store a battery when it is empty. Make sure the battery is charged before storing.

9. Design of Experiment

9.1 Component Testing

Most of the components tested involved the transition from horizontal to vertical flight. The experiments conducted involved the airspeed sensor's approval to transition, the back motor shutting off, the front bar transition forward, the elevon control after transitioning, and general motor calibration.

When the airspeed sensor records an airspeed higher than the requirement set by the "vt_arsp_trans" variable within the firmware, the aircraft will go from the transition mode (front motors tilted slightly forward) to fixed wing mode. To test how the airspeed sensor would behave, the aircraft was armed (without props on), and sent into transition mode. To simulate an airflow, a team member would blow onto the side of the airspeed sensor. This tricked the craft into thinking it had an achieved an adequate airspeed, and it went form transition mode to fixed wing mode.

After transitioning to fixed wing mode, the back motor should have shut off completely. This did not happen in the first few transitional experiments. After comparing the connection from the motor to the Pixhawk and the parameter "vt_fw_mot_offid", it was found that they did not match. The motor was connected to the output main_out3, while the parameter was set to 4. After adjusting this error, the motor turned off after transitioning. It should be noted that the amount of time it takes for the back motor to shut is set by the variable "vt_b_trans_dur".

The front tilt bar should move in way that tilts the front two motors forward when transitioning. It was found that the bar would make a complete transition when the transmitter switched modes, instead of waiting for the airspeed sensor to approve. It was thought that the airspeed sensor was at fault, but after flipping the servo and reversing its motion, it behaved as it should have.

The elevens, which control the flight surface on the wings, cannot be activated when in multicopter mode or transitional mode, only in fixed wing mode. To test the elevens controls, the aircraft had to be "tricked" into fixed wing mode using the method mentioned before. After a complete transition, the right elevon would move in the opposite direction. After adjusting the output on the transmitter associated with that control, it behaved as expected.

9.2 Flight Testing

Two different flight areas had been secured to test the different modes of the aircraft. The first mode to test was the multicopter mode, vertical flight. After assuring that all required components behaved as they should have and batteries were adequately charged, the props were attached and the aircraft was armed. The first few tests showed that the aircraft would rotate in flight, which was caused by the back motor not tilting as it should have. The safety pilot described the flight as “touchy” and “hard to control”. This meant that the motor parameters would have to be tuned to fit the needs of the aircraft.

After integrating the multicopter prototype with the fixed wing fuselage, other vertical flight experiments had to be done to assure that the integration would work as expected. The aircraft did not rotate as it once had, meaning that the tuning had been successful. After initial takeoff, the propellers would create an “upwash” of air, which would deflect off the ground and push against the bottom of the aircraft’s surface. This made takeoff awkward and hard to maintain. After attaining a high enough height to avoid this, the aircraft stabilized and behaved as expected.

The next mode to test was the horizontal flight. Instead of transitioning to this mode in midflight, the aircraft was once again tricked into fixed wing mode, and took off from the ground. It was safer to do it this way, as its behavior in horizontal flight had yet to been tested, and could have resulted a crash. The first few takeoffs were compromised by the back castor wheel, as it tended to favor one side. The main components to test in this experiment would simply be the ones that created thrust, mainly the motors, and if they could create enough lift for the aircraft to stay in horizontal flight. After achieving adequate lift, it was found that the craft produced more thrust than originally anticipated, meaning it could appropriately fly horizontally.

The final mode to test was the transition mode. After achieving a vertical takeoff, it was found that the transition forward was unsteady and caused the aircraft to misbehave. It was theorized that transition took too long and must be executed faster via the corresponding parameters in the firmware.

10. Project Management

This project management section serves to illustrate how Team 8's time, money, and correspondence were managed throughout the project's life.

10.1 Schedule

The project followed our Gantt Chart and critical path very well until the scope of the project changed for the Spring of 2016. When the AUVSI competition officials closed the registration early the team was forced to reexamine their goals going forward. After deliberation it was decided the team would focus the rest of their time on final assembly, flight optimization, and legally acquiring permission to perform flight test. This would mean the responsibility for completing competition objectives like obstacle avoidance, object recognition, and payload delivery would be given to the future teams for the project. Due to these changes both the critical path and Gantt Chart were both altered, with a heavy focus on the vehicles flight optimization. After these changes were made the team followed the schedule without problems.

10.2 Project Status

In previous reports and presentations, Team 8 have provided conceptual designs and theoretical analysis. They have continued with their project plan and created a prototype platform for firmware implementations, this can be seen in Figure 16.

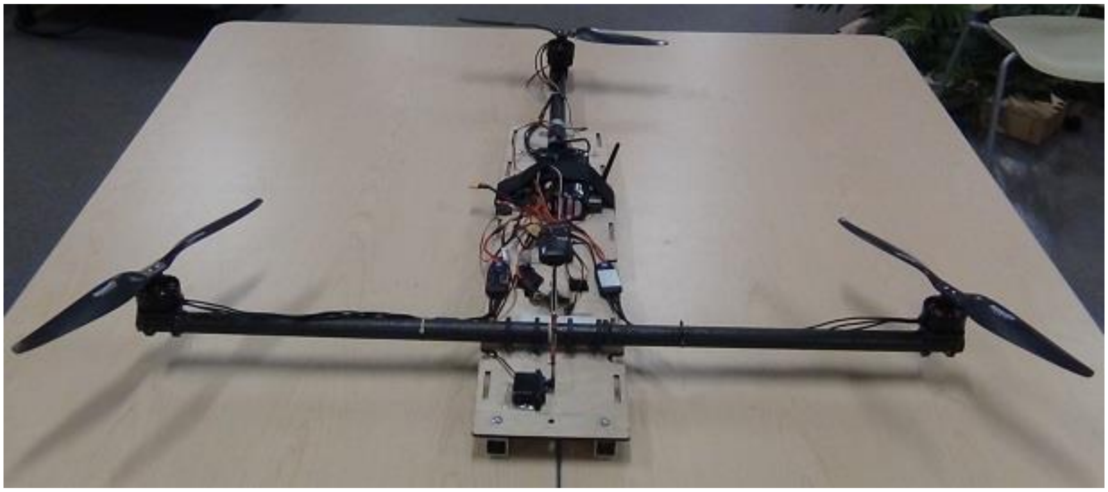

Figure 27 - Prototype Platform

Team 8 has continued to test and verify all components of this platform for optimal performance. They recently have transferred all components over to our final build fuselage for final verification, this can be seen below in Figure 17.

Figure 28 - Final Platform

At this time they are on schedule, and are optimizing the final design. They have concluded that their system is fully capable of manual vertical flight in the tri-copter mode and horizontal flight when transitioned. They will continue optimizing the proportional, derivative, and integral (PID) control parameters for stable vertical flight. Once permission to fly has been granted again horizontal flight will be retested and long-range flight tests will begin. Once both flight modes have successfully been optimized they will implement the transitional phase of our flight controller’s firmware and begin transitional flight tests.

10.3 Resources

Outside of our project base of operations being in the Aero-Propulsion, Mechatronics, and Energy building, the team had limited access to the CISCO/STRIDe lab laser cutter. All other manufacturing was done by the team with hand tools. The resources we were provided were handled appropriately but we would have liked to have had easy access to a 3D printer.

10.4 Procurement

The budget for this project was $1500 and we have done very well to remain on budget throughout the project. There is almost half our budget still available to us even as the project winds down.

However, Team 8 has expressed concerns for competition fees for future teams and foresee complications in staying within the budget if the team is expected to pay. It is important to state that they have concluded all purchases in respect to the aircraft, and have begun looking further in depth to their sensor package and ground station. Although these complications will be on future teams we plan to begin detailed conversations with our sponsor as soon as more research has been conducted. Overall the budget was sufficient for the aircraft itself but we believe the budget will most likely be insufficient for ground support equipment and competition cost. As for the funds that have already been utilized, we have provided a detailed list of purchases made, Table 13.

Table 14 - Bill of Materials

PO #	Description	QTY	Cost	Total
1	Skywalker Black X8 Flying Wing	2	$216.00	$432.00
2	Steel Needle-Roller Bearings (5905K77)	2	$6.86	$13.72
2	Metric Steel Ball Bearings	2	$13.25	$26.50
3	ABS Sheet - .236" Thick, Black, 24" x 24"	1	$18.42	$18.42
4	(2 Pairs) Propeller Quick Detach CW CCW	1	$9.99	$9.99
4	(4 pairs) TM 16x5.5" CW CCW Propeller	1	$57.99	$57.99
5	Servo - Hitec HS-5625	2	$39.99	$79.98
5	Servo - Hitec HS-5245	2	$39.99	$79.98
5	Lightweight Servo Hub	2	$3.99	$7.98
5	1/4" ID x 1/2" OD ball bearing	1	$1.99	$1.99
6	Metric Steel Ball Bearings	1	$13.43	$13.43
6	Timing Belt	1	$13.43	$13.43
6	6061 Aluminum tube Stock 12"	1	$5.81	$5.81
6	Black Epoxy, 5 Oz Tube	1	$20.08	$20.08
			Total:	$781.30

This Table provided a list of all the materials we have purchased this semester for our prototyping and final build of the aircraft. Our design also utilizes previous years' components (motors, batteries, etc.) and a Pixhawk microcontroller donated by the 3D Robotics Educational program. They have only request that we provide a photo of our project team for social media purposes.

10.5 Communications

Communication was handled in person or through email and Facebook between team members, while reports and presentations were compiled together on Microsoft OneDrive. Furthermore our team did not have any issues communicating with our advisor and sponsor, either we were able to speak in person or correspond through emails to get things done. Weekly face to face meetings with the TA's and professors were scheduled ahead of time and because of this were not a problem.

11. Conclusion

11.1 Summary of Project

Despite not being able to compete at their original competition Team 8 has had a great year in senior design. In just the first semester the team was able to complete and test a prototype of the final design, demonstrating multirotor flight as well as the concept of the transition bar. In the same semester the team was also able to complete the final integration of the multirotor and fixed wing aircraft. This last semester dealt with and of back and forth with trying to obtain the authorization to fly outside. The team had gotten permission to legally fly indoors at the FSU Tennis Courts near the College of engineering and once the team got their own FAA N-Number they tested their aircraft's capability of transition and horizontal flight which was successful. This team did all of that with only spending half of their allocated budget. Team 8 also won the prestigious award, at FSU's Digitech convention, taking home the "Best in Show for Innovation", which in the competition's words, "For best demonstrating strength and influence through the creation and use of novel technologies". This senior design group was also asked to be one of three presenters to the president and two directors of General Atomics when they came to the campus.

11.2 Future Recommendations

Going back and rebuilding the airframe as well as remounting the integral components to the frame for a cleaner build would be beneficial for overall management as well as providing much smoothing flight surfaces. There are a good amount of unplanned additions to the aircraft which would look and function better if we knew about them beforehand. Another improvement could be to invest in lighter batteries considering the batteries weighing 800g each accounting for ~30% of our total all up weight. It would be wise to invest in a couple wire foam cutters of different sizes for clean easy cuts, in the airframe, when they are needed as well as other tools or materials you might need (soldering station, sheets of ABS plastic, etc.). Also, the aircraft would be much easier to transport if the wings were removable. The best advice to give a future team is that senior design is not a course to take lightly. It's a course that will challenge everything that one has learned in engineering and each person should give their all in their project not only for the completion of the project, but for the experiences and knowledge you gain and opportunities that can stem from it.

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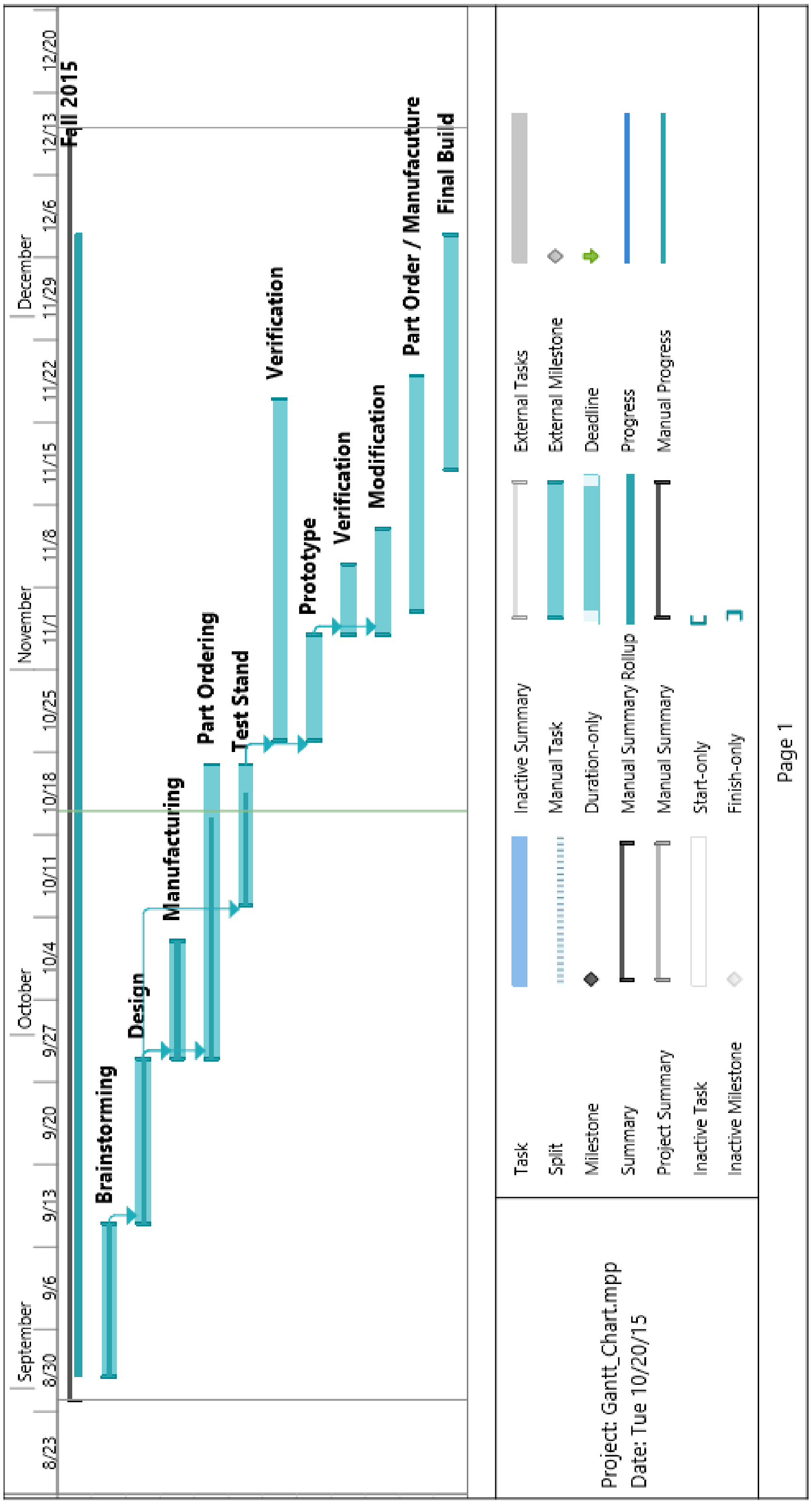
Appendix A

H-FMEA

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

Gantt Chart


September
October
November
December
8/23
8/30
9/6
9/13
9/20
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

Equations

Front Tilt Rotor

Force on Servo

$\text{mass} := 0.772\,\text{gm} \qquad a := 9.81\,\frac{\text{m}}{\text{s}^2}$

$F := \text{mass}\cdot a \qquad \boxed{F = 7.573 \times 10^{-3}\,\text{N}}$

Torque on Servo

$r := 0.08128\,\text{m}$

$T := r\cdot F \qquad \boxed{T = 0.087\,\text{in}\cdot\text{ozf}}$

Tail Tilt Rotor

Force on Servo

$\text{mass} := 0.300\,\text{gm} \qquad a := 9.81\,\frac{\text{m}}{\text{s}^2}$

$F := \text{mass}\cdot a \qquad \boxed{F = 2.943 \times 10^{-3}\,\text{N}}$

Torque on Servo

$r := 0.08128\,\text{m}$

$T := r\cdot F \qquad \boxed{T = 0.034\,\text{in}\cdot\text{ozf}}$

Elevon

Force on Servo

$Cd := 1.32 \qquad \rho := 1.225\,\frac{\text{kg}}{\text{m}^3} \qquad v := 22.35\,\frac{\text{m}}{\text{s}} \qquad A := 0.02288\,\text{m}^2$

$Fd := \frac{1}{2}\cdot\rho\cdot v^2\cdot Cd\cdot A \qquad \boxed{Fd = 9.24\,\text{N}}$

Torque on Servo

$r := 0.04537\,\text{m}$

$T := r\cdot Fd \qquad \boxed{T = 59.369\,\text{in}\cdot\text{ozf}}$

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 Mård 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 the 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.