AAE 25100: Introduction to Aerospace Design

Credit Hours	3
Offered	Fall and Spring
Pre-requisites	ENGR 13200 or 14200 or 16200 or EPCS 12100
Co-requisites	CGT 16300 and (CS 15900 or 17700 or 18000) and AAE 20000
Instructional Method	3 hours of lecture per week
Required	Yes

1. Course Description

The course is intended to serve as an introduction to the design of aerospace systems. Students work in teams over the semester to develop either a space system or an aircraft design. Students will learn about the process of designing a system, from figuring out how to turn a vague idea into a detailed concept design, to how to communicate their idea in writing and orally. The course will introduce the key aerospace engineering concepts, principles, and technical knowledge.

2. Instructor Information

Prof. Karen Marais
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3. Topics Covered

- *Needs and Requirements*: Stakeholder roles and perspectives. Mission statements for system design projects and programs. Development of proper requirements engineering.
- *The Flight Project Lifecycle*: Mission concept development, the design process, integration and testing, flight operations.
- *Aircraft Mission and Operating Environment*: Layers in the atmosphere. Temperature and pressure variations with altitude. Aircraft mission for different types of aircraft. Design parameters of aircraft mission. Equations of motion. Bernoulli's principle. Parts of aircraft and their function.
- *Wind Tunnels:* Parameters of fluid flow (pressure, temperature, density, and velocity). Airfoil geometry and the wing. Forces on aerodynamic surfaces. Continuity and momentum equations. Flow in a wind tunnel. Finite and infinite airfoils. Reynold's number.
- *Space Environment:* Hazards in orbit, their effects on spacecraft, and mitigations. The radiation environment. Planetary atmospheres.
- *Introduction to Orbits:* Newton's Law of Gravitation. Orbit trajectory equations. Categories of trajectories. Kepler's laws.
- *Launch Vehicles and Launch Trajectories:* Impulse of engines. Ideal rocket equation. Specific impulse. Rocket staging. Conservation of momentum. Orbit selection and launch location. Rocket trajectories and loss terms. Payload delivery to orbit.
- *Orbit Transfers:* Orbital maneuvers and applications. Cost requirement for transfers. Vis-viva equation. Geocentric Orbits. Heliocentric Orbits. Orbital elements. Hohmann transfers.
- *Introduction to Lift & Drag:* Structural Design Process. Design Criteria. Structural Design Layout. Aircraft Structure Types and Materials.
- *Aircraft Performance, Thrust, and Power:* Required thrust & power. Breguet Range equation. Endurance equation. Take-off weight. Drag polar plot.
- *Aircraft Engines:* Stages of turbofans, turbojets, and turboprop engines and their functions. Selection of engine type for given applications.

4. Intended Learning Outcomes

On completing this course, the student shall be able to:

- Systems
  - Identify stakeholders and their roles and perspectives.
  - Write a mission statement for a system design project or program.
  - Describe the importance to system development of proper requirements engineering.
  - Establish the steps in stakeholder needs elicitation and generate needs statements.
  - Write proper requirements statements for an engineering system.
- Underlying Theory
  - Identify the layers in the atmosphere and derive equations showing how temperature and pressure vary with altitude.
  - Identify and list the parameters that describe fluid flow (pressure, temperature, density, and velocity) and apply the relationships between them to simple design problems.
  - Derive the equations that describe flow in a wind tunnel.
  - Use Reynolds number to appropriately scale models for testing in wind tunnels.
  - Identify the forces acting on an aerodynamic surface (lift, drag, thrust, gravity).
  - Apply Bernoulli's principle, the continuity equation, and the momentum equation to determine the lift acting on an aerodynamic surface.
- Aircraft
  - Identify the parts of an aircraft and describe their function.
  - Write down the terms used in the aerospace community to describe the geometry of an airfoil and wing.
  - Describe the elements of an aircraft mission for different types of aircraft.
  - Use the elements of an aircraft's mission to derive design parameters.

- Apply the aircraft sizing algorithm and appropriately estimate the weight fractions used in the algorithm.
    - Identify the various parameters used in determining take-off weight.
    - Identify and describe the mechanisms through which the different types of drag arise (pressure, induced, skin friction, and wave).
    - Explain the difference between finite and infinite airfoils. Explain why the infinite airfoil concept is useful.
    - Construct the theoretical drag polar plot.
    - Apply the correct equation to calculate the drag on a finite airfoil given the drag polar for an infinite airfoil.
    - Use the drag polar plot to predict aircraft performance.
    - Derive the equations of motion for an aircraft.
    - Derive the thrust and power required for steady, level, unaccelerated flight as a function of velocity
    - Derive the thrust and power required for steady, level, unaccelerated flight as a function of weight and aerodynamic efficiency.
    - Analyze altitude effects on required thrust and power.
    - Derive the minimum thrust and minimum power required for steady, level, unaccelerated flight.
    - Use the maximum thrust (power) available to derive the maximum possible velocity at a given altitude.
    - Determine and motivate the appropriate engine for a given aircraft application.
    - Identify and list the stages in turbofan, turbojet, and turboprop engines and their functions.
    - Derive and apply the Breguet Range equation.
    - Derive and apply the Endurance equation.
- Rockets and Spacecraft
    - Identify and describe the hazards faced by a spacecraft in orbit, their effects on spacecraft, and ways to mitigate these hazards.
    - List and describe the parts of a launch vehicle and their functions.
    - Categorize propulsion systems into air breathing and rocket engines.

- Define and categorize launch vehicles based on their destination, payload, nature of propellants, and number of stages.
- Discuss the key parameters in the design of a rocket (e.g., payload, deltaV, engines, propellant, feasibility, etc.).
- Determine and motivate the appropriate propellant(s) for a given rocket application.
- Derive the thrust equation for a rocket engine by applying the conservation of momentum.
- Identify and describe over- and under-expansion and their effects on performance.
- Derive the ideal rocket equation by applying the conservation of momentum.
- Identify and discuss the factors that reduce performance from that determined by the ideal rocket equation.
- Define the specific impulse of an engine.
- Identify and demonstrate the need for multi-stage rockets and detail the methods and calculations used to design multi-stage rockets.
- Determine the number of stages and amounts of propellants required to provide a given deltaV for a rocket application.
- Write MATLAB code to solve rocket staging problems.
- Orbits
- Derive the orbit (trajectory) equations.
- Categorize the different types of trajectories in space.
- Apply Kepler's laws and explain their significance.
- Describe different types of orbital maneuvers and their application.
- Derive and apply the deltaV requirement for a given maneuver.
- Apply the vis-viva equation.
- Describe the trade-offs involved in orbit selection and launch location.
- Categorize the different types of trajectories in space.

5. Assessment Method

During this course students are evaluated on both individual and teamwork. Teamwork consists of regular small exercises as well as a semester-long design project.

Individual assignments (homework) will be given out every week. Students will also be graded on class participation. The course also includes three scheduled "mid-terms" and one final exam.

Students can also earn bonus points over the course of the semester by performing various challenge exercises or attending selected talks.

6. Relation to ABET Outcomes

	Program Learning Outcomes	Included?
1.	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Yes
2.	An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Yes
3.	An ability to communicate effectively with a range of audiences.	Yes
4.	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	Yes
5.	An ability to function effectively on a team whose members together provide leadership, create a	Yes

	collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	
6.	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	No
7.	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	No

Astronaut Trainer Aircraft Design Report

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AAE251
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Abstract

Due to the high cost of operating existing NASA trainer airplanes and the development of new technologies, a new family of trainer aircraft must be developed by 2025 to provide astronauts with their required flying hours. Currently, NASA uses the Northrop T-38 Talon, a twin-engine, twin-seat supersonic aircraft as a trainer for its astronauts and spends $25-30 million per year to maintain and fly the T-38. The mission statement of the project is to develop a family of cost-effective, feasible trainer aircraft for NASA astronauts, to replace existing trainers, with a single and multi-engine variant that can be introduced by 2025. Stakeholders, needs, and requirements were identified, and a preliminary risk analysis was created. Design parameters, such as gross takeoff weight, wing loading, wing size and airfoil characteristics were mathematically estimated using research from existing designs for similar trainer aircraft. Multiple design concepts were generated using possible design features such as engine type and placement and wing type, and a final design was chosen using decision matrixes. Due to the inability to accurately estimate maintenance and unit costs at the current stage of development, it is not possible to accurately predict if NASA would accept a contract to replace the T-38 Talon with our designed aircraft, regardless if it meets the required performance. It is also concluded that the T-38 Talon has become an ingrained tradition in NASA astronaut training and culture, and as such, the financial benefit of switching from the Talon to a new platform would have to greatly outweigh the cost of ending such a tradition.

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1 Introduction

Due to the high cost of operating existing NASA trainer airplanes and the development of new technologies, a new family of trainer aircraft must be developed by 2025 to provide astronauts with their required flying hours. Two trainer airplanes, one single-engine, and one twin-engine have been designed to meet the basic requirements provided by NASA below in Figure 1.

	Single-Engine	**Multi-Engine**
Takeoff and Landing	Asphalt/concrete runway	Asphalt/concrete runway
Operation Type	VFR and IFR	VFR and IFR
Endurance	>3 hr	>4 hr
Range	>800 nmi	>1000 nmi
Service Ceiling	>12,000 ft	>18,000 ft

Figure 1: NASA Requirements

Currently, NASA uses the Northrop T-38 Talon, a twin-engine, twin-seat supersonic aircraft as a trainer for its astronauts. It was first introduced in March 1961 and is still in service as a trainer aircraft. NASA spends $25-30 million per year to maintain and fly the T-38. It can reach a speed of 1.05 Mach (812 mph) and has a range of 1,093 miles. Each unit costs around $756,000, adjusted for inflation from 1961 *(T-38 Talon,* 2005). The aircraft designed will replace the Northrop T-38 Talon utilizing current technology in a cost-effective manner.

The mission statement of the project is to develop a family of cost-effective, feasible trainer aircraft for NASA astronauts, to replace existing trainers, with a single and multi-engine variant that can be introduced by 2025.

This report details the stakeholders and requirements for the aircraft, a preliminary risk analysis, an estimation of design parameters, concept generation and selection, performance analysis, and a discussion of the final design, next steps, and lessons learned.

2 NEEDS, REQUIREMENTS, AND RISK ANALYSIS

The first step in the design process is developing a set of requirements and assessing the risk associated with these requirements. Section 2 details the process of identifying the stakeholders for the project and their needs, deriving requirements from stakeholder needs, and the development of a risk analysis.

2.1 STAKEHOLDERS AND THEIR NEEDS

In order to identify the stakeholders of the aircraft, the team brainstormed the people or organizations which would use the aircrafts and who would pay for them in the end. Those who would be needed in the process of designing and creating these aircrafts were also considered along with those who would be affected by this aircraft, such as those living around the area that it would be flying.

To identify the needs the team developed a list of stakeholders and brainstormed the possible ways the stakeholders could be impacted by the development of the aircraft. Needs included those derived from the NASA requirements in Figure 1 and factors such as safety or noise were also considered. The most important needs were those associated with safety since the absence of these needs could potentially result in the loss of life. The list of stakeholders, a description of the stakeholders, and their needs are listed in Table 1 below.

Table 1: Stakeholders and Needs

Stakeholder	Description	Needs

Astronauts or Pilot Trainees	They are operators of aircrafts. They are the primary user for the aircrafts	Aircraft will train pilots mentally and physically to fly actual missions Aircraft will either meet or exceed the expectations created by the previous trainer aircraft (Northrop T-38 Talon) Will be able to operate the aircraft with either VFR (Visual Flight Rules) or IFR (Instrumental Flight Rules) as needed The aircraft will have an endurance of 3 hours for a single-engine and 4 hours for a multi-engine The aircraft have a range of more than 800 nautical miles for a single engine and 1000 nautical miles for a multi-engine The aircraft have a service ceiling of greater than 12,000 feet for a single engine and 18,000 feet for a multi-engine Aircraft meet safety standards to prevent damage or loss of life
Aircraft Maintainers	They will be maintaining aircrafts constantly after they are implemented to make sure aircrafts operate correctly. It is important to consider them since they need to understand components and systems of our aircrafts.	There are clear, complete designs and requirements that are easily understood There are specifications of what needs to be maintained the most Development of the aircrafts generate profits for the company
Nonusers Living Near Airports	They include people who live near training airports. Will be affected by the noise level of the aircraft operating in the area and may be affected by the safety standards of the aircraft.	Aircraft produces less or the same amount of noise level as the previous trainer aircraft to be non-disruptive to daily life Aircraft meet safety standards to prevent damage or loss of life to bystanders

NASA	They are the customer of the aircraft. They are the one who needs and pays for our aircrafts.	Aircraft will train their astronauts mentally and physically to fly actual missions Feasible aircraft with reasonable cost to manufacture aircrafts Aircraft enter service by 2025 Aircraft able to either meet or exceed the capabilities of the previous trainer aircraft (Northrop T-38 Talon) Aircraft able to operate the aircraft with either VFR (Visual Flight Rules) or IFR (Instrumental Flight Rules) as needed Aircraft have an endurance of 3 hours for a single-engine and 4 hours for a multi-engine Aircraft have a range of more than 800 nautical miles for a single engine and 1000 nautical miles for a multi-engine Aircraft has a service ceiling of greater than 12,000 feet for a single engine and 18,000 feet for a multi-engine
Taxpayers	They provide funding for the development of the aircraft. We want to make sure taxpayers will be willing to pay for our aircrafts and receive a benefit.	Feasible aircraft with reasonable cost to manufacture aircrafts Feasible aircraft with reasonable cost to maintain aircrafts Development of the aircraft provides a benefit for the public
Aircraft Manufacturer	They build the aircraft given the schematics and instructions. They are important since they are the one who needs to understand our design and continue creating our aircrafts	There are clear, complete design and requirements that are easily understood Development of the aircrafts generate profits for the company

2.2 REQUIREMENTS

Table 2 below contains the list of aircraft requirements, derived from the stakeholder needs, which specify what the system must do. There is also a justification of whether each requirement is verifiable and dependent, and each requirement's associated needs from Table 1. The set of requirements are complete because they specify all aspects of the system's functions and properties of the basic aircraft design. Below are the design decisions addressed by the vehicle requirements.

- *Reliability*
- *Safety*
- *Maintenance*
- *Impacts on the environment*
- *Noise*
- *Range*
- *Endurance*
- *Payload—type, dimensions, and mass*
- *Flight ceiling*
- *Maximum landing and takeoff distance*
- *Minimum landing and takeoff distance*
- *Types of runway*
- *Capability to operate in various operating environment*
- *Communication and telemetry requirements*
- *Number of engines*
- *Flow of information to contractor*
- *Cost*
- *Similarity to previous trainer aircraft*

Table 2: Vehicle Requirements

Requirement	Verifiable?	Dependent?	Associated Needs
Fully loaded flight endurance is greater than 3 hours for the single-engine aircraft and greater than 4 hours for the multi-engine aircraft to allow pilots to train for the maximum amount of time in one session	Yes, we can verify this with calculations based on the lift to drag ratio, mass, mass of propellant, and engine used	Dependent on the amount of fuel the aircraft can carry, the weight of the aircraft, and the aircraft engine	Aircraft will train pilots mentally and physically to fly actual missions The aircraft have endurance of 3 hours for a single-engine and 4 hours for a multi-engine
Fully loaded flight range is greater than 800 nautical miles for the single-engine aircraft and greater than 1000 nautical miles for the multi-engine aircraft	Yes, we can verify if our aircraft can fly more than 800 or 1000 nautical miles with calculations based on the lift to drag ratio, mass, fuel mass, type of engine, and wing area	Dependent on the lift to drag ratio, mass, fuel mass, type of engine, and wing area	Aircraft will train pilots mentally and physically to fly actual missions The aircraft have a range of more than 800 nautical miles for a single engine and 1000 nautical miles for a multi-engine

Service ceiling is greater than 12,000 feet for the single-engine aircraft and greater than 18,000 feet for the multi-engine aircraft to allow pilots to safely perform necessary maneuvers and have time to recover in the event of a failed maneuver	Yes, this can be verified with calculations based on the velocity, wing area, drag coefficient, and mass	Dependent on the aircraft velocity, wing area, drag coefficient, and mass	Aircraft will train pilots mentally and physically to fly actual missions The aircraft have a service ceiling of greater than 12,000 feet for a single engine and 18,000 feet for a multi-engine Aircraft meet safety standards to prevent damage or loss of life
Operation type is VFR and IFR because the aircraft should be able to operate in a variety of environments and weather conditions to maximize training time	Yes, this can be verified through the design process.	Dependent on the surrounding weather conditions, the navigational computers, and instruments included in the aircraft design	Aircraft will train pilots mentally and physically to fly actual missions Will be able to operate the aircraft with either VFR (Visual Flight Rules) or IFR (Instrumental Flight Rules) as needed Aircraft meet safety standards to prevent damage or loss of life

Instructions to contractors should have a clear and complete design and requirements so contractors are able to fulfil all of NASA's requirements	Yes, this can be verified during the contracting process.	Dependent on the process of outsourcing work.	There are clear, complete design and requirements that are easily understood There are specifications of what needs to be maintained the most Feasible aircraft with reasonable cost to manufacture aircrafts Aircraft enter service by 2025
Aircraft should be able to successfully fly repeated missions with minor maintenance costs since the safety of the pilots and those in the surrounding area is dependent on the reliability of the aircraft	Yes, this can be verified through the testing process	Dependent on the design process and constraints.	Feasible aircraft with reasonable cost to maintain aircrafts
Aircraft should be able to successfully operate without major failures which could risk the safety of the pilots	Yes, this can be verified through testing and design considerations.	Dependent on the design process and constraints	Aircraft meet safety standards to prevent damage or loss of life

The operating cost of the aircraft should be less than $25-30 million per year since the operating cost should be less than that of current NASA trainer aircraft	Yes, this can be verified through testing of the aircraft and seeing the effect of flights on the aircraft structure and components	Dependent on the design and strength of the aircraft components and structure, environmental operating conditions, and average hours of flight per year	Development of the aircraft generates profits for the company Feasible aircraft with reasonable cost to manufacture aircraft Feasible aircraft with reasonable cost to maintain aircraft
Carbon emissions should be minimized to support local communities and protect the environment	Yes, can be verified through emissions testing	Dependent on fuel type and fuel efficiency	Aircraft meet safety standards to prevent damage or loss of life to bystanders
Runway length should be similar to that of currently used NASA trainer aircraft to remove the need for new runways	Yes, we can verify the takeoff and landing distances using calculations from variables such as the lift of the aircraft, thrust, and weight.	Dependent on the weight, thrust, airfoil lift, runway material, and environmental effects	Aircraft either meet or exceed the capabilities of the previous trainer aircraft (Northrop T-38 Talon)

Aircraft should be able to land on a variety of terrains to allow for emergency landings	Yes, the safety of landing can be calculated from properties and characteristics of the material	Dependent on material type, aircraft weight, velocity, and weather conditions (snow, ice, water, dry, heat/cold)	Aircraft meet safety standards to prevent damage or loss of life
Noise level should be less than 65 dB due to FAA requirements and minimize impact to those living around airports	Yes, can be tested with acoustic measurements	Dependent on material around the engine compartment, noise level of the engine, noise reduction design choices	Aircraft produces less or the same amount of noise level as the previous trainer aircraft to be non-disruptive to daily life
Aircrafts should be able to able to operate within the same environments as other aircraft of similar purpose to maximize training time	Yes, this can be verified through the design and test process.	Dependent on the aircraft design and ease of use.	Aircraft either meet or exceed the capabilities of the previous trainer aircraft (Northrop T-38 Talon) Development of the aircraft provides a benefit for the public

The communication and telemetry systems used should allow the pilots and ground team to communicate with each other and other nearby aircraft. Additionally, the telemetry should be able to be monitored by the pilots and ground teams to mitigate hazards while flying	Yes, this can be verified through the design and test process.	Dependent on available resources and design constraints.	Aircraft meet safety standards to prevent damage or loss of life

There should be a single-engine aircraft and a multi-engine aircraft. The difference in number of aircraft engines would allow the pilots to perform different maneuvers and training activities. The number of engines would also affect the dynamics of the aircraft, such as maneuverability, range, speed, service ceiling, and endurance	Yes, this can be verified in the design process.	Dependent on design decisions and engine choice	Aircraft will train their astronauts mentally and physically to fly actual missions Aircraft either meet or exceed the capabilities of the previous trainer aircraft (Northrop T-38 Talon)

2.3 Preliminary Risk Analysis

The preliminary risk analysis identifies potential risks, their consequences, and possible methods of mitigating each risk. In order to identify system risks, the team analyzed all mission phases and systems on the aircraft to develop a list of risks associated with these mission phases and systems. After this, the team developed ideas for consequences if the risk were to occur, possible ways to mitigate the risk, and the likelihood of each risk occurring (Table 3).

Table 3: Risks

Risk	Description	Consequences	Mitigation	Probability

R1: Loss of Control	Pilot error or mec hanical/electrical issues with control surfaces	Severe damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Redundant safety systems to prevent loss of control and proper training of pilots.	Moderate
R2: Engine Failure	Failure of the engine due to debris strike or component degradation.	Severe damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Testing of engines at extreme conditions and a durable engine design, designing to allow multi-engine aircraft to fly with loss of an engine.	Moderate

R3: Bird/ Debris Strike	Birds and other objects may hit aircrafts during takeoff, landing, or in-flight.	Damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Track objects around airports, develop aircraft to withstand the strikes, test at similar conditions.	Unlikely

R4: Landing/ Takeoff Failure	Failure of components during takeoff or landing procedures, airplane does not have long enough runway due to engine failure at takeoff, pilot error in landing/takeoff,	Severe damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Testing of takeoff and landing procedures and ensuring the runway is enough for takeoff and landing in flight plan, ensuring multi-engine aircraft can takeoff with an engine failure,	Unlikely
R5: Weather	Weather may disturb the o peration of aircrafts. Harmful weather conditions include fog, lightning, blizzard s, tornados, etc.	Damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Track weather conditio n and delaying or cancel flights	Moderate
R6: Turbulenc e	Turbulence may damage aircraft components or injure pilots.	Some damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	There could be an alternative route or possible delay or cancel of flights Accounting for turbulence predictions in flight path, increasing	Likely

			structural stability, reliability, and resistance to intense aerodynamic forces	
R7: Loss of Communications	Loss of communications may result in loss of direction from ground teams which may lead to the damage of aircraft or collision with other aircrafts in the air or on the runway	Some damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Multiple redundancy systems of communication, training pilots in worst-case scenarios, more reliable communication	Moderate

R8: Failure of Navigatio n Systems/ Pilot Error in Navigatio n	Navigation systems error/failure that causes a pilot to take wrong path, pilot error in navigation with poor weather that leads to airplane crash, airplane collisions	Some damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Multiple redundancy systems of navigation, training pilots in worst-case scenarios	Moderate

R9: Injury/Loss of the Consciousness of Pilot	Injury to pilot could not allow him/her to operate the aircraft, pilot can pass out in hard maneuvers, pilot suffers a medical emergency while flying	Severe damage to the airplane, airplane crash, pilot death/injury, risk of hitting population areas or infrastructure	Develop system to operate aircraft without pilot in the event of emergency, autopilot systems that can pull airplane out of a deadly maneuver without pilot input, autopilot can navigate and land without pilot input, train pilots to handle high-G maneuvers effectively	Unlikely

Once a set of risks, consequences, mitigations, and likelihoods were developed, the team decided to identify the most important ways the system could fail. To do this, risk matrices were created to represent the likelihood and consequence scores of each risk before mitigation (Figure 3) and after mitigation (Figure 4). The risk matrix assigns scores for the likelihood and consequence of each risk according to the risk matrix key (Figure 2) from the data in Table 3. The result of this assessment has identified Risk 1: Loss of Control and Risk 2: Engine Failure as the most prominent risks due to their high likelihood and consequences. If mitigation plans are implemented for all risks, the consequences remain the same but the likelihood decreases.

Likelihood		Consequence	
1	Highly Unlikely	1	Minimal
2	Unlikely	2	Minor
3	Moderate	3	Moderate
4	Likely	4	Major
5	Highly Likely	5	Catastrophic

Figure 2: Risk Matrix Key

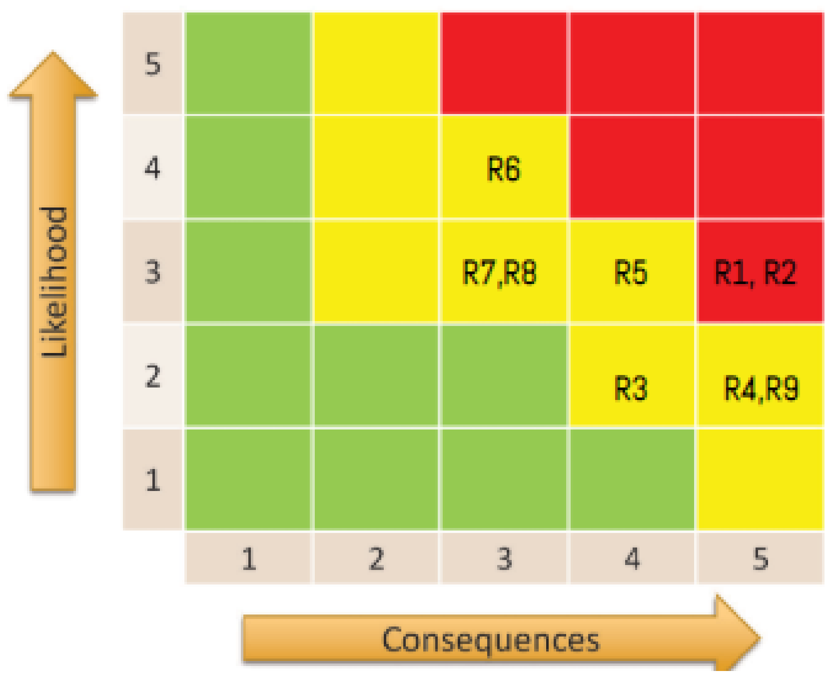

Figure 3: Pre-Mitigation Risk Matrix

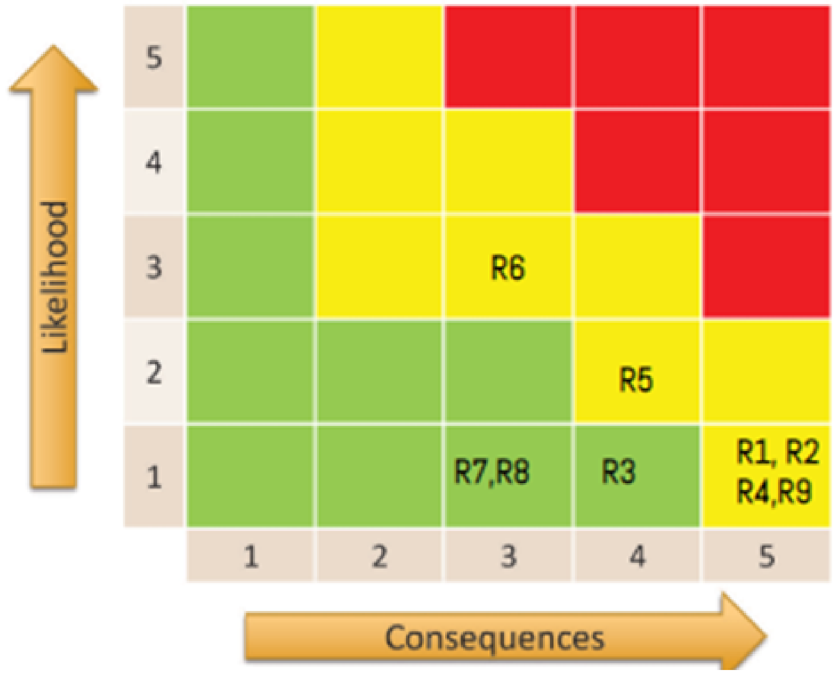

Figure 4: Post-Mitigation Risk Matrix

3 ESTIMATING DESIGN PARAMETERS

The process of estimating design parameters for aircraft requires research into existing designs of similar aircraft to accurately estimate parameters for a new aircraft. Section 3 outlines the research into existing design parameters, a weight estimation, wing sizing, and airfoil selection.

3.1 *EXISTING DESIGNS*

Northrop T-38 Talon (Figure 5)

Figure 5: Northrop T-38 Talon (U.S Air Force, 2005)

Description of design features:

- *A two-seat twinjet supersonic jet trainer that is currently used to train astronauts.*
- *Double engine*
- *Maximum speed: Mach 1.3 (858 mph, 1,381 km/h)*
- *Range: 1,140 mi (1,835 km, 991nmi)*
- *Service ceiling: 50,000 ft (15,240 m)*
- *Wing loading: 69.53 lb/ft^2 (339.4 kg/m^2)*
- *Empty weight: 3,270 kg*
- *Loaded weight: 5,360 kg*
- *Empty weight fraction = 3,270/5,360 = 0.610*
- *Lift to drag ratio = 9:1*

Source: T-38 Talon, 2005

L-39 Albatros (Figure 6)

Figure 6: L-39 Albatros (SkyTamer, 2020)

Description of design features:

- *Advanced jet trainer and light strike aircraft developed by Aero Vodochody in Czechoslovakia*
- *Single engine*
- *Maximum speed: 740 km/h*
- *Range: 1,100 km*
- *Endurance: 2 hours 30 minutes*
- *Service Ceiling: 11,000 m*
- *Empty weight: 3,455 kg*
- *Loaded weight: 4389 kg*
- *Empty weight fraction = 3,455/9,028 = 0.7872*
- *Lift to drag ratio can be approximated at 11:1 based on data from airplanes of similar style.*

Source: Skytamer, 2020

McDonnell Douglas T-45 Goshawk (Figure 7)

Figure 7: McDonnell Douglas T-45 Goshawk (All-Aero, 2020)

Description of design features

- *Carrier-borne trainer developed by British Aerospace*
- *Single engine*
- *Max speed: 1,038 km/h (645 mph)*
- *Service ceiling: 42,500 ft*
- *Range: 700 nmi*
- *Empty weight: 4,460 kg*
- *Loaded weight: 5624 kg*
- *Empty weight fraction: 4,460 kg / 5624 kg = 0.793*

- *Lift to drag ratio can be approximated at 12:1 based on data from airplanes of similar style.*

Source: All-Aero, 2020

3.2 Estimating Gross Takeoff Weight

Single-Engine Aircraft Mission (Figure 8)

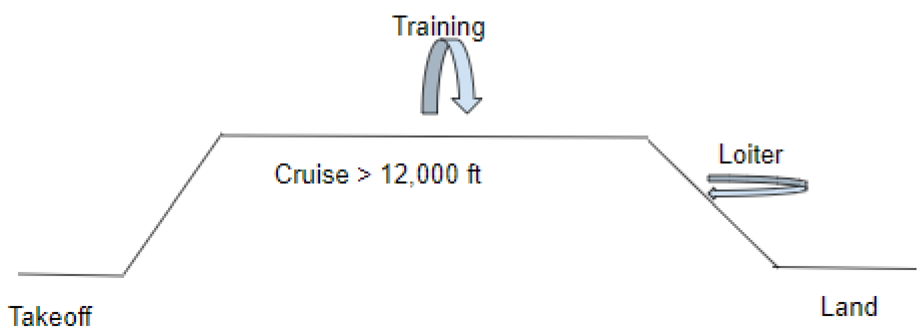

Figure 8: Single-Engine Mission

The single-engine aircraft must be able to take off from an asphalt or concrete runway. If weather is nominal, the aircraft must be able to navigate by Visual Flight Rules, and if not, the aircrafts systems should allow it to fly using Instrumental Flight Rules. The aircraft must then be able to fly up to a height of greater than 12,000 feet, have a range of greater than 800 nautical miles, and must be able to have a mission endurance of longer than 3 hours.

Multi-Engine Aircraft Mission (Figure 9)

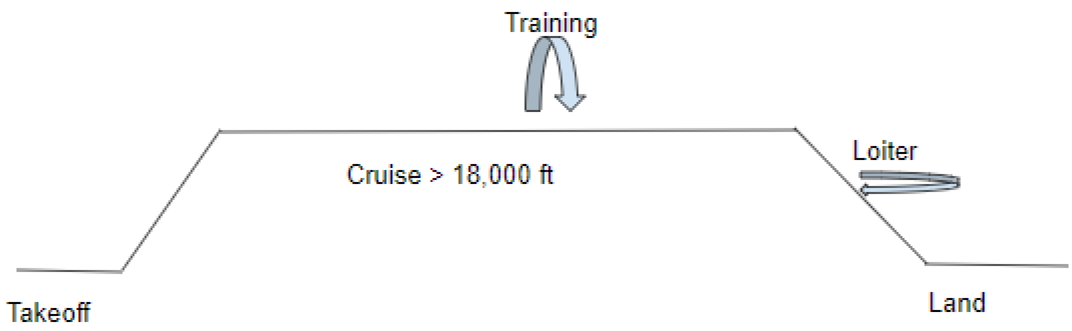

Figure 9: Multi-Engine Mission

The multi-engine aircraft must be able to take off from an asphalt or concrete runway. If weather is nominal, the aircraft must be able to navigate by Visual Flight Rules, and if not, the aircrafts systems should allow it to fly using Instrumental Flight Rules. The aircraft must then be able to fly up to a height of greater than 18,000 feet, have a range of greater than 1000 nautical miles, and must be able to have a mission endurance of longer than 4 hours.

A major step in the aircraft design process is a total weight estimation of each aircraft. In order to develop an estimate for the weight of the aircraft, a sizing algorithm was developed (Figure 25 in Appendix). The sizing algorithm estimates the gross takeoff weight using the equation

$$W_{gross} = \frac{W_{crew}+W_{payload}}{1-\frac{W_{fuel}}{W_{gross}}-\frac{W_{empty}}{W_{gross}}}$$

First, the gross weight is estimated and the fuel fraction, and empty weight fraction are calculated using the equations

$$\frac{W_{fuel}}{W_{grose}} = 1.06 * (1 - \frac{W_{mission}}{W_{gross}}) \qquad \frac{W_{empty}}{W_{grose}} = AW_{empty}^{C}K_{vs}$$

and the following equations are used to calculate the mission weight ratio

$$\frac{W_{mission}}{W_{grose}} = \frac{W_{end\_takeoff}}{W_{start\_takeoff}} * \frac{W_{end\_climb}}{W_{start\_climb}} * \frac{W_{end\_cruise}}{W_{start\_cruise}} * \frac{W_{end\_loiter}}{W_{start\_loiter}} * \frac{W_{end\_descent}}{W_{start\_descent}} * \frac{W_{end\_land}}{W_{start\_land}}$$

$$\frac{W_{end\_cruise}}{W_{start\_cruise}} = \exp \frac{-R * SFC}{V * L/D} \qquad \frac{W_{end\_loiter}}{W_{start\_loiter}} = \exp \frac{-E * SFC}{L/D}$$

Once the gross weight is calculated, the algorithm checks if the new gross weight is equal to the guessed gross weight and changes the estimated gross weight for the next loop to the calculated gross weight. The parameters used in this algorithm, the source of the parameters, and the justification for using these parameters are shown in Table 4.

Table 4: Sizing Parameters

Parameter	Value	Source	Justification
Range	800nmi for single-engine and 1000nmi for multi-engine	NASA requirements state the aircraft must have ranges of at least 800nmi and 1000nmi	The range impacts the cruise weight fraction
Payload Weight	600 lb	Online research of similar trainer aircrafts showed an average payload mass of 600 lb	The payload mass will increase the gross aircraft mass

Crew Weight	300 lb	The average human weight is 150 lb assuming 2 crew members are on aircraft	The crew mass will increase the gross aircraft mass
Speed	Mach 0.65	Averaged values of average speed from similar trainer aircraft	Velocity will impact the cruise weight fraction
L/D ratio	9.5	Averaged values of L/D from company websites of aircraft manufacturers for jet trainers	L/D impacts the cruise and loiter weight fractions
Loiter Time	1200 seconds	Loiter times of small aircraft prior to landing	A longer loiter time will increase the loiter weight fraction

Specific Fuel Consumption (Cruise and Loiter)	0.9 Cruise 0.8 Loiter	Table from Raymer chapter 3	A higher SFC will increase the cruise and loiter weight fraction
Endurance	4hr for single-engine and 5hr for multi-engine aircraft	NASA requirements state the aircraft must have endurances of at least 4hr and 5hr	A higher endurance will increase the cruise and loiter weight fraction

The result of the team's sizing code shows a gross takeoff weight of 10,215lb for the single-engine aircraft and 13,988lb for the multi-engine aircraft. These are reasonable results, as the gross takeoff weight of similar trainer aircraft such as the Northrop T-38 Talon are around 11,000lb.

3.3 WING LOADING

The requirements which drive the design are the flight endurance and loaded range requirements. In order to achieve a greater flight endurance, a higher wing loading is required. Maneuverability is also another requirement which drives the design and directly conflicts with the flight endurance and loaded range requirements. This is because more maneuverability requires a lower wing loading. The team decided maneuverability is more important to meet the stakeholder's needs as it allows the pilots to complete required training activities.

$$Q = \frac{1}{2}\rho V^2 = \frac{1}{2}(0.002377)(733.333)^2 = 239.31psf$$

$$C_L = 0.5\ (From\ similar\ aircraft)$$

$$\frac{W}{S} = QC_L = (239.31)(0.5) = 119.66psf$$

The estimated wing loading for the aircraft are 119.66psf, calculated using the equations above. The value is reasonable because wing loading values range between 70 to 150psf for trainer aircraft (Nicholai & Carichner, 2010).

3.4 Wing Size and Airfoil Characteristics

The wing area and wingspan calculations are shown below for each aircraft. These values are reasonable because the wing area of other trainer aircraft average around $120ft^2$ and the wingspan averages around 25ft (FAA, 2020), which are both similar to the calculated values.

$$\frac{W}{S} = 119.66psf$$

$$S = \frac{W}{119.66}$$

$$b = \sqrt{AR * S}$$

$$AR = 7.5\ (From\ similar\ aircraft)$$

$$W_{single-enigne} = 10{,}215lb$$

$$W_{multi-enigne} = 13{,}988lb$$

$$S_{single-engine} = \frac{10{,}215}{119.66} = 85.37ft^2$$

$$S_{multi-engine} = \frac{13{,}988}{119.66} = 116.90ft^2$$

$$b_{single-engine} = \sqrt{7.5 * 85.37} = 25.30ft$$

$$b_{multi-engine} = \sqrt{7.5 * 116.90} = 29.61ft$$

Trapezoidal wings (Figure 10) would be ideal for the aircraft due to their increased maneuverability at higher speeds compared to other wing types, such as swept and rectangular, and its efficiency at all stages of flight.

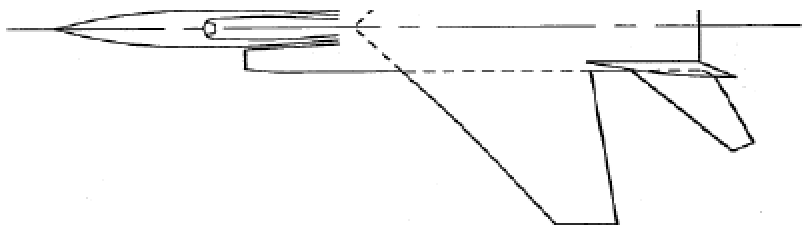

Figure 10: Trapezoidal Wing

The airfoil affects aircraft performance parameters such as cruise speed, landing and takeoff distances, and stall speed. Based on the aircraft requirements, the team identified characteristics that the airfoil must have. The high cruise speed of both aircraft requires a low drag coefficient for the airfoil, a relatively low stall speed requires a high lift coefficient, and in order to achieve high maneuverability, a low aspect ratio is required. Due to these requirements, the ideal airfoil would have a high lift to drag ratio. One of the NACA 6-series airfoils would be appropriate for the mission due to a high maximum lift coefficient and low drag over certain operating conditions. Additionally, the 6-series airfoil is commonly used on other jet trainers (Lednicer, 2010). Below is the geometry (Figure 11) and the airfoil charts (Figure 12) for the NACA 63A010 airfoil.

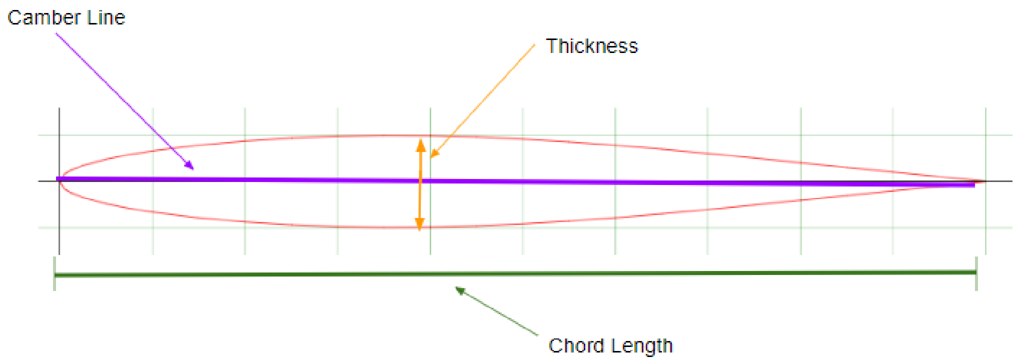

Figure 11: NACA 63A010 Airfoil Geometry

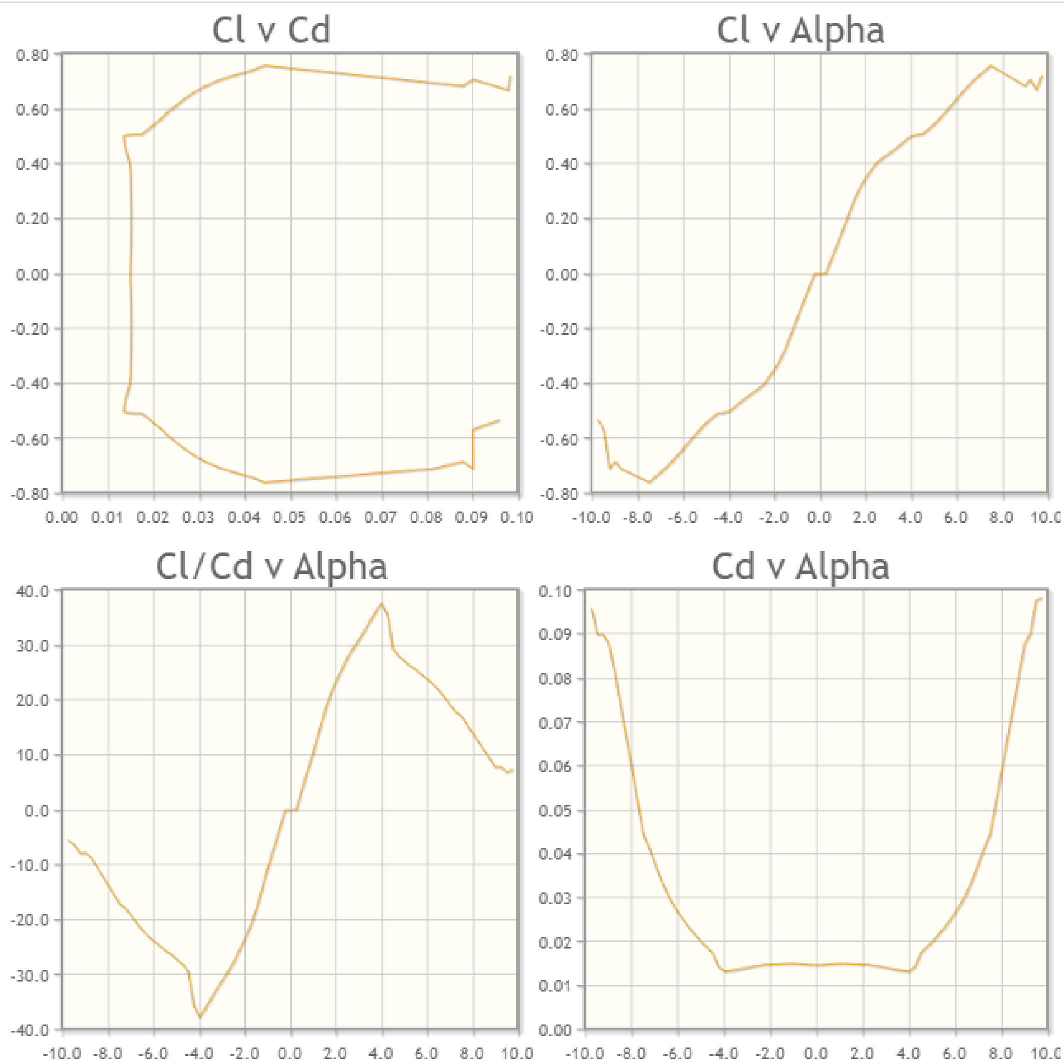

Figure 12: NACA 63A010 Airfoil Charts (Airfoil Tools, 2020)

The estimated maximum lift coefficient for the NACA 63A010 airfoil is 0.75, stall angle is 7.5, parasitic drag coefficient is 0.015, and maximum lift to drag ratio is 38.

4 Concept Generation, Selection, and Performance Analysis

After an initial aircraft size is created, important design features are selected, and calculations are performed to assess the performance of the aircraft. Section 4 details the concept generation and selection process for design features, concept selection, and calculations such as thrust, power, range, endurance, drag, and velocity.

4.1 Concept Generation and Selection

The two aircraft designs are very similar to each other and are based on a common platform. The only main difference between the two will be the single vs. multi-engine variants. The reasoning for this is that the astronauts should be able to easily use either plane in their training, and we do not want the planes to differ drastically from each other. The astronauts should have the option to use the multi-engine plane for longer distances and higher flight ceilings, and the single engine for maneuverability and speed.

Single-Engine Concepts

Concept 1

Type of wing: Trapezoidal

Type of engine: Turbofan

Number of engines: 1

Placement of engines: Rear-center on fuselage

Landing gear type: Tricycle

Concept 2

Type of wing: Swept Back

Type of engine: Turbojet

Number of engines: 1

Placement of engines: Rear-center on fuselage

Landing gear type: Tricycle

<u>Concept 3</u>

Type of wing: Variable Sweep

Type of engine: Turbofan

Number of engines: 1

Placement of engines: Rear-center on fuselage

Landing gear type: Tricycle

Multi-Engine Concepts

<u>Concept 1</u>

Type of wing: Trapezoidal

Type of engine: Turbofan

Number of engines: 2

Placement of engines: Rear-center on fuselage

Landing gear type: Tricycle

<u>Concept 2</u>

Type of wing: Swept Back

Type of engine: Turbojet

Number of engines: 2

Placement of engines: Under wings

Landing gear type: Tricycle

<u>Concept 3</u>

Type of wing: Variable Sweep

Type of engine: Turbofan

Number of engines: 2

Placement of engines: Rear-center

Landing gear type: Tricycle

Concept Selection

After the team developed a list of concepts for the wing type, engine type, number of engines, engine placement, and landing gear type for each aircraft, decision matrices were created to select the best type based on factors such as reliability, environmental impacts, maintenance, noise produced, maneuverability, safety, and flight endurance. Each of these criteria are assigned a weight, determined by the team's assessment on the importance of each criteria, and the total scores are calculated to determine the best option for each component.

Criteria	Weight	Trapezoidal	Swept Back	Variable Sweep
Reliability	4	5	5	4
Environmental Impacts	3	5	5	5
Maintenance	3	5	5	4
Noise Produced	2	5	5	5
Maneuverability	3	5	4	4
Safety	5	5	5	5
Flight endurance	3	5	4	4
Sums:	23	115	109	102

Figure 13: Wing Type Decision Matrix (Data from Dauntless, 2019)

The aircraft will both use trapezoidal wings due to their increased maneuverability and range compared to other wing types, such as swept back wings and variable sweep wings. (Figure 13)

Criteria	Weight	Turbofan	Turbojet
Reliability	5	5	4
Environmental Impacts	3	4	3
Maintenance	4	4	3
Noise Produced	4	5	2
Safety	4	5	4
Flight endurance	4	5	3
Sums:	24	113	77

Figure 14: Engine Type Decision Matrix (Data from NASA GRC, 2008)

The aircraft will also use a turbofan engine. This is because the turbofan engine is more efficient at creating thrust and as such is also a more modern design used in most modern aircraft. This means it has had more advances in safety and reliability compared to a turbojet engine. Since the engine is more reliable at combusting fuel, this means it is also more environmentally friendly as it uses less fuel per unit thrust. (Figure 14)

Criteria	Weight	Rear-center on fuselage	Under Wings
Reliability	5	4	4
Environmental Impacts	3	4	4
Maintenance	4	4	4
Noise Produced	3	4	4
Maneuverability	4	5	3
Safety	5	4	5
Flight endurance	4	4	4
Sums:	28	116	113

Figure 15: Engine Placement Decision Matrix (Data from Cox, 2015)

The multi-engine aircraft will have its engines placed in the rear-center on the fuselage due to an increased maneuverability by placing the engines rear-center on the fuselage than under the wings. (Figure 15)

For the landing gear arrangement, the team only considered the triangle arrangement. The reasoning for this is because it is the most common arrangement for fast, jet powered aircraft due to its ability to allow for more forceful application of the brakes. This means the aircraft can land at much higher speeds than with other gear arrangements, which is very important for a fast aircraft. It also allows for a more equal distribution of weight on the landing gear, better visibility during ground maneuvering, and has a higher safety margin. Therefore, it was clearly the best choice for our aircraft design. (Jenkins & Donovan, 1942)

Once the concept selection process was complete, the team was able to develop an initial design for both aircraft. Below is the CAD drawing of this preliminary design. (Figures 16-19)

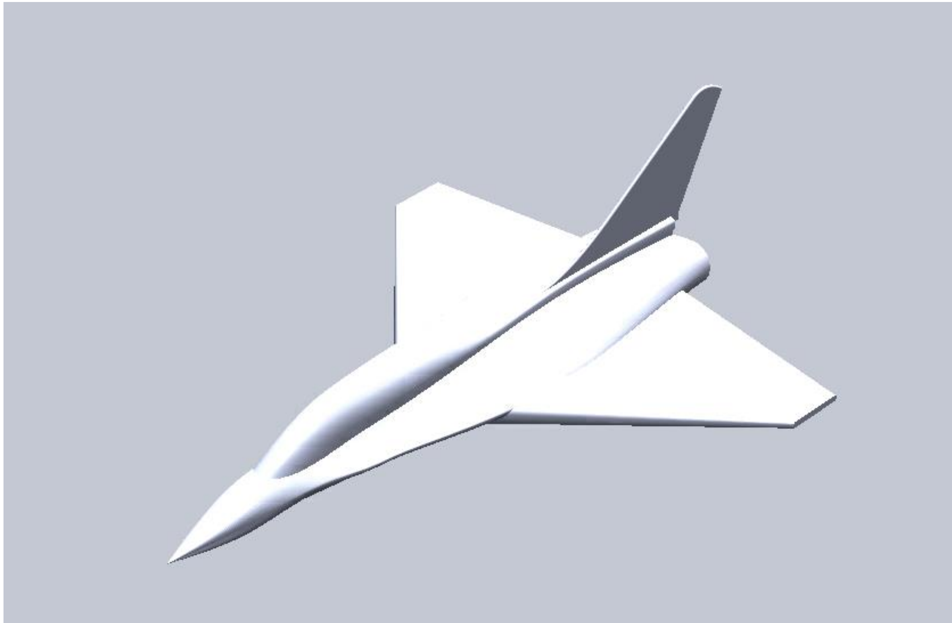

Figure 16: CAD Isometric View

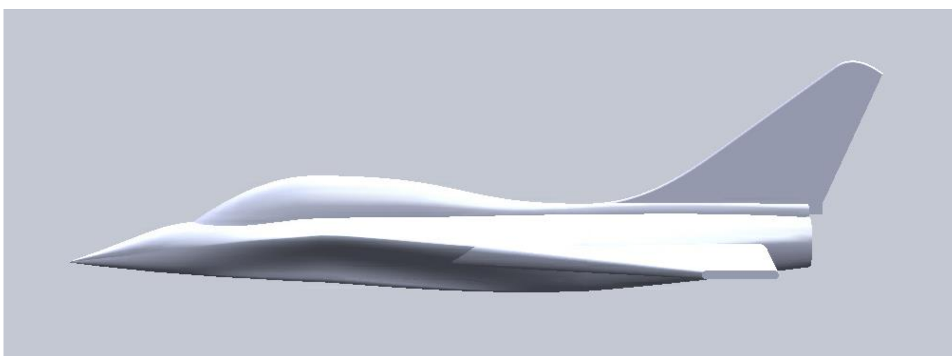

Figure 17: CAD Side View

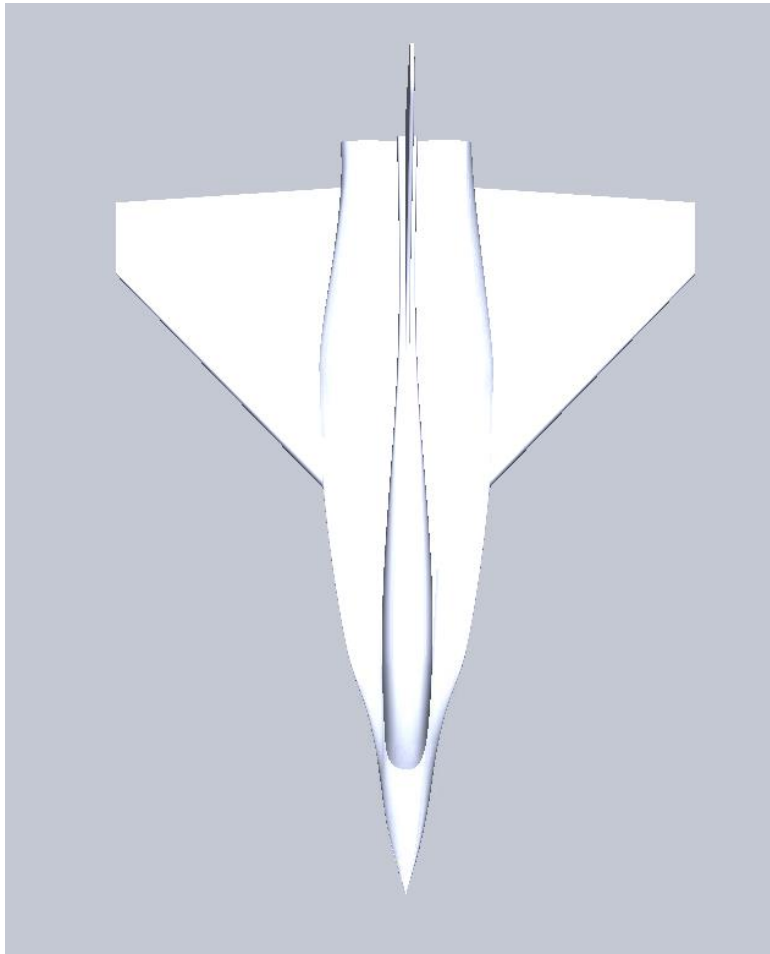

Figure 18: CAD Top View

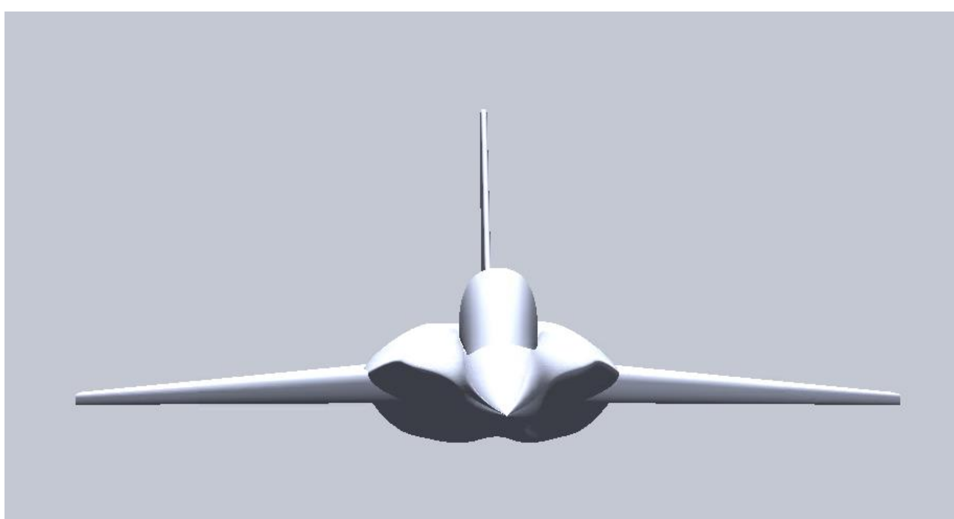

Figure 19: CAD Front View

4.2 PERFORMANCE ANALYSIS

Drag Polar

$$C_D = C_{D0} + K(C_L)^2$$

$$C_{D0} = 0.015 \; (From\ airfoil\ charts)$$

$$K = \frac{1}{\pi * e * AR}$$

$$e = 0.75 \; (From\ similar\ aircraft)$$

$$AR = 7.5 \; (From\ similar\ aircraft)$$

$$K = \frac{1}{\pi * 0.75 * 7.5} = 0.0566$$

$$C_D = 0.015 + 0.0566(C_L)^2$$

Maximum Range and Endurance

$$R = \frac{2}{c_t}\sqrt{\frac{2g}{\rho S} * \frac{C_L}{C_D^2}} * \left(\sqrt{m_1} - \sqrt{m_2}\right)$$

$$\max\left(\frac{C_L}{C_D^2}\right) = \frac{9}{16}\sqrt{\frac{1}{3KC_{D0}^3}}$$

$$E = \frac{1}{c_t} * \frac{C_L}{C_D} * \ln\left(\frac{m_1}{m_2}\right)$$

$$\max\left(\frac{C_L}{C_D}\right) = \frac{1}{2}\sqrt{\frac{1}{KC_{D0}}}$$

$$K = \frac{1}{\pi * e * AR}$$

$$g = 32.17\frac{ft}{s^2}$$

$$\rho = 0.076\ \frac{lb}{ft^3}$$

$$c_t = 3.472E - 4\ s^{-1}\ (From\ similar\ engine\ type)$$

$$e = 0.75\ (From\ similar\ aircraft)$$

$$AR = 7.5\ (From\ similar\ aircraft)$$

$$K = \frac{1}{\pi * 0.75 * 7.5} = 0.0566$$

$$C_{D0} = 0.015\ (From\ airfoil\ charts)$$

$$\max\left(\frac{C_L}{C_D}\right) = \frac{1}{2}\sqrt{\frac{1}{0.0566 * 0.015}} = 17.16$$

$$\max\left(\frac{C_L}{C_D^2}\right) = \frac{9}{16}\sqrt{\frac{1}{3 * 0.0566 * 0.015^3}} = 743.048$$

Single-Engine

$$M_{single-enigne\ 1} = 10{,}215lb$$

$$M_{single-enigne\ 2} = 7{,}968lb\ (With\ empty\ weight\ fraction\ of\ 0.78)$$

$$S_{single-engine}\ =\ 85.37ft^2$$

$$R_{single-engine} = \frac{2}{3.472E-4}\sqrt{\frac{2 * 32.17}{0.076 * 85.37S} * 743.048} * \left(\sqrt{10{,}215} - \sqrt{7{,}968}\right)$$
$$= 5{,}837{,}258ft = 1{,}105mi$$

$$E_{single-engine} = \frac{1}{3.472E-4} * 17.16 * \ln\left(\frac{10{,}215}{7{,}968}\right) = 24{,}556\ seconds = 6.82\ hours$$

Multi-Engine

$$M_{multi-enigne\ 1} = 13{,}988lb$$

$$M_{multi-enigne\ 2} = 9{,}791lb\ (With\ empty\ weight\ fraction\ of\ 0.70)$$

$$S_{multi-engine}\ =\ \frac{13{,}988}{119.66} = 116.90ft^2$$

$$R_{multi-engine} = \frac{2}{3.472E-4}\sqrt{\frac{2*32.17}{0.076*116.90}*743.048}*\left(\sqrt{13{,}988}-\sqrt{9{,}791}\right)$$
$$= 8{,}164{,}012ft = 1{,}564mi$$

$$E_{multi-engine} = \frac{1}{3.472E-4}*17.16*\ln\left(\frac{13{,}988}{9{,}791}\right) = 35{,}261\ seconds = 9.79\ hours$$

Minimum Thrust/Power Required vs Altitude

$$T = \frac{1}{2}\rho V^2 S C_{D0} + 2K\frac{(mg)^2}{\rho S V^2}$$

$$P = \frac{1}{2}\rho S V^3 C_{D0} + 2K\frac{(mg)^2}{\rho S V}$$

The MATLAB code (Figure 26) in the appendix uses the 2 equations above to plot the thrust and power required vs altitude for the single-engine (Figure 20) and multi-engine (Figure 21) aircraft.

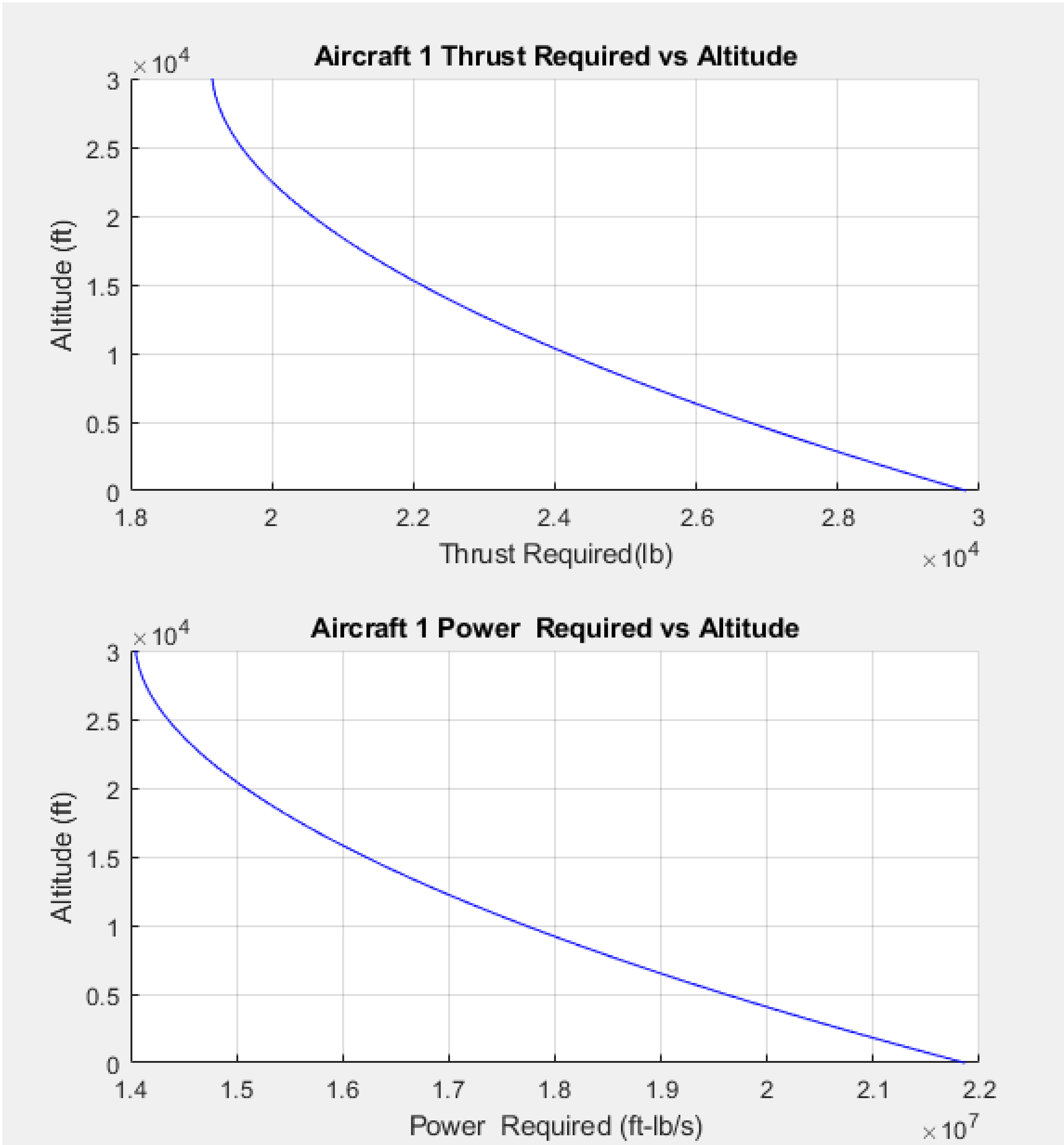

Figure 20: Thrust and Power Required vs Altitude for Single-Engine

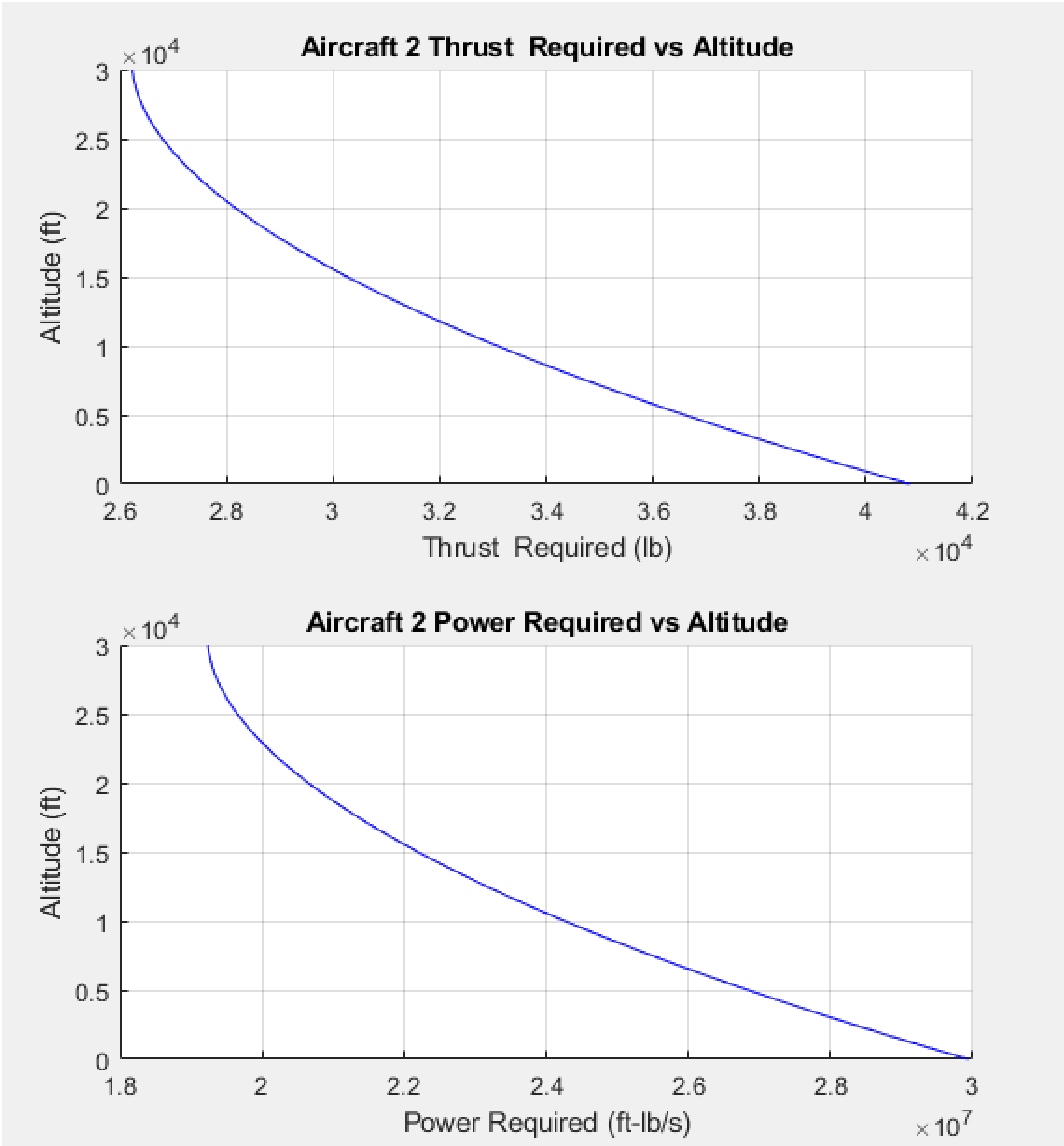

Figure 21: Thrust and Power Required vs Altitude for Multi-Engine

Thrust/Power Required and Max/Min Velocity

$$T = \frac{1}{2}\rho V^2 S C_{D0} + 2K\frac{(mg)^2}{\rho S V^2}$$

$$V_{T_{min}} = \left[\frac{2mg}{\rho S}\sqrt{\frac{K}{C_{D0}}}\right]^2$$

The MATLAB code (Figure 27) in the appendix uses the thrust equation above to plot the power required and max engine power vs velocity for the single-engine and multi-engine aircraft at the required flight ceiling (Figure 22). The intersection of these curves is equal to the maximum velocity, and the minimum velocity is found using the velocity equation above.

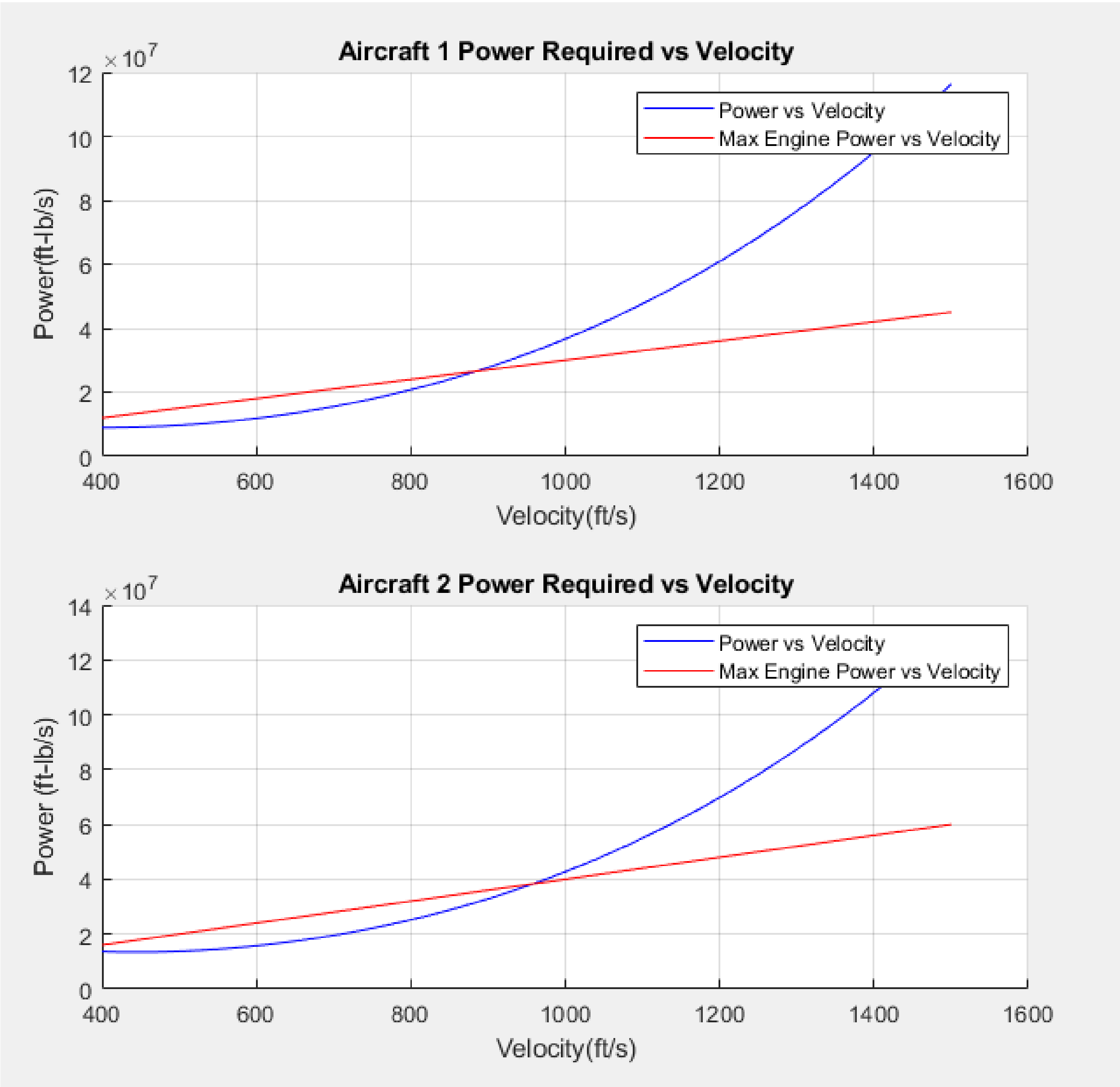

Figure 22: Power vs Velocity

Single-Engine

$$Service\ Ceiling\ \geq 12{,}000ft$$

$$Density\ @\ 12{,}000ft = 0.0530\frac{lb}{ft^3}$$

$$T_{required} = \frac{1}{2} * 0.0530 * 733.333^2 * 85.37 * 0.015 + 2 * 0.0566\frac{(10{,}215 * 32.17)^2}{0.0530 * 85.37 * 733.33^2}$$
$$= 23{,}273lb$$

$$V_{min} = \left[\frac{2 * 10{,}215 * 32.17}{0.0530 * 85.37}\sqrt{\frac{0.0566}{0.015}}\right]^2 = 531.19\frac{ft}{s}$$

$$V_{max} = 879\ \tfrac{ft}{s}\ (From\ power\ required\ vs\ velocity\ assuming\ 30{,}000lb\ maximum\ thrust)$$

Multi-Engine

$$Service\ Ceiling\ \geq 18{,}000ft$$

$$Density\ @\ 18{,}000ft = 0.0436\frac{lb}{ft^3}$$

$$T_{required} = \frac{1}{2} * 0.0436 * 733.333^2 * 116.9 * 0.015 + 2 * 0.0566\frac{(13{,}988 * 32.17)^2}{0.0436 * 116.9 * 733.33^2}$$
$$= 28{,}920lb$$

$$V_{min} = \left[\frac{2 * 13{,}988 * 32.17}{0.0436 * 116.9}\sqrt{\frac{0.0566}{0.015}}\right]^2 = 585.66\frac{ft}{s}$$

$$V_{max} = 958\ \tfrac{ft}{s}\ (From\ power\ required\ vs\ velocity\ assuming\ 40{,}000lb\ maximum\ thrust)$$

Engine Selection

The team selected a turbofan engine due to its efficiency and reliability. The type of engine used by our single-engine aircraft will be the General Electric F101 engine primarily due to its reliability and lower weight compared to other engines (Figure 23). The engine produces a thrust of over 30,000 lbf (GE Aviation, 2019), which exceeds the required thrust of 23,273 lbf. For the multi-engine aircraft, we have selected the Pratt and Whitney F100 engines due to their thrust production and strong reliability (Figure 24). Each engine produces over 20,000 lbf of thrust (Pratt and Whitney, 2020), and with two engines our required thrust of 28,920 lbf is exceeded.

Criteria	Weight	General Electric F110	Pratt & Whitney F119	General Electric F101
Reliability	5	4	4	5
Dry Weight	3	5	5	4
Maintenance	3	4	4	4
Safety	4	4	4	5
Thrust	5	5	4	4
Sums:	20	88	83	89

Figure 23: Engine Decision Matrix for Single-Engine (Data From P&W, 2020 and GE Aviation, 2019)

Criteria	Weight	General Electric CF34-8C	Pratt & Whitney PW1120	Pratt & Whitney F100
Reliability	5	4	4	5
Dry Weight	3	5	5	4
Maintenance	3	4	4	4
Safety	4	4	4	4
Thrust	5	3	4	5
Sums:	20	78	83	90

Figure 24: Engine Decision Matrix for Multi-Engine (Data From P&W, 2020 and GE Aviation, 2019)

5 Conclusions

In a conclusion to the report, the final design will be evaluated using the initial design requirements and criteria. The next steps in the design process are described, and the lessons learned throughout the design process are narrated.

5.1 Design Evaluation

In order to evaluate the final design, it must be compared to the current trainer aircraft used by NASA, the T-38 Talon. The Northrop T-38 Talon is a twin-engine, twin-seat supersonic aircraft that can reach a speed of 1.05 Mach and has a range of 1,093 miles. NASA currently spends an estimated $25-30 million per year in order to maintain and fly the T-38, and each unit costs around $756,000 as adjusted for inflation from 1961 (*T-38 Talon*, 2005). NASA currently operates 28 T-38 Talon's, according to the Federal Aviation Registry (FAA REGISTRY, 2020). For NASA to consider replacing the T-38 Talon, an aircraft must meet or exceed its performance while having a lower yearly repair cost in order to justify the large sum of money required to buy replacement aircraft. For example, if the designed aircraft only has a repair cost of $20 million per year or a saving of $10 million per year (assuming 28 aircraft are operated), and each aircraft has a cost of $1.5 million for a total cost of $42 million, it will take a minimum of 4 years for NASA to gain a net benefit from the lower maintenance cost of the aircraft. However, this is most likely a best-case scenario, as we are unable to accurately predict the maintenance cost and unit price of the aircraft in the current stage of development. The minimum time will most likely be longer, and in that time the maintenance costs may change in unpredictable ways. This means that for the teams designed aircraft to be successfully chosen by NASA, it must have a strict emphasis on low-cost, low maintenance design while meeting and exceeding the expectations set by the T-38 Talon.

Lastly, it cannot be excluded the fact that the T-38 has a great history at NASA and has thus become a deeply rooted tradition for astronauts. Before shuttle flights, astronauts would fly to the Kennedy Space Center in the T-38 and look upon their ride to space from the sky and would train for shuttle landings using the Talon. The T-38 Talon has also been used to train

NASA astronauts due to its quick maneuverability and high G load, a necessity for astronauts who will be strapped to a rocket (Siceloff, 2011). As such, generations of astronauts at NASA have trained using the T-38 Talon, and it has become an important part of the training process and a constant tradition (Creech, 2005). Replacing the T-38 Talon would mean the end of more than half a century of tradition. The financial benefits of replacing the Talon would need to vastly outweigh the cost of ending such a tradition.

5.2 NEXT STEPS

The next steps in the design process of this aircraft would include the physical creation and testing of a scaled model of the aircraft body. Testing would include using a Purdue University wind tunnel to collect data on the aerodynamics of the aircraft body. Using this data, a Reynold's Number can be found to better understand and create theoretical mathematical models of the aerodynamics and performance of the full-sized aircraft, including the lift and drag that would be experienced. This would also include conferring with research professors to gain insightful critiques on our design and process of testing in order to learn how to best proceed past this point.

5.3 LESSONS LEARNT

From this design project, the team learned valuable experience on the design process of creating a new experimental aircraft. From the broad overview of initial design specifications such as stakeholders and risks to estimating specific qualities such as range, flight time, and maximum velocity, the project gave first-hand experience in creating an aircraft from a few simple requirements and specifications. The team learned that it is best to start the design process with a broad view and slowly create a narrower and more specific design, as this prevents the team from having tunnel vision on a singular design instead of choosing the best design out of multiple possible ideas. The team also learned the value of using online team-based document creation tools such as Word Online, as this allowed for the constant progression of the project regardless of time schedules or member locations. By using the internet to communicate concisely and quickly, meeting times were reduced, and milestones were able to be quickly finished.

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6 APPENDIX: MATLAB CODE

```
Weight_payload = 600; %lb
Weight_crew = 300; %lb
R1_nm = 1000; % Range - Nautical Mile
M = 0.65; % Cruise speed

W0_est = 200000; % Inital Weight Estimate (lb)
W0_new_est = W0_est;
W0=0;
tol=50; % Weight tolerance (lb)
iter = 0; % Iteration Counter

%Warmup and takeoff
W1_W0 = .97;  %Weight fration takeoff

%Climb
W2_W1 = .985; %Weight fraction climb

%Cruise
R = R1_nm * 6076.11549; % Range to ft
C = 0.9/3600; % 1/s specific fuel consumption
V = M*994.8; % Velocity in ft/s
L_D = 0.866*9.5;  %Lift to drag cruise
W3_W2 = exp(-R*C/(V*L_D)); %Cruise weight fration using equation

%Loiter
E = 1200; %Endurance
C = 0.8/3600; % 1/s
L_D = 9.5;  %Lift to drag loiter
W6_W5 = exp(-E*C/(L_D)); %Loiter weight fration using equation

%Land
W7_W6 = 0.995;    %Weight fraction climb

%Calculate GTOW
W7_W0 = W7_W6 * W6_W5 * W3_W2 * W2_W1 * W1_W0;

while abs(W0_est - W0) >= tol %Repeats until guess=real
    W0_est = W0_new_est;
    Wf_W0 = 1.06*(1 - W7_W0);  %Fuel fraction calculation
    We_W0 = 1.59* W0_est^-0.1;    %Empty fraction calculation
    We = We_W0 * W0_est;
    W0 = (Weight_payload+Weight_crew)/(1 - Wf_W0 - We_W0);  %Gross
 Weight Guess Using Equation
    W0_new_est=W0;
    iter = iter + 1;
end

disp(['Range 1: ', num2str(R1_nm)])
disp(['Weight Payload: ', num2str(Weight_payload)])
disp(['Weight Crew: ', num2str(Weight_crew)])
disp(['Iterations: ',num2str(iter)])
disp(['W0: ',num2str(W0)])
```

Figure 25: Aircraft Sizing Code

```
Ae = 0:100:30000;%ft ALtitudes
As = Ae./3.281;%m to metric
[T, a, P, Ds] = atmosisa(As); %Density array
D = Ds/16.018; %density to lb/ft^3
V = 733.333; %Plane velocity ft/s
G = 32.17; %Gravitational Accelaration ft/s^2
S1 = 85.37; %Wing area 1 ft^2
S2 = 116.90; %Wing area 2 ft^2
M1 = 10215;%Mass 1 lb
M2 = 13988;%Mass 2 lb
CD0 = 0.015;%Parasitic drag coefficient
K = 1/(pi*0.75*7.5);%K value

T1 = (0.5.*D.*(V^2).*S1.*CD0) + 2.*K.*(((M1.*G).^2)./
(D.*S1.*(V^2)));%Thrust equation
P1 = T1.*V;%Power equation
T2 = (0.5.*D.*(V^2).*S2.*CD0) + 2.*K.*(((M2.*G).^2)./(D.*S2.*(V^2)));
P2 = T2.*V;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure(1)
subplot(2,2,1);
hold on
title("Aircraft 1 Thrust Required vs Altitude");
grid on
xlabel("Thrust Required(lb)");
ylabel("Altitude (ft)");
plot(T1,Ae,"b-");
hold off
subplot(2,2,3);
hold on
title("Aircraft 1 Power  Required vs Altitude");
grid on
xlabel("Power  Required (ft-lb/s)");
ylabel("Altitude (ft)");
plot(P1,Ae,"b-");
hold off
subplot(2,2,2);
hold on
title("Aircraft 2 Thrust  Required vs Altitude");
grid on
xlabel("Thrust  Required (lb)");
ylabel("Altitude (ft)");
plot(T2,Ae,"b-");
hold off
subplot(2,2,4);
hold on
title("Aircraft 2 Power Required vs Altitude");
grid on
xlabel("Power Required (ft-lb/s)");
ylabel("Altitude (ft)");
plot(P2,Ae,"b-");
hold off
```

Figure 26: Min Thrust/Power Required vs Altitude Code

```
V1 = 400:1:1500;%ft/s Velocities
V2 = 400:1:1500;%ft/s
G = 32.17; %ft/s^2 Gravitational Acc
S1 = 85.37; %ft^2 Wing area
S2 = 116.90; %ft^2
M1 = 10215;%lb Mass
M2 = 13988;%lb
CD0 = 0.015; %Parasitic drag coefficient
K = 1/(pi*0.75*7.5);%K value
D1 = 0.053; %Density at altitude
D2 = 0.0436;
Tmax1 = 30000;%Max engine thrust estimation
Tmax2 = 40000;

T1 = (0.5.*D1.*(V1.^2).*S1.*CD0) + 2.*K.*(((M1.*G).^2)./
(D1.*S1.*(V1.^2)));%Thrust Equation
T2 = (0.5.*D2.*(V2.^2).*S2.*CD0) + 2.*K.*(((M2.*G).^2)./
(D2.*S2.*(V2.^2)));
P1 = T1.*V1;%Power Equation
P2 = T2.*V2;

TV1 = Tmax1.*V1; %Max velocity
TV2 = Tmax2.*V2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Plots%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Subplots
figure(1)

subplot(2,1,1);
hold on
title("Aircraft 1 Power Required vs Velocity");
grid on
xlabel("Velocity(ft/s)");
ylabel("Power(ft-lb/s)");
plot(V1,P1,"b-");
plot(V1,TV1,"r-");
legend('Power vs Velocity','Max Engine Power vs Velocity');
hold off

subplot(2,1,2);
hold on
title("Aircraft 2 Power Required vs Velocity");
grid on
xlabel("Velocity(ft/s)");
ylabel("Power (ft-lb/s)");
plot(V2,P2,"b-");
plot(V2,TV2,"r-");
legend('Power vs Velocity','Max Engine Power vs Velocity');
hold off
```

Figure 27: Max Velocity Code