Memorandum

To: Dr. Kosaraju

From: Team 04

Date: 4/18/20142014

Re: Final Report

Dr. Kosaraju,

This is the final report for the up scaling of the U13A remote controlled helicopter.

In this document you will find, a summary of our teams' problem, the concepts we have come up with and chosen to solve the problem, the analysis of the chosen concepts, the cost analysis of the final version of our project, the preliminary final design of the helicopter, test results, and lastly, the final design and performance.

Remote Control Helicopter

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Project Proposal

Document

Submitted towards partial fulfillment of the requirements for

Mechanical Engineering Design II – Spring 2014

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Nomenclature

- A_D → Area of the blade perpendicular to the drag
- A_R→Area of the rotor disk
- C_D→ Coefficient of drag
- d→ blade length
- D→ drag force
- F→ loading on blade
- i→ current
- I→ moment of inertia
- L→ lift force
- M→ bending moment on each blade
- P→ power
- PL→ power loading
- TL→ thrust loading
- U_{avg}→ average blade velocity
- U_{tip}→ blade tip velocity
- V→ voltage
- y→ distance from the neutral axis
- η→ motor efficiency
- σ→ bending stress in each blade
- ρ → density of air at 7000 feet
- ω→angular velocity

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Abstract

In this document, we will be discussing the scaling U13A remote controlled helicopter. To begin with, we will be giving a brief description of our client and an overview of the problem description from our client. Next we will be identifying the need, project goal, objectives, operating environment and the constraints of our project.

Next, we will introduce the concepts generated by our team. We will look at all the different areas in which we plan to improve upon, as well as the ideas proposed for these improvements. Decision matrices will be introduced in this section to show how our group decided on the chosen ideas.Lastly, in this section we will be including visuals for the chosen concepts.

After concept generation was completed, our team went through the engineering analysis phase. Here we will be discussing the analysis which was done on the chosen areas for improvement from the concept selection stage. We will present analysis for the blades and landing gear.

Once engineering analysis was completed, the cost analysis began. Here we will present the bill of materials, along with the total cost of production. This section includes all final parts necessary to be made and ordered for the up scaling of the U13A helicopter.

Lastly, we will be summing up the whole proposal document. We will be restating all decisions made as well as where we are and where we are headed.

Chapter 1.Introduction

1.1 Introduction

We are team four, and our capstone project is the remote controlled helicopter. In this report we will be discussing, who our client is, what our project is, as well as, needs, goals, objectives, constraints, quality function deployment chart, the concept generation, engineering analysis, and cost analysis for our project.We will also give a brief look at what is in the near future for team four through a Gantt chart. To begin with we will introduce our client Dr. SrinivasKosaraju.

1.2 Client Information

Our client is the capstone instructor Dr. SrinivasKosaraju. He is a current mechanical engineering professor at Northern Arizona University. He has his doctorate in mechanical engineering. He had an idea that it would be a great all around engineering project to have students buy and research a remote controlled helicopter that was roughly ten inches and then upscale it for various applied applications. This project includes many different engineering subjects such as machine design and aerodynamics. It will prove to be a challenging project, but our team is very enthusiastic and ready to do what is necessary for a successful project.

1.3 U13A Remote Control Helicopter

For this project we will be up scaling a U13A Remote Controlled Helicopter made by UDIR/CFigure 1. The helicopters body is 11 inches long and 2 1/4 inches wide. One of the blades of the center rotor is 4 3/4 inches long and the rear rotor is 1 7/8 inches. It has four blades on

Figure 1: U13A Helicopter

the center rotor two blades are spinning clock wise while the other two are spinning counter clock wise. The helicopter has several led lights on it one in the front and five along the tail. This helicopter has a 3.7 V battery it lasts for 5 to 8 minutes per 90 minutes of charge. This helicopter is already equipped with a camera so it has the capability to take photos and video which can be viewed through a micro S.D. card. This helicopter does not have live feed. There is a gyroscope inside of the helicopter it also has a balance beam along the top of the center rotors both of there are to help keep the helicopter stable during flight.

The controller for the helicopter, as seen in Figure 2, controls the functions such as up and down and right and left. It also has a screen on the controller to display the throttle percent and the trim of the helicopter. The screen also displays how well the frequency is reaching the helicopter. The remote sends out a 2.4 GHz signal and has a controlling radius of 40 m. the controller is powered by four AA batteries and displays how much power is left in the batteries on the display. The controller has buttons on it to use the video and the camera fetchers and the display shows which fetcher is being used at a given time. The controller also has a button to turn on or off the lights and a button to accelerate the helicopter.

Figure 2. U13A remote control

1.4 Needs

The main need,created by our group for this project, through discussion with Dr. Kosaraju, is that the U13A helicopter is too small. Through this statement, we have broken it up in to several smaller needs to make the process of working on it more fluent. One of the first needs we have to work on is studying this helicopter and determining any problems with it that we may need to fix or any aspects of the helicopter that we can improve upon. We will need to upscale the model by 1.5 per the client’s request. Lastly, one of the client’s requests was to have capability for attachments so we need to determine what attachments may be useful and how to attach them.

1.5 Goals

From studying all the clients requests and all the needs we have determined a goal for this project. Our goal is to "successfully improve and upscale a remote controlled helicopter by 1.5 with the ability to add mission specific accessories." We believe at this point this goal covers all the aspects of this project. As we work on this project we may have to alter our goal but this will happen as we go.

1.6 Objectives

The objective for this project is to design and build a remote controlled helicopter that has interchangeable attachments. A live feed camera will be attached to the final design that can provide live video to the users. The helicopter weight will be minimize in order to have the ability to add many attachments if needed.

The design should be able to accept batteries from different manufacturers. This includes using the ability to switch adaptors that can connect the battery to the helicopter. There will be two sets of batteries, one set in the helicopter, and one set in the remote control. The helicopter will contain a chargeable battery that can lasts for one-third the charging time. The remote control will consist of four AA batteries that provide a power to send/receive signal to the helicopter.

Carrying capability will be maximized in the prototype design. The materials that will be used in our design should be light and stiff, to maintain a high level of performance. The carried weight will be used to achieve stability in our design. Also the weight will be placed in the center of mass in the helicopter to increase the stability and resist wind flow.

We also are playing with the idea of using waterproof materials in building the helicopter, so it can be used in different weather conditions. There is still no specification of what materials that will be used, and how much would it cost. Upon further investigation and cost analysis we will be able to decide whether this is a task worth pursuing.

The altitude that the helicopter will achieve is forty meters in all directions. Currently we are considering stiff plastic propellers will be used in building the design to minimize the overall weight of the helicopter and create a maximum lift for the prototype. The range will be determined more specially based on the attachments and the weight lifted for each different run. The table of objectives can be seen in the following table, Table 1.

Table 1. Objectives

Objectives	Measurement Basis	Units
Design and build a RC helicopter	Amount of materials	Dollars
Attachments	Camera parts	Dollars
Batteries	Two sets of batteries	Dolars
Carrying Capabilities	Weight	lbs
Waterproof Materials	Cost for materials	Dollars
Lift Capabilities	Height range	Meters

1.7 Constraints

For the final design of the upscale remote control helicopter, the preliminary constraints are the following:

The helicopter must be at least 1.5 times the size of the model helicopter. In order to successfully upscale the helicopter 1.5 times, the dimensions of all of the components of the design, ranging from the tail length to the frame width must be at least 1.5 times larger than the original remote control helicopter.

The helicopter must be made out of a durable material that is also lightweight. In order for the helicopter to succeed at flight and survive all of the stresses associated with flying, landing, and even crashing the helicopter, it must be made of a lightweight and durable material with a high strength to density ratio.

Additionally, the operator must be able to control the helicopter at a long range. The range at which the helicopter can be controlled will be measured by the longest distance at which the remote control can still communicate with the helicopter.

The helicopter must have a satisfactory battery life. The duration of time that the helicopter can stay in the air for a single flight is determined by the battery life; it must be maximized to allow for the longest flight possible.

In addition to the battery life, the battery power must be capable of creating a lift force great enough to carry the weight of the helicopter and any accessory that may be mounted to the helicopter.

In order to demonstrate that accessories can be added to the helicopter, an onboard video camera will be mounted to the design. The data gathered aboard the helicopter must be communicated to the operator at real time and the helicopter must transmit a live video feed from the onboard camera to the remote operator.

Lastly, all costs associated with designing and building the upscale helicopter must be thoroughly justified with the customer, Dr. Raju, before funding will be received.

1.8 Quality Function Deployment

In the approach of making the quality function development matrix our team discussed the engineering requirements that needed to be included in the design. This includes the different possibilities of customer and engineering requirements. To begin with, our client requires that we scale our helicopter to a certain size ratio. The engineering target that our team chose to work with is English Standard units. The reason is because our helicopter was given in inches. Upon being given the request of scaling the helicopter to a 1.5 to 1 ratio, as shown in (table 1), the team is going to measure the weight and length of the helicopter. This will determine how our helicopter will perform during test flight. The yield strength and lift force on the helicopter needs to be addressed as well because the customer wants to have a helicopter that does not fail. Failure of the helicopter can cause the customer to give bad reviews on the product. In order to make a successful design, our team discussed the power usage of each flight by recording its duration time. On average, our flight time approximated out to be 8 minutes. The customer expects a longer duration time so that it would make charging the battery less of a hassle for people. Lastly, our team decided to add attachments to the helicopter to make it more treasured. Each of these requirements, as seen in Figure 3,are important to note when designing the helicopter. It satisfies our customer needs and engineering requirements.

			Engineering Requirements				
			Yield Strength	Weight	Power	Length	Lift
Customer Requirements	**Scale**	Scale Ratio to 1.5	0	5	0	10	7
	1	Perfomance	5	0	0	0	7
	5	Durability	7	0	0	0	0
	7	Flight Duration	0	0	7	0	0
	10	Attachments	1	5	5	0	0
		Total	50	55	99	10	42
		Units	psi	lb	ft-lb/s	in	lbf
			Engineering Targets				

Figure 3.Quality Function Deployment

Chapter 2.Concept Generation and Selection

2.1 Testing

Before our team took apart the helicopter, we decided to test different aspects of the aircraft. We wanted to measure the lift, lift without lights, mass, the battery life, and the dimensions. First, we measured the mass and found it to be just over 0.3lb. To measure the lift we slowly added weights to the helicopter until it could not lift anymore. During this process it was noted that without the lights turned on, on the aircraft, the helicopter had more power allocated to the lift. A graph of the lift of the helicopter without lights can be seen in Figure 4, and the table of values for that plot can be seen in Table 2.The battery life varies from around 6-10 minutes. This varies depending on if there is a load. Lastly, the dimensions are the following: length is 13.39 inches, width is 2.36 inches, and the height is 5.9 inches.

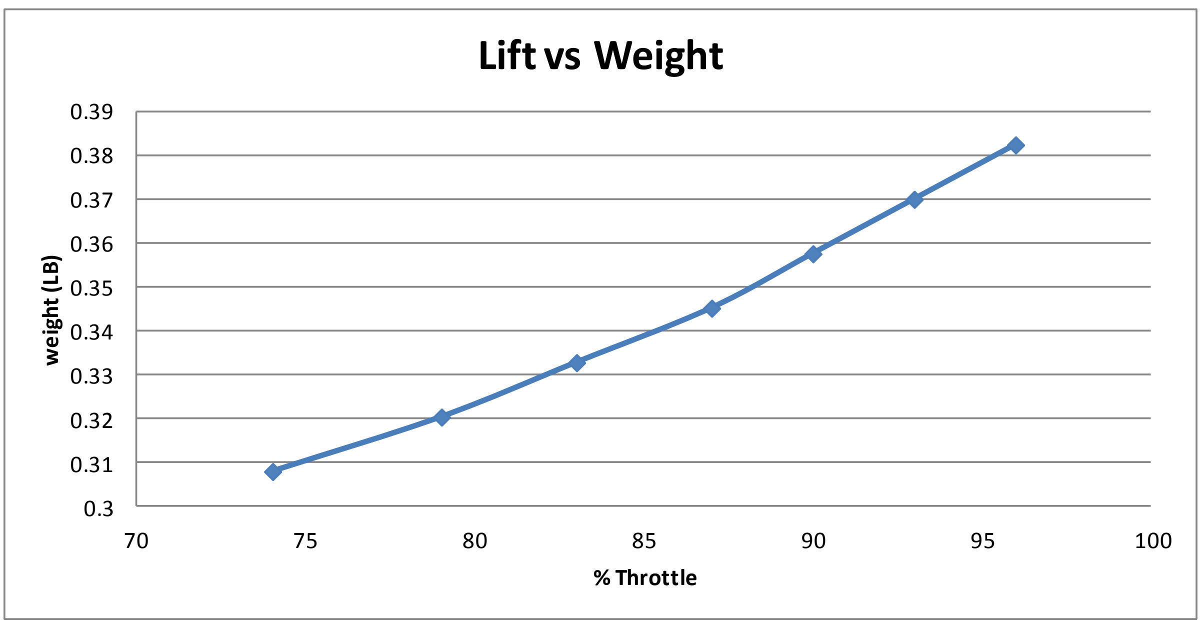

Figure 4. Graph of Lift vs Weight

Table 2: Data from lift testing

Object	% Throttle	Weight (lb)
just helicopter	74	0.307853503
1 pencil	79	0.320265533
2 pencil	83	0.332677563
3 pencil	87	0.345089593
4 pencil	90	0.357501623
5 pencil	93	0.369913653
6 pencil	96	0.382325683

2.2 Design Ideas

Since our project is composed of many different subsections, we have divided the helicopter up in to five different subsections for design improvement. Those subsections are: blade durability, longer battery life, increase in lift, improved landing gear, and a live feed video camera. In these subsections we have at least three ideas to improve the design of the helicopter.

2.3 Blade Durability

In the testing of the helicopter we quickly realized that there is a major flaw in the durability of the blades. It appears as though the blades from the upper level hit the blades on the lower level, once the throttle has been engaged and disengaged. With this realization we have come up with three ideas on how to improve upon this design. The first idea is to increase the height of the top rotor blades, which creates a bigger gap and thus gets rid of contact all together. The foreseen problem with this is that it may decrease the lift capabilities of the helicopter. The second design idea to reduce blade contact is to use a stronger more durable material that can absorb the damage without yielding any plastic deformation. This does not get rid of the blade contact, but rather is a way to prepare for it to hopefully allow for a longer blade life. The last idea for blade contact is to make the blades more rigid. On the original helicopter, the upper blades are able to swivel freely in either direction for a range of about 180 degrees. If the blades were made more rigid, in that they cannot swivel this range, then it is believed that this will eliminate the blade contact. Our decision matrix for this design can be seen in Table 3. We graded each category based upon ease of design, safety, cost, and estimated life. It can be seen through the table that the best design for the blade contact is making the blades more rigid.

Table 3: Blade contact decision matrix

Blade Contact:	Column1	Column2	Column3	Column4	Colu
Category	Ease of Design	Safety	Cost	Estimated Life	Total
Raised Upper Rotor	3	5	8	7	5.8
Durable Blade Material	7	5	4	6	5.5
Rigid Blade Design	8	5	8	8	7.1
Weight (%)	20	30	20	30	

2.4 Battery Pack

Another drawback of the small-scale helicopter that became apparent during testing is its poor battery life. During testing, the average time that the helicopter could remain in flight on a single charge did not exceed 8 minutes; for the enlarged helicopter, the flight time should be at least doubled.

The first decision to be made is regarding the type of battery to be used. One needs not to look far before concluding that a lithium polymer (or LiPo) battery is the optimal battery for the situation. Although lithium polymer batteries come at a relatively high cost, the benefits of LiPo batteries justify their cost. Lithium polymer batteries have both a higher capacity and power output than alternative battery types, but they also weigh much less [9].

After determining that a lithium polymer battery will be utilized in the enlarged helicopter, the configuration of the lithium polymer battery pack must be chosen. The options for different LiPo battery pack configurations are: a single LiPo cell, multiple LiPo cells in parallel, multiple LiPo cells in series, and multiple LiPo cells in both series and parallel. Each configuration has its own criteria in which it excels and falls short. The criterion for selecting a lithium polymer battery configuration is defined as follows:

- Voltage- the voltage supplied by the configuration. A higher voltage results in many benefits and is assigned a weight of 25%; it allows for a more consistent power to be delivered throughout the flight, which allows for better control in addition allowing for a higher power output resulting in a larger lift force [7].
- Capacity- the amount of power that can be supplied by the configuration on a single charge. A larger battery capacity results in a longer flight time for the helicopter and is assigned a weight of 30%.
- Weight- the total weight of the components making up the battery configuration. The batteries weight directly affects the lift force that can be generated by the helicopter and is assigned a weight of 25%.
- Durability- the ability of the configuration to withstand impact forces is given a weight of 5%. Impact forces will occur eventually and replacing the battery will result in a large cost.
- Cost- the total cost associated with the battery configuration. All costs associated with the battery must be justified and the cost therefore receives a weight of 15%.

The above criterion were analyzed for all four battery configurations and combined in Table 4, the decision matrix used to determine which battery configuration fit best. Each criterion was assigned a weight based on its importance; values were then assigned for each configuration, based on how well the configuration fulfills the needs of the battery.

Table 4.Battery pack decision matrix.

Battery	Column1	Column2	Column3	Column4	Column5	Column6
	Voltage	Capacity	Weight	Durability	Cost	Total
Single LiPo	5	5	10	4	9	6.15
LiPos in Parallel	5	10	7	8	6	7.1
LiPos in Series	10	5	8	8	6	7.45
Parallel+Series	10	10	6	8	3	7.9
Weight (%)	25	30	25	5	15	

The voltage value assigned to each configuration was assigned keeping in mind that in series, voltages add, and while in parallel, amperages add. For both the single LiPo cell and LiPo cells in parallel, the voltages do not add so a smaller voltage results. For the LiPo cells in series, however, the voltages do add and a larger voltage results. The same larger voltage results from the LiPo cells oriented in both series and parallel.

The capacity of a battery pack increases when in parallel[15]. For this reason, the single LiPo and the LiPo cells in series are assigned smaller values, and the LiPo cells in parallel received a higher value; the configuration including cells in parallel and series has the same potential for increased capacity and receives this same higher value.

The weight values assigned to each configuration based not only on fact that a larger number of LiPo cells results in a larger weight, but that a larger current requires thicker connections. The single lithium polymer cell is the lightest weight. Next to that is the series configuration, which has more cells, but a small current. After comes the parallel configuration, which has more cells in addition to a large current. The heaviest of the configuration takes advantage of connections in parallel and series and has the most cells in addition to a large current.

In the situation that a crash occurs, it is likely that the battery will be destroyed; however, if the battery is broken into several different cells, it is more likely that one or more of these cells will survive the crash. For this reason, the single cell is rated the least durable, and the other three configurations are rated equally durable.

The last criterion used in the decision matrix is the cost; as more cells and connecting components are utilized in the battery pack, the cost increases. For that reason, the cost value decreases from the simplest (the single LiPo cell) to the most complicated (the LiPo cells in parallel and series).

After deciding the values for each criterion as described above, the weight was applied to each value and totaled up. The battery configuration resulting with the highest total score and the configuration that will be utilized in the enlarged helicopter is the lithium polymer cells configured in both parallel and series. Figure 5 shows the battery configuration that utilizes lithium polymer cells in both parallel and series.

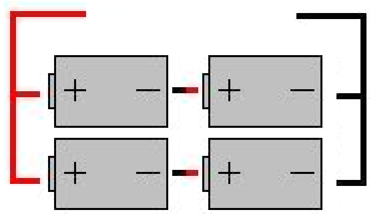

Figure 5. Configuration combining lithium polymer cells in parallel and series.

2.5 Landing Gear

The landing gear includes wheels, but in some cases, helicopters are equipped with skis for snow or water terrains. In our case of a vertical take-off and landing aircraft such as the helicopter, the wheels are replaced with skid designs to improve landing and taking off. Choice of landing gears depends upon numerous factors and one should not automatically assume that each landing gear design is necessarily the best. There are several design requirements which affect our decision on selecting the right landing gear design. These include: helicopter weight, take-off/landing, stability on ground, landing impact, and cost. In order to choose the right design, the candidate must decide which design suits them best.

In the design process, the team came up with four possible designs to use which are flatted skis and rounded skis which are both large and small. The idea of the first design is to make the skis large and flat. This will help stabilize the helicopter when lifting off the ground.

The second idea is small and flat skis. By making the skis much smaller and flat this would allow the helicopter to land much faster and also to allow more lift. The third idea is making a smaller landing gear rounded. Lastly, the final idea is to make a large and rounded landing gear. Based on the comparison of the designs, the results can be seen below in Table 5.

Table 5. Landing gear decision matrix

Landing Gear:	Column1	Column	Column3	Column4	Colu	Colum
Category	Weight	Landing	Ground Stability	Landing Impact	Cost	Total
Larger Landing Gear (Flat)	7	5	7	7	5	6.4
Smaller Landing Gear (Flat)	1	1	4	6	7	3.2
Smaller Landing Gear (Rounded)	1	2	4	8	7	3.8
Larger Landing Gear (Rounded)	7	8	7	9	5	7.4
Weight (%)	30	20	20	20	10	

2.6 Lift

One of the tests we ran on our helicopter was to determine how much weight our helicopter could lift as you can see in Figure 4. The helicopter could not carry as much weight as we will need when we enlarge the final design. After figuring this out we chose three different solutions to increase the overall lift of the helicopter. The first idea we had was to get larger motors which would be able to spin the rotors at a larger rpm. This idea has a large draw back though these larger motors would increase the weight and this would decrease the extra weight we could lift. The second idea is to gear the motors in a way that would increase the rpm of the rotors. After reading parts of Principles of Helicopter Aerodynamics by J. Gordon Leishman [8], we decided our third idea. We could lengthen the blades to increase the overall lift. After making these three ideas we made a decision matrix as you can see in Table 6. Idea three, lengthening the blades, will be our solution to gain more lift.

Table 6. Lift decision matrix

Lift	Columr	Column2	Colum	Colun	Column5	Colu
Category	ease of design	Minimize Cost	Safety	Weight	Minimize Power	Total
Larger Motors	6	4	7	3	3	4.55
gear ratio	7	6	7	7	7	6.85
Longer Blades	8	9	3	8	8	7.15
Weight (%)	20	15	20	25	20	

2.7 Improved Camera

One of the requirements for this helicopter is that it must have the capability to give live feed video. As we thought about this requirement we found three different cameras that would work to meet this requirement. The first camera that we looked at is GoPros HERO3 White Edition. This camera has its own power source so it would not be taking power from the helicopter and it is durable. The down side is it is heavy with regards to the helicopter and its lifting capabilities and it is fairly expensive. The second idea is a wireless hidden camera this camera also will also have its own power source and it is the least expensive of all the cameras. The largest down side to this camera is not as durable as the other choices. Our final idea was to take a live feed camera off of another helicopter. The down side to this camera is it will have to use the helicopters battery.After researching these three ideas we made a decision matrix as you can see in Table 7.

Table 7. Camera decision matrix

Improved Camera Capability	Colu	Column2	Column3	Column4	Column5	Col
	Weight	Minimize Helicopter Power Usage	Minimize Cost	Durability	Ease of Use	Total
Go Pro	4	10	2	10	8	7
Spycam	7	10	9	3	8	7.55
Wi-spi camera	9	3	4	9	8	6.8
Weight (%)	30	25	10	15	20	

Chapter 3.Engineering Analysis

3.1 Analysis Overview

For analyzing the U13A helicopter, our team wanted to focus on three main sections of the helicopter that we deemed important and worth analyzing. As a result, we will be discussing the engineering analysis on the blades, and the landing gear. We want to investigate the blades to ensure that when we scale the helicopter they are able to function properly without failure, and the landing gear to ensure that hard impacts will be withstood by the helicopter.

3.2 Blade Analysis

The analysis of the blades of the helicopter began with testing the original U13A helicopter for its lift capabilities. The weight of the un-scaled helicopter was determined to be 0.3078 pounds. To determine the maximum load that could be lifted, the weight of the load on the helicopter was gradually increased, until the helicopter could no longer achieve flight; this maximum load was found to be 0.0745 pounds amounting to a total lift force of 0.3823 pounds, or 24.2% more than the helicopter's weight. For the scaled helicopter design, it is desired for the lift to weight ratio to be increased with respect to the un-scaled helicopter.

In order to begin analysis on the scaled helicopter, several assumptions had to be made. The first assumption was for the total weight of the helicopter to be three times larger than that of the un-scaled helicopter, for a total of 0.9234 pounds. Next, several assumptions regarding the dimensions of the final blade were made. The same blade shape as the un-scaled helicopter would be utilized in the scaled design, however, the blade is not uniform throughout its length and the geometry must first be simplified before calculations can be made. The total length of the blades would be scaled up to at least 7.5 inches, somewhat greater than the 1.5 times scaling requirement; this is in order to account for the rapid weight increase that occurs when up-scaling. Similarly, the chord length, or width of the blade, would be scaled up to an average of 1.2 inches across. The thickness of the blade will be at least 0.1 inches. After assuming the rotor geometry, the coefficients associated with the lift and drag forces were also assumed. For helicopter blades of similar size and shape, the coefficient of lift can range from 0.1 to 0.7 [13]; for this reason, the average value from this range, 0.4, was used for the coefficient of lift. In order to accurately assume a value for the coefficient of drag on the blades, the value of 0.04 for a fully streamlined body was considered, but then increased to 0.1 in order to embed a design factor into the calculations [11]. In addition to the assumptions listed above, several more key assumptions were made to complete the analysis and will be mentioned throughout the section. Figure 6 below shows a free body diagram of the basic forces occurring while the helicopter is in flight.

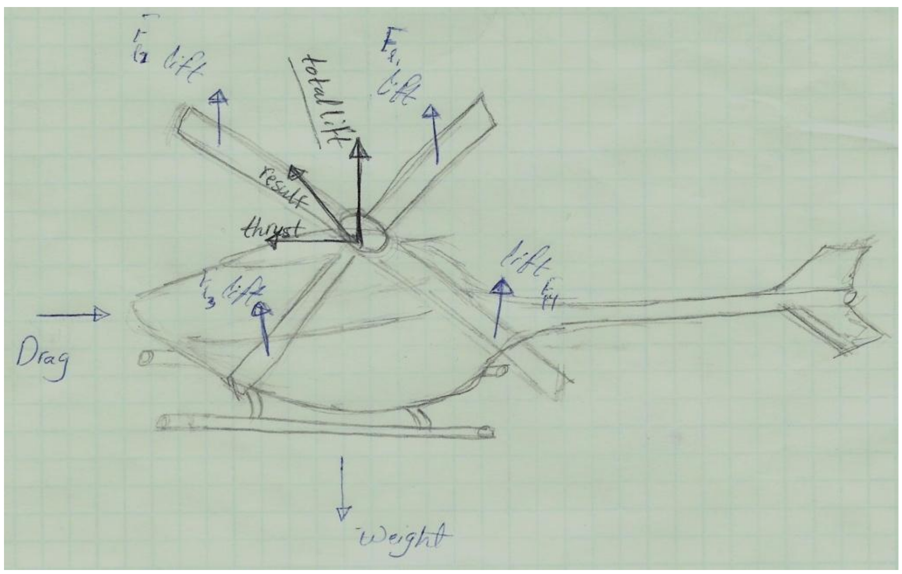

Figure 6. Free body diagram of the helicopter in flight.

The first calculation made is for the power supplied to each of the motors that powers each one of the two rotors. Each motor has an efficiency of 90% and each is powered by a lithium polymer battery capable of delivering 7.4 volts and at a current of 30 amps. The power that can be transmitted by each motoris calculated in the following equation:

$$P = \eta \times V \times i = .9 \times 7.4 \times 30 = 199.8\ W = 147.4\ \frac{ft-lb}{s} = 0.268\ hp,$$

After calculating the power, the lift force created by the rotor was calculated [8]. First, the power loading is calculated as:

$$\mathrm{PL} = \frac{\mathrm{P}}{\mathrm{A_R}} = \frac{0.268\ \mathrm{hp}}{\pi(\frac{7.5}{12})^2} = 0.2184\,\frac{\mathrm{hp}}{\mathrm{ft}^2}.$$

The thrust loading can then be calculated using the formula:

$$\mathrm{TL} = 8.6859 \times \mathrm{PL}^{-0.3107} = 13.94\,\frac{\mathrm{lbs}}{\mathrm{hp}}.$$

And finally, the lift can be calculated as:

$$\mathrm{L} = \mathrm{TL} \times \mathrm{P} = 13.94 \times 0.268 = 3.74\ \mathrm{lbs}.$$

In order to calculate the drag force on the helicopter blades, the angular velocity must first be known. For helicopters of similar size to the scaled helicopter, the average angular velocity is 1600 RPM, or 167.6 rad/s [9]. This gives us a maximum tip velocity of [9]:

$$U_{tip} = \omega \times d = 167.6 \times \left(\frac{7.5}{12}\right) = 104.75\ ft/s.$$

The following equation relates the drag force to air density, velocity, area, and the coefficient of drag [9]:

$$\mathrm{D} = 4 \times \frac{1}{2} \times \mathrm{C_D} \times \rho \times \mathrm{A_D} \times {\mathrm{U_{avg}}}^2 = 2 \times 0.1 \times 0.062 \times \frac{(0.1 \times 7.5)}{(12)^2}(\frac{104.75 + 0}{2})^2$$

$$= 0.1417\ \mathrm{lbs}$$

The final step in the blade analysis is to analyze the stresses that will develop along the blades during flight. Modeling each blade as a cantilever beam, a bending moment due to the lift force will be the dominant stressor during flight. The bending due to the drag force is ignored in this analysis because aspect ratio suggests that very little stresses will occur in that direction. For a lift of 3.74 lbs. per rotor, each blade will experience a distributed load across the length amounting to 1.87 lbs. To ensure that each of the blades are designed to survive the loading, the stresses will calculated using a point load of the total lift at the tip of the blade instead of the distributed load that is truly exhibited. Using simple statics, the moment is given by:

$$\mathrm{M} = \mathrm{d} \times \mathrm{F} = 7.5 \times 1.87 = 14.025\ in - lbs$$

After calculating the maximum moment, the stress in the beam can be calculating using the following equation:

$$\sigma = \frac{My}{I} = \frac{14.025 \times 0.05}{\frac{1.2 \times 0.1^3}{12}} = 7012.5\ psi$$

At this stress level, almost all of the common RC helicopter blade materials will all handle the stresses without a problem.The common RC blade materials include high strength polypropylene, carbon fiber, fiber glass, wood, and aluminum. Polypropylene is commonly chosen for RC helicopter blades for its low cost, low density, and high impact resistance; however, the maximum yield strength of polypropylene only reaches 6000 psi [13]. Carbon fiber, fiber glass, and wood are all also common choices because they are light weight and would have no problem withstanding the necessary stresses; however they all have a higher cost and poor impact resistance. Aluminum has an unnecessarily high strength and weight to be a practical application on a helicopter of this size. Because none of the common materials completely satisfy our needs, uncommon options were also explored.

Apart from the common blade materials used in RC helicopters, one additional option remains: to use rapid prototyping and 3D print the helicopter blades. Because of how exposed the helicopter blades are to potential damage, a process like rapid prototyping is desirable because when a blade breaks, a replacement can be printed without having to worry about the cost or wait time associated with receiving a replacement. Additionally, rapid prototyping allows for the blade geometry to be easily modified. The materials that are available to use for 3D printing include both ABS and Ultem thermoplastics. The yield strength for both materials is great enough to handle the maximum stresses that the blades will face, although the Ultem has a higher strength to weight ratio [6]. Additionally, both materials are exhibit great impact resistance and have similar densities. Both materials are readily available to use for rapid prototyping and will work for this application. Going forward, rapid prototyping will be used to create the blades; the first choice for material is Ultem, however, if the Ultem cannot be arranged, ABS will also work as an effective blade material.

3.3 Landing Gear Analysis

The landing gear was deemed a very important subject for engineering analysis. This is due to the fact that our team is going through a lot of effort to successfully scale the U13A helicopter, and if upon use of the helicopter, it failed due to landing impact that would be a serious problem. So here is the analysis for the landing gear.

Besides power plant and thrust systems one of the most important pieces on any helicopter is a reliable landing gear. The landing gear provides a stable means of support for the helicopter when landing. The material for the skid support structure, as seen in Figure 4 below, is Ethylene-Vinyl Acetate (EVA). EVA is a very resilient plastic with excellent shock absorbing properties. The ultimate compressive strength for EVA is 1450 PSI and the tensile strength is 2000PSI [4]. Using a strong shock absorbing material will ensure that a minimum amount of force from a landing will be imparted to sensitive systems like the motors or battery. With more forceful landings it will be advantageous if the landing gear breaks on impact so the forces will be diverted into breaking the members and not directly into the aircraft.

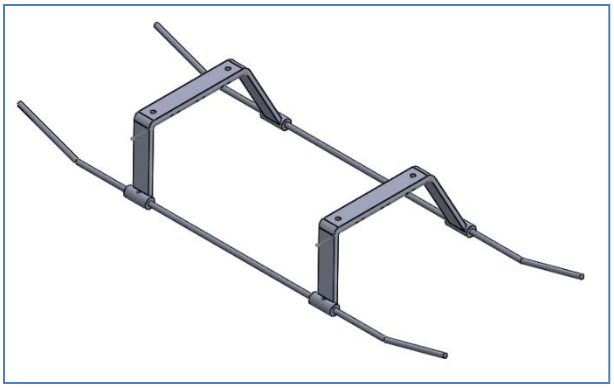

Figure 7. New upscale landing gear

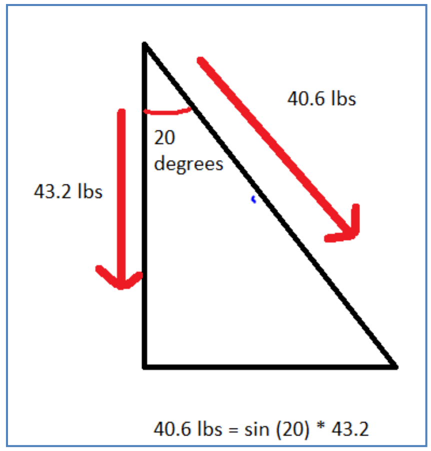

Figure 8. Static analysis of landing gear

Figure 7 shows the Team's updated landing gear for the 1.5 scaled helicopter. The skid support structures which are the thicker pieces attached to the rods, have a constant cross sectional area of 0.15 in^2. To analyze whether this landing gear can absorb the shock the Team must find the impact force and use the cross section area to get a stress. By comparing the stress in the member to the compressive strength of EVA the Team can assess whether the landing gear can survive a fall from a specified height. The Team has chosen to analyze the landing gear falling from a height of 6 ft. The chosen weight was slightly over 3 times the original weight. This is well over the 1.5 scale, however the Team chose to go 3 times the original weight so as to take into account any increases in weight from materials selection or add ons such as cameras. The Team is using the Impact Force equation which is as follows: $F_I = \frac{W \times h}{s}$. In the equation to the left W is the weight of the object in pounds, h is the height as which the object is dropped in feet, and s is the slow down distance in feet. The impact force is measured in pounds. The Team found the slow down distance to be 0.2 inches which measures to 0.0167 feet. This distance is measured from the testing of the displacement of the original landing gear. Through the use of the impact force equation the impact force is found to be 172.8 lbs. By diving among the four vertical members the force turns into 43.2 lbs. Using this vertical force and doing some statics analysis as shown in Figure 8 above, we can see that the force that compresses the member in the landing gear is 40.6 lbs. The next step is to find the stress in the member and assess whether it can handle the impact. Stress is found using the equation: $= \frac{F}{A}$. The stress is found to be 270.67 PSI. This stress is well below the ultimate compressive strength of 1450 PSI so it is safe to assume that this landing gear will survive a six foot fall with an abrupt stop.

3.4 Modeled U13A

Over the past three weeks we have started to model our helicopter as you can see in Figure 9. This model is just about done we are missing the fins in the back and the tail supports. In the upcoming weeks we will be scaling this model by 1.5 and making changes to the design of the helicopter to make it perform better. These changes will consist of a new landing gear, new blades, new gear ratio, and changing the pivoting angle of the blades. While we chose all the new designs we will finish all of our analyses on the helicopter and finish selecting the material that the new parts will be made out of.

Figure 9. SolidWorks model of the U13A helicopter

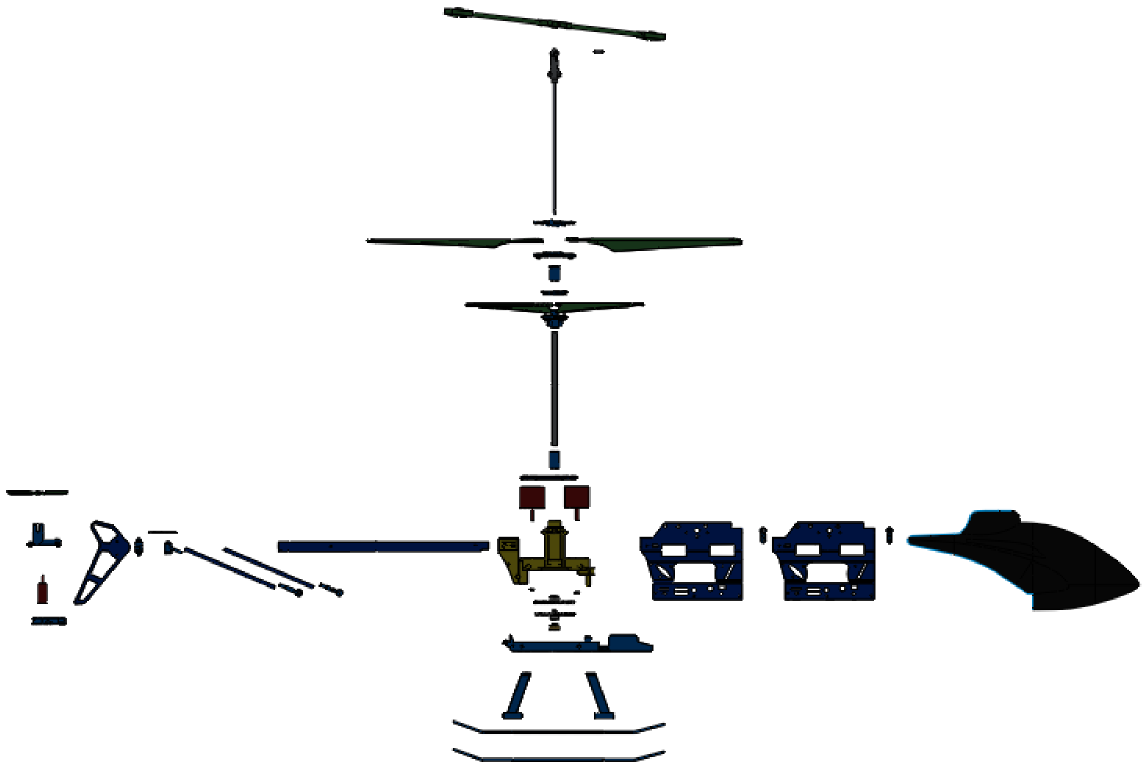

Figure 10. Exploded SolidWorks model of the U13A helicopter

Chapter 4. 3D Printing

4.1 Up scaled model

Over the past year we have modeled and designed a new helicopter as you can see in figure 11. Figure 12 is an exploded view of the up-scaled model. This model has every component on it, except the fairing, which was not made using 3D printing. When designing this model we had to take into account the weaknesses of the 3D printing process. This is why, when you compare figure 11 (Up-scaled helicopter) and figure 9 (original helicopter) the parts of the model below are thicker and bulkier compared to the original U13A helicopter. We also added many larger components such as the batteries and motors, which required we make more room for storing these components in the design of the up-scaled helicopter.

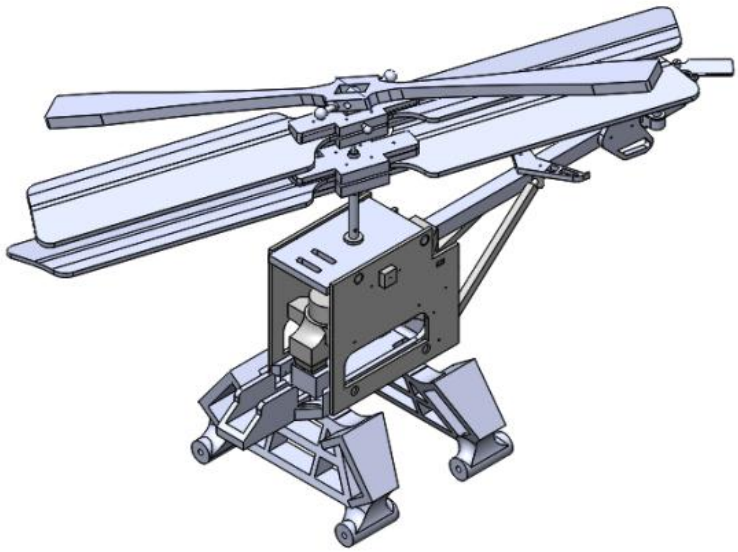

Figure 11. SolidWorks model of the up scaled U13A helicopter

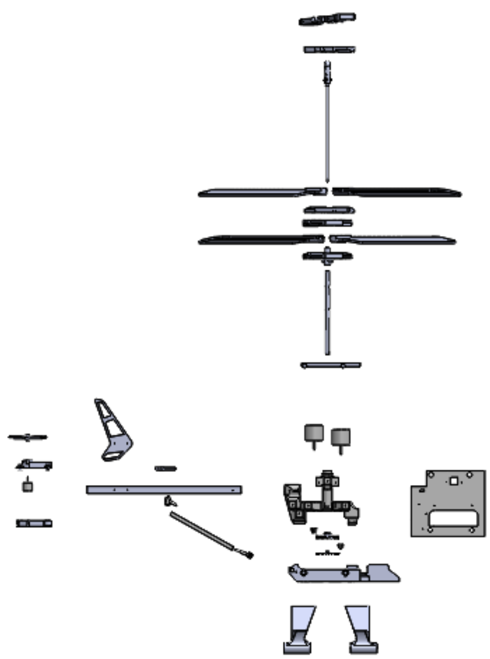

Figure 12. SolidWorks model of the up scaled U13A helicopter exploded

4.2 3D printing

First, let me tell you about the process of 3D printing. 3D printing is done by laying a thin layer of some melted substance, Ultem in our case, in the shape of the bottom of the part you are printing. Then you layer another and another layer until you have the whole part printed. The printer is also laying down support material for the pieces that have over hangs so that when it is time to print that layer it has something to print it on.

Our group printed a total of four blade designs and multiples of some of the other parts such as the main body. 3D printing does not always turn out as planned. We learned this with our first print when a couple of our parts came out deformed because the support material collapsed in the printing process. We also had the printer break in the middle of one of our prints so some of the parts were not finished. If someone was to do this project again I would tell them to account for the tolerance of the machine for that specific material. The 3D printed Ultem is heavy compared to its strength. Those were the challenges we faced due to our need to 3D print our parts. In the, end we printed parts that we thought would achieve what we needed to.

Modifications

As we tested the helicopter we learned the helicopter was too heavy for the amount of lift we were producing. We started to solve this problem by using two batteries instead of three. Then we started to remove material from the landing gear which was the bulkiest part and also the side panels. After it was still not light enough, we started to drill holes in all the components that we could without making the helicopter unsafe. Currently the helicopter is still too heavy to fly so we will keep modifying it until it can fly.

Chapter 5. Powertrain

The powertrain of the original U13A helicopter was not optimized for remote controlled helicopter flight. Each component in the original powertrain was analyzed and adjusted to optimized performance in the up-scaled helicopter. Modifications in the powertrain were made to the following components: the motors, batteries, speed controller, and transmitter/receiver combination.

The original, un-scaled U13A helicopter utilized three motors in its powertrain. Two brushed motors rotate each of the coaxial rotors, while an additional, smaller brushed motor rotates the tail rotor; no specifications were given for the stock motors. Brushed motors have several advantages such as their low cost and simple design that allows for reliable operation even under the most extreme conditions. However, brushed motors also have several disadvantages; these disadvantages include: required periodic maintenance, decreased torque as speed increases, poor heat dissipation, and a low range of speeds. The alternative to brushed motors is brushless motors. Brushless motors are more expensive than their brushed counterparts, and offer many advantages. Brushless motors require almost no maintenance, the torque is independent of speed, are highly efficient, and offer a very large range of speeds; for these reasons, brushless motors were selected for the up-scaled helicopter. The number of motors for the scaled helicopter remains the same as the original U13A. The two motors used to rotate the coaxial rotors are rated at 5000 kV, while the tail motor is rated at 1000kV. The increased size and performance of these motors required us to also modify other powertrain components, especially the power supply.

The original U13A helicopter utilized a single 3.7 V, 580 mAh, lithium polymer battery. This battery was capable of powering the un-scaled helicopter for approximately 7 minutes, shorter than desired for our up-scaled helicopter. This battery would last even shorter in our up-scaled helicopter, so a larger power source was chosen. To power the larger motors and to greatly increase the flight time, three 2S, 7.4 V, 1600 mAh lithium polymer batteries were chosen to increase our flight time to over 15 minutes in our final design.

After selecting the new motors and batteries, a decision had to be made on the method for controlling the helicopter. On the unscaled helicopter, a PCB board governed the motor speed and provided the sending and receiving of transmissions from the pilot. A PCB board is a computer chip that is built and programmed to govern the motor speed and transmissions, however, PCB boards require extensive programming that could be greatly simplified by adopting a standalone transmitter/receiver conjoined with speed controllers. This method still requires programming, but only a fraction of the programming that would need to be done on a PCB board, and comes without any loss in functionality. After selecting all of the individual components the work shifts to integrating all of the components together into a functional powertrain.

Chapter 6. System Integration

6.1 System Integration

All electronics are connected as shown in figure 13 below. As can be seen the ESC is the central point in the system. It receives a signal from the receiver which it then draws the appropriate voltage from the battery. It then conditions the voltage to a correct current for the motor and finally sends the voltage to the motor.

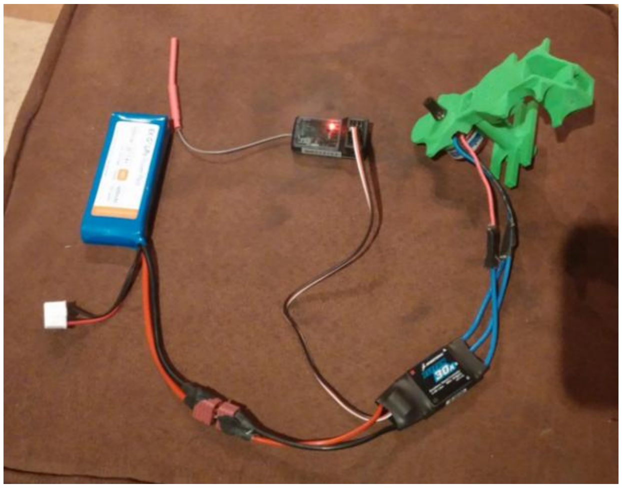

Figure 13: Electronic System Integration

This setup is shown using the 30A ESC, however it is the exact same when using the 10A ESC. When all the different ESC's are connected to their respected channels only the channels receiving signals are being activated so there is no chance of overlapping signals unless you program the transmitter to mix signals.

When the main motors are spinning they are usually spinning greater than 30,000 RPM. In order to not burn out the motors when a torque is applied one must use a gear train to increase the torque handling capabilities of a motor. The gear train also helps lower the RPM of the output shafts. Figure 14 below shows the gear train for the helicopter. This gear train is approximately a 1:6 reduction which provides a balance of power and speed. Since both gears are coaxial they have to be stacked the way they are shown. Thus, the individual motors must be raised and lowered appropriately along with the pinion gears.

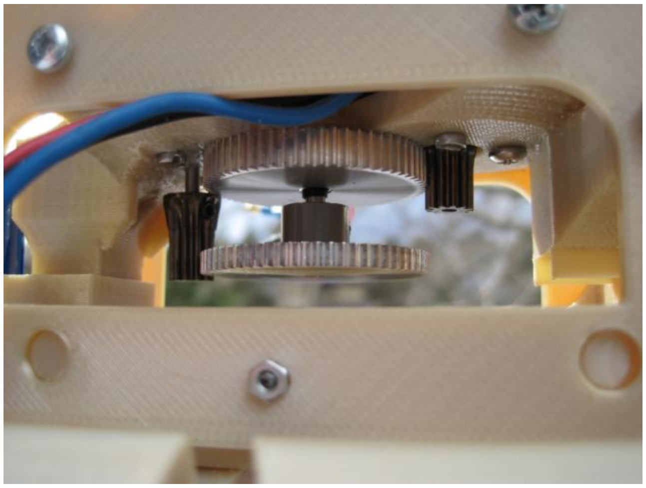

Figure 14: Integration of Motors and Gears

As shown above the receiver is integrated with the ESC. Everything in that system is just a plug and play. However, the transmitter is not a plug and play system. It requires specific programming for the specific tasks the motors are performing. The programming will be explained in the next section. You can see in figure 15, how the transmitter ties in with the whole helicopter.

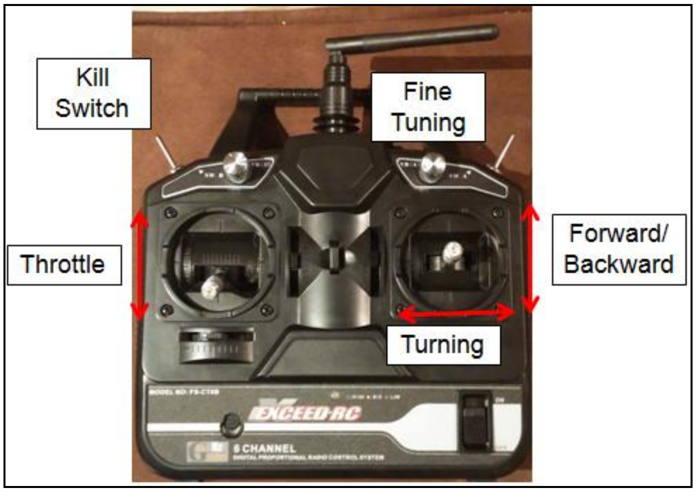

Figure15: Transmitter Integration

You have a throttle on the left which is mixed with the turning channel. There is also the forward and backward channel which controls the rear rotor making the helicopter go forwards or backwards. As can be seen towards the top of the Figure is a kill switch and a fine tuning knob.

The kill switch is used to shut off the main rotors so that in case of a hard landing or if the helicopter needs minor work done the rotors cannot spin. The fine tuning knob is used to calibrate the voltage range of the turning channel. With these types of transmitters they do not always zero themselves out after every use. The helicopter can be in a steady hover but when the transmitter is turned off and turned on the zero point can shift very slightly making the helicopter turn even when the stick is not being actuated. The fine tuning knob allows the user to find the zero point so that the helicopter does not rotate unless the stick is being actuated. For future improvements the other switch and knob can be used to perform any task such as tuning channels or if there are spare channels available they can control something specific like turning on a spotlight.

6.2 Transmitter Programming

To ensure complete integration and functionality with the helicopter the transmitter must be programmed and tuned to the specific roles that the different channels are to be performing. In addition to setting tasks the channels had to be calibrated for the full range of movement of the sticks. The transmitter programming took to separate programs to complete. Of which the first was the program used to calibrate the transmitter and set endpoints on all channels.

Both programs use the same name, T6 Configuration. They may have the same name but they both had their own strong points. The one failing point of both programs is that neither has presets for a coaxial type helicopter. Both programs are optimized for traditional variable pitch helicopters and airplanes. This fact means that each channel has to be individually calibrated set individually.

Using the first program to calibrate and set endpoints was quite simple. To calibrate the sticks all channels are moved to their lowest and highest points to ensure the full range of voltage the motors are capable of. The program used for this purpose can be seen in figure 16 below.

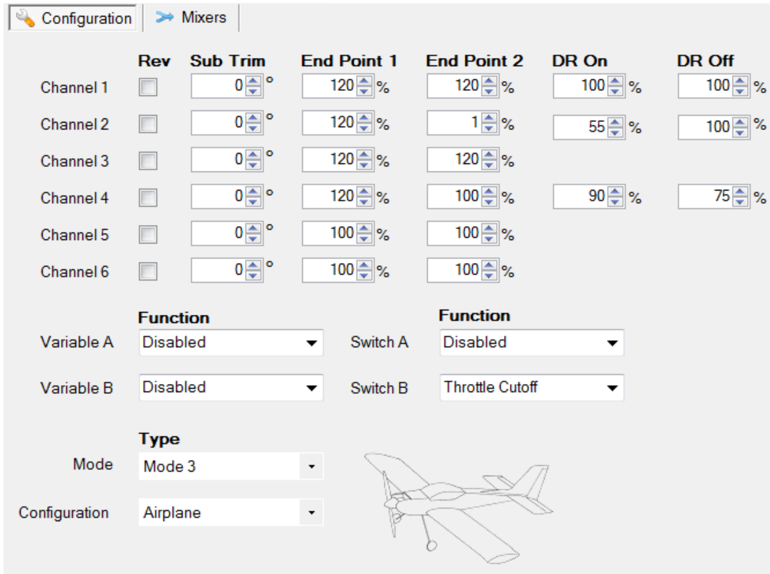

Figure 16: Calibration Program

The specific setting cannot be seen in the Figure but the calibration can be done simultaneously for each channel. This is in contrast to the other program where everything has to be done individually. On the bottom of the Figure you can see the Mode and Configuration settings. This is where a user can choose between helicopter and airplane settings. The airplane settings are chosen for our helicopter because this ensures a simple interface without the clutter of setting pitch angles.

The next program was used exclusively to mix the throttle channel and turning channel. Because of the nature of a coaxial helicopter in order to turn one rotor has to either spin slower or faster than the other rotor. In order to accomplish this, the turning channel is mixed in with the throttle channel. This means that when the throttle is pushed both rotors will spin at the same speed. However, when the turning stick is used the rotor will either slow down or speed up depending on the direction desired. The program is shown in figure 17 below.

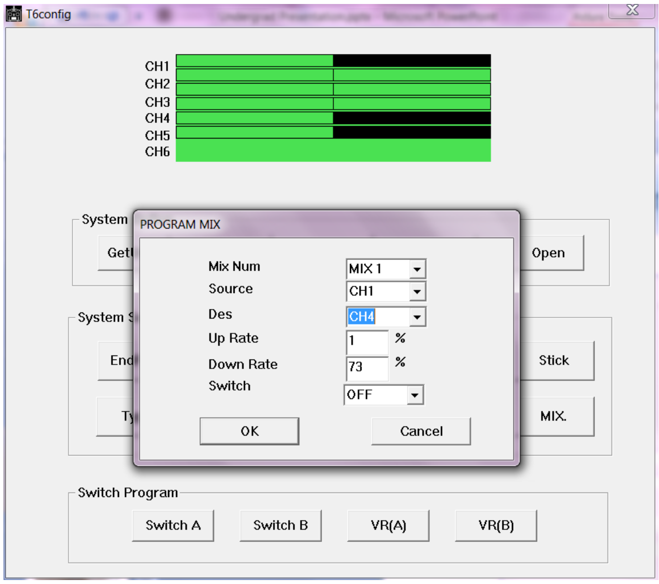

Figure 17: Mixing Program

This program was more specific to the individual channel which helps when you need to set all the settings for one channel only. Otherwise the operator may inadvertently set up the wrong channels with the other program.

The main difficulty when programming the helicopter came when the mixing of channels would not spin both rotors at the same time. In order to correct this error both the end points and the mixing had to be individually checked one degree at a time. All the while the endpoints must remain within the voltage range of the motors. This is an easy albeit time consuming problem to fix.

Chapter 7. Testing and Modifying

7.1 Fairing design

For the fairing design, the outside shell attachment is constructed with carbon fiber material. The reason that the team chose to go with carbon fiber is because it is cheaper and lightweight. As you can see in the figure 18 below, the design is kept smooth in order to help with the aerodynamics. Aerodynamics is an important issue when trying to fly the helicopter. The design needed to be lightweight and smooth in order to achieve the proper airflow through the fairing. In addition, the material was denoted to us by the human power vehicle team in which they helped us mold together the fairing at Nova Kinetics. Thus, the fairing fits nicely onto the main body core without having any slippage.

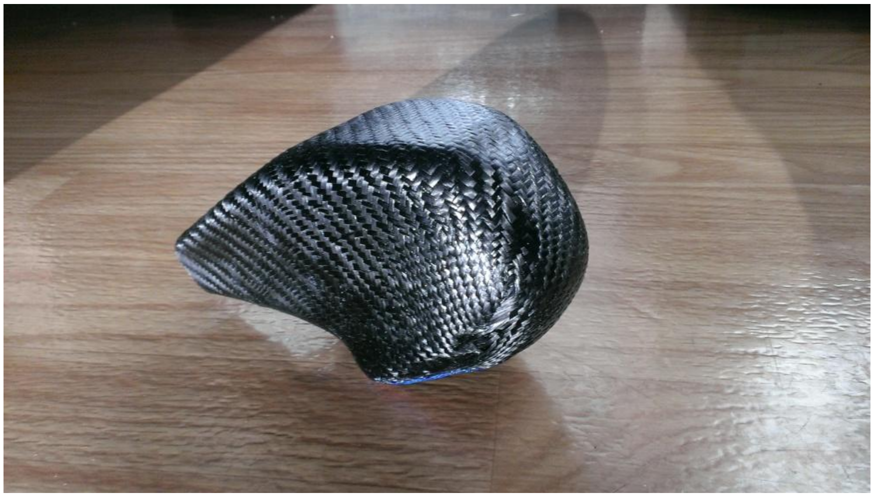

Figure 18. Outside shell fairing design

7.2 Comparison

When comparing the original U13A helicopter to the upscaled rapid prototype helicopter, there is a huge difference in the size. Based on original U13A helicopter in figure 19, every single part is smaller and made out of plastic material. This results in a much lighter and maneuverable helicopter that can be lifted off the ground pretty easily. In addition, the rotors are much smaller in size as well as the blades. The upscaled helicopter which is shown in figure 20 displays a much heavier and bulky type of remote control helicopter. The reason why the team chose to go with the bulkier material is so that it will have enough support to withstand the force applied to the helicopter upon landing or taking off. The lifted rotors provided a much better lift force to help budge it off the ground. The team also had to drill out the excess support material in order to gain more lift as well as decreasing the weight. Also, the balance beam was taken off the upscaled helicopter because it had no use when having the top rotors spin. The purpose of the balance beam is to protect it from making contact with the lower blades. As a result, the team ended up adding a washer with O-rings to replace the balance beam and help lighten the weight.

Figure 19. Original U13A

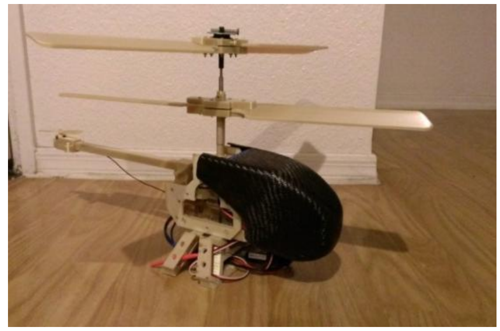

Figure 20. Upscaled Helicopter

Figure 21. Original Rotor Connector

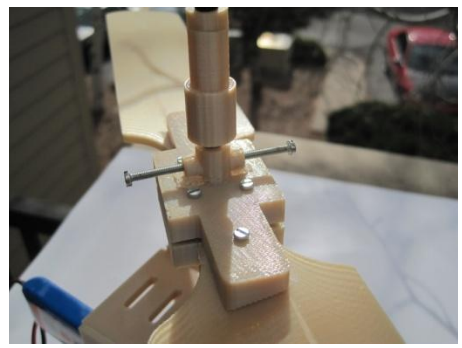

Figure 22. Upscaled Rotor Connector

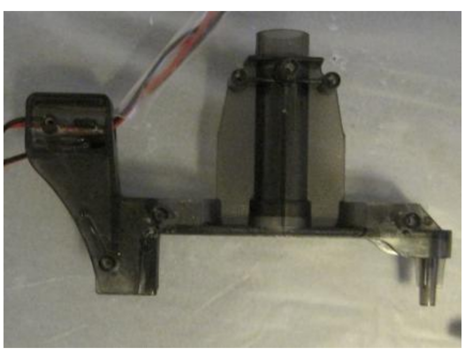

Figure 23. Original Main Body Core

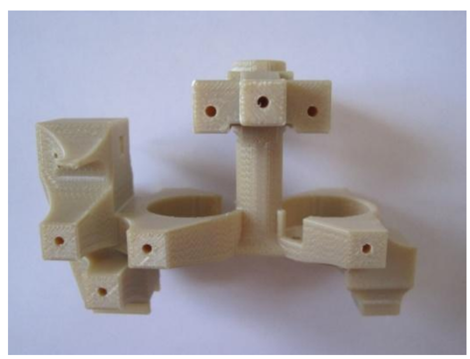

Figure 24. Upscaled Main Body

Figure 25. Original Landing Gear

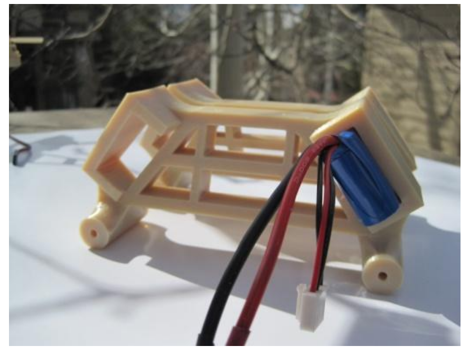

Figure 26. Upscaled Landing Gear

7.3 Initial testing

For the initial testing, there were multiple tests that the team needed to accomplish. First, the helicopter was really heavy from the 3D printing material. The team did not know how much the Ultem was really going to weigh and having printed thicker parts made the helicopter weigh way more than expected. Second, the top rotors kept on slipping because the gears weren't properly meshing together. This has been a major issue for the team to resolve because the 3D main core part wasn't printed correctly and shifted the upper motors to a slight angle. Third, the pin hole in the gear kept on stripping. After screwing the pin in and out of the gear multiple times, by multiple people, it made it difficult to unscrew the pin itself because of over usages. The solution to this is that the team ended up drilling out the old pin and screwing in the new one. Fourth, calibrating the six channel remote control was pretty difficult because there were over 1000 combinations of different possibilities and eventually the team figured it out after 600 attempts of trial and error. The ports in the receiver that the team ended up using were two and four. Lastly, the shaft had a lot of uncontrolled movement making the upper rotor unstable. The reason why the shaft was wobbly is because the inner shaft was too small. In addition, the gear and pinion would not properly mesh correctly while running it at high speeds. Therefore, after performing some modifications the helicopter is assumed to fly with no problems.

Chapter 8.Cost Analysis

In order to successfully scale the U13A helicopter, much cost analysis must be done for each individual part. Upon completion of this analysis, we will be ordering and constructing the parts of the helicopter. Once the helicopter is constructed we can begin its testing phase.

For the cost analysis we will be focusing on Table 8. This table includes quantity, a bill of materials, and the total cost of production. The manufacturing costs will not be applicable since we will not be making our parts. Also, the cost of man power is not included since we will be constructing the helicopter without any outside sources. Lastly, there is no mass production thus there is no payback period.

Table 8. Cost analysis

Quantity	Part	Name	Price Per Part	Price
2	Main 250 Motors	Hobbymate HB2622-5000kv Brushless Motor	$ 24.80	$ 49.60
1	Tail Rotor	12000KV Brushless Tail Motor for Micro Heli	$ 14.99	$ 14.99
2	Main Rotor ESC	New HobbyWing Flyfun ESC 30A	$ 17.49	$ 34.98
1	Tail ESC	New HobbyWing Flyfun ESC 10A	$ 11.99	$ 11.99
3	Batteries	HYPERION G3 EX 1600 MAH 2S 7.4V 45C/90C LIPOLY PACK	$ 25.95	$ 77.85
1	Top Shaft	HP Heli's Inner Main Shaft for the X-2 helicopter	$ 10.99	$ 10.99
1	Lower Shaft	HP Heli's Outer Main Shaft w/Gear for the X-2 helicopter	$ 10.99	$ 10.99
1	Transmiter-Reciver	Fly Sky CT6B OEM Version Exceed RC 6-Ch 2.4Ghz Transmitter w/ Receiver	$ 44.70	$ 44.70
2	Pinions	Mod 0.5, 10 Tooth, 2.3 mm ID Pinion	$ 1.99	$ 3.98
2	Large Gears	Mod 0.5, 80 Tooth, 6 mm ID Gear	$ 30.00	$ 60.00
1	Screws	LPPM3006 - M3 x 6mm - Thread forming screws For Plastic (100)	$ 2.40	$ 2.40
10	Pins	M2 - 8mm Roll Pins	$ 0.11	$ 1.10
1	Remote	Exceed-RC 6 Channel / Digital proportional Radio Control System	$ 49.99	$ 49.99
1	3d Printer Material	Ultem for Rapid Prototyping	$ 500.00	$ 500.00
Total				**$ 862.57**

We can see by looking at Table 8, that the total projected cost is 798.00 dollars. This is largely in part due to the 500 dollar charge for the materials when using a 3d printing for the blades and other various parts. This charge shall be covered by our student fees according Dr. Tester the instructor in charge of the 3d printing. All of these listed parts have been found to meet specifications of our team, as well as, being easy to order. Therefore, we will be ordering these parts this weekend and receiving reimbursement from NAU.

Chapter 9. Conclusion

In chapter one, the problem was introduced and a brief description about our client Dr. Kosaraju was given. The task that was assigned for our team is to upscale a U13A remote controlled helicopter that was provided by our client. The prototype needs to be durable and operates by a remote control. Rapid prototype needs to have the capability of adding mission specific accessories in order to send early warning for forest fires. The rapid prototype that was designed and built has been up scaled up by a factor of 1.5. Next, the objectives for this project were addressed and broke down to many components to achieve the task successfully. Then as a team, we analyzed the major component in the system such as total lift, blade size, and landing gear stress, in order to satisfy the conditions that the rapid prototype will experience.

Approaching chapter two, our team discussed the concept and generation selection. We tested and analyzed what the lift capacity is by analyzing all the data into a lift versus weight graph. The team found out that the maximum lift capacity that the helicopter can lift is approximately six mechanical pencils, roughly .38 lbs. After collecting all the data needed for the helicopter, it was then taken apart and modeled in CAD. Designs were then discussed by selecting which concept design was better through decision making. The first design is the major flaws in the blade designs. As a team, we quickly knew that the blades were not durable from the chips within the blades. We also discussed the battery pack life design. There were two main battery packs and we choose to design ours in both parallel and series. The third design was its lifting capabilities. The team discussed how to improve the lift capabilities by increasing the rotor length size. In addition, landing gear designs were discussed as the forth design in order to provide a safe landing and take-off. The team thought that having a larger skid rack would help provide the helicopter for a softer landing. The final design concept was improving camera capabilities. This allowed the team to figure out how much of a range our helicopter can fly with live feed streaming.

In chapter three, we discussed the engineering analysis on the blades and landing gear. We had to make assumptions when considering what equations to use for each the blade and landing gear analysis. In the analysis, we chose to analyze the blades first. We wanted to analyze forces acting on the blades so that we can investigate whether or not the blades will fail when we upscale the original part size. We first calculated what the power output is and that came out to be .268 hp. After that we calculated the lift force created by the rotor and that is .2184 hp/ft^2. We then calculated the thrust loading to be 13.94 lbs/hp. Finally, after calculating all those results we calculated the lift force to be 3.74 lbs. To ensure that each of the blades are designed to survive the loading, the stresses will calculated using a point load of the total lift at the tip of the blade instead of the distributed load that is truly there. The moment came out to roughly be 14.025 in-lb and the stress in the beam is 7012.5 PSI. In addition, the way we are going to produce our materials is rapid prototyping. These materials include ABS and Ultem. The material we chose to use in rapid prototype is ABS because the yield strength for both materials is great enough to handle the maximum stresses that the blades will face, although the Ultem has a higher strength to weight ratio. The second analysis was the landing gear. We chose to analyze this because the landing is the most important thing to keep in contact because it has many components; such as, the motor, battery, rotors, and gears. These are all important when considering a soft or hard landing. Again, we had to make assumptions for that and we chose a height of six feet. The result of the impact force is 172.8 lbs. Dividing that number by four we go that each vertical member of the skids to be 43.2 lbs. After calculating the impact force we calculated the stress on the skids to be 270.67 PSI. This stress is well below the ultimate compressive strength of 1450 PSI so it is safe to assume that this landing gear will survive a six foot fall with an abrupt stop. In addition, we discussed the model of the U13A helicopter and colored in the parts that were changed accordingly to the client's needs. The two main parts we chose to increase are the blades and landing gear. In the blades, we increased the length and width in order to have it left off the ground quicker. The other part we changed is the landing gear. In this, we extended the body and rounded the ends of each skid in order to provide safer landings.

The next topic discussed, was designing and 3D printing the parts for the rapid prototype. Some parts were modified in SolidWorks, in order to maximize the strength of the components used. A total of twenty four parts where designed and 3D printed using Forester 3D printing machine. The final material selection for rapid prototype is Ultem 9085 including all the components in the design, except the fairing will be constructed from Carbon Fiber. The materials used in the design are stiff and durable to perform the task and to achieve the need without any failure. Some issues were experienced once the parts had been 3D printed and modification was thus necessary to eliminate the extra weight. These modifications were to cut and drill some of the components to eliminate the extra weight, however without affecting the performance of the helicopter.

In chapters five and six, we addressed and described the function of each individual component in the power train, as well as, the system integration of these components. The helicopter will be consist of two 5000 KV motors for the blades, along with 1000 KV motor for the tail rotor. One LiPo battery having 1600 mAh and 7.4V will be responsible for supplying the sufficient power for the system. Three electronic speed controllers (ESC’s), and one 6-channel 2.4 GHz transmitter and receiver will be responsible for controlling the helicopter remotely.

Features for each component in the power train were analyzed individually and a selection was made regarding best fit for our design. Attachments such as (lights & Camera) might be applied on the rapid prototype; however it depends on the time frame since it is a minor issue. Now our team is performing more test runs after the recent modification, since a lot of weight was eliminated and switching to one LiPo battery for the prototype instead of two.

In chapter seven, we looked at the initial testing on the helicopter as well as the modifications that were made. When initial testing began it was clear that the Ultem material was simply going to be very heavy to get off the ground. After many tests, it was decided that the helicopter must be reduced in the amount of material. As a result, the team cut as much of the unnecessary material off as possible, and went back to the testing phase. Upon testing, we found that the helicopter was still unable to get off the ground. This might not be entirely due to weight however. After modifying the helicopter the gears were having trouble meshing and thus maximum rotor speed was unachievable. In the end, we could never quite get a perfect test run to find out if the helicopter would really fly. We also compared the original U13A helicopter to the upscaled version our team created.

Lastly, in chapter eight, the cost analysis was discussed. The budget totaled out to be 862.57 dollars. The reason why the cost is so high is because the rapid prototyping itself is going to cost us 500.00 dollars for the Ultem material. According to Dr. Tester, the cost for the rapid prototype will be taken out of our class fees for the course. This will ensure a smaller budget for our client to fulfill his needs.

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