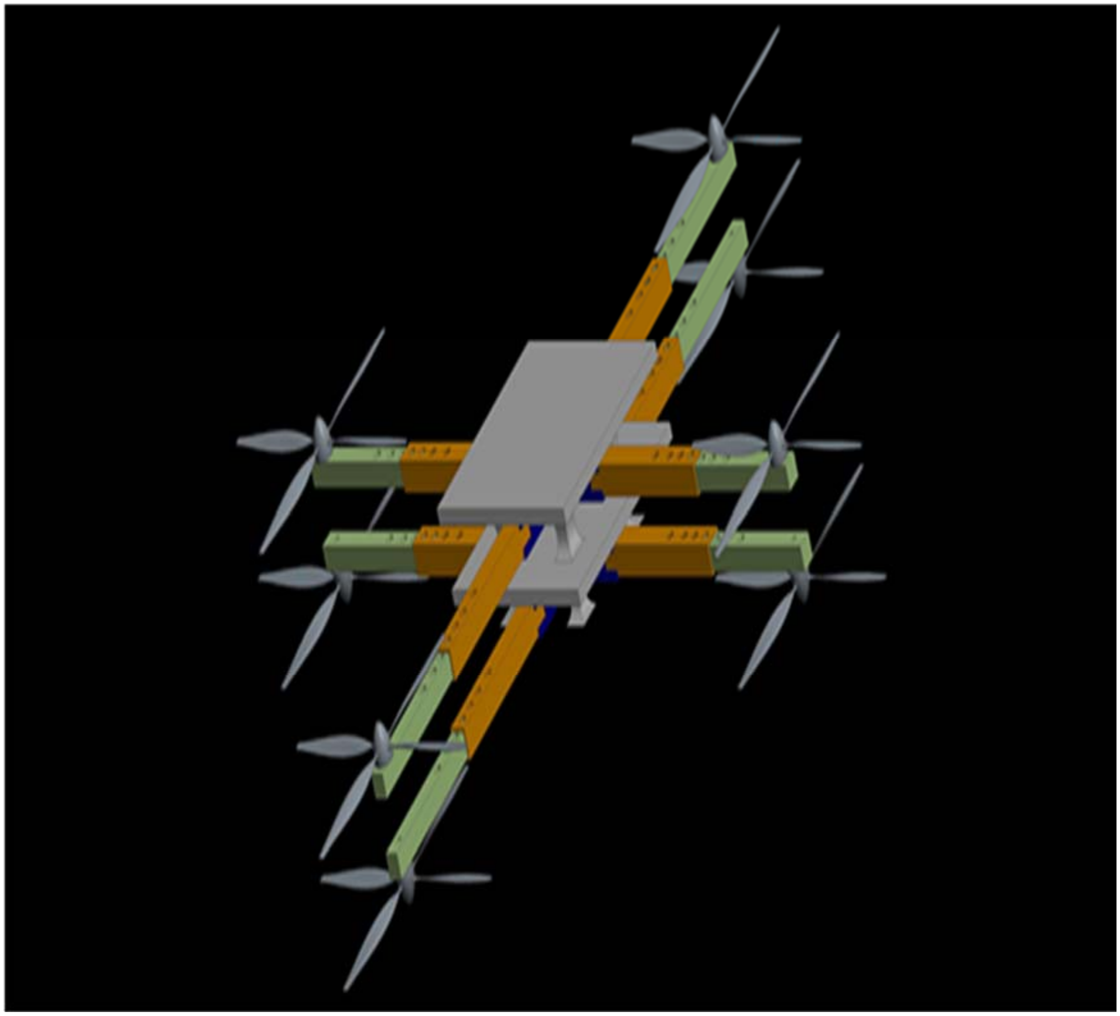
For our report, the errors were so numerous that editing the entire report was justified. As such, the entire report has been revised, rewritten, and reordered. Section numbers included in the major revisions list refer to the section numbers in the new report.

Major revisions include:

- Addition of specific section numbers for the List of Figures, List of Tables, and Abstract, which also changed the numbering of all other sections
- Correction of grammatical and technical errors in all sections
- Clarification of team roles and responsibilities (Section 5)
- New opportunity statement (Section 6.4)
- Revised Voice of the Customer diagram to be one figure instead of two sub-figures (section 7.1)
- Revised House of Quality matrix (Section 7.1)
- Revised Fishbone diagram and explanation of Fishbone diagram (Section 7.2)
- Major revisions in Functional Analysis, Material Selection, and Design Concepts (Section 8.1-8.3)
- Combined Evaluation of designs (originally Section 5.4) with Design Concepts
- Revised Gantt chart (Section 8.4)
- Revised Conclusion (Section 9)
- Added references as needed

Design and Manufacture of a Rotorcraft

Define Phase Report Revisions



Team Members: Chabely Amo, Louisny Dufresne, Robert Johnson, Mohammed Nabulsi, Taniwa Ndebele, Victoria Rogers, Kimberlee Steinman, and Mitchell Stratton

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Submitted To: Margaret Scheiner and Emily Hammel

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3 Abstract

This paper represents an overview of the first of five phases in this project. This phase is known as the Define phase, in which the customer requirements, business case, project scope, and other project charter elements are thoroughly explored and defined. The project definition is explored in detail in Section 3 of this paper, while customer requirements are explored in Section 4.

Rotorcraft vehicles typically fall into two categories: high portability with a low payload capacity or low portability with a high payload capacity. Despite these categories, there exists a need for highly portable rotorcrafts with a high payload capacity, particularly in military applications. As such, this paper presents investigation into the design and manufacture of a rotorcraft that meets this need.

Key rotorcraft components will be examined in order to ensure a highly portable design capable of carrying a high payload. These key components include the frame, the propeller, the battery, the motor, the microcontroller, the RC transmitter, and the sensors. Payload capacity and lift performance of the rotorcraft is determined via the capabilities and characteristics of these key components, particularly the battery, the motor, and the rotor. The results of the component selection process and the equations demonstrating the portability and payload capacity of the rotorcraft are examined in further detail in Section 5.

4 Introduction

Rotary unmanned aerial vehicles often fall into one of two classifications: high portability with a low payload capacity or low portability with a high payload capacity. However, there is a need for rotorcrafts that are capable of transporting heavy payloads while still maintaining high portability, and that need is increasing over time due to the military applications of an unmanned aerial vehicle capable of carrying large payloads while being portable by a single soldier on the ground. The objective of this project is to design and build a rotorcraft with high portability and high payload capacity. Such a device would be beneficial in situations requiring quick deployment of a device carrying a payload up to fifty pounds, such as in battle or during covert military operations.

The advantages of using a rotorcraft flying machine include an ability to take off and land vertically. Some rotorcrafts already exist that can carry fifty pounds, but these rotorcrafts have low portability due to their size. One of the heaviest loads carried by a rotorcraft was 129.4 pounds; however, the rotorcraft could only hover a few feet off the ground [1].

Major design considerations and potential problems include the rotor number and configuration, the raw materials, folding/transport ability, and specifications of the electrical controls that will influence the overall performance of the device. In order to be useful to the Air Force, the sponsoring organization for this project, the vehicle must be small enough to be carried by a single user (in this case, a soldier on the ground) in a military backpack. This places both a size and a weight constraint on the vehicle. After being carried for some unknown distance and time, the vehicle must be easily deployed, able to travel unmanned, able to carry a payload weighing up to fifty pounds up to a mile away from the user where it will subsequently drop the payload. The most common application for these needs would be delivering explosive devices to enemy territory.

Using the needs of the Air Force as communicated to the team through Dr. Okenwa Okoli, this report defines the project requirements and how the team plans to meet these requirements.

5 Team Organization

For this senior design project, the team consists of three industrial engineers, three mechanical engineers, and two electrical engineers. The team reports to the department of Industrial and Manufacturing Engineering and to Dr. Okenwa Okoli, who is also the contact between the team and the sponsor.

The team aims to work together in creating a positive, productive, and professional learning environment. This environment is established through mutual trust and respect, integrity and ethics, and open communication among all members. The team aims to work together in a timely yet careful manner to ensure that the project is completed properly and on time. Figure 1 illustrates the roles delegated to each team member for the Define phase and who each team member reports to.

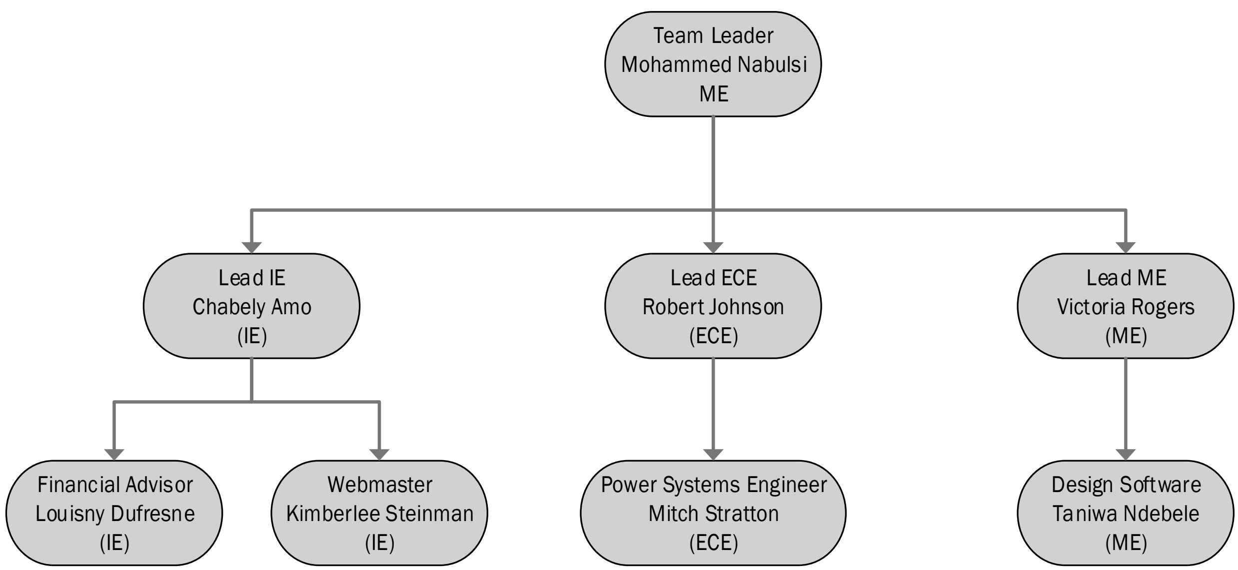

Figure 1. Organizational Chart of Team

- The Define Phase Team Leader is responsible for setting reasonable goals and managing project completion. The Team Leader assures that workload is distributed evenly between the team members. The Team Leader also sets meeting agendas and keeps the communication flowing between team members, faculty members, and the sponsor.
- The Mechanical Engineering Lead is responsible for managing mechanical engineering members of team and scheduling meetings with the mechanical engineering advisor. The

Mechanical Engineering Lead maintains constant contact with the Electrical and Computer Engineering Lead to ensure compatibility between mechanical and electrical components of the project and is in charge of maintaining the documents created by the Software Designer.

- The Industrial Engineering Lead is responsible for managing industrial engineering members of team and scheduling meetings with the industrial engineering advisor. The Industrial Engineering Lead is in charge of ensuring that the team meets deliverable deadlines and is in charge of the material selection and manufacturing process of the project.
- The Electrical and Computer Engineering Lead is in charge of scheduling meetings with the electrical and computer engineering advisor. The Electrical and Computer Engineering Lead is also in charge of selecting electrical components of the project and programming the rotorcraft.
- The Financial Advisor is responsible for the group finances as well as keeping track of purchased parts and overall inventory. The Financial Advisor maintains appropriate expenses and plans for funding and ensures the group stays in budget.
- The Webmaster is responsible for maintaining the team project website with up to date information and media and for facilitating the sharing of research with all team members.
- The Software Designer is in charge of the creation of all drawings, reports, and all other necessary documents regarding the design of the project.

The primary sources of communication between team members are through emails, phone calls, and text messages. A group me app is used to coordinate team meetings as well. Each member must check their email at least daily for important information regarding the group. If a team meeting is canceled, an email must be sent to the group members and other invitees at least 24 hours in advance by the Team Leader.

Meetings have been established once a week. These meetings are weekly on Sundays at 2:00pm. All members are expected to attend meetings and missing these meetings without a valid excuse will not be tolerated. If a team member must miss a scheduled meeting, they must notify the entire team and the Team Leader of their absence at least 24 hours in advance. Additional meetings will be scheduled as necessary.

6 Project Definition

6.1 Background Research

In 1907, Louis Breguet designed the earliest rotorcraft [2]. The four-rotor helicopter was only able to fly a few feet above the ground. Since then, unmanned aerial vehicles (also known as UAVs) have become commonly used for many applications. There are several programs working on improving these rotorcrafts including [2]:

- Bell Boeing Quad TiltRotor
- Aermatica Spa's Anteos
- AeroQuad and Ardu Copter
- Parrot AR.Drone

However, all these programs have not come up with a design that meets this senior design project. These programs have a variety of uses including world class engineering research laboratories, military and law enforcement, and as well as commercial use for aerial imagery [3]. The primary difference between this senior design project and the rest of these programs is the rotorcraft's portability. Most of these rotorcrafts are designed with no limitation on size. So an essence having a rotorcraft capable of lifting 50+ lbs. and still being small enough to fit in a military size backpack has never been done before.

Over this past summer, FAMU-FSU College of Engineering have took on the task of building a rotorcraft with the same requirements as this senior design project has. However, Dr.Okoli has decided to keep the literature about the design concept and journals of calculations on the rotorcraft the school is building confidential until our senior design team comes up several new ideas. Based on the next meeting with Dr.Okoli, he will decide if we will continue with the new designs proposed, or if our team will continue the project FAMU-FSU COE started this past summer.

Reviewing the various configurations available for rotorcrafts is necessary before an optimal platform can be designed. A rotorcraft is a heavier than air flying machine that uses lift generated by wings called rotor blades that revolve around a mast [3]. An example of a rotorcraft is a quad rotor. A quad rotor generates lift by four set of rotors vertically oriented propellers [4]. A rotorcraft which is capable of being quickly deployed and carrying a large payload has several applications, including the transportation of equipment to remote areas where the terrain is unsuitable for ground-based vehicles.

As seen in Figure 2, a quad rotor uses four rotor blades. The M_f and M_b rotate in the clockwise direction, while the M_l and the M_r Pair rotate counter clockwise. This allows the rotorcraft to be fly because it creates a balance for the drag created by each spinning rotor pair. Additionally, varying the number of rotations per minute for each rotor blade individually allows the user to control lift and torque forces. Other characteristics affecting the rotorcraft's performance include raw materials, frame structure, and electrical components.

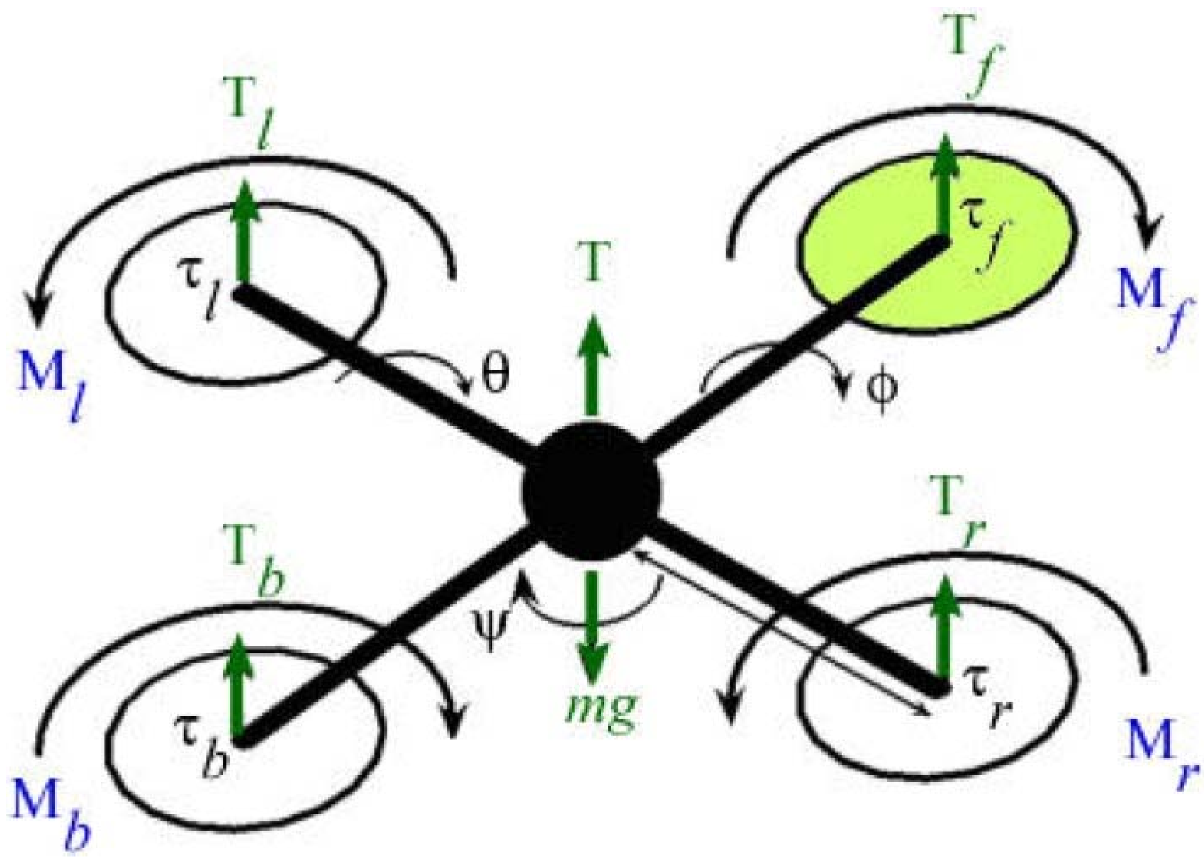

Figure 2. QuadRotor [5]

In this report, several configurations of rotorcrafts are explored. In particular, this report examines a quadcopter, a hexacopter (six rotors), an octocopter (eight rotors), and a dodecacopter (twelve rotors). The relationship between the number of rotors and the rotor size determines how much thrust is needed per rotor to lift the vehicle and its payload.

6.2 Need Statement

While there exist rotary unmanned aerial vehicles that carry high pay loads, they lack the portability for practical applications. Rotorcrafts are beneficial in comparison to more traditional aerial vehicles as they can take off and land vertically, instead of requiring horizontal ground travel to take off. Rotorcrafts have seen an increase of 21.5% in military applications since 1992 [6]. For applications requiring a single soldier-user in the field, a portable rotorcraft with a high payload capacity is desirable. It is expected that a rotorcraft capable of carrying a large payload while remaining light enough and small enough to fit within this single soldier-user's military regulation backpack (and thus maintaining high portability) would greatly benefit the Air Force in comparison to other military forces without this technology.

6.3 Business Case and SIPOC

Current rotorcrafts on the market prioritize either payload capacity or rotorcraft size. However, there are applications where both payload capacity and rotorcraft size are desired, such as equipment delivery in the military or more martial and offensive deliveries. By designing a rotorcraft with the given specifications (must carry at least 50 pounds and must fit in a military backpack), along with designing the processes required to manufacture the rotorcraft and building a prototype, this project will result in a revolutionary product in the rotorcraft field. It will initiate a market for rotorcraft that carry large loads while being small.

Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis can be a good starting point for analyzing an organization. The SWOT analysis for this project team can be seen in Table 1 below. For this team, the greatest strengths lie in communications and scholastic backgrounds. There is open communication among all team members and all members agree to maintain this level of communication, preventing any miscommunication before it has a chance to occur. The team members are divided among three different majors in the College of Engineering, so each team member has different training and experience to use as tools in solving any problem encountered during the course of the project.

Weaknesses lie in group size and management ability. Managing and organizing eight people and their unique schedules is a challenge in and of itself, even without involving outside resources or advisors and their schedules. The team must work together to keep each other accountable and work around difficult schedules in order to make this project successful.

Table 1. SWOT Analysis Quadrants

STRENGTHS	WEAKNESSES
• Interdisciplinary group means that there are several diverse outlooks on problems encountered during the course of the project. • A group text message (GroupMe) allows for open communication for discrete questions, while weekly meetings and email allow for in-depth progress reports and assistance. This open communication prevents problems from falling through the cracks. • Our advisors and resources (primarily Dr. Okoli, Dr. Dickens, Margaret, Emily, and Cameron) are reliable in their communication and availability to the team.	• It is more difficult to maintain order in a group of 8 students, which is one of the largest groups this year. • Finding published literature for rotorcraft carrying high payloads at a small size is difficult, as normally researchers and hobbyists prioritize one over the other. This leads to a higher need for synthesis of several vehicles instead of one or two that suit our needs. • Enforcement of internal deadlines is difficult with eight members, but it is not impossible.
OPPORTUNITIES	**THREATS**
• War or other military action in areas known for volatile terrain might lead to a spike in demand for unmanned aerial vehicles instead of unmanned terrain vehicles.	• Another military body or another funded group also developing a rotorcraft similar to the one described in this report might devalue the results of our project.

Another organizational tool is Suppliers, Inputs, Processes, Outputs, and Customers (SIPOC) analysis, which as the name implies allows an organization to explicitly identify suppliers, inputs, processes, outputs, and customers. The SIPOC analysis for this project can be seen in Table 2.

Identifying all the elements in SIPOC analysis helps to define the scope of the project. For this project, half of the process is the design of the rotorcraft and manufacturing processes, while the other half of the process is building a prototype for design chosen. Splitting this process into its two halves lets the team identify the input for each part and the supplier for that part. For instance, designing the rotorcraft and manufacturing processes requires the team's collective knowledge and training in engineering as an input, which has been supplied by the College of Engineering and its various departments, while building the prototype requires the team to build a frame for the rotorcraft using materials and process knowledge provided by HPMI.

Table 2. SIPOC Analysis Chart

Suppliers	Input	Process	Output	Customers
College of Engineering departments (Industrial and Manufacturing, Electrical and Computer, and Mechanical)	Group member's knowledge and training in design and manufacturing	Design a rotorcraft that meets the customer's requirements and the manufacturing processes required to create the rotorcraft	A rotorcraft that can fit in a military backpack (23x14.5x15), can carry a payload of at least 50 pounds, is made with commercial off the shelf components, has a range of approximately 1 mile, and is easy to maintain and use in the field, along with the manufacturing processes and data required to produce this rotorcraft.	The Department of Industrial and Manufacturing Engineering at FAMU/FSU
Online retailers	Rotorcraft components: rotors, propellers, battery, IMU sensors, microcontroller, RC transmitter	Build a prototype rotorcraft		Military bodies
HPMI	Materials for the frame for the rotorcraft			

6.4 Opportunity Statement

The main application for the UAV being designed in this project is delivering explosives into enemy territory. Traditionally, larger explosives would be dropped from overhead by a pilot in a bomber. With this rotorcraft a trained soldier could control the rotorcraft from the ground and drop a smaller explosive.

This soldier/rotorcraft combination would save the Air Force money as compared to the pilot/bomber combination. Assuming that the soldier would be an Airman (E-2) who has been with the military for two years, which would allow for training in rotorcraft control, the soldier earns $1,760.90 a month [7]. Being a pilot in the Air Force requires at least officer enlistment [6], which begins at the rank of Second Lieutenant. If this pilot has been in the Air Force for the same two years as the Airman, he earns $2,905.20 a month [7].

This project will save the Air Force $1,144.30 in wages per month per replacement of a pilot and plane with a less trained airman and rotorcraft in situations where a range of one mile and payload size of fifty pounds are adequate.

6.5 Goal Statement & Objectives

Using the SIPOC, SWOT, and other analyses described in this report, our goals are as follows:

1. Design a rotorcraft that can:
    a. Fit in a military backpack (23”x14.5”x15”)
    b. Carry a payload of at least 50 pounds
    c. Be made with commercial off the shelf (COTS) components
    d. Travel up to approximately 1 mile
    e. Be easily maintained and used in the field
2. Design the manufacturing processes to be used in creating the rotorcraft described in Goal 1.
3. Build a prototype of the rotorcraft described in Goal 1.

These three goals together are the overall goals for this project. Variables in these goals include the customer requirements and the deadlines for each phase of the DMADV (Define, Measure, Analyze, Design, Verify) process associated with this project.

6.6 Project Scope

The team will work with any and all processes that help to achieve the goals listed above in section 3.5. The scope of this project does not include elements outside of the goals described above. Excluded elements include but are not limited to high-level material research and operation above the specifications listed in the project requirements. These exclusions could form the basis of further projects after the completion of this project.

6.7 Constraints

This rotorcraft must be both compact and have high pay load lifting abilities. The rotorcraft must have a payload capacity of at least 50 pounds. Additionally the rotorcraft cannot exceed the 23” x 15” x 14.5’’ dimensions of a military backpack. The rotorcraft should also be able to travel up to a mile. Furthermore, the rotorcraft’s electrical components should be easily obtained at American retail locations where electrical components are sold to prevent costly repairs. The total budget of this project should be kept under $2,500.

7 Analysis of Customer Requirements

7.1 Critical Customer Requirements (CCR)

The Voice of the Customer tree is a diagram used to capture the customer requirements in depth. Figure 3 illustrates the rotorcraft customer requirements and the approaches to achieve the design and manufacture of the rotorcraft. There are eight critical requirements the design of the rotorcraft must meet. These requirements are:

- The rotorcraft must lift a payload of at least 50 pounds
- The rotorcraft must fit in a military backpack
- The rotorcraft should be easy to carry
- Safety to the user should be considered
- The rotorcraft design must use off the shelf electrical components
- The rotorcraft must have a flight range of one mile
- The project's budget is $2,500
- The rotorcraft must be easy to assemble and use in the field.

In order to lift the desired payload, the rotors, batteries, and propellers must be capable of providing the necessary lift and thrust forces. Additionally, the list and thrust forces must account for both the weight of the rotorcraft and the weight of the payload. Since the weight of the payload is fixed, the only way to minimize the required lift and thrust forces is to minimize the weight of the rotorcraft. Therefore, the body of the rotorcraft will be made out of composites to reduce weight while maintaining strength and the electrical and mechanical components will be lightweight as well. Further, the payload will be attached to the rotorcraft with a karabiner and a cable or rope of adequate strength.

The rotorcraft must fit in a military backpack, which is 23 inches in length by 15 inches in width by 14.5 inches in height. Foldable arms will be implemented to achieve this requirement and make it possible to fold and unfold the arms when necessary.

Since it is a military application, the rotorcraft must be easy to carry, quickly assembled for take-off, and safe for the user. An ergonomic analysis will be performed to determine the most efficient folding mechanism the user can accomplish in the field and the electrical wires will be insulated to avoid any electrical shock.

Off the shelf electrical components will be used to facilitate replacement if needed. Additionally, using commercial off the shelf (COTS) components is more feasible than using custom components due to cost and time investment.

The rotorcraft has to have a flight range of one mile. Therefore, the battery needs to provide enough power to keep the rotorcraft in the air for the amount of time required to travel one mile and the range of the RC transmitter must be adequate to maintain user control of the rotorcraft over the entire flight range.

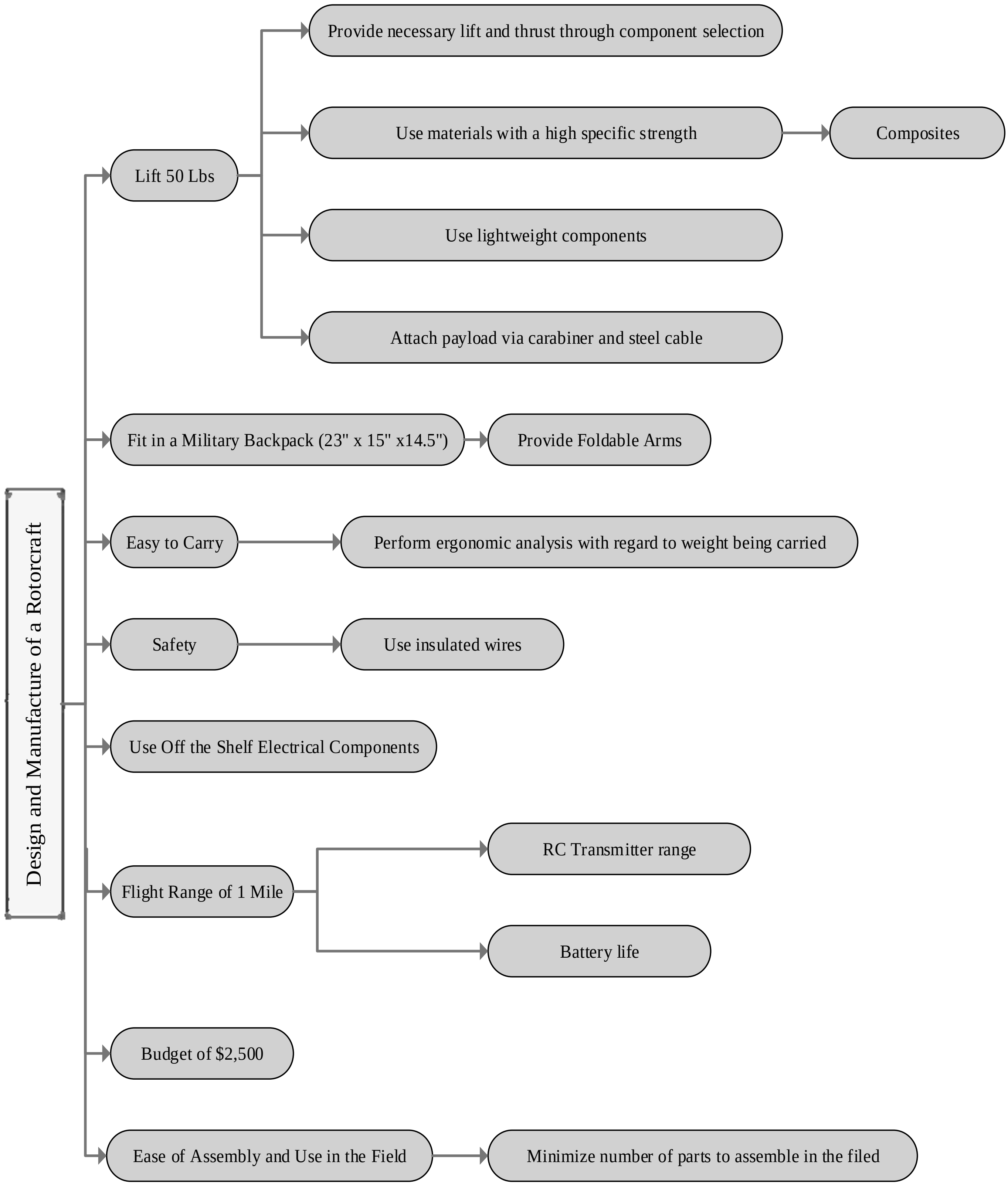

Figure 3. Voice of the Customer Tree

The House of Quality matrix uses the voice of the customer to define a relationship between customer requirements and how the team is going to achieve those requirements. Figure 4 shows the House of Quality matrix created for this project. The left side of the House lists what the customer requirements are. Importance ratings from one to five were assigned to each of these requirements via discussions between the stakeholders and the team about the importance of each requirement. The top side of the House represents how the team will meet the customer requirements.

The box located at the center of the House of Quality is a matrix used to provide a connection between the requirements and the methods the team is going to implement to meet them. The requirements and methods are paired together using symbols that indicate if the relationship is strong, moderate or weak. The symbols are assigned with indexes of nine, three, and one with nine being the strong relationship and one being the weak relationship. For example, providing the necessary lift and thrust forces is strongly related to the requirement of lifting a 50 pound payload, while the number of rotors is only moderately related.

The technical weights located at the right of the quality matrix determines the most critical customer requirements. The weights were calculated by adding all the products resulting from multiplying the customer requirement ranking by the index number assigned to the relationship between the approach and the customer requirement. For example, there is a strong relationship between providing the necessary lift and thrust forces and lifting fifty pounds. Since lifting fifty pounds has a customer index rating of five and a strong relationship represents an index of nine, multiplying five and nine will give a portion of the technical weight. This calculation is performed for each relationship and all the products for each requirement are added together. Based on the weights for the customer requirements, the most important requirement is that the rotorcraft is able to lift fifty pounds.

The technical weights located at the bottom of the targets list determine the most critical method. The weights were calculated in a method similar to that for the customer requirements, except the sum is along each column instead of along each row. For example, having foldable arms is strongly related to fitting in the military backpack and a moderate relationship with ease of assembly and use in the field. Therefore, multiplying nine and four and adding it to the product of three and four will result in the technical weight for that method. The necessary lift and thrust forces has the highest technical weight and is thus the most critical method.

The technical weights can also be described via a percent weight, which is merely the technical weight of each requirement or method divided by the total amount of weight for all requirements or all methods. The roof of the house identifies the correlations that exist between the methods that will be used to fulfill the requirements. For example, providing necessary lift and thrust forces is positively correlated with using lightweight components because a lighter rotorcraft means that lower lift and thrust forces can be adequate to fly the rotorcraft. The box below the roof represents the objective of each method, whether it is to minimize, maximize or hit the target.

The box above the technical weights of the methods and below the matrix itself lists the components that fall under each method. This House of Quality matrix justifies a focus on the requirements of lifting the payload and having a flight range of one mile. Similarly, this matrix justifies focusing on the lift and thrust force provided by the rotorcraft, the weight of the components, and the specific strength of materials used to build the frame.

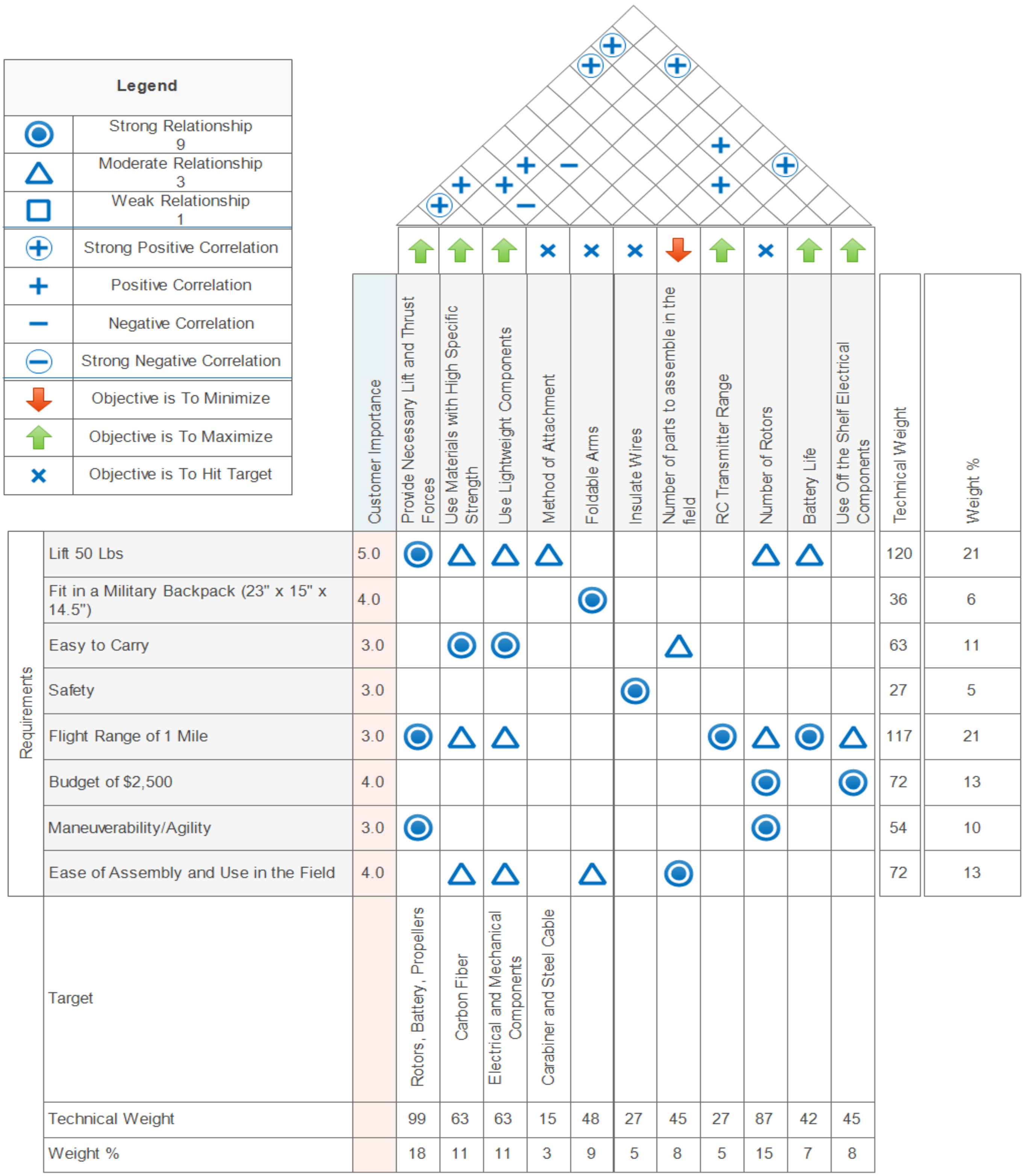

Figure 4. House of Quality

7.2 Meeting CCR

Meeting critical customer requirements includes predicting and preventing problems that may arise. To this end, a cause and effect diagram (also known as a fishbone diagram) was created to predict any potential causes of an overall failure in terms of project completion or meeting the requirements of this project. This fishbone diagram can be seen below in Figure 5 and each cause is explained by category.

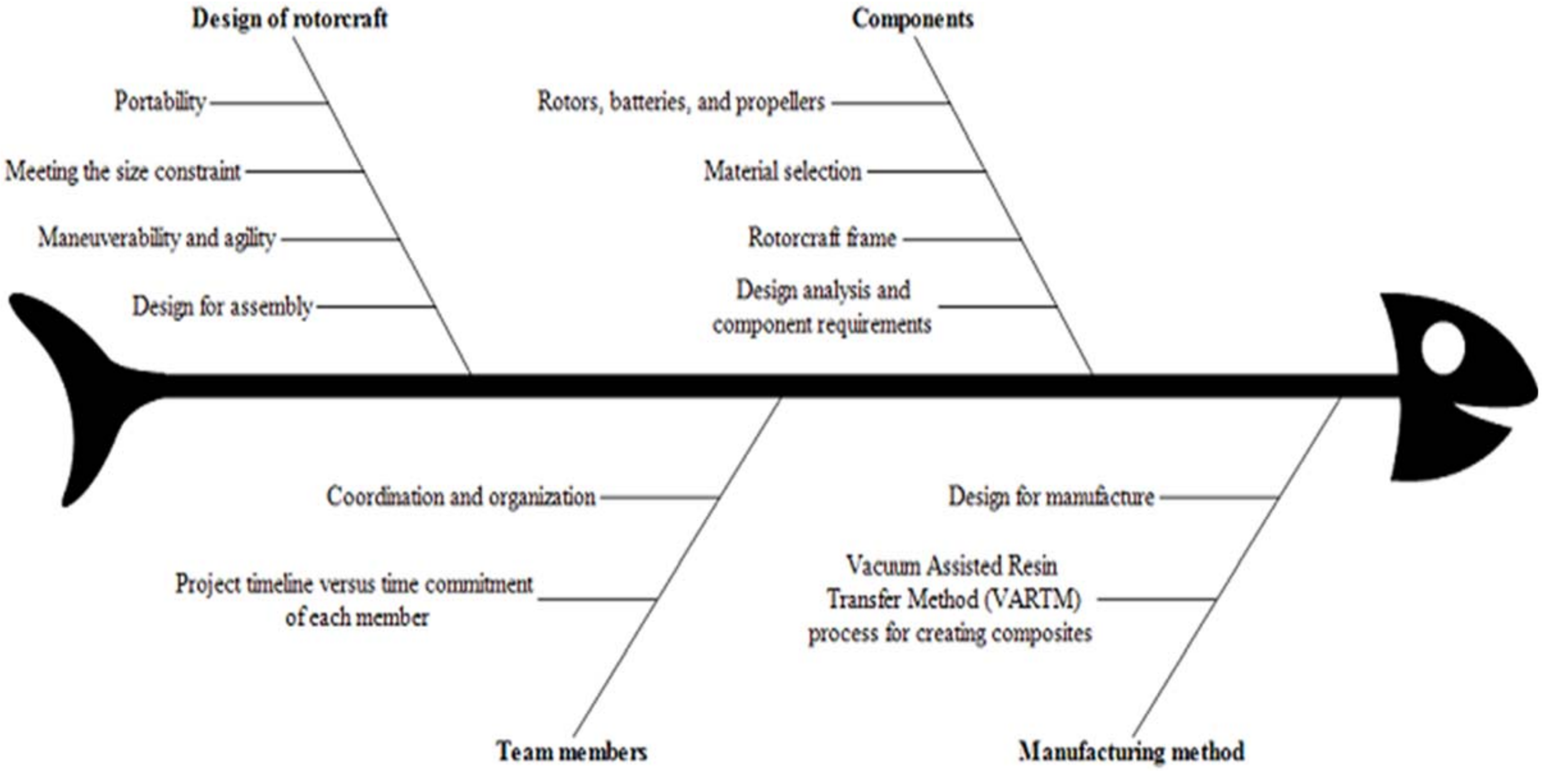

Figure 5. Fishbone Diagram

Design of rotorcraft

This category refers to problems caused within the actual design of the rotorcraft. In order to be useful to the project sponsor, the rotorcraft must be portable, meet the given size constraint of fitting in a military backpack, and be maneuverable and agile during flight. Failing to consider these aspects during the design phase will result in a failed project, as the designed rotorcraft will not meet the customer requirements.

Principles of design for assembly must be considered during design, otherwise the user will not be able to easily assemble the rotorcraft in the field. Again, failing to consider this aspect will result in a failed project.

Components

This category refers to problems caused by the specifications of the components or in component and material selection. Design analysis and component requirements must be strictly and carefully calculate and considered. An unchecked error in these calculations might snowball into selecting, purchasing, and using a component that does not sufficiently meet the actual requirements. These sorts of errors might result in a failed project, depending on how large the error is and how large the margin of error between the calculated requirements and selection component specifications are. In particular, the components with the largest potential to cause a problem are the rotors, batteries, and propellers, as they have the greatest effect on the lift and thrust forces. Additionally, quality control issues on the part of the suppliers of these components could have an effect on the final rotorcraft and could result in a failed project if the quality is poor enough.

Similarly, incorrect material selection could result in a failed project because of the failure of individual pieces of the rotorcraft. The rotorcraft frame holds all the other components and as a result, a faulty frame could lead to a failed project.

Team members

This category refers to problems caused by the team members themselves. A project team of this size requires a large degree of coordination and organization. A failure in this area, such as losing project documentation or not properly coordinating schedules, could lead to an incomplete and failed project.

Each of the eight team members have unique commitments outside of this project, such as other coursework or outside employment. The time commitment of each member must be coordinated and the overall project timeline must be factored into this time commitment or else the project will be incomplete or failed at the end of spring semester.

Manufacturing method

This category refers to problems caused by the manufacturing methods. Failing to consider principles of design for manufacturing during the design process could result in a design that is incredibly difficult or even impossible to manufacture. If these difficulties are not caught early enough, the manufacture of the rotorcraft could be delayed significantly and result in an incomplete project.

A common method for creating composite materials is the Vacuum Assisted Resin Transfer Method (VARTM) and this method has several quality control concerns, such as using a consistent and correct amount of resin and adequately creating a vacuum during the process. A quality control issue during the creation of the composite materials needed for this project could result in a failed project.

8 Design and Analysis

8.1 Functional Analysis

In the preliminary design phase, critical design parameters associated with the frame, rotors, propellers, battery, sensors, microcontroller, and RC (radio control) transmitter were investigated. Trade studies related to these critical design parameters evaluated the trade-offs between each aspect's design alternatives. In other words, through analyzing each design alternative (such as battery or motor selection), the best overall design for the rotorcraft could be produced. Through extensive research and trial and error, the analysis and optimization of the preliminary design created by the team can determine the rotorcrafts flight performance.

8.2 Material Selection

Some of the customer requirements for the rotorcraft's frame include minimizing both weight and price of the rotorcraft, while maximizing its strength. Composite materials offer these characteristics because they are lighter and less expensive than alternative materials, such as aluminum. Composites are defined as two or more constituent materials combined by an interface. This combination results in a material with better properties that cannot be achieved by either of the constituents on their own [8]. Composite materials typically have a lower density, therefore are lighter than other materials used in rotorcrafts. For example, the density of carbon fiber is about 1.55 g/cm^3 while aluminum's density is 2.7 g/cm^3.

There exist different types of composite materials that can be distinguished depending on the type of matrix and reinforcement used. The particulate reinforced material that will be used for the frame is a polymer matrix. Carbon fiber or Glass fiber will be used as the reinforcement material in an epoxy resin matrix. The following paragraphs include comparisons between carbon fiber and glass fiber, a brief explanation of epoxy resin properties, and the process that will be used to manufacture the frame of the rotorcraft.

First, a comparison of carbon fiber and glass fiber is necessary to select the better material for the frame of the rotorcraft. The rotorcraft has to tolerate a wide range of stresses from changing frequency vibrations, heat, centrifugal forces, hard landings, and many more.

Therefore, the material has to be strong and stiff to endure all those factors. Tables 3 compare properties and characteristics of carbon and glass fiber.

Table 3. Mechanical Properties and Price of Carbon Fiber and Glass Fiber

Material	Tensile Strength (MPa)	Young Modulus (GPa)	Density (g/cm^3)	Price/Yard ($)
Carbon Fiber [8,9]	4127	125 – 181	1.58	30 - 40
Glass Fiber [9,10]	3450	30 – 40	2.66	5

It should be mentioned that the numbers shown in Table 3 are estimations and actual values vary from sample to sample. Because there are many types of carbon and glass fibers, such as E-glass and S-glass, the numbers tend to vary between the different types of carbon and glass fibers. However, the figures in Table 3 are suitable to make comparison between carbon fiber and glass fiber.

Table 3 shows that carbon fiber is stronger than glass fiber. Carbon fiber has a tensile strength of 4127 Mpa, while glass fiber has a tensile strength of 3450 MPa. The difference between their strengths is nearly 18 percent. The stronger the material the greater the durability of the rotorcraft. Also, carbon fiber presents a young modulus of 125-181 GPa and glass fiber of 30-40 GPa. As such, carbon fiber is much stiffer than glass fiber, which is another important factor enabling the resistance of stresses in the rotorcraft.

Another aspect to be taken into consideration is density. The rotorcraft needs to be as light as possible in order to minimize the thrust and lift forces needed to maintain flight. Because carbon fiber has a density of 1.58 g/cm3 while glass fiber of 2.66 g/cm3, it is favorable to use carbon fiber because a higher amount of strength can be obtained for a lesser weight of material. Finally, budget is an important constraint in this project. Carbon fiber price per yard ranges from $ 30-40 while glass fiber price is between $3 and $6 for the same amount. Carbon fiber is significantly more expensive than glass fiber, however its greater strength and lower density make the difference in price worth the expense so long as the remainder of the project's material remain within budget. Because of this, carbon fiber was selected for the frame of the rotorcraft.

Next, epoxy resin is formed when it reacts with a polyamine hardener. It presents a highly cross-linked network that makes it strong, hard, and rigid. Its main purpose is to work as an adhesive with strong resistance coatings and finishes, and it is used as the matrix in fiber reinforced plastics [10]. Epoxy resin was chosen opposed to alternative resins such as vinylester resins or polyester resins because epoxy resin has more than three times the strength of either vinylester or polyester resin and bonds to carbon fiber significantly better. It is recommended that polyester resin never be used in carbon fiber and vinylester resin only be used with carbon fiber in cosmetic applications [11]. The Young Modulus of epoxy resin is 3 GPa meaning it is a very elastic material. Additionally the density ranges between 1 and 1.15 g/cm^3 meaning epoxy resin has a similar, through slightly lower density than carbon fiber. The price of a half-gallon of epoxy resin ranges from $30-$40.

Further in order to manufacture the carbon fiber, vacuum-assisted resin transfer molding (VARTM) is utilized. VARTM is one of the processes use to manufacture composites and is the one that will be used to create the frame of the rotorcraft. The VARTM process was selected as there are resources available in Tallahassee to learn the process. This process consists of using pressure to vacuum seal a flexible bag that encloses the reinforcement and the matrix together until the resin cures. The process occurs in three steps: the creation of the mold (based on the design of the rotorcraft), the manufacturing, and post processing.

The manufacturing process of the vacuum bag can be seen in Figure 6 and the materials and equipment required in the process include [12]:

- Mold Release → prevents sticking between the matrix and the mold
- Release Fabric → separates the flow medium from the composite and leaves a good surface finish
- Flow Medium → allows the resin to flow with ease
- Vacuum Bag → seals the reinforcement and matrix together and increases the permeability of the process
- Mastic Sealant → sticks the bag, the tubes, and the mold together
- Plumbing System → two tubes are used: the gate and the vent. The gate tube filtrates the resin and the vent tube is used to control the vacuum pressure
- Pump → use to apply the vacuum

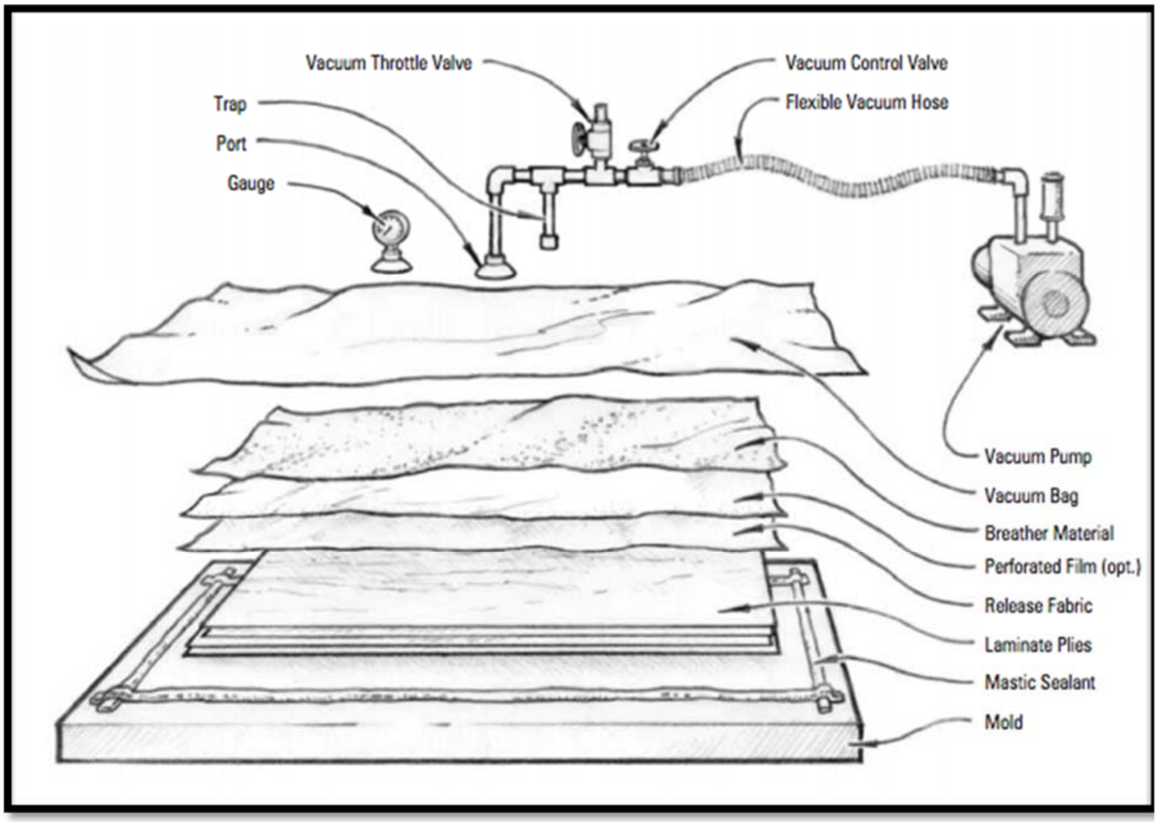

Figure 6.Materials and equipment for the Vacuum Bagging Process [12]

The vacuum bagging process of a composite consists of six steps that are:

1. Prepare the area where the composite will be manufactured
2. Cut, clean, and prepare all the materials require for the process
3. Place all the materials and equipment in their respective order, as illustrated in Figure 6
4. Prepare the resin. Add curing agent and stir as necessary
5. Start the vacuum bagging process. Connect the pump to the correct tube, infiltrate the resin, and let it cure
6. Applied post processing to the composite

8.3 Design Concepts

In define phase process, design concept should be pursued and what components to use on that design should be determined. In order to design a frame, thrust calculations must be looked at first to identify an adequate number of rotors. Thrust was examined for a rotorcraft with four, six, eight, and twelve rotors by simply dividing two times the required thrust (accounting for a factor of safety) by the number of rotors in each design. A minimum of four rotors was examined so that the rotor craft would be balanced and so that no one rotor would have to produce an unrealistic thrust. A maximum of twelve rotors was examined because of the limited size of rotor craft due to backpack size constraints. Equations 1, 2, 3, and 4 provide the relationship between thrust required per rotor and the number of rotors used in that particular configuration.

$$\frac{150\ lbs.}{4\ rotors} = 37.5\ lbs.thust\ per\ rotor \qquad \textbf{Eq. (1)}$$

$$\frac{150\ lbs.}{6\ rotors} = 25\ lbs.thust\ per\ rotor \qquad \textbf{Eq. (2)}$$

$$\frac{150\ lbs.}{8\ rotors} = 18.75\ lbs.thust\ per\ rotor \qquad \textbf{Eq. (3)}$$

$$\frac{150\ lbs.}{12\ rotors} = 12.5\ lbs.thust\ per\ rotor \qquad \textbf{Eq. (4)}$$

Examining these values, using four rotors was out of the question because generating 37.5 pounds of thrust per rotor is unrealistic due to motor limitations. Therefore the team started by designing a rotorcraft with six rotors. The utilization of six rotors would make the design fit more easily into the backpack with the use of hinges, however the fewer amount of rotors utilized in the design the greater thrust per rotor would have to be generated. Next, the twelve rotor design was examined. With the use of twelve rotors for the same size rotorcraft, one could easily generate enough thrust to lift the fifty pounds. However some disadvantages for using twelve rotors is the difficulty of fitting it in a backpack, which could also limit the size of the individual propellers on the rotors. Further as more rotors are added to a rotorcraft its weight typically increases. Finally, an octocopter was analyzed. Using eight rotors would allow for having a reasonable 18.75 pounds of thrust per rotor. A huge advantage to having eight rotors as opposed to four rotors is that if one of the rotors were to fail, then the pilot would still have partial control over the rotorcraft.

Frame - The frame is the structure that holds all the components together. They need to be strong, but also lightweight. The frame should be rigid to minimize the vibrations coming from the motors by transmitting them through the frame. The frame can consist of two or three parts which don't necessarily have to be the same material. The electronics will be mounted on the center plate. A picture of the hexacopter design can be seen in Figure 7.

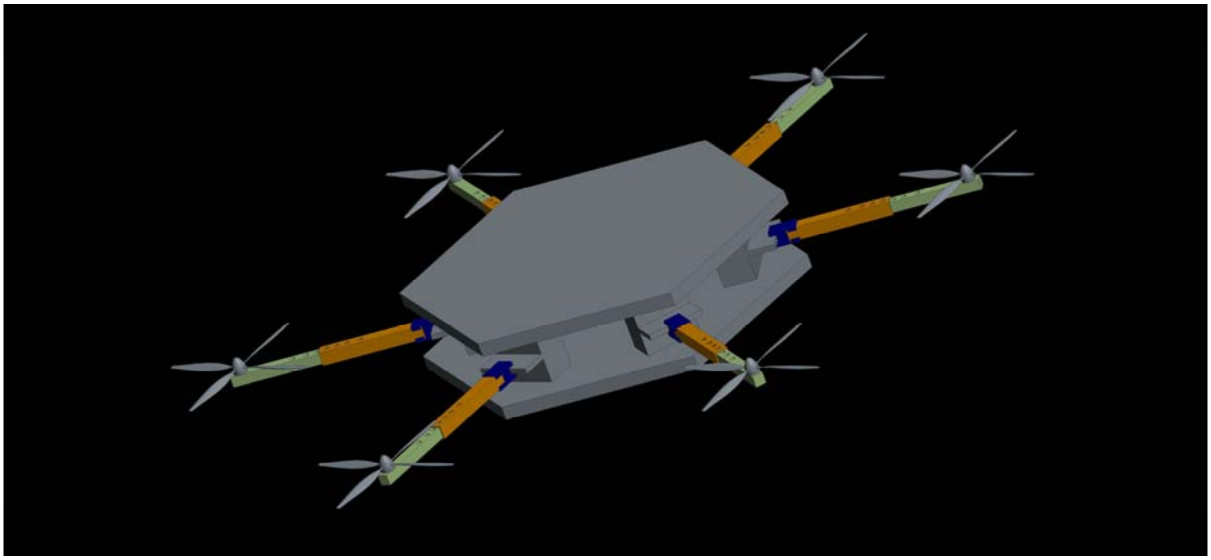

Figure 7. Hexacopter Design in Creo-Parametric 2.0

While using six rotors would make it simpler to fit in a backpack due to less rotors, it would be more difficult to generate 25lbs than 18.75lbs of thrust per rotor. Because collapsing the rotors to make the design fit into the backpack currently appears simpler than finding a way to generate such a high thrust, the six rotor design was eliminated from consideration. Therefore, the team began examining the octocopter. Using eight rotors would allow for having a reasonable 18.75 pounds of thrust per rotor. A picture of the octocopter designed in Creo-Parametric 2.0 can be seen in Figure 8.

A closer examination of the octocopter frame shows there will be eight arms mounted on to the center plate in four pairs. Pairing four sets of rotors allows for a more compact design than having all eight rotors separate which is ideal due to size constraints of the rotorcraft. At the end of each arm there will be motor brackets to connect the motor to the arms, seen in Figure 8. In order to stay within the size constraint, the arms will be able to slide into themselves like a telescope. These arms could be detachable, which helps make it easier to fit into the military backpack. Because a collapsible octocopter could fit into the backpack and have a reasonable amount of necessary thrust the octocopter was the selected design for this project.

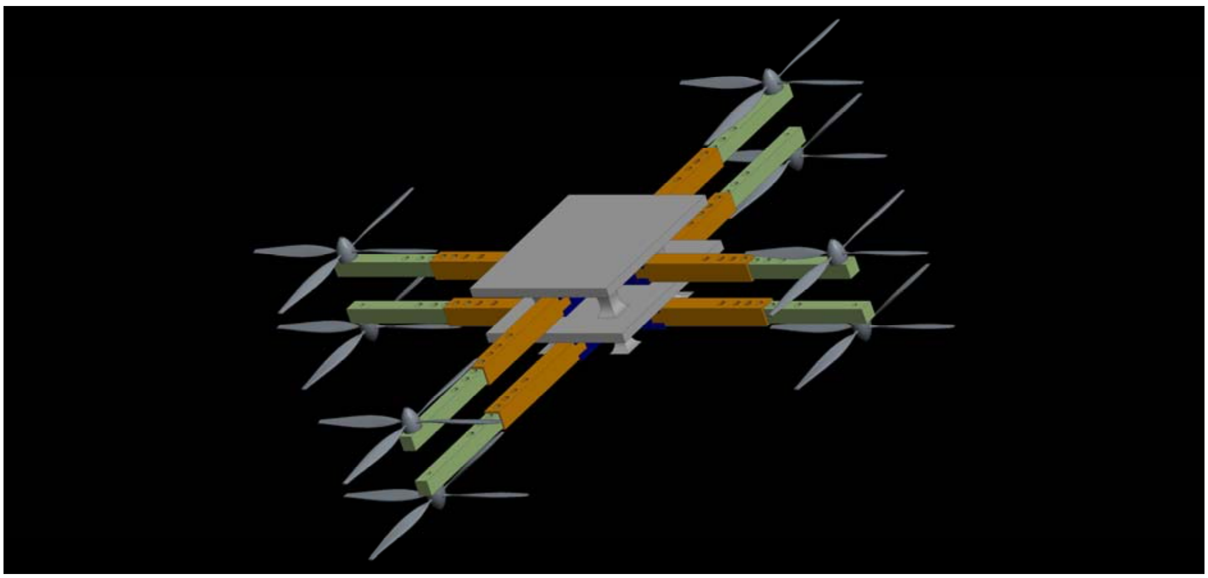

Figure 8. Octocopter Design in Creo-Parametric 2.0

Motor - The selected motor must be lightweight and capable of rotating the propeller at the desired angular velocity. Selecting the correct motor is essential in producing the required thrust to lift the rotorcraft off the ground. The motor selection was based on several desired characteristics: lightweight, high efficiency, and high power. In order to get these characteristics a brushless motor is going to be used. DC motors fall into two classifications, brushed and brushless. Brushless motors spin in much higher speed and use less power at the same speed than brushed motors [13]. In addition, brushless motors don't lose power in the brush-transition like the brushed motors does, so it's more energy efficient [13]. An important specification when considering brushless motors is the "Kv-rating". Kv-rating shows how many RPMs the motor will achieve if provided with v-number of volts. A picture of the Turnigy G60 brushless motor that will be considered can be seen in Figure 9. Another motor under consideration is the E-Flite power 52 Brushless Outrunner Motor which can be seen in Figure 10. The E-Flite power 52 brushless motor is designed to deliver clean and quiet power while still being capable of delivering up to 65 amps of continuous current using 4S-6S Lipo pack batteries.

Figure 9. E-Flite Power 52 Brushless Motor [14]

Figure 10.Turnigy G60 Brushless Motor [13]

In Table 4 a comparison of the two motors can be seen. In order to generate more thrust, lower Kv values and larger propellers are required. The Turnigy G60 Brushless Outrunner motor has a 500Kv value as compared to 590Kv for the E-Flite Power 52 Brushless Outrunner motor. When comparing these two motors, there are many similarities such as weight, max current, and max voltage. For the rotorcraft, mass of the motors should be minimized, however the small difference in mass shown in Table 6 is negligible. Further the motors have the same max current. The two motors under consideration both have greater than the required 11 volts that will be supplied by the battery. However, the biggest difference is the cost. Due to budget constraints it is practical to choose the Turnigy G60 Brushless Outrunner motor since we will be using eight motors. The cost of using eight Turnigy motors is $432 as compared to $872 for the E-flight power motor. It should be noted that for all designs each propeller has its own motor.

Table 4. Motor Specs

Motor	Kv (RPM/V)	Mass (g)	Max Current (A)	Max Voltage (V)	Power (W)	Cost ($)
Turnigy G60 Brushless Outrunner [13]	500	360	65	25	1500	54
E-Flite Power 52 Brushless Outrunner [14]	590	346	65	22	1650	109

Battery Pack - The selected battery will be lightweight and provide the necessary power to the motor to run the propellers at a sustained 5550 RPM for a specific period of time. The propulsion battery pack must supply high voltage per unit weight in order to minimize the required current draw by the motor [15]. With this in mind, the battery cells will be oriented in series to maximize the battery pack voltage and must be composed of cells with an appropriate electric charge. The battery pack must be composed of several individual cells oriented in a desired configuration to allow for easy installation and removal. The batteries that possess both a higher current capacity, electric charge, and typically have higher weight and lower voltage.

Battery packs with lower current capacity are lightweight with high pack voltage but have limited lifetime. The Turnigy nano-tech 5000mAh (milli-amper hour) 6S Lipo Pack battery, compared to other batteries with low current capacity, has higher capacity during heavy discharge, longer cycle life, and faster charge capability which is great for this military application [15]. A picture of the Turnigy Nano-Tech battery under consideration to supply power is shown in Figure 11. The second battery under consideration is the E-Flite 3200mAh 6S Lipo pack battery which can be seen in Figure 12. This battery will have high capacity during heavy discharge and chargers relatively fast. There will be four batteries used, with each battery pack supplying power to two rotors. Pictures of the batteries are included as a visual representation of the shape of the battery that will need to fit on the rotorcraft.

Figure 11. Turnigy Nano-Tech [15]

Figure 12. E-Flite [16]

Keeping the motor decision in mind, Table 5 shows the specifications on the Turnigy battery as well as the E-Flite battery. The most important thing here as far as generating enough power to have enough thrust to lift the aircraft is the capacity and the voltage supplied. Both six cell batteries supplies 22.2 volts. Both batteries have a configuration of six cells in series. Comparing the capacity, the Turnigy motor has a capacity of 5000 mAh as compared to 3000 mAh for the E-flight battery. The current capacity measures how much current a battery will discharge over a specified period of time. Higher mAh ratings do not necessarily reflect how fast current can be drawn, but rather how long a current can be drawn. For this application, in order to travel a mile, a higher mAh rating is needed.

When comparing the discharge of the two batteries, the Turnigy battery has a discharge rating (©) of 65 amps while the E-flight battery has a discharge of 30 amps. The discharge simply lets one know how many amps can be safely drawn from the battery constantly. Since the rotorcraft needs to be as lightweight as possible for the user carrying the backpack as well as to generate more thrust, weight is a significant factor. The E-flight battery weighs 1.49 pounds while the Turnigy battery weighs 1.86 pounds. Using four batteries, this results in a total additional 1.48 pounds to use the Turnigy battery instead of the E-flight battery. Looking at all these variables and comparing them to the cost of each battery, it would be a simple choice to choose the Turnigy nano-tech battery because of its higher capacity, which translates to a longer run time for only an extra $16 per battery.

Table 5. Battery Specifications

Battery	**Capacity (mAh)**	**Voltage (V)**	**Discharge (©)**	**Weight (Pounds)**	**Cost ($)**
Turnigy Nano-Tech Lipo Pack [15]	5000	22.2	65	1.86	116
E-Flight Lipo Pack [16]	3200	22.2	30	1.49	100

Propeller - The propeller must be large enough to provide the minimum thrust values. Further, it must have the required pitch to maintain speed so that navigation within a desired amount of time is possible, even with headwind. With the battery and motor already selected the propeller size could be evaluated. Propeller dimensions are characterized by diameter and pitch (displayed as DIAMETER X PITCH), which are the primary variations in propeller specifications. Larger diameter propellers generate higher thrust but also consume more power. Pitch refers to the angle or twist of the blade. A larger pitch value generally results in a higher maximum velocity but also puts more load on the motor. This results in higher power consumption when velocities are close to the maximum velocity. There are three main factors used to assess propeller effectiveness: thrust coefficient, power coefficient, and propeller efficiency [17]. Each of these factors is evaluated with respect to the advance ratio, which is a comparison of linear aircraft velocity to propeller blade velocity. It is desirable for the advance ratio to be larger as this indicates that fewer propeller rotations are needed to move a specified shape aircraft at a specified velocity. Due to the constraint of fitting the rotorcraft in the backpack, foldable propellers will be used. Foldable propellers were chosen because the propellers need to be able to be disassembled from the rotorcraft in order to fit in the backpack. A Graupner CAM 16”x10” propeller was considered and an image of this prop can be seen in Figure 13. This propeller allows for it to be taken off and it does not affect the integrity of the same. A Plastic 16.5”x10” propeller assembly shown in Figure 14 is also under consideration.

Figure 13. Plastic Propeller Assembly [19]

Figure 14. Graupner CAM Folding Prop [18]

There are some minor differences when comparing the two propellers. The plastic propeller is slightly larger, therefore being able to generate 25 pounds of thrust as compared to the CAM folding prop which can only generate 22 pounds. The plastic propeller only costs $6.75 as compared to the Graupner which cost $17. Due to how expensive the Graupner prop is and due to the fact that carbon fiber props have slightly shorter flight time than plastic prop of the same size/pitch as well as providing less thrust than plastic props, it is an easy decision to choose the plastic propeller assembly.

Microcontroller - The microcontroller is the brain of the rotorcraft. A microcontroller is a small and programmable computer on a single integrated circuit which contains memory and programmable input and output parameters. The preferred microcontroller for this project is an Arduino board because it is one of the most common brands of microcontrollers. Also, it is easy to find source, assistance with program design, is low-cost, and can be programed in the C++ programming language, which suits the project best because both electrical and computer engineering team members are familiar with C++.

A parameter to consider when choosing a microcontroller is the number of input and output pins, as each rotor will require two pins. If there are eight rotors, then there will need to be 16 pins to cover the inputs and outputs of the rotors. Pins are the components that transfer data from the microcontroller to the electrical devices. For example, the microcontroller will output a code that translates into ones and zeros, which is later sent to the rotors. The proper sequence of ones and zeros will make each motor spin in the direction it needs to. For this project it may be beneficial to have a 32-pin board to account for all the rotors, the IMU (Inertial Measurement Unit) and the RC transmitter.

Another potential microcontroller is the Arduino mini. This chip is compatible with many IMU units. There are differing power and frequency ranges for the chips depending on how much power is needed by the IMU and how much extra power can be taken from other sources. The main source of power for the IMU units comes from the microcontroller, while additional IMU units can receive extra power from the batteries if necessary. The prices of the microprocessor board vary from $25 for the smallest to $100 for a more effective version. The more effective version would have more memory space, allowing it to process data faster. However, the microcontroller inputs will be non-complex, so a difference in data speed would not be noticed by the user [20].

The microcontroller selection is based on the current provided and the ease of programming of the controller. A comparison between a HobbyKing SS Series 90-100A and an 80A Pro Switch Mode BEC Brushless microcontrollers can be seen in Table 6. Both microcontrollers have very similar continuous current and both currents are higher than the minimum current required for the rotors. The programming abilities of both microcontrollers are very similar, but the 80A Pro Switch shown in Figure 16 has the additional ability of low voltage cutoff and soft startup of the propellers. Since the HobbyKing SS Series 90-100A microcontroller is a quarter of the price of the 80A Pro Switch and both microcontrollers have almost identical specifications, the HobbyKing SS Series 90-100A shown in Figure 15 was selected.

Figure 15. HobbyKing SS Series 90-100A [21]

Figure 16. 80A Pro Switch Mode BEC Brushless [22]

Table 6. Microcontroller Specifications

Microcontroller	Continuous Current (A)	Max Current (A)	User Programming Abilities	Cost ($)
HobbyKing SS Series 90-100A [21]	90	100	Battery Setting Throttle Range Brake Setting Timing Mode Setting	25
80A Pro Switch Mode BEC Brushless [22]	80	80	Battery Setting Throttle Range Brake Setting Timing Mode Setting Low Voltage Cutoff Soft Start Up	100

IMU (Inertial Measurement Unit) - Another component that must be considered is the IMU. This component is able to measure and report the velocity, orientation, and gravitational forces acting on the rotorcraft. This is important because this system will allow the rotorcraft to align itself on a pre-set zero plane so that the weight is as balanced as possible. There are varying degrees of freedom in IMU sensors [22]. The degrees of freedom relate to the components that are part of the rotorcraft. This project requires at least six degrees of freedom, because that allows movement in all three dimensions. Along with the set-up of the rotors, the IMU will prevent the craft from spinning on all of its axes without user input. The difference between six degrees and nine degrees of freedom is that nine degrees of freedom would also allow for a compass. This could be helpful in the project if the rotorcraft is to be tracked while in flight.

Since the final design of the rotorcraft has not been decided, the IMU that will be implement has not been stated yet. However, the possible brands for the IMU sensor are the SparkFun Element shown in Figure 17 and the Adafruit. These brands use analog outputs on their sensors, which can be plugged directly into the analog inputs in the Arduino microcontroller. The number of analog inputs on the microcontroller also determines how many degrees of freedom the sensor can have. For instance, if there are only six analog inputs on the arduino board, then the IMU can only have six degrees of freedom. This does not relate to the number of pins. Pins are solid objects that can be turned on or off based on necessity, and also can be set as inputs or outputs [23].

Figure 17. SparkFun 6 Degrees of Freedom IMU Digital Board [23]

RC Transmitter- The third major electronic component is the RC transmitter. This is the system that will enable the rotorcraft to be controlled wirelessly with a remote control of some sort. This has not been decided yet because the team needs to have a final design of the rotorcraft before it can be chosen. The selection will be based on the range and the size of the device. This system uses frequencies to send radio waves from the transmitter (the remote control), to the receiver (the rotorcraft). The RC transmitter will be connected to the microcontroller so that when a signal is sent from the transmitter, the receiver will take the signal and that received signal will become the input of the microcontroller. As stated, the transmitter and receivers use frequencies to transmit the signals. There is a limited range of frequencies available for commercial use because many of the frequencies in the Florida area are used for First Responders. Frequencies that are higher than those used for First Responders are military frequencies that are strictly off limits to civilians. The transmitter that is used must not only utilize a frequency that is approved for usage, but it also must be fairly unique so that other civilians cannot tap into the rotorcraft's frequency and control it without the team's permission. It is also important to have a unique frequency because other RC users such as small planes, helicopters, and cars can overlap the rotorcraft's frequency and offset the inputs, ultimately crashing the rotorcraft [24].

Since one of the customer requirements is that the rotorcraft has to travel a range of one mile, there are two brands that can be used to accomplish this task while also meeting the frequency and size requirements needed. The first is the XTend 900 1W RPSMA transmitter shown in Figure 18, which has a range of 40 miles. The other potential option is the XBee-Pro 900 XSC S3B transmitter shown in Figure 19, which covers 28 miles. Some differences in these two components besides their range include power consumption, mass, and how the antenna is attached. The antenna for the XTend board is attached much more securely, but it weighs slightly more and uses more power than the XBee board. The XBee board has a smaller antenna and costs approximately $70 while the cost of the XTend board costs approximately $200.

Figure 18. XTend 900 1W RPSMA Transmitter [25]

Figure 19. XBee-Pro 900 XSC S3B Transmitter [26]

8.4 Schedule

Gantt chart – This senior design project is constructed as a Define, Measure, and Analyze, Design, and Validation (DMADV) project. The Define and Measure phases are completed in the fall semester and the Analyze, Design, and Validation phases are completed in the spring semester. Major milestones for the fall semester are choosing a final design, selecting materials and components, and ordering those components. This allows for the team to build a prototype as soon as possible after winter break.

A detailed outline of the define phase schedule may be seen in Figure 20 in the Gantt chart. By setting short term goals, the team will assure the client of a product that meets their needs and is finished by the appropriate deadline. Several steps are to be taken along the way including the research required, development of the equations needed to evaluate lift properties, creating drawings for later machining, and communicating with advisors and sponsors along the way.

The team will begin by performing thorough research on the subject, then create design concepts, get them approved, build drawings, simulate how the rotorcraft’s arms will come out of the backpack as well as stress analysis in Creo-Parametric 2.0, and then present final designs at the end of the semester. The Gantt chart will help complete these short term goals throughout the semester. It also helps manage unforeseeable obstacles since the overall timeline for the project will be laid out for the define phase. Any new tasks that needs to be added will be completed immediately in order to give the team as much time as possible to adjust to the changes. It is critical to the project to manage time wisely and the Gantt chart will help guide the team as far as time management.

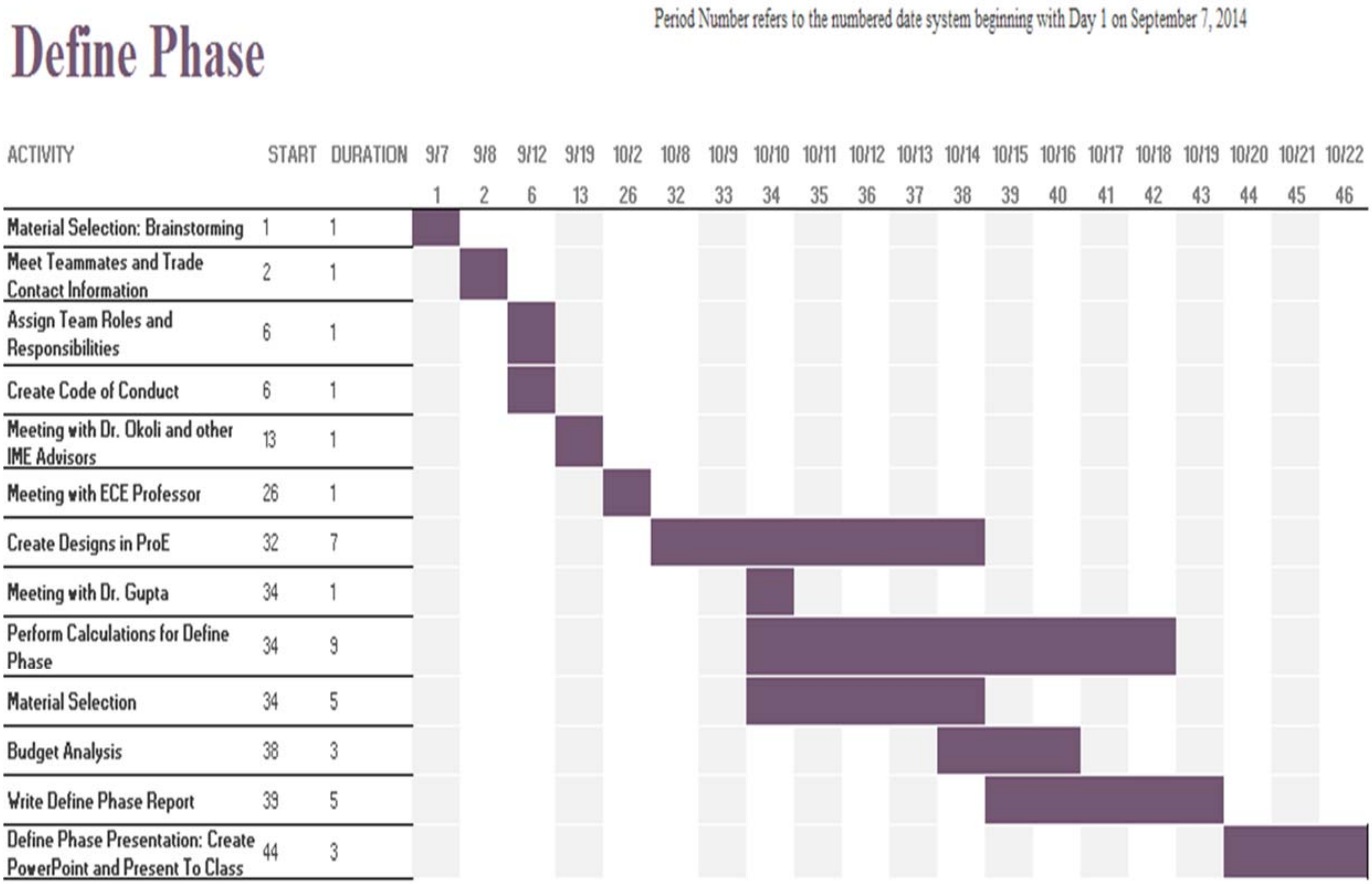

Figure 20. Gantt chart for Rotorcraft Project

8.5 Bill of Materials

The budget was provided by Dr. Okoli, who is the contact point between the sponsor and the project team, and Dr. Dickens. The budget given for building this rotorcraft is $2,500. After doing research on the components necessary for this project, a bill of materials was compiled and can be seen in Table 7. Once the fabrication is tested of the carbon fiber and the necessary dimension of the rotorcraft is finalized, the correct amount of carbon fiber will be determined. We do have a rough estimate for the carbon fiber and epoxy resin that is needed to build the rotorcraft. Table 7 shows the list of the materials required and the estimated total cost for the manufacturing of this rotorcraft. The most expensive component is the power source, which would require four batteries costing $466.80. The cheapest component is the microcontroller which only cost $24. Overall, the project is within budget at this point. There is still $813 for money to be saved, or to be used on unknown additional components in the future.

Table 7. Bill of Material

Part Number	Quantity	Unit Cost	Cost
E-Flite Power 52 Brushless Outrunner Motor [14]	8	$109.99	$879.92
E-Flight LiPo Battery [16]	4	$116.70	$466.80
Plastic Propeller Assembly [18]	8	$6.75	$54.00
Arduino Leonardo with Headers [21]	1	$24.95	$24.95
Adafruit 9-DOF IMU Breakout - L3GD20 + LSM303 [22]	1	$19.95	$19.95
HobbyKing SS Series 90-100A [22]	1	$24.85	$24.85
Carbon Fiber [10]	5 ft.	$35.00	$175.00
Epoxy Resin [10]	1 Gal	$41.95	$41.95
Total Cost:			$1.687.42

9 Conclusion

Meetings with Dr. Okoli and Dr. Dickens as well as the various analyses performed by the project team have determined that the objectives for this project are as follows:

1. Design a rotorcraft that can:
   a. Fit in a military backpack (23x14.5x15)
   b. Can carry a payload of at least 50 pounds
   c. Made with COTS components (off the shelf)
   d. Has a range of approximately 1 mile
   e. Easy to maintain and use in the field
2. Design the manufacturing processes to be used in creating the rotorcraft described in Goal
3. Build a prototype of the rotorcraft described in Goal 1.

Based on critical customer requirements, the fishbone diagram, and the House of Quality diagram, the team focused on being able to generate enough thrust to lift 50 pounds for this define phase. The three essential components necessary to generate thrust are the battery, motor, and propeller. In order to find thrust, applicable equations such as propeller efficiency were used. After extensive research in to find the cheapest components that falls within the specifications necessary, the Turnigy G60 motor, Turnigy 5000mAh battery, and a 16x10 propeller were selected to be used in building a high portable and high payload capacity design. Since using eight rotors means only 18 pounds of thrust per rotor must be generated, the octocopter was chosen as the ultimate design. Several materials were analyzed, including glass fiber and carbon fiber. Ultimately carbon fiber was chosen because it provides the best combination of strength and weight. Some electrical components such as the RC transmitter and IMU sensor are still being analyzed.

The next step for this project is to speak with Dr. Okoli and Dr. Dickens in order to verify the final design choice. The following steps would be to finish Creo-Parametric drawings and find out what parts are already here. Once an inventory of the components is constructed, the team will be able to move forward and order any additional parts if needed. This lightweight, high portability, high payload rotorcraft is going to change the rotorcraft industry for the better.

10 References

[1] "CARBON FIBER - GRAPHITE - KEVLAR." *CARBON FIBER - GRAPHITE - KEVLAR*. US Composites, n.d. Web. 16 Oct. 2014.

[2] DeMerchant, Cristine. "Comparison of Carbon Fiber, Kevlar (Aramid) and E Glass Used in Composites for Boatbuilding." *Comparing the Characteristics of Glass, Kevlar (Aramid) and Carbon Fiber*. N.p., n.d. Web. 16 Oct. 2014.

[3] "Epoxy : Epoxy Resins and Hardeners." *Epoxy : Epoxy Resins and Hardeners*. US Composites, n.d. Web. 16 Oct. 2014.

[4] "Fiberglass Cloth." *Fiberglass Cloth*. US Composites, n.d. Web. 16 Oct. 2014.

[5] "Chapter 12." *Intelligent Flight Control of an Autonomous Quadrotor*. Web. 11 Nov. 2014. <http://www.intechopen.com/books/motion-control/intelligent-flight-control-of-an-autonomous-quadrotor>.

[6] "2014 Military Pay Scale." - *For US Army, Navy, Air Force and Marines*. Web. 11 Nov. 2014. <http://www.militaryfactory.com/military_pay_scale.asp>.

[7] "Want to Become an Air Force Pilot? Read This First." *About*. Web. 11 Nov. 2014. <http://usmilitary.about.com/od/airforcejoin/ss/afpilot_3.htm>.

[8] "High Strength Fiberglass." - *Fiberglass E Glass Woven Cloth, Fiberglass Cloth for Grinding Wheel Disc and Fiberglass S Glass Woven Cloth Manufacturer & Supplier from Mumbai, India*. N.p., n.d. Web. 16 Oct. 2014.

[9] Liang, Richard. “Composite and Green Fabrication 2014.” *FAMU-FSU College Of Engineering.* Power Point. 2014. 21 March 2014.

[10] "Mechanical Properties of Carbon Fibre Composite Materials, Fibre / Epoxy Resin (120°C Cure)." *Mechanical Properties of Carbon Fibre Composite Materials*. Performance Composites, n.d. Web. 16 Oct. 2014.

[11]"Fabricchoice."*Fabricchoice*.Web.11Nov.2014.<http://www.sollercomposites.com/epoxyresinchoice.html>.

[12] *Vacuum Bagging Techniques*. Bay City (Michigan): Gougeon Brothers, 2004. *Vacuum Bagging Techniques*. Gougeon Brothers, Inc., Bay City, MI USA., Apr. 2010. Web.

[13] "Turnigy G60 Brushless Outrunner 500kv (.60 Glow)." *HobbyKing Store*. N.p., n.d. Web. 19 Oct.2014.<https://www.hobbyking.com/hobbyking/store/__19029__Turnigy_G60_Brushless_Outrunner

[14] "Power 52 Brushless Outrunner Motor, 590Kv." *(EFLM4052A): E-flite*. Web. 9 Nov. 2014. <http://www.e-fliterc.com/Products/Default.aspx?ProdID=EFLM4052A>.

[15] "Turnigy nano-tech 5000mah 6S 65~130C Lipo Pack." *HobbyKing Store*. N.p., n.d. Web. 19 Oct.2014.<http://www.hobbyking.com/hobbyking/store/__19156__Turnigy_nano_tech_5000mah_6S

[16] "3200mAh 6S 22.2V 30C LiPo, 12AWG EC3." *(EFLB32006S30): E-flite*. Web. 9 Nov. 2014. <http://www.e-fliterc.com/Products/Default.aspx?ProdID=EFLB32006S30>.

[17] "- Propeller Performance Factors -." *Propeller Performance: An introduction, by EPI Inc.*. N.p.,n.d.Web.16Oct.2014.<http://www.epieng.com/propeller_technology/selecting_a_propeller.htm>.

[18] "Plastic Folding Propeller Assembly 16.5x10 (Alloy Hub) (1pc/bag)." *HobbyKing Store*. Web.9Nov2014.<http://www.hobbyking.com/hobbyking/store/uh_viewitem.asp?idproduct=13159&aff=131767>.

[19] "[RC Sailplanes, Gliders and Electrics]." *[icare-icarus]*. N.p., n.d. Web. 19 Oct. 2014. <http://www.icare-icarus.com/CAM-Folding-Prop-16-x-10_p_413.html>.

[20] "How Microcontrollers Work - HowStuffWorks." *HowStuffWorks*. N.p., n.d. Web. 18 Oct. 2014 http://electronics.howstuffworks.com/microcontroller.htm

[21] "Hobbyking SS Series 90-100A ESC (USA Warehouse)." *HobbyKing Store*. N.p., n.d. 18 Oct.2014<https://www.hobbyking.com/hobbyking/store/__18920__Hobbyking_SS_Series_90_100A_ESC_USA_Warehouse_.html>.

[22] "80-Amp Pro Switch-Mode BEC Brushless ESC, EC5 (V2)." *Eflite*. N.p., n.d. Web. 19 Oct. 2014.<http%3A%2F%2Fwww.efliterc.com%2FProducts%2FDefault.aspx%3FProdID%3DEFLA1080B>.

[23] "SparkFun 6 Degrees of Freedom IMU Digital Combo Board - ITG3200/ADXL345." - *SEN-10121*. N.p., n.d. Web. 19 Oct. 2014. <https://www.sparkfun.com/products/10121>.

[24] "RC Toy Transmitter - HowStuffWorks." *HowStuffWorks*. N.p., n.d. Web. 19 Nov. 2014. <http://www.howstuffworks.com/rc-toy1.htm>.

[25] "XTend 900 1W RPSMA - 40 Mile Range." - *WRL-09411*. SparkFun, n.d. Web. 13 Nov. 2014. <https://www.sparkfun.com/products/9411>.

[26] "XBee-Pro 900 XSC S3B Wire." - *WRL-11634*. SparkFun, n.d. Web. 13 Nov. 2014. <https://www.sparkfun.com/products/11634>.