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EML4551-2

Team 518: Light-Weight UAV

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Abstract

The purpose of our project is to reduce the weight of a drone, resulting in a longer flight time. Drones provide aerial surveillance and data collection at a fraction of the cost of ordinary aircraft. They have various applications, both in military and civilian settings. In the military domain, drones gather intelligence. For civilian use, the farming and agricultural industries use drones to survey land, count livestock, and check water conditions.

Considering the necessity and function of each part's purpose helped reduce the weight of the drone. We questioned the job of each part and tried to find other ways to combine them. Changing a single piece impacts other parts of the drone. Reducing the weight means the drone needs less power to fly at the same rate as before. Using a lighter battery that provides a more precise amount of power, results in even more weight savings.

We are applying three weight reducing techniques to the Believer 1960mm aerial surveying drone. We are reducing the weight of the battery and motors, replacing parts with 3D printed pieces, and improving the weight of the propellers. Decreasing the weight of the battery and motors is done by replacing the original parts with lighter versions. The 3D printed pieces are made of a lightweight filament. Propellers made of carbon fiber are lighter and stronger than those made of plastic. We aim to have a flight time over one hour. Another part of this project is developing a tool to measure the effectiveness of the light-weighting techniques used. This tool can be applied to other projects with weight cutting goals. Looking at the energy consumed by the drone, after the weight savings, shows the effectiveness of the work performed.

Keywords: UAV, Weight Reduction, Drone, 3D Printing

Disclaimer

No disclaimer was needed for this project.

Acknowledgement

Team 518 would like to thank our project sponsor, Northrop Grumman, and our point of contact, Jennifer Tecson, for all of their help. Jennifer provided great insights and helpful criticism during our project. Without her, we would not have been nearly as successful as we were. Through our meetings with Jennifer, we also learned what working in industry is like and how certain tasks are done at Northrop Grumman.

Team 518 would also like to thank Dr. Lance Cooley and Dr. Shayne McConomy for all of their advice and support during the project. Without them, the project may have taken a different path, but their guidance helped shape our project and meet our goals.

Team 518 would like to thank the FAMU-FSU College of Engineering and the Innovation Hub for all of the materials and resources available to us during the building and testing phase of the project. We were able to validate our methods and create a successful project utilizing the resources available.

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Notation

UAV	Unmanned Aerial Vehicle
F_L	Force of Lift
F_D	Force of Drag
T	Thrust
F_G	Force of Gravity
m	Mass
a	Acceleration
g	Acceleration due to Gravity
V	Velocity
E	Energy
A	Area
PLA	Polylactic Acid
LW-PLA	Light Weight Polylactic Acid
$\dot{m}$	Mass Flow Rate
ρ	Density
C_L	Coefficient of Lift
C_D	Coefficient of Drag

Chapter One: EML 4551C

1.1 Project Scope

Project Description:

The objective of this project is to develop a lightweight UAV to directly increase the flight time while maintaining surveillance capabilities. Multiple light-weighting processes will be used to complete this task.

Key Goals:

The key goals of this project are what the team aims to accomplish by the end of the project:

- Increase the flight time of the UAV.
- Keep the UAV lightweight compared to market ready UAV's.
- Develop the UAV with multiple light-weighting techniques.
- The UAV can be easily transported and operated.
- The UAV will have quality surveillance recordings.

Markets:

The markets for this project are those that the lightweight UAV can be used in. These markets include primary and secondary markets. The lightweight UAV is mainly designed to be used in the primary markets, but the members of the secondary markets also have an interest in the product. The primary market of this project are farmers and members of the agricultural community. Secondary markets for this project include the US Military, infrastructure companies, hobbyists, land surveyors, and teaching facilities.

Assumptions:

- The UAV will be operated in Earth's atmosphere.
- The flight conditions are typical of the climates in the United States.
- The UAV is remotely controlled.
- The UAV is category 1, as defined by the DoD.
    - A category 1 UAV has a maximum gross takeoff weight within 0-20lbs, normal operating altitude less than 1,200ft AGL (above ground level), and an airspeed less than 100 knots.
- The UAV will be flown in clear airspace.
- The UAV will follow all state and federal laws.

Stakeholders:

The stake holders for this project are those that are directly influenced by the work done to develop the lightweight UAV. These parties have invested resources or control of the outcome of the lightweight UAV. For this project, the stakeholders are:

- Northrop Grumman
- Dr. Shayne McConomy
- Dr. Lance Cooley
- Senior Design Team 518

1.2 Customer Needs

The customer needs are interpreted answers provided by the project sponsor when asked questions by the team. Team 518 asked the project sponsor various questions pertaining to the overall objective of the project and received the answers shown in Table 1 below. The responses of the customer were then translated into engineering needs to better define the objective of the project.

Table 1 *Customer Needs*

Questions	Customer Statements	Interpreted Need
What materials should be used?	The team last year found an innovative composite to use as a lightweight material.	Use available materials and stay within budget and design capabilities.
Is there a pre-existing drone to work from or will the drone design be original?	Utilize the previous SD project to interpret a direction for this year's project.	The drone will be designed and constructed with selected lightweight materials.
How much of the work should be continued from last year?	With the budget issues we have, figure out what can be used from last year's work.	The drone implements previously purchased components to be cost effective.
Are there take-off and landing requirements?	There is no take-off or landing requirements.	The drone will take off and land either unassisted or assisted.

Quadcopter or fixed wing drone?	Look at the work of last year. A quad rotor is harder to control.	The UAV will be of the fixed wing style.
What kind of payload is expected to be a part of the UAV?	Payload can be for surveillance or data collection purposes.	The UAV will have a payload.
Can the components be outsourced**,** or will the components need to be self-created?	Decide a payload size/range. Unnecessary to create sensors.	The drone will use outsourced components.
What is the size requirement for the UAV?	Look at existing design from last year.	The drone is smaller than double the reference drone.
What is the weight restriction of the UAV?	Look at the work of last year but light-weighting can come in forms of efficiency.	The drone will be a category 1 UAV.

Team 518 asked the project sponsor questions regarding customer needs during a conference call. As a team, the recorded customer statements were translated into interpreted needs. With these interpreted needs, Team 518 knows what the customer wants from the design. As the engineers, we use the wants of the customer to create the functions of our design. Many of the needs are up to Team 518 to decide utilizing the work of last year's group. This allows us to gear the design towards what we choose as our market, what our goals are, and the objective created. One area that will have future implications on our design is the unestablished budget. Team 518 will be developing a lightweight UAV with the purpose of increasing the flight time and having an incorporated payload.

1.3 Functional Decomposition

The functional decomposition allows the overall project system to be broken down into smaller functions and subsystems. The functional decomposition portrays the actions the project's systems must fulfill. Figure 1, below, is the functional decomposition for the lightweight UAV of this project. This functional decomposition was developed through discussions with the project sponsor, Northrop Grumman, and by referencing the work of the previous group.

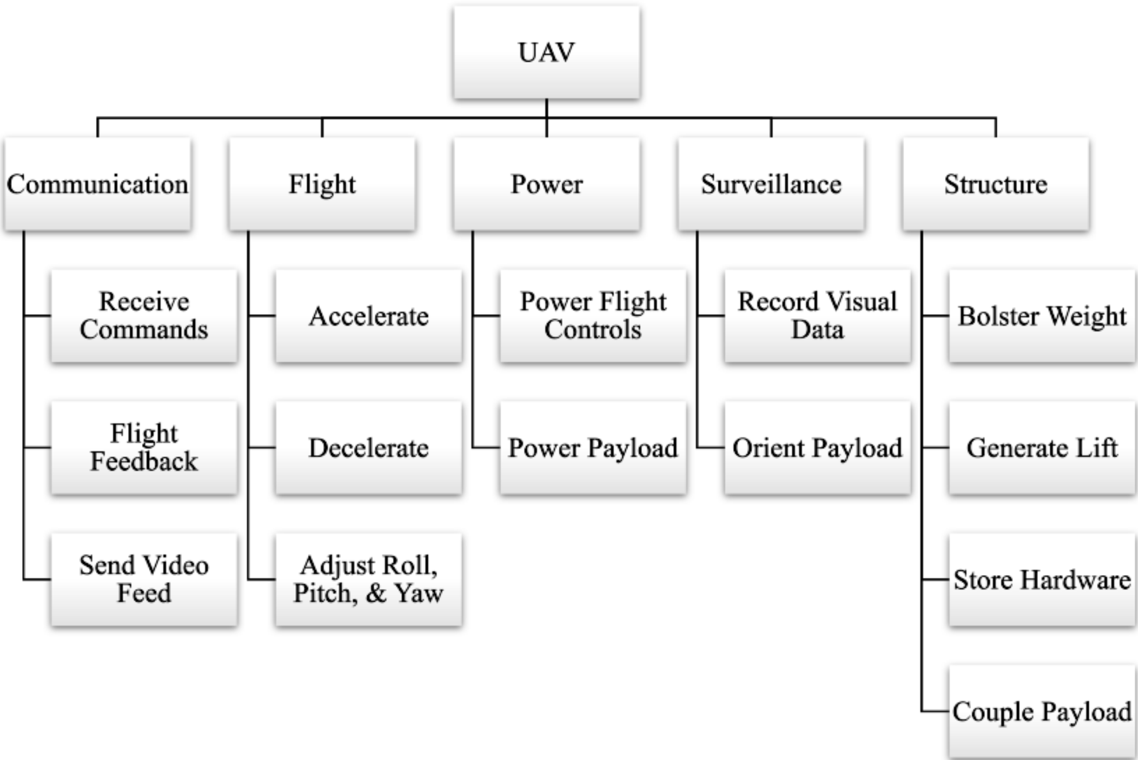

Figure 1 *Functional Decomposition*

The five main functions of the lightweight UAV are communication, flight, power, surveillance, and structure. As a team, we discussed what was necessary to make the UAV fly properly and perform proper surveillance. Each one of these major functions is broken down into subfunctions. The subfunctions are what is needed for the major functions to perform properly. For the communication function to succeed, the UAV must receive commands from the user as well as send video feed back to the user. Another aspect of the communication function is that the UAV must provide feedback about its flight status to the user. For the flight function to succeed, the UAV must accelerate, decelerate, and adjust roll, pitch, and yaw. These are the dynamics that go into making a plane, or in this case a UAV, fly. The power function succeeds when there is power to the flight control and payload subsystems. Without power to the flight controls (motors, actuators, receivers) the plane won't move. Also, there must be power to the payload for the payload to function correctly. The surveillance function needs to record video as well as orient the payload in a direction to be successful and complete the project objective of providing surveillance. The structure function is needed to support the weight of the UAV, generate lift to get the UAV off the ground, store all the hardware involved in making the UAV work, and allow the payload to attach to the UAV. All these functions and sub-functions are what allows the lightweight UAV to perform and meet the project objective.

Priorities of Main Functions:

Structure- This function is placed in first because the craft must be able to support itself in flight as well as during takeoff and landing. If the UAV doesn't support its own weight, and the structural system fails, there will be no UAV to fly. Looking at table 2, all the other functions rely on the structure function.

Power- The power function is ranked second on or list of functions. Without adequate power the UAV is unable to move, and unable to achieve flight. Also, the power is necessary for the communication and surveillance functions to work. Power is critical because it supports the other main systems throughout the UAV.

Flight- Flight is necessary to get airborne. Due to the UAV's default flight setting, it is neither dependent on communication nor surveillance. If the drone is unable to fly, the Team's mission will fail, no matter how well the rest of the UAV is designed.

Communication- The communication function ranks fourth in our priorities list. The communication function relies on the power system because it needs power before it can work. The drone relies on the communication between the user and flight controller on the UAV in order to relay how the drone needs to maneuver during flight. Also, the drone will need to be flying before it can communicate the desired feedback data to the user.

Surveillance- Surveillance is the last function to receive priority because it is dependent on all the other functions being accomplished. The first objective of this project is to achieve an increased flight time using light-weighting techniques, then provide surveillance. The drone can still fly without the surveillance aspect working.

1.4 Target Summary

Targets and metrics are used to establish the certain values the functions and needs of the design must meet. These define the goals the product will be compared to in order to validate the work done to create the project. Each function has a metric, what is used to validate the function, as well as a target, the specific value of the metric. Metrics are the length used to measure an object, determining the volume of container, or using a thermometer to measure the temperature. The targets that match these measuring techniques would be establishing the length as 12 inches, calculating the volume to be 3 cubic-meters, or saying the temperature is 100° Fahrenheit. For our project, we developed targets and metrics for each function. These can be seen in Appendix B. These targets and metrics were developed using data on the Believer 1960 mapping UAV, further research on UAVs, and basic physics concepts. The technical data for the Believer 1960 was used to generate most of the targets in the overall targets and metrics table in Appendix B. However, the data listed for the Believer 1960 was very limited. We had to manipulate the data to create certain targets to match the metrics. Since our primary market is the farming and agricultural industry, we used data based on farm sizes in Florida to acquire some targets.

In order to test and validate our product and to establish whether our targets were met, many tools will be used. The biggest tool will be a computer and software we can acquire. We will use the computer to manipulate designs, change the material the design is constructed of, and validate targets for functions like the support function. This tool allows us to analyze stress points in our designs too. Another tool we will have to use is a stopwatch. This may be used to time the running endurance of components like battery and motors under certain loads. A third tool we may need to validate our design is a multimeter. A multimeter will be used to analyze currents drawn by electric components as well as voltage differences in the electrical system.

In order to help further define the project objective, certain targets and metrics were chosen as critical. These critical targets and metrics are essential for the customer needs to be met as well as the project objective. Table 4. below highlights these critical targets and metrics.

Table 2 *Critical Targets and Metrics*

Functions	Metrics	Targets
Bolster Weight	Support moment due to wing	1.128N/m
Generate Lift	Airfoil produces greater lift force than gross weight	54 Newtons
Couple Payload	Mass of Payload supported	600g
Endurance	Overall Flight Time	60 mins

Bolstering the weight is considered a critical target because for the UAV to fly correctly it needs to be able to support all the components inside the UAV. Without the UAV being able to hold the wings, battery, electrical components, and other hardware, the UAV will not be structurally sound. This will ultimately lead to us not hitting our objective. Supporting the wings is the weight that is mainly hanging off the plane. The moment calculated due to the wing, assumed that the weight was all the way at the tip of one wing. One wing's weight is .11736kg and has a length of 980mm. Converting .11736kg to 1.1513 newtons and converting 980mm to .98m. The moment was taken just by multiplying 1.1513 by .98m to get 1.128N/m.

Generating lift is a critical element of any flying vehicle. The target of greater or equal to 54 Newtons for lift was determined by calculating the required lift the UAV must generate in order to achieve flight (Believer 1960mm, n.d.). To takeoff the lifting force must be greater than the weight of the UAV and to maintain altitude above the ground the lifting force must be equal to weight of the UAV. To test our target for generating lift the profile of the UAV along with the estimated airspeed of the UAV will be used to calculate the aerodynamic properties of the UAV to include lift.

By enabling the drone to transport a camera or some other device, it transforms from a cool toy to a highly valuable piece of equipment for many industries. The target of 600g was obtained by researching cameras designed to be used in small drones (UAV Cameras, n.d.). This mass range satisfies the need to compromise high quality camera capabilities and light weight with the price of the camera. Many cameras that fall within this mass range can take quality video footage and will not overload the drone. They also satisfy our budget by not being the most expensive. By constraining within these three specifications, we will be able to choose the appropriate camera to aid our overall goal. To test the UAV's ability to carry the payload, analyses on the affects the payload has on the center of gravity will be performed. If the payload moves the center of gravity too much, causing instability in the UAV, then a different payload will need to be selected. These calculations can be performed by formulating simple moment equations.

The primary driving force behind the objective of light-weighting a UAV is to increase the flight time. This is not a function of our system but is critical to meeting our objective. The metric that will be used to validate the flight time, or endurance, of the UAV will be time. The target that is paired with this metric is to increase the flight time to be greater than or equal to 60 mins. Flight time is a quality of a UAV that is influenced by many factors, the speed the UAV is operated at, the battery charge, etc. To obtain this target, we investigated the listed flight times of multiple drones. The typical flight time of a Quadrotor drone is shy of 30 minutes (Wales, 2020). Some advanced fixed wing mapping drones can operate in the air for over an hour, nearly 90 minutes (Why Fly A Fixed-Wing Drone, 2019). So, having the endurance of our UAV being at least 60 minutes will allow our UAV to outperform quadrotor drones that are extremely popular and be competitive with other fixed wing drones. To validate whether this target is met, tests will be performed to investigate the battery life while electrical components of the UAV are run. Once a physical prototype is developed, timing the actual flight time of the UAV in the air can also be used to validate this target. If the UAV operates for 1 hour or longer, the UAV has met its endurance target. If this target is not met, design changes will be made to the UAV to ensure it is met while maintaining the lightweight project objective.

1.5 Concept Generation

In order to develop the best product and meet our objective, the team underwent a concept generation session. In this session, multiple concept generation techniques were used.

Our goal is to lightweight the Believer 1960mm, a commercially available mapping UAV, and through brainstorming and other methods, we developed concepts to successfully do so.

To develop many of the concepts, the team took a biomimicry approach to brainstorming. This is when you think of your project in a way that relates to nature. What in nature represents aspects or a solution to your problem? For us, we looked at birds. Some birds can fly long periods of time since they have large wingspans that generate lift as they glide in the air. However, in general, birds have very light weight bones. If we can develop a structure similar to the bone structure of birds, that would help us reach our objective greatly.

Another approach we took to develop concepts was the anti-problem approach. This style of brainstorming is when the team thinks of the opposite of the problem. For us, that would be looking at making the UAV heavier. What can we do to make the UAV heavier? Well, a big heavy aspect of the UAV is the battery and electrical system. So, from there, we reverse the question and focus back to our goal of light weighting. We can develop a lighter UAV by reducing the weight of the battery and electrical system.

A third approach Team 518 took to generate concepts was to take an approach similar to a morphological chart. We took our systems and analyzed the current components that exist in the UAV. We have an electrical system, made of batteries, controllers, and receivers. We have a flight system, made of motors to drive the plane through the air and control the ailerons. We have a support system that holds the plane together. And we have a payload system made of a camera to capture the necessary data. Analyzing these subsystems individually, we can look at how to light weight each one and then combine these to get an overall reduction in weight. One example of light weighting the flight system is by improving the propellor design. Also, analyzing the support structure, using a more efficient rib structure may allow us to reduce the weight of the supports while maintaining the needed strength.

After brainstorming, we had 100 concepts listed. As a team, we were able to narrow these down to a total of eight concepts. Five of these concepts are medium fidelity concepts and three of them are high fidelity concepts. The medium fidelity concepts are listed in the table below:

Concept 1.

Regenerative Power Source: Utilizing a battery that charges as the device flies can eliminate the need for a large battery. This may extend the flight time and light weight the UAV

Concept 2.

Generative Design: Utilizing generative design programs in CAD programs we can create optimally designed parts for the UAV. Generative design eliminate waste material by taking in parameters set by the designer. It would reduce the weight of parts but retain the structural qualities.

Concept 3.

Honeycomb Structures: Using honeycomb shaped structures can help reduce the weight of solid parts. By making parts hollow and keeping rigidity, the UAV would be lighter but retain the needed structural qualities.

Concept 4.

Electrical Components Used as Support: This concept implies that the wiring of the electrical system would also have a structural purpose. By having a single component serve two purposes, the needed strength of other components is less, and the weight of the UAV is reduced.

Concept 5.

Complete Wing Design: This idea assumes that redesigning the fuselage and wings of the UAV to resemble the B-2 Stealth Bomber can help reduce the weight of the UAV. By eliminating the long fuselage, the weight can be reduced, and the entire body of the UAV now creates lift, instead of the wings and tail alone.

Concept 6.

LW-PLA Constructed Parts: Recreating parts of the UAV using additive manufacturing can help reduce the weight of the UAV. LW-PLA is a new 3D printing filament that expands when printing at certain temperatures making it extremely lightweight.

Concept 7.

Lighter Electrical Components: The electrical components of the UAV are the heaviest parts. Implementing smaller batteries and motors will help light-weight the UAV. If the weight is reduced, the UAV won't need as much power and a smaller battery will be needed.

Concept 8.

Improve Propeller Construction: Propellers made of a lighter material save weight from the overall UAV. Also, with less rotating mass, the lighter propellers don't need as much energy to turn and help meet the project objective.

1.6 Concept Selection

Once the concepts were generated, the next step was to select the best concept to meet our objective. To do so, the team narrowed down the medium fidelity concepts, based on feasibility and predicted best results, to just two. These were then combined with the three high fidelity concepts to be analyzed and selected as the best concept. The analysis techniques used to select the best concept were a House of Quality, iterations of Pugh charts, and an Analytical Hierarchy Process (AHP) examination. Each of these analysis techniques analyzes how well the concepts meet the project objective. The end goal is to use these techniques to find the concept that best accomplishes the project objective.

Table 3 *House of Quality*

House of Quality		Engineering Characteristics										
Improve Direction												
Units		Kg	Sec	m	m	g	N	n/a	m/s	m	m	deg
Customer Requirements	Importance Weight Factor	Overall Weight	Endurance	Wingspan	Length	Payload Weight	Wing rigidity	Material Durability	Velocity Control	Altitude	Signal Range	Payload Control
UAV constructed of lightweight materials	7	9	7	5	7		7	7	3	3	1	1
UAV implements previously purchased components	3	1				5					1	3
UAV takes off and lands assisted or unassisted	1				3			5	7	1		
The UAV is of the fixed wing style	3	3	9	9	1		9		3	5		3
The UAV has a payload	6	5	5		3	9	1		5	1	1	7
The UAV uses outsourced components	1					9					3	3
The UAV is smaller than double the reference drone	3	7	1	3			1		1		1	
The UAV is category 1	4	7				7			3	9		
Raw Score	905	154	109	71	73	106	85	54	82	79	22	70
Relative Weight %		**17.02**	**12.04**	**7.85**	**8.07**	**11.71**	**9.39**	**5.97**	**9.06**	**8.73**	**2.43**	**7.73**
Rank Order		**1**	**2**	**8**	**7**	**3**	**4**	**10**	**5**	**6**	**11**	**9**

The purpose of the House of Quality is to determine the top engineering characteristic by comparing them to customer requirements. The House of Quality contains 11 engineering characteristics as well as customer requirements. These customer requirements were given importance factors based on the binary pairwise comparison table found in appendix D. The 11 engineering characteristics were individually compared to each customer requirement and given a score depending on how much that customer requirement affects each engineering characteristic. The scoring system has 1 being the lowest score and 9 being the highest possible score for each engineering characteristic. We chose the top five engineering characteristics to move forward with in the concept analysis because they best define the project objective. After each individual score was marked down, the scores for the columns were determined by taking the individual score, multiplying it by the importance factor, and finally summing it all up at the end. From our House of Quality our engineering characteristics were ranked in order of importance as follows: overall weight, endurance, payload weight, wing rigidity, and velocity control.

The Pugh Charts below were used to identify the concepts that would be most beneficial in helping us achieve our goal of light weighting a UAV. Pugh Charts compare multiple concept ideas to a known datum based on criteria in the left most column. The criteria consist of the engineering characteristics that were ranked in the House of Quality. A concept is rated (+) if it would meet a criterion better than the datum could. A (-) if the concept would not do better, and an S if it would produce about the same result. The concept with the worst score is eliminated as a viable idea.

The following Pugh Chart stacks our three high and two best medium fidelity concepts against Styrofoam. Styrofoam was chosen as the datum because that is the material the UAV is currently made of.

Table 4 *Pugh Chart Iteration One*

Pugh Chart Iteration One	Datum	Concepts				
Selection Criteria	Styrofoam	LW-PLA Constructed Parts	Lighter Electrical Components	Improve Propeller design	Generative Design	Regenerative Power Source
Overall Weight	**Datum**	S	-	-	+	-
Endurance		+	+	+	+	+
Payload Weight		S	S	-	S	-
Wing Rigidity		+	+	S	S	S
Velocity Control		+	+	+	S	S
# of pluses		3	3	2	2	1
# of minuses		0	1	2	0	2

Most of the concepts in the chart above were able to outscore the datum because they effect different portions of the drone, not just the structure. Styrofoam directly effects the structure and wing design but has a small impact on other aspects of the UAV, like velocity control.

Another Pugh Chart was made using the “Improve Propeller Design” concept as the datum. This datum was chosen because in comparison to Styrofoam, in the chart above, it did not create any noticeable change.

Table 5 *Pugh Chart Iteration 2*

Pugh Chart Iteration Two	Datum	Concepts			
Selection Criteria	Improve Propeller Design	LW-PLA constructed parts	Lighter Electrical Components	Generative Design	Regenerative Power Source
Overall Weight	**Datum**	-	-	+	-
Endurance		+	S	+	+
Payload Weight		S	S	S	-
Wing Rigidity		+	S	S	S
Velocity Control		-	+	S	-
# of pluses		2	1	2	1
# of minuses		2	1	0	3

The results of this Pugh Chart reveal that once again “Regenerative Power Source” will not be the best concept to apply to reach our end goal. It also shows that the “Generative Design” concept will aid our project or, at the very least, it will not hinder it. With the results of this chart, the “Regenerative Power Source” concept can be eliminated as a possible technic for light weighting the UAV.

The last Pugh Chart consists of the remaining concepts, with the "Lighter Electrical Components" concept being used as the datum. By comparing our concepts to each other in this manner, it can be determined which concepts are best to pursue further based on side-by-side comparison.

Table 6 *Pugh Chart Iteration Three*

Pugh Chart Iteration Three	Datum	Concepts		
Selection Criteria	Lighter Electrical Components	LW-PLA Constructed Parts	Improve Propeller Design	Generative Design
Overall Weight	**Datum**	+	+	+
Endurance		S	S	S
Payload Weight		-	S	S
Wing Rigidity		+	S	S
Velocity Control		+	-	-
# of pluses		3	1	1
# of minuses		1	1	1

The datum chosen this time was harder to overcome in the different categories. The electrical components are such an intricate part of a drone that it influences many other functions. The "LW-PLA Constructed Parts" has consistently scored well in the Pugh Charts, as well as the "Improved Propeller Design", "Generative Design", and "Lighter Electrical Components". These are all concepts that warrant further scrutiny in order to obtain the best results possible. However, as discussed prior, parts designed using generative design can be hard to manufacture as the design technique is more advanced than available manufacturing techniques. As a group, we decided to eliminate that concept for that reason as it also does not significantly differentiate itself from the datums it was compared to.

Looking closer at the Pugh charts, the design concepts that performed the best throughout each iteration were the “LW-PLA Constructed Parts” and “Lighter Electrical Components” concepts. Moving forward in the concept selection process, these are our top two candidates.

AHP

The Analytical Hierarchy Process is performed to select the best concept by performing comparisons between the engineering characteristics and the top concepts. This also checks for bias in the concept selection process. To begin, the top 5 engineering characteristics were put into a matrix where they were compared and given a score based on which characteristic is more important in meeting the project objective. This is seen below in Table 11.

Table 7 *Matrix Criteria*

Matrix [c]					
	Overall Weight	Endurance	Payload Weight	Wing Rigidity	Velocity Control
Overall Weight	**1.000**	1.000	0.333	0.200	0.200
Endurance	1.000	**1.000**	0.333	0.200	0.143
Payload Weight	3.000	3.000	**1.000**	0.333	0.200

Wing Rigidity	5.000	5.000	3.000	**1.000**	1.000
Velocity Control	5.000	7.000	5.000	1.000	**1.000**
Sum	15.000	17.000	9.666	2.733	2.543

Once the matrix was solved above, it was then normalized by dividing the weighted value in each box by the sum of that column. This action was performed to make the data more usable and compute the Criteria Weight of each engineering characteristic. This is seen below in Table 10.

Table 8 *Matrix Criteria Weight*

Normalized Matrix [norm c]						
	Overall Weight	Endurance	Payload Weight	Wing Rigidity	Velocity Control	Criteria Weight {W}
Overall Weight	0.067	0.059	0.034	0.073	0.079	**0.06**
Endurance	0.067	0.059	0.034	0.073	0.056	**0.06**
Payload Weight	0.200	0.176	0.103	0.122	0.079	**0.14**
Wing Rigidity	0.333	0.294	0.310	0.366	0.393	**0.34**

Velocity Control	0.333	0.412	0.517	0.366	0.393	**0.40**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	

The following table calculates the Consistency Vector for each engineering characteristic using the Criteria Weight from Table 10. Matrix multiplication between the Criteria Weights and the Criteria Matrix is used to compute the Weighted Sum Vector for each characteristic. That is then used to get the Consistency Vector. These values are noted below in Table 11.

Table 9 *Criteria Consistency Check*

Criteria Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	{Ws}/{W} Consistency Vector
0.31	0.06	5.24
0.29	0.06	4.86
0.69	0.14	4.95
1.76	0.34	5.18
2.16	0.40	5.40

Using the table above to calculate the Average Consistency, the Consistency Index and the Consistency Ratio could be tabulated in Table 12 below. This shows that our decisions made in the Analytic Hierarchy Process do not show bias toward any engineering characteristics since the Consistency Ratio is less than 0.1. This means that going forward, we can use the data from that chart to help us select a concept without worrying about skewed results.

Table 10 *Criteria Bias Check*

Consistency and Bias Check			
Average Consistency	Consistency Index	Consistency Ratio	Is Comparison Consistent
5.127	0.033	0.029	Yes

The process used to get the results from Table 7 through Table 10 was then repeated for each engineering characteristic and giving weights to the three concepts. Using that data, the Final Rating Matrix was able to be computed. This is shown in Table 11 below.

Table 11 *Final Rating Matrix*

Final Rating Matrix			
	Lighter Electrical Components	LW-PLA constructed parts	Improve Propeller design
Overall Weight	0.20	0.60	0.20
Endurance	0.30	0.61	0.09
Payload Weight	0.11	0.63	0.26
Wing Rigidity	0.20	0.34	0.46
Velocity Control	0.72	0.19	0.08

Performing a matrix multiplication of the transpose of Table 11 and the Criteria Weights from Table 8, the Alternative Weights of the concepts were calculated. These can be seen in Table 12 below.

Table 12 *Alternative Weight of Concepts*

Alternative Weight of Concepts	
Concepts	Alternative
Lighter Electrical components	0.401
LW-PLA Constructed parts	0.352
Improve Propeller design	0.242

The alternative values are determined using the Final Rating Matrix in Table 11 and the Criteria Weights in the second column of Table 9. The alternative values reveal the ranking of the concepts compared to one another. The highest-ranking concept from table 12 is the Lighter Electrical Components concept with a .401 ranking. From our Pugh charts, the top two concepts were consistently LW-PLA constructed parts and Lighter Electrical Components. This conclusion matches the conclusion from the Pugh charts. The top two concepts from the iterations of the Pugh charts were the top two concepts in Table 12. Therefore, the Lighter Electrical Components concept is the best concept to meet the project objective.

Selected Concept

Out of all the concepts generated by Team 518 to best meet our project objective, the best concept is to introduce lighter electrical components to the existing UAV. Introducing a smaller, lighter battery and motor can help reduce the weight of the UAV. Using the tools to select the concepts, this was found to be the best concept to lightweight the UAV, increasing the flight time, and providing surveillance data. However, the light weighting process is very iterative. Changing one piece of the design can allow you to reduce the weight in other areas outside of what you directly improved. When we improve the electrical components of the Believer 1960, reducing the weight, we then will not need to have as strong of a support structure for those parts. That allows for weight to be reduced in the support structure. This kind of process and analysis can be applied to many of the UAV's systems.

1.8 Spring Project Plan

The figure below shows the project plan for the spring semester.

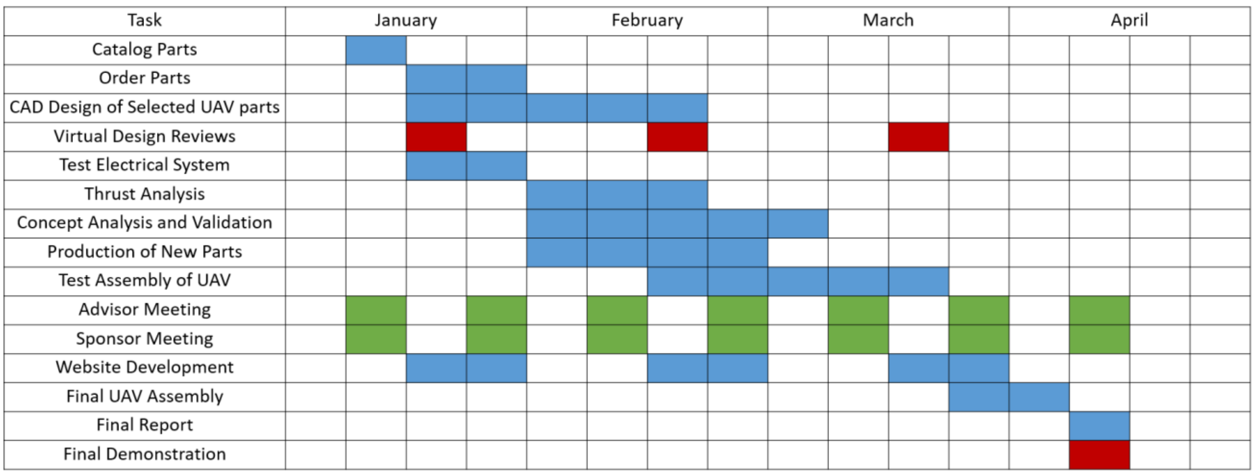

Figure 2 *Spring Project Plan*

Utilizing a Gantt chart, we were able to create a plan to complete our project for the spring semester. The blue boxes are project tasks, the red boxes are design review presentations, and the green boxes are meetings with sponsors and advisors. This plan is to keep us on track and ensure the project is completed by Engineering Design Day at the end of the spring semester.

Chapter Two: EML 4552C

2.1 Restated Project Definition and Scope

Project Description:

The objective of this project is to use multiple light-weighting techniques to reduce the overall weight of a UAV and increase the flight time.

Key Goals:

The key goals of this project are objectives the team intends to meet to accomplish the overall objective. These goals include keeping the UAV lightweight compared to market ready UAV's, ensuring the UAV can be easily transported and operated, and the UAV will provide quality surveillance recordings. These goals can be influenced by and tailored to meet the primary and secondary markets of the product.

Markets:

The markets for this project are those that the lightweight UAV can be used in. These markets include primary and secondary markets. The lightweight UAV is mainly designed to be used in the primary markets, but the members of the secondary markets also have an interest in the product too. The primary market of this project are farmers and members of the agricultural community. Secondary markets for this project include the US Military, infrastructure companies, hobbyists, land surveyors, and teaching facilities.

Assumptions:

For the project, assumptions are made based on the objective. The assumptions allow the designers to meet the objective while not having to designate some parameters. The assumptions will not need to be investigated or verified by the team, as they are assumed to be correct and understood. The assumptions made by the team are listed below.

- The UAV will be operated in Earth's atmosphere.
- The flight conditions are typical of the climates in the United States.
- The UAV is remotely controlled.
- The UAV is category 1, as defined by the Department of Defense.
    - A category 1 UAV has a maximum gross takeoff weight within 0-20lbs, normal operating altitude less than 1,200ft AGL (above ground level), and an airspeed less than 100 knots.
- The UAV will be flown in clear airspace.
- The UAV will follow all state and federal laws.
- The UAV will be flown in a limited space around other equipment, buildings, and power lines.
- The UAV will be used by non-professionals.
- The UAV will remain in the line of sight of the user.

Stake Holders:

The stake holders for this project are those that are directly influenced by the work done to develop the lightweight UAV. These parties have invested resources, interests, or control of the outcome of the lightweight UAV. For this project, the stakeholders are:

- Northrop Grumman
- Dr. Shayne McConomy
- Dr. Lance Cooley

- Senior Design Team 518
- Florida Department of Agriculture
- Keith Dixon (Florida farmer/possible customer)

2.2 Results & Discussion

The UAV that the focus of this project revolves round is the Believer 1960. The believer 1960 is an aerial mapping UAV, constructed of Styrofoam, and has plenty of space for a payload. We chose to stick with this UAV, originally selected by the previous year's group, for ease of work and its availability. The Believer 1960 is pictured below.

Figure 3 *Believer 1960*

Lighter Electrical Components:

From the 2019-2020 Team 518 that originally started this project, we inherited two batteries. The batteries that we worked with were the Turnigy 20,000mAh 14.8v battery and the Lumenier 22,000mAh 14.8v battery. The two batteries are pictured below.

Figure 4 *Turnigy and Lumenier Batteries*

The Believer came with a manual that recommended parts to implement to fly the UAV. The manual recommends the Turnigy battery be used due to its large capacity and voltage rating. The Lumenier battery was the battery selected previously as the lighter battery to replace the Turnigy battery due to it being lighter. The Turnigy battery weighed 1729 grams while the Lumenier battery weighed 1702 grams. This resulted in 27 grams of weight savings and a greater flight time due to the 2000mAh extra capacity. One thing to note about the batteries is the difference in their size and weight from the manufacturer compared to what we recorded. The Turnigy battery was actually smaller and weighed less than what the manufacturer said. The Lumenier battery was bigger and weighed more than what its manufacturer reported. If the manufacturers data was correct, the implementation of the Lumenier battery would have a far greater impact on the weight savings. At first, we noted the Lumenier battery would reduce the weight of the UAV by 175 grams. That is a large difference from the actual 27 grams it saved.

The second part of the electrical system that was analyzed to be replaced by lighter components was the motors. The motors that were recommended for the Believer were the SunnySky X2814 900kv motors. These motors weighed 110 grams each but are suited for large drone applications like the believer. Through research we decided to replace these motors with the iFlight XING X2814 880kv motors.

Figure 5 *iFlight XING x2814 880kv Motor*

These motors rotate at nearly the same speed, are also suited for large drone applications, and weigh just 91 grams per motor. Utilizing these motors, we were able to save 38 grams. All in all, switching to lighter electrical components reduced the weight of the Believer 1960 by 65 grams.

Improved Propeller Construction:

The propellers are a crucial part of the UAV. They provide the thrust needed to propel the Believer through the air. The original motors recommended 3 different propellers choices to be used. The recommended propellers were 11x8, 11x7, and 11x5.5 inch propellers. The qualities of each propeller are shown in the table below.

Table 13 *Propeller Characteristics*

	APC 11x8	APC 11x7	APC 11x5.5
Mass(g)	41.10	39.97	22.96
Thrust(gf)	2020	2020	1950
Current Draw(A)	37.5	34.4	29.3
Power Consumption(W)	555	509.12	433.64
Efficiency(gf/W)	3.64	3.97	4.50

Utilizing the propeller data, when matched with the original motors, the APC 11x5.5 inch propellers were chosen due to their weight, power consumption, efficiency, and thrust capabilities. With these selected as a baseline propeller, we selected the Quanum 11x5.5 inch carbon fiber propellers to replace the APC ones.

Figure 6 *Quanum Carbon Fiber Propellers*

These lighter carbon fiber propellers weigh just 9 grams each, saving 28 grams in total compared to the APC 11x5.5 inch propellers. These lighter propellers also consume 61% less energy from the motors, conserving energy to be used elsewhere.

LW-PLA Constructed parts:

The third light-weighting method that was implemented on the Believer 1960 was utilizing LW-PLA to make replacement parts on the UAV. The LW-PLA is 1/3 the density of traditional PLA resulting in lighter components. We recreated most of the plastic, wood, and metal parts of the UAV out of the LW-PLA resulting in direct weight savings. We also made geometry changes to some of the larger parts to maximize the weight savings capabilities of the material. The initial weight of the UAV was 3812.6 grams while the final weight of the UAV was 3436 grams. A total of 376.6 grams was saved with the three weight reduction techniques. The lighter electrical components and the lighter propellers saved 93 grams. The other 283 grams of weight savings mainly came from the LW-PLA parts that replaced original ones. However, optimizing the amount of glue applied and the length of wires in the electrical system is a part of that 283 grams.

Thrust Testing

To ensure our propeller and motor selections would meet the performance requirements of the UAV, static thrusts tests were performed. A static thrust stand was used to measure the thrust output of the original and new motors. However, APC 11x4.5 inch propellers were used in the tests since there were no APC 11x5.5 inch propellers in the lab and the Quanum propellers we ordered never arrived. The tables below show the results of the thrust tests.

Table 14 *Original Thrust Data from Manufacturer*

SunnySky X2814 900KV	
APC 11x5.5	**Thrust (N)**
100% Throttle	19.123

Table 15 *Thrust Data from Original Motor Test*

SunnySky X2814 900KV	
APC 11x4.5	**Thrust (N)**
100% Throttle	23.257

Table 16 *Thrust Data from New Motor Test*

iFlight XING 2814 880KV	
APC 11x4.5	**Thrust (N)**
100% Throttle	19.735

The thrust tests proved that the new motors would work on the Believer 1960. Even though they produce slightly less thrust than shown in the original motor test, the test performed on the new motors showed that they supply more force than what is stated by the original motor manufacturer. The 11x5.5 inch carbon fiber propellers never arrived to be tested but with a more aggressive pitch than the propellers used in testing, they would provide a greater amount of thrust and be suitable for this application.

LW-PLA Part Testing

Stated previously, the geometry of most of the parts that were replaced by LW-PLA constructed ones was never changed. However, the geometry of the wing and empennage connecting pieces were changed. The original wing connecting pieces are pictured below.

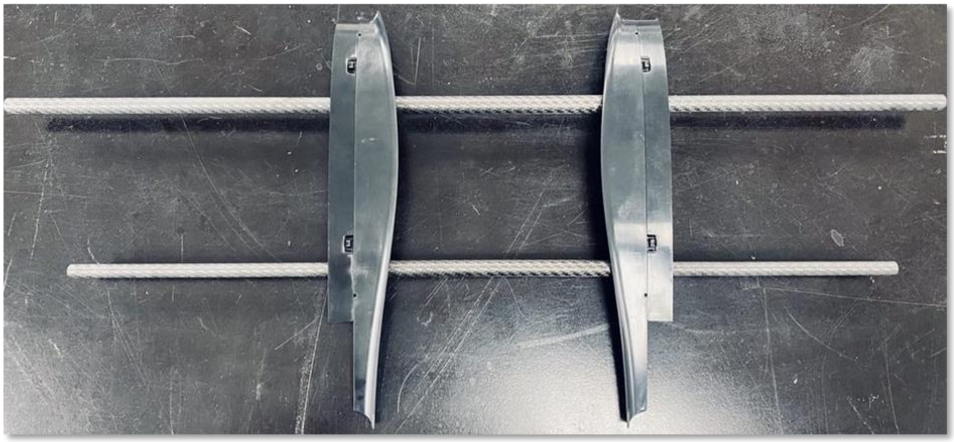

Figure 7 *Wing Connecting Parts*

The wing connecting pieces and the empennage connecting pieces are nearly identical, but the empennage pieces are just a little smaller. We started by recreating the original pieces in Creo.

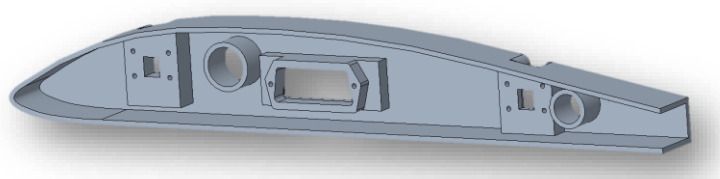

Figure 8 *Creo Model of Wing Connecting Parts*

The result of reprinting this piece out of LW-PLA was that there was little weight savings for such a large part. After analyzing the pieces further, we determined that the strength of the mounting pieces, what holds the wings and tail stabilizers to the fuselage, really comes from the carbon fiber rods that the thread through. This meant that significant geometry changes could be made without sacrificing the structural integrity of the UAV. To determine how much material could be taken off of the pieces, we tested the strength of the LW-PLA when glued to a piece of

Styrofoam. A 1-inch by 1-inch square was glued onto a test piece of Styrofoam with a hook threaded through it. This is pictured below.

Figure 9 *LW-PLA Strength Test*

Pulling on the test piece of LW-PLA with a scale resulted in a failure at 1700 grams. From that data, the needed surface area for the wing and empennage mounting brackets was calculated using a ration of surface area to weight. The minimum surface area needed was calculated to be 0.258 square inches. The existing surface area that glues to the fuselage and wing was already greater than that amount, 0.37 square-inches. This meant that no additional material would need to be added to the connecting pieces where they glue to the Styrofoam and connect together. The final design of the wing connecting pieces and the empennage connecting pieces is pictured below.

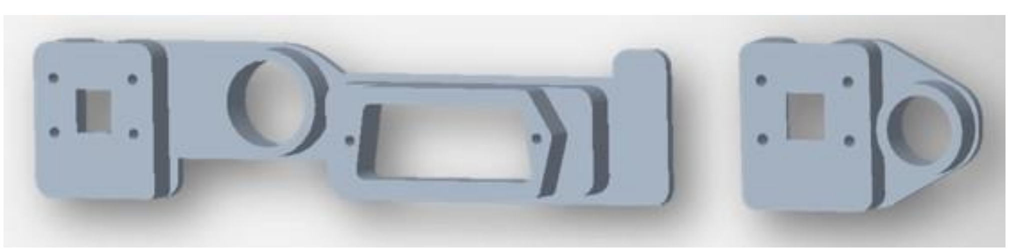

Figure 10 *Final Design of Wing/Empennage Connecting Pieces*

The new design retains the holes for the carbon fiber rods to maintain strength, the hole for the wiring harnesses to connect, and the locations of the hooks that snap the two sides together. The drastic geometry change had a significant impact on the weight savings.

Energy Analysis

The energy consumed by the UAV before and after the weight savings was analyzed. The first part of this process was to analyze the force that act on the UAV. The force of lift, the force of drag, the force of thrust, and the force of gravity all act on the UAV as it flies. These are pictured below.

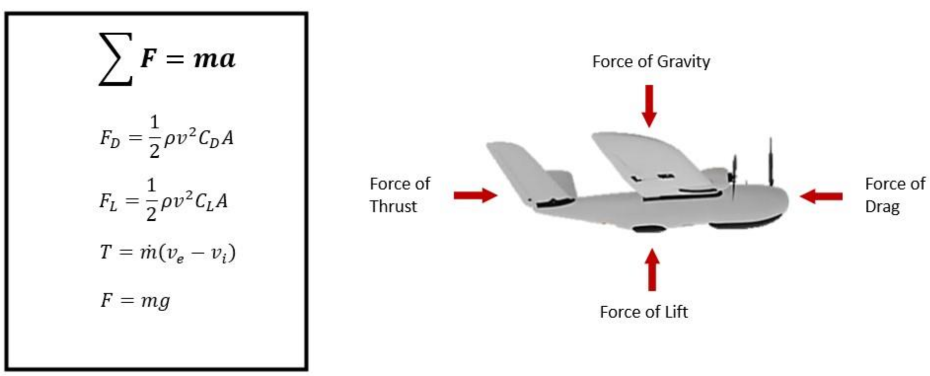

Figure 11 *Forces Acting on UAV*

The forces are used to analyze the energy consumed by the UAV. The energy can be calculated by taking the integral of the force times the velocity over time.

$$E = \int Fv\,dt$$

However, a velocity profile was needed. The highway fuel efficiency test driving velocity was taken and modified for this purpose. The original and modified velocity profiles can be seen below.

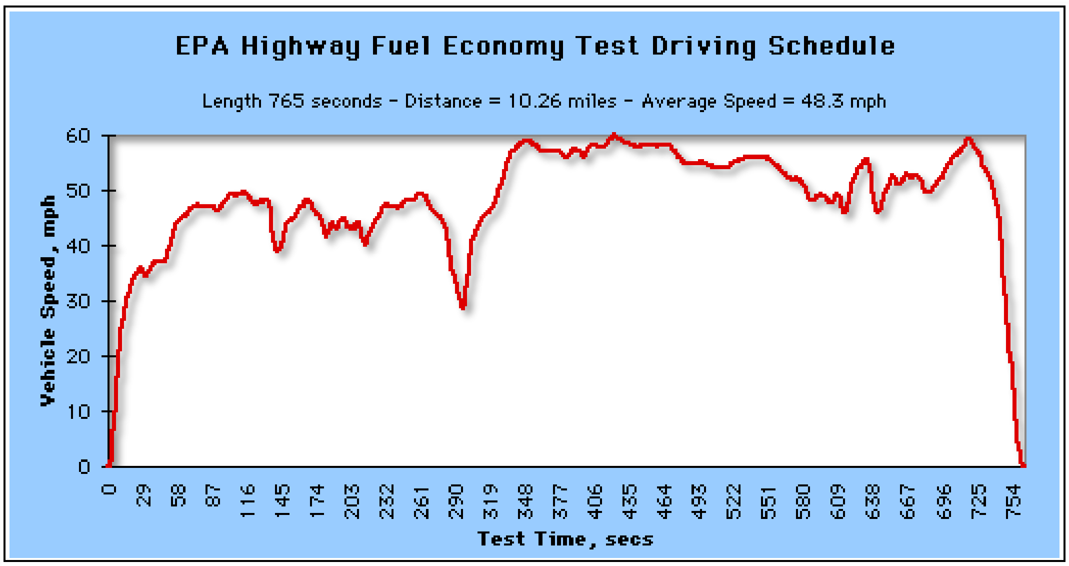

Figure 12 *Highway Fuel Economy Test Velocity Profile*

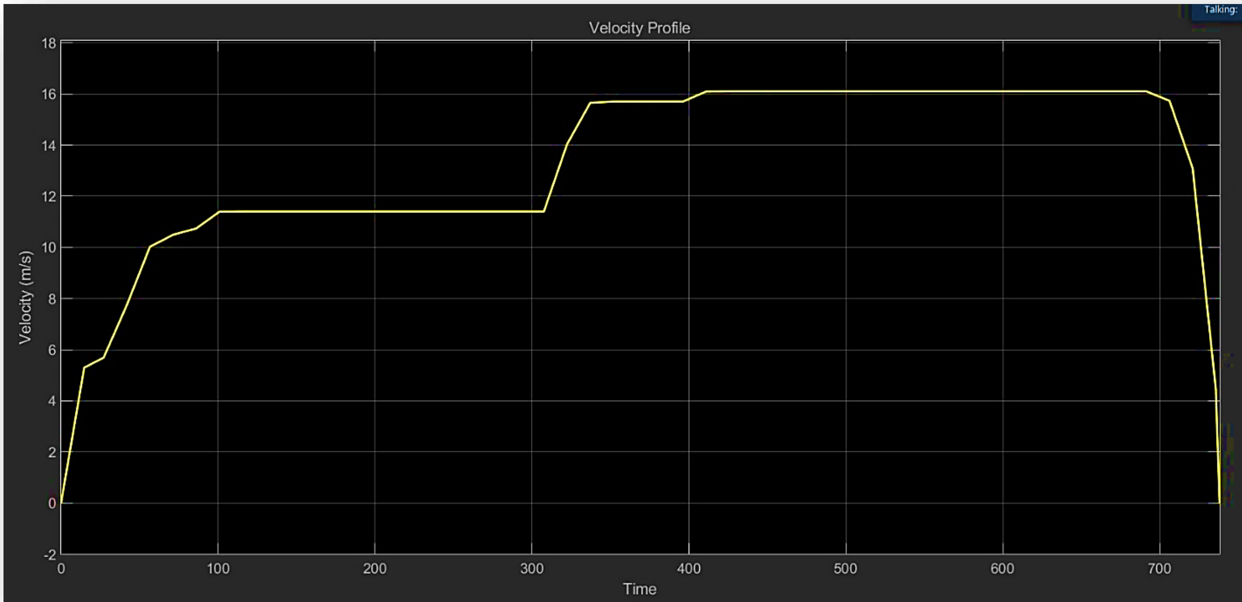

Figure 13 *Modified Velocity Profile*

Using this velocity profile and the forces acting on the UAV, a Simulink model was created to analyze the energy consumption. The figure below shows the energy consumption of the UAV over time.

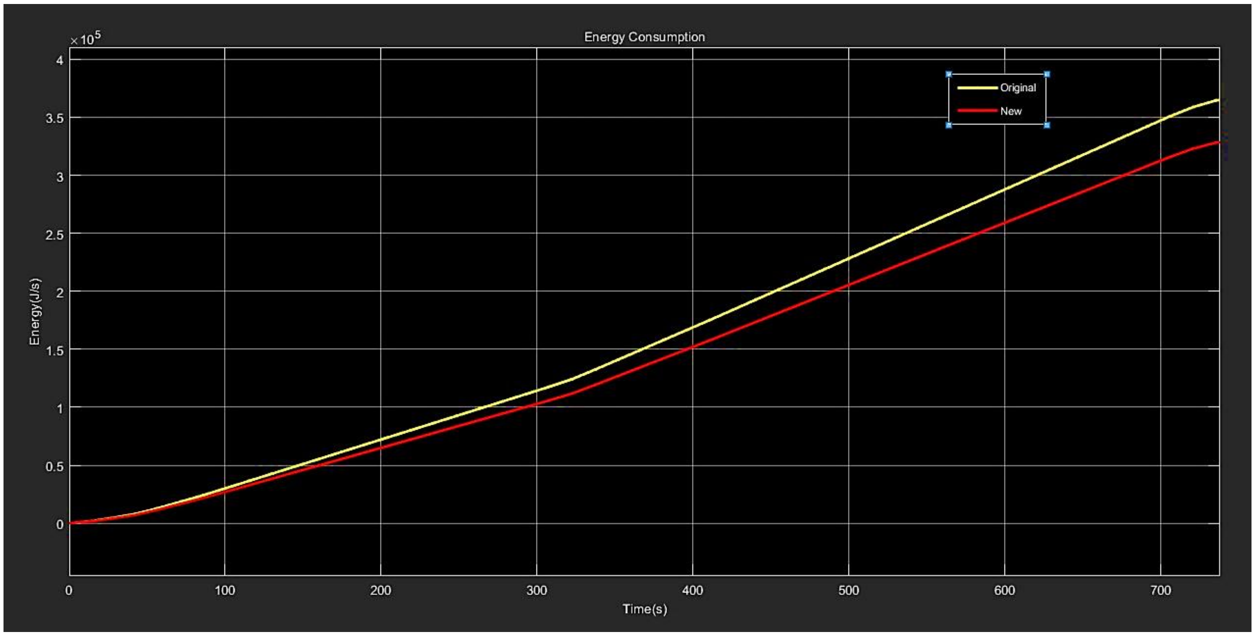

Figure 14 *Energy Consumption of the UAV*

The yellow line is the energy consumed by the UAV based on the original weight. After the 376.6 grams of weight savings was applied, the red line was plotted. The red line shows the energy consumed after the weight reduction techniques were implemented resulted in an energy decrease. The weight loss resulted in an energy consumption decrease of 10%.

After the change in weight was manipulated, a sensitivity analysis was done to see where future energy savings could come from. The theoretical changes and the amount of energy they save are shown in the table below.

Table 17 *Future energy Savings*

Design Changes	Energy savings
800g weight savings	20%
1900g weight savings	49%
Improve CL/CD ratio to 14	0.3%
Increase CL to 1.5	0.49%
Increase CL to 2(double)	1.85%
Decrease CD to .06	0.03%
Decrease CD to 0.04(half)	0.03%

Increasing the weight reduction to 800 grams and then 1900 grams shows how much weight plays a role in energy savings. Also, it is important to note that there is almost a 1 to 1 ration of weight savings percentage to energy savings percentage. The 376.6 grams we removed from the UAV was nearly 10 percent and the energy consumption decrease due that was also 10 percent. When the coefficients of lift and drag were theoretically changed, they had a much smaller impact on the energy consumption.

2.3 Conclusion

The light weighting process is very difficult. As engineers, we ran into problems that we did not expect. Some methods of weight reduction were better than expected and some did not work as well as we had hoped. Through completing this project, we learned the effects of weight reduction on an aircraft and how to best approach the light weighting process. It is most effective to implement multiple techniques to reach your weight savings goal. However, the iterative process that weight reduction is, is much more challenging than one may expect. With all of that being said, utilizing our three selected weight reduction techniques, we were able to save close to 400 grams from the UAV. We would have hoped for better light weighting results from the electrical system, specifically the battery, but we gained better than expected weight savings from the LW-PLA parts. These weight savings techniques also led to a decrease in energy consumption of 10 percent. Pictured below are some images of the completed Believer 1960 after the implementation of our light weighting methods.

Figure 15 *Complete Assembly of the Believer- Front*

Figure 16 *Complete Assembly of the Believer- Rear*

2.4 Future Work

Ideally, we would have liked a little more time to do some further testing on the UAV. The carbon fiber propellers never arrived so we were unable to test and implement them. Also, we would have liked to fly the Believer after construction was finished. There would have been many legal hurdles to jump through in order to make that happen. However, if we had an additional semester to work on this project, we would begin by finding a location to fly and perform test flights. We would then analyze the flight time and performance of the UAV. Additionally, we would like to reassess the light-weighting methods. We would want to investigate further battery changes due to the new decrease in energy needed. Lastly, we would want to look at implementing new weight reduction techniques. We want to look at possible aerodynamic changes and material changes. The material changes would likely be implementing exotic materials (titanium, carbon fiber, etc.) that are lighter than the current ones used on the UAV.

2.5 References

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Appendices

Appendix A: Code of Conduct

Mission Statement

The mission of team 518 is to provide an innovative solution for Northrop Grumman that is both cost effective and sustainable. Team 518 strives to not only meet but exceed the standards set forth by our customer.

Team Member Roles

Ethan Hale: Manufacturing and Systems Engineer

The role of the manufacturing engineer is to ensure a high-quality product is created. The product is ensured to meet design requirements and be operational. Part of the role as the manufacturing engineer is also to create and integrate the many systems (mechanical and electrical) of the product. The manufacturing engineer also strives to complete the product in the most cost-effective manner.

John Storms: Test Engineer

Responsible for warranting high quality of the product through extensive testing and data collection from numerous scenarios through digital/real-world simulations. Team collaboration is essential in communicating the necessary changes to make through found errors/flaws and create testing plans.

Maxwell Sirianni: Flight Dynamics Engineer

The role of the flight dynamics engineer is that they are responsible for the dynamics behind the performance and control of the vehicle during flight. This role also includes determining the necessary forces needed to keep the vehicle stable in flight, while also relaying important information and equations to design and software engineers.

Joseph Ledo-Massey: Design Engineer, Project Manager

The role of the design engineer is to create new designs based on research performed by the team and other sources. Working in parallel with all team members, the design engineer utilizes CAD to conceptualize an innovative product that meets all the requirements put forth by the customer. The project manager is responsible for managing the schedule, budget, and progress of the project.

Jackson Dixon: Supply Chain Engineer

As the supply chain engineer, it will be my responsibility to assist the other members in completing their assigned tasks by researching current products and materials available on the market. This will include contacting the appropriate providers or representatives to get the supplies and parts needed. Also, making sure the needed supplies will arrive on time or finding an adequate substitute.

Role Statement:

As for duties that are not specifically assigned to an individual, the team will discuss and agree who is to perform those duties. These discussions will take place during the daily team meetings and each team members workload will be taken into consideration. The duties may require knowledge beyond an individual's current experience, but proper research is to be done to ensure the quality of the product is maintained.

Communication

The team will communicate virtually through platforms such as Zoom, email, texting, calling, Base Camp and GroupMe. During each meeting, notes will be taken to ensure a record of work is established. It is expected of all team members to respond to calls, texts messages, and emails in a timely manner (24-hours).

Dress Code

The dress code will be shirt and tie when presenting a formal presentation. Shirt and tie must have the colorway of blue, white, black, grey, or neutral color. When talking to the Northrop Grumman sponsor and our academic advisor, collared shirts and khakis are to be worn.

Attendance Policy

Team members must attend all team, sponsor, and advisor meetings, except for a planned absence that has been communicated to all other team members. A 24-hour notice of absence is required, and each team member is expected to show up at least 5 minutes early to every meeting. Excused absences include, but are not limited to, what is listed in the EML 4551c syllabus. Attendance will be recorded in the meeting notes of every gathering. If any issues arise regarding attendance, they will be first discussed within the group. If attendance issues continue to persist then they will be brought to the attention of Dr. McConomy.

Statement of Understanding

By signing this document, the members of team 518 agree to all the above statements and will abide by the code of conduct set forth by the group for the remainder of the project.

Name	**Signature**	**Date**
Ethan Hale	*Ethan Hale*	9/3/2020
Max Sirianni	*Max Sirianni*	9/3/2020
John Storms	*John Storms*	9/3/2020
Joseph Ledo-Massey	*Joseph Ledo-Massey*	9/3/2020
Jackson Dixon	*Jackson Dixon*	9/3/2020

Appendix B: Functional Decomposition

Table 18 *Major Functions Cross Reference Table*

	Communication	Flight	Power	Surveillance	Structure
Communication	x	x	x	x	x
Flight	x	x	x		x
Power	x	x	x	x	x
Surveillance	x		x	x	x
Structure	x	x	x	x	x

Table 19 *Major Functions and Subfunctions Cross Reference Table*

	Communication	Flight	Power	Surveillance	Structure
Receive Commands	x	x	x	x	
Flight Feedback	x	x	x		
Send Video Feed	x			x	
Accelerate	x	x	x		x
Decelerate	x	x	x		x
Adjust Roll, Pitch, & Yaw	x	x	x		x
Power Flight Controls	x	x	x		x
Power Payload	x		x	x	x

Record Visual Data	x		x	x	
Orient Payload	x		x	x	x
Bolster Weight		x			x
Generate Lift		x			x
Store Hardware					x
Couple Payload		x		x	x

Appendix C: Target Catalog

Table 20 *Targets and Metrics for UAV Functions*

Functions	Metrics	Targets
Receive commands	Range	1400 meters
Flight Feedback	Range	1400 meters
Send Video	Bandwidth	10 Mbps for HD feed at 25 FPS
Accelerate	Accelerate from cruising speed	2 m/s^2
Decelerate	Decelerate from cruising speed	2 m/s^2
Adjust Roll, Pitch, & Yaw	Control Ailerons, Elevators, & Rudders	90° range of motion
Power Flight Controls	Voltage supplied by battery	12.0 V
Power Payload	Voltage supplied by battery	12.0 V
Record Visual Data	Video Quality	2.1 Megapixels
Orient Payload	Fixed Position Perpendicular to ground within:	2°

Bolster Weight	Support moment due to wing	1.128N/m
Generate Lift	Airfoil produces greater lift force than gross weight	54 Newtons
Store Hardware	Volume	$0.001964m^3$
Couple payload	Mass of payload supported	600g
Endurance	Overall Flight Time	60 mins
Transported Easily	Disassembled Dimensions: (L x W x H)	1100mm x 2000mm x 200mm
Battery	Capacity	22,000 mAh
Start of mission	Take off force	9 Newtons
Cruising Speed	Constant Velocity	$20 m/s^2$

Appendix D: Operation Manual

The purpose of this project was to implement weight reduction techniques to reduce the weight of a fixed-wing drone and increase the flight time. To do so, our team chose to utilize three light-weighting techniques to meet the objective. The drone we chose to use was the Believer 1960mm. This is an aerial mapping drone, suited for our market. It can be used for surveying fields, counting cattle, and checking crop conditions. The large fuselage allows for a camera or other payload to be used.

The first way we chose to reduce the weight was to use lighter electrical components. The heaviest electrical component is the battery, so we began there. Using a lighter battery, we were able to save weight and extend the flight time as the new battery had a greater electrical capacity. After the battery, we expanded the weight reduction of the electrical system by analyzing the motors. Implementing lighter motors, with similar speeds helped us cut weight and stay within the recommended flight specifications.

The second way we chose to reduce the weight was to recreate parts of the UAV with LW-PLA, which is a lightweight 3D printing filament. The heat that the filament is printed with causes the filament to expand, reducing its density. Utilizing a less dense material means parts of the same size weigh less. Along with this, we made geometric changes where applicable in order to reduce the weight of the pieces even more.

The third way we chose to reduce the weight of the drone was to implement lighter propellers. For the new propellers, we chose to utilize carbon fiber propellers. The material change allowed us to cut the weight of the propellers in half compared to the original.

Utilizing these three techniques, we successfully reduced the weight of the Believer 1960mm drone and increased the flight time. The following details how to assemble, operate, and fix the drone. This resource will help you operate and repair the drone if needed.

Power system

The electrical system was the first component of the drone that was analyzed. To light weight this part of the drone, we started with the battery. The original battery was a Turnigy 20,000mAh, 4-cell, 14.8V, and 12-24C battery. We replaced it with a Lumenier 22,000mAh, 4-

cell, 14.8V, 12-24C battery. If the battery were to go bad, you would need to replace it with a high mAh capacity, 4-cell, and 14.8V battery so that the system would operate at the same specifications. This battery saved nearly 30 grams from UAV while extending its capacity by ten percent.

If the battery were to die or run low on power, you will need to charge the battery using the LiPo battery charger in the lab. The charger will need to be set at the correct voltage settings. To reach full charge, the battery will need to remain on the charger for a couple of hours.

Motors

The DC motors recommended by the Believer handbook are the SunnySky X2814 900KV motors. We replaced these with the iFlight XING X2814 880KV motors. These motors are the only source of propulsion for the drone, so they are essential. If the motors were to break, you would need to replace them with a motor that is in the 880-1000KV range. Staying close to the recommended motor specs ensure the motors supply enough thrust and can turn the large propellers required for this aircraft. If you wish to have higher KV motors (higher RPM), then additional weight will need to be taken out and the propeller size will need to decrease.

Propellers

The propellers for this UAV are 11x5.5-inch Quanum carbon fiber propellers. Using these propellers saved weight and energy, leading to a greater flight time. Other propellers that can be used are 11x8, 11x7, 11x5.5, and 11x4.5-inch APC propellers. In order to test the thrust generated and to see if the new motors we selected would be suitable, we had to test with APC 11x4.5-inch propellers since the carbon fiber ones did not arrive in time. However, these propellers proved to provide enough thrust and still saved weight from the APC 11x5.5-inch propellers.

The larger pitch propellers were not selected since they consumed more energy and weighed more while providing just slightly greater thrust. The thrust increase was not worth the weight increase.

Wiring

The wiring is one of the more complex parts of the drone. The wiring diagram below does a good job simplifying the many connections needed. Please refer to this diagram for any wiring needs.

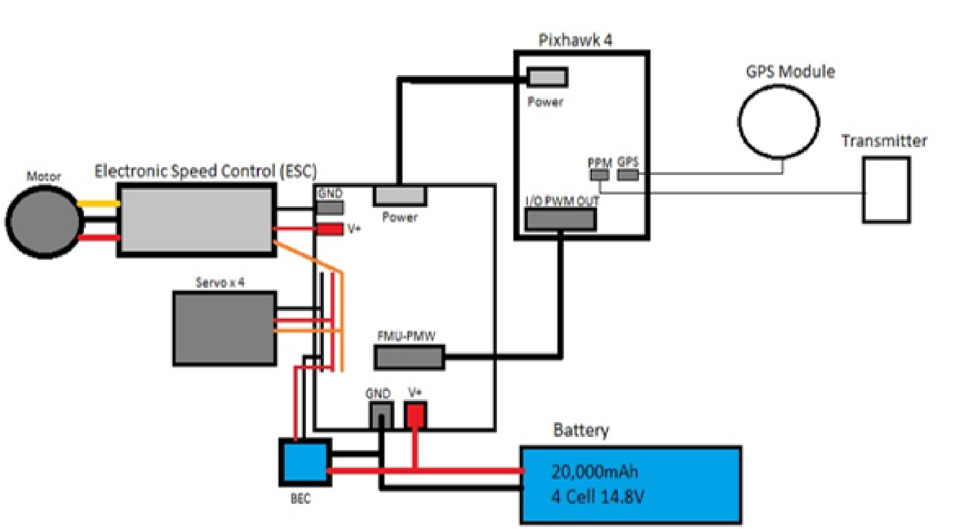

Figure 17 *Wiring Diagram 1*

This diagram shows how the electrical components are plugged into the power control board, the battery, and the flight controller. If anything becomes unplugged, this can be referred to. A single motor is shown in the diagram but the other one gets wired the exact same. Please see the pictures below for any additional help.

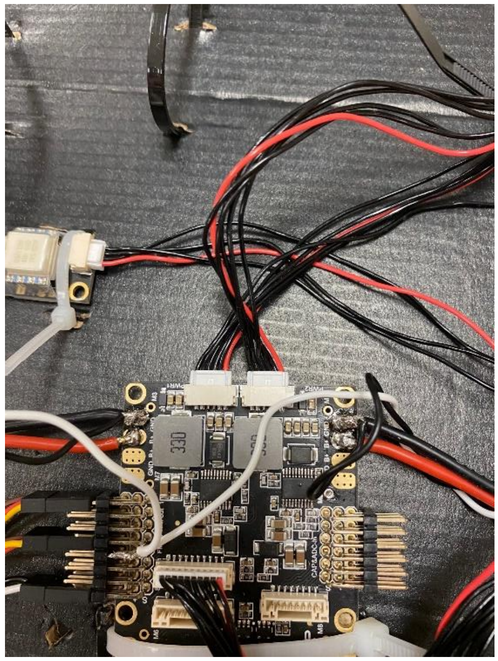

Figure 18 *Power Control Board Wiring*

The thick black and red wires on the top left and right corners of the power control board are the positive and negative terminals of the speed controllers and connect to the motors. The first four pins on the left side show two of the servo motors plugged in. There are two empty spots between them for the other two servo motors to go into. The first two pins are for the servos in the wings that control the roll and the second two are for the servos in the tail that control pitch and yaw. The two plugs at the top of the board are for power 1 and power 2 that have corresponding slots on the PixHawk flight controller.

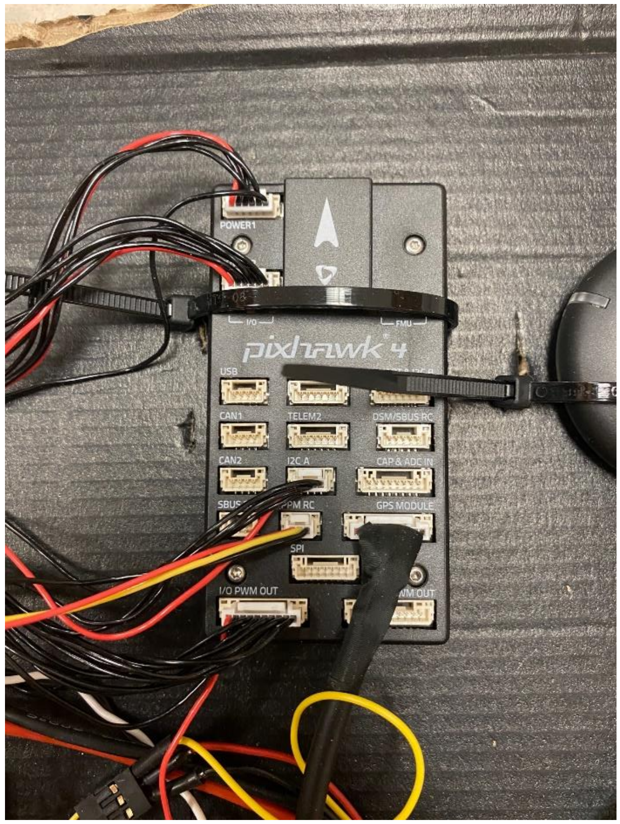

Figure 19 *Flight Controller Wiring*

This figure shows how the connections are managed on the PixHawk flight controller. The top two are the two power connections that connect to the top of the power board. The wires in the middle connect to the receiver for the controller and an air speed sensor. The thick black wire on the right is the connection to the GPS module of the flight controller. Lastly the wire at the bottom left connects to the PWM on the power control board.

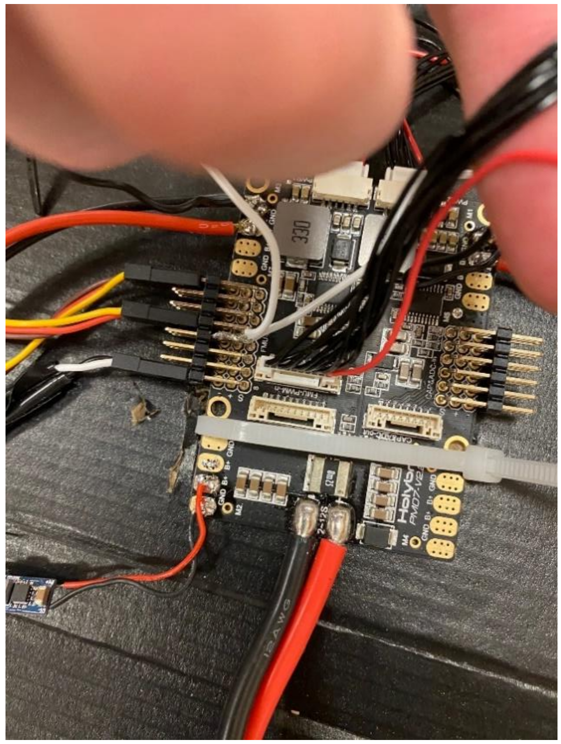

Figure 20 *Power Leads*

This figure shows the bottom half of the power control board. The plug in the middle connects to the PWM on the flight controller and the power and ground leads on the bottom connect to the battery.

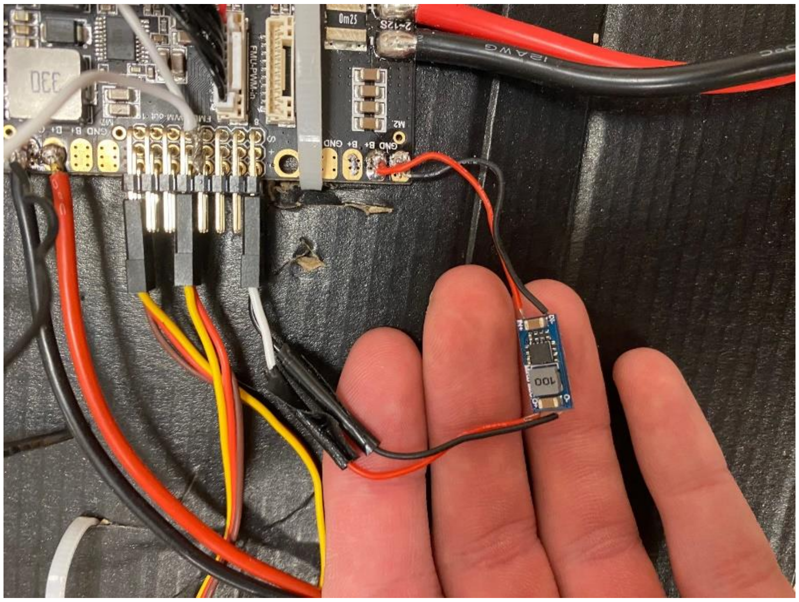

Figure 21 *Battery Eliminator Circuit*

This figure shows the BEC (battery eliminator circuit). This is what enables the servos to get power directly from the battery. It is located on the bottom left of the power control board and can be seen in the original wiring graphic above.

If additional accessories, like cameras, transmitters, and sensors, need to be added to the system, you can visit: https://docs.px4.io/master/ for help. This is the Pixhawk information center and contains everything needed to setup the flight controller to your specifications. For any additional help, a quick Google search about the Pixhawk 4 and the flight controller software, QGroundControl, will result in lots of help. This software and flight controller are open source materials and there are lots of forums on the internet that can be very helpful.

CAD

The following CAD images are examples of the parts that were recreated using LW-PLA. If any of the printed parts break, the original parts that came with the Believer can be referenced to replace them.

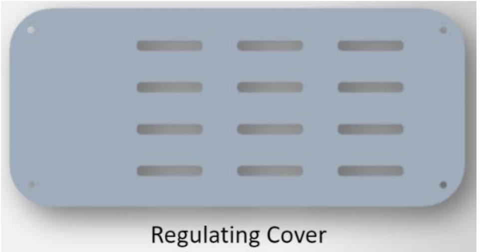

Figure 22 *Regulating Cover*

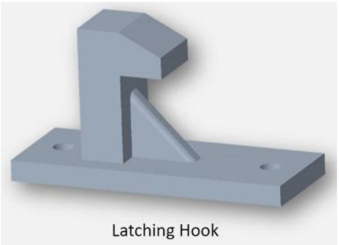

Figure 23 *Latching Hook*

Some parts were completely redesigned to make as light as possible. These consisted of the motor installing base, battery fixing board, servo installing bases and covers, empennage connecting brackets, and wing connecting brackets. These parts are largely based on the original parts and can be duplicated if examined while using the original as a reference. The wing and empennage connecting brackets are nearly identical, just differ in size. The figure shows the original and the new geometry of the wing connecting bracket.

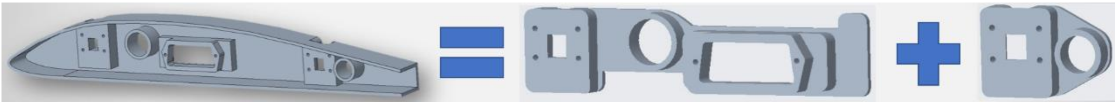

Figure 24 *Wing Connecting Part Design*

If any parts CAD files are needed to replace broken parts, do not hesitate to contact Joseph Ledo-Massey or Jackson Dixon.

3D Printer Settings

The following table shows the 3D printer settings we used to recreate the various pieces of the drone. These settings are essential to replicating the pieces identically. We used the Innovation Hub on FSU's main campus for all of our 3D printing needs. Due to the kind of material LW-PLA is, the repeatability across different kinds of 3D printers is limited. If you use the Dremel 3D45 printer at the innovation hub and the settings below, the parts should be identical to what is currently on the drone.

Table 21 *3D Printer Settings*

Print Settings	
Nozzle Temperature	240 C
Flow Rate	50%
Layer Thickness	0.2 mm
Shell Thickness	0.8 mm
Infill	0%
Print Speed	40 mm/s
Part Cooling	0%

Drone Parts

There are many places to get the necessary parts to fly, improve, or repair the drone. The listed websites below are sources for other batteries, motors, propellers, and many other parts:

https://www.getfpv.com , https://hobbyking.com/en_us

One tricky part of the Believer 1960 is the assembly of it. The drone comes with a manual with performance specifications and a parts list. However, the manual does not give assembly instructions or details. In order to assemble the drone, we referenced an online forum. The link below is an assembly thread written by a user named Arxangel:

https://arxangelrc.blogspot.com/2017/11/believer-1960mm-professional-mapping-fpv-platform-best-designed-aerial-platform.html

As a hobbyist, he goes in depth about the assembly of his Believer drone. One thing to note about his assembly is that parts like the motors, servos, propellers, and batteries that are bought separately from the Believer are different from what is recommended by the manufacturer. If you combine this assembly thread with the manual supplied with the believer, the drone can be assembled. The parts we changed were the motors, batteries, and propellers from the recommended components. We used the Lumenier 22,000mAh 4s 14.8v battery, the iFlight XING X2814 880KV motors, and 11x5.5-inch Quanum carbon fiber propellers. The rest of the pieces were either recommended to purchase in the manual, came with the Believer, or were reprinted out of LW-PLA using the CAD files above. The next links below provides additional names of the Believer parts and sources to replace them.

Believer Recommended Parts, Large Parts, Small Parts

The new parts can be used to assemble the drone with the supplied parts. The hardware from the new motors is used to attach them to their mounts on the drone but you will need to use the x-mount that came with the old motors. Since we were in possession of the old motors, we were able to do so. The propellers mount the motors utilizing the spacers that come with them as well as the nut that came with the motor. For the battery, we sourced double sided tape to secure it to the battery mounting plate. Velcro could have been used as well. For all of the plastic pieces and the pieces that we created with the LW-PLA material, we used the glue that was provided with the Believer to secure them into their respective places. Using the online thread, we were able to successfully assemble the drone.

To safely and properly operate the Believer 1960mm, the operators should become familiar with all aspects of the drone and proper flying procedures. It is recommended that someone with drone operating experience fly this drone. It should be flown in an open area with no obstructions like trees, buildings, or powerlines. Be sure to notify appropriate local municipalities, and school personnel of your activities and location. Some areas, specifically the college of engineering, are too close to the airport to operate the UAV at. Always be aware of your surroundings and where people are around you. Before flying, double check that the wings and empennages are securely mounted to the fuselage and that the latching hooks are locked in place. Then inspect the motor assembly and propellers before starting them to make sure they are properly assembled. Also check that the servo motors are mounted properly to the ailerons and that they work properly. The operation of the Believer 1960mm drone begins with plugging in and securing the battery. For the motor and control functions to be initialized, the user must first turn off the safety switch located on the PixHawk 4 flight controller (see figure below). The LED indicator on the flight controller will illuminate and an audible sound will indicate that the safety has been turned on or off.

Figure 25 *GPS Module/Safety Switch*

Then the user must then prepare the Flysky FS-i6X RC Transmitter for use. The remote controller (transmitter) should already be synced with the flight controller in the UAV. The initialization process was done using the QGround Control flight software. The final step in preparing the transmitter for proper use is to arm the controller. This is done by moving the left analog stick (throttle stick) to the bottom right position for two seconds. A constant, audible sound will be produced by the flight controller indicating that the transmitter is synced, and the drone is armed. The RC transmitter is now ready for use. It is crucial that all users and participants know when the system is being armed as the propellers may spin rapidly, for a couple of seconds, after the system is armed. It is important to make sure the throttle stick is in the lowered position to stop the propellers from spinning further until the drone is ready to take off.

Start the motors to check that they are working properly and that the remote control is properly synced. During operation, be aware of the vulnerable areas of the drone. The major areas to monitor on the Believer are the wing connecting parts, empennage connecting parts, aileron assemblies, motor and propeller mounts, and the antenna. These areas will experience multiple stresses acting on them throughout the flight and will vary as the drone moves through the different phases of flight. Take off, cruise flight, and landing will apply different size forces from different angles, and these areas will absorb the brunt of these forces. To launch the Believer, the pilot or co-pilot will need to throw the drone like a football and apply throttle. The application of throttle will need to be quick so the drone can climb. To land the drone, make sure there is an available flat are for the drone to skid along. This is a skid landing drone, the black foam pads on the underside will protect the body. Bring the drone to a slow speed and approached the ground at a conservative angle. The speed should decrease, and the drone should skid safely along the ground.

To transport the Believer, simply push the latching tabs down and slide the wings and empennages off the carbon fiber tubes. The long carbon fiber tubes that extend from the left wing through the fuselage to the right wing can then be removed. This will greatly decrease the overall footprint of the drone and allow for easier storage. When assembling or disassembling the drone, double check all wiring harnesses and connections for possible damage or defects.

Figure 26: *Believer 1960 Top View*

Figure 27: *Believer 1960 Side View*

Listed are suggested solutions to possible issues that may arise throughout the project. If more issues arise, please visit the Senior Design web page, and don't hesitate to reach out to Team 518 with more questions.

- 3-D printer must be calibrated for specific filament being used. For the LW-PLA filament, refer to ColorFabb's recommendation for calibrating 3D printer. Small adjustments to the calibrated print settings may be required to optimize print quality of full-scale parts.
- Utilize resources at Innovation Hub for 3-D printing assistance, be aware 3-D printing is much more complex than might be anticipated.
- Failed 3-D prints occur due to a variety of factors, some associated with the printer itself and others linked to the GCode submitted to the printers. Consult the FabLab tech at the Innovation Hub to determine the best course of action for trouble shooting.
- If shipping delays are experienced, as should be expected, tests can still be conducted with available parts to validate designs and testing methods.
- QGround Control can have a hard time getting a GPS lock. Make sure the flight controller is in an open area, preferably one with good cell reception. If you are inside the college of engineering, the flight controller will have a hard time getting a GPS lock.

- Sometimes you will need to reset the PixHawk flight controller in QGround Control. To do so, you will need to keep the flight controller plugged in to the computer with the USB cable and position the drone in the various positions shown in the screen. This resets the orientation of the flight controller.
- If you are having trouble arming the drone, getting it ready to fly, make sure the safety switches are turned off. The first safety switch on the PixHawk controller will need to be pressed and then the throttle input stick on the controller will need to be pressed down and to the right to arm the system. If the drone is not flown within 10 seconds of being armed, the arming sequence will need to be performed again. A built-in safety mechanism is used to prevent injury.

Appendix E: Engineering Drawings

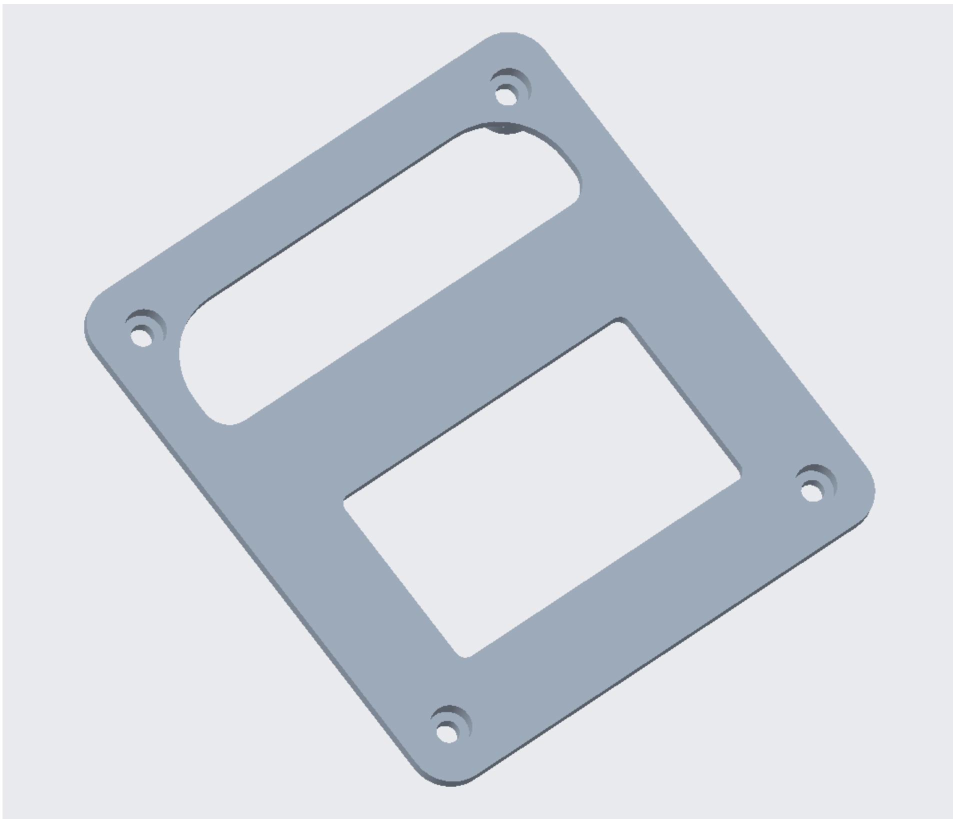

Figure 28: *Servo Motor Installing Base Top*

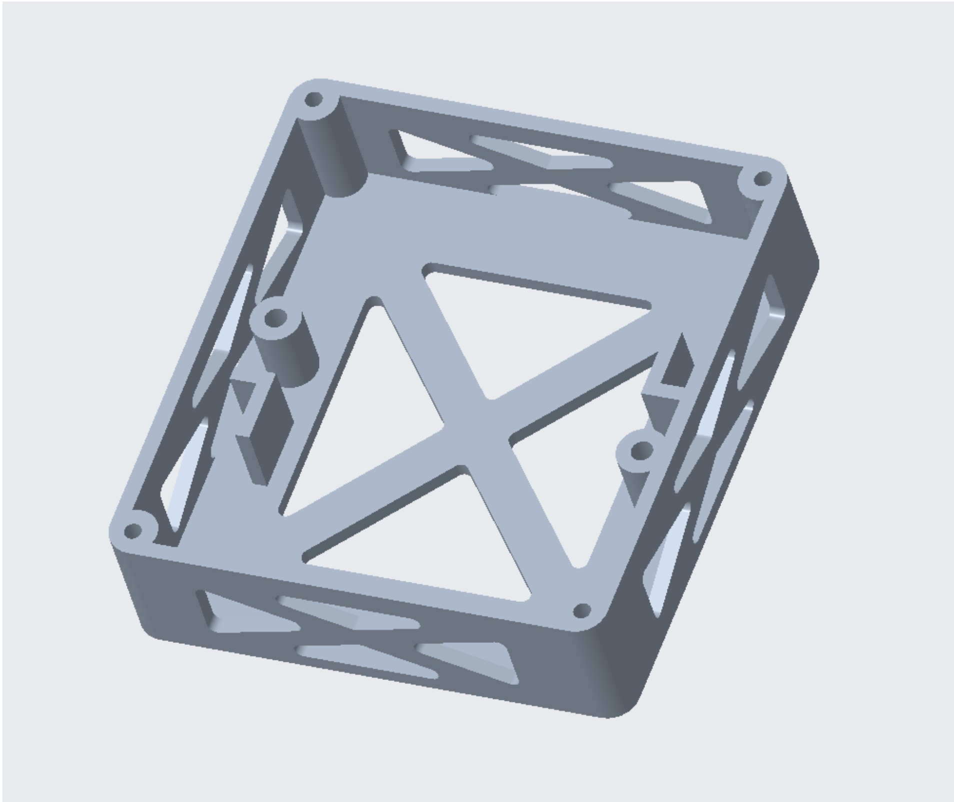

Figure 29: *Servo Motor Installing Base*

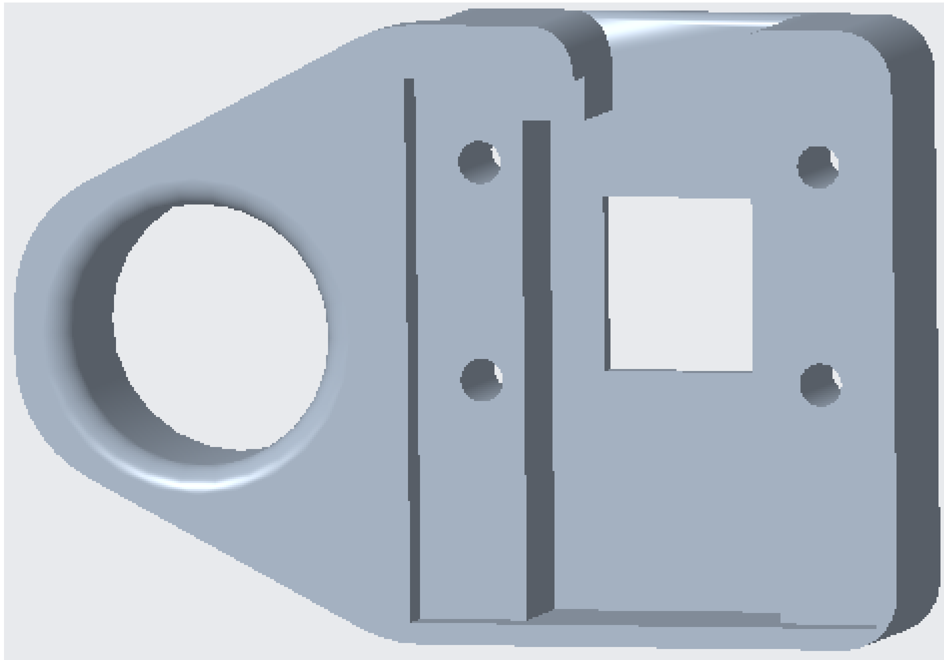

Figure 30: *Latching Hook (Female)*

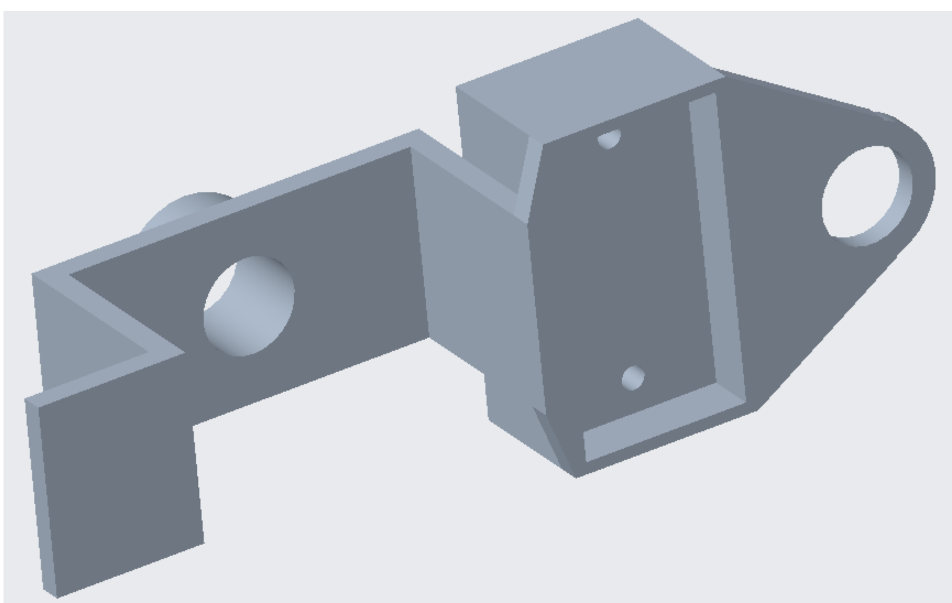

Figure 31: *Empennage Connecting Part (male)*

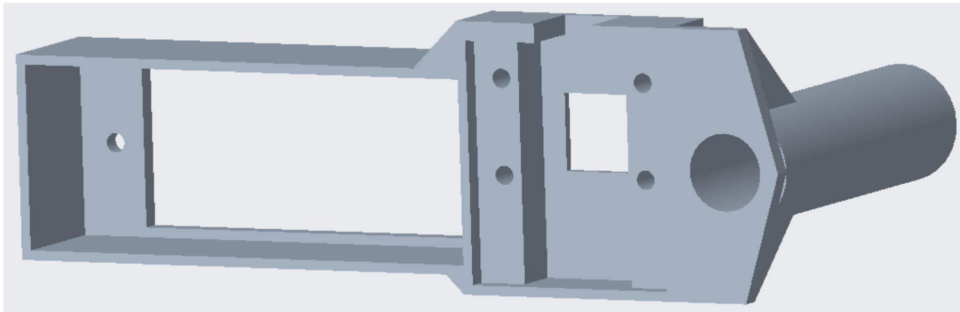

Figure 32: *Empennage Connecting Part (female)*

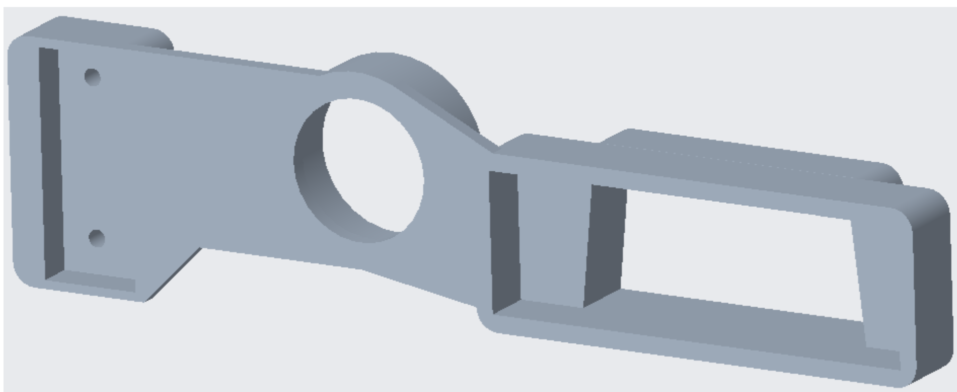

Figure 33: *Wing Connecting Part (male)*

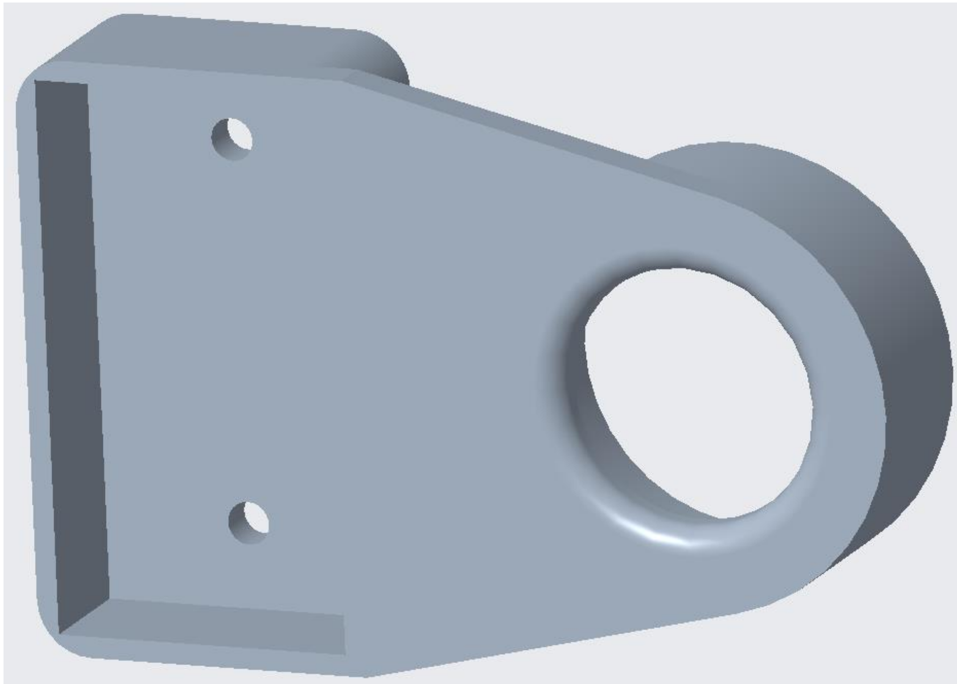

Figure 34: *Latching Hook (male)*

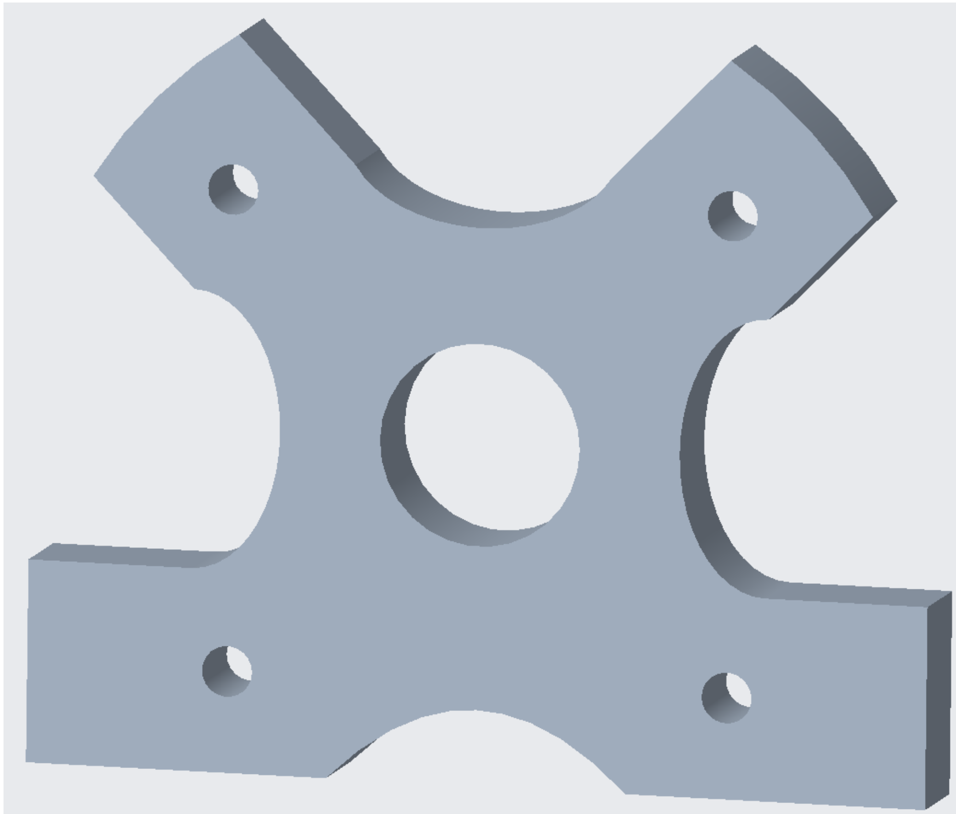

Figure 35: *Motor Installing Base*

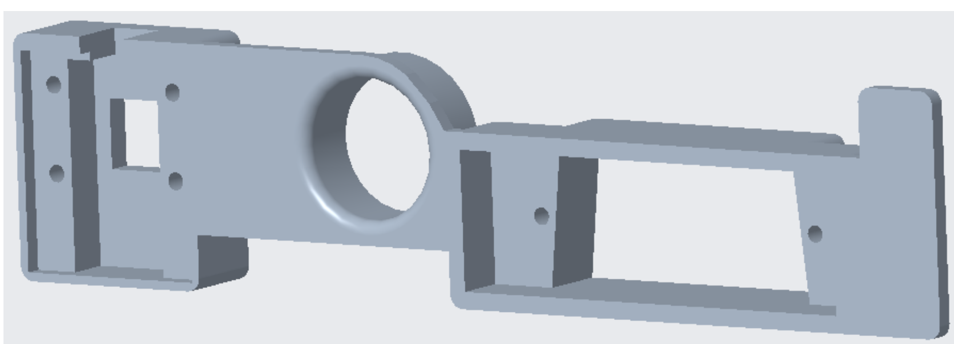

Figure 36: *Wing Connecting Part (female)*

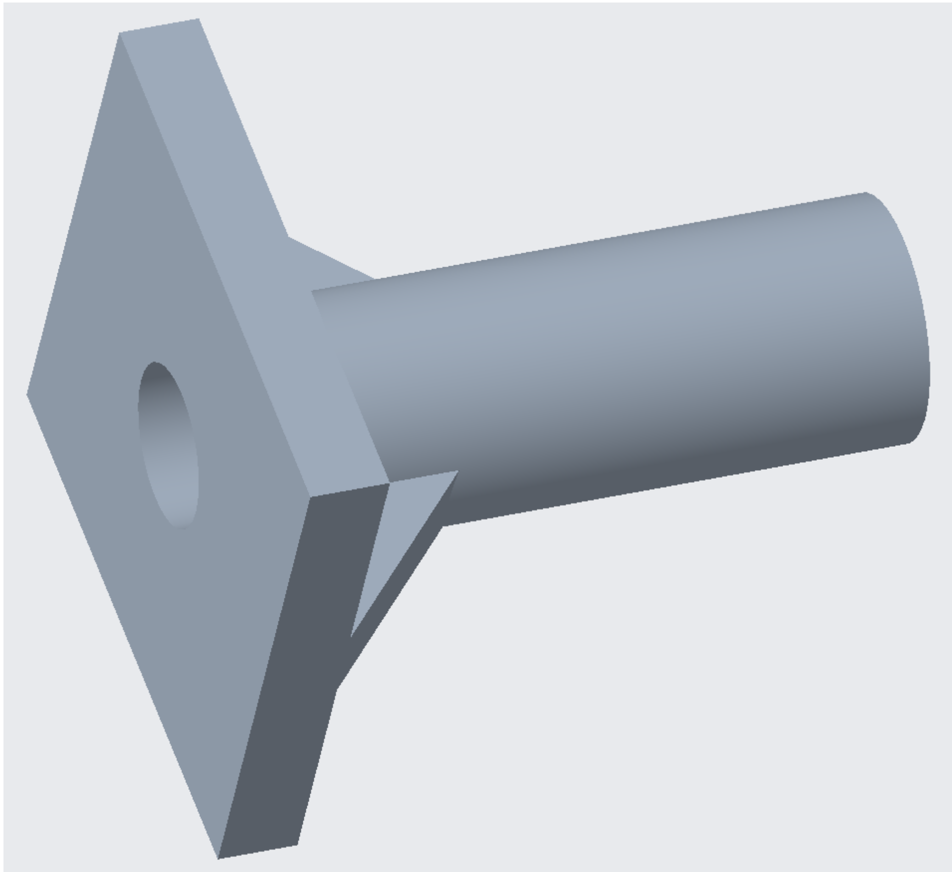

Figure 37: *Rear Empennage Connecter*

Appendix F: Risk Assessment

FAMU-FSU College of Engineering
Project Hazard Assessment Policy and Procedures

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted, and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards, and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e. graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.
2. PI/instructor must review, approve, and sign the written PHA.
3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.
4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g. stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.
5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.

6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).
7. PI/instructor must ensure that approved methods and precautions are being followed by :
    a. Performing periodic laboratory visits to prevent the development of unsafe practice.
    b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.
    c. Assigning a safety representative to assist in implementing the expectations.
    d. Etc.
8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor: Dr. Shayne McConomy	Phone #: (850) 410-6624	Dept.: ME	Start Date:	Revision number:
Project:			Location(s): COE A212 Senior Design Lab	
Team member(s): Ethan Hale, Max Sirianni, John Storms, Joseph Ledo-Masey, Jackson Dixon			Phone #: (904) 860-4712	Email: Ewh18h@my.fsu.edu

Experiment Steps	Location	Person assigned	Identify hazards or potential failure points	Control method	PPE	List proper method of hazardous waste disposal, if any.	Residual Risk	Specific rules based on the residual risk
Disassemble UAV and organize parts	COE A212 Senior Design Lab	Ethan Hale, Max Sirianni	-Using sharp tools to open boxes, remove packaging. -Electrical hazards when examining electrical components	-Appropriate space provided for user -Eye protection provided	Long pants, closed toe shoes, eye protection	N/A	HAZARD: 3 CONSEQ: Minor Residual: Low Med	Batteries disconnected before any work is performed.
Implement light weighting techniques in the UAV		Ethan Hale,	-Hot 3D printers,	-Signs implemented	Long pants,	N/A	HAZARD: 3	Always check if 3D printers

	COE A212 Senior Design Lab	Max Sirianni, John Storms, Joseph Ledo-Masey, Jackson Dixon	filament, and pieces -Electrical hazards when connecting systems	noting 3D printer in use, -Eye protection provided -Appropriate amount of workspace sectioned off	closed toe shoes, eye protection, heat resistant gloves		CONSEQ: Minor Residual: Low Med	are on. Batteries disconnected when connecting electrical systems
Testing Electrical system improvements	COE A212 Senior Design Lab	John Storms, Joseph Ledo-Masey, Jackson Dixon	-Electrical hazards when connecting systems -Heat dissipated from electrical systems -Spinning motors at high speeds	-One person operating system at a time. -Teammates monitor for failures -Eye protection provided -Appropriate amount of workspace sectioned off	Long pants, closed toe shoes, eye protection	N/A	HAZARD: 3 CONSEQ: Moderate Residual: Medium	Batteries disconnected before any work is performed.
Reassembly of UAV and systems	COE A212 Senior Design Lab	Ethan Hale, Max Sirianni, John Storms, Joseph Ledo-Masey, Jackson Dixon	-Electrical hazards when connecting systems -Pinching due to connecting components	-Eye protection provided -Appropriate amount of workspace sectioned off	Long pants, closed toe shoes, eye protection	N/A	HAZARD: 3 CONSEQ: Minor Residual: Low Med	Batteries disconnected before any work is performed.

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	Signature	Date	Name	Signature	Date
________________________	______________	________	________________________	______________	________

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	Signature	Date	Name	Signature	Date
________Ethan Hale_________	____Ethan Hale____	___11/29__	_______ John Storms_______	____ John Storms____	___11/29__
_____Joseph Ledo-Massey _	Joseph Ledo-Massey _	___11/29__	_______Jackson Dixon______	____Jackson Dixon___	___11/29__
_____ Max Sirianni_______	_____Max Sirianni____	___11/29__			

Project Hazard Control- For Projects with Medium and Higher Risks

Name of Project: Light weight UAV		**Date of submission: 12/4/2020**
Team member	**Phone number**	**e-mail**
Ethan Hale	(904) 860-4712	Ewh18h@my.fsu.edu
Max Sirianni	(630) 418-8002	Mss17b@my.fsu.edu
John Storms	(706) 701-0616	Jgs18d@my.fsu.edu
Joseph Ledo-Masey	(850) 294-9937	Jbl17b@my.fsu.edu
Jackson Dixon	(850) 902-0452	Jkd17@my.fsu.edu
Faculty mentor	**Phone number**	**e-mail**
Dr. Shayne McConomy	(850) 410-6624	smcconomy@eng.famu.fsu.edu

Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

Disassemble UAV and organize parts:

This step of the experiment includes opening all the packages the items were shipped in, organizing the materials, and noting what has arrived and what has not. During this step in the project, batteries may be handled so it is important to ensure they are not in use. Sharp objects used to open packages may be handled at this point, so it is important wear safety glasses, long pants, and closed toe shoes. Blades should be pointed away from yourself and your teammates. When not in use, make sure all blades are covered by correct casing/enclosure. It is also important to only use cutting tools in the way they are intended to be used.

Implement light weighting techniques in the UAV:

This step of the experiment involves the main procedures that will be used in the experiment to complete our objective. To implement light weighting techniques in the UAV, we will be handling hot 3-D printers, hot filaments, and hot printed pieces of the UAV. In addition to hot 3-D printing materials there is also the electrical hazards when connecting systems together. In order to keep ourselves protected during this stage of the project we will need to first place signs noting that 3-D printers are in use. Then we will need to provide an appropriate amount of workspace sectioned off, so nobody needs to get close and accidently hurts themselves. In addition to these spacing procedures, long pants, closed toe shoes, eye protection, and heat resistant gloves should be always worn when operating the 3-D printers. When connecting the electrical systems all the same clothing and Personal protective equipment should be worn. In order to keep everyone safe only one person should be connecting electrical systems at a time. In addition to one person operating on the electrical systems at a time, teammates should be watching whoever is working on the electrical system monitoring for any failures or hazards.

Testing Electrical system improvements:
This step includes testing all the electrical components that make up the UAV. The electrical components include the power source, flight controls, communications, and surveillance. To ensure this step is performed in a safe manner the operator will verify all electrical connections are correct and all moving parts are clear from obstructions before connecting the power source and performing the test.

Reassembly of UAV and systems:

This step consists of reassembling the UAV after all of the systems have been tested. Safety precautions will be taken to minimize potential risks during this step. These precautions include wearing appropriate clothing (closed toe shoes, pants, long sleeve shirt, gloves, and eye protection), following standard guidelines for handling various tools/objects, and aware of your surroundings.

Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

All personnel using or near the laboratory equipment will follow standard safety procedures and will wear appropriate Personal Protective Equipment. Closed toe shoes, long pants, or skirts which fully cover the legs are required at all times when in the lab. OSHA's eye and face protection standard, 29 CFR 1910.133, requires the use of eye and face protection when personnel are exposed to eye or face hazards such as flying objects or other hazardous materials.

Cut or Impalement:
For shallow cuts and pricks, ensure no foreign debris is in wound. Wash wound thoroughly using soap and water to remove any debris. Apply bandage and check to see that bleeding is not profuse.
For deep cuts or impalement, notify others immediately and turn off all involved equipment. If impaled, do not remove item. Apply clean bandage around area to mitigate bleeding from wound and contact emergency services and wait for their arrival.

Eye Irritation:
In the case of debris contacting eyes, turn off equipment and notify others in case of impaired vision. Go to sink or eye wash station and attempt to flush eyes with water for a few minutes. If metal debris is in eye, contact emergency services to remove object and treat injuries.

Electrical Shock:

If electrical shock occurs, turn off source of shock and notify others. Check for burn at contact point and clean area with soap and water. Apply burn ointment and bandage if low degree of burn. If burn appears to be high degree contact emergency services.

List emergency response contact information:

- Call 911 for injuries, fires, or other emergency situations.
- Call your department representative to report a facility concern or to report and incident.

Name	**Phone number**	**Faculty or other COE emergency contact**	**Phone number**
Cory Stanley	(850) 566-4472	Dr. Shayne McConomy	(850) 410-6624
		Dr. Lance Cooley	(850) 645-7485

Safety review signatures:

Team member	**Date**	**Faculty mentor**	**Date**
Ethan Hale	11/30/20	Dr. Lance Cooley	11/30/20
Max Sirianni	11/30/20		
John Storms	11/30/20		
Joseph Ledo-Masey	11/30/20		
Jackson Dixon	11/30/20		

Report all accidents and near misses to the faculty mentor.