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Unmanned Aerial Power line Surveillance Drone

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ISYE 4803 - Aeronautics Senior Design Project

Unmanned Aerial Powerline Surveillance Drone

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Executive Summary

The purpose of this paper is to explain the design process for our Senior Design Powerline Surveillance UAV. We were tasked with designing an unmanned aerial vehicle to survey 200 linear miles of power lines while weighing less than 55 pounds. The UAV has to maintain an altitude of 150 ft while never exceeding 450 ft. The aircraft has to operate from an f-150 pickup truck and takeoff grassy or rocky runways, and must start its flight in the middle of the power line section being surveyed. Our UAV underwent several changes. It started as a tilt wing/rotor VTOL capable aircraft and then developed into a traditional flying wing that resembled the Northrop YB-49 and used a turbofan engine. After struggling through the design process due to sticking with a 40 mph flight velocity, we decided to modify how we went about creating a flying wing. We then settled on a more traditional aircraft that resembled a straight flying wing with a tail section for stability. It is essentially a traditional aircraft without a fuselage or cockpit to save weight. It was also found that a 40 mph cruise speed was too slow for a turbofan engine, so we adopted a piston prop setup. This caused issues for us because our aircraft is essentially a large scale RC type aircraft. Performance Data for RC piston prop engines essentially non-existent from the manufacturer, so we had to rely on data given on forums from hobbyists for parameters such as specific fuel consumption. One way to counteract the need for a bigger and stronger engine was to design a pneumatic launch system to get the aircraft in the air, and a net system to capture it. This allows to forgo the landing gear, and allowed us to use a smaller engine that could meet only the cruise thrust requirements that are much lower than the takeoff ones. In the end, we were able to design an aircraft that met all of the required specifications.

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Chapter 1

1.1) Problem Statement

There are miles of power lines that expand miles across uninhabited or otherwise difficult to reach places. The ability to properly assess and therefore respond problems that may occur along these long stretches of land is limited. Traditionally this role is performed by fixed or rotary wing aircraft which is both costly and inconvenient. A company would have to hire a pilot per incident or have one on salary with that sole role.

1.2) Introduction

Power transmission is an essential part of life as we know it. The modern world depends on it and would simply not function the same without it. The need for power transmission is fulfilled primarily through power lines that span long distances. These power lines are exposed to the elements, and are required to be inspected for damage to ensure proper function and safety.

Often times these power lines can span areas that are not developed and are not easy to reach with vehicles for workers to inspect them. This issue can also arise in over developed areas that are crowded and hard to maneuver for workers. Power line inspection can also be very dangerous and fatal if errors are made by the inspector. Any developments to alleviate these issues with help increase the safety of not only the line workers, but the general population as well.

1.3)Overview

We believe that an unmanned surveillance drone could effectively solve the issue of inspecting remote, hard to access areas. We have come to the decision that a single engine pusher oriented flying wing will provide the optimum performance points for our mission profile.

1.4)Objective

The objective of the aircraft is to fly a total of 200 linear miles. Our altitude constraints consist of flying between 150 ft and 450 ft. The desired takeoff is to be launched from the back of a F-150 truck. The desired weight constraint we want for our plane is to be 55lb's as our max parameter. This is entirely dependant on the fuel requirement because of our long range distance. It may be necessary to increase our maximum weight if our fuel requirement is very high.. Our final and most important objective is to be able to carry the hardware necessary for surveillance, autopilot, gps, and survey.

1.5)Requirements

A project with a scope like this one comes with many requirements. Some are concrete and cannot be deviated from, and some are desirable but not necessary for the success of the project. These desirable requirements are such that will improve the functionality of the aircraft,

but can affect the performance, so they must be evaluated to be deemed worthy of implementation for the final design. Our design requirements for this project are as follows:

- Aircraft should weight 55 pounds or less
- Aircraft must survey 100 linear miles from a central starting location (200 mile total flight)
- Maintain a flight altitude of 150-400 feet above ground
- Be able to take off and land in less than ideal locations
- Survey and record and/or transmit video footage of the powerline being observed

1.6) Minimum Success Criteria

There are many factors that govern the overall success of our mission. From the flight conditions themselves, the performance of individual components, even the competency of the pilot in various scenarios are all fluid. Being said for our mission, the minimum we want our plane to do is:

- Reach necessary flight velocity and altitude.
- Stay airborne for duration of mission.
- Complete mission within one working shift
- Meet weight requirement
- Relay necessary info back to responsible parties.
- RTB when running low on fuel or in event of connection loss.
- Take off from back of F-150 truck.
- Be recovered via net on truck or improvised runway.

1.7) Mission Profile

The mission has been specified to be performing surveillance over a span of about 200 miles. The plane will be fitted with a LIDAR and surveillance package for assessing the status of power lines in remote places. It will take off from the bed of an F-150 pickup truck using a facilitated launch system embedded within the bed of the truck. The aircraft will then achieve a height not to exceed 400 feet while not falling below 150 feet. It will fly a linear distance of 50 miles one way, return to center, fly 50 miles in opposite direction, and return to base. The plane will be retrieved via net that will be raised prior to landing. We calculated our cruise flight speed to be about 40 mph.

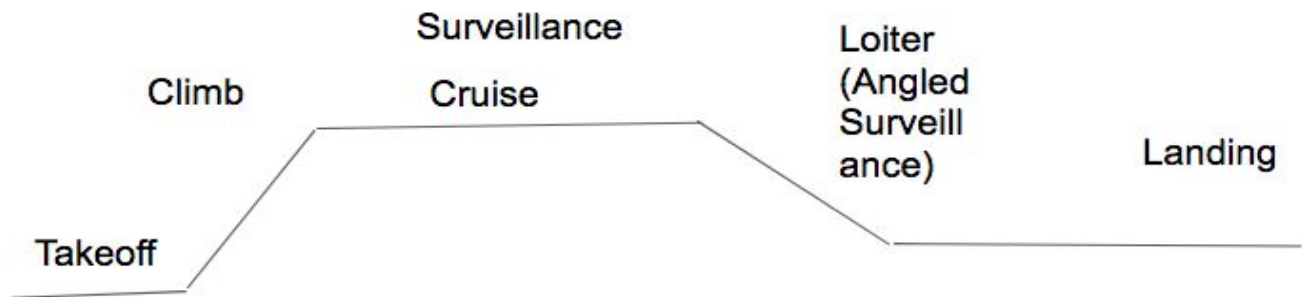


Figure 1: Mission Profile

1.8)Justification

There is no amount of money that can quantify the value of a human life. This fact alone justifies the need to make the power transmission industry safer for linemen that work closely with these power lines. Creating an unmanned aerial surveillance drone that can eliminate the need for linemen to be as up close and personal with dangerous lines. The design and implementation of a drone that can be operated by one or two workers will be beneficial from a cost perspective as well. This drone will have an initial cost, but will save the company over its lifespan by decreasing the cost of man hours and the Hazardous duty pay that comes with it. We live in an ever changing and evolving world, and all aspects of life should strive to keep up with technological advances. This especially applies to aspects as crucial and important as the power generation and transmission industry.

1.9)Project Background and Scope

This particular request for proposal (RFP) came about through issues that arose in the power supply industry. These issues are often spasmodic, isolated events that take place in locations that aren't always the easiest to get to. Beyond damaged and downed power lines, this solution could extend to a number of instances where attention and expertise need to be brought to remote, hazardous, or otherwise difficult places to get to. Issues concerning mountain communities or other places separated by terrain that is difficult to traverse by land would benefit greatly from this. It could save time and assist in assessing and addressing a variety of situations. To assess the request for proposal and satisfy requirements we decided to a design an approach that would be able to could fly long terrain for with a adequate fuel consumption for long distance flight. This design would have the appropriate avionics to properly complete the mission requirements of assessing power lines within unsatisfactory conditions. Using multiple analytical methods from multiple Aerospace classes we will assess the design the appropriate constraints to satisfy the mission.

Chapter 2

2.1) Literature Review

We referenced Aircraft Design: A Conceptual Approach by Daniel Raymer and based our aircraft design process off of the fundamentals taught within. After deciding on the flying wing approach we looked more into the aerodynamics and avionics associated with various designs. In tandem with this was airfoil selection as well as engine selection. We based these selections off of historical data and basic rules of thumb for designing aircraft. We want to maintain as much lift as possible while minimizing drag. It will spend most of its flight time in leveled flight therefore we can choose an engine whose thrust to weight ratio is close to the lift to drag ratio. This plane won't be pulling in-depth maneuvers or even manned, eliminating the need of a tail and fuselage altogether.

The website mh-aerotools.de has published information on the basics of flying wing models. While they are different in many ways from a conventional fixed wing aircraft, they are similar in that the same calculations can be used to find factors such as lift coefficient and other key elements for initial design sizing. This website was especially useful because it had a lot of useful information on stability for flying wing models as well as some airfoil geometry selections.

The website aviation.stackexchange.com has a lot of useful information on the stability of flying wing models. This website noted that where the two airfoils meet at the leading edge, they angle is usually close to 90 degrees. When the aircraft is yawed one way or another, a higher drag force is applied to the leading wing which corrects the yaw. Because flying wings have no vertical stabilizers and tails, they have a thicker airfoil at the center which forces more lift to act at the center and stabilize the aircraft. A high sweep angle is desired and allows the aircraft to be controlled using only the rear ailerons.

Lorenzo went “shopping” for engines and, based on our estimated wing loading and lift to drag ratios, ultimately decided etc....

The fluid dynamics section of the [NCEES Reference Handbook](#) was used alongside [Aircraft Design: A Conceptual Approach](#) by Daniel Raymer to determine the torque that would be applied to the control surfaces of the aircraft by the airflow over them. This was done to allow for the efficient sizing of the servos required to actuate them during flight, without making them oversized and thus excessively heavy. Once this torque was found the online catalog

“ServoCity.com” was used to locate a production servo that met or just slightly exceeded these parameters.

After researching materials that would be viable for our aircraft, it was found that EPP was the best candidate for the foam material. The website rcgroups.com was useful for this research. It has many threads of hobbyists talking about what they use in their planes and why they use it, and it helped us get a grasp on which materials to research and which ones to ignore.

Chapter 3: Dash One Design

3.1) Problem Solving Approach

Initially we were going to attempt a tilt-wing/rotor design (similar to the V-22 Osprey).

This design would be able to hover closer to problem sites for a greater level of surveillance and allow for a broader spectrum of takeoff and landing conditions. While ideal fundamentally, this design would prove not only difficult to produce, but it would also be incredibly inefficient and introduce an undesirable level of maintenance and upkeep (more moving parts and weight). This resulted in abandoning the tilt wing/rotor concept altogether.

We ended up deciding to go with a flying wing concept as it would prove more efficient aerodynamically and since it's unmanned, it won't need a fuselage per se. It would also not need a vertical tail but vertical stabilizers, lowering weight. The mission profile doesn't require a high level of maneuverability so control surfaces such as rudders and elevators could be eliminated altogether, reducing weight further. Since it is a flying wing concept, every bit of the wingspan (minus the tips more or less) will be used to generate lift. This would maximize its performance in leveled flight and, in case of engine failure, glide.

3.2)Initial Design

Using the airfoil data points obtained from mh-aerotoools.de, an airfoil was created in Solidworks. A lofting technique was then used to extrude the airfoil geometry into half of the wing planform. It was then mirrored about its central longitudinal axis.

3.3) Airfoil Selection

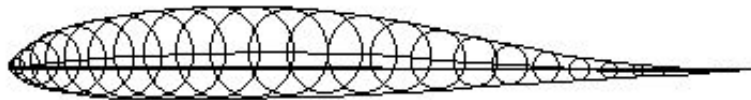
The airfoils selected were from the MH series. The MH-45, 46, and 49 were selected for their relatively high coefficients of lift and reported performance at low Reynolds numbers (100-200k+). This particular lot of airfoils all have low center of moments, and thicknesses between 9.85% and 11.4% making them favorable at lower speeds. There was not much useful information as far as drag polar and lift coefficient curves published however these can be generated using SolidWorks Flow Sim and Matlab.

MH 45



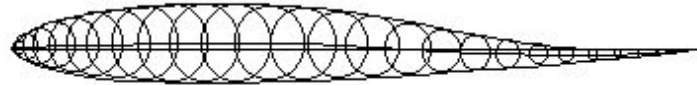
Low moment coefficient airfoil for tailless model aircraft

MH 46



Low moment coefficient airfoil for tailless model aircraft

MH 49



Low moment coefficient airfoil for tailless model aircraft

Figure 2: Airfoil selections

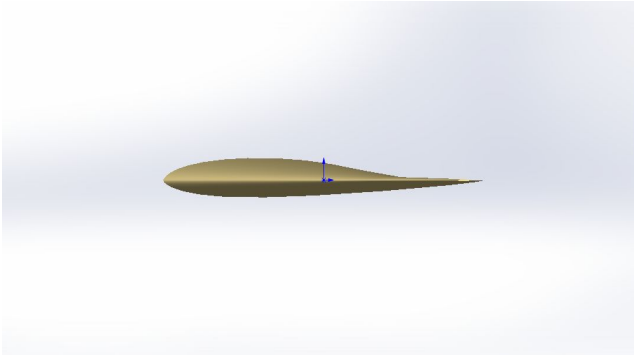


Figure 3a: Side view

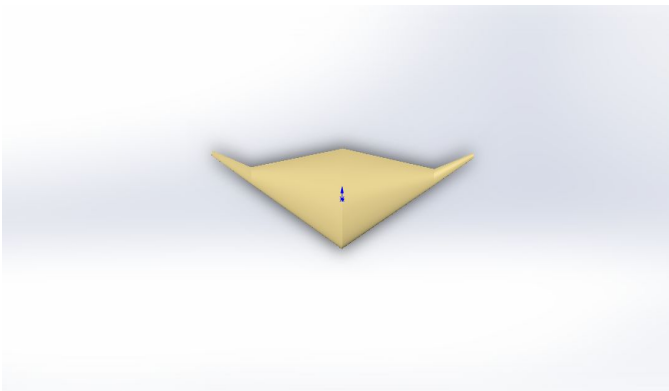


Figure 3b: Top view

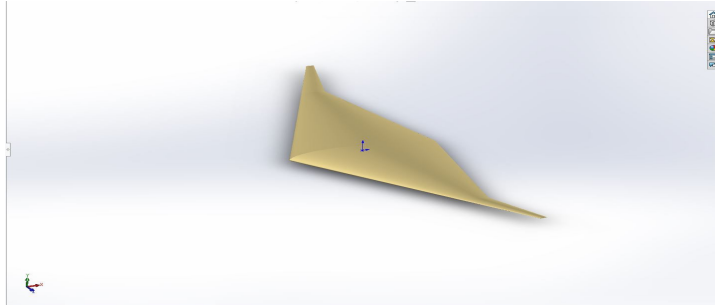


Figure 3c: Isometric View

3.4) Engine Selection First Iteration

TURBOFAN VS TURBOPROP COMPARATIVE ANALYSIS

The goal of this study is to analyze using multiple sources whether Turboprop is better for our mission profile than Turbofan. The hypothesis being for our engine selection is that Turboprop would be proven to be an effective engine. Over several studies shown we will test said hypothesis.

The Turbofan and Turboprop have a few defining characteristics of each engine. Turbofan is known for fuel economy in the turbojet family. Turboprop is known for its ability to be efficient at low-speed mission profiles. The two engines are also known to be not known for their Mach speed at cruise. Followed below is a profile of engine profiles for specific mission profile and speeds. Acquired from the Indian Institute of Technology Madras we used the following Table to determine our needs.

Type of engine	Speed / Mach number range	Application – airplanes in the following categories
Piston engine-propeller combination	Upto 300 kmph	General aviation, trainer, agricultural and sports.
Turboprop	250 to 600 kmph; upto 750 kmph with advanced propeller	Short and medium range transport/cargo, aerial survey, feeder liner and executive transport.
Turbofan	M from 0.7 to 1.0	Medium and long range transports, cargo, maritime patrol, executive transport, jet trainer.
Turbojet	M from 1 to 3	Trainers, supersonic transport, fighter, interceptor, bomber.
Ramjet	M from 2 to 8	Intended for hypersonic transport.

Table 1: Speed Range and applications of different types of engines.

Given observation and inference. We elected to use the Turboprop for our desired mission. As our mission is that of a surveillance craft it meets generalized parameters as suggested by the Indian Institute of Technology Madras. Additional Evidence is provided by this trend graphic of engines of TSFC vs. Bypass Ratio. As bypass ratio increases the favorability of turboprop vs turbofan increases.

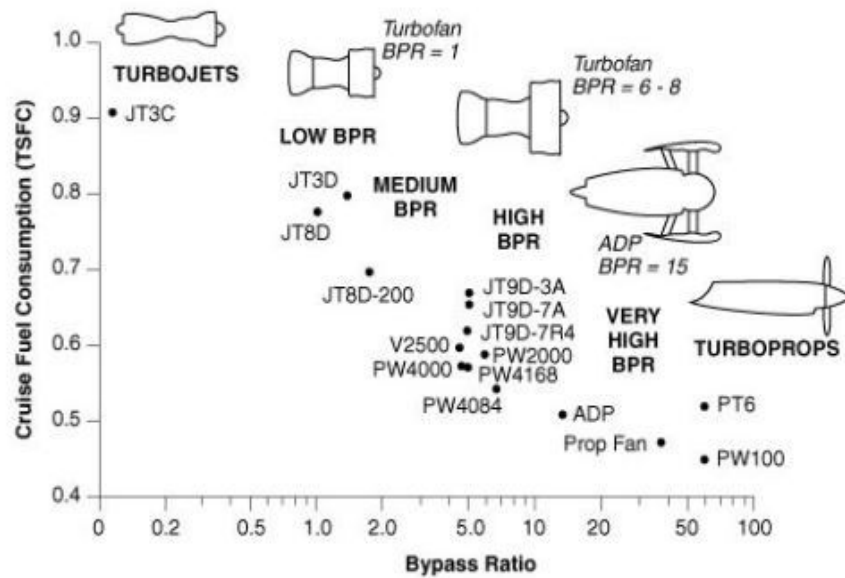


Figure 3d: TSFC VS BYPASS RATIO ENGINES

Another piece of evidence is from “Historical Fuel Efficiency from Regional Aircraft from Technological, Operational, and Cost Perspectives.” It shown below is figure is a figure on decreasing Energy consumption. The Lockheed L-188 and the DHC-8-300 are used for trend curve purposes. Over time, of 50+ years the energy consumption gap has closed between Jets and Turboprop aircraft. In the end, the turboprop is still the most least fuel consuming.

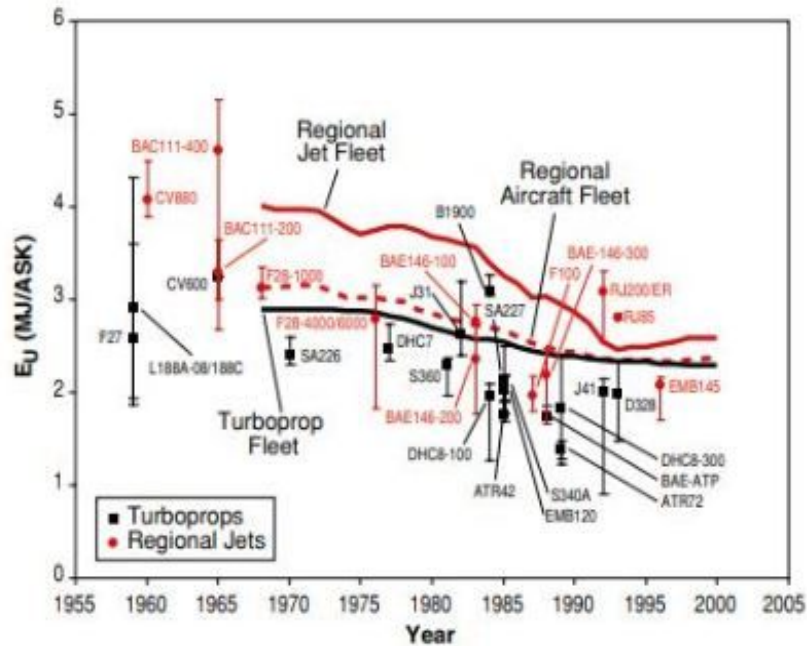


Figure 4: Energy Consumption vs Year

Chapter 4: Dash Two Design

4.1) Design Changes

Many changes were made from the -1 design to the -2 design. The biggest is that we changed our airframe from a delta flying wing to a sailplane style flying wing. We are calling it this because it mimics a sailplane in almost every aspect except it will not have a cockpit or designated fuselage. There is no need to carry payload with this aircraft, and it is unmanned which means that a cockpit and fuselage will just be unnecessary weight. The craft will essentially be a long rectangular profile wing with a tail

attached for stability. The goal for this design is to potentially use the aircraft as a powered glider. This will allow us to take the aircraft up to the service ceiling of 450 ft under power, and kill the engine to allow the plane to glide. Once it reaches the lower end of its operating zone, the engine will power back on and take the plane back up to 450 ft. This process will repeat until the mission is completed. A cyclic process like this will allow us to dramatically reduce fuel consumption which will make our flight time and range more plausible.

After some literature review, it was found that sailplanes are actually superior to flying wings from a stability aspect. A case study was then conducted to determine the performance and viability of sailplanes for this mission profile. There is not a lot of literature on sailplanes, or flying wings for that matter, of this scale. We had to rely on the expert opinion of remote controlled (RC) model pilots. Eventually it was found that sailplanes, due to the aft tail, are far more stable than flying wings. It was argued in several blogs that sailplanes could perform just as well if not better in glide (depending on the airfoil).

To be able to find justification for one design over the other, a solid baseline had to be found. Currently there are no model scaled flyers that fulfil the mission profile in terms of distance. Much praise and recommendation were given to the Zagi (and Zagi-styled planes) as well as the Radian XL planes for their simple designs, readiness to fly, and performance in glide as well as cruise. One pilot reported in his video that he could fly his model sailplane seemingly indefinitely by cycling between powered flight and glide. This performance would surely fulfill our mission profile.

4.2) Initial Sizing

The preliminary sizing was done using fundamental techniques found in the beginning of the Raymer textbook. This round of sizing was done using refined methods found later in the book. These methods took into account calculated and published values whereas initially they considered mainly historical and empirical data. With locked in values for flight speed from preliminary calculations, engine thrust published by the manufacturer, and lift to drag ratios supplied by airfoil databases, we were able to get more reasonable numbers pertaining to the performance of the aircraft. The calculations initially done by hand were ultimately transferred into MATLAB in order to be able to change parameters as needed.

A guess weight of 20 lbs was used to solve for the actual weight (see Raymer, Ch. 6). This was an over estimation that included the weight of the surveillance package which is about 3.5 pounds (RC sailplanes and flying wings are typically under ten pounds). The takeoff weight was determined to be 45.5 lbs, 30 lbs of it being fuel. This gave us approximately 10 pounds of wiggle room for added fuel or electronics packages (probably fuel).

Additional sizing calculations will have to be made in order to figure out how allowing it to glide for various mission segments would affect the corresponding weight fractions and overall fuel consumptions. We may be able to reduce the weight of the fuel and size/weight of the aircraft once we figure out exactly how far or long it can glide before returning to powered flight.

4.3) Wing Planform

This project poses a big challenge to us as aircraft designers. The long flight range and time are difficult to achieve due to the limited weight we must adhere to. Fuel will be an issue and will be required to take up most of our required weight. With the new design comes new planform calculations to adjust for the changes. The most drastic planform change is the big increase in aspect ratio from the span increase and the decrease in chord width. It is important to note that these are just the current iterations values and are subject to change for future iterations. The current planform values for the new design are as follows:

- Wingspan: 22.5 ft
- Wing Chord: 2 ft
- Wing Area: 44.999 ft²
- Wing Loading: 1.222 lb/ft²
- Aspect Ratio: 11.25
- Lift Coefficient: 0.3456

4.4) New Airfoil Selection

The airfoil selection for this design iteration is the NACA 24105. The selection is tailored to give us the lift coefficient we need from our planform calculations, but it has a few aspects that need to be addressed. This is a thin airfoil, and we are flying at a slow flight velocity, so our airfoil for the next iteration needs to be thicker. We will ideally look to decrease the wingspan for our next iteration, so we will also need to find an airfoil that can supply a higher lift coefficient.

4.5) New ENGINE Selection Second Iteration

Upon further study and in-depth analysis we came across information that disputed challenged the idea of Turboprop being the optimal engine for our design. Our hypothesis previously was that Turboprop would be the best ideal engine for our Mission Profile's distance at our desired cruise speed vs Turbofan. We then found numerous pieces of historical data below and conducted a trade study to challenge the former.

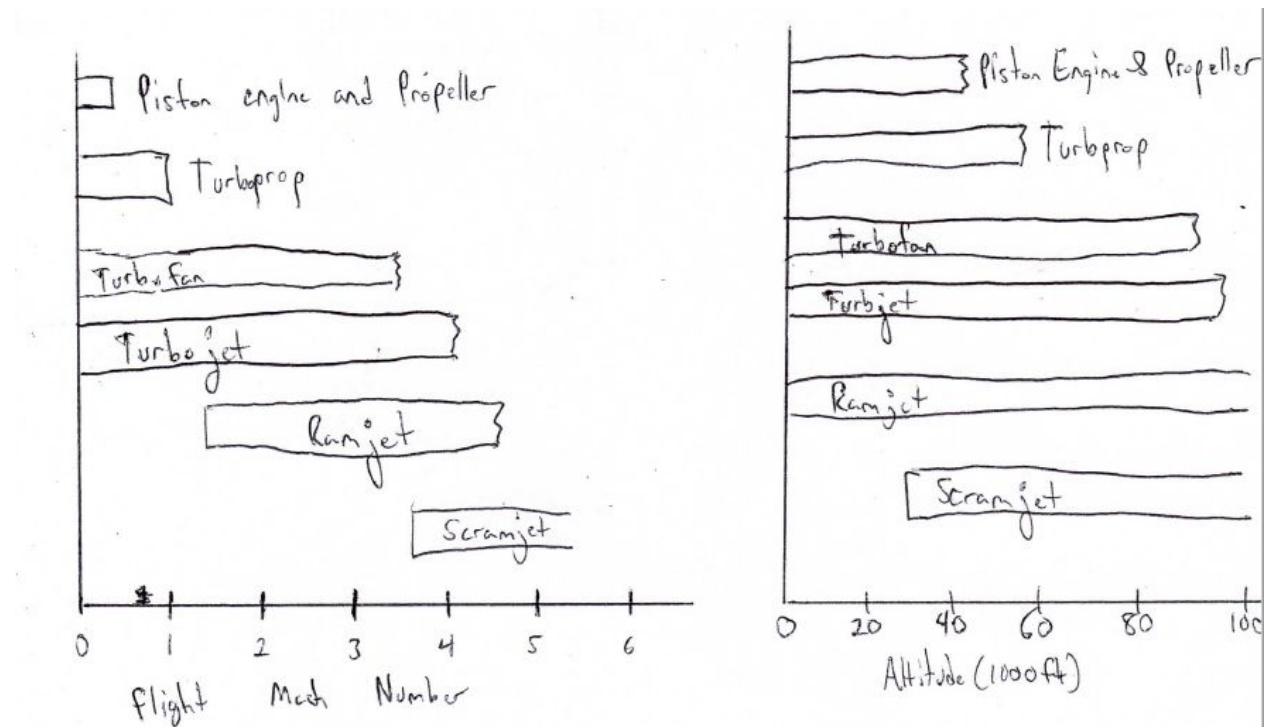


Figure 5: Flight Mach Number and Altitude Parameters vs Engine

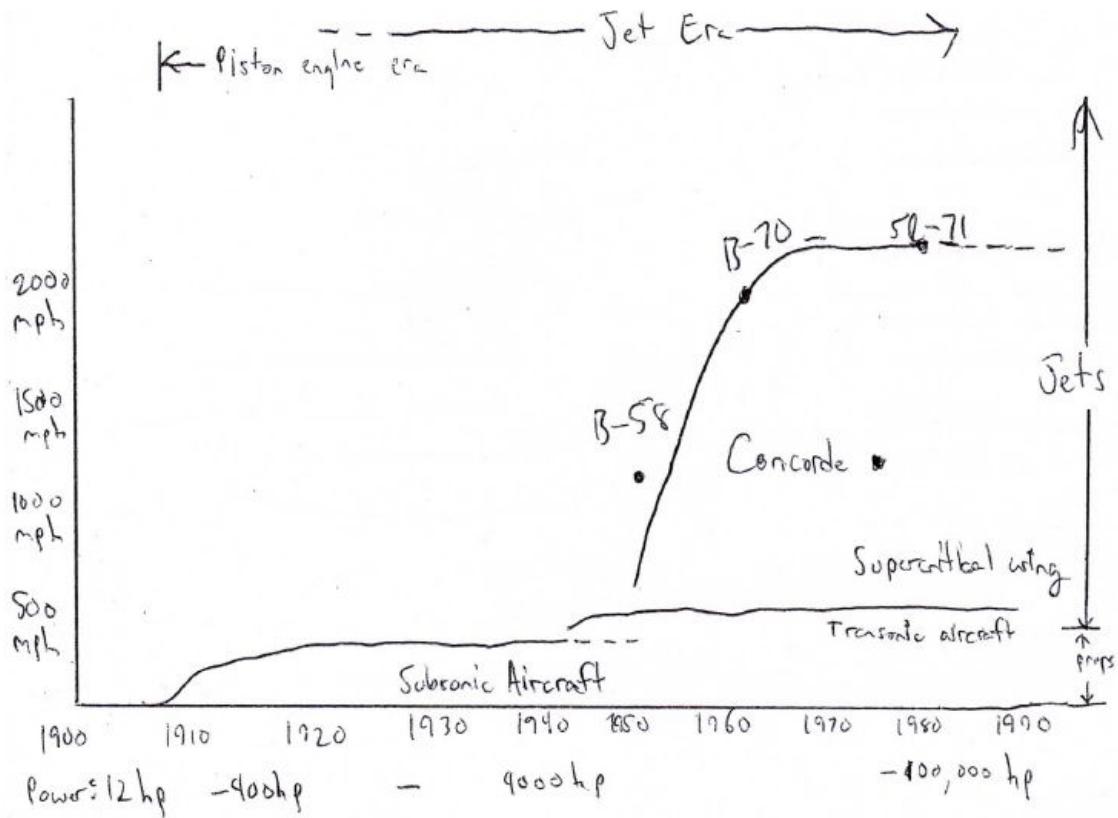


Figure 6: Horsepower vs Velocity over time of Engines

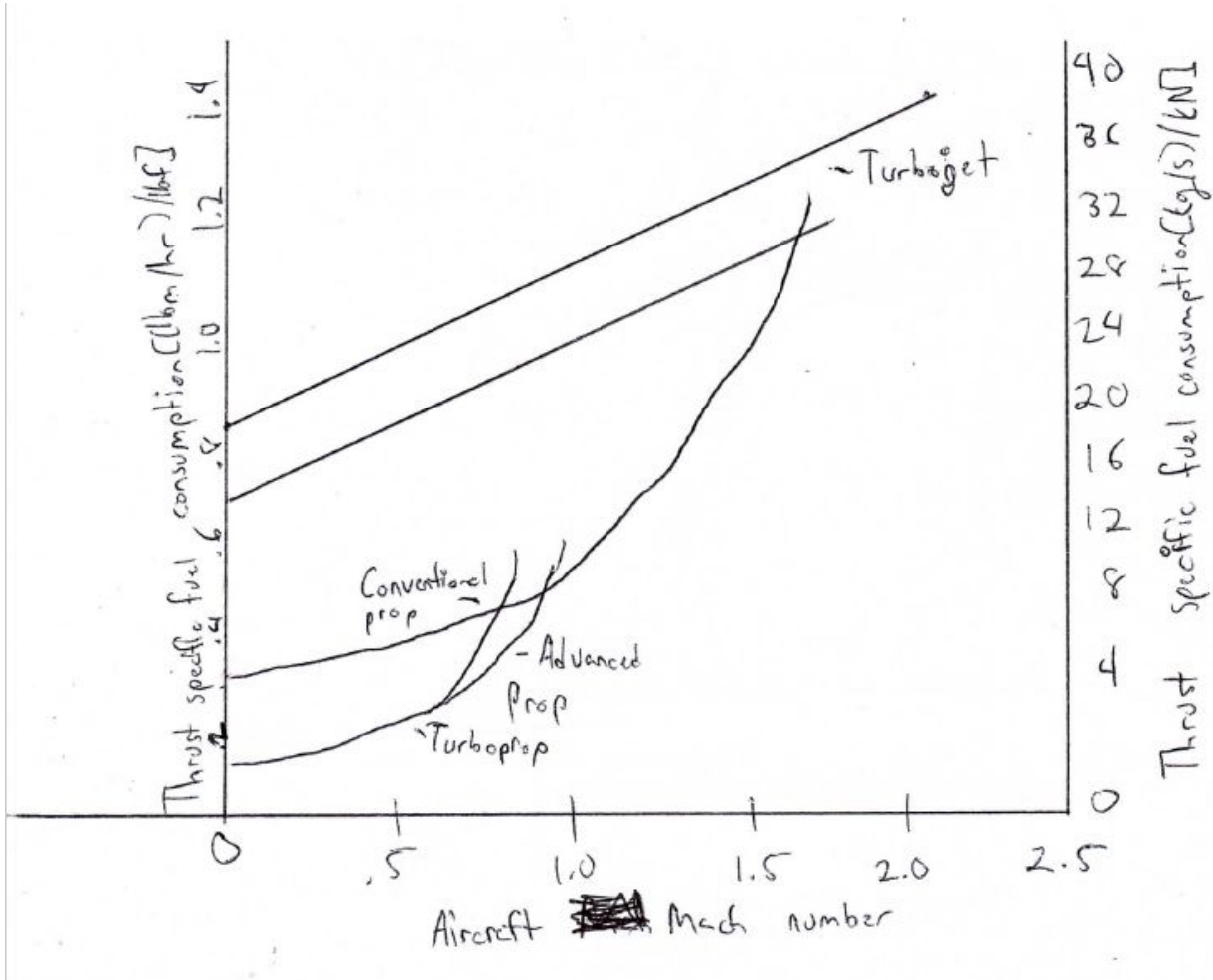


Figure 7: Aircraft Mach # vs TSFC

ENGINE SELECTION MATRIX PARAMETERS

The scores are allotted are based on

- Our Mission profile of 150-400 ft.
- Speed 0.05 Mach #.
- Be the most fuel efficient with respect to the constraint of speed of altitude to reach our distance of 200 miles in flight.
- Numbers 1-10 are ranked from Least to Greatest Relative Advantage in terms of the parameter scored as compared with the listed engines. The point system is dimensionless as there is no way to equally rank the parameters based on their traditional units.

Design Parameters	Priority	Dimensions	Scoring
	Critical	HP	1.0
		SFC	.9
	Important	Altitude	.8
	Optional	Flight Mach	.7

Table 2A : Design Matrix of Final Engine Selection

ENGINES	ALTITUDE	FLIGHT MACH	HP	SFC	Adjusted for (Weight) TOTAL
Piston-prop	9*.8=7.2	10*.7=7	9*1.0=9	10*.9= 9	32.2
Turboprop	7*.8=5.6	8*.7 =5.6	7*1.0=7	7*.9=6.3	24.5
Turbofan	5*.8=4.0	7*.7 =4.9	6*1.0=6	6*.9=5.4	20.3
Turbojet	4*.8=3.2	6*.7 =4.2	5*1.0=5	4*.9=3.6	16
Ramjet	3*.8=2.4	5*.7 =3.5	4*1.0=4	3* .9=2.7	12.6
Scramjet	2*.8=1.6	4*.7 =2.8	3*1.0=3	2*.9=2.43	9.83

Table 2B : Design Matrix of Final Engine Selection

In conclusion, it led us to discover that while the hypothesis of the engine being better than Turbofan, a Piston-Prop engine would be much more effect for our TSFC, and mission profile of such a low cruise Mach. The Engine selected currently is DLE Engines DLE-20cc Gas Airplane Engine w/Muffler which has a thrust of 13.2277 lbf at 328.084 ft.

4.6) Flight Control systems

The ailerons in this design are 5.25ft in span and 0.4ft in chord. At on spec cruise (40mph) and maximum deflection (25deg) the control surface will experience 0.516ft-lbs (99inoz) of torque at its mounting point.

The servo we have chosen to provide this torque is the hitec model HS-645MG.

Chapter 5: Dash 3 Design (Current)

5.1) Blended Wing Concept

After some literature review, it was determined that sailplanes perform just as well if not better in the same mission profile. Due to their typically high aspect ratios, they perform just as well in glide. They also have an added bonus in the form of the stability provided from the aft tail. This would add weight to the aircraft but the selection of a new airfoil allowed us to reduce the overall area of the flying wing portion, decreasing weight also. Due to the incredibly low mach number, a swept wing was not needed. This mandated a change in planform as well as airfoil (see new airfoil selection).

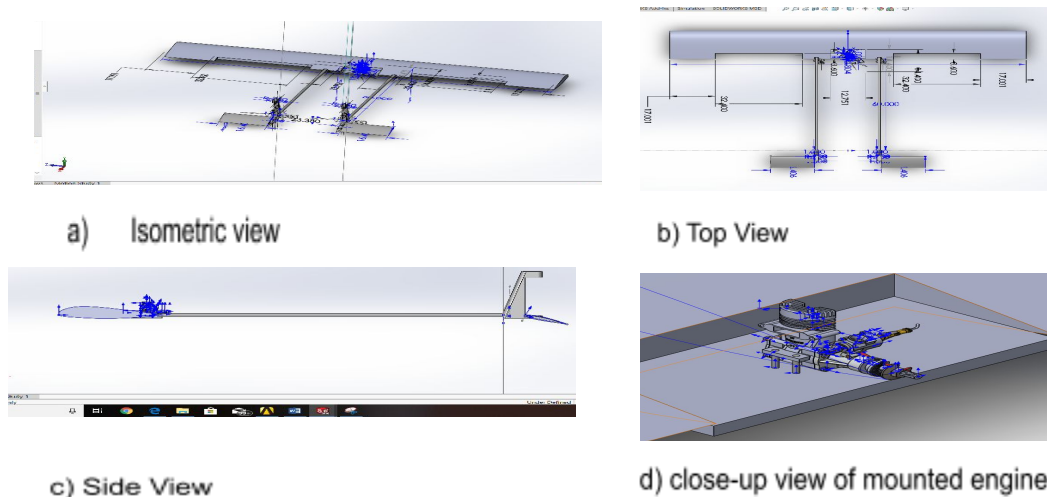


Figure 8:3D VIEW

5.2) Updated Wing Planform

There were a few substantial changes to the planform from design iteration 2 to 3. These changes helped to add to the ease of use for the operators by vastly reducing the wing area required. We were able to make these changes after our refined take off weight was calculated to be around 35 pounds instead of the 55 pounds used for initial assumptions. The new planform dimensions are as follows:

- Airfoil: DAE-11
 - $C_l = 0.667$; $C_L = 0.6$; $C_d = 0.013$; $CD_0 = 0.0188$
- Wing Area - 16.544 ft²
 - Wing Span - 11.029 ft; Chord - 1.5 ft
- Wing Loading - 2.115 lb/ft²
- Aspect Ratio - 7.35
- Taper Ratio - 1; Wing Sweep - None
- Lift to Drag Ratio - 16.641
- T/W at cruise - 0.06
- T/w at Takeoff - 0.3779

These changes to the aircraft's planform will help in many areas. They will add to ease of operation like previously stated, but they will also make manufacturing and structural integrity be much more easily obtainable.

5.21) New Airfoil Selection

The changes we made to the planform area required an airfoil change to meet the wing lift coefficient requirement for steady level flight. With our current planform, we required a wing lift coefficient of 0.6 which corresponds to an airfoil lift coefficient of 0.667 as seen in the calculations appendix. To meet this requirement, we selected the DAE-11 airfoil which is similar

to that of the reaper drones that the military uses. This airfoil is exceptional for endurance and range which will help us achieve our flight distance more efficiently. The following is an image of the airfoil from the airfoiltools.com website:

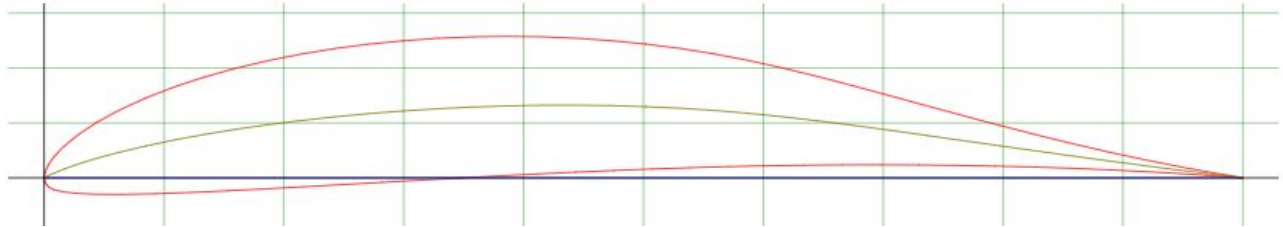


Figure 9A: DAE-11

The following are images from the airfoiltools.com website of the drag and lift coefficients that are compared over different Reynolds number values that our aircraft will fly in:

Blue: 50,000 Reynolds Number

Orange: 100,000 Reynolds Number

Green: 200,000 Reynolds Number

Purple: 500,000 Reynolds Number

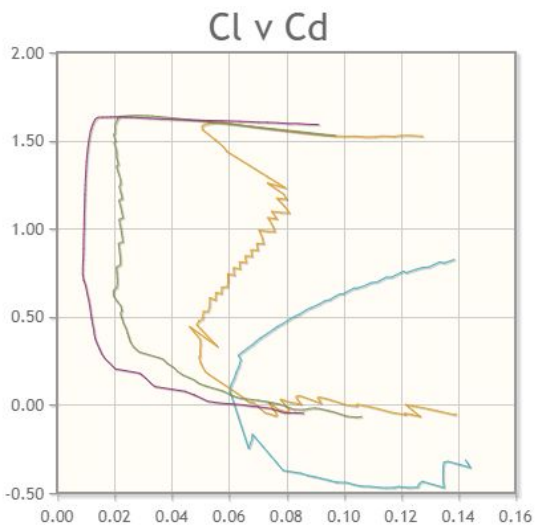


Figure 9B: Drag Polar Plot

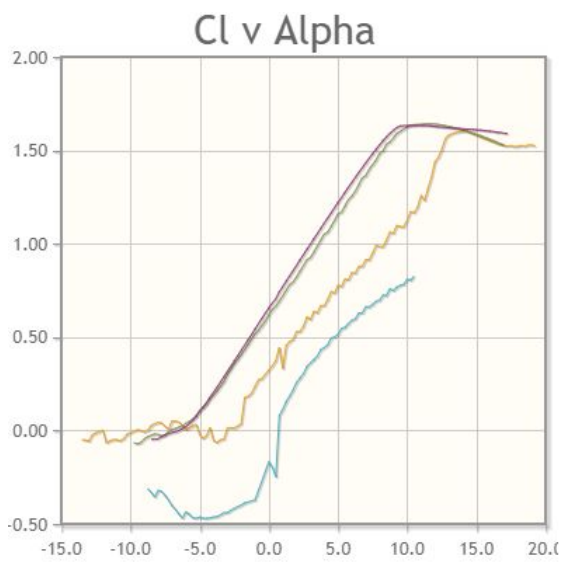


Figure 9C: Coefficient of Lift vs Angle of Attack

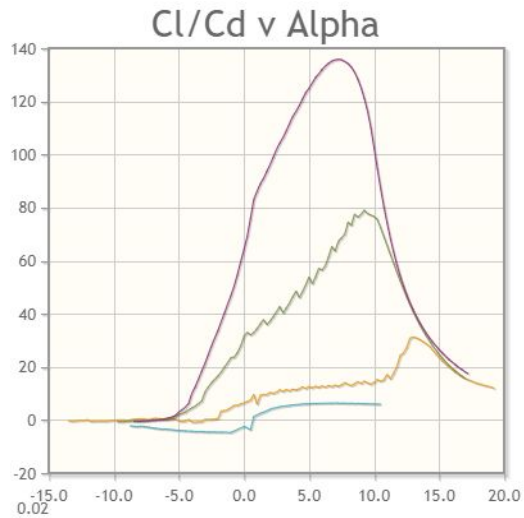


Figure 9D: C_l/C_d v Angle of Attack

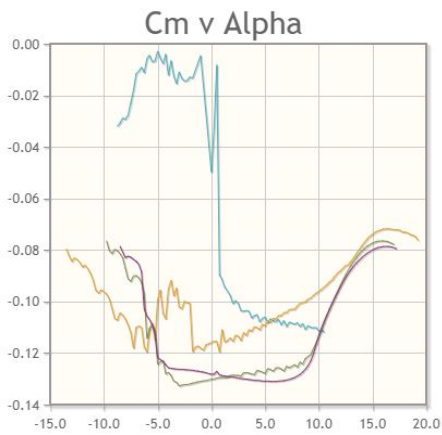


Figure 9E: Center of moment vs Angle of Attack

Taken at face value, these graphs can be confusing to decipher because they are not given with units on the website. However, the values that are graphed are either coefficients or angles. Therefore, any value for C_l , C_d , or C_m is unitless, and the value for alpha (which is angle of

attack) is in degrees. It is important to note that on the C_l vs. α graph, the values of the green and purple lines which represent our Reynolds numbers are equal to the lift coefficient needed for cruising conditions.

5.3) Control Surfaces

The ailerons, elevator and rudders were sized using the sizing recommendations for sail plane type aircraft found in the 6th chapter of Aircraft Design: a Conceptual Approach 6th edition. These recommendations result in the following control surface dimensions.

Aileron

Span: 2.7 ft

Chord: 0.3 ft

Elevator

Span: 2.5 ft

Chord: 0.25 ft

Rudder

Height: 1 ft

Chord: 0.25 ft

Through the use of fluid dynamics equations the torque necessary to actuate the ailerons was determined. An appropriate servo, the HS-645MG, was selected for its adequate torque and light weight. One such servo will be required for each aileron. For the sake of ease of maintenance it was decided to use the same servo for the other control surfaces as well. The singular elevator will require a single servo and both rudders will be operated by a single servo, at the base of one rudder and connected to the other via tie-rod.

5.4) Tail Configuration & Geometry

Initial Design

The tail configuration chosen is a boom-mounted, twin-tailed set up. This would not only grant more stability, but maneuverability as well. The boom is 5 ft long which would keep the tail out of the down wash of the main wing as well as the wake from the propeller. Another design choice we considered is having one elevator placed between the vertical stabilizers, making it an H-tail. This would grant a simpler build without the need of an additional servo and structural support. The viability determination and CAD of the alternative design is being done currently

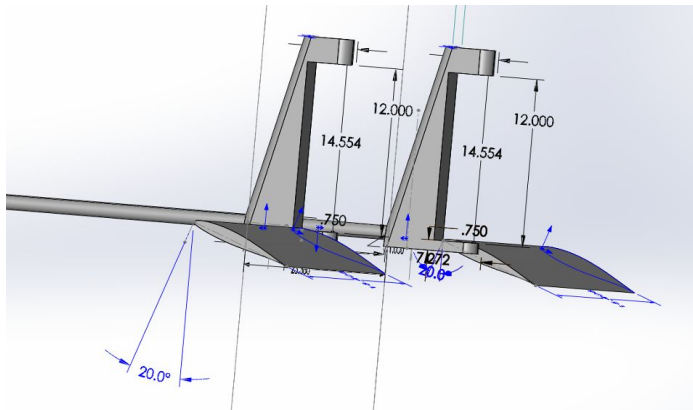


Figure 10: Tail Geometry

Alternative Design

It was found that the horizontal stabilizers/elevators could interfere with the rudders. Therefore, the two elevators that operated independently, were exchanged for a single elevator and the rudders were shortened to simplify the design as well as eliminate interference. This resulted in a slightly larger horizontal stabilizer than originally calculated and the effect on performance is to be determined.

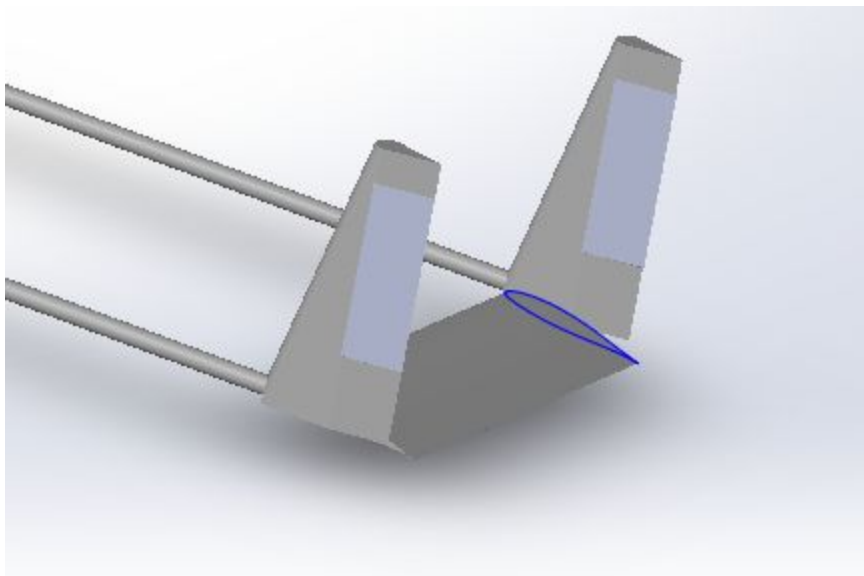


Figure 11: alternative tail design

5.5) Engine and Propeller System

Our engine thrust has to match the drag of our plane. We calculated the CFD to model the appropriate drag requirements.

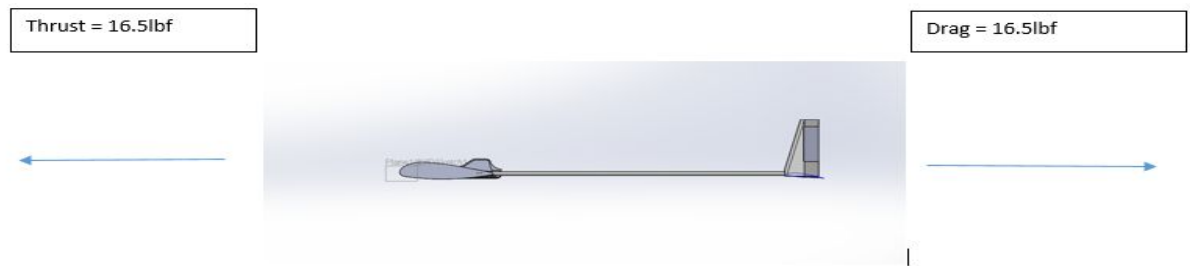


Figure 12: of Thrust vs Drag

From the following we decided the drag needed to be matched by the thrust. Our engine is 2.5hp at 9,000rpm. We used the efficiency equation for a propeller to make the decision of whether our propeller and engine were appropriate to match the thrust. Our calculation had given us efficiency output of 69% to meet our requirements of hitting the appropriate thrust of 16.5lbf. Fortunately most propellers only lose 20% in tip loss. The propeller had to be appropriately selected to fit our plane. The initially sizing of our propeller was determined by the clearance from spar to spar of 1.831ft between the tail-boom and the launch system. This led us to disqualify the usage of any propeller blade selections beyond 2. Now with the issue of the propeller blade solved we decided to move on to our next issue. This issue would be known as Mach Critical Number. We had to make sure that our propeller did not create excessive drag as that was a possibility of grounding our aircraft, and becoming a detriment to our SFC. We calculated the velocity at the tip. From the velocity at the tip and the forward speed velocity we

calculated the velocity helical. This velocity helical is then compared with tabled values for a metal prop, wood prop, and noise concern. Along with a drag issue noise pollution is a still an issue that the FAA declared that is not acceptable. Below is a table illustrating our value helical satisfying requirements of vehicle being lower than the desired values.

189.731	< 950 ft/s	Metal Prop
189.731	< 950 ft/s	Wood Prop
189.731	< 950 ft/s	Noise Concern

Table 3 : Prop Requirements Satisfied

5.6) Final Design

The final design will take into account all the considerations mentioned above and entail the best configurations based on the various scoring matrices and general rules of thumb while designing aircraft (Raymer). This resulted in the plane below

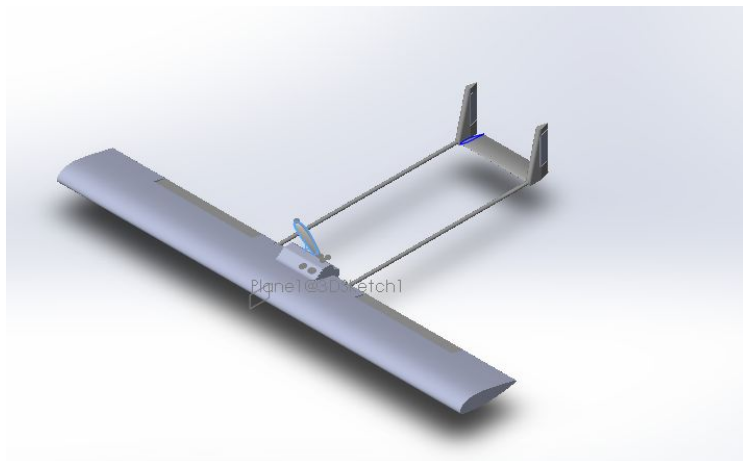
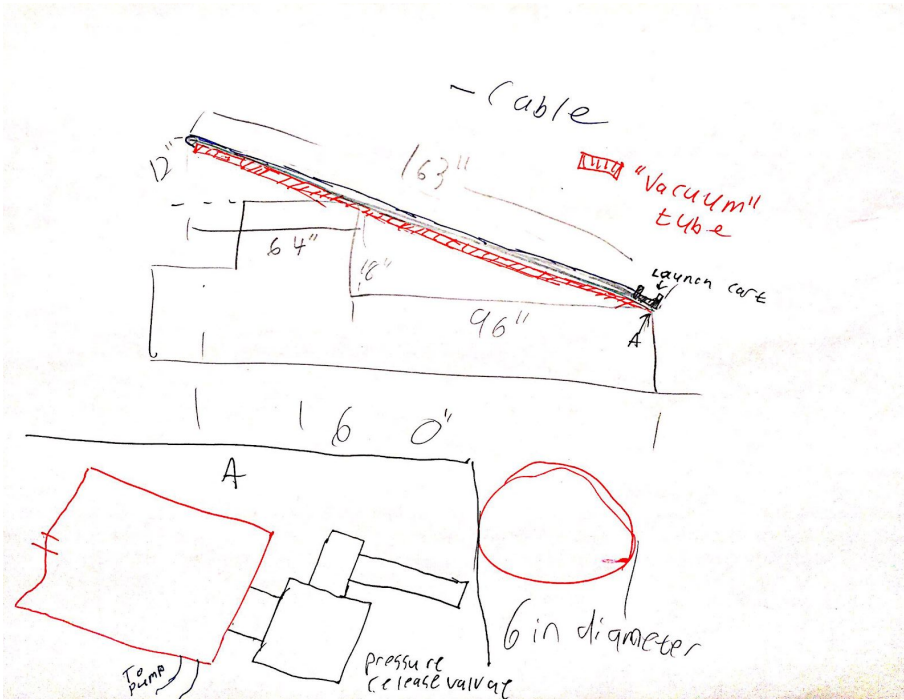


Figure 13: Final Design

Chapter 6: Launch/Land Mechanism

Figure 14: Pneumatic Assisted Launch Sketch



6.1) Pneumatic Assisted Launch System

Due to our requirements of being able to launch and land within a limited area a traditional takeoff method is non-viable. As such we have chosen to employ a pneumatically-driven, rail-guided

catapult to assist in the takeoff procedure. An initial sketch of this system can be found to the right. The system works on a relatively simple mechanism, a main launch tube runs the length of the rail, with an airtight piston at the far end and an air pump at its base. The piston is secured in place with a release mechanism and connected to the launch cart via a cable run over a pulley at the far end of the rail. The tube is evacuated of air by the pump until a 90% vacuum is achieved. Once this state is reached the system is ready for launch, the piston is then released and pushed down the length of the tube by the atmospheric pressure pulling the launch cart along the rail with a constant force and thus launching the craft.

6.12) Refined Pneumatic Assisted Launch System

With the progression of the design process we have refined our weight estimate to a reduced value of 35lbs, this allows a proper launch assist force at a lower and more easily achieved percent vacuum. The more detailed sketch of the updated launch system has also been completed seen here alongside initial CADs. These CADs are of the launch cart and vacuum tube/rail assembly respectively.

Figure 15: Updated Pneumatic Assisted Launch Sketch

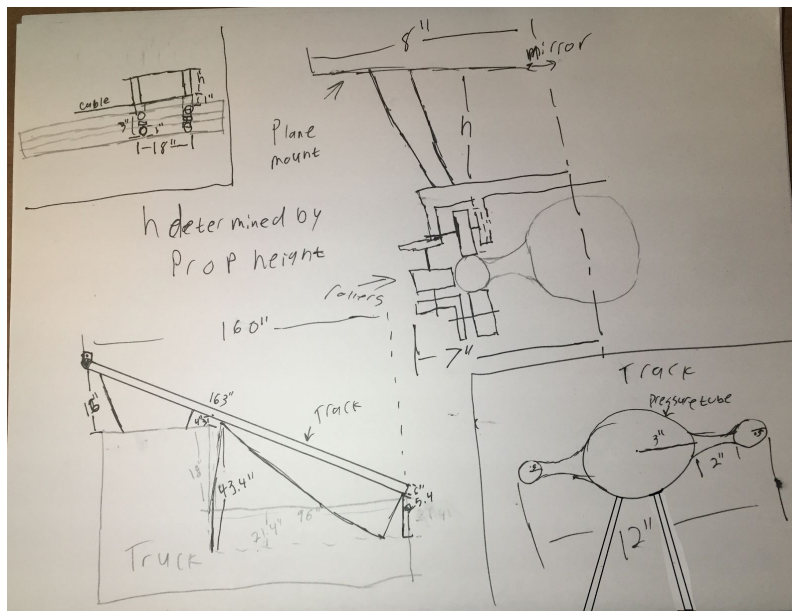
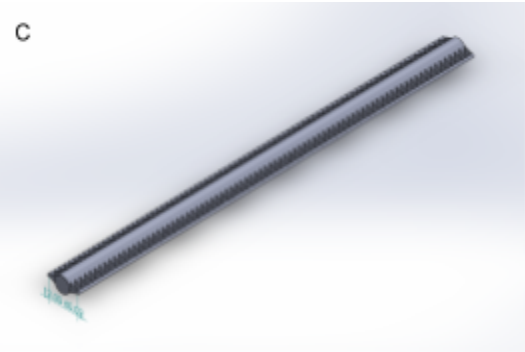
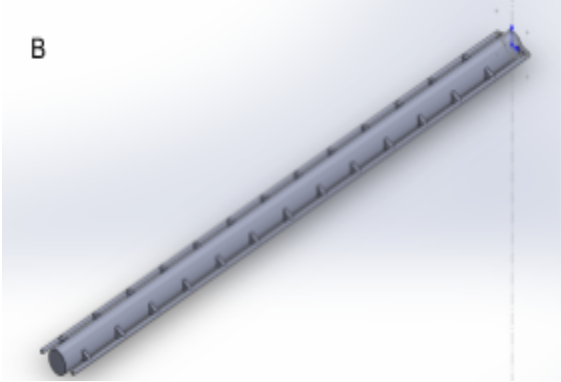


Figure 16:Launch System CAD



Chapter 7: Management

7.1) Project Management

The organization of our group is a straightforward system where in we have one chosen leader, Cameron Whigham, who directed the other three members in what parts of the project to focus on. Once assigned to our designated project sections we were then expected to self supervise until we had a finalized project section to add to the final project. These individual parts are then open for review by the other group members before being implemented into the overall project.

Updated Gantt Chart

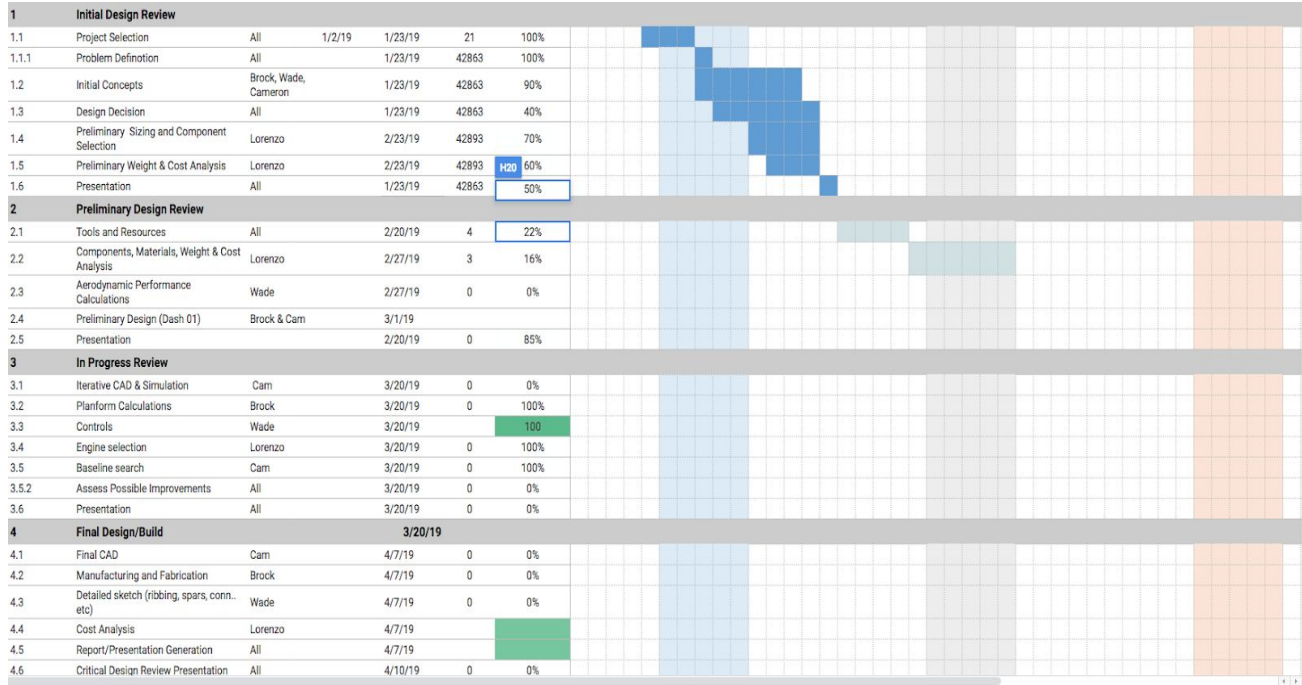


Figure 17. Gantt Chart

7.2)Flow Charts

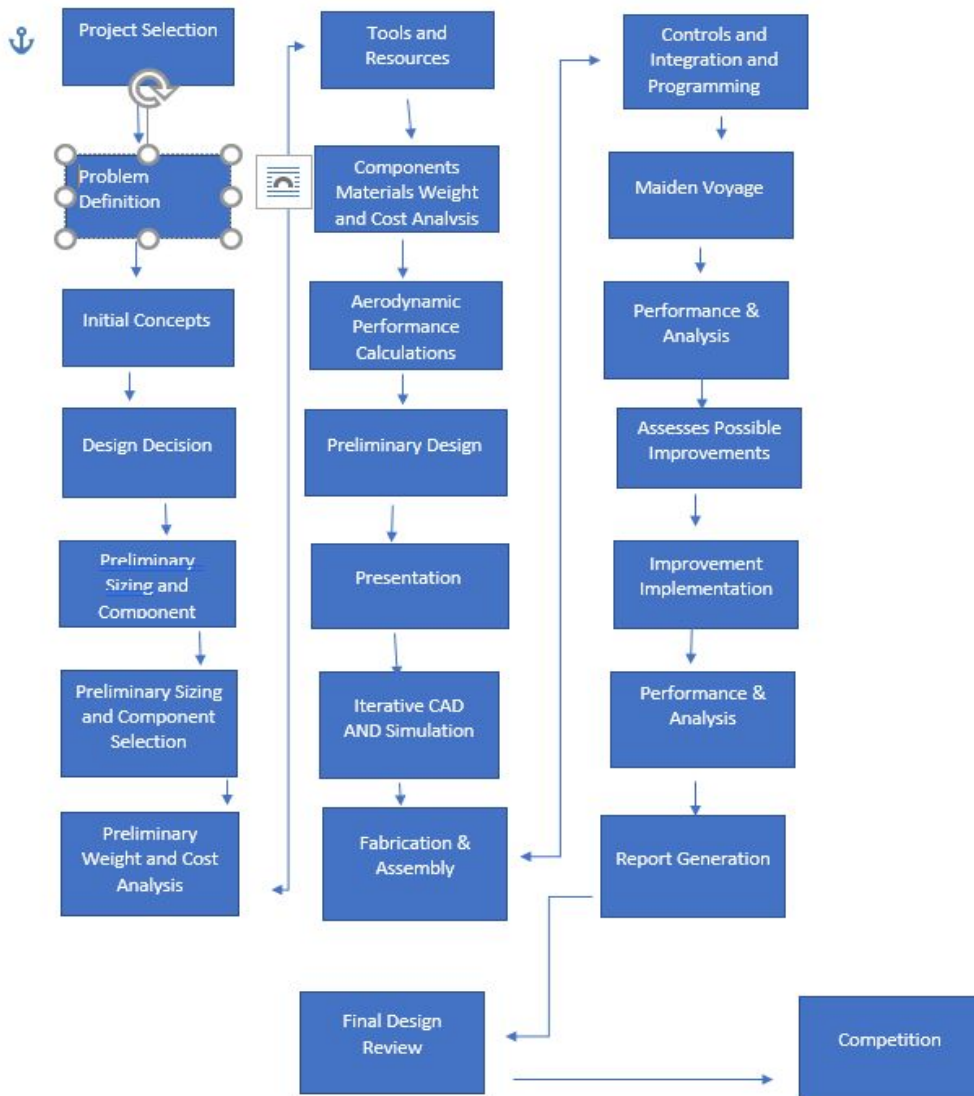


Figure 18:Flow Chart

Resources and Credentials

There is an abundance of resources that will aid us in bringing our design and goals into fruition. As far as the design and performance of the aircraft itself goes, we will follow a similar approach as prescribed in the Raymer book (see references). When it comes to determining the best engine to be used, we will be using historical data and trade studies. We will use Ideal and Real Parametric Cycle Analysis in order to determine engine performance. Solidworks will be used to draw our initial and subsequent designs and the Flow Simulator package housed within will be used to determine the performance. Scheduling and tasking is kept track of via gantt chart and our general order of operations and thought processes are expressed by way of flow charts. Our literature review covered the textual resources that will be used.

All of the aforementioned will be used in tandem with the host of skills possessed by the team. Brock has a decent background and skill using Solidworks/FlowSim as well as a working fundamental knowledge of aircraft/engine design and performance analysis. He will essentially be building the plane. Lorenzo has experience building planes from being a part of the Aerial Robotics club and assessing what needs to take place in order to fly and component logistics. He will be doing the initial calculations to determine an appropriate wing geometry, airfoil, and engine selection. Wade is solid on fundamental concepts that govern various design choices as well as performing calculations. Therefore will be great at conducting post-analyses and ironing out finer details and playing devil's advocate (much needed). Cameron, a jack of all trades while

a master of none, will be assisting the group members with various individual tasks, record keeping, and report/presentation generation. He is serving as team lead and intermediary when needed.

All four members are Senior Students of Kennesaw State University, this report is for the capstone project to obtain a minor in Aerospace. As per the prerequisites for this course, All members have a solid background in Physics and Mathematics, and chiefly their applications in aerospace and aircraft design.

Responsibilities

The objectives of this project are divided into four sub-categories, initial design review, preliminary design review, prototyping, and optimization. Within the initial design review section there were four parts that all members of the group worked on, problem selection, problem definition, design decision, and the presentation. There were an additional three parts which were handled by only some members; initial concepts were covered by Brock, Wade, Cameron. Preliminary sizing was handled by Cameron and component selection was covered by Lorenzo, as was preliminary weight and cost analysis. The preliminary design review consisted of two parts worked on by all four members, tools and resources, and presentation. Lorenzo worked on solidifying an engine selection. Wade performed the aerodynamic performance calculations. Brock ran calculations that would determine the planform and Cameron developed the -01 design. Cameron created and iterated the CAD and ran simulations. Wade covered aileron sizing and servo selection. The final sub-category is optimization where improvements and implementations were done by all, as was the final design review. The report generation was handled by the collective, each group member providing narrative and graphics to support their findings.

Chapter 8: Manufacturing

8.1) Material Selection

With weight being such a big defining factor for this aircraft, material selection is paramount to the design process. The material must be light enough to allow the aircraft to meet its design requirements while also being strong enough to withstand the forces that affect it while in flight. One advantage in this category is the fact that this aircraft will not undergo any high G maneuvers and will fly at a lower flight velocity.

For this project, a high strength foam material will be used in construction to allow us to meet our weight constraints. The foam we selected was EPP(Expanded Polypropylene). EPP has a good mix of strength and resilience. This is important because it will allow our aircraft to withstand the impact force of catching it in the net for landing. This foam will be covered/coated in a high strength epoxy to create a skin that will protect the foam and create a smooth surface. Lightweight Aluminum or Carbon Fiber rods will be used in the wing and other critical components to increase the overall structural integrity and combat the bending moment on the wing. Lightweight Aluminum or Carbon fiber will be used to create the wing's ribs as well. This section of the report is a topic that we are still researching and will require more knowledge at a later point to complete.

8.2) Manufacturing Processes

A long endurance surveillance aircraft of this size will likely have applications outside the scope of our intended use. This implies that a process to mass produce the aircraft will be important to implement. Given the materials selected to create the aircraft, the manufacturing process should be relatively simple. It will involve both additive and subtractive techniques to complete. The use of foam implies a subtractive technique to shape and mold the foam used in the wing and tail sections. The additive portion will involve mating the foam to the aluminum or carbon fiber ribs and supporting rods as well as the rest of the aircraft. Finally, the epoxy skin will be applied to the aircraft to ensure that the surface is slick.

8.3) Assembly/Disassembly

Due to time constraints, we were not able to fully develop our procedure for breaking down the aircraft for storage and reassembling it. The topic is to be considered for future work going forward. However, the wing will have to split in half, and the tail section will have to be removed from the wing in order for the aircraft to fit in the bed of the f-150 truck. We will ideally determine some type of system to interlock the components with the supporting rods instead of using heavy brackets or hinges. Due to the lack of high G maneuvers and the slow flight velocities, our plane will not experience extreme bending moments or external forces. This will allow us to assemble the plane without needing to use super strong and heavy supporting hinges and brackets. The connection point will be subjected to all of the forces on the wing, and

will need to be strong enough to retain its shape and not break, and having lower forces on the aircraft will help with this. As previously mentioned, we do not have disassembly design mechanism done yet, but here is an exploded view of the aircraft from solidworks:

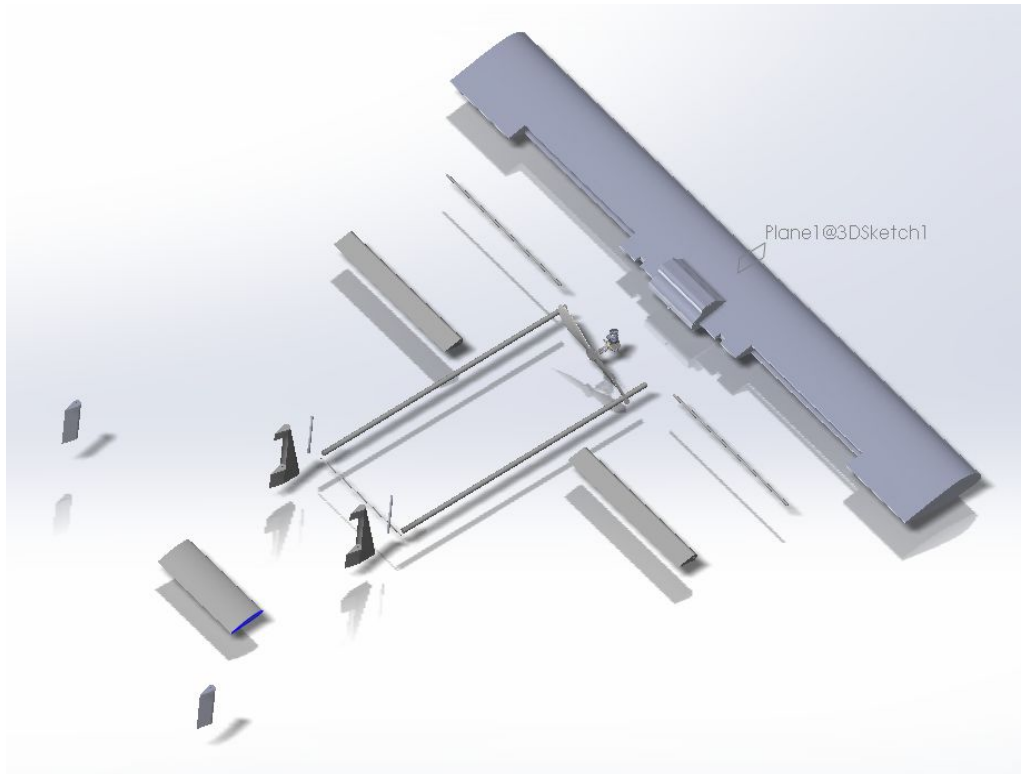


Figure 19: Exploded View of Full-Assembly of Plane

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Appendix A: ACKNOWLEDGEMENTS

We would like to thank Dr.Khalid and Faculty for the opportunity to work on Aerospace related projects, and the ability to apply our cumulative knowledge from Aerospace courses in a semester long manner. This capstone has given us a well-rounded ABET accredited experience that we will carry on for the rest of our lives.

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Appendix Z: Equations Used

$N = (TV)/P = \text{Efficiency Equation}$

$D = \frac{1}{2} * V^2 * C_d * \rho = \text{Drag Force}$

T= Thrust

V=Velocity

P=Power=T*V

C_d = Coefficient of Drag

p=density

Vertical Tail Volume Coefficient: $S_{VT} = C_{VT} B_W S_W / L_{VT}$

Horizontal Tail Coefficient: $S_{HT} = C_{HT} C_W S_W / L_{HT}$

$$L = 0.5\rho V^2 C_L S$$

$$AR = \frac{b}{c}$$

$$C_L = 0.9C_{lmax} \cos(\lambda_{0.25c})$$

$$\frac{T}{W_{cruise}} = \frac{1}{L/D_{max}}$$

$$T/W = \eta_p / V * P/W$$

$$W/S = q\sqrt{\pi A e C_{D0}}$$

$$AR = 0.19\left(\frac{L}{D}max\right)^{1.3}$$

P=VI

P/V=I

I*t=capacity