The Possibility of Electric Parabolic Flight

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The report overviews the contemporary breakthroughs in electrical propulsion technology and its potential integration into the zero-gravitation force flight industry. Current zero g corporations such as GoZeroG spend substantial amounts of money in funding their development of new planes and purchasing jet fuel and maintenance to keep their business model running. In addition to implementing electric-based propulsion, the industry believes that there is a potential to incorporate autonomous experiments, which can be conducted midst the zero g maneuver to produce results analogous to those conducted in space, without the necessity of space travel. The report surveys our research and development of potential solutions which factor the needs of our direct clients and stakeholders, and the requirements specified by the company in terms of the specific subsystems and goals which our final aircraft system should incorporate.

The initial approach to solving the central problem stems from identifying the individuals and groups involved in the project through identifying stakeholders. Understanding who plays a role in the project allows for the discernment of factors that need to be highlighted in the development of requirements for the system and the potential risks involved in this multifaceted initiative. Moreover, after making distinctions between the risks of the central system, the research and development of mitigations to those risks were necessary to begin development of the systems on the plane and effecting the s surroundings to implement a near risk-free zero g system. The stakeholders' needs and requirements were used to define a set of parameters for the aircraft's initial sizing. Along with a definition of the mission of the flight and each step throughout the flight. By researching various aircraft, Eviation Alice, Boeing 727-200, and Cessna 172, we were able to base unknowns of our aircrafts design from them. A reiterative process was used to improve aircraft sizing and ensure realistic values for the final calculations. The wing loading of the aircraft was determined by finding a balance between acrobatics and cruise efficiency to allow our aircraft to complete as many parabolas as possible

The wing sizing was done based on the calculations of the wing loading and estimated aspect ratio. While choosing our planforms we focused on maximizing lift at the same time noting that the parabolic maneuvers required a certain level of speed. Therefore, leading to a tapered and swept back wing. Moreover, using our estimated values we were able to choose an airfoil (A18) best suited to our needs.

We included calculations including range, endurance, flight ceiling, minimum velocity, maximum velocity, thrust required, and power required. These calculations can be important for planning missions and setting up safety procedures to not push the aircrafts limits. These calculations also help us in identifying if our aircraft meets its goals, and areas where the aircraft could be changed.

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1 INTRODUCTION

Space exploration and research is becoming increasingly important as humans venture further and further beyond Earth's surface. However, space travel continues to be prohibitively expensive and testing and verifying experiments in zero-gravity remains critical to success in space. Zero-G flight is the most modern solution to this problem, placing passengers and experiments on a commercial aircraft and carrying them through several parabolic arcs along its flight path. As the aircraft moves through these arcs, everything onboard experiences several minutes in a zero-gravity environment during the downward portion of the flight arcs. Though this is currently the most feasible solution to zero-gravity simulation, these flights are also extremely expensive, costing upwards of 8000 dollars per ticket. Our group was tasked with designing a plane capable of simulating a zero-gravity environment while carrying scientific experiments with the ultimate goal of being significantly cheaper than current zero-g experiences, allowing it to be more accessible to all. Additionally, our aircraft is designed to be all-electric and autonomous, reducing the project's economic costs and environmental impact over a conventional aircraft while improving its usability in the future. Overall, this aircraft is designed to make zero-g flights more viable in today's world.

Upon initial research of the current zero gravity flight experience, the pricing per person for parabolic flight is $8,200 per person, from the company GoZeroG. (Zero Gravity Corporation, n.d.). The plane, which is a modified Boeing 727, starts by maintaining an altitude of 24,000 feet and then increases at a 45 degree angle to 32,000 to complete the parabolic arc, and each arc gives 20-30 seconds of weightlessness. (Zero Gravity Corporation, n.d.). Each experience includes a 90 to 100 minute flight, during which the plane experiences 15 parabolas (Zero Gravity Corporation, n.d.). Before the availability of commercial GoZeroG flights, the US governments and numerous other governments abroad used zero g flight for the training of astronauts prior to a space mission. An electric vehicle that recently flew for the first time in September 2022, the Eviation Alice, stayed in the air for eight minutes at 3,500 feet in the air. (III, 2022). Our assumptions from the research we did include that zero gravity simulation in aircraft is very expensive, and having our aircraft be fully electric can increase the price even more. We also assumed that given current electric power aircraft, parabolic flight will be incredibly difficult due to the low cruising altitude and low flight time. All these assumptions are valid given our focal plane, the Alice, flew on September 27th, 2022. We would like to be mindful however, that was just Alice's first flight. Eviation has set an ambitious goal of getting Alice into service by 2027 (III, 2022). This supports the idea that an electric aircraft can carry passengers at an adequate cruising altitude, and therefore potentially perform aerobatics.

The aircraft's mission will start with loading the test into the aircraft. The aircraft will then take off from a runway and climb to a certain height for the tests. Next, the aircraft can run parabolic tests with possible breaks in between tests. After the tests are completed, the aircraft must land and allow the test to be removed so that the data can be collected and studied.

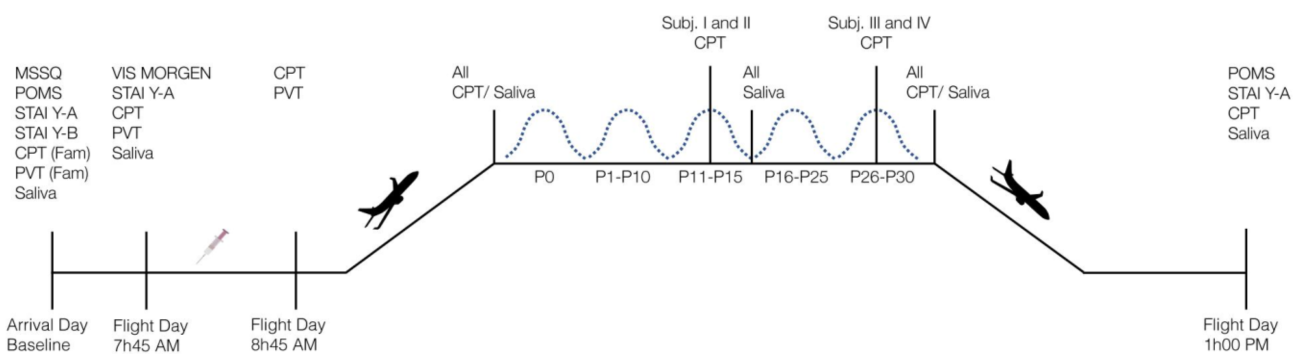

Figure 1: General flight path (Friedl-Werner et al., 2021)

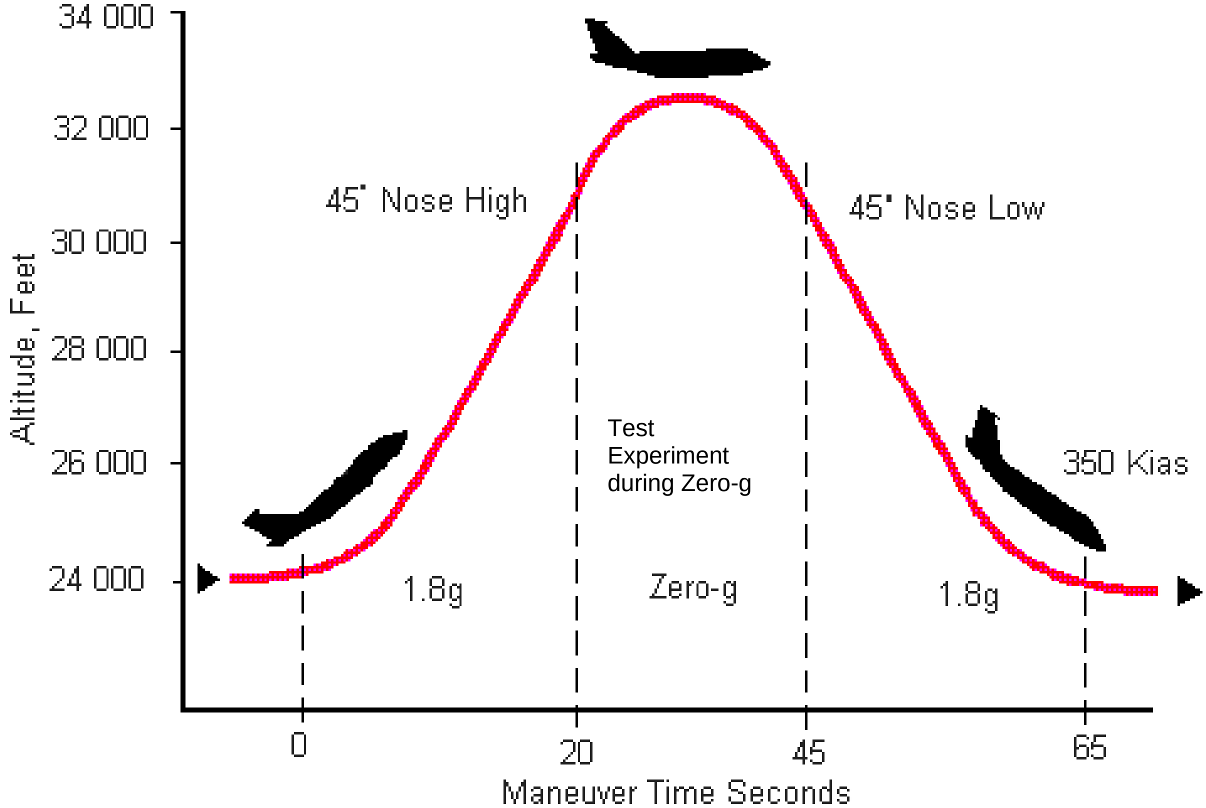

Figure 2: A Parabolic Arc (NASA, n.d.)

The overall flight path will be similar to that of Figure 1 where the aircraft will climb to an altitude of ~4600 meters and then proceed through the planned parabolic arcs. Each arc will be executed by climbing to a peak and then descending back down to the original altitude. A breakdown of each individual parabolic arc is shown in Figure 2.

The remainder of this report is laid out as follows. Section 2 discusses the diverse group of stakeholders that have their respective needs and requirements for this project. The section also qualitatively evaluates the various risks associated with the project based on their impact and severity on the project's goals. Section 3 transitions to look at the initial design steps of the project's aircraft and the various decisions and research it encompassed. This includes reviewing existing aircraft designs with similar goals to that of the project and estimating and evaluating initial flight parameters for the aircraft. Section 4 goes on to look at aircraft concept generation and concept selection, as well as the overall refinement of the final design and the testing of various performance metrics. Finally, section 5 evaluates the final design of the aircraft holistically, considering its mission and operational goals. It also explains the numerous lessons learned over the course of the aircraft's development and the opportunities for future project development.

2 Needs, Requirements, and Risk Analysis

Given the problem that we are tasked with solving, we need to analyze the various components of the situation in regard to what is desired of the employer, the intrinsic requirements corresponding to the aspects of the task, and the potential risk involved with the various scenarios that may present themselves in the process of determining a solution for the problem. Particularly, this section shall cover the needs specified by the company, the requirements which correspond to those needs in a technical matter referencing the metrics and quantitative values, and a risk analysis surrounding the physical aspects of the project that may hinder our objective while illustrating mitigations to these potential risks.

2.1 Stakeholders and their needs

Stakeholders are individuals, organizations, or groups of people that are directly influenced or have an interest in the proceedings of an activity conducted by an organization. With this as a basis to identify stakeholders, the first component that was considered was the system's objective of carrying out autonomous zero gravity experiments and projects, involving multiple sets of stakeholders in this design project. Additionally, the Zero-G Experience goes over the stakeholder throughout the process of the Zero-G flight experience. The GoZeroG website covers the process of how everyone will be aided and supported throughout the process and how the organization themselves will be ensuring the safety and success of the flight, thus directly relating to the stakeholders (Zero Gravity Corporation, n.d.).

Stakeholders

- *Airlines* - Airlines are a stakeholder for our project because designing a more versatile and easily accessible zero G flight experience presents a key business opportunity for them, presenting more revenue and profit for the company. It also allows them to provide zero G services more cost-effectively and competitively alongside previously established zero G experience companies.

- *Pilot(s)* - Our specific task will only require one pilot who will fly the modified plane through the parabolic maneuvers. Our design will provide jobs for some pilots.

- *Space Researcher(s)* - Researchers will be able to test small experiments and designs in a weightless environment. Our design should also be cheaper and more repeatable so that Researchers can do repeated tests of more designs at a lower cost.

- *Engineers* - Engineers are responsible for modifying the plane and for the experiments occurring onboard. They will also be able to test small designs repeatedly at a lower cost.

- *Investor(s)* - Those investing in the potential of the Go Zero G experience are directly impacted by the success or failure of the corporation's commercial activities.

- *General Populous* - Future zero g flyers will have a stake in this project, with the success of this test which shall determine the project's commercial feasibility.

Needs

The needs of our system were identified by the criteria that GoZeroG presented us with in the technical brief, which included the desires for how the system could be changed and improved to reflect the more advanced and capable technology to create a more economically, environmentally, sustainable efficient system.

The most important needs highlighted by the company:

- The overall flight is cheaper than its meaning: the electrical charge (fuel), the plane itself, maintenance, and other factors that go into the process of the zero g experience regarding the plane are cheaper than they previously were with gas powered engines.
- The aircraft uses electric motors for propulsion on onboard circuitry, and uses a certain amount of fuel for each zero gravity maneuver for safety reasons for the plane and the people onboard.
- The aircraft is sustainable and long-lasting so it doesn't break under the force of the g's the plane experiences when ascending and descending. Additionally, the aircraft undergoes many parabolic arcs so it needs to withstand the large amount of g's consistently and continuously.
- For the Space Researchers and Engineers, the autonomous mechanisms and

experiences taking place during the flight maneuvers should be autonomously conducted and should be performed accurately while the flight is smooth overall.

- The cabin/avionics bay should also be big enough to hold the experiments.

The needs required by stakeholders related to the GoZeroG corporation:

- **Airline:** The airline is responsible as both an investor in the commercial potential in this venture and the development of the next generation G-Force One plane. They want the flight to use an electric engine, they want the experience to be both reliable and sustainable for a long period of time, and they want this alternative flight system to be cheaper than their previous G-Force One Zero G experience.

- **Pilot:** The single pilot in the plane will need the plane to function accordingly which includes the aircraft to be reliable through its intensive parabolic maneuvers, the circuitry and controls of the aircraft are functioning, and that it has a similar operation procedure compared to smaller planes like the Cessna.

- **Engineers and Space Researchers:** The engineers and researchers are responsible for assembling the plane in respect to the specs of the plane desired by the Go Zero G corporation and for the autonomous experiments that will occur onboard. They want the autonomous experiments to function throughout the zero g period, and the modified aircraft to sustain its structure and performance throughout the experience.

- **Investors -** Those invested in the success of this project will want to see a return on their investment in the form of success and information gathered through the successful implementation of an electrical power grid onboard, and results gathered from the onboard experimentation.

2.2 Requirements

1. *The aircraft shall have an internal volume in the range of 2.35 m^3 to 3.91 m^3.* The aircraft's internal volume does not have to be that large as only an autonomous experiment will be occuring while the pilot is flying in the parabolic maneuvers. Having a smaller internal volume makes for a more compact and structurally sound

aircraft. This requirement is verifiable through inspection, and is reliant on the fact that the aircraft needs to be on the smaller side for internal volume to house the autonomous experiment.

2. *The aircraft shall have 1 to 2 propellers.* This is due to the inefficiencies found in the lack of thrust and power generated from electric propulsion, so the propellers will support the electric propulsion to perform the maneuvers required for the zero g flight. Our system can only realistically use 2 engines to maximize our thrust to weight ratios, so our system will use 2 propellers. The requirement is verifiable through inspection, and is dependent on the lack of propulsion power from the electric engine.
3. *The aircraft shall contain an autonomous experiment with a maximum volume of 0.08 m^3 and a minimum mass of 80 kilograms.* There will be an experiment that will take up a small portion of the cabin volume, so that the experiment has room to operate. The requirement is verifiable through inspection of the space that the experiment takes up and is one of the main criteria for this procedure, so it is an independent requirement.
4. *The aircraft shall be manned by a single pilot.* We will be using a smaller aircraft, and to allocate a singular pilot to each aircraft makes for a more streamline commercial system. Having a single pilot satiates the needs of our system to use as the plane will only contain an autonomous experiment. The requirement is verifiable through inspection and is relative to the smaller sized plane that will be used.
5. *The aircraft shall use a fully electric system with electric engines and controllers with a power density of 10 kW/kg at the peak, and a max continuous power density of 7kW/kg during cruise and descent.* This requirement highlights the need to use motors that are of lower energy densities that will allow for optimal aircraft operation with their lighter masses and the thrust and power they generate through electric propulsion. This requirement is verifiable through testing and analysis to determine the power densities at their respective periods through the flight path, and the electric density requirement is dependent on the small structure of our aircraft. Also due to the need for power efficiency per weight over the need for stronger batteries which occupy a large volume and mass on the aircraft.

6. *The aircraft shall use battery packs with a maximum specific energy of 250 kW/kg, and battery cells with a maximum specific energy of 350 Wh/kg.* These batteries have a significant role in operating the power and circuitry on the plane used for monitoring, control algorithms, and cooling systems. Our goal is to maximize the Wh/kg for these batteries so that extraneous weights are not added onto the plane to downsize its efficiency. This requirement is verifiable through demonstrating the power output and measuring its weight to determine its specific energy, and thus its power efficiency on the aircraft. This requirement is reliant on the need for using electric systems on the aircraft, which do not occupy more mass than needed to reduce the optimization of the flight path.
7. *The aircraft shall perform the maximum parabolic maneuvers with 80% of the battery's maximum capacity.* This is to allow the reserve to perform an emergency landing, and to ensure that most of the batteries and motors charge is used to perform the maneuvers. This requirement is verifiable through testing the electric systems onboard to calculate an approximate number of safe parabolic maneuvers that can be performed with the given motor and battery charges. The requirement depends on the availability of power and thrust found in the electric propulsion systems.

The requirements stated above that reflect the current initiative are complete in a sense where the functionality of each of the components are accurately described, in respect to the other components of the aircraft which are dependent on the other requirements needed for this initiative. The hardest requirements to meet probably include the maximum internal volume of the aircraft, as the aircraft we have selected has a larger internal volume, and downsizing from a larger plane also includes the decrease in mass, which significantly impacts other factors. Similarly, verifying the requirement about the power densities at their given values will be difficult to approximate and analyze with the given information we have on hand. Fortunately, most of the requirements are interconnected with each other meaning that there will be no conflicting requirements in theory, however, the impact on the mass numbers due to the downsizing of the aircraft will impact the success of the other requirements.

2.3 PRELIMINARY RISK ANALYSIS

There are several aspects in the system that could inevitably fail due to a plethora of factors that undergo changes and loads of force throughout the parabolic maneuver of the aircraft. Below we discuss the risks involved in our aircraft systems during the desired Zero G maneuver. Additionally, each of the risks have corresponding mitigation plans formulated to prevent or limit the risks in both chance of occurring and severity to the mission plan.

Risk Mitigation Plan

Table 1: Identifying risks and Developing Mitigation Plans

Risk #	Category	Risk Identified	Mitigation Plan
1	Electrical System	The aircraft is based on an electrical system with the integration between the circuitry and the electrical engines. Given that the system runs on a local power grid involving batteries to initiate the processes in the electrical system, issues in the circuitry, such as short circuiting, exposed wiring without insulation, and poor integration between the engines and batteries will lead to negative impacts in the overall system. Communication,	Verifying the state of the electrical system and maintaining its processes prior to the flight can mitigate most of these electrical circuit-based issues by alleviating PCB and circuit board problems. Maintaining the connections between the engine and onboard systems will be a crucial association in the execution of the onboard systems the day of operational usage.

		Particularly, the Eviation Alice, the model aircraft's systems that we are using, supports a Fly-by-Wire electronic interface, which is both susceptible to hardware and software malfunctions: categorized into operational failures and generic software failures. Software failures include issues with the code such as redundancies, and hardware issues include sensors integrated with the software being unable to anticipate environmental changes. (Knoll 2-3)	Testing the software and hardware systems of the Fly-by-Wire electronic interface prior to the flight of the aircraft would significantly reduce the risks garnered from computational errors. Additionally, flying on days where environmental conditions are easier to predict for the software to adapt to would decrease the changes of the hardware-software interface from malfunctioning.
2	Structural Integrity	Given that our aircraft will have to fly in parabolic maneuvers, there will be a high level of loads and forces on the structure of the aircraft, which may result in the complete collapse and compromise of the aircraft's structural integrity.	The structure can be reinforced with different polymers and materials to withstand much greater loads than it should experience in the flight.
			Adding more spars and support components to the infrastructure of the plane's frame in addition to adding more ribs to the wings will result in a more solidified aircraft.
		The aircraft undertakes a substantial number of g's involved in the high-speed maneuvers involved with parabolic flight, which may result in the collapse of the	Measures can be taken to make the aircraft more aerodynamic

		aircrafts infrastructure while it undergoes the heavy load of g's on its upward path.	to mitigate the drag on the plane on its upward and downward paths.
3	Aircraft Stalling	The aircraft will be required to fly at extremely steep angles due to the nature of the maneuvers that the aircraft will perform. Due to this, the testing of the aircraft and its large flight angles throughout the parabolic arc, may lead to periods of aircraft stalling. Aircraft stalling is an explicit result of there being a lack of lift, which is because of the steep angles of attack which may result in the wings experiencing minimal to no lift during flight.	To reduce this risk of stalling, we can use larger engines on the aircraft so that it can maintain enough speed to not stall, but we are limited to the power of the electrical engine we can use in addition to the power generated from the propellers.
		Stalling in this context of parabolic flights is hazardous and may lead to uncontrollability of the aircraft and an immediate loss of altitude. Furthermore, these components combined will result in the aircraft crash if said stalling is not corrected.	The pilots can also be trained in preventing stalls by knowing the speeds they need for flight at certain angles. Additionally, altering the airfoil geometry of flaps and leading-edge slats can reduce air stalling.

4	Batteries	Possible failure of the aircrafts battery, or an electrical shortage, will result in an emergency landing or a halting mid parabolic maneuver, which could potentially be detrimental to the structural components of the aircraft.	Ensure batteries are charged properly, as both overcharging and undercharging the batteries lead to detrimental outcomes for the aircraft system.
		Overcharging batteries will lead to harmful gasses being released from the batteries, the shell can be exposed to heat, and the battery may potentially burst, leading to significant integration problems with the circuity and overall aircraft systems. *Reference Figure 3 for graphic representation* (Flight Safety Australia).	Using alternative energy methods which are environmentally benign and more efficient energy sources to charge and to store within the battery for usage, will lead to greater trajectory optimizations and streamline energy allocation within the electrical systems throughout the aircraft.
		Undercharging batteries will lead to premature landing and failures in calculating a safe number of parabolic maneuvers.	
5	Extraneous Obstacles	This includes such as bird strikes, aircrafts collisions, and other flying objects that may potentially intersect with our flight path within	Adopting previous methods used by airports, firing air cannons within the vicinity, and altering nearby landscapes is an effective method to prevent collisions with birds and other flying

		our airblock during the zero g maneuver. Each of these flying objects, regardless of scale, will impede the flight path of the aircraft, which can be detrimental towards the intended parabolic flight path.	animals during takeoff, and our lowest altitude is far higher than the heights that birds fly at.
			Our local ground controller will be responsible for communicating the location of our aircraft in relation to other aircrafts to prevent crashes.
			Following the Go Zero G model, there will be members working at a local ground station to ensure the aircraft is stable throughout its maneuvers.

Figure 3: An example of a plane battery bursting due to improper use (Flight Safety Australia)

Risk Matrices

Before Mitigations:

Table 2: Justifications of risk chance and severity prior to implementation of Mitigation Plan.

Risk #	Chance	Severity
1	*60-79%* - Given that there are many moving parts in the system, the chance of this risk occurring is quite high.	*Major* - The electrical system is the key aspect which interfaces with the engines, batteries, and circuitry. If this is nonfunctional, then the aircraft will fail.
2	*40-59%* - Our base plane, the Eviation Alice was not developed to meet the specifications of the Zero G flight maneuver, so there is a medium-level chance of this occurring.	*Catastrophic* - Our aircraft will need to handle at least the gravitational force of almost 2 times our Earth's standard gravity. If the aircraft is not built to withstand this, the entire structural infrastructure will collapse.
3	*40 -59%* - There is definitely an over 50% chance that this risk may actuate due to the nature of our aircrafts mission to fly in parabolic arcs and varying steep angles of attack.	*Hazardous* - Stalling is a genuine issue that we will have to accommodate for given that our angle of attack will be changing significantly. If this risk is not mitigated, stability and control over the aircraft will be lost.
4	*40 -59%* - The batteries need to be charged optimally to enhance performances and to mitigate the possible risks involved in mishandling them during the	*Major* - The batteries are a central part of the aircraft's mechanisms and functionality, however, if the batteries are to only

	refueling process.	slightly malfunction, the mission is salvageable through an emergency landing.
5	20-39% - The chances of this risk occurring are low given the preexisting technologies and accommodations for aircrafts.	*Hazardous* - The collision of a flying object into the aircraft mid-flight is a serious hazard that can impact the safety of the pilot and aircraft, due to the intense and precise nature of the aircraft's maneuvers.

Chance/ Severity	**Negligible**	**Minor**	**Major**	**Hazardous**	**Catastrophic**
80-100%					
60-79%					**1**
40-59%			**4**	**3**	**2**
20-39%				**5**	
1-19%					

Figure 4: Risk Matrix prior to Mitigations

After Mitigations:

Table 3: Justifications of chance and severity of risks after implementation of Mitigation Plan.

Risk #	Chance	Severity
1	*20-39%* - Our mitigations reduce the chances of problems in the electrical system from occurring, but this facet of the aircraft still should be regulated.	*Major* - Through the mitigations, we can significantly reduce the severity of this risk, though it is still a genuine risk to heed.
2	*1-19%* - With the structural mitigations given to our aircraft to support the Zero G maneuver, there should be no issues.	*Major* - While there is little chance of this risk actually occurring, if the structural integrity is compromised, then it will be difficult to deal with mid flight.
3	*1 -19%* - The mitigations significantly reduce the chances of stalling.	*Major* - Stalling is still an important issue to consider within the confines of our parabolic maneuver.
4	*1 -19%* - Properly handling the battery according to our mitigations, will almost diminish the chances of issues occurring within this subset of the power system onboard.	*Minor* - Given that the aircraft runs on an electrical system, the battery is still a crucial facet of the aircraft, which may compromise the mission.
5	1-19% - Our mitigations along with pre-existing contingencies for flying	*Negligible* - Our mitigations along with pre-existing contingencies for this risk

	objects support a little to no chance of occurring.	are encouraging.

Chance/ Severity	Negligible	Minor	Major	Hazardous	Catastrophic
80-100%					
60-79%					
40-59%					
20-39%			1		
1-19%	5	4	2,3		

Figure 5: Risk Matrix after Mitigations

3 ESTIMATING DESIGN PARAMETERS

The following section will lay out the process that was taken to estimate the parameters of our aircraft. We show the equations, explain and validate our assumptions, and define the parameters used in our calculations.

3.1 EXISTING DESIGNS

Eviation Alice

Figure 6: Eviation Alice (Hydrogen Fuel News, 2020)

The main aircraft that we referenced for our aircraft was Eviation Alice. The main proponent for choosing Eviation Alice is it’s an electric aircraft and has a top cruising speed of 407 km/h—we need a top speed for our aircraft of about 320 km/h ~ 200 mph (Eviation, 2022). This plane is similar to our aircraft in that it's a smaller fully electric aircraft; however, it differs in that it's for normal passenger flights and not completing zero gravity tests like our aircraft will be.

Eviation Alice is currently under development and measurements of the aircraft have changed since its initial announcement. The current design for Alice has the aircraft flying 9 passengers for up to an hour at 44 nautical miles (Eviation, 2022).

Table 4: Specifications of Eviation Alice (Eviation, 2022)

Length	*17.4 m*	**Range**	*463 km*
Wingspan	*19.2 m*	**Max Speed (Cruise)**	*407 km/h*
Max takeoff Weight	*8346.1 kg*	**Engine**	*2 x Magni650*
Landing Distance	*621.8 m*	**Take Off Distance**	*838.2 m*

Boeing 727-200

Figure 7: GoZeroG's Modified Boeing 727-200 (NickFlightX, 2014)

Another aircraft referenced was the Boeing 727-200, which was modified by GoZeroG to conduct zero-g flights (Zero Gravity Corporation, 2020). This plane is a narrow-body jet liner and a trijet (having 3 engines) whose purpose was to address the growing demand for shorter flights from smaller airports. This plane was also quite popular as a cargo and charter aircraft, but eventually phased out due to noise regulations (Boeing, n.d.).

We specifically referenced the flight path followed by the Boeing 727-200 to achieve zero gravity within the hull of the aircraft. The cruise altitude, angles of attack, and air block played a key role in aiding us in our design.

Table 5: Specifications of Boeing 727-200 (Modern Airliners, n.d.)

Length	*46.69 m*	**Range**	*3,100 km*
Wingspan	*32.92 m*	**Max Speed (Cruise)**	*865 km/h*
Max takeoff Weight	*184,800 lb*	**Engine**	*3 x Pratt & Whitney JT8D-7/9/11*
Landing Distance	*N/A*	**Take Off Distance**	*2,600 m*

Cessna 172

Figure 8: Cessna 172 (Flyer, 2020)

Other aircraft considered include the Cessna 172. Due to its small size we used it as reference for our aircraft size as well as our flying/diving heights. However, because of the Cessna 172 the aircraft didn't fit some of our requirements such as being electric or having the capabilities for parabolic flights safely. Additionally, we found our design needed to have a higher maximum power than the Cessna and the airframe did not allow the modifications necessary to make that change.

Table 6: Specifications of Cessna 172 (Textron, n.d.)

Length	*8.3 m*	**Range**	*1,185 km*
Wingspan	*11 m*	**Max Speed (Cruise)**	*230 km/h*
Max takeoff Weight	*1,157 lb*	**Engine**	*3 x Pratt & Whitney JT8D-7/9/11*
Landing Distance	*407 m*	**Take Off Distance**	*2,600 m*

3.2 Estimating Gross Takeoff Weight

The sizing of an aircraft requires the definition of the mission that the aircraft is being designed to accomplish. For our aircraft the mission is to reach zero gravity throughout the flight. The flight path required to do so includes repeated parabolic maneuvers in the air. The aircraft will first take off and then climb to an altitude safe enough to maneuver at. Next, to complete a parabolic maneuver our aircraft will enter a climb and be followed directly by a descent. The parabolic maneuver will be repeated until the final maneuver has ended. Following the final parabolic maneuver, the aircraft will descend and land. A mapping of this general flight path can be seen in Figure 1. Inspiration for this flight path comes from the modified Boeing 727-200 zero gravity flights. However, due to the size decrease and improvement of accessibility to our design compared to the Boeing 727-200 we do not fly as extreme climbs and descents in our parabolic maneuvers. The Boeing 727-200 climbs with a 50-degree pitch attitude and descends at a 42-degree pitch attitude. Our design will follow a decreased pitch attitude angle resulting in less time for zero gravity in the cabin. The aircraft will reach a maximum angle of attack of 8 degrees during the climb portion of the parabola.

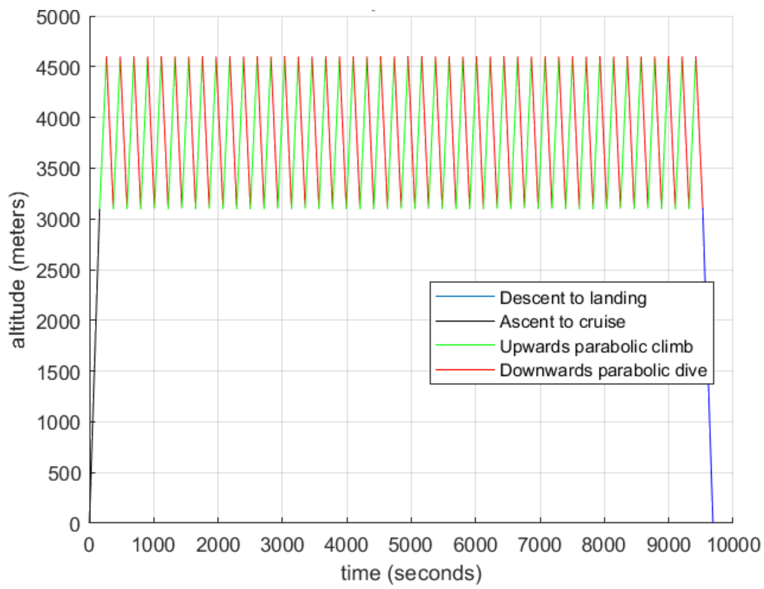

Figure 9: Model of Maximum Number of Parabolas and Altitudes Over Time

The aircraft can complete a total of 44 parabolic flights before landing with a 20% reserve as shown in Figure 9. To estimate this value, we assumed that the aircraft would complete the climb and descent of each parabolic maneuver in a straight line. This allowed us to find a Rate of Climb of 56.9153 ft/s using the RoC = V × sin(γ) equation. Once we found the rate of climb, we estimated the time it took for the initial climb and descent and the climb and descent of each parabolic maneuver. This time divided by the endurance of our aircraft gave us the estimation for the maximum number of parabolas through the aircraft mission. To validate the assumptions made we compared our total number of parabolas during the flight to other zero gravity flights. Other zero gravity flights generally consist of 30 to 60 parabolas during flight (Karmali, F., & Shelhamer, M, 2008). Our maximum parabolas during flight fall within this range, which supports the assumptions our team made.

The sizing of the aircraft required a set of parameters that needed to be researched to match the mission of the aircraft. The first was the crew weight of our aircraft. The aircraft is to be piloted by a single pilot. Thus, we determined our crew weight to be 84.05 kg because this is the average weight of an adult in America (CDC, 2021). The next parameter was payload weight. Stakeholders required the payload weight to be at least 80 kg. We determined that we wanted to maximize the amount of zero g flight time in a single mission, thus we set our payload weight to be the minimum 80 kg. The aircraft can handle a larger payload; however, this will cause a decrease in the amount of zero g flight time in a single mission. Another input parameter to determine the aircraft sizing is whether the wings have variable sweep or if the wings are fixed. Usually, aircraft with variable sweep wings are designed to be able to complete a multitude of different missions and the variable sweep wings allow for the aircraft to adapt to be most efficient for a specific mission. Nonetheless, our aircraft will be completing a single defined mission regularly, so it has fixed wings, resulting in a K constant of 1. Finally, the last parameter that must be inputted is the type of aircraft that is being sized. This parameter has 13 options, unpowered sailplane, powered sailplane, homebuilt wood/metal, homebuilt composite, single engine GA, twin engine GA, agricultural aircraft, twin turboprop, flying boat, jet trainer, jet fighter, military cargo/bomber, and jet transport (Raymer, 2018).

$W_e/W_0 = AW_0^C K_{vs}$	A	{A-metric}	C
Sailplane—unpowered	0.86	{0.83}	−0.05
Sailplane—powered	0.91	{0.88}	−0.05
Homebuilt—metal/wood	1.19	{1.11}	−0.09
Homebuilt—composite	1.15	{1.07}	−0.09
General aviation—single engine	2.36	{2.05}	−0.18
General aviation—twin engine	1.51	{1.4}	−0.10
Agricultural aircraft	0.74	{0.72}	−0.03
Twin turboprop	0.96	{0.92}	−0.05
Flying boat	1.09	{1.05}	−0.05
Jet trainer	1.59	{1.47}	−0.10
Jet fighter	2.34	{2.11}	−0.13
Military cargo/bomber	0.93	{0.88}	−0.07
Jet transport	1.02	{0.97}	−0.06

Figure 10: We/W0 equation constants table (Raymer, 2018)

The selection of the type of aircraft will relate to the A and C constants in the following equation: $\frac{W_E}{W_O} = A \times (W_O)^C \times K$. The best fit description of our aircraft is a twin engine general aviation aircraft. This corresponds to an A constant of 1.51 and C constant of -0.10 (Raymer, 2018). The other inputs in the aircraft sizing code are not relevant to our aircraft because it is electric and does not have the fuel fractions that other aircraft require.

The initial takeoff weight of our aircraft is 2744.42 kg. To arrive at this value, we input the parameters explained above along with a guess of our aircraft weight. The initial aircraft weight guess does alter the initial takeoff weight; it solely affects the run time of the code.

The farther the guess is from the initial takeoff weight the longer the code runs for. Once all the parameters are inputted the code will enter a function to calculate the empty weight fraction shown in Figure 10. Using that empty weight fraction the code will then calculate the gross weight using the following equation: $W_0 = \frac{Wcrew + W\,payload}{(1 - Wf/W_0 - We/W_0)}$ (Raymer, 2018). We assumed the fuel fraction to be zero because the aircraft is electric. After W_0 is calculated it is compared back to the initial weight guess, if the two numbers are within 4.53 kg of each other than the W_0 is returned as the initial gross takeoff weight. If the two numbers are not within 4.53 kg of each other than the average between the calculated W_0 and W_0 guess is taken and then inputted back into the function as the new W_0 guess. This loop will iterate until the two numbers are within the 4.53 kg range. To validate the assumptions made in our calculation we compared our takeoff weights to the Eviation Alice. Alice has a maximum takeoff weight of 8346.1 kg and a maximum payload of 1100 kg (Eviation, 2022). Our aircraft payload weighs less than the payload of the Alice, however, you cannot scale down the takeoff weight using this fraction because this is not our aircraft's maximum payload capacity. Additionally given our battery mass fraction of 0.6 over half of the weight of aircraft is accounted for by the battery. A more accurate scaling down of the Alice to our aircraft would be about ⅓. Scaling the maximum takeoff weight of the Alice by ⅓ gives a mass of 2782 kg. This value is within 1.38% of our initial takeoff weight. This displays the validity of our calculation and the assumptions we made.

3.3 WING LOADING

For our aircraft we will need it to be maneuverable for the parabolic flight path, but we also did not want to lose sight of its cruise efficiency. The stakeholders in our design require our team to complete as many parabolas as possible, by including cruise efficiency as a factor determining our wing loading it will assist us in maximizing the total number of parabolas flown in a single mission. The two driving requirements of the project were maneuverability and cruise efficiency. These two requirements are contradictory. High cruise efficiency requires high wing loading, but better maneuverability requires lower wing loading. Considering our vehicle is focused on aerobatics, we can define it under air-to-air combat because it focuses on maneuverability. Under air-to-air combat, there are two further options being acceleration dominant and combat dominant. While our aircraft needs to perform aerobatics like an air-to-air combat aircraft it does not need the acceleration that is required of this vehicle. This meant we solely looked at a combat dominant aircraft. The wing loading estimate for air combat dominant aircraft is $W/S = (qC_{Lmax})/n$ where q is dynamic air pressure, C_{Lmax} is maximum coefficient of lift and n is load factor (Nicolai, L. M., & Carichner, G., 2010).

Dominant Mission Requirement	$(W/S)_{TO}$	Example
High-altitude, long-endurance solar-powered ISR[a]	0.5–3.0	Helios
Competition sailplanes	7–12	ASW 17
Light civil aircraft with short range and field length	10–30	C-172
High-altitude, long-endurance hydrocarbon-powered ISR	25–50	RQ-4A
STOL[b] and utility transports	40–90	C-130
Short or intermediate range with moderate field length	50–90	Learjet 35
Long-range transports and bombers (>3000 n mile)	110–150	B 747
Fighter, high-altitude	30–60	F-106
Fighter, air-to-air	50–80	F-15A
Fighter, close air support	65–90	A-10A
Fighter, strike interdiction	90–130	F-4E
Fighter, interceptor	120–150	F-104G
Low-altitude subsonic cruise missiles	200–240	AGM-109

Figure 11: Trends in Wing Loading (Nicolai, L. M., & Carichner, G., 2010)

There is no W/L equation given for cruise efficiency, but there is a table of W/L trends for various aircraft. Figure 11 represents trends for range dominated aircraft (cruise efficiency) and considering our aircraft an air-to-air fighter for maneuverability, the W/S values range from 50-80, so we took (50+80)/2 for an average, being 65.

Our team discussed that these two driving factors should be treated equally, as an aerobatic focus may not leave enough efficiency for the required number of parabolas. As for the opposite, range focused, too much engine efficiency and the aircraft may not be able to perform a parabola. So, we decided to take an average from the two values we found from the W/S equation and W/S table.

Considering n is 1.078 for standard fighter jets, which we will use considering our vehicle should be similar acrobatically, q at 10,00F0 feet is 51.3949 lbf at a cruise velocity of 340 fps, and we can calculate C_{Lmax} using average drag for aerobatic vehicles and our L/D, which are .05 and 25 respectively (Nicolai, L. M., & Carichner, G., 2010). W/S = (51.3949 * 1.25) / 1.078 = 59.6. From the table, we took a higher wing loading of 40 to not completely make it range-dominant but leave it in the upper range of 35 - 50 for aerodynamic emphasis. Finally, taking the average between 59.6 and 40, our wing loading should be a value of 49.8 lb/ft^2. By combining the table value with our calculated value not only does it allow us to balance aircraft characteristics

3.4 WING SIZE AND AIRFOIL CHARACTERISTICS

Wing Size

Calculating the wing area using a rearranged wing loading equation, $W_L = \frac{W}{S}$, we get $S = \frac{W}{W_L} = \frac{2744.418\ kg}{243.15\ kg/m^2} \approx 121.49 ft^2\ or\ 11.287\ m^2$. Knowing the aspect ratio (AR) relates the wing area (S) and chord values, we get a chord length total of $c_t + c_r = \frac{S}{AR} = \frac{11.287m^2}{8} \approx 1.4109\ m\ or\ 14.5199\ ft$. Since the taper ratio will be 0.35, the root chord length will be 1.76 m and the tail chord length is 0.62 m. The aspect ratio also can be written as $AR = \frac{b^2}{S}$, where b = wingspan. Using this equation, we get a wingspan of $b = \sqrt{AR \times S} = \sqrt{8 \times 11.287\ m^2} \approx 9.5029\ m$. The wingspan based on the measurements of Eviation Alice is about 19.2 m or 63 ft because our plane has a smaller wingspan as taken from Eviation (2022). While the Eviation Alice has a taper ratio of approximately 0.6 - 0.75 which is almost double our taper ratio, our chord lengths are reasonable because the mission requirements are different than that of the Alice. Therefore, it's reasonable to say that our values are reasonable.

Planforms

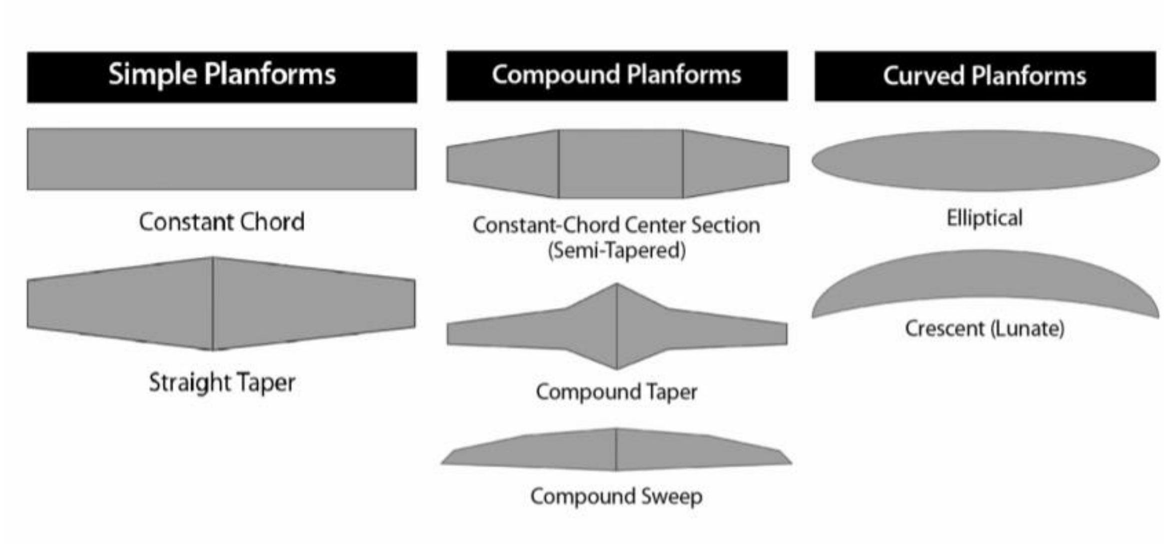

Figure 12: Different Wing Planforms (Wainfain, 2020)

There are plenty of planforms such as straight, compound, curved, and swept in which some are pictured in Figure 12. According to Wainfain (2020), the simplest planform is the constant chord. This planform is cheap to produce and design; however, these planforms have poor aerodynamic performance. The straight taper planform on the other hand has better aerodynamic efficiency than the constant chord and is more structurally efficient. The shape does mean that the aircraft would stall at the tip, so washouts would be needed. The semi-tapered wing is an "extended" version of the straight taper which allows the wing to have a better aerodynamic efficiency than the constant-chord wing, while maintaining many of the same advantages of the constant cord. The elliptical planform has the highest aerodynamic efficiency, and its manufacturability is poor (Wainfain, 2020). Swept planform wings are common for high-speed aircraft and are often used in military and commercial aircraft. The downside of swept wings is it reduces the potential lift.

The goal of our aircraft is to fly in parabolic arcs, so lift needs to be maximized and drag minimized. Given the different planforms a tapered planform seems appropriate; however, because the aircraft will need considerable speed compared to most general aviation aircraft it makes sense to have some sweep to the wings. Therefore, it makes sense to have a straight tapered planform with low back sweep. Moreover, a low sweep means that the lift potential will not be too hindered. Overall, this planform can provide low drag at high speeds with plenty of lift meaning it has a reasonable aerodynamic efficiency. Therefore, our aircraft will have low back-swept planforms as our aircraft needs to maximize lift and there is no need to go supersonic. The taper ratio will be about 0.35 as it minimizes induced drag and finite span downwash effects (Nicolai & Carichner, 2010).

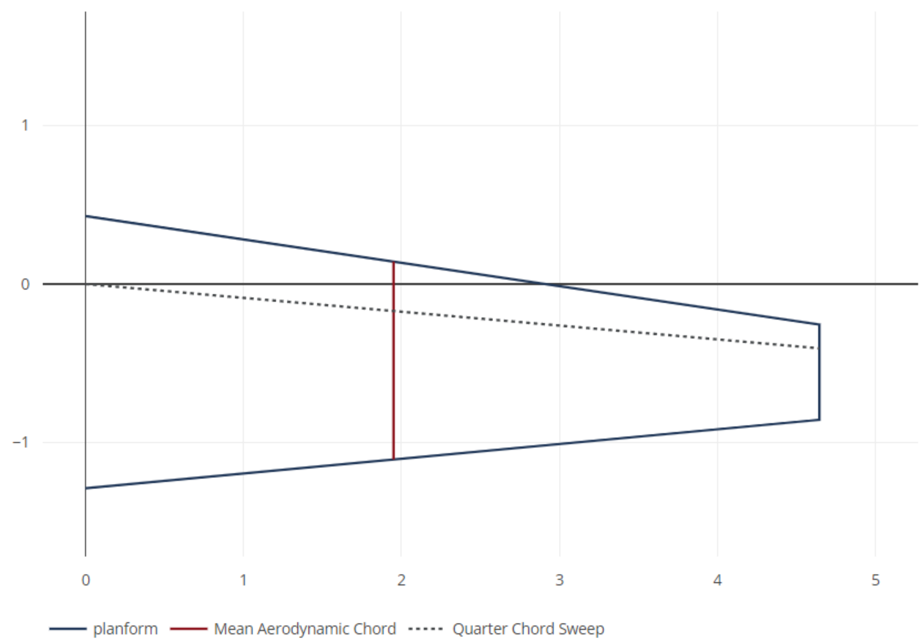

Figure 13: Representation of Planform with 5° Sweep Back generated from Aero Toolbox (Wood, 2022)

Airfoils and Lift/Drag Ratio

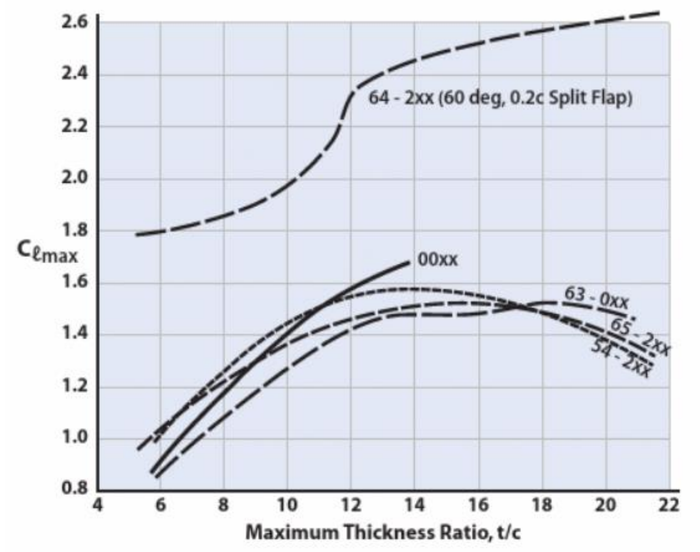

Figure 14: C_{Lmax} vs. t/c (Nicolai, 2010)

Since our C_{Lmax} was found to be approximately 1.25, the maximum thickness to chord ratio (t/c) is estimated to be 8% based on Figure 14. According to Carichner and Nicolai (2010, 171-194), the lower the t/c is generally associated better with better aerodynamics at the cost of wing weight. However, this tradeoff was necessary as our aircraft needs to maximize lift so better aerodynamics means a better lift to drag ratio. Moreover, 8% is a reasonable number because it balanced the tradeoffs, while prioritizing lift as t/c ranges from 3% to 21%.

The location of the t/c was considerably more difficult to determine because of the tradeoffs. The location determines the end of the favorable pressure gradient and the start of the adverse pressure gradient. Front loaded aircraft generate more lift but generate more skin friction drag while aft loaded aircraft have the opposite issue (Nicolai & Carichner, 2010, pp.171 - 194). Since the planform focuses a lot on maximizing lift, we need to focus on minimizing drag so we chose an aft loaded aircraft with a t/c location of 60%. This location would allow for some drag minimization, while not hurting lift potential too much.

The chamber should be a larger percentage to increase lift. Therefore, we will have a 5% chamber for near symmetry. In addition, a positive trailing edge chamber increases lift more than a positive leading-edge chamber. We don't want a massive chamber as it may upset our aerodynamic optimizations.

Figure 15: A18 (original) Airfoil (Airfoil Tools, 2022)

Using the UIUC Airfoil Coordinates Database, we chose to use the (al8-il) A18 (original) airfoil because its parameters best match our estimates with a max thickness of 7.5% and max chamber of 3.9% at 45% chord.

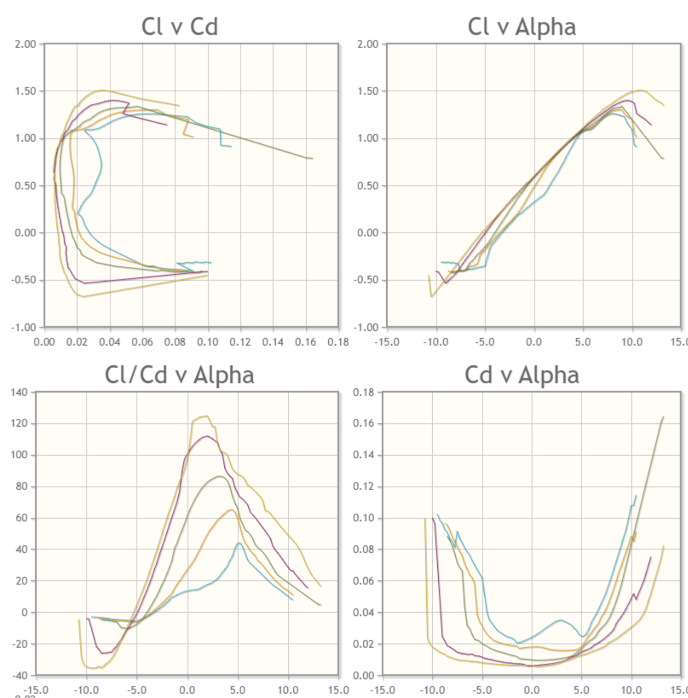

Figure 16: CL, CD, and Alpha Graphs (Airfoil Tools, 2022)

Looking at Figure 16, the C_{Lmax} is within the range of possible C_Ls, so our C_D will be about 0.05. This makes sense as our lift-to-drag ratio is 25, which while it is quite high, makes sense as we need a substantial amount of lift to complete parabolic arcs.

4 Detailed Concept, Selection, and Performance Analysis

In this section the final design parameters of the aircraft will be discussed. We will discuss the possibility of parabolic flight with our configuration and why we chose these values.

4.1 Concept Generation

To start our concept generation, we looked at vehicles with similar missions to ours. We looked at these aircrafts' overall design and design feathers to see features we may include in our own design. Three aircraft that we looked at were the Boeing 727-200, the Eviation Alice, and the Cessna 172. The 727 has a similar mission to our aircraft in that it is used for zero gravity test flights by the company Zero Gravity Corporation (Zero-G). One major difference between the use of the 727 and our aircraft is Zero-G's tests were on a much larger scale, our tests will have only one ~80 kg experiment and one crew member while the 727 could carry multiple passengers and very large tests (Zero Gravity Corporation, 2020). The Eviation Alice is what we based much of our design off, it does not have a similar mission to our aircraft in the zero g aspect, but it is a mid-sized electric aircraft. From the Alice we could find general numbers for electric aircraft parameters such as battery energy capacity, battery mass fraction, and engine types. We also took general aircraft parameters from the Alice like wing loading, wing surface area, and landing gear type. The Cessna 172 was a basis for the size of our aircraft, but the Cessna does not share a similar mission to our aircraft.

The major concepts we generated were two MagniX 650 engines, aft loaded wings with a surface area of 11.287 m^2, and tricycle landing gear. Alice uses two MagniX 650 engines to power itself (MagniX,2022). Given the assumption established in section 3.2 of our aircraft being smaller than the Alice, we believed two MagniX 650 engines would provide sufficient power to our aircraft, because it would have a more intensive mission than the Alice. The Magnix provides 650 horsepower, which is approximately equal to one million watts. The concept was confirmed to be adequate because in our climbing code we got realistic values for thrusts, powers, flight path angles, and number of parabolas. For our wings, the outputs did not depend on the location of the wing, but they did depend on the surface area. Plugging the surface area into the code for the parabolic flight in combination with the power values from the MagniX's, we were still achieving realistic outputs for our mission. As for the tricycle-oriented landing gear, we chose this concept because of its safety. Tricycle landing gear is the most conventional of aircraft because of its safety (N., 2020). This kind of landing gear reduces the chances of nosing over during takeoff by aiding handling and increase visibility for the pilot(s) (N., 2020). In our CAD model in section 4.3, the landing gear can be seen protruding from bays in the fuselage and wings. This landing gear is retractable, which increase performance by reducing a major source of drag (N., 2020).

4.2 CONCEPT SELECTION

The criteria we used for concept evaluation and selection were the number of parameters, the ease of visualization for a viewer, and the importance of the concept. We decided that each concept is equally important to the aircraft, because without one of them our aircraft would not function. For ease of use, we thought the wings and engines would be easiest to visualize and more useful to be represented in CAD for a viewer. This is due to the landing gear having external components like wiring and a bay door, which would be hard to capture in CAD and not as interesting to a viewer. We also had no numerical values associated with our landing gear, just the type, so we would not be able to properly dimension them. Our engine also did not have any numerical values except for power, which could not be physically represented in CAD. This led us to select the wings for our concept. Our wings were heavily analyzed due to the stress of aerodynamic efficiency in this project. The wings have the most numeric values associated with them, and we believe them to be easy and intuitive for the viewer to understand, so they would therefore be best represented using dimensioning in CAD.

4.3 CONCEPT REFINEMENT

Throughout milestones our aircraft design evolved dramatically. Our code was improved, and sizing parameters were continuously being re-evaluated to make sure outputs were realistic to our mission. One of our most reiterated design parameters was the takeoff mass. We used MATLAB code from previously in the semester to perform aircraft gross takeoff weight calculations. We realized that an essential component of aircraft mass sizing, fuel consumption rate, would be zero because of our electric powered propellers. To fix this and improve the code, we researched electric aircraft sizing and found a solution. But, when the code ran, our calculated take off mass was under 300 kilograms, very unrealistic. We did not use that idea and instead went back to the original sizing using zero as our fuel consumption rate, to obtain a more realistic mass for our aircraft.

Another way our project evolved was our reference aircraft. We began looking at a Cessna 172 and moved on to jets due to their aerodynamic capabilities and aerobatic ability. Our team quickly realized that these two kinds of aircraft were unrealistic in basing our calculations off. We found a very similar aircraft, the Eviation Alice, with two propellers and fully electrically powered. Alice did not have the same mission as ours, but we determined it a good reference aircraft because ours would be lighter with the same engines, so it could likely preform parabolas with its configuration.

The wings as discussed earlier would have a straight taper and a five degree sweep back. Each wing's root chord length is 1.76 meters and the tail chord length 0.62 meters. Using the thickness ratio (t/c) of .08 established in section 3.4, we can determine root and tail thicknesses by plugging in root lengths for c and solving for t. We found the root thickness to be .1408 meters and the tail thickness to be .0496 meters. The landing gear we decided on were retractable tricycle gears. We wanted to ensure safety and minimization of drag which is what tricycle landing gear offered as discussed in section 4.1. A secondary option was tail dragger gear which offered better rough terrain control and a more aggressive takeoff (N., 2020). However, the tail dragger decreases visibility, is prone to nosing over with too much breaking, and less steering control, we chose the tricycle format (N., 2020). Those reasons combined with the likelihood that we would not be taking off from or landing on rough ground, The two MagniX 650's worked very well with our configuration, so we finalized them as our engines for our aircraft. The 650's are an electric powerhouse powered by hydrogen fuel cells (MagniX, 2022). The supply 650 horsepower to the aircraft, which was a very good amount for our aircraft, according to our program for climbing flight discussed in section 4 (MagniX, 2022). The 650's power densities were not publicly listed, but according to a competing electric engine company H3X, their engines housed three times the power density of existing powerful engines (Blain, 2021). The proposed H3X engine has a power density of 13.3 kW/kg, and if we assume they are three times as powerful as the MagniX 650, we can assume each MagniX 650 has a power density of 4.43 kW/kg which falls within our requirements.

At this point we have discussed most of the parameters needed to calculate the thrust and power required, thrust and power available, and number of parabolas our aircraft can perform. Some parameters have not yet been discussed due to a necessary foundation until this point. In section 3.3 we determined our maximum lift coefficient to be 1.25, and according to Figure 16, the angle of attack corresponding to a maximum lift coefficient is 5 degrees. So, the angle of attack for our parabolic flight will be a constant 5 degrees. The second parameter we still need for our final design is the propeller efficiency. According to MIT, “in practice, the propulsive efficiency typically peaks at a level of around 0.8 for a propeller before various aerodynamic effects act to decay its performance” (n.d.). All our values up until now have been optimized for peak performance, so it is reasonable to assume propeller performance should also be at peak. The third parameter we need define is the Oswald efficiency factor. We have our aspect ratio, but we need the efficiency factor. Using a calculator for estimating the factor, by plugging in our aspect ratio of 8, we found an estimated Oswald efficiency factor of 0.8 (Calculator Academy, n.d.). The last parameter we need determined is the air density exponent. We used the air density exponent, being 0.6, from a recent lecture on a general aviation aircraft (Marais & Pourpoint, 2022). We used this due to the lack of information about air density exponents. Because of how new electric aircraft are, we deemed this value reasonable to use due to the lack of existing data and similarity of the Alice to general aviation aircraft.

The CAD we used for our aircraft was Kerbal Space Program. We constructed a full model of our aircraft in three orthographic views and dimensioned the wing according to our existing calculations.

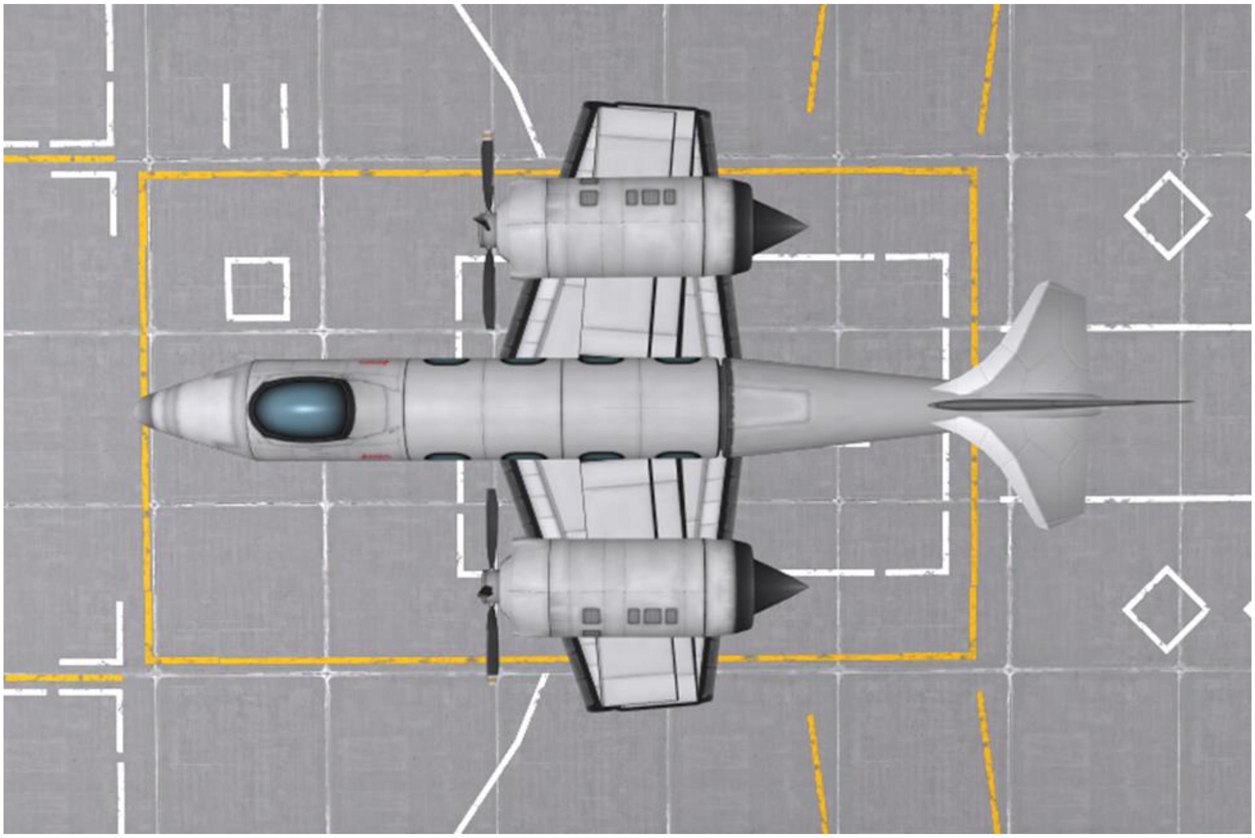

Figure 17: 3D Model Top View (Falanghe,2011)

Figure 18: 3D Model Frontal View (Falanghe,2011)

Figure 19: 3D Model Side View (Falanghe,2011)

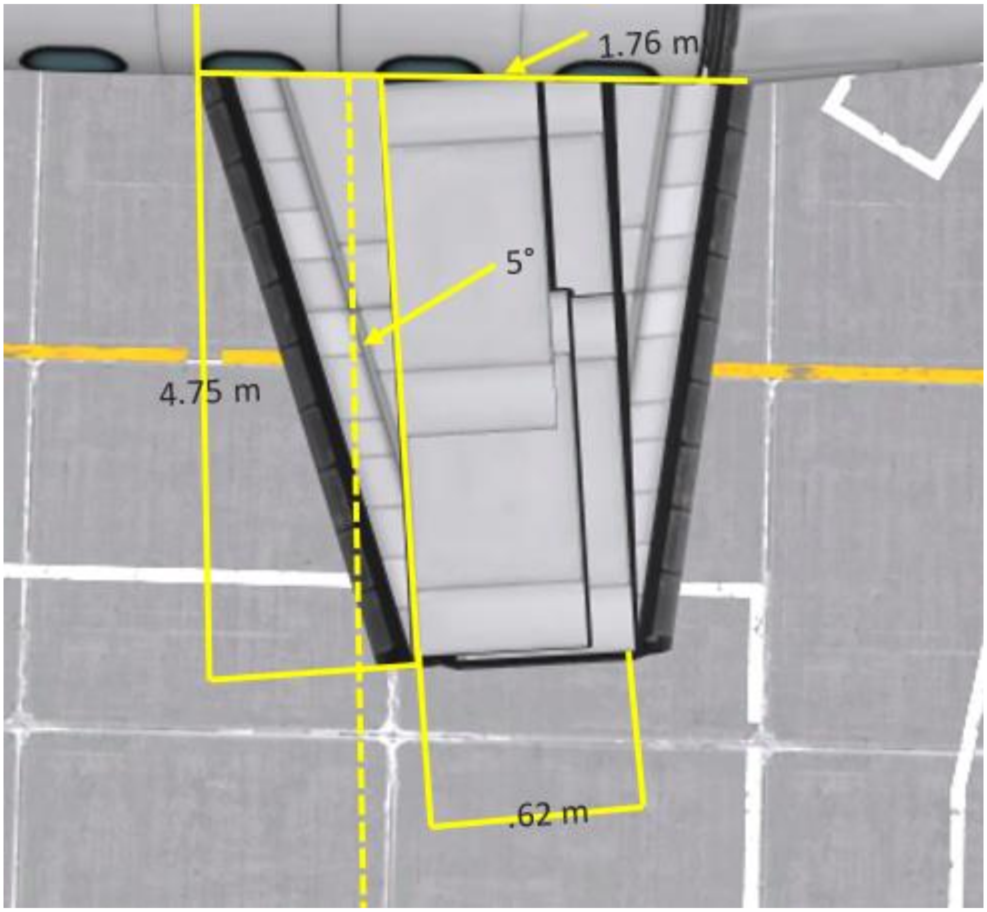

Figure 20: Wing 3D Model Top View (Falanghe,2011)

Figure 21: Wing 3D Model Side View (Falanghe,2011)

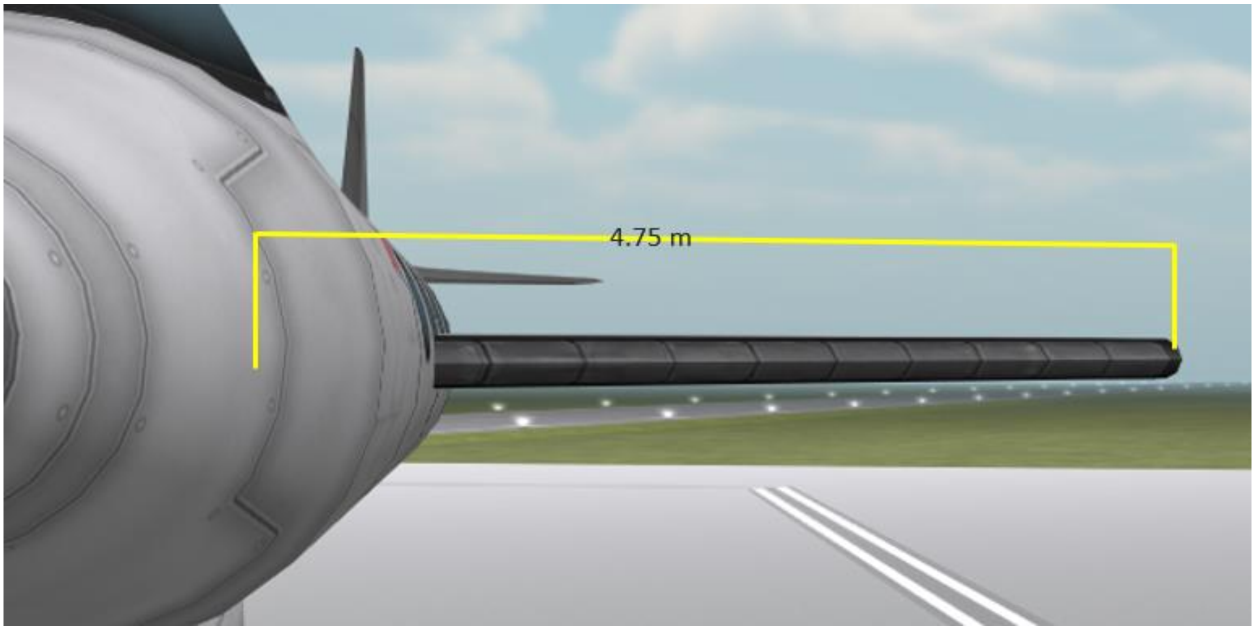

Figure 22: Wing 3D Model Frontal View (Falanghe,2011)

4.4 PERFORMANCE ANALYSIS

Drag polar

To estimate our zero-lift drag coefficient which would be needed in many calculations, we graphed our lift coefficients against our drag coefficients to determine a zero lift drag coefficient of 0.01.

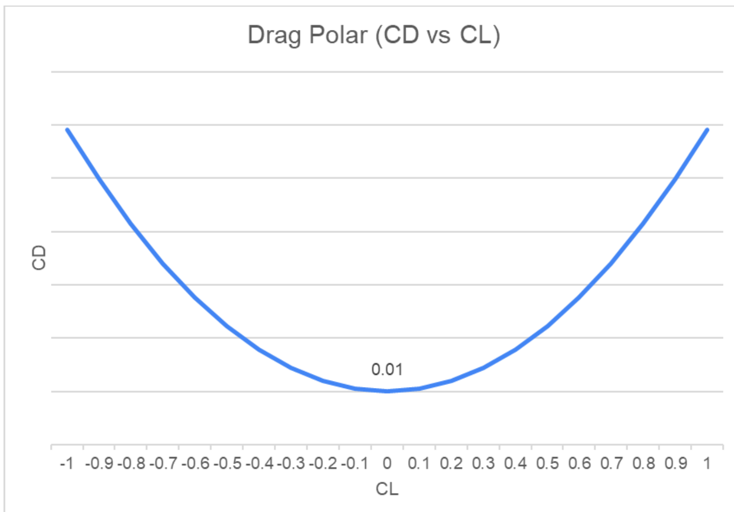

Figure 23: Drag Polar

Range And Endurance

To find the range and endurance for our aircraft we cannot use the standard range and endurance equations for propeller aircraft because those equations depend on fuel mass consumption and change in mass throughout the mission. Because our aircraft is battery powered there will not be any fuel mass consumption or change in mass throughout the mission. For electric aircraft there are Range and Endurance equations that use the batteries energy density instead of the fuel consumption and the battery mass to total mass fraction instead of the change in mass. These equations are as follows:

$$R = 3.6(E_{sb})\left(\frac{C_L}{C_D}\right)\left(\frac{\eta}{g}\right)\frac{m_b}{m}$$

$$E = E_{sb}\left(\frac{C_L}{C_D}\right)\left(\frac{\eta}{gv}\right)\frac{m_b}{m}$$

(Nicolai & Carichner, 2010)

Using a specific energy capacity for the battery of $E_{sb} = 250\ Wh/kg$, a battery mass fraction of $\frac{m_b}{m} = 0.6$, a propeller efficiency of $\eta = 0.8$, or zero lift drag coefficient of $C_{D,0} = .01$, and our k value of $k = .0491$ we can solve for the lift to drag ratio which will be at maximum aerodynamic efficiency for range:

$$\left(\frac{C_L}{C_D}\right)_{max} = \frac{1}{2}\sqrt{\frac{1}{kC_{D,0}}}$$

Plugging all of these into our range equation we get:

$$R = 3.6(250)\left(\frac{1}{2}\right)\sqrt{\frac{1}{.0491(.01)}}\left(\frac{.8}{9.81}\right)(0.6)$$

This gives us a maximum range of 993.67 km or 617.4 miles.

For maximum endurance the lift to drag ratio should be:

$$\left(\frac{{C_L}^{\frac{3}{2}}}{C_D}\right)_{max} = \frac{1}{4}\sqrt{\frac{3}{kC_{D,0}}}$$

The Endurance equation also requires the velocity which can be found through:

$$V = \sqrt{\frac{2mg}{\rho S C_L}} \text{ where } C_L = \sqrt{\frac{3C_{D,0}}{k}}$$

Plugging in our velocity and endurance lift to drag ration we get the maximum endurance is:

$$E = (250)\left(\frac{1}{4}\right)\sqrt{\frac{3}{(0.0491) * 0.01}}\left(\frac{.8}{9.81\sqrt{\frac{2(2744.4)(9.81)}{1.225(11.2)\sqrt{\frac{3(.01)}{.0491}}}}}\right)(0.6)$$

This gives us a maximum endurance of 3.37 hours.

Thrust, power, velocity, ceiling, and parabolic performance

Minimum thrust and power required were determined from a MATLAB script to calculate the maximum number of parabolas. We used the climbing flight equations from a lecture on what climbing flight looks like with constant velocity (Marais & Pourpoint, 2022). These equations only apply to unaccelerated flight, so we had to pick one velocity for our aircraft during flight. To decide what this velocity would be, we first ran the code to determine which index in our matrices would represent the peak of our parabola, or the location of the final value we would consider. WE determine our flight ceiling to be 4600 meters which marked the peak of the parabola, and the end of the parabola marked 3100 meters. We settled on these values because they were a little more than half of the go zero indicated parabolic altitudes, and because they translate to nice United States Customary Units of approximately 10,000 feet and 15,000 feet respectively. Now knowing our peak altitude, we want the flight path angle to be maximum at this altitude so we can get the best zero-g experience. We used an equation for velocity in which flight path angle is maximized from the same climbing flight lecture (Marais & Pourpoint, 2022). These velocities were calculated at every altitude in case we decided to change our flight ceiling, and once our ceiling was finalized, we settled on a constant flight velocity of 116.6726 meters per second because this optimized the flight path angle at the parabola's peak. This led to a flight path angle of 8.55 degrees, and with our constant angle of attack of five degrees, our pitch angle at peak parabolic height is 13.55, roughly three to four times less than GoZeroG's pitch angle. Parabolic flight is certainly possible with our aircraft but given what we know about the intense pitch angles needed for zero gravity simulation, the duration or quality would very likely be lower.

Because we had our flight paths calculated, at every altitude, we could calculate the amount of time it took to reach any altitude. We could also calculate the minimum power required and minimum thrust required of the aircraft. We chose to approximate the time it takes for one full parabola by finding the time it takes to reach 3100 meters from takeoff, the time it takes to reach 4600 meters from takeoff, take the difference, and multiply by two to account for the ascent and descent of the parabola. This is a very rough approximation as there is instantaneous change in rate of climb unaccounted for. We then used the SLUF (steady level unaccelerated flight) endurance to calculate the maximum number of parabolas. This endurance value was multiplied by 0.8 to ensure 20 percent battery reserves at landing. We determined this number of parabolas an acceptable estimate because both were the best values, we could come up with the information given. We could not calculate the aircraft endurance from climbing flight due to the complexity, only from SLUF. One very important note is that the matrices in our code, or arrays, can store a total of 300 values for the sake of sizing different aircraft, meaning that any values past our 46th calculated value, our maximum altitude of our aircraft, for any matrix are not necessarily accurate.

We calculated the velocity where flight path would be maximized, but we also calculated the minimum and maximum velocity of the aircraft at any altitude. For these velocities, we used a SLUF minimum velocity equation from a thrust required and power required lecture, as well as a maximum velocity derivation from the same lecture (Marais & Pourpoint, 2022). After running the program, it was determined that the minimum velocity is 92.89 m/s (not necessarily accurate because of SLUF, we are climbing) the maximum velocity is 241.6496 m/s, the minimum power required is 606,260 watts, and the minimum thrust required is 5196.2 newtons. These minimums and maximums were found within indices one to forty-six of our matrices, which is our flight range. The graphs however may show different minimum and maximum values because of the much larger 30-kilometer range. Finally, with all this information, the program produced a total of five important graphs, including Figure 9 previously shown.

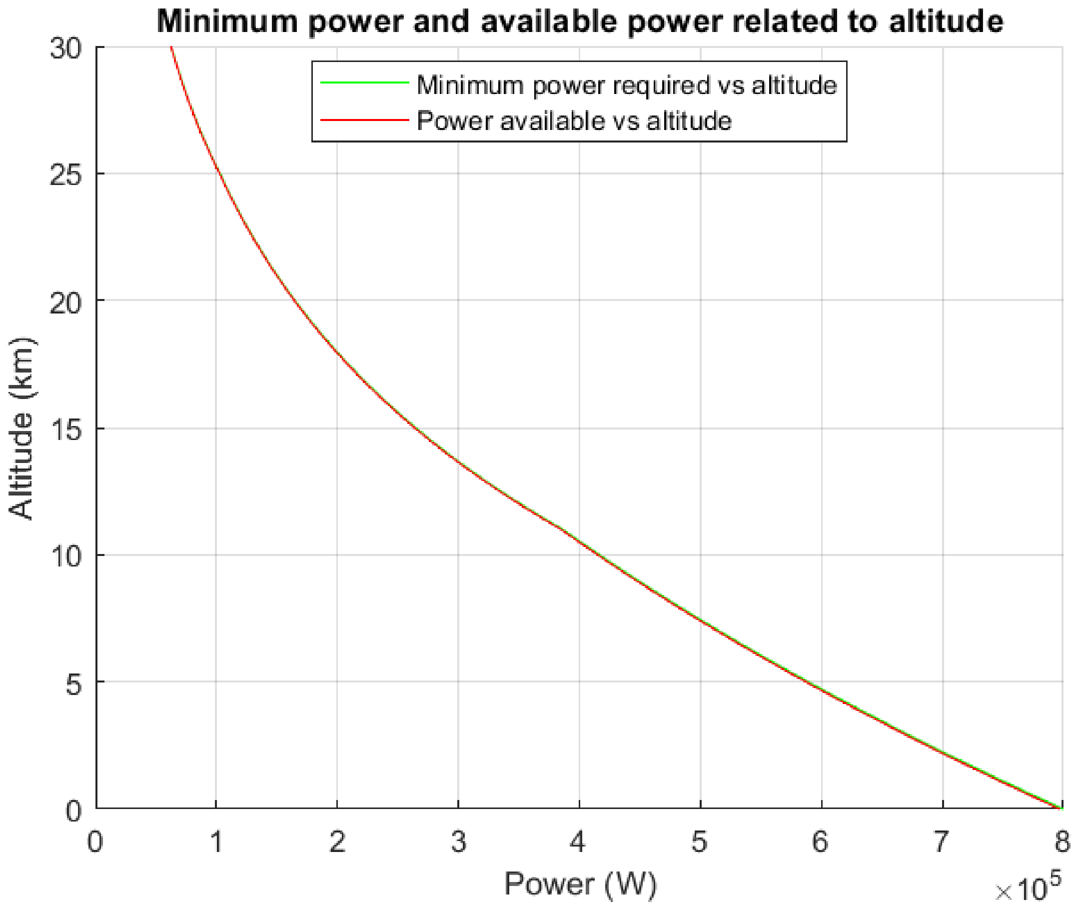

Figure 24: Power available and power required at varying altitudes

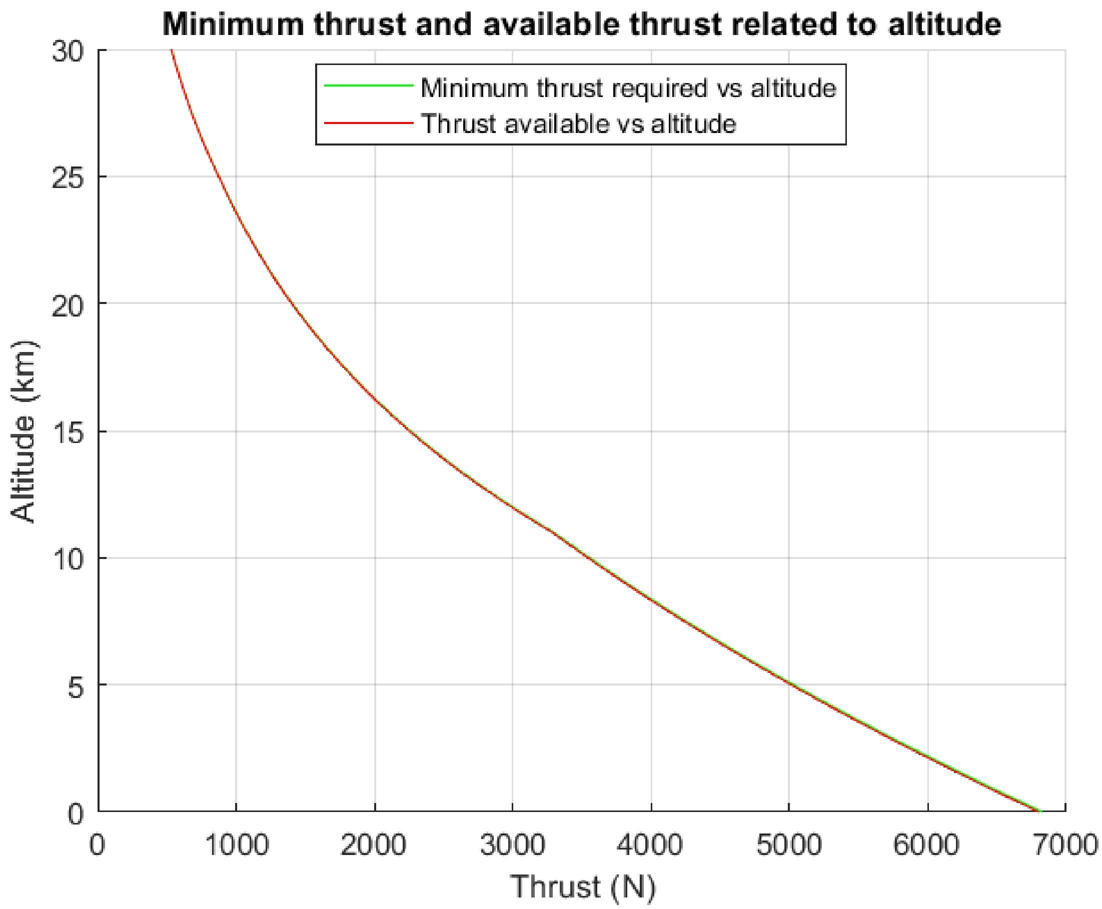

Figure 25: Thrust available and thrust required at varying altitudes

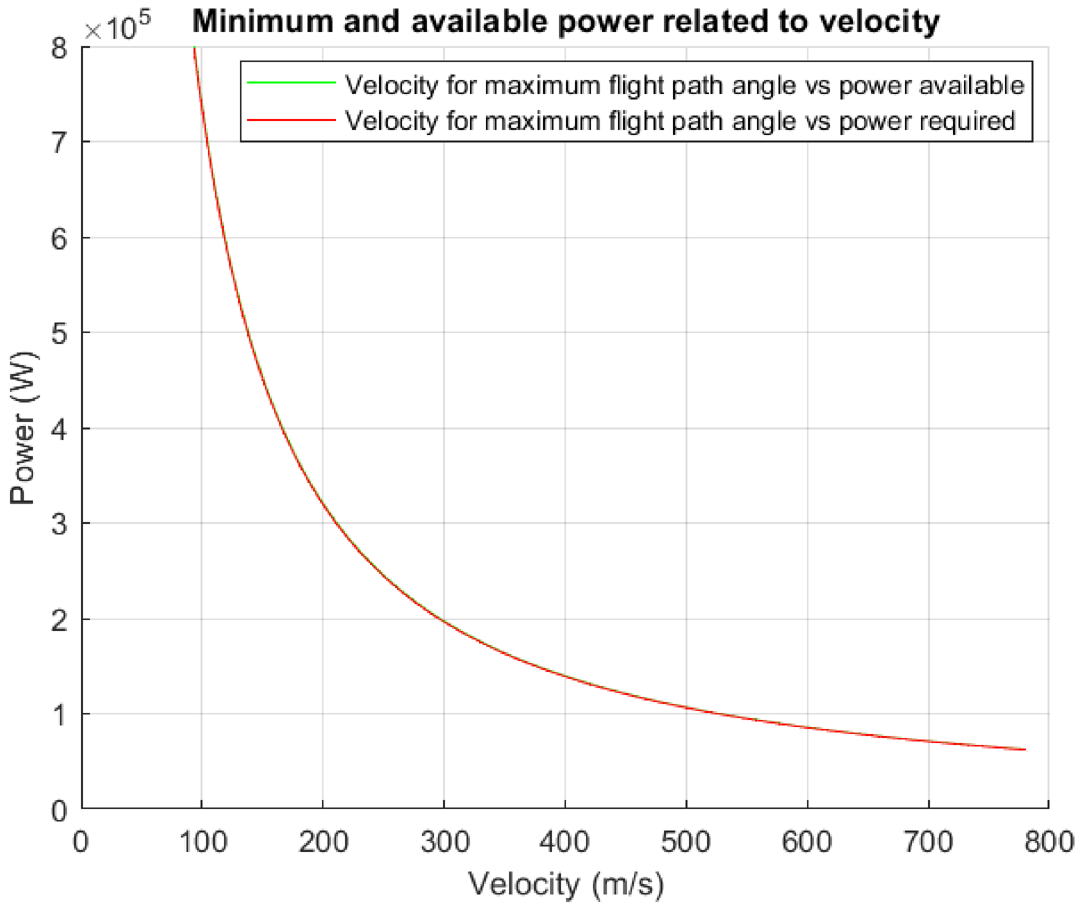

Figure 26: Power available and power required at varying velocities

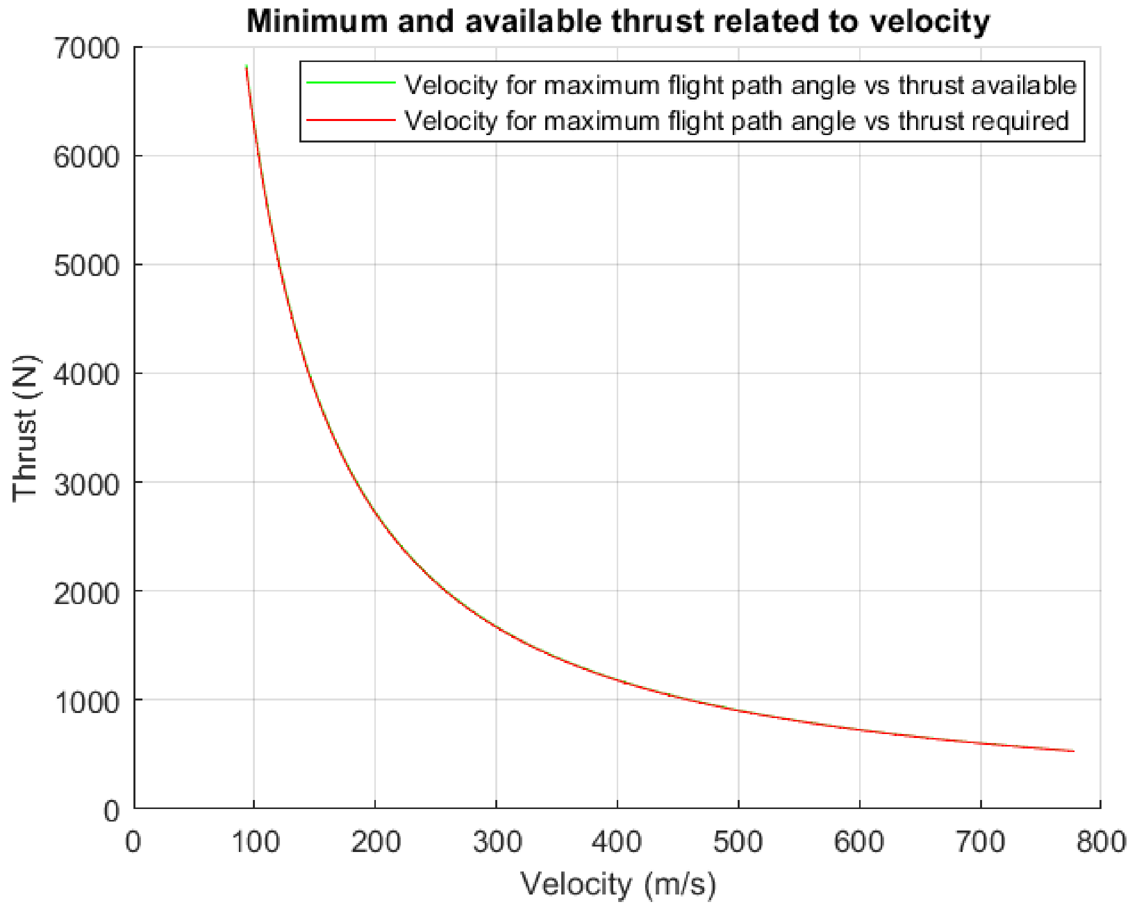

Figure 27: Thrust available and thrust required at varying velocities

5 CONCLUSIONS

In this section, we'll evaluate the final design of the aircraft and consider the various changes and characteristics that will allow it to succeed in its mission. We'll also discuss the numerous lessons learned throughout the design process of the aircraft and go over next steps that can be taken in its development.

5.1 DESIGN EVALUATION

We believe that we've ultimately designed an aircraft that will work and be successful in its mission to perform zero-gravity flight maneuvers. This is due to two main factors: our rigorous research and the references to current aircraft included in our final design. On the research side, each value that was determined for the aircraft, from the range to the lift/drag ratio, is rooted in thorough background research and was repeatedly validated. This starts by finding and analyzing equations and programs that have been historically successful in determining aircraft parameters. After entering known characteristics of the aircraft and receiving a final value for our target parameter, it's compared to the rest of the aircraft's parameters to ensure that it's a reasonable figure to apply. In this way, we've ensured that all aspects of aircraft were determined mathematically and have evidence to support them. The second factor our group has relied on is referencing aircraft that are currently flying with a mission that is similar to ours. By examining the existing designs referenced earlier in this report, we were able to both determine estimates for design parameters early on based on the other aircraft and verify that our final values were in-line with our design. By using these two strategies in conjunction, we were able to create a final design that maximizes performance for the project's mission while achieving and maintaining the design requirements.

5.2 NEXT STEPS

Though our group's final design for this project is complete given the current set of requirements, there are several steps that can be taken to both improve the aircraft's design and the overall project. One step that can be taken is improving the accuracy of calculations and parameters across the board. Even though the process for determining the aircraft's parameters is evidence based and rooted in real-world models, the overall accuracy of both the inputs to various equations and their outputs should be improved as more is determined about the aircraft and the design requirements evolve. Another step that can be taken is the development of a higher-fidelity CAD model of the aircraft. The one the group has currently developed is appropriate given our goals and use of the model, but if the project were to progress and more characteristics were able to be determined about the aircraft, a model with greater detail would display the work done by the group more accurately. Beyond improvements to the current design of our aircraft, there are several steps the project can take in the future. One of these steps is more research into batteries, including different chemistries, brands, and sizes that would be suitable to use on the aircraft. Since different batteries vary with respect to energy density, capacity, and risks associated with their design, this would be an important problem to solve for the project's future. Another step that can be taken is the determination of construction characteristics of the aircraft, including materials used in the airframe and exterior. This would have a considerable impact on aircraft weight and design, so estimating its construction could be useful for future cost analysis and performance parameters. One final thing that can be done in the project's future is the creation of a physical model of the aircraft. This would not only improve understanding of the overall design of the aircraft, but it could also be used for testing of aerodynamics and other characteristics that would improve the feasibility of the aircraft's design.

5.3 LESSONS LEARNT

Since this project has several different components and needs, there were also a wide variety of lessons learned over the course of the project. For one, the group learned how to apply concepts that were taught throughout the semester, such as aircraft sizing, airfoil selection, range calculations, etc., to an actual problem. We also learned how to employ an evidence-based approach to the design of an aircraft and ensure that we were using proper engineering techniques to develop a final design. Finally, the group spent a lot of time learning how to coordinate everyone's efforts, including assigning different roles and tasks, using google docs as an effective collaboration platform, and using meeting time to discuss ideas and the future of the project.

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APPENDIX: MATLAB CODE

Aircraft flight performance code:

```
% AAE 251 Fall 2022
% Title of the code: Parabolic flight configurations

% Authors: Aidan Morrison

%% ____________________
%% INITIALIZATION

full_mass = 2744.418; % mass of aircraft (kg)
K = .0491; % oswald aspect ratio coefficient (unitless)
CD0 = .01; % parasitic drag coefficient (unitless)
SA = 11.287; % aicraft surface area (m^2)
max_power = 1000000; % power that two 350 hp magnix's deliver (watts)
prop_efficiency = .8; % traditional propeller efficiency of a prop aircraft
(unitless)
AD = .6; % air density exponent (unitless)
throttle_setting = 1; % throttle setting (unitless)
G = 9.81; % gravitational acceleration (m/s^2)
H1 = 0; % sea level height (m)
T1 = 288.16; % sea level temperature (K)
A = -6.5e-3; % change in temperature constant for first altitude layer (unitless)
rho1 = 1.225; % reference density (kg/m^3)
S_rho = 1.225; % sea level density (kg/m^3)
R = 287; % gas constant (unitless)
P1 = 1.01325e5; % sea level pressure (N/m^2)
AA = 5; % ascending angle of attack (degrees)
cruise_velocity = 116.6726; % cruise velocity at 3100 meters (meters/second)
W2S = (full_mass * G) / SA; % wing loading ratio
AR = 8; % aspect ratio
cruise_altitude = 3100; % cruising altitude or beginning of parabolic climb (meters)
peak_altitude = 4600; % peak altitude of parabolic arc (meters) --- Maximum altitude,
so aircraft not optimized past indices of 46
endurance = 12132; % maximum time aircraft can stay in air (seconds)

% create empty arrays
Preq = zeros(1,301); % minimum power array
Pavail = zeros(1,301); % available power array
Treq = zeros(1,301); % minimum thrust array
Tavail = zeros(1,301); % available thrust array
densities_si = zeros(1,301); % densities array
altitudes_si = zeros(1,301); % altitudes array
flight_paths = zeros(1,301); % flight path angles array
drag = zeros(1,301); % drag array
cruise_speeds = zeros(1,301); % aircraft speed for max flight path angle array
max_velocities = zeros(1,301); % aircraft maximum velocity array
min_velocities = zeros(1,301); % aircraft minimum velocity array
ROCS = zeros(1,301); % aircraft rates of climb

%% ____________________
%% CALCULATIONS
```

```
i = 1; % index for storing calculations in vectors
for h = 0:100:30000
    if h <= 11000 % calculations for first altitude segment

        temp = T1 + A *(h - H1); % calculate temperature
        pressure = P1 * (temp / T1)^(-G/(A * R)); % calculate pressure
        density = rho1 * (temp / T1)^-(G /(A * R) + 1); % calculate density
        densities_si(i) = density; % store density in vector

        cruise_speeds(i) = sqrt(((2 * full_mass * G) / (densities_si(i) * SA))  *
sqrt(K/CD0)); % ascending speed at which flight path is maximized (m/s)

        Pavail(i) = max_power * prop_efficiency * (densities_si(i) / S_rho)^AD; %
calculate available power
        Tavail(i) = Pavail(i) / cruise_velocity; % calculate thrust available using
power = thrust * velocity relation
        drag(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^2 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity^2)); % calculate drag
        flight_paths(i) = asind((((Tavail(i) * cosd(AA)) - drag(i))) / (full_mass *
G)); % ascending flight path angle (degrees)

        ROCS(i) = cruise_velocity * sind(flight_paths(i)); % aircraft rate of climb
at a given altitude (meters/second)
        Treq(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^2 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity^2)) + full_mass * G *
sind(flight_paths(i)); % calulate required thrust
        Preq(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^3 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity)) + full_mass * G *
sind(flight_paths(i)) * cruise_velocity; % calulate required power

        T2W_max = Tavail(i) / (full_mass * G); % thrust to weight ratio for maximum
velocity
        T2W_min = Treq(i) / (full_mass * G); % thrust to weight ratio for minimum
velocity

        max_velocities(i) = sqrt(T2W_max * W2S + (W2S * sqrt(T2W_max^2 - (4 * K *
CD0)) / (density * CD0))); % maximum aircraft velocity at a given altitude
        min_velocities(i) = sqrt((2 * full_mass * G) / (density * SA) *
(sqrt(K/CD0))); % minimum aircraft velocity at a given altitude

        if h == 11000 % change reference numbers for calculations in next altitude
section
            H1 = h;
            T1 = temp;
            P1 = pressure;
            rho1 = density;
        end

    elseif h >= 11100 && h <= 25000 % calculations for second altitude segment
(constant temp)

        temp = T1; % calculate temperature
        pressure = P1 * exp(-(G / (R * temp) * (h - H1))); % calculate pressure
        density = rho1 * pressure / P1; % calculate density
```

```
        densities_si(i) = density; % store density in vector

        cruise_speeds(i) = sqrt(((2 * full_mass * G) / (densities_si(i) * SA))  *
sqrt(K/CD0)); % ascending speed at which flight path is maximized (m/s)

        Pavail(i) = max_power * prop_efficiency * (densities_si(i) / S_rho)^AD; %
calculate available power
        Tavail(i) = Pavail(i) / cruise_velocity; % calculate thrust available using
power = thrust * velocity relation
        drag(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^2 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity^2)); % calculate drag
        flight_paths(i) = asind((((Tavail(i) * cosd(AA)) - drag(i))) / (full_mass *
G)); % ascending flight path angle (degrees)

        ROCS(i) = cruise_velocity * sind(flight_paths(i)); % aircraft rate of climb
at a given altitude (meters/second)
        Treq(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^2 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity^2)) + full_mass * G *
sind(flight_paths(i)); % calulate required thrust
        Preq(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^3 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity)) + full_mass * G *
sind(flight_paths(i)) * cruise_velocity; % calulate required power

        T2W_max = Tavail(i) / (full_mass * G); % thrust to weight ratio for maximum
velocity
        T2W_min = Treq(i) / (full_mass * G); % thrust to weight ratio for minimum
velocity

        max_velocities(i) = sqrt(T2W_max * W2S + (W2S * sqrt(T2W_max^2 - (4 * K *
CD0)) / (density * CD0))); % maximum aircraft velocity at a given altitude
        min_velocities(i) = sqrt((2 * full_mass * G) / (density * SA) *
(sqrt(K/CD0))); % minimum aircraft velocity at a given altitude

        if h == 25000 % change reference numbers for calculations in next altitude
section
            H1 = h;
            T1 = temp;
            rho1 = density;
            A = 3e-3;
        end

    elseif h > 25000 && h <= 30000 % calculations for last altitude segment

        temp = T1 + A *(h - H1); % calculate temperature
        pressure = P1 * (temp / T1)^(-G/(A * R)); % calculate pressure
        density = rho1 * (temp / T1)^-(G /(A * R) + 1); % calculate density
        densities_si(i) = density; % store density in vector

        cruise_speeds(i) = sqrt(((2 * full_mass * G) / (densities_si(i) * SA))  *
sqrt(K/CD0)); % ascending speed at which flight path is maximized (m/s)

        Pavail(i) = max_power * prop_efficiency * (densities_si(i) / S_rho)^AD; %
calculate available power
        Tavail(i) = Pavail(i) / cruise_velocity; % calculate thrust available using
power = thrust * velocity relation
```

```
        drag(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^2 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity^2)); % calculate drag
        flight_paths(i) = asind((((Tavail(i) * cosd(AA)) - drag(i))) / (full_mass *
G)); % ascending flight path angle (degrees)

        ROCS(i) = cruise_velocity * sind(flight_paths(i)); % aircraft rate of climb
at a given altitude (meters/second)
        Treq(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^2 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity^2)) + full_mass * G *
sind(flight_paths(i)); % calulate required thrust
        Preq(i) = 0.5 * densities_si(i) * SA * CD0 * cruise_velocity^3 + (2 * K *
((full_mass * G)^2) / (densities_si(i) * SA * cruise_velocity)) + full_mass * G *
sind(flight_paths(i)) * cruise_velocity; % calulate required power

        T2W_max = Tavail(i) / (full_mass * G); % thrust to weight ratio for maximum
velocity
        T2W_min = Treq(i) / (full_mass * G); % thrust to weight ratio for minimum
velocity

        max_velocities(i) = sqrt(T2W_max * W2S + (W2S * sqrt(T2W_max^2 - (4 * K *
CD0)) / (density * CD0))); % maximum aircraft velocity at a given altitude
        min_velocities(i) = sqrt((2 * full_mass * G) / (density * SA) *
(sqrt(K/CD0))); % minimum aircraft velocity at a given altitude

    end

altitudes_si(i) = h / 1000; % convert altitudes from m to km

i = i + 1; % add index so values get stored in unique locations

end

%% ____________________
%% ROUGHLY CALCULATE NUMBER OF PARABOLAS AND DISPLAY FINAL CALCULATIONS

% calculate times of maneuver starts
T2cruise = cruise_altitude / ROCS(31); % calculate time until cruise altitude reached
(parabolic arc starting altitude)
T2peak = peak_altitude / ROCS(46); % calculate time until peak of parabola is reached
from takeoff
parabola_time = 2 * (T2peak - T2cruise); % calculate time it takes to complete one
parabola

%calculate time and number of parabolas
total_parabola_time = (endurance - 2 * T2cruise) * 0.8; % calculated by subtracting
times to get up to initial parabolic altitude and down from parabolic altitude, and
multiplied by 0.8 to ensure 20% battery reserves
total_parabolas = total_parabola_time / (2 * (T2peak - T2cruise)); % calculate the
number of total parabolas possible

% create vectors for plotting parabolic flight
climb_times = [0 T2cruise];
climb_altitudes = [0 cruise_altitude];
```

```
descent_altitudes = [cruise_altitude 0]; % descent times are not calculated here due
to their dependence on the final parabolic descent times

parabola_ascent_times = [T2cruise T2peak];
parabola_ascent_altitudes = [cruise_altitude peak_altitude];

parabola_descent_times = [T2peak (T2peak + (T2peak - T2cruise))];
parabola_descent_altitudes = [peak_altitude cruise_altitude];

% print final values
fprintf('Total number of parabolas is %.2f\n',total_parabolas);

%% ____________________
%% PLOT FIGURES

% plot power avail and required vs altitude
figure(1)
grid on
hold on
plot(Pavail,altitudes_si,'g-')
plot(Preq,altitudes_si,'r-')
title('Minimum power and available power related to altitude')
legend('Minimum power required vs altitude','Power available vs
altitude','Location','best')
xlabel('Power (W)')
ylabel('Altitude (km)')

% plot thrust avail and required vs altitude
figure(2)
grid on
hold on
plot(Tavail,altitudes_si,'g-')
plot(Treq,altitudes_si,'r-')
title('Minimum thrust and available thrust related to altitude')
legend('Minimum thrust required vs altitude','Thrust available vs
altitude','Location','best')
xlabel('Thrust (N)')
ylabel('Altitude (km)')

% plot velocity vs power avail and required
figure(3)
grid on
hold on
plot(cruise_speeds,Pavail,'g-')
plot(cruise_speeds,Preq,'r-')
title('Minimum and available power related to velocity')
legend('Velocity for maximum flight path angle vs power available','Velocity for
maximum flight path angle vs power required','Location','best')
xlabel('Velocity (m/s)')
ylabel('Power (W)')

% plot velocity vs thrust avail and required
figure(4)
grid on
hold on
```

```
plot(cruise_speeds,Tavail,'g-')
plot(cruise_speeds,Treq,'r-')
title('Minimum and available thrust related to velocity')
legend('Velocity for maximum flight path angle vs thrust available','Velocity for
maximum flight path angle vs thrust required','Location','best')
xlabel('Velocity (m/s)')
ylabel('Thrust (N)')

% roughly plot parabolic arcs over time
figure(5)
grid on
hold on

plot(0,0);
plot(climb_times,climb_altitudes,'k-')

for i = 1:total_parabolas

    plot(parabola_ascent_times,parabola_ascent_altitudes,'g-')
    plot(parabola_descent_times,parabola_descent_altitudes,'r-')

    parabola_ascent_times = parabola_ascent_times + (2 *(T2peak - T2cruise));
    parabola_descent_times = parabola_descent_times + (2 *(T2peak - T2cruise));

end

descent_times = [parabola_ascent_times(1) parabola_ascent_times(1) + T2cruise];

plot(descent_times,descent_altitudes,'b-');

title('Model of maximum number of parabolas and their altitudes over time')
xlabel('time (seconds)')
ylabel('altitude (meters)')

legend('Descent to landing','Ascent to cruise','Upwards parabolic climb','Downwards
parabolic dive','Location','best')


%% ____________________
%% ACADEMIC INTEGRITY STATEMENT
% I have not used source code obtained from any other unauthorized
% source, either modified or unmodified. I have not provided
% access to my code to anyone in any way. The script I am
% submitting is my own original work.
```

Aircraft Sizing Code:

```
% AAE 251 Fall 2022

% Final Project

% Title of the code: simulated take off weight calculation of an aircraft.

% Authors: Amrith Akula, Vishva Chidambaram, Aidan Morrison, Dan Powley, Ryan Swanson, Leean Zhong

%% ____________________

%% INITIALIZATION

fprintf('Please enter all inputs in english units. They will be converted to metric if you wish.\n')

units = input('Please input 1 if you want metric or 2 if you want english units\n');

aircraft = input(['Please input 1 for unpowered sailplane, 2 for powered sailplane, 3 for homebuild wood/metal, ' ...

   '\n4 for homebuilt composite, 5 for single engine GA, 6 for twin engine GA,\n7 for agricultural aircraft, 8 for twin turboprop, ' ...

   '9 for flying boat,\n10 for jet trainer, 11 for jet fighter, 12 for military cargo/bomber, or 13 for jet transport.\n']);

engine = input(['Please input 1 for pure turbojet, 2 for low bypass-turbofan, 3 for high-bypass turbofan,' ...

   '\n4 for fixed piston-prop, 5 for variable piston-prop, or 6 for turboprop.\n']);

M = input('Please enter mach number.\n');

R = input('Please enter range in nautical miles.\n');

LD1 = input('Please enter lift/drag ratio.\n');

CC1 = input('Please enter specific fuel consumption per hour for cruise 1.\n');
```

```
CC2 = input('Please enter specific fuel consumption per hour for cruise 2.\n');

E1 = input('Please enter loiter 1 time in hours.\n');

E2 = input('Please enter loiter 2 time in hours.\n');

KVS = input('Please enter 1 for fixed sweep or 1.04 for variable sweep\n');

payload_weight = input('What is the payload weight?\n');

crew_weight = input('What is the crew weight?\n');

weight_guess = input('Please enter guess for aircraft weight\n');

% given weight ratios

W1_W0 = .97;

W2_W1 = .985;

W7_W6 = .995;

%% ____________________

%% CALCULATE  W7_W0

% Conversions

R = R * 6076.12; % range in feet

CC1 = CC1 / 3600; % 1st cruise C

CC2 = CC2 / 3600; % 2nd cruise C

V = M * 994.8; % velocity

E1 = E1 * 3600; % 1st loiter E

E2 = E2 * 3600; % 2nd loiter E

LD2 = LD1 * .866;

% Cruise 1
```

```
if engine >= 1 && engine <= 3

   W3_W2 = exp((-R * CC1 / V) / LD2); % weight ratio of cruise 1 for jets

else

   W3_W2 = exp((-R * CC1 / V) / LD1); % weight ratio of cruise 1 for propellers

end

% Loiter 1

if engine >= 1 && engine <= 3



   W4_W3 = exp(-(E1 * CC2) / LD1); % weight ratio of loiter 1 for jets



else

   W4_W3 = exp(-(E1 * CC2) / LD2); % weight ratio of loiter 1 for propellors



end

% Cruise 2

W5_W4 = W3_W2;

% Loiter 2

if engine >= 1 && engine <= 3



   W6_W5 = exp(-(E2 * CC2) / LD1); % weight ratio of loiter 1 for jets



else
```

```
    W6_W5 = exp(-(E2 * CC2) / LD2); % weight ratio of loiter 1 for propellers

end

W7_W0 = W7_W6 * W6_W5 * W5_W4 * W4_W3 * W3_W2 * W2_W1 * W1_W0;

%% ____________________

%% CALCULATE W0

% calculated W0

W0 = AAE251_HW2_function(W7_W0,weight_guess,crew_weight,payload_weight,KVS,aircraft);

% loop to find W0 within certain error

while W0 - weight_guess >= 10 || W0 - weight_guess <= -10

    weight_guess = (weight_guess + W0) / 2;

    W0 = AAE251_HW2_function(W7_W0,weight_guess,crew_weight,payload_weight,KVS,aircraft);

end

if units == 1

    fprintf('Takeoff weight within 4.53 kg error is %f\n',W0 * 2.205);

else

    fprintf('Takeoff weight within 10 lb error is %f\n',W0);

end

%% ____________________

%% ACADEMIC INTEGRITY STATEMENT
```

```
% I have not used source code obtained from any other unauthorized

% source, either modified or unmodified. I have not provided

% access to my code to anyone in any way. The script I am

% submitting is my own original work.

function [W0] =
AAE251_HW2_function(W7_W0,weight_guess,crew_weight,payload_weight,KVS,aircraf
t)

switch aircraft

   case 1

       We_W0 = .86 * weight_guess^-.05 * KVS;

   case 2

       We_W0 = .91 * weight_guess^-.05 * KVS;

   case 3

       We_W0 = 1.19 * weight_guess^-.09 * KVS;

   case 4

        We_W0 = 1.15 * weight_guess^-.09 * KVS;

   case 5

        We_W0 = 2.36 * weight_guess^-.18 * KVS;

   case 6

        We_W0 = 1.51 * weight_guess^-.1 * KVS;

   case 7

        We_W0 = .74 * weight_guess^-.03 * KVS;

   case 8
```

```
        We_W0 = .96 * weight_guess^-.05 * KVS;
    case 9
        We_W0 = 1.09 * weight_guess^-.05 * KVS;
    case 10
        We_W0 = 1.59 * weight_guess^-.1 * KVS;
    case 11
        We_W0 = 2.34 * weight_guess^-.13 * KVS;
    case 12
        We_W0 = .93 * weight_guess^-.07 * KVS;
    case 13
        We_W0 = 1.02 * weight_guess^-.06 * KVS;
end


%% ____________________
%% CALCULATE FINAL W0
Wf_W0 = 1.06 * (1 - W7_W0);
W0 = (crew_weight + payload_weight) / (1 - Wf_W0 - We_W0
```