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Team 507: SAE Aero Design

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Abstract

Our project is to design a radio-controlled cargo plane for the Society of Automotive Engineers (SAE) Aero Design Competition. This project is a mix of two teams. We are the Aero-Propulsion group. The second team is the Geometric team. We focused on design features and calculations for the plane during flight. Our goal is to complete the flight path while keeping a stable flight with a cargo load. We used the project to test a new design by adding a canard. It is a smaller wing in front of the main wing that produces lift. The plane is about 4 feet long and has 3 wings: the canard, main wing, and tail. The main wing has the largest surface touching the airflow. This means our main wing produces the most lift. Planes with two wings are hard to fly. However, we found that adding a tail made the plane more stable. The tail features a T-tail design, where a vertical section holds the tail wing in a plane above the main wing. We placed our cargo bay between the canard and the main wing. This allows for easier loading and unloading of cargo. Our plane can resist crosswinds up to 30 miles-an-hour, making the plane stable during landing. The plane produces a maximum thrust of 222 pound-force. We calculated performance of our plane during takeoff and landing to figure out our plane needs at least 360 feet of runway space to work. Our plane can carry a maximum cargo load of 11 pounds. We use servomotors to move control surfaces. Our plane works under large forces with the servos we selected. This design shows that a canard wing plane can create stable flight with a cargo plane.

Disclaimer

At the time of writing, the team was waiting for FSU Police Department to approve the flight test. As theoretical work suggests that the plane should be able to fly, the evidence manual assumes that the plane will successfully fly (unless specified otherwise).

Calculations provided in appendix I use values gathered from the initial CAD designed to predict physical properties of the plane, such as the weight. Furthermore, while the calculations are included in the order they were created, as the project got further developed, some initial calculation files have values taken from other calculation files. Hence, they could be very particular to our design, especially stability calculations. The team do not take responsibility for the calculations been used for other projects. All calculations were done in MATLAB, hence they might not work with other calculation program.

Due to limited budget, we are using electrical and propulsion components that were used by previous teams. Those parts are susceptible for reliability failures. The team does not take responsibility for reliability failures related to such components. Furthermore, as the geometric team (T508) were in-charge of CAD design of most components (except for the main wing and the initial vertical tail design, before it was modified by T508), 3-D printing, and assembly/connectivity of printed parts, and the manufacturing of the landing gear, our team (T507) does not take responsibility for those components in the project. Read the evidence manual provided by the geometric team for more information.

Acknowledgement

We would like to thank Florida Space Grant Consortium for funding our project, which allowed us to by new components for our project and pay the registration fee for the SAE Aero Design Competition: Design Knowledge Event.

We also like to thank our advisor, Dr. Chiang Shih, who provided us with very useful information for the project. Dr. Shih brought the ground effect issues to our attention, and also provided information regarding control surface movement.

We would also like to thank the Seminole R/C Club in Tallahassee, who allowed us to attend their monthly meetings, which allowed us to talk about our design procedure. As they often fly model planes, their input was very helpful, especially when designing the control surface movement procedure. Furthermore, our pilot, Fredrich Murch, was provided by the R/C club. We would also like to thank him. Fredrich was kind enough to meet us multiple times in person to discuss about the design process and provided extra servos. He also provided his controller and the receiver for our flight. Crucially, he helped with selecting the flight test location, Cairo County Airport.

We also like to thank Dr. Rajan Kumar, who met with our team on multiple occasions via zoom to discuss stability calculations and check if they were correct. As our plane has a unique 3-wing layout, this was very helpful as it was difficult to find information regarding stability for our wing layout from books. He also allowed us to use the subsonic wind tunnel at Florida Center for Advanced Power Systems (FCAAP) for the project, which helped us to validate our design. We would also like to thank Devon Foster, who is a graduate student working at FCAAP, who helped us with designing the model for the test and operated the wind tunnel during the test. He also did the post processing for our wind tunnel test, which was very useful as our team had very limited experience with the processing software used in the wind tunnel lab.

We would also like to thank our senior design professor, Dr. Shayne McConomy, for the very useful feedback provided to us related to the project and also in filling out documents necessary for the test flight. We also like to thank our teaching assistants, Melanie Munroe and Joshua Jones, who provided useful feedback on our project submissions. Melanie also directed us towards the "aero-tape" that will be used to cover connection points between parts, which will reduce drag.

Finally, we would also like to thank the geometric team (T508) for their contributions for the project, including test prints and landing gear manufacturing.

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Notations

SAE	Society of Automotive Engineers
AoA/α	Angle of Attack
C_m	Coefficient of Moment
C_L	Coefficient of Lift
C_D	Coefficient of Drag
R/C	Remote Control
CG	Center of Gravity
CFD	Computation Fluid Dynamics
CAD	Computer Aided Design
LE	Leading Edge
TE	Trailing Edge

Chapter 1: EML 4551C

1.1 Project Scope

The team assigned to this project is comprised completely of Mechanical Engineering students attending FAMU-FSU College of Engineering. The team will complete the project, build a prototype, and compete in SAE Aero Competition. The following section defines the scope of the project.

2.1.1 Project Description

The objective of this project is to design and manufacture a remote-controlled plane within the rules and regulations of the SAE Aero Design East Competition 2021. The plane will primarily be 3D printed. It will be able to take-off and land carrying the required cargo and complete the necessary flight path.

The Objective of the aero-propulsion team is to ensure that the plane take-off and land while carrying a payload and complete the flight path.

2.1.2 Key Goals

This section explains the goals set to comply with the SAE Aero Design Competition East and meet the project sponsor requirements. The plane is required to take off and land successfully from a short runway while carrying a cargo load.

- The plane is primarily 3D printed, with the help of the geometric team
- The plane takeoff, cruise, and land while carrying a cargo load
- The plane carries a minimum of one soccer ball as the cargo load
- The cargo bay can is accessible with minimum effort

- The plane can withstand environmental conditions at the time of flying

2.1.3 Market

The markets for this project include professionals in the field of aviation, aviation companies, competitive RC hobbyists, and scholars that reference this project (probably next year's SAE Aero senior design team) and the Society of Automotive Engineering International Aero Design Competition.

2.1.4 Assumptions

Senior Design Team 507 is fully expecting a flying competition ready remote-controlled airplane. To accomplish this, we are making the following assumptions:

- Will be flown in atmospheric conditions at sea level including gravity, pressure, and temperature.
- The majority of the airplane will be 3D Printed.
- Will be used for competition purposes.
- Motors and electronics used to control and propel the airplane will be store bought and not custom-made.
- Will be controlled by one pilot.

2.1.5 Stakeholders

The stakeholders for this project include: Senior Design Teams 507 & 508, Dr. McConomy and Dr. Shih, SAE Aero Design Competition, recruited RC pilot. These stakeholders have the common goal of both teams being successful in this project. The teams are required to be successful to graduate but to also capture the eye of any companies for future opportunities. The students will be representing the FAMU-FSU College of Engineering at the competition and the performance will reflect the school as well as the sponsor and advisor, Dr. McConomy and Dr. Shih. The team's sponsor (Dr. McConomy) has also applied for a grant from Florida Space Grant Consortium (FSGC). The SAE Design competition is tasked with pushing students to find new and creative ways to tackle this project. This in return attracts RC competitors along with companies to learn about and recruit young engineers. The RC pilot has a vested interest because he/she will need to work with the students to properly configure the plane's controls and will also be in the competition.

1.1.6 Differentiation from Team 508

Team 507 has been designated as the "Aero Propulsion" team as opposed to Team 508 being the "Geometric Integration" team. What has been decided between the two teams regarding the scope between the two groups is as follows.

Team 507 will oversee theoretical calculations and initial design for plane components. They will perform aerodynamic, physical, and mass calculations for the plane. Team 508 will oversee the physical integration of the components that Team 507 has designed. If a component designed by Team 507 is deemed unfeasible by Team 508 then Team 507 will have to recalculate and make the design more able for physical integration.

1.2 Customer Needs

The customer needs for this project are defined by the rules and regulations given by the SAE Aero competition and the project sponsor (Dr. McConomy). We aim to not only meet but exceed the competition guidelines.

1.2.1 Customer Statement

All the customer needs mentioned below are related to aero and propulsion team. As the project is for a competition, the customer needs are interpreted from the competition rule book. The regulations provided by the competition state that the Regular Class is an "all-electric class intended to develop a fundamental understanding of aircraft design." (SAE International, 2021). The team met with the project sponsor (Dr. McConomy) to gather sponsor's needs for the project.

1.2.2 Competition Customer Statements

The following customer needs were derived from the rules of the competition. Since the competition rules specify numerical values (targets), they were changed in interpreted needs to be broader and not be specific. While the competition rules include restrictions and minimum requirements, Team 507 will abide by the competition rules while remaining competitive by exceeding the bare minimum.

Table 1 : SAE Rule Book Customer Needs Interpretation

Prompt	Customer Statement	Interpreted Need
General Aircraft Requirements	1. Designs are limited to fixed wing aircrafts only	The aircraft can have fixed wings
	2. The aircraft must be flyable at the designated empty center of gravity location as submitted in the design report	The aircraft can fly without a cargo load with designated center of gravity

	3. The aircraft wingspan is limited to a maximum of 120 inches	The wingspan of the aircraft is less that the maximum amount allowed
	4. The aircraft gross take-off weight may not exceed fifty-five (55) pounds	The aircraft weighs less than maximum weight allowed
Control Requirements	5. If aircraft has ground wheels the controller should be able to control plane without aerodynamic components	The plane can be steered using ground wheels
	6. All aircraft must be controllable in flight.	The aircraft can be controlled when it is flying
	7. Aircraft must have a shut off in case of lost control	The aircraft has safety switch-off feature
	8. The aircraft must only be powered by the motor on board the aircraft.	The aircraft is power by on-board power sources
Material Requirements	9. Metal propellers are not allowed.	The aircraft can use non-metal propeller

	10. All types of gyroscopic or other stability assistance are prohibited	The plane can be stabilized using manual remote input
Electronic Requirements	11. The battery pack must have enough capacity to safely drive all the servos in the aircraft	Aircraft can be efficiently designed to operate using minimal power
	12. The aircraft must be propelled by a single electric motor.	The aircraft can be propelled by a single electric motor
Payload Requirements	13. The payload cannot contribute to the structural integrity of the airframe, meaning, the airframe must be able to fly without the payload installed.	The structure of the aircraft can be stable and fly without the payload
	14. Only one cargo bay is allowed.	The plane utilizes one cargo storage
	15. The length of the cargo bay must be detailed on the	The length of the cargo bay remains the same as the

	drawing for technical inspection.	specified length in the design report
	16. All payload must be unloaded within one minute to be scored.	The cargo can be unloaded with ease
Mission Requirements	17. The aircraft must remain on the runway during the take-off roll.	The aircraft can take off without touching ground again
	18. The take-off distance limit is 100 ft.	The plane can be airborne within the required distance
	19. The distance from the initial start before the turn is 400 ft.	The plane can maintain control for the minimum distance required from the start
	20. The landing distance limit is 400 ft.	The plane can land and come to a complete stop within the required distance

1.2.3 Dr. McConomy's Costumer Statements

As the project does not have a corporate sponsor, Dr. McConomy acted as the sponsor for the project. The team met with Dr. McConomy and asked about additional needs and constraints that the project is required to meet. The following were compiled based on his responses.

Table 2: Dr. McConomy's (sponsor) Responses

Prompt/Question	Customer Statement	Interpreted Need
General Aircraft Requirements	I. Mostly 3D printed components	The aircrafts main physical components can be 3D printed
	II. “Cool new thing”	The aircraft can introduce a new innovative feature
“What changes need to be made to the last year’s design?”	III. Wheel Positioning are wrong in the current available model	The wheels can stabilize motion of the plane
	IV. The control surfaces are not strong enough to operate under high air pressure in the rear wing	The control surfaces in the rear wing create enough force/lift to take off under high air pressure loads
	V. The distance between center of gravity and center of pressure is wrong in the current available model	The center of gravity and center of pressure are positioned correctly
	VI. Fuselage design along with its connection with the wings	The fuselage & the wings can improve dynamic stability of the plane

	VII. The dynamic stability calculations are not done in the current available model	The dynamic stability of the plane can be verified mathematically
"What weather conditions do we account for when designing the plane?"	VIII. The cross wind effected the current available model during the competition	The plane can withstand expected crosswind conditions during takeoff/landing
"What performance goals should we aim for?"	IX. Take off and land with minimum cargo load requirements	The plane can take off and land with the minimum cargo load allowed by the competition

Table 1 contains customer statements taken from the rules and regulations of the competition. Hence, some of the customer needs contain numerical constrains that the project team has to adhere to participate in the competition. Two key constraints are the max weight (55 pounds) and max wingspan (120 inches) requirements. The key propulsion requirement is that only one electric motor can be used for propulsion. However, there are no limitations on the make and the model of the motor. These customer needs were made broader (with no target values) in interpreted needs. For example, the customer need related to weight requirement was interpreted as the plane weighs less than the maximum weight allowed.

Table 2 outlines the customer statements gathered by meeting the sponsor (Dr. McConomy). A key requirement stated by the sponsor was that the project group has to include an innovative feature in the design. Furthermore, as the project is based off last year's design, the sponsor requested certain design changes to this year's design. Most of the requested changes are to the aerodynamic characteristics of the plane, such as the fuselage and control surfaces. Furthermore, the sponsor was keen on the plane being mostly 3-D printed. This suggests that the plane has to be designed to carry a small cargo load.

1.3 Functional Decomposition

To understand the functionality of the airplane, a functional decomposition was created. The team conducted a brainstorming session to generate fundamental functions of the plane with consideration to customer needs. Based on the brainstorming session major systems and minor functions (low-level functions) were generated. A cross-reference chart was created to better understand which functions fulfill customer needs fulfill project requirements.

1.3.1 Discussion of Data Generation

Data gathered during customer needs were analyzed to create functions for functional decomposition. The key goals were also considered in this process. Some customer needs considered are as follows.

General Requirements	The aircraft must be flyable at the designated empty center of gravity location as submitted in the design report	The aircraft can fly without a cargo load with designated center of gravity

Control Requirements	If aircraft has ground wheels the controller should be able to control plane without aerodynamic components	The plane can be steered using ground wheels
	All aircraft must be controllable in flight.	The aircraft can be controlled when it is flying

Mission Requirements	The take-off distance limit is 100 ft.	The plane can be airborne within the required distance
	The landing distance limit is 400 ft.	The plane can land and come to a complete stop within the required distance

"What changes need to be made to the last year's design?"	The control surfaces are not strong enough to operate under high air pressure in the rear wing	The control surfaces in the rear wing create enough force/lift to take off under high air pressure loads

"What performance goals should we aim for?"	Take off and land with minimum cargo load requirements	The plane can take off and land with the minimum cargo load allowed by the competition

According to the customer needs gathered, the plane should takeoff within the designated space, maintain altitude and stability while cruising, and land within the designated space while carrying at least the minimum cargo load allowed in the competition. Furthermore, the airplane should have dynamic steering while on the ground. Other customer needs were also considered to create functions. Based on this analysis, the following major systems were created: Take off, Maneuvering/Cruising, Landing and Carrying Payload. Minor functions were created to achieve these functions. From the moment the plane accelerated from the stationary position on the runway to the moment it achieves cruising altitude, the plane is in take-off motion. From the moment the plane leaves the cruising motion for the final approach to the moment the plane comes to a complete stop, the plane is in the landing motion.

1.3.2 Hierarchy Chart

Based on the data collected, the following hierarchy chart was created. The flow starts with the project objective and breaking down into low level functions that are needed to complete the project objective. A higher resolution version of the hierarchy chart is included in Appendix C.

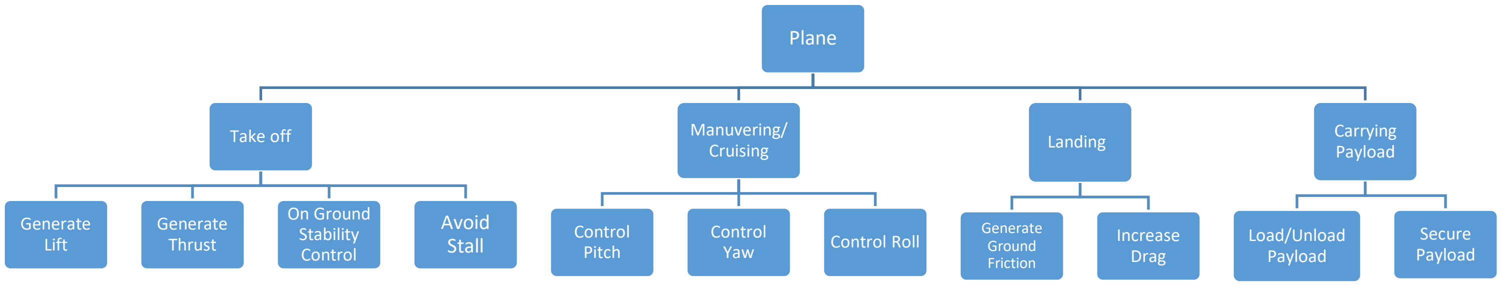


Figure 1: Functional Decomposition Hierarchy

The hierarchy chart was created based on the major systems of the aircraft and how they can be divided into minor functions (low-level functions).

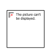
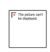
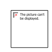
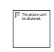
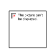
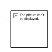
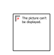
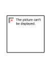
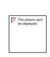
1.3.3 Discussion

The RC plane must fly stably while carrying a payload. It should generate enough lift to take off, should have aerodynamic stability while cruising, and land within the designated area and come to a complete stop. The control surfaces should perform adequate while under high aerodynamic pressure. Furthermore, the thrust should be enough to generate forward momentum and create an air pressure differential, which leads to lift. The plane needs to carry the minimum cargo load (a soccer ball) which adds to the weight of the plane and be able to fly without the cargo. This change in weight distribution needs to be considered when designing. Though securing the payload seems like a geometric integration aspect Team 507 needs to consider the aerodynamic aspects that affect the process of securing the payload such as the drag associated and where exactly the payload will be secured.

1.3.4 Cross reference Chart

The following is the cross-reference chart created to understand the relationships between major systems and low-level functions. As the customer needs were gathered using competition rules and the sponsor requirements, there are two sets of customer needs. Twenty customer needs gathered using the rulebook are numbered 1-20. Nine customer needs gathered from the sponsor are numbered I-IX.

Table 3: Cross-reference Table

Minor Functions	Related Customer Needs	Major Systems				Minor Functions Rankings
		Take-Off	Maneuvering/Cruising	Landing	Carrying Payload	
Generate Lift	1,2,3,4,10,11,18,19,20 IV, V, VI					2
Generate Thrust	1,2,4,7,8,9,11,12,18,19 IV, VIII					1
On Ground Stability Control	2,5,11,17,18,19 I, II, III, VII, VIII					3
Avoid Stall	2,3,7,10, IV, VII, VIII					4
Control Pitch	2,6,10 IV, VII,					7

Control Yaw	2,6,10 IV, VII, VIII		✓	✓		8
Control Roll	2,6,10 IV, VII		✓	✓		9
Generate Ground-Friction	2,20 IV, VIII			✓		11
Increase Drag	2,20 I, II IV, VIII			✓		10
Load/Unload Payload	13,14,15,16, I, II, IX	✓		✓	✓	5
Secure Payload	13,14,15,16 II, V, VI, XI	✓		✓	✓	6
Systems Rankings		2	4	1	3	

The check marks ([check mark image]) in the cross-reference chart indicate the which low-level functions relate to systems. In the customer needs column, the top line on each row is for the customer needs in table 1 (from the rule book), and the second row is for the customer needs in table 2(from the sponsor). Rankings were generated for both rows (based on the importance of functions) and columns (based on importance of major systems). The rankings are determined by the number of "[check mark image]" assigned to a row or a column. When there is a tie, the rank was determined by the team based on the importance of the function/systems to the project. While thrust and lift have the same “”, thrust was considered more important as the plane requires forward motion to create an airflow around it, which generates lift. Hence, generating thrust and landing were ranked 1st. Maneuvering/cruising and deceleration were ranked the lowest based on the cross-reference chart. This makes sense as the other systems and functions are more important to for the motion of the plane.

1.3.5 Connection to Systems and Smart Integration

Lift is required for all 4 systems as lift is the key requirement for flying. The same applies to thrust as thrust will generate forward momentum in the plane, causing air to flow over the plane. While lift is necessary during all periods of flight, the amount changes in each stage. It is highest during takeoff because it has a steep angle of attack, when the plane levels at cruising altitude, lift is still generated but heavily decreased. The plane has the possibility to go into stall during take-off and landing if the angle of attack is too high. Furthermore, the weight of the cargo load and how its positioned can play a part in stall, as the added weight will change the center of gravity location, which will change the distance between the center of gravity and center of pressure. This would affect the angle of attack needed to create lift. Hence stall is related to both take-off and landing systems. Generating lift is required for all major systems of the project, lift keeps the plane in the air as does the generation of thrust since they are relatively proportional. When considering landing, lift and thrust are still relevant in order to control the deceleration and angle of attack.

Pitch is necessary to change the angle of attack, especially for a fixed wing airplane such as this project. Furthermore, control of pitch is necessary to maintain altitude. Hence it is included in all the systems, except for payload carrying. Because the pitch of the plane doesn’t necessarily change when the plane is maneuvering and cruising avoiding stall is not being considered in that major system. Avoiding stall is an important consideration when taking off and landing due to the higher angle of attack during these processes. Because of the added weight from the payload the angle of attack will have to change depending on how much payload and how much momentum the plane has during takeoff and landing. Controlling pitch is important during takeoff and landing because it controls the elevation rate of the plane. While cruising the pitch of the plane needs be controlled in order to remain constant to maintain the cruising altitude.

Both roll and yaw allow to turn the plane while in the air, using the ailerons and the rudder respectively. However, in the event of a cross wind, yaw is needed to land the plane at an angle to reduce the effect of the crosswind. Furthermore, in the approach to land, the roll needs to be controlled to ensure that the wing tips won't touch the ground before the wheels do. Hence, both yaw and roll are related to both maneuvering/cruising and landing systems. When taking off it is assumed that roll and yaw remain constant and are therefore not affected much during this process. While maneuvering and landing these are taken into account because they affect the turning of the plane and the landing orientation since it is preferable to land straight.

Landing and maneuvering on the ground is also related to all the systems except for maneuvering in the air, as the plane needs to maintain its stability while on the ground. When the plane is approaching for the landing, it needs to create drag to mitigate some of the lift and reduce speed. Furthermore, once on the ground, the plane needs to generate friction between the wheels and the ground using physical brakes.

While the payload handling is mainly a task of the geometric team, the fuselage design put constraints on the payload handling. The position of the payload determines the center of gravity location. As the center of gravity and center of pressure positions effect the aerodynamics, it is important that the payload is loaded and secured within the fuselage and that the position of the payload is at the expected position, so the payload won't affect aerodynamic characteristics of the plane.

On ground stability control is affected by the three major systems due to the landing gear needing to be able to support the weight of the plane whenever it is in contact with the ground and needs to be able to dampen the impact when the plane lands to protect from damage. The wheels also need to be able to maneuver on the ground without solely relying on aerodynamics.

After reviewing the cross-reference chart, the team determined that certain functions and systems can be integrated. As lift, stall and roll involve manipulation of the air flow around the plane, the same control surfaces (ailerons) can be used for all 3 tasks. Using the ailerons as air brakes during landing and reverse thrust from the propeller would decrease speed. This would allow to remove brakes or reduce the physical braking. Hence, control surfaces can be used to assist wheel friction.

The functional decomposition will be used by the team during the design process. It will be used as reference to ensure that both the customer needs and minor functions are satisfied to accomplish the major systems of the project, and ensure that the plane will take off, cruise and land.

1.4 Targets and Metrics Summary

Metrics are the measurable components of the project and targets are the measurements of these components themselves. To get these components our team analyzed the functions of the project and devised systems for deriving and testing targets and metrics for this project.

1.4.1 Derivation of Necessary Metrics

Each function was analyzed to derive the necessary metrics. Several metrics were created for every function because they depend on multiple components. Notice that most of the values are based on extreme values for functions (such as max weight of the plane or minimum lift to fly). This is due to the fact that the project is still in concept generation stage.

- Generating Lift
  - Necessary Metrics: Angle of attack, Coefficients of Lift and Drag, Chord Length, and Wingspan
    - These are all values used to create the upward net force on a plane necessary for flight. Values were found based on the max weight of the plane (55 lbs. limit set by the competition) and minimum coefficient values needed to counter that weight (characteristic values (Lennon, 2005)).
- Generating Thrust
  - Necessary Metrics: Thrust Force, Electric Motor Kv Rating, Voltage, Propeller Diameter, and Electric Motor Maximum Power
    - These values deal with the performance of the motor and its ability to provide the plane with a forward force. Values related to the motor were given by the manufacturer. Thrust force will be found using the

aerodynamic drag coefficient and the weight of the plane. Since the project is still in concept generation stage, thrust force was taken from the RC Aircraft Design book (Lennon, 2005).

- Ground Stability Control
  - Necessary Metrics: Gross Take-off Loading, Thrust Line Positioning, and Center of Mass Positioning
    - The takeoff load was based on the max weight permitted by the competition. Thrust line and center of mass position was based on recommended values for plane, while accounting for a small error (Pilots Handbook of Aeronautical Knowledge, 2017).
- Avoid Stall
  - Necessary Metrics: Stall Speed and Stall Angle of Attack
    - These are all values used to create the upward net force on a plane necessary for flight. Values were based on characteristic stall values for airfoils (Lennon, 2005).
- Maneuvering/Cruising
  - Necessary Metrics: Control Pitch, Roll, and Yaw
    - These are the basic maneuver controls to fly the plane. Servo motors will be attached to the ailerons to control the roll, to the rudder to control the yaw, and to the elevator and flaps to control the pitch. The angle of rotation is based on the conventions provided in the RC Aircraft Design book (Lennon, 2005).

- Generate Ground Friction
  - Necessary Metrics: Coefficient Rolling Friction, Landing Velocity, and Landing Gear Force Absorption
    - These metrics control how the plane will act during landing. The values were based on the max weight allowed for the plane and preliminary values calculated for lift of the plane. For example, 25 mph was the takeoff speed (value at which lift is large enough counter the weight of the plane). Hence, the plane needs to travel slower than 25 mph to create less lift.
- Increase Drag
  - Necessary Metrics: Coefficient of Drag and Air Brake Force
    - These are values used to create a force opposite the direction of motion, particularly for landing the plane. The values are based on characteristic coefficient values and expected drag from flaps (Lennon, 2005). For example, when drag coefficient is 1, the drag is sufficient to stop the plane to move forward and keep it stationary. Hence a drag coefficient bigger than 1 is expected to create sufficient drag to slow down the plane.

- Securing Payload
  - Necessary Metrics: Payload Weight
    - The competition rules state the payload has to be a standard size soccer ball, weighing 16oz, and addition of weight plates to any amount the team likes, while staying within 55 lbs. max weight requirement. The team decided to

make the total weight of the cargo be 2 lbs., hence add 1 lbs. worth of weight plates.

- Loading Payload
  - Necessary Metrics: Loading Time
    - The rules state teams have 1 minute to unload and reload the cargo load of the plane.

1.4.2 Discussion of Measurement

The Maximum thrust produced will first be theoretically calculated through the use of MATLAB based on the motor specifications. The motor maximum power will be tested with use of a voltmeter. The thrust produced by the motor will be then tested through the use of a thrust stand and force gauge. The thrust stand will also be used to test different sized propellers to get the best configuration for maximum thrust generation. Using Fluent by Ansys we can take CFD measurements to simulate the factors of lift and drag. This program will also allow us to test to evaluate how chord length, wingspan and wing loading will affect the aircraft. Analytical software such as MATLAB, Fluent, and SolidWorks, can generate all of the factors needed to find the control characteristics for the plane. Characteristics such as the max pitch, roll and yaw while the plane is in flight as well as ground controls when the plane has landed. The drag between the landing gear will be theoretically determined through MATLAB based on the materials of the wheels and runway. In terms of the payload, the process at which the payload is unloaded and reloaded into the fuselage will be timed using a stopwatch. The effects of its weight and position on the aerodynamic characteristics will be calculated using simulations from Fluent.

1.4.3 Mission Critical Targets

Targets critical to the mission can be found in the table below. These Targets must be met to create a plane that fly stably while carrying the minimum required cargo load. (SAE International, 2021).

Function	Metric	Target	Method of Validation	Tools for Validation
Take Off				
Generate Lift	Coefficient of Lift	>1	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Coefficient of Drag	<1	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Wingspan	60 in -120 in	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
Generate Thrust	Thrust Force	15 lbf	Experimental	Force Gauge, Scale

Ground Stability Control	Gross Take-off Loading	<55 lbf	Simulation and Experimental	SolidWorks, Scale
	Thrust Line Positioning	+/- 0.2 in from Center of Gravity	Simulation and Theoretical Calculations	MATLAB, Solidworks
Landing				
Generate Ground Friction	Landing Gear Force Absorption	>55 lbf	Experimental	Force Gauge, Scale
Increase Drag	Coefficient of Drag	>1	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
Carrying Payload				
Load/Unload Payload	Time	1 minute	Experimental Testing	Stopwatch

Table 4: Mission Critical Targets

The targets were selected to match the rules of the SAE Aero Design competition. Aerodynamic characteristics such as lift coefficient, drag coefficient, wingspan, and chord length will be calculated using fundamental equations plugged into MATLAB, and will be verified using

Fluent CFD. Coefficient values were selected to create minimum lift and max drag for a flight (i.e.- to meet the minimum requirement to fly, which is based on the weight of the plane) (Anderson, 2011). If the lift coefficient is over 1, the plane is expected to create enough lift to overcome weight and create positive lift. If the drag is less than 1, the drag created is less than the drag required to stop the weight of the plane from moving, resulting in forward movement. Wingspan target was selected based on the limitation provided in the competition rulebook (SAE International, 2021). The Thrust force requirement was selected based on the drag coefficients given in the RC Model Aircraft Design Book (Lennon, 2005). The takeoff weight was selected based on the weight requirement given in the rulebook (SAE International, 2021). The thrust line of the plane is expected required to be on the center of gravity point of the plane for a stability (Pilots Handbook of Aeronautical Knowledge, 2017). However, a small margin of error was allowed when selecting the metric. During landing, control surfaces are expected to minimize the load felt by the landing gears. However, considering the max possible force, a metric equivalent to the weight of the plane was given to the absorbing force. Converse to takeoff, the plane must create drag bigger than drag required to stop the weight of the plane. Hence the drag coefficient value should be bigger than 1. Since loading and unloading procedure is time restricted according to the rulebook, the maximum time allowed in the competition was used as the metric (SAE International, 2021).

A full catalog of targets and metrics related to each low-level function of the project is given in Appendix – D. These metrics will be verified using experiments, theoretical calculations, and using the aforementioned simulation software. The results will be compared to limitations provided by the competition, to ensure that the plane is not violating any rules.

1.5 Concept Generation

By analyzing the major and minor functions developed in our functional decomposition, the team generated possible solutions that would satisfy the major and minor functions of the airplane. The functions utilized included wing layout, wing type, wing positioning, control surfaces, fuselage shape and tail configuration. Breaking the airplane design down into these functions allowed for a wide array of airplane designs. Keeping these functions in mind, we used the concept generation tools of a morphological chart, biomimicry and the crap shoot method to develop 98 possible solutions.

1.5.1 Concept Generation Tools

To assist in generating our 100 concepts, different concept generation tools were used. For our first 37 concepts a morphological chart was used. Different variations of planes were generated from the functions that included wing type, wing positioning, control surfaces, fuselage shape and tail configuration. The team ensured that no concepts were repeated by inspecting each of the 37 concepts and taking note of which combinations had already been used. Team 507 also used methods such as competitive benchmarking and looking at other models of planes to see which ones most resembled what is needed to be achieved. It had been decided that the models that most resembled what needs to be accomplished were either cargo planes or models that had high lift and lightweight qualities. Using this method 30 concepts were generated. To further assist in generating concepts, the tool of biomimicry was used. For this we thought about direct analogies from biological systems that relate to what we are trying to accomplish. The team thought about biological systems and organisms that would be able to carry large loads while being lightweight, be able to fly for long periods of time, have aerodynamic bodies or be able to easily store items. 17 biological systems and organisms were generated in this process. The remaining 14 concepts were crap shoot ideas. From these 98 generated ideas the team selected 3 high fidelity and 5 medium fidelity ideas that would be pursued. This selection was done as a team by going through and examining the feasibility of each of the 100 designs; if an idea didn't seem feasible it was eliminated from the possibility of being a high or medium fidelity concept. The 8 that remained were classified into medium and high fidelity by applying our knowledge of aerodynamics and design; deciphering which combination of solutions would work the best for our goal of the project.

1.5.2 High Fidelity Concepts

When considering all the concepts generated, these three models seemed the most feasible for the design:

Concept 1: Boomtown

This is considered a modified model of last year's team. It would feature lightweight PLA, tricycle landing gear, a flying boat fuselage shape, tail opening with a tray for cargo, and a tapered boom with a traditional tail and rudder. This model would be using a NACA 2420 airfoil with flaps, ailerons, elevators, and wingtips. The loading for the competition would be accomplished using a tail loading method where the tail opens and the cargo can placed and secured. This is our number one concept because it is the best combination of last years basic concept with some new modifications.

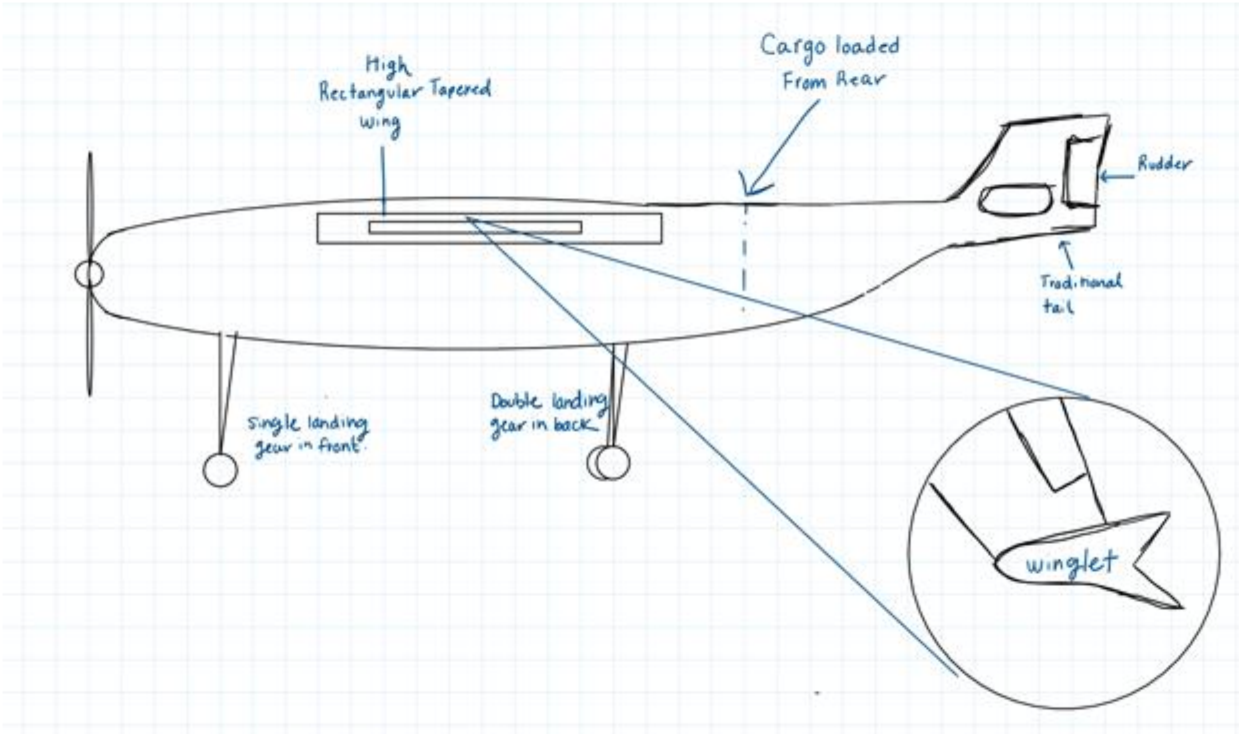


Figure 2: Boomtown Concept

Concept 2: Rutan Long EZ

The Rutan Long EZ is a non-conventional plane that is back propelled. This model has a canard in the front in order to help with stability and lift, along with a high delta wing which also helps with stability. It features a high lift Eppler 1230 airfoil, a supersonic fuselage, 2 sets of flaps, ailerons, and topsails. Because this model is back propelled it does not feature a tail, instead of a rudder on the tail it has rudders on tipsails protruding from the wing. The loading for this model would be from the top, this is possible because the two wings are offset and not at the center of gravity and there are no wing supports impeding top loading.

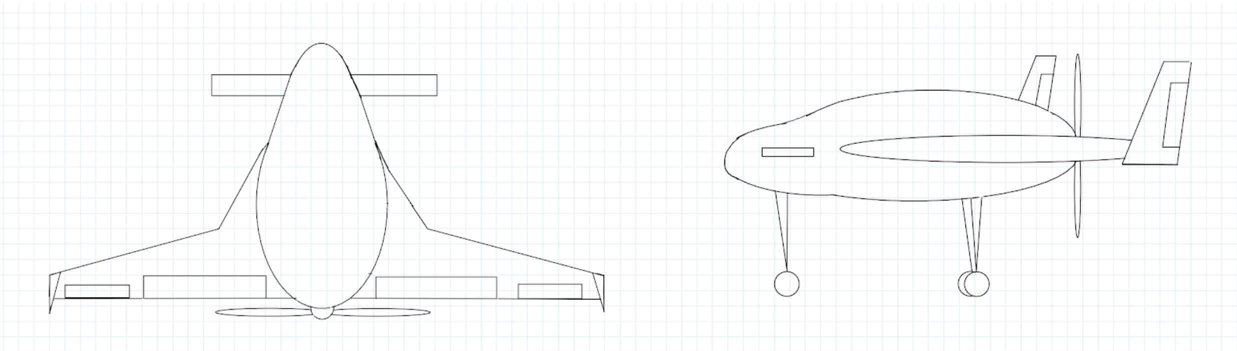


Figure 3: Rutan Long-EZ

Concept 3: Rutan Quickie Q2

The Rutan Quickie Q2 is another high-fidelity concept that is a variation of the Rutan Long EZ that is front propelled. It features a NACA 2420 airfoil, a main rectangular high wing with low canards; the rectangular high wing has upward facing wingtips while the canards have downward facing wingtips. The high wing placement improves the stability of the aircraft while the low canards provide additional lift, reduces the main wing loading and makes it difficult for the airplane to stall. Even though the wings are on two different positions on the airplane, the effects from the vortices from the wings do not interfere with one another. The tail for this model has a rudder but no elevators (as the flaps act as elevators, with flaps on both canards and the main wing), the additional lift from the canards make up for this lost lift from the elevator on a traditional wing. This model would also feature two sets of flaps, ailerons, and wingtips to control the roll, pitch and yaw on the plane. The fuselage for this model would be flying boat with a top loading mechanism; the top loading mechanism will make it easier to load and unload the airplane in competition.

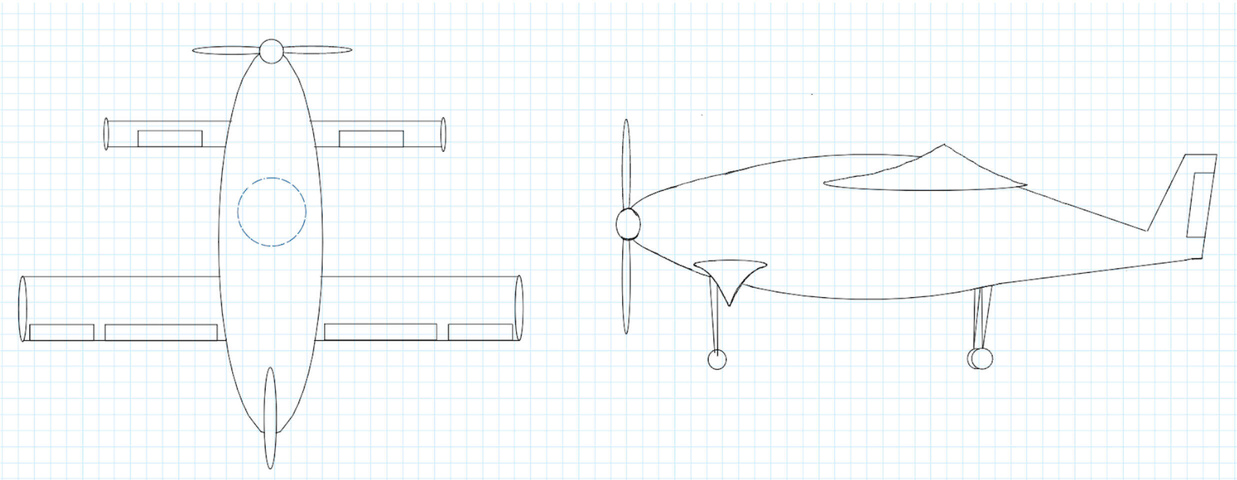


Figure 4: Rutan Quickie

1.5.3 Medium Fidelity Concepts

These concepts are also considered feasible but not as likely to be used after considering the necessities for the project.

Concept 4: Boeing 747 Dreamlifter

Concept 4 was the Boeing 747 Dreamlifter. This plane serves as a large cargo transport plane. This concept features a swept back low wing set that allows the plane to be more stable during flight. This plane uses four jet engines (two engines on each wing) for thrust but in this design, it would only have one front propeller to provide thrust instead. The Dreamlifter This plane also uses a BAC 449 airfoil, one of Boeing's standard energy efficient transport airfoil. The Dreamlifter has a conventional tail and features control surfaces such as flaps, elevators, ailerons, and rudders.

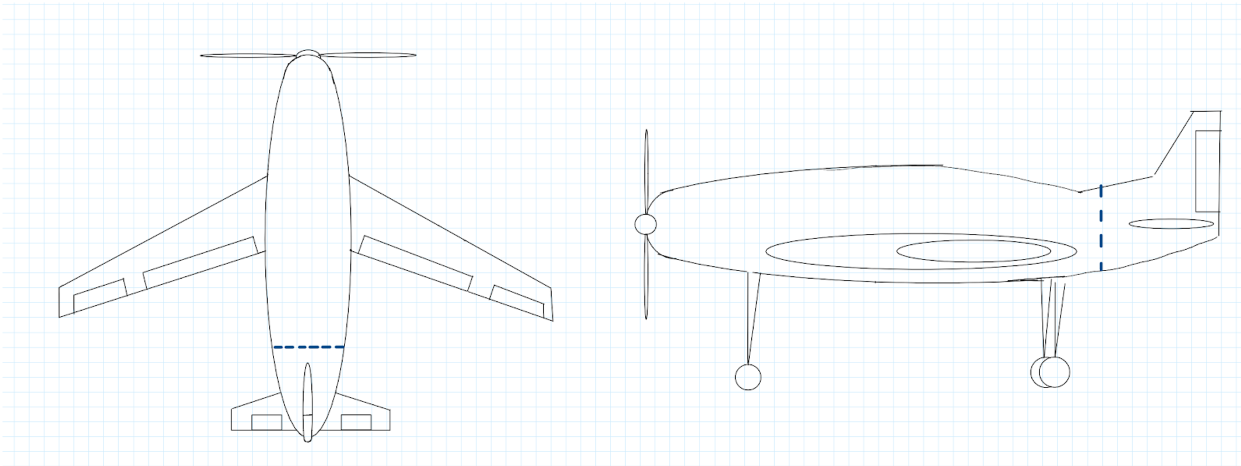


Figure 5: Boeing 747 Dreamlifter

Concept 5: Cessna 208 Grand Caravan

The Cessna 208 Grand Caravan is a common small passenger plane. One engine in the front propelled by one single propeller. It has a conventional tail with a rectangular wing. This design would feature flying boat type fuselage which is more fitting for subsonic plane flights. This design control surfaces are like any standard plane. It has flaps, elevators, ailerons, and rudders. The Cessna would have rear access to unload and load any cargo needed.

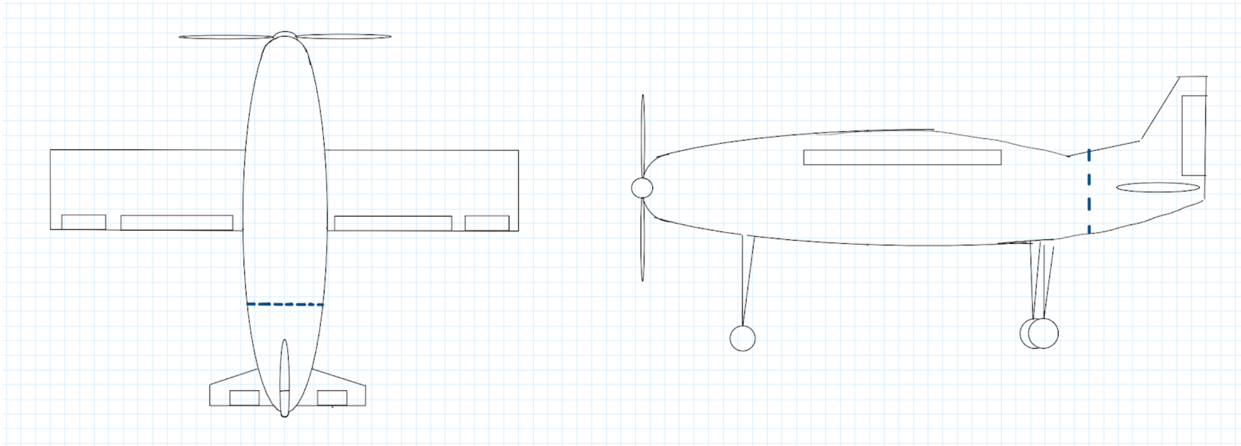


Figure 6: Cessna 208

Concept 6: OMAC 300 Laser

The OMAC 300 Laser300 Laser has a similar design to the Long EZ with some slight variations. The OMAC features a high wing low canard system that is much like the Long EZ. The canards will add to the overall lift of the plane. The canards also add stability, making it difficult for the plane to go into a full stall. Unlike most planes this one does not have a tail. This design utilizes wing sails to control yaw and the canards will have elevators on them to control the height of the plane. The OMAC is propelled from the back by one single propeller and uses an NACA 2412 airfoil.

Concept 7: Aero Spacelines Super Guppy

The Aero Spacelines Super Guppy, much like the Dreamlifter, is one of the largest cargo planes in the world. It stands at a whopping 48 feet tall, is 143 feet long, and has a 156 foot wingspan. Its incredible size allows for it to house a cargo bay of nearly 70,000ft^3, and carry almost 80,000 pounds of cargo. This plane utilizes a low wing formation with a Boeing 117 airfoil, which is common in largo cargo planes. The large cylindrical body tapers down from the top to the tail so there is not much of boom, and the tail is shaped in the traditional formation. An incredible feature of this plane is that the nose of the plane opens vertically on a hinge to allow cargo loading. It was considered for the amount of cargo space, and innovative cargo hold.

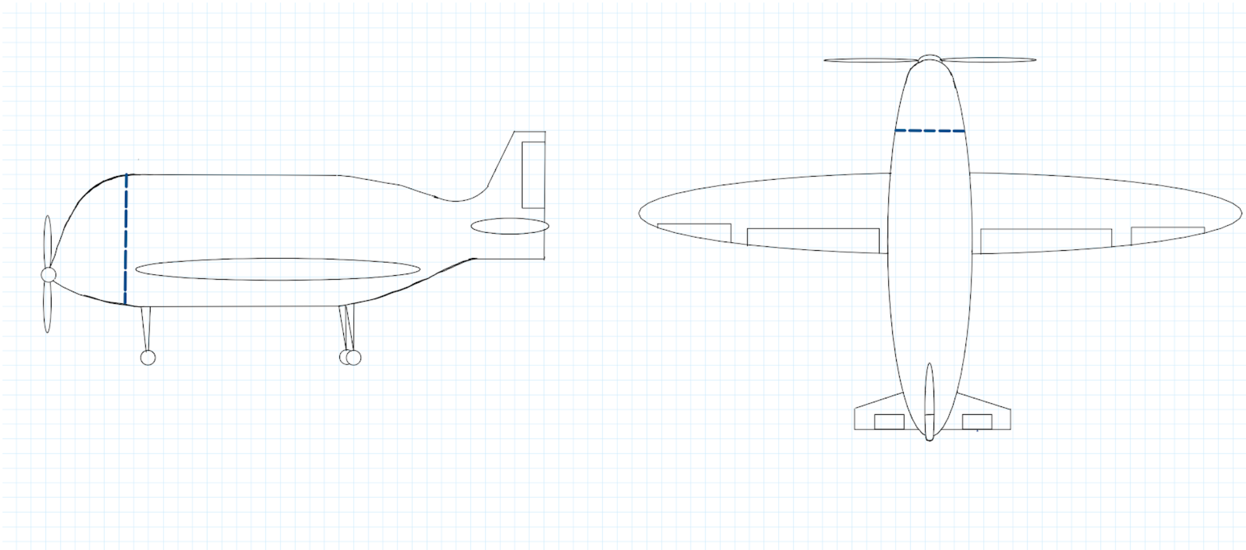


Figure 7: Aero Spacelines Supper Guppy

Concept 8: Kawasaki C-2

The Kawasaki C-2 is a military transport plane from Japan introduced in 2016. This plane was designed to carry four times the amount of cargo as a C-130, while having a range 6 times larger. This plane features a NACA 2412 and a swept back wing, this is desirable for long periods of stable cruising. The rear of the plane has a T-tail above a classically designed rear cargo bay. The cargo space afforded by the design is incredible, and the design is optimal for cruising.

1.5.4 Some Low Fidelity Concepts

The remaining concepts generated were low fidelity ideas. Most of them were generated through biomimicry, crap shoot and forced analogy methods. Some interesting low fidelity ideas as follows

- Modified Antonov AN – 22
- Modified Antonov AN – 225 Miriya
- Modified Grumman C-2 Greyhound

While these ideas had certain advantages, such as high lift capability in both Antonov planes, they were not considered for the concept selection process. These planes had certain downsides, such as complexity to make, lack of creativity (which was required by the sponsor), and not desirable for the cargo load requirements of the competition. Biomimicry was investigated for interesting design aspects that occur in nature. While unique characteristics were found, none were incorporated into a top 8 design. All the concepts generated are in Appendix E: Concepts Catalog.

Following the concept generation, the 3 high and 5 medium fidelity ideas were considered in the concept selection method, where varies concept selection tools were used to narrow down a single concept for the project.

1.6 Concept Selection

3 high fidelity concepts and 5 medium fidelity concepts from the concept generation process were considered for the concept selection process. These concepts were processed through House of Quality, Pugh Chart and Analytical Hierarchy Process tools to select the based concept. These tools required selecting the most important customer needs and targets for the process. As the final build of the project is a collaboration between the aero team (T507) and geometric team (T508), customer needs and targets from both teams were included in all the tools used to select one concept. This report will mainly focus on data necessary for the aero team. The following is the list of concepts considered.

- Concept 1: Boomtown
- Concept 2: Rutan Long EZ
- Concept 3: Rutan Quickie Q2

- Concept 4: Boeing 747 Dreamlifter
- Concept 5: Cessna 208 Grand Caravan
- Concept 6: OMAC 300 Laser
- Concept 7: Aero Spacelines Super Guppy
- Concept 8: Kawasaki C-2

1.6.1 Binary Pairwise Comparison

From the customer needs gathered, the most important customer needs were selected for the concept selection process. Interpreted needs from these customer needs were considered in this process. The following is the table created in this process. Grey rows in the table are customer needs related to the geometric team.

Table 5: Binary Pairwise Comparison

Binary Pairwise Comparison													
	1	2	3	4	5	6	7	8	9	10	11	12	Total
1. Material	-	0	0	0	0	0	0	1	0	0	0	0	1
2. Stability	1	-	0	0	0	1	1	1	1	0	0	1	6
3. CG in front of CP	1	1	-	1	1	1	1	1	1	1	1	1	10
4. Meet takeoff/landing requirements	1	1	0	-	1	1	1	0	1	0	0	1	7
5. Wingspan meets restrictions	1	1	0	0	-	1	1	1	1	0	0	1	7
6. Sufficient Power	1	0	0	0	0	-	0	0	1	1	1	1	5

7. Maneuverability	1	0	0	0	0	1	-	0	1	0	0	1	4
8. Light Weight	0	0	0	1	0	1	1	-	1	1	0	1	6
9. Touch-down Impact	1	0	0	0	0	0	0	0	-	0	0	1	2
10. Ground Controls	1	1	0	1	1	0	1	0	1	-	1	1	7
11. Carry the Minimum Cargo Load Required	1	1	0	1	1	0	1	1	1	0	-	1	8
12. Easy to Load/Unload	1	0	0	0	0	0	0	0	0	0	0	-	1
Total	10	5	0	4	4	6	7	5	9	4	3	10	-

In the table above, a row was compared to a column. The following is the index used for the table

1 – A row is important than a column

0 – A column is important than a row

The above customer needs were considered mission critical as fulfilling these needs would allow the plane to accomplish the minimum requirement of the competition, which is to successfully complete the flight path while carrying a cargo load. A sum of a row and the corresponding row should equal to n-1, where n is the number of customer needs considered. For the table created, the expected sum was 11. This is true for all needs. Hence the chart is valid. The key takeaways from the chart was that CG positioning had the highest importance weight factor, while material and effortless loading/unloading of the cargo had the least importance.

1.6.2 House of Quality

Customer needs and corresponding weight factors along with mission critical targets (engineering characteristics) were used in the House of Quality. Using this tool, the most important engineering characteristics were taken for the concept selection process. The following is the table created for concept selection. The greyed rows and columns are related to geometric team and will not be discussed in this report.

Table 6: House of Quality

House of Quality													
				Engineering Characteristics (***From Main Targets***)									
Improvement Direction		↑	↓	↑	↑	↑	↑	↑	↓	↓	↑	↑	=
Units		lbf	lbf	lbf	degrees	ft/s	ft/s^2	degrees	seconds	lbs	ft/s^2	psi	psi
Customer Requirements	Importance Weight	Lift	Drag	Thrust	Max Angle of Attack	Stall Speed	Acceleration	Control Surface	Loading/ Unloading	Weight	Deceleration	Joint Strength	Material Strength
1. Material	1		1							9		9	9

2. Stability	6	9	3	3				9					
3. CG in front of CP	10	9	3	9	9	9		9		3			
4. Meet takeoff/landing requirements	7	9	3	9			9				9		
5. Wingspan meets restrictions	7	9	3		3	3		1				3	3
6. Sufficient Power	5	1	1	3			3	3		1	1		
7. Maneuverability	4				3	3		9		3		3	1

8. Light Weight	6	3		3			3			9	3		
9. Touch-down Impact	2							3		3	9	9	9
10. Ground Controls	7							1					
11. Carry the Minimum Cargo Load Required	8	9		3			3		9	9	3	9	9
12. Easy to Load/Unload	1								9	3		3	
Raw Score		365	96	228	123	123	120	215	81	191	128	135	124

Relative Weight %	18.92	4.98	11.82	6.38	6.38	6.22	11.15	4.20	9.90	6.64	7.00	6.43
Rank Order	1	11	2	6	6	10	3	12	4	8	5	9

The following is the index used for the weights.

0 - Blank (Not Important)

1 - Weak (Relatively unimportantly)

3 - Medium (Average Importance)

9 - High (Very Important)

The following is the index used for improvement direction

⬆ - Increase

〓 - Target met

⬇ - Decrease

The improvement direction indicates the directions in which each characteristic is considered to be an improvement. For example, lift is considered an improvement when the corresponding value increase and drag is considered an improvement when the corresponding value decrease.

The targets selected for this process were the mission critical targets. They allow for the plane to get to take off velocity (thrust, acceleration), take off without going into stall (lift, maximum angle of attack, stall speed, weight), successfully follow the flight path (control surface movement), and land within the designated runway space (drag, deceleration, control surface movement).

Using the weight values, the importance of characteristics was calculated. Then each characteristic was compared to the net sum of all characteristic values to get the relative weight. Engineering characteristics were ranked based on the relative weight. A cut-off weight of 6.75% was selected to select characteristics that will be used to compare medium and high-fidelity concepts. The columns in blue were the selected characteristics. Notice that ”joint strength” is in both blue and grey as it was a selected characteristic that is relevant to the geometric team.

The selected 5 engineering characteristics were used in the remaining selection tools to select the best concept.

1.6.3 Pugh Charts

Two Pugh charts were created to eliminate narrow down medium and high fidelity ideas. The following is the index used in the Pugh chart.

+ : Better than the datum

S : Same as the datum

- : Weaker than the datum

The sum of the each above index was used to compare the concepts. The grey row is the engineering characteristic related to the geometric team. The following is the first Pugh chart created using last year's design (2020 design) as the datum.

Table 7: Pugh Chart 1

		Concepts	
		High	Medium

Selection Criteria	**2020 Competition Entry**	1	2	3	4	5	6	7	8
Lift	DATUM	+	+	+	-	-	+	-	-
Thrust		S	S	S	S	S	S	S	S
Control Surface Movement		+	+	+	+	S	+	S	S
Weight		-	S	-	-	-	S	-	S
Joint Strength		+	+	+	+	+	+	+	+
# of pluses		3	3	3	2	1	3	1	1
# of S's		1	2	1	1	2	2	2	3
# of Minuses		1	0	1	2	2	0	2	1

Compared to 2020 design, concepts with canard have more lift as canard wings adds more lift to a plane (concept 2 and 3) (Lennon, 2005). Furthermore, concepts with a larger wing surface area would create more lift as the surface area is proportional to the amount of lift created (concept 1) (Anderson, 2011). Concepts 4, 5, 7 and 8 has relatively low lift as they were considered to have a conventional wing layout. Since the team will use the same battery, motor and the propeller as 2020 design, the thrust was expected to be the same. All concept except for concept 5,7,8 have more control surfaces (5,7 and 8 just ailerons, a rudder and elevators). The remaining designs have flaps, elevators, ailerons and a rudder or tip sails. Since 2020 design had only ailerons, a rudder and elevators, designs with more control surfaces were given a positive.

Since weight is less desirable to a good flight, an increase in weight is represented by a negative. Concepts with more control surfaces compared to 2020 design would have more servos. Hence, those concepts would have a higher weight. While concept 2 and 6 has more control surfaces, they were considered to weigh less as they are compact plane designs (Anderson, 2011).

Concept 2, the Long EZ, is the best concept according to the above Pugh chart as that one has the most positive (3, tied with concept 1,3 and 6) and least negatives (zero). Since it is the best concept, it was taken as the datum for the second Pugh chart. The remaining 3 concepts with 3 positives were considered in the second Pugh chart (blue columns), concept 1 the Boomtown, #3 the Quickie Q2, and #6 the OAMC 300 Laser.

Table 8: Pugh Chart 2

		Concepts		
		High		Medium
Selection Criteria	Concept 2	1	3	6
Lift	Datum	-	+	-
Thrust		S	S	S
Control Surface Movement		+	+	+
Weight		-	-	-
Joint Strength		S	S	S
# of pluses		1	2	1

# of S's	2	2	2
# of Minuses	2	1	2

Concept 2 weighs less than other concepts as it is a compact design. While concept 6 is also a compact design, the material used in this concept is heavier than concept 2 (related to geometry team). Wings in concept 3 has more surface area as they have rectangular wings with no taper, compared to swept or tapered wings in other designs (including the datum). Thrust is similar in all concepts as mentioned previously mentioned. Concept 2 has less control surfaces than all the concepts considered here.

While concept 3 has the most positives, the difference between concept 3 and the rest is minimal (just 1 in both positives and negatives). Hence all 3 concepts were considered in the Analytical Hierarchy Process.

1.6.4 Analytical Hierarchy Process

Analytical Hierarchy Process is a more mathematical selection process. 5 engineering characteristics collected in the House of Quality were taken as the comparison criteria, while the 3 concepts from the 2nd Pugh chart were compared in this tool. A pairwise comparison was made, where rows (A) are compared to columns in each comparison table. The following is the index used for the comparison.

1 - A and B have equal importance

3 - A is moderately more important than B

5- A is strongly more important than B

7- A is very much more important than B

9- A is significantly more important than B

In all the tables, the horizontal has a value of 1 as both rows and columns represent the same criteria. The triangle below the horizontal has reciprocal values to the triangle above the horizontal in each table. The initial step was to compare criteria, get criteria weights and check for the consistency of the criteria. The following is the tables created in this step.

Table 9: Criteria Comparison Matrix

Development of a Candidate set of Criteria Weights {W}					
Criteria Comparison Matrix					
	Lift	Thrust	Control Surface Movement	Weight	Joint Strength
Lift	1.00	0.33	3.00	9.00	9.00
Thrust	3.00	1.00	3.00	9.00	9.00
Control Surface Movement	0.33	0.33	1.00	5.00	3.00
Weight	0.11	0.11	0.20	1.00	0.11
Joint Strength	0.11	0.11	0.33	9.00	1.00
Sum	4.56	1.89	7.53	33.00	22.11

Table 10: Normalized Criteria Comparison Matrix

Normalized Criteria Comparison Matrix [NormC]						
Criteria Comparison Matrix						
	Lift	Thrust	Control Surface Movement	Weight	Joint Strength	Criteria Weight
Lift	0.22	0.18	0.40	0.27	0.41	0.295
Thrust	0.66	0.53	0.40	0.27	0.41	0.453
Control Surface Movement	0.07	0.18	0.13	0.15	0.14	0.134
Weight	0.02	0.06	0.03	0.03	0.01	0.029
Joint Strength	0.02	0.06	0.04	0.27	0.05	0.089
Sum	1.00	1.00	1.00	1.00	1.00	1.000

Table 11 (a) and (b): Criteria Weight Consistency Check

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector
1.911	0.490	3.899

λ Average Consistency	CI Consistency Index	CR Consistency Ratio
6.053	0.027	0.051

2.802	0.230	12.184
0.796	0.140	5.683
0.149	0.040	3.720
0.478	0.100	4.780

In table 9, thrust was considered more important than lift as thrust generates the velocity required to produce lift. However, Lift is more important for a successful flight compared to rest of the criteria as lift a necessity to successfully taking off. Joint Strength is related to the geometric team (grey rows and columns). Control surfaces are more important than the reducing the weight as control surfaces allow control the flight path of the plane, including the initial yaw increase during taking off.

The value in each cell was normalized using the corresponding sum value in table 10. The average value of each row was taken to find the criteria weights. The sums of each column added up to be 1, which validates the normalized matrix. A consistency check was done by doing a matrix multiplication for values in table 9 and 10. These values were multiplied by criteria weights to get the consistency vector. The average consistency value was found and was used to get the the consistency index. The consistency ratio was found using that value. A consistency value below 0.1 is desired, which is achieved in for the criteria comparison.

The same process was done comparing each concept with others for each engineering characteristic. A comparison matrix was followed by a normalized matrix, then a consistency check was done. The following is the process done was Lift. Tables for all engineering characteristics are in Appendix F: Concept selection Tools.

Table 12: Lift Comparison Matrix

Lift Comparison			
	Concept 1	Concept 3	Concept 6
Concept 1	1.00	0.33	3.00
Concept 3	3.00	1.00	7.00
Concept 6	0.33	0.14	1.00
Sum	4.33	1.48	11.00

Table 12 shows the lift comparison of our final concepts. The lift is one of the most important factors that goes into plane taking off and maintaining a cruising altitude. These comparisons were based on physical characteristics such as the airfoil shape, wing type and configuration. Concept 3 is seen to have to have the best lift capacity out of the rest of the concepts. This is due to the high wing low canard configuration of the wings of the plane. This process was normalized as s shown in table 13 below. The sum of all of the concepts and weights are 1 which verifies that the process was done correctly. Table 14 shows the consistency matrix for the lift comparison just as it was done for the weight comparison. The consistency ratio is seen to under 0.1 which is desired.

Table 13: Normalized Lift Comparison Matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 1	Concept 2	Concept 6	Criteria Weight
Concept 1	0.231	0.226	0.273	0.243
Concept 2	0.692	0.677	0.636	0.669
Concept 6	0.077	0.097	0.091	0.088
Sum	1.000	1.000	1.000	1.000

Table 14: Consistency Check for Lift Comparison

Consistency Check 1		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector
0.731	0.243	3.005
2.015	0.669	3.014
0.265	0.088	3.002

λ Average Consistency	CI Consistency Index	CR Consistency Ratio
3.00703	0.00352	0.00676

Table 15: Final Rating Matrix and Alternate Values

Final Rating Matrix			
Selection Criteria	Concept 1	Concept 2	Concept 6
Lift	0.243	0.669	0.088
Thrust	0.333	0.333	0.333
Control Surface Movement	0.236	0.110	0.654
Weight	0.260	0.633	0.106
Joint Strength	0.333	0.333	0.333

Concept	Alternative Value
Concept 1	0.292
Concept 3	0.411
Concept 6	0.297

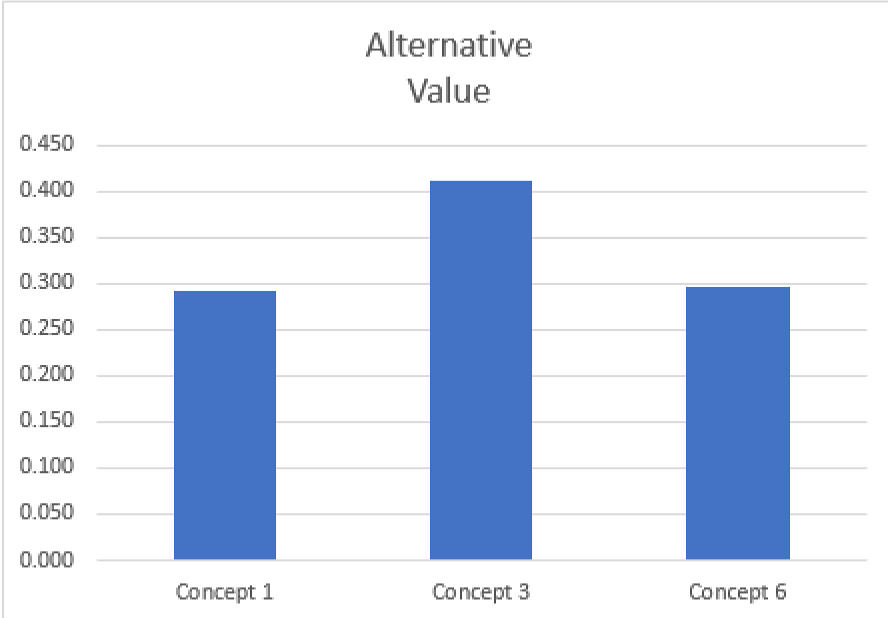


Figure 8: Alternative Value Comparison Plot

The values in table 15 come from the criteria weight for each concept when compared to all the functions in each concept and the alternate value is the transpose multiplied by the criteria weight for each engineering characteristic and represents the calculated "best option". According to the calculations, concept 3: **Rutan Quickie Q2,** is the best concept. As mentioned in section 1.5.2, concept 3 has a canard wing layout, with a higher main wing, which increases total lift of the plane. Furthermore, it has a top loading mechanism. While it does not have an elevator due to its wing configuration, it has flaps on the main wing and the canard. The following is a graphical drawing of the concept.

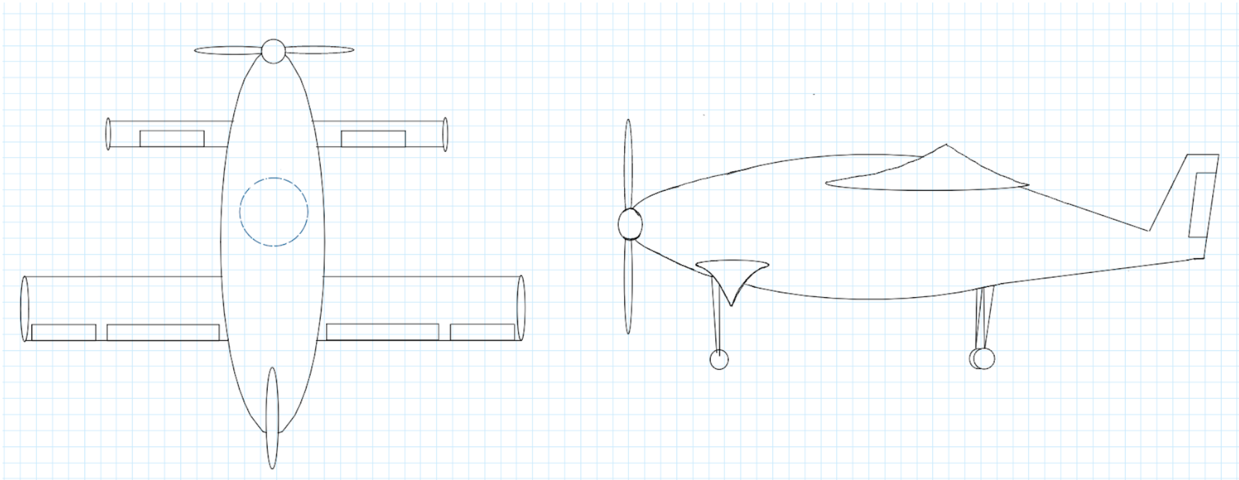


Figure 9: Rutan Quickie Design

The concept will be further analyzed, refined, and modeled after when making a prototype.

1.7 Spring Semester Plan

Spring Semester Plan																														
Month	January								February								March								April					
Week	1		2		3		4		1		2		3		4		1		2		3		4		1		2		3	
Day	3	9	10	16	17	23	24	30	31/1	6	7	13	14	20	21	27	28/1	6	7	13	14	20	21	27	31/1	3	4	10	11	17
Activities	Test Print			XFLR5 Stability				Electrical Setup Configuration				Electrical Setup Test (With R/C club)				SAE Technical		Competition					Second Test Flight (With R/C Club)		Flight Evaluation				End of Semester Submissions	
		Finalize Stability																			DR 6									
			Main Wing CAD																Flight Evaluation											
				Tail CAD																							Engineering Design			
						Wind Tunnel CAD					DR5		Wind Tunnel Test																	
				DR 4																										

Figure 10: Spring Semester Plan

At the beginning of the Spring semester, a test print will be done to validate the density used in the CAD file. This will be used to finalize the stability of the plane using MATLAB. This will be validated using XFLR5. We also plan to help the geometric team with some CAD design, including the main wing and some parts of the tail wing. Towards the end of January, the electrical setup procedure will begin, where the extensions for the servos will be created. In mid-February, we expect to have enough parts to start assembling the plane, which will give us the opportunity to start wiring the plane and test the electronics with the assistance of the R/C club. We also plan to conduct a wind tunnel test before the competition in March. Following the competition, we will evaluate the flight results and possibly conduct a second test flight, with the assistance of the R/C Club.

Chapter 2: EML 4552C

2.1 Restated Project Definition and Scope

The team assigned to this project is comprised completely of Mechanical Engineering students attending FAMU-FSU College of Engineering. The team will complete the project, build a prototype, and compete in SAE Aero Competition. The following section defines the scope of the project.

2.1.1 Project Description

The objective of this project is to design and manufacture a remote-controlled plane within the rules and regulations of the SAE Aero Design East Competition 2021. The plane will be able to take-off and land carrying the required cargo and complete the necessary flight path.

The Objective of the aero-propulsion team is to ensure that the plane take-off and land while carrying a payload and complete the flight path.

2.1.2 Key Goals

The following section explains the goals set to comply with the SAE Aero Design Competition East and meet the project sponsor requirements. The plane is required to take off and land successfully from a short runway while carrying a cargo load.

- The plane is primarily 3D printed, with the help of the geometric team
- The plane takeoff, cruise, and land while carrying a cargo load
- The cargo bay can is accessed within time limit set by the competition
- The plane can withstand environmental conditions at the time of flying

The above key goals were taken into consideration when making assumptions for the project as discussed in the **Assumptions** section.

2.1.3 Market

The markets for this project include professionals in the field of aviation, aviation companies, competitive RC hobbyists, scholars and student that reference this project (probably next year's SAE Aero senior design team) and the Society of Automotive Engineering International Aero Design Competition.

2.1.4 Assumptions

Senior Design Team 507 is fully expecting a flying competition ready remote-controlled airplane. To accomplish this, we are making the following assumptions:

- Will be flown in atmospheric conditions at sea level including gravity, pressure, and temperature.
- Will be used for competition purposes.
- Motors and electronics used to control and propel the airplane will be store bought and not custom-made.
- Will be controlled by one pilot.

These assumptions play a role in goals set by the team. The assumption that the plane will be flown in atmospheric conditions at sea level would decrease the maximum weight the plane can carry, as the air density decreases with increase in altitude, which in turn reduces lift. Furthermore, as the plane is assumed to be controlled by one pilot, the functions of takeoff, cruise and land must be controllable by that one pilot. Hence, controls of the plane must be designed to be usable by one person.

2.1.5 Stakeholders

The stakeholders for this project include: Dr. McConomy and Dr. Shih, SAE Aero Design Competition, recruited RC pilot. These stakeholders have the common goal of both teams being successful in this project. The teams are required to be successful to graduate but to also capture the eye of any companies for future opportunities. The students will be representing the FAMU-FSU College of Engineering at the competition and the performance will reflect the school as well as the sponsor and advisor, Dr. McConomy and Dr. Shih. The team's sponsor (Dr. McConomy) has also applied for a grant from Florida Space Grant Consortium (FSGC). The SAE Design competition is tasked with pushing students to find new and creative ways to tackle this project. This in return attracts RC competitors along with companies to learn about and recruit young engineers. The RC pilot has a vested interest because he/she will need to work with the students to properly configure the plane's controls and will also be in the competition.

2.1.6 Differentiation from Team 508

Team 507 has been designated as the "Aero Propulsion" team as opposed to Team 508 being the "Geometric Integration" team. What has been decided between the two teams regarding the scope between the two groups is as follows.

Team 507 will oversee theoretical calculations and initial design for plane components. They will perform aerodynamic, physical, and mass calculations for the plane. Team 508 will oversee the physical integration of the components that Team 507 has designed. If a component designed by Team 507 is deemed unfeasible by Team 508 then Team 507 will have to recalculate and make the design more able for physical integration.

2.2 Results and Discussion

2.2.1 Stability

Stability plots were generated using calculations in appendix I 2 to ensure that the plane will fly stably. Initially, the canard-main wing layout was used. The following stability plot was generated for the 2-wing layout.

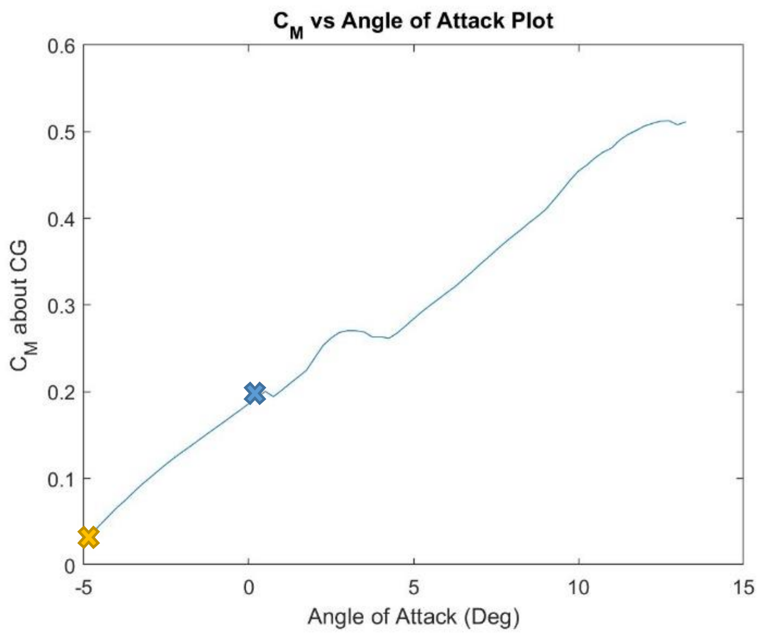


Figure 11: Stability plot for the 2-wing layout

Based on the requirements mentioned in the methods section, this configuration does not provide a stable flight. As shown by the blue X, the C_M value is positive when AoA is zero. However, as shown by the yellow X, the AoA is a negative value when C_M equals zero. This means the plane will not fly upright. As this produces a negative slope, the plane will not return to a stable flight after leaving its stable angle. To fix this instability, the canard-main wing-tail stabilizer layout was considered.

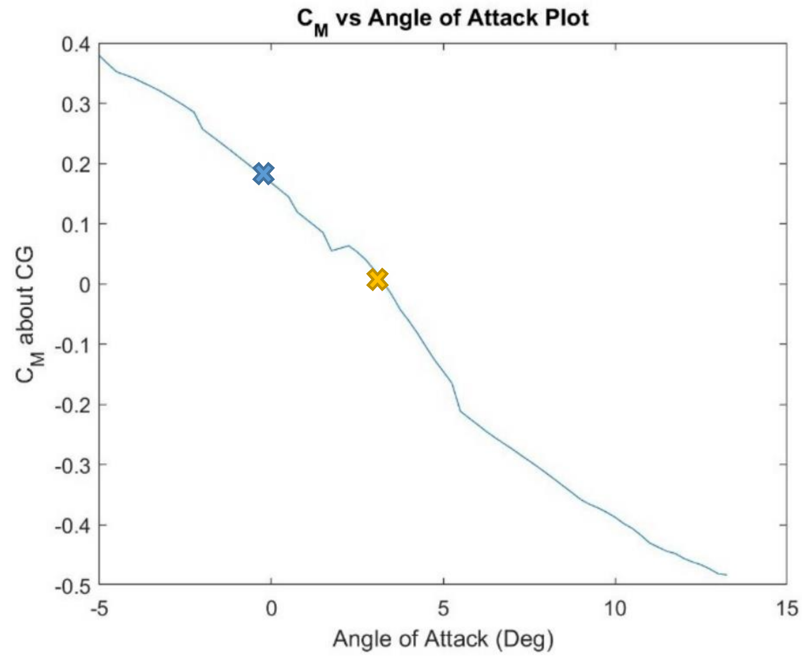


Figure 12: Stability plot for the 3-wing layout

Similar to the initial plot, this also has a positive C_M value when the AoA is zero. However, the AoA value is also positive when the C_M is zero. Hence, we get a positive plot. Not only is the plane flying at a positive AoA, meaning it is upright, but the plane also returns to stable flight automatically when it is not stable. Following this, XFLR was used to simulate the results.

2.2.2 XFLR

An Xfoil analysis was conducted on the selected airfoils to validate their usage on the plane.

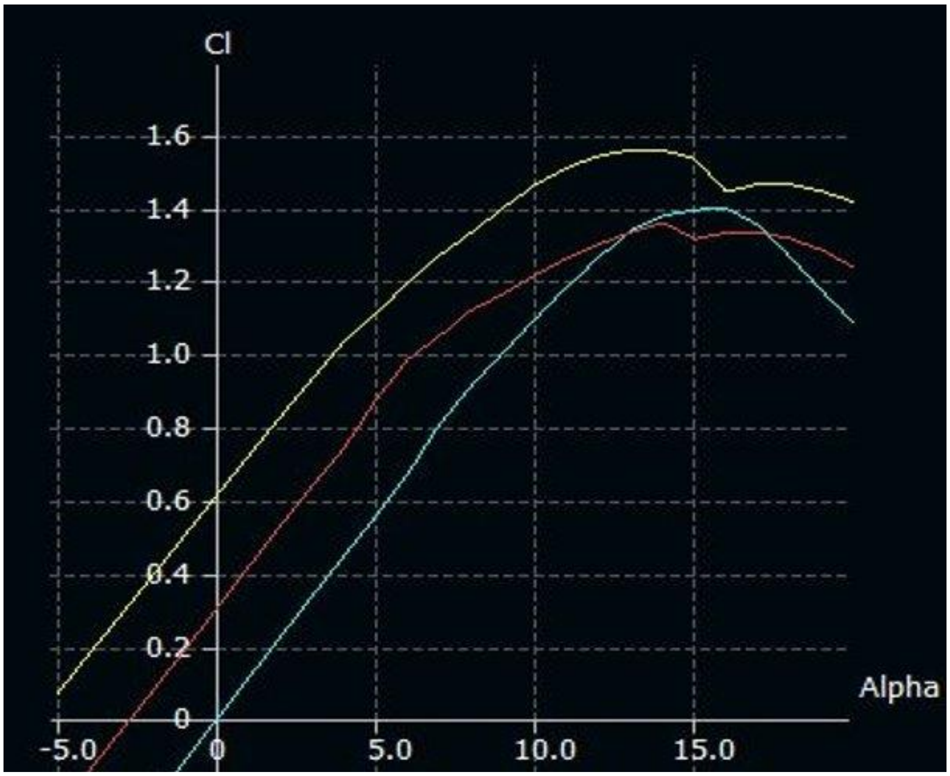


Figure 13: Coefficient of Lift plots from XFLR5

The yellow line represents the canard that peaks first. This represents a smaller stall AoA than the red line representing the main wing. This is essential to the design so the main wing can stabilize the plane in event of a stall. After analyzing the Eppler airfoils a model of the plane was designed. A Cm vs. AoA plot produced by the experiment shows that the plane will be stable, as indicated by the negative slope. However, it says that the Equilibrium AoA is 10 degrees, far higher than the calculations showed.

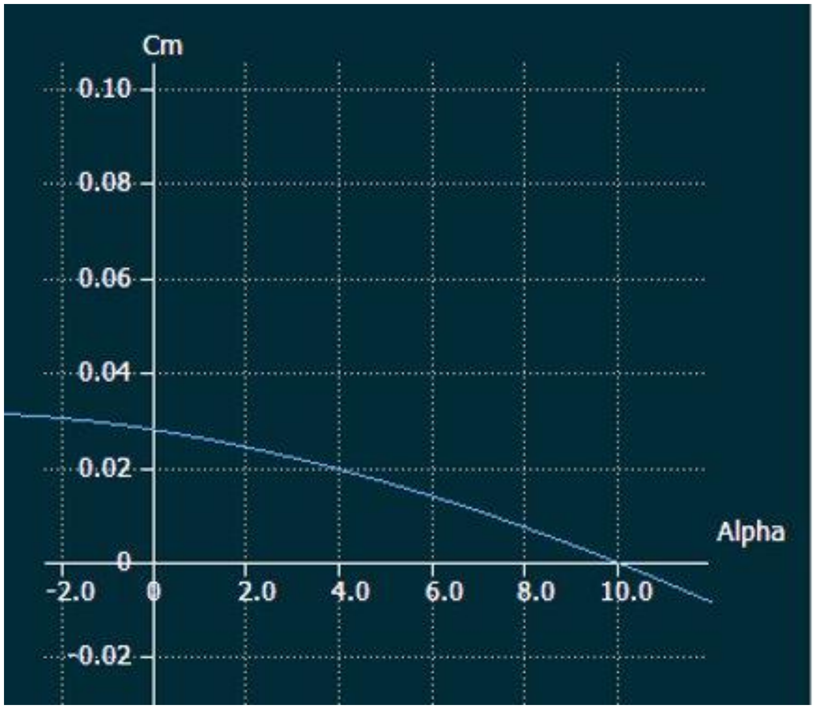


Figure 14: Stability plot according to XFLR5

As XFLR5 uses a more general method to calculate stability, we concluded that the program is not accurate for canard planes, as this AoA is after the stalling (flow separation) has begun for our plane and just 2 degrees below the max stall AoA.

2.2.3 CFD

CFD were performed for the following 3 AoA values. Zero degree, which would be the starting AoA, 5-*degree* AoA, which will be the takeoff AoA, and 12-*degree* AoA, where the plane is expected to stall. In the plots, red values mean higher turbulence/vorticity values and blue values mean lower turbulence/vorticity values. The canard is the left-most wing, and the tail wing is the right-most wing. The other wing is the main wing.

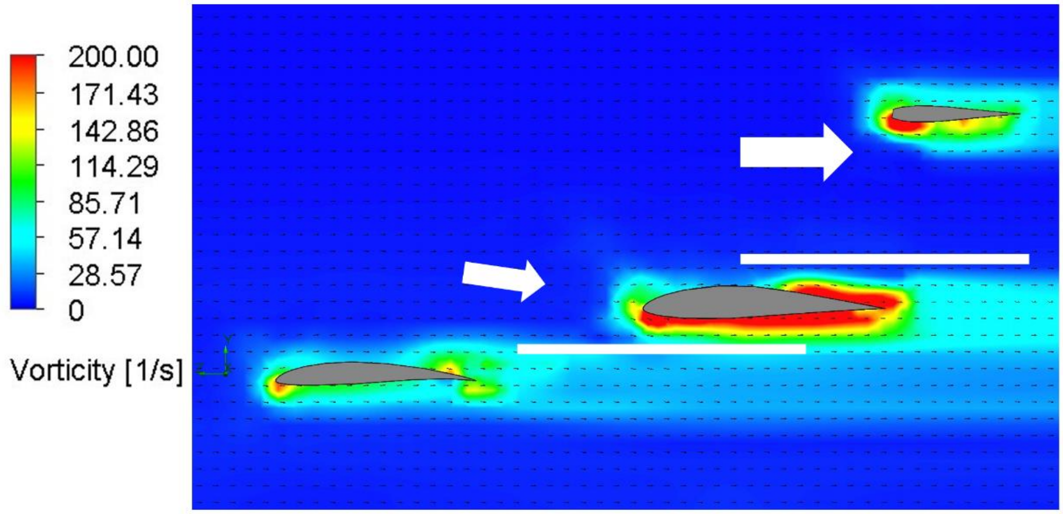


Figure 15: CFD for the zero-degree AoA

The white lines show the boundary layers for the turbulence produced by each wing. The dark blue regions show the free-stream air flow speed. Notice that around airfoils, the airflow speed increases. As shown by boundary layers, the airflow from the canard does not affect the main wing, and airflow from the main wing does not affect the tail wing, as no flow from the canard goes over the main wing and no flow the main wing goes over the tail wing. Hence, at zero-degree angle of attack, the plane is stable and does not stall. Then the same simulation was done for the takeoff AoA, 5 *degrees.*

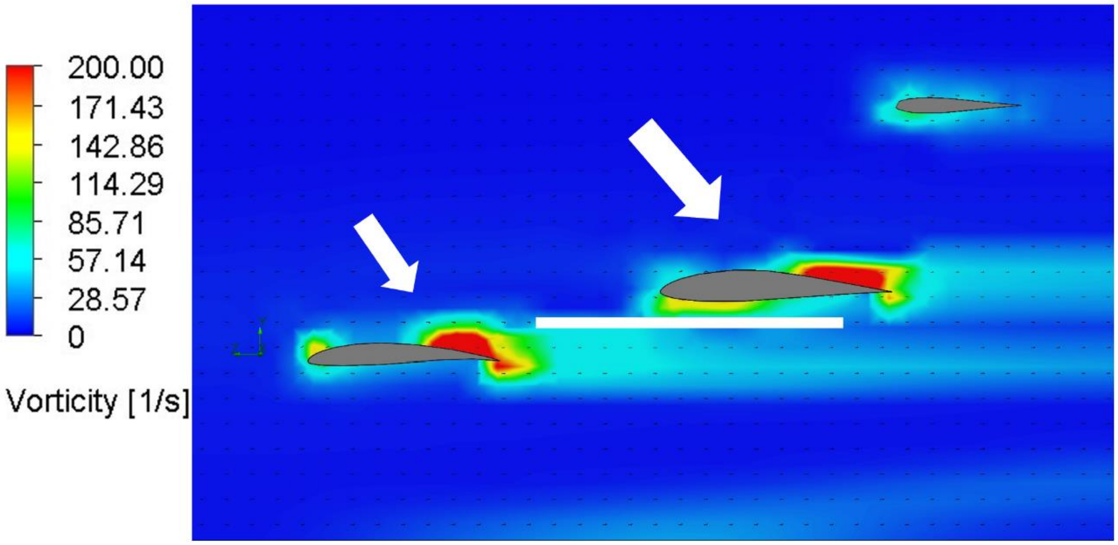


Figure 16: CFD for 5-degree AoA

While there is more turbulence compared to the zero-*degree* AoA, there is no affect from the canard flow on the main wing or the main wing floe on the tail wing as shown by the boundary layer. Therefore, the plane does not stall at the takeoff angle of attack, 5-*degree*. The same CFD simulation was performed for the 12-*degree* AoA, where the plane is expected to stall.

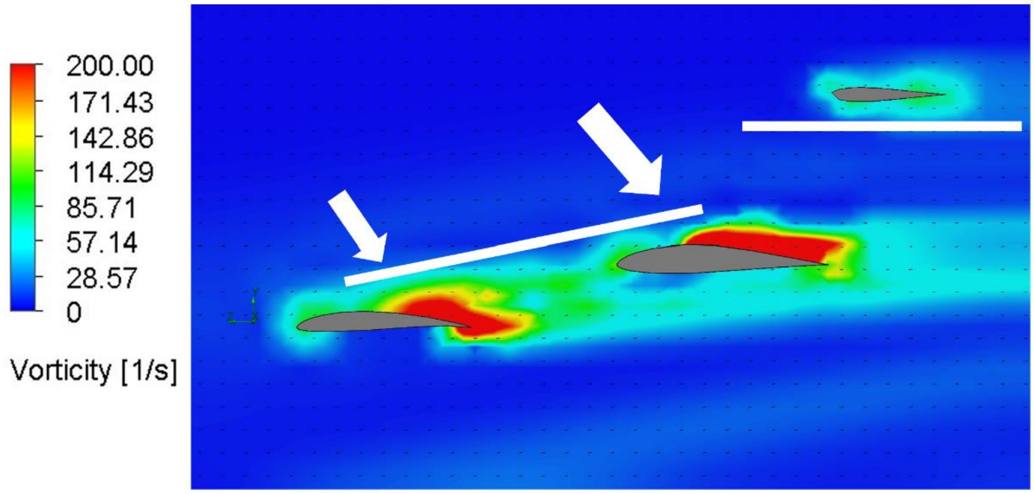


Figure 17: CFD for 12-degree AoA

The plane is expected to stall at 12-*degree* AoA. According to the CFD image above, the boundary layer from the canard flow extends over the main wing. Medium speed (green) flow is going over the main wing. This turbulence suggests the plane is stalling at this angle. Hence this validates that the plane is not stable at this angle of attack.

2.2.4 Wind Tunnel

Similar to CFD, wind tunnel tests were performed for zero *degree*, 5-*degree* and 12-*degree* AoA values. Smoke images taken for those AoA values. They show streamlines (airflow lines) around the wing. With the equipment available to us at the FCAAP sub-sonic wind tunnel, we had to select a small region for the smoke flow study as the laser beams had to be focused to a certain region. As the stall occurs from the main wing and the tail is further up from the other wings (as shown by the CFD, tail wing is not affected by the main wing or the canard flow), the region around the canard and the main wing was considered.

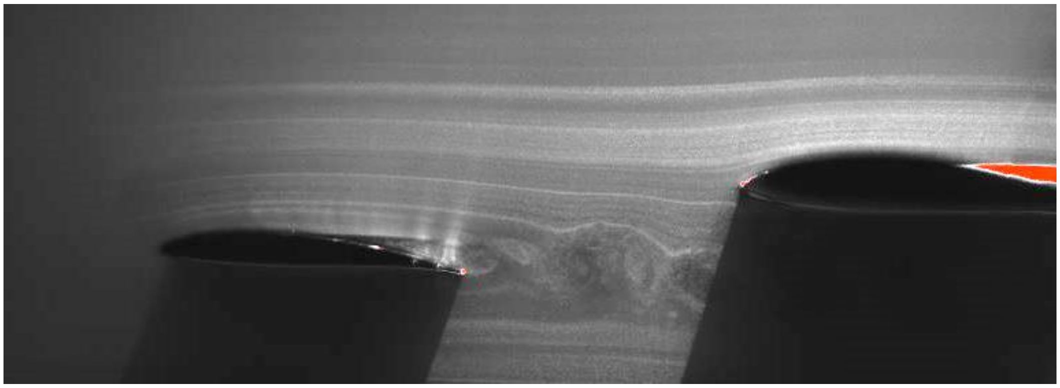


Figure 18: Streamlines for zero-degree AoA.

The flow follows the airfoil shape except at the tail for the canard. However, the disturbance caused there does not affect the main wing. The airflow at the front (LE) of the main wing is not affected by the main wing. Hence, there is no effect on the lift produced by the main wing. Therefore, this matches with the CFD and proves the stability plot conclusion that the plane is stable at zero-*degree* AoA.

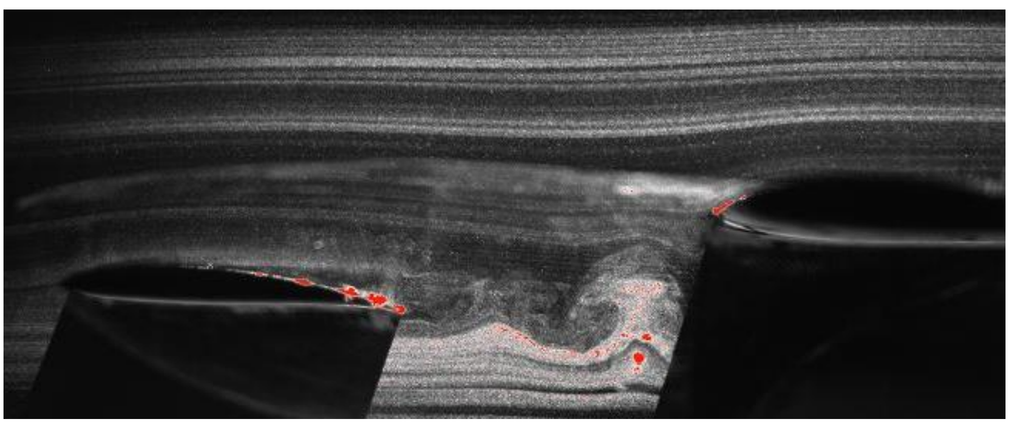


Figure 19:Streamlines for 5-degree AoA.

For the 5-degree AoA, there is more turbulence at the TE of the canard, but it still does not affect the main wing. The airflow is darker here, which means that the intensity is higher, which is expected as higher AoA accelerated the velocity of the flow around the main wing. Similar to the precious case, this does not show stalling for our plane as the flow disturbances do not interact with each other. this matches with the CFD and proves the stability plot conclusion that the plane is stable during take-off AoA.

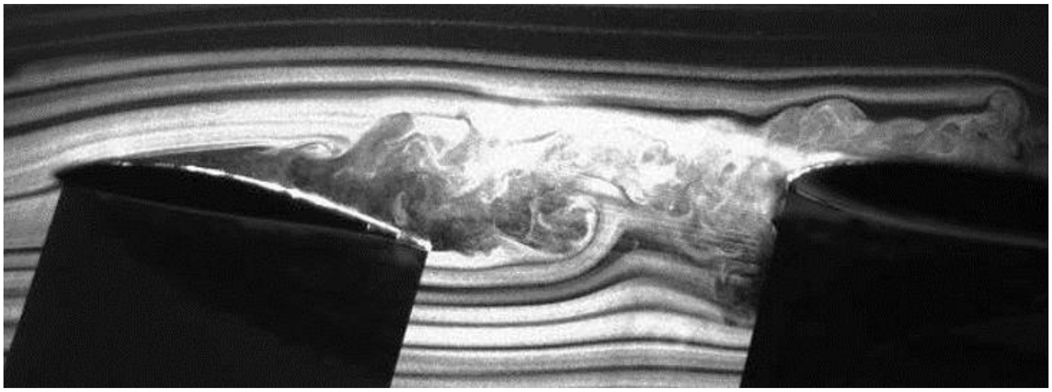


Figure 20:Streamlines for 12-degree AoA.

Based on stability calculations/simulations and CFD, the plane is expected to stall at 12-*degree* AoA. The smoke image does confirm this. There is a much larger flow separation, starting from the middle of the canard, and it affects the LE of the main wing and flows over the main wing. Hence, as the flow is not attached to the main wing, the main wing will not produce the amount of lift expected at this AoA. Therefore, the plane is stalling. This validates the stability calculations and CFD done for this AoA.

2.3 Conclusions

The theoretical stability calculations showed that when the plane has a 2-wing layout with the canard and the main wing, it does not achieve a stable flight. However, with the addition of a tail wing, it does. The XFLR5 simulations validated this. Furthermore, it showed that the plane stalls at a 12-degree AoA. Both the CFD and the wind tunnel tests performed on the plane at zero-degree, 5-degree and 12-degree AoA values are very similar. Furthermore, they prove that the plane is stable at zero and 5-degree angles and is not stable, and stalling, at the 12-degree AoA value. Therefore, we can conclude that a canard wing cargo plane can be stabilized with the addition of a third wing, a tail stabilizer. Furthermore, the theoretical calculations and equations discussed in this paper provide values that are valid for the design. CFD method used in this paper is accurate as they show similar results to the wind tunnel test data.

2.4 Future Work

Following the electrical and control inspection, our pilot from the R/C club recommended some minor changes to the design. Mainly, adding tension to the belts used to move the control surfaces, and shortening the extension wires to reduce resistance. These changes will be done in the week of 12-18 April. Following this, a test flight will be conducted on either the 19th of April or the 26th of April, depending on the pilot's availability. Following that, the team will do a short evaluation of the flight to be used as a reference for the future teams. This will be attached to the OneDrive of the team.

References

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Lennon, A. (2005). RC Model Aircraft Design. Air Age Media Inc.

Pilots Handbook of Aeronautical Knowledge. (2017). Federal Aviation Administration.

SAE International. (2021). *Collegiate Design Series SAE Aero Design Rules.*

Appendix A: Code of Conduct

Mission Statement

Team 507 is dedicated to creating a positive work environment that nurtures respect and trust between members. All members of Team 507 will dedicate their full effort to the cause. With regards to the competition aspect of the project we shall give our best effort to remain competitive and approach with intent to win.

Team Roles

The expected roles of each team member are described below. As the group learns more about the project and their expectations broaden, they will amend the team roles on a case by case basis [see amendment policy].

Hardware/Systems Engineer – Adrian Moya

Hardware and Robotics Engineer is in charge or researching the hardware (i.e. motors, wire, etc.) and deciding how all the electronics go together. They will oversee the testing of components that are acquired and provide information of component metrics to the teams.

System engineer oversees that both teams are always in contact and aware of any changes made to design that may affect the work of the other team. They work with the other team in order to set the scope of the project and detail responsibilities of team members.

Materials / Hardware Engineer – Cameron Riley

The Materials and Hardware Engineer is tasked with researching, designing and ensuring that the materials and equipment used are up to code and can withstand everything the plane may endure. Calculations for stress, strain, fatigue, total weight and other material properties will be performed to contribute to the design of the airplane. Using the calculations, research will be done to find the best and cost-efficient materials to accomplish the project goal.

Aeronautics / Propulsion Engineer & Project Engineer– Sasindu Pinto

The main responsibilities of the aeronautics and propulsion engineer are to do lift, drag and thrust calculations to ensure that the plane creates enough uplift to take off, while considering the weight of the load. Furthermore, calculations related to aerodynamic stability while in the air will be done. Research will be done to find the best aerodynamic and propulsion methods for the project, while considering the geometry, dynamic stability, cost etc. Hence the aeronautics engineer will need to be in constant communication with both the aero team and the geometrics team of the project.

The main responsibilities of the project engineer are to manage the work assigned to the team and get progress updates to ensure that the team is on-track with its goals. Furthermore, the project engineer is responsible for submitting group assignments and recording attendance. The project manage is also the point of contact for the project.

Aeronautics / Aerodynamics Engineer– Noah Wright

This engineer is in charge of ensuring the vehicle is as aerodynamic as possible. Calculations for drag force, center of pressure, and other aerodynamic properties will be conducted to help adjust the vehicle design. This will help ensure the plane can take flight and remain stable while airborne. This may overlap with work being done by the propulsion engineer, as they conduct similar tests, so the two will collaborate heavily. Since this directly affects the shape of the plane, this position will work closely with the geometric team.

Fluid Designs Engineer/Financial Lead – Michenell Louis-Charles

The purpose of the Fluids Design Engineer is to help calculate the flow factors of the aircraft. Also, to calculate related to any atmospheric conditions such as temperature, density and pressure. This will help ensure that the plane will be able to fly in various weather conditions.

The Financial Lead will oversee budget and spending for the materials for this project. This will ensure that the group will be cost effective when comes down to the materials that are needed for the project.

Communication

The main communication mode of our group will be mainly through the app, GroupMe. For this mode, team members are expected to be active from 10 AM through 8 PM Monday-Friday but are not limited to only those hours. Another form of communication that will be used is student emails. All members of the group will be expected to be up to date with all pertinent project information.

Basecamp project management software will be used for file sharing and task management. Group meeting invitations will also be sent though Basecamp. As this is a combined group project between the aero-propulsions team and the geometric integration team, a single Basecamp project will be used. This would allow for the teams to stay updated with the progress made by each other.

Team members are required to respond to messages and invitations within 24 hours. If a person is unable to respond within 24 hours, they should respond as soon as possible. Afterwards, the case will be reviewed by the team and will contact advisors if necessary.

Attendance Policy

All team members are required to attend all team meetings, which includes aero team meetings, combined group meetings with the geometrics team, meetings with the sponsor and meeting with the advisor for the project, Dr. Chiang Shih. All meetings will be held through Zoom for the foreseeable future. Team meeting invitations will be sent out at least 48 hours in advance though communications methods used by the group [see communication section], and members will be required to respond at least 24 hours prior to the meeting time. Attendance will be taken at the beginning of the meeting. Team members who are more than 20 minutes late without a notice will be considered absent. Responses to meeting invitations can be sent though Basecamp and the GroupMe used by the group. In case of an emergency, notice must be provided as soon as possible. Reasons for excused absentees will be considered on a case by case basis, as this is a relatively subjective. The team will notify and seek advice from Dr. McConomy and Dr. Shih for disciplinary action after 2 absences per semester.

All group members are expected to keep at least one vacation date valid throughout the semester to be used for a group assignment. Use of a vacation date for a group assignment must be agreed by all group members at least 48 hours prior to the due date. on group consensus.

Team members are expected to complete their tasks regardless of their availability. However, in case of an emergency, if the team member is temporary incapacitated for at least a week, the work will be temporary shared among other members. The team will seek advice from Dr. McConomy and Dr. Shih in such situations.

Team Meetings

The team will meet for up to 9 hours per week based on the tasks that have to be completed. Furthermore, the team will stay in contact with the geometric team throughout the project and will meet through Zoom as necessary. The team plan on meeting with the project advisor, Dr. Shih, biweekly.

All meetings are scheduled in advance to avoid conflicts with the class schedules of the members and other activities. If a member cannot attend a meeting, they need to inform at least 24 hours prior to the meeting. In case of an emergency, the team member/s should inform as soon as possible through any communication method used by the team.

The team will stay in contact with the correspondent of the project sponsor throughout the project and will schedule meetings as necessary or as requested by the sponsor.

Team Dynamics

All team members can share their opinions, suggestions and constructive criticisms with no fear of being reprimanded. If a team member finds a task too difficult, they need to reach out to other team members.

Conflict

If there is a disagreement between two team members about a project aspect, they will first reference their role in the team. If the disagreement coincides with both team member roles' the members will bring the topic up for discussion within the group.

If there are any personal conflicts between team members, they are expected settle their conflicts personally. In the case that personal conflicts interrupt the team they are to bring the conflict up to the whole team and/or seek advice from the advisors.

There will be no tolerance for undermining individuals by going behind a team member's back and gaining consensus for a conflict.

Assignment Submission

Unless the team has decided to use a vacation date [see amendment policy], all assignments will be submitted at least 15 minutes prior to the deadline. While the whole team is responsible for assignments, it is the responsibility of the project engineer to turn in the assignments before the due date and due time. All team members will be notified at least 3 hours prior to submission through communication methods used by the group [see communication section]. Any team member who wants to make an edit in this window should notify the team. Once the edit has been completed, they should notify the team. All team members are responsible to finish the assignment prior to the deadline unless a vacation date has been used.

Ethics

All team members are required to abide by the NSPE Engineering Code of Ethics. As upcoming engineers, they are responsible for their actions and how they affect the client, the public, the sponsor and the profession. There will be a zero-tolerance policy for not abiding by the NSPE Engineering Code of Ethics.

Dress Code

For standard group meetings and working events there is no requirement and casual attire is acceptable. However, for presentations a business professional attire is mandatory. For sponsor meetings, a business casual attire is mandatory.

Decision Making

Decisions made by the group will take precedent over individual decisions, no individual can supersede the decision of the group. If an individual wants to bring forth a new idea or suggestion, they need to consult with all team members beforehand. Once an idea has been presented or if a critical issue has arisen, the team will meet and decide after the gathering necessary data and evaluating the available data. If a team member finds new information that pertains to the selected resolution, the team will reconvene to re-evaluate the solution. In case there is no clear resolution among the team members, a vote will be carried out to find a solution.

Amendment Policy

When there appears to be a conflict with what is written in Team 507's Code of Conduct and new possible expectations and guidelines the team shall have a meeting on Zoom and vote on whether the Code of Conduct needs to be amended. A majority vote is needed for an amendment to be passed.

Code of Conduct Violations

In case of a violation of the Code of Conduct the procedure, the team will follow in terms of violations shall be:

1. Verbal warning from team
2. Verbal warning from team
3. Team meeting and intervention
4. Refer to Dr. McConomy and Dr. Chiang Shih

In the event that a violation occurs or is repeated more than one time within a span of a week, the procedure will go from step 1 directly to step 3.

Statement of Understanding

I understand and agree with what is written in Team 507's Code of Conduct and shall abide to the Code of Conduct.

Name	Signature	Date
Michenell Louis-Charles		9/8/2020
Adrian Moya		9/8/2020
Sasindu Pinto		9/8/2020
Cameron Riley		9/8/2020
Noah Wright		9/8/2020

Appendix B: Work Break Down Structure

Milestone Number	Milestones & Breakdown	Person Responsible
1	1. Work Break Down Structure	
	1.1 Table Formulation	Adrian Moya
	1.2 Grammar Check	Cameron Riley
	1.3 Rubric/Quality Check	Sasindu Pinto
	1.4 Submission	Sasindu Pinto
2	2. Project Scope	
	2.1 Project Description	Michenell Louis-Charles
	2.2 Key Goals	Sasindu Pinto
	2.3 Market	Adrian Moya
	2.4 Assumptions	Noah Wright
	2.5 Stakeholders	Cameron Riley

		2.6 Grammar & Communication		Michenell Louis-Charles
		2.7 Submission		Sasindu Pinto
3	3. Customer Needs			
		3.1 Customer Statement		Michenell Louis-Charles
		3.2 Interpreted Need		
			3.2.1 States "What" not How	Adrian Moya
			3.2.2 Specificity	Sasindu Pinto
			3.2.3 Positive not Negative	Noah Wright
			3.2.4 Avoids "Must" and Should	Adrian Moya
		3.3 Grammar		Cameron Riley
		3.4 Explanation of Results		Cameron Riley
		3.5 Submission		Sasindu Pinto
4				

	4. Functional Decomposition			
		4.1 Function Validation		
			4.1.1 Starts with Verb	Sasindu Pinto
			4.1.2 Connection to Systems	Adrian Moya
			4.1.3 Smart Integration	Cameron Riley
		4.2 Explanation of Results		Noah Wright
		4.3 Action and Outcome		Sasindu Pinto
		4.4 Function Resolution		Noah Wright
		4.5 Hierarchy Chart		Adrian Moya
		4.6 Cross Reference Chart		Michenell Louis-Charles
		4.7 Grammar & Communication		Noah Wright

	4.8 Submission	Sasindu Pinto
5	5. Targets & Metrics	
	5.1 Critical Targets and Metrics	Cameron Riley
	5.2 Critical Functions	Noah Wright
	5.3 Summary/Derivation of Targets and Metrics	Adrian Moya
	5.4 Discussion of Measurements	Sasindu Pinto
	5.5 Metrics and Method of Validation	Michenell Louis-Charles
	5.6 Grammar	Cameron Riley
	5.7 Submission	Sasindu Pinto
6	6. Virtual Design Review 1	
	6.1 Project Scope	Michenell Louis-Charles

	6.2 Customer Needs	Noah Wright
	6.3 Functional Decomposition	Sasindu Pinto
	6.4 Targets & Metrics	Adrian Moya
	6.5 Slide Editing and Animations	Adrian Moya
	6.6 Grammar	Cameron Riley
	6.7 Submission	Sasindu Pinto
7	7. Concept Generation	
	7.1 Brainstorm	Noah Wright
	7.2 Functional Methods	Adrian Moya
	7.3 Decomposition	Sasindu Pinto
	7.4 Systematic Design Methods	Michenell Louis-Charles
	7.5 Grammar	Cameron Riley
	7.6 Submission	Sasindu Pinto
8	8. Computation/Analysis	

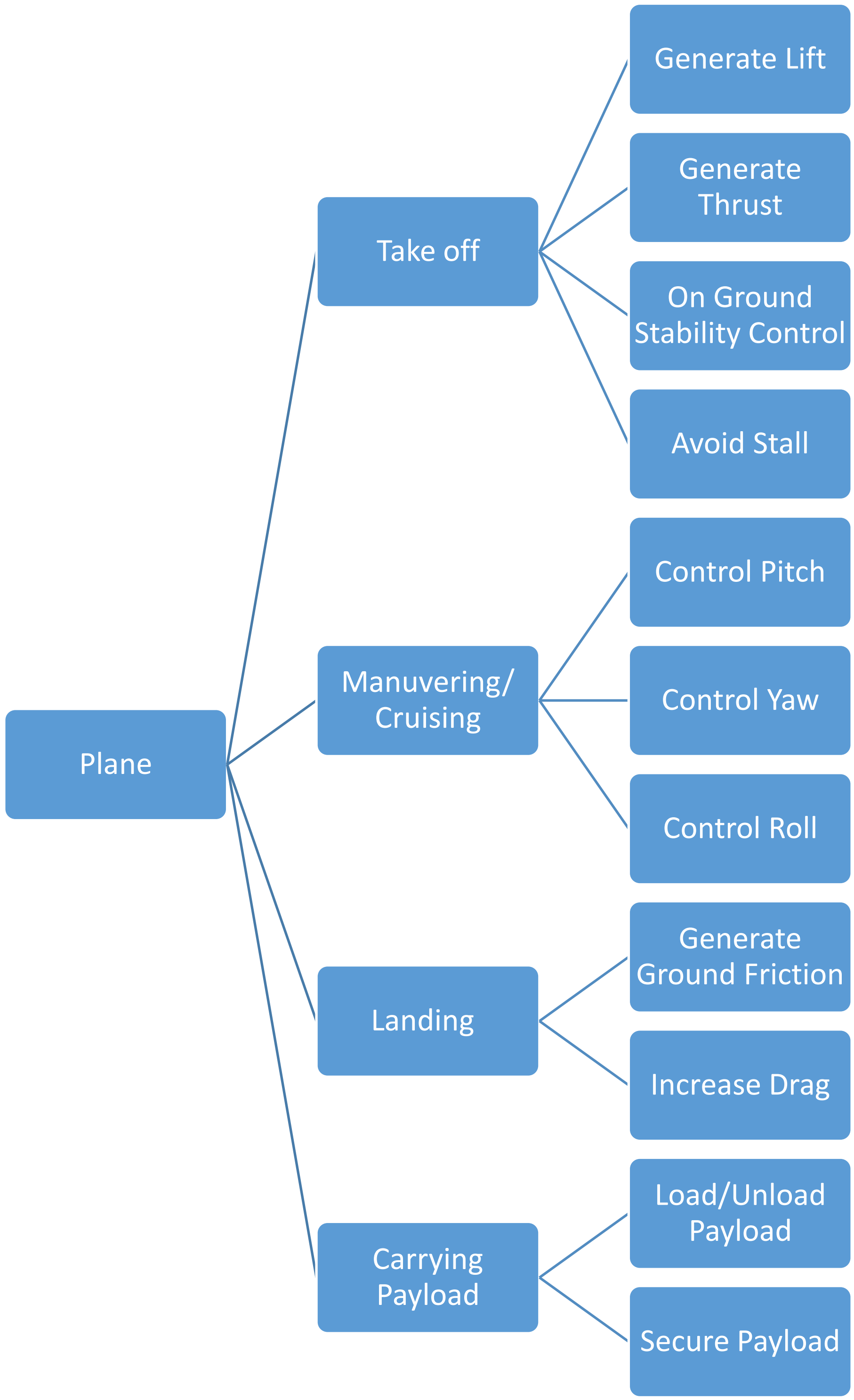
	8.1 Propulsion	Michenell Louis-Charles
	8.2 Airfoil	Sasindu Pinto
	8.3 Aerodynamics	Noah Wright
	8.4 Driving on Tarmac	Adrian Moya
9	9. Concept Selection	
	9.1 Concept Generation	Adrian Moya
	9.2 Decision Making	Michenell Louis-Charles
	9.3 Selection Criteria	Noah Wright
	9.4 Pugh chart	Sasindu Pinto
	9.5 Decision Matrix	Adrian Moya
	9.6 Analytical Hierarchy Process (AHP)	Cameron Riley
	9.7 Grammar	Noah Wright
	9.8 Submission	Sasindu Pinto
10		

	10. Virtual Design Review 2		
		10.1 Summary of VDR 1	Noah Wright
		10.2 Concept Generation	Adrian Moya
		10.3 Computation/Analysis	Cameron Riley
		10.4 Concept Selection	Michenell Louis-Charles
		10.5 Slide Editing and Animations	Sasindu Pinto
		10.6 Grammar	Noah Wright
		10.7 Submission	Sasindu Pinto
11	11. Simulations		
		11.1 Create CAD	Cameron Riley
		11.2 Simulate Aero/Fluid Characteristics	Sasindu Pinto
12			

	12. Prototyping	
	12.1 Purchase Material	Michenell Louis-Charles
	12.2 Build Plane	
	12.2.1 Test Electrical Components	Adrian Moya
	12.2.3 Test Component Strength	Cameron Riley
	12.2.3 Work on wiring	Adrian Moya
	12.2.4 Print additive manufacturing components	Michenell Louis-Charles
	12.2.5 Assemble plane	Noah Wright
13	13. Virtual Design Review 3	

		13.1 Summary of VDR 2	Cameron Riley
		13.2 Simulations	Noah Wright
		13.3 Prototyping	
		13.3.1 Purchase Material	Michenell Louis-Charles
		13.3.2 Build Plane Sections 1 & 2	Adrian Moya
		13.3.3 Build Plane Sections 3,4 & 5	Sasindu Pinto
		13.4 Slide Editing and Animations	Cameron Riley
		13.5 Grammar	Noah Wright
		13.6 Submission	Sasindu Pinto

Appendix C: Functional Decomposition Hierarchy Chart



Appendix D: Targets and Metrics Catalog

Function	**Metric**	**Target**	**Method of Validation**	**Tools for Validation**
Take Off				
Generate Lift	Angle of Attack	4-6 Degrees	Computational Fluid Dynamics Analysis	Ansys - Fluent
	Coefficient of Lift	>1	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Coefficient of Drag	<1	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Chord Length	12 in - 18 in	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Wingspan	60 in -120 in	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
Generate Thrust	Thrust Force	15 lbf	Experimental	Force Gauge, Scale
	Electric Motor Kv Rating	390 Kv	Given by Manufacturer	Manufacture Validated

	Voltage	22.2 V	Experimental	Voltmeter
	Propeller Diameter	16 in - 20 in	Experimental and Theoretical Calculations	Inch-scale meter, thrust calculations using MATLAB and DriveCalc
	Electric Motor Maximum Power	950W	Experimental	Voltmeter, Ammeter
Ground Stability Control	Gross Take-off Loading	<55 lbf	Simulation and Experimental	SolidWorks, Scale
	Thrust Line Positioning	+/- 0.2 in from Center of Gravity	Simulation and Theoretical Calculations	MATLAB, Solidworks
	Center of Mass Positioning	6 in to 9 in from the Airfoil Leading Edge	Simulation	SolidWorks
Avoid Stall	Stall Speed	>30 mph	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Stall Angle of Attack	>10 degrees		Ansys - Fluent, XLFR5

			Simulation and Experimental	
Maneuvering/Cruising				
Control Pitch	Angle about the X-Axis	+/- 60 deg from Neutral Axis	Simulation and Experimental	Ansys - Fluent, Control Surface Rotation
	Servo Motor Torque Produced	> 66.6 oz-in	Given by Manufacturer	Manufacture Validated
Control Yaw	Angle about the Y-Axis	+/- 60 deg from Neutral Axis	Simulation and Experimental	Ansys - Fluent, Control Surface Rotation
	Servo Motor Torque Produced	> 66.6 oz-in	Given by Manufacturer	Manufacture Validated
Control Roll	Angle about the Z-Axis	+/- 60 deg from Neutral Axis	Simulation and Experimental	Ansys - Fluent, Control Surface Rotation
	Servo Motor Torque Produced	> 66.6 oz-in	Given by Manufacturer	Manufacture Validated
Landing				
	Coefficient of rolling friction	0.03 - 0.06	Experimental	Fish Scale, Different Loads

Generate Ground Friction	Velocity for Landing	<25 mph	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Landing Gear Force Absorption	>55 lbf	Experimental	Force Gauge, Scale
Increase Drag	Coefficient of Drag	>1	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
	Air Brake Force	2-5 lbf	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent
Carrying Payload				
Load/Unload Payload	Time	1 minute	Experimental Testing	Stopwatch
Secure Payload	Payload Weight	2 lbf	Simulation and Theoretical Calculations	MATLAB, Ansys - Fluent

Appendix E: Concepts Catalog

Concept #	Wing Layout	Wings Type	Wing Positioning	Control Surfaces	Fuselage	Tail
Morphological Chart						
1	Main-Tail	Main - Elliptical Tail - Symmetric	High Wing	Aileron - Flaps - Elevator	Double Boom	Boom
2	Canard-Main	Delta Wing	High Wing	Aileron - Flaps	Bullet	Wing Tips Instead of Tail
3	Main	Flying wing (b-2 Bomber)	Mid Wing	Aileron-Flaps	Flying Boat	NA
4	Main-Canard	main-forward swept tail-symmetric (x-29)	Low Wing	Aileron - Flaps - Elevator	Double Boom	V-tal
5	Main-Tail	Main - Elliptical Tail - Symmetric	Mid Wing	Aileron - Flaps - Elevator	Double Boom	T-Tail

6	Main-Tail	Main - Elliptical Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Double Boom	H-Tail
7	Trapezoidal	Main - Trapezoidal Tail - Symmetric	High Wing	Aileron - Flaps - Elevator	Flying Boat	Boom
8	Main-Tail	Main - Elliptical Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Bullet	T-Tail
9	Main-Tail	Main - Elliptical Tail - Symmetric	Mid Wing	Aileron - Flaps - Elevator	Double Boom	Boom
10	Main-Tail	Main - Elliptical Tail - Symmetric	High Wing	Aileron - Flaps - Elevator	Double Boom	Tapered
11	Trapezoidal	Main - Elliptical Tail - Symmetric	Mid Wing	Aileron - Flaps - Elevator	Flying Boat	Boom

12	Trapezoidal	Main - Elliptical Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Flying Boat	Boom
13	Main-Tail	Main - Tapered Tail - Symmetric	High Wing	Aileron - Flaps - Elevator	Double Boom	Boom-Mounted
14	Canard-Main	Delta Wing	Mid Wing	Aileron - Flaps	Bullet	Tripletail
15	Main	Flying wing (b-2 Bomber)	Mid Wing	Aileron-Flaps	Flying Boat	Twin-Tail
16	Main-canard	main-forward swept tail-symmetric (x-29)	Low Wing	Aileron - Flaps - Elevator	Double Boom	V-tal
17	Main-Tail	Main - Elliptical Tail - Symmetric	Mid Wing	Aileron - Flaps - Elevator	Double Boom	T-Tail
18	Main-Tail	Main - Elliptical Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Double Boom	H-Tail

19	Trapezoidal	Main - Trapezoidal Tail - Symmetric	High Wing	Aileron - Flaps - Elevator	Flying Boat	Boom-Mounted Inverted V
20	Main-Tail	Main - Tapered Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Bullet	T-Tail
21	Main-Tail	Main - Tapered Tail - Symmetric	Mid Wing	Aileron - Elevator	Double Boom	Boom
22	Main-Tail	Main - Tapered Tail - Symmetric	High Wing	Aileron - Elevator	Double Boom	Ring-Tail
23	Main-Tail	Main - Trapezoidal Tail - Symmetric	Mid Wing	Aileron - Flaps - Elevator	Flying Boat	Boom
<u>24</u>	Main-Tail	Main - Trapezoidal Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Flying Boat	T- Tail

25	Main-Tail	Main - Rectangular Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Flying Boat	Cruciform
26	Main-Tail	Main - Tapered Tail - Symmetric	High Wing	Aileron - Flaps - Elevator	Double Boom	Cruciform
27	Canard-Main	Delta Wing	Mid Wing	Aileron - Flaps	Bullet	Triple-Tail
28	Main	Flying wing (b-2 Bomber)	Mid Wing	Aileron-Flaps	Flying Boat	Twin-Tail
29	Main-canard	main-forward swept tail-symmetric (x-29)	Low Wing	Aileron - Flaps - Elevator	Double Boom	Inverted-V
30	Main-Tail	Main - Rectangular Tail - Symmetric	Mid Wing	Aileron - Flaps - Elevator	Double Boom	T-Tail

31	Main-Tail	Main - Rectangular Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Double Boom	H-Tail
32	Trapezoidal	Main - Trapezoidal Tail - Symmetric	High Wing	Aileron - Flaps - Elevator	Bullet	Boom-Mounted Inverted V
33	Main-Tail	Main - Tapered Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Bullet	H-Tail
34	Main-Tail	Main - Tapered Tail - Symmetric	Mid Wing	Aileron - Elevator	Bullet	Twin-Tail
35	Main-Tail	Main - Tapered Tail - Symmetric	High Wing	Aileron - Elevator	Bullet	Tapered
36	Trapezoidal	Main - Elliptical Tail - Symmetric	Mid Wing	Aileron - Flaps - Elevator	Bullet	Triple-Tail

37	Trapezoidal	Main - Elliptical Tail - Symmetric	Low Wing	Aileron - Flaps - Elevator	Bullet	Y-Tail
Competitive Benchmarking						
38	Modified Boeing 747 Dreamlifter					
39	Modified Airbus A380					
40	Modified Boeing 737					
41	Modified Aero Spaceline Super Guppy					
42	Modified Airbus A400M Atlas					
43	Modified Antonov An 124 Condor					
44	Modified Cessna 208 Grand Caravan					
45	Modified Cessna 408					
46	Modified Antonov An -22					
47	Modified Kawasaki C-2					
48	Modified Lockheed C-130j					
49	OMAC Laser 300					
50	Modified Long EZ					
51	Modified Dc2					
52	Rutan Quickie Q2					
53	Rutan AMSOIL Racer					

54	Beechcraft Starship Model 2000
55	Antonov An -12
56	Douglas C-47 Skytrain
57	Fairchild C-123 Provider
58	Fairchild C-82 Packet
59	Grumman C-2 Greyhound
60	Aeritalia G.222
61	Cosy Classic
62	e-Go
63	Concorde
64	Lockheed Vega
65	Enola Gay
66	Apache
67	SpaceShip One
68	Antonov An-225 Mriya
Biomimicry	
69	Attach go-pro on a bird
70	Pelican (storage and flight capabilities)

71	Condor (Wingspan)
72	Kangaroo (Storage)
73	Eagles (High flying range/ transportation of large prey)
74	Hummingbirds (stability in flight)
75	Wasps (Mobility in flight and ability to fly with a large load)
76	Bats for their wing configuration
77	BeeBees (howeir bodies can be bigger than their wings and still fly)
78	Pterodactyl (wingspan/mobility with large prey)
79	Penguins (Streamline/Aerodynamic bodies)
80	Alpine Swift (wingspan and flight time)
81	Artic Tern (Flight Time)
82	Reindeer (mobility and ability to carry heavy loads)
83	Bird Beaks (Leading Edge of Plane)
84	Albatrosses (Wingspan and Ability to fly with wind)
85	Goat (Ability to remain stable in tough conditions)
86	Horse (ability to carry heavy loads and maneuver well)

87	Dung Beetle (lightweight and small but can carry 1141 times their body weight)
Crap Shoot	
88	Not change anything from last year and compete anyway
89	Buy an RC plane kit
90	Completely rectangular body with cylindrical wings
91	Don't make the necessary calculations and just build a plane
92	Buy a model jet and fly it as our own
93	Modified Star Wars A-Wing Bomber
94	USS Enterprise
95	Star Wars Jedi Starfighter
96	Star Wars Republic Gunship
97	Star Wars X-Wing
98	Millennium Falcon

Morphological Analysis					
Wing Layout	Wing Type	Wing Position	Control Surfaces	Fuselage	Tail

Main-Tail	Main-forward swept tail-symmetric (x-29)	High Wing	Aileron	Bullet	Boom-Mounted Inverted V
Trapezoidal	Delta Wing	Mid Wing	Flaps	Flying Boat	H-Tail
Canard-Main	Main - Elliptical Tail - Symmetric	Low Wing	Elevators	Double Boom	Twin-Tail
	Main - Trapezoidal Tail - Symmetric				Tapered
					Triple-Tail
					Y-Tail

Appendix F: Concept Selection Tools

[Grey cells are related to geometric team]

Binary Pairwise Comparison													
	1	2	3	4	5	6	7	8	9	10	11	12	Total
1. Material	-	0	0	0	0	0	0	1	0	0	0	0	1
2. Stability	1	-	0	0	0	1	1	1	1	0	0	1	6
3. CG in front of CP	1	1	-	1	1	1	1	1	1	1	1	1	10
4. Meet takeoff/landing requirements	1	1	0	-	1	1	1	0	1	0	0	1	7
5. Wingspan meets restrictions	1	1	0	0	-	1	1	1	1	0	0	1	7
6. Sufficient Power	1	0	0	0	0	-	0	0	1	1	1	1	5
7. Maneuverability	1	0	0	0	0	1	-	0	1	0	0	1	4
8. Light Weight	0	0	0	1	0	1	1	-	1	1	0	1	6
9. Touch-down Impact	1	0	0	0	0	0	0	0	-	0	0	1	2
10. Ground Controls	1	1	0	1	1	0	1	0	1	-	1	1	7
11. Carry the Minimum Cargo Load Required	1	1	0	1	1	0	1	1	1	0	-	1	8
12. Easy to Load/Unload	1	0	0	0	0	0	0	0	0	0	0	-	1
Total	10	5	0	4	4	6	7	5	9	4	3	10	-

House of Quality												
		Engineering Characteristics (***From Main Targets***)										
Improvement Direction												
Units		lbf	lbf	lbf	degrees	ft/s	ft/s^2	degrees	seconds	lbs	ft/s^2	psi
Customer Requirements	Importance Weight	Lift	Drag	Thrust	Max Angle of Attack	Stall Speed	Acceleration	Control Surface	Loading/ Unloading	Weight	Deceleration	Joint
1. Material	1		1							9		
2. Stability	6	9	3	3				9				
3. CG in front of CP	10	9	3	9	9	9		9		3		
4. Meet takeoff/landing requirements	7	9	3	9			9				9	
5. Wingspan meets restrictions	7	9	3		3	3		1				
6. Sufficient Power	5	1	1	3			3	3		1	1	
7. Maneuverability	4				3	3		9		3		
8. Light Weight	6	3		3			3			9	3	
9. Touch-down Impact	2							3		3	9	

10. Ground Controls	7							1				
11. Carry the Minimum Cargo Load Required	8	9		3			3		9	9	3	
12. Easy to Load/Unload	1								9	3		
Raw Score		365	96	228	123	123	120	215	81	191	128	1
Relative Weight %		18.92	4.98	11.82	6.38	6.38	6.22	11.15	4.20	9.90	6.64	7
Rank Order		1	11	2	6	6	10	3	12	4	8	

Pugh Chart 1		Concepts							
		High			Medium				
Selection Criteria	**2020 Competition Entry**	1	2	3	4	5	6	7	8
Lift	DATUM	+	+	+	-	-	+	-	-
Thrust		S	S	S	S	S	S	S	S

Control Surface Movement		+	+	+	+	S	+	S	S
Weight		-	S	-	-	-	S	-	S
Joint Strength		+	+	+	+	+	+	+	+
# of pluses		3	3	3	2	1	3	1	1
# of S's		1	2	1	1	2	2	2	3
# of Minuses		1	0	1	2	2	0	1	1

Pugh Chart 2		Concepts		
		High		Medium
Selection Criteria	Concept 2	1	3	6
Lift	Datum	-	+	-
Thrust		S	S	S
Control Surface Movement		+	+	+
Weight		-	-	-
Joint Strength		S	S	S

# of pluses	1	2	1
# of S's	2	2	2
# of Minuses	2	1	2

Development of a Candidate set of Criteria Weights {W}					
Criteria Comparison Matrix					
	Lift	Thrust	Control Surface Movement	Weight	Joint Strength
Lift	1.00	0.33	3.00	9.00	9.00
Thrust	3.00	1.00	3.00	9.00	9.00
Control Surface Movement	0.33	0.33	1.00	5.00	3.00
Weight	0.11	0.11	0.20	1.00	0.11
Joint Strength	0.11	0.11	0.33	9.00	1.00
Sum	4.56	1.89	7.53	33.00	22.11

Normalized Criteria Comparison Matrix [NormC]
Criteria Comparison Matrix

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector

	Lift	Thrust	Control Surface Movement	Weight	Joint Strength	Criteria Weight
Lift	0.22	0.18	0.40	0.27	0.41	0.295
Thrust	0.66	0.53	0.40	0.27	0.41	0.453
Control Surface Movement	0.07	0.18	0.13	0.15	0.14	0.134
Weight	0.02	0.06	0.03	0.03	0.01	0.029
Joint Strength	0.02	0.06	0.04	0.27	0.05	0.089
Sum	1.00	1.00	1.00	1.00	1.00	1.000

1.911	0.490	3.899
2.802	0.230	12.184
0.796	0.140	5.683
0.149	0.040	3.720
0.478	0.100	4.780

λ Average Consistency	CI Consistency Index	CR Consistency Ratio
6.053	0.027	0.051

Lift Comparison			
	Concept 1	Concept 3	Concept 6
Concept 1	1.00	0.33	3.00
Concept 3	3.00	1.00	7.00
Concept 6	0.33	0.14	1.00
Sum	4.33	1.48	11.00

Normalized Criteria Comparison Matrix [NormC]				
	Concept 1	Concept 2	Concept 6	Criteria Weight
Concept 1	0.231	0.226	0.273	0.243
Concept 2	0.692	0.677	0.636	0.669
Concept 6	0.077	0.097	0.091	0.088
Sum	1.000	1.000	1.000	1.000

Thrust Comparison			
	Concept 1	Concept 3	Concept 6

Normalized Criteria Comparison Matrix [NormC]				
	Concept 1	Concept 2	Concept 6	Criteria Weight

Concept 1	1.00	1.00	1.00
Concept 3	1.00	1.00	1.00
Concept 6	1.00	1.00	1.00
Sum	3.00	3.00	3.00

Concept 1	0.333	0.333	0.333	0.333
Concept 2	0.333	0.333	0.333	0.333
Concept 6	0.333	0.333	0.333	0.333
Sum	1.000	1.000	1.000	1.000

Control Surface Movement Comparison			
	Concept 1	Concept 3	Concept 6
Concept 1	1.00	3.00	0.20
Concept 3	0.33	1.00	0.20
Concept 6	3.00	5.00	1.00
Sum	4.33	9.00	1.40

Normalized Criteria Comparison Matrix [NormC]				
	Concept 1	Concept 2	Concept 6	Criteria Weight
Concept 1	0.231	0.333	0.143	0.236
Concept 2	0.077	0.111	0.143	0.110
Concept 6	0.692	0.556	0.714	0.654
Sum	1.000	1.000	1.000	1.000

Weight Comparison			
	Concept 1	Concept 3	Concept 6
Concept 1	1.00	0.33	3.00
Concept 3	3.00	1.00	5.00
Concept 6	0.33	0.20	1.00
Sum	4.33	1.53	9.00

Normalized Criteria Comparison Matrix [NormC]				
	Concept 1	Concept 2	Concept 6	Criteria Weight
Concept 1	0.231	0.217	0.333	0.260
Concept 2	0.692	0.652	0.556	0.633
Concept 6	0.077	0.130	0.111	0.106
Sum	1.000	1.000	1.000	1.000

Joint Strength Comparison			
	Concept 1	Concept 3	Concept 6
Concept 1	1.00	1.00	1.00

Normalized Criteria Comparison Matrix [NormC]				
	Concept 1	Concept 2	Concept 6	Criteria Weight
Concept 1	0.333	0.333	0.333	0.333

Concept 3	1.00	1.00	1.00
Concept 6	1.00	1.00	1.00
Sum	3.00	3.00	3.00

Concept 2	0.333	0.333	0.333	0.333
Concept 6	0.333	0.333	0.333	0.333
Sum	1.000	1.000	1.000	1.000

Consistency Check 1 (Lift)		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector
0.731	0.243	3.005
2.015	0.669	3.014
0.265	0.088	3.002

Consistency Check 2 (Thrust)		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector
1.000	0.333	3.000
1.000	0.333	3.000

1.000	0.333	3.000

Consistency Check 3 (Control Surface Movement)		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector
0.697	0.236	2.959
0.320	0.110	2.898
1.912	0.654	2.924

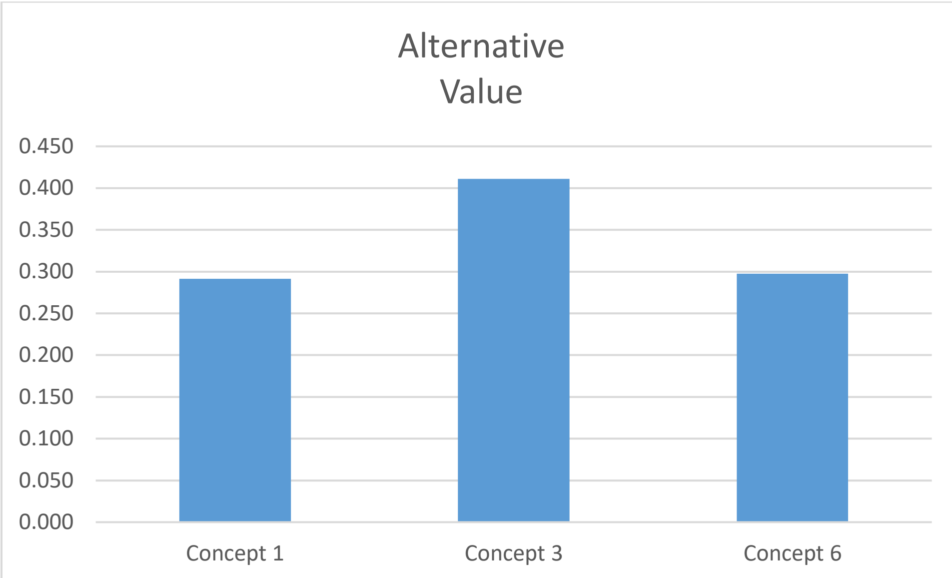
Consistency Check 4 (Weight)		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector
0.790	0.260	3.033
1.946	0.633	3.072

0.320	0.106	3.011

Consistency Check 5 (Joint Strength)		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con={Ws}./{W} Consistency Vector
1.000	0.333	3.000
1.000	0.333	3.000
1.000	0.333	3.000

Final Rating Matrix			
Selection Criteria	Concept 1	Concept 2	Concept 6
Lift	0.243	0.669	0.088
Thrust	0.333	0.333	0.333
Control Surface Movement	0.236	0.110	0.654
Weight	0.260	0.633	0.106
Joint Strength	0.333	0.333	0.333

Concept	Alternative Value
Concept 1	0.292
Concept 3	0.411
Concept 6	0.297


Alternative Value
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
Concept 1
Concept 3
Concept 6

Appendix G: Operations Manual

G 1. Overview

G 1.1 Project Overview

SAE Aero Design competition is an aircraft design competition for college students which is held annually. This year the entry from our school is comprised of two teams. T508 is the geometric team and we, T507, are the aero propulsion team. The overall objective is to design and manufacture a remote-controlled plane within the rules and regulations of the SAE Aero Design East Competition 2021. The objective of the aero propulsion team is to ensure that the plane takes off, completes the flight path, and lands safely while carrying a payload. We included 2 innovative designs in our plane. We added a canard wing, which is an extra wing added in front of the main wing to ensure that our plane will take off easily. We also decided to use a belt-gear system to operate control surfaces, which are used to control the plane when it is in the air. Our plane has 3 wings and weighs 12 pounds without cargo. We estimate our plane to take off in just under 55 ft.

G 1.2 Collaboration with the geometric team (T508)/ RC club interactions

As this year's project is a combined effect of the aero team and the geometric team, we made sure to collaborate with T508 and held all team meetings, except for a handful, with them. While we focused on aerodynamic and propulsion calculations, we checked with T508 dimensions of our design to ensure that those parts can be made. This is very important as they have information on 3-D printing, and some parts could be difficult to print even if their dimensions are within restrictions. Hence, we recommend checking every design with the geometric team (if the geometric system is handled by another team). Furthermore, T508 were in charge of contacting the Seminole R/C club, who provided useful information during the design stage. We found out this to be very helpful, as they provided key information on designing the landing gear of our plane. Furthermore, they provided the pilot and the controller for our plane. We recommend contacting the RC club early for the future teams as well.

G 2. Model

G 2.1 Propulsion

Onyx22.2V 4000mAh 6S 30C LiPo Battery coupled with a power limiter to supply power to the motor. E-flite Power 90 Brushless Outrunner 325Kv high torque motor used to spin the propellor. The propellor featured on this plane is an APC 18x10E. This propellor has a diameter of 18in and a pitch of 10°. All these components come together to make the propulsion system for our plane, producing approximately 222 lbf of the thrust.

G 2.2 Fuselage and Vertical Tail

The fuselage and tail configuration were modeled after the Lockheed Martin X-55. Particularly, the curvature of the back of the fuselage into the tail, and the T-tail layout. The drag coefficient for the body of the X-55 was used for aerodynamic calculations. The payload is secured in the fuselage. One top half of a fuselage section can be removed by unscrewing two bowties. The soccer ball is placed in a bowl towards the front of the hatch. The box weight payload is screwed down to a plate at the back of the hatch, where the fuselage begins to taper into the tail.

G 2.3 Wing Layout

The plane features three lifting surfaces, canards, main wing, and tail. The wings closest to the leading edge are the canards. These smaller wings provide lift and help prevent stalling. The canard airfoil will reach its stall angle of attack before the main wing. Then the plane will start to tilt down, however the lift provided by the main wing will stabilize the body pulling the nose back up providing a natural feedback loop for the plane. The main wing is located 25 inches from the leading edge of the plane and provides two thirds of the lift of the plane. It has the longest chord length and wingspan of all the wings, giving it the largest surface area. The canard is positioned on the bottom third of the fuselage, the main wing is in the top third, and the tail lays on top of a vertical tail so all three surfaces are on different planes.

G 2.4 Control Surfaces

There are control surfaces located on the trailing edge of the main wings, rudder, and tail. The ailerons on the main wings help steer by controlling roll stability. When performing a bank maneuver, the inner aileron deflects down, and the other angles upward. The ailerons have a differential deflection setting of 8:20. This means that when both are fully rotated, the downward pointed aileron is at an 8-degree angle while the upward facing aileron is at 20 degrees. The rudder is found on the vertical tail wing and helps control yaw. The rudder can rotate 25 degrees either direction, it can be used to turn, as well as combat crosswinds. The elevator is placed on the tail to control pitch. It can deflect 30 degrees and will be used to help the plane takeoff and land.

A belt and a gear system are used to operate control surfaces. We used a GT2 belt and gear system, which can be accessed using the link here. The belt was cut to into smaller pieces to create the correct amount of tension and soldered together. Make sure to put the soldered part in a section that doesn't go over a gear.

Figure 21: Belt and Gear

G 2.5 Landing Gear

The landing gear design is based on research done on typical landing gear designs for RC planes and information provided by the Seminole R/C club. The landing gear needs to create at least 3 inches of ground clearance for the propeller. Our plane has around 4 inches of ground clearance. We used a tricycle landing gear layout with one wheel at the front and two wheels at the back, opposed to reverse tricycle design which has the reverse layout to the layout mentioned above. As the center of gravity of our plane is towards the back, the layout we use creates a more even weight distribution. We placed our landing gear to have a 1:2 weight distribution between the front landing gear and each back-landing gear. It is important to place the back-landing gear closer to the center of gravity as the back of the plane touches the ground first during takeoff and this layout reduces the chance of our plane tipping over during landing. The canard layout makes sure that the plane has a moment towards the ground during landing, reducing the load on the back-landing gears and reducing the chance of tipping over. Due to these reasons, we recommend a tricycle landing gear layout.

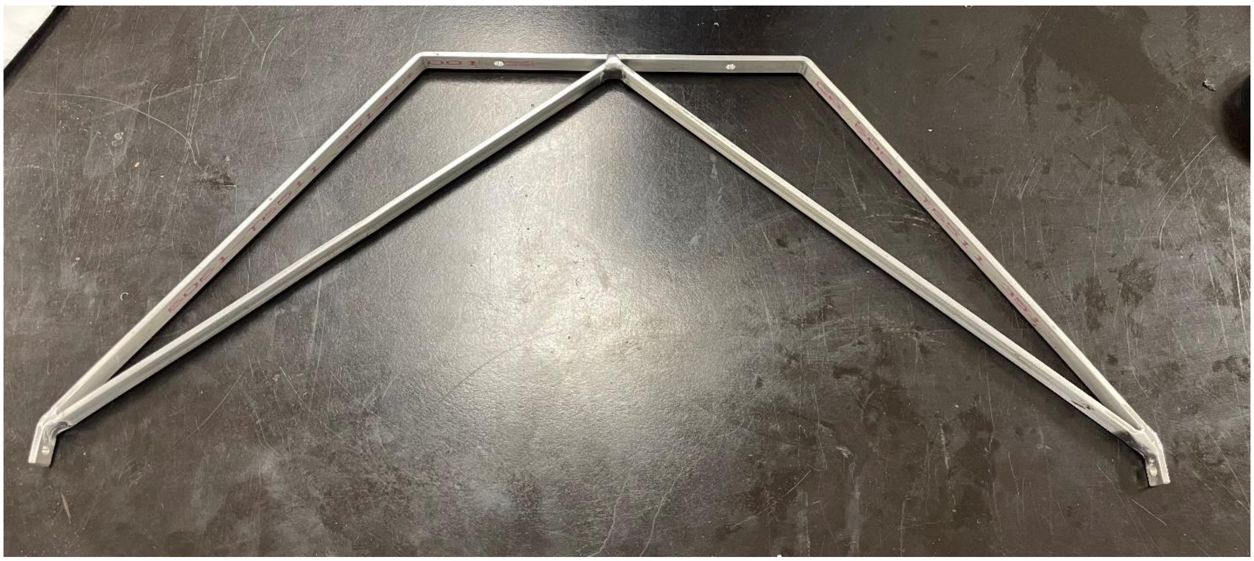


Figure 22: Rear Landing Gear

For information on integration, read the operation manual written by T508 (geometric team). For calculations related to the design process, including stability calculations, center of gravity determination, and determining dimensions of the plane, access our calculations here. Visit our one drive folder for more details on the overall project through here.

G 3. Power Setup

G 3.1 Controller

Our plane was set up and programmed with the Futaba T6J transmitter. This transmitter is linked to the Futaba 6J 6-Channel S-FHSS system receiver and features 6 different channels. The channels were used for our ailerons, elevator, rudder, and front landing gear for our design this year. Shown in the figure below are the main functions of the plane and which part of the transmitter controls it.

Figure 23: Controller and its controls

To program the remote, hold the button below the thrust-cut button for approximately 3 seconds until you hear a long beep. The menus on the display can be navigated with the silver '+' and '-' arrows located on the right side of the display. To see what each menu does more in-depth and how to alter it, the manual for the controller is located in the following link: [books folder in T507 One Drive.]

For the actual flight, we recommend using a controller and a receiver that the pilot is comfortable with. For more information about the controller and programming the controller, please contact Fredrich Mursch from the Seminole R/C club through email: fredrichmursch@aol.com

G 3.2 Wiring

The wiring of the plane begins at the battery, near the front of the plane. This position was chosen to avoid any unnecessary resistance from the battery to the plane's motor as any extensions on those wires increase the resistance in the circuit and decrease the voltage drop to the motor. The battery is a part of a closed circuit that includes the E-flite Power 90 Brushless motor, the ZTW Gecko 85A Electronic Speed controller, the power limiter (1000W), and the Futaba 6J 6-Channel S-FHSS system receiver. From the receiver, wires that connect to the servos in the main wings will flow along the bottom of the fuselage and split around the battery and cargo. One path will lead to the servo in one of the main wings and the other path will lead to the servo in the other main wing and to the remaining servos in the rudder and tail. In the main wings, there are pathways printed into the airfoil that the wires will go through to reach the servos. The wires going to the rudder and tail will be placed along the vertical side of the fuselage of the plane extending to the rear of the plane. Pathways in the tail will lead them to the servos that are in the rudder as well as the elevator servos in the tail. The elevator servos in the tail will be paired using servos splitting wires. Due to the wiring system being a closed-circuit system, we implemented a red arming plug located on the back of the plane; used for safety to turn off the plane. This red arming plug is coupled with the throttle kill switch on the controller, so the user can disable the plane manually or remotely. Shown below is a wiring diagram showing what each receiver port each of the plane's functions correspond to.

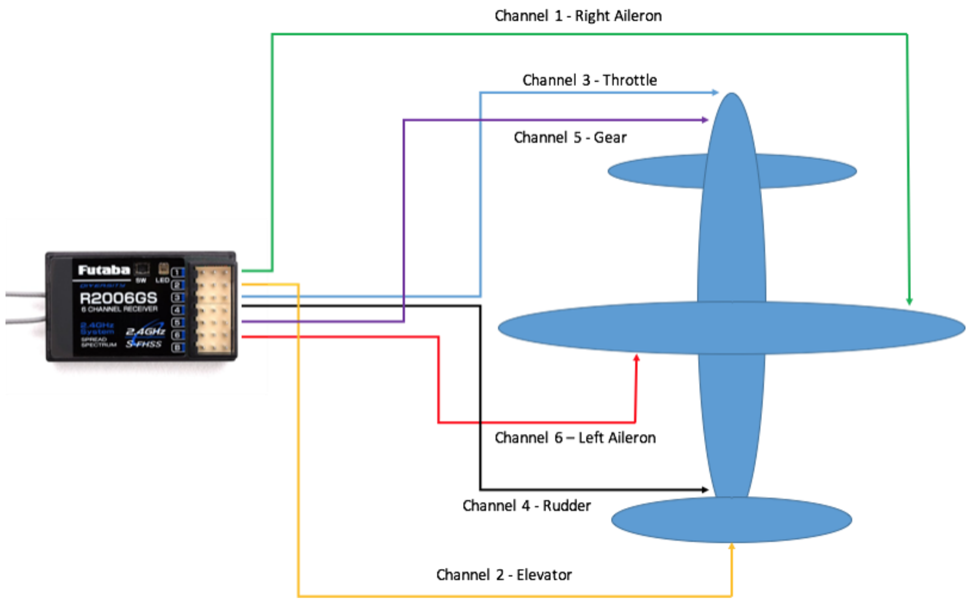


Figure 24: Wiring setup

G 4. Validation

Validation is a very important step in making the plane. As the design process involves innovative concepts and an intricate electrical setup, it is important to ensure that the plane performs as expected before the test flight.

G 4.1 Power Test

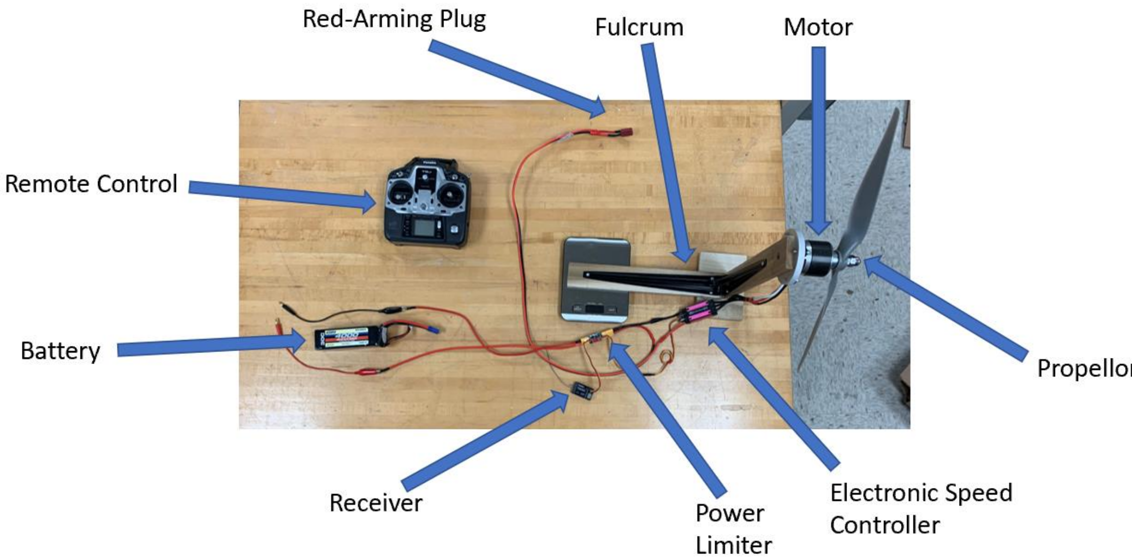


Figure 25: Propeller Test Setup

The above figure shows the power test setup for the propeller. The propeller and the motor are attached to a L-shaped fulcrum, which is resting on a scale. The wiring procedure is explained in section 3.2 above and the control procedure is explained in section 5.1 below.

G 4.2 Wind Tunnel Test

We recommend a wind tunnel test for a scaled down model of the actual aircraft. The CAD for the model can be found here. Contact Dr. Rajan Kumar to gain access to the subsonic wind tunnel at Florida Center for Advanced Aero-Propulsion (FCAAP). At minimum, conduct a qualitative study at different angles of attack (5 degrees and 12 degrees at least) to double check stalling properties of the plane. As light weight PLA prints often could give inconsistent prints, the aerodynamic properties of the plane could change from theoretical calculations to the actual plane. Therefore, make sure that the CG for the model is still within the stability margin for the plane (+/- 2 inches from the location market on the fuselage). If possible, try to do a quantitative wind tunnel test with simple lift and drag values, to ensure that the plane produces the same lift and drag as expected. Both lift and drag should be slightly higher than the calculated value, as interference drag, fuselage lift etc. is found through testing and hard to be estimated through calculations. Shown below is the setup for the wind tunnel model. Note that only the scaled down model and the attachment to it must be printed. The rest of the parts in the assembly is available in the wind tunnel lab.

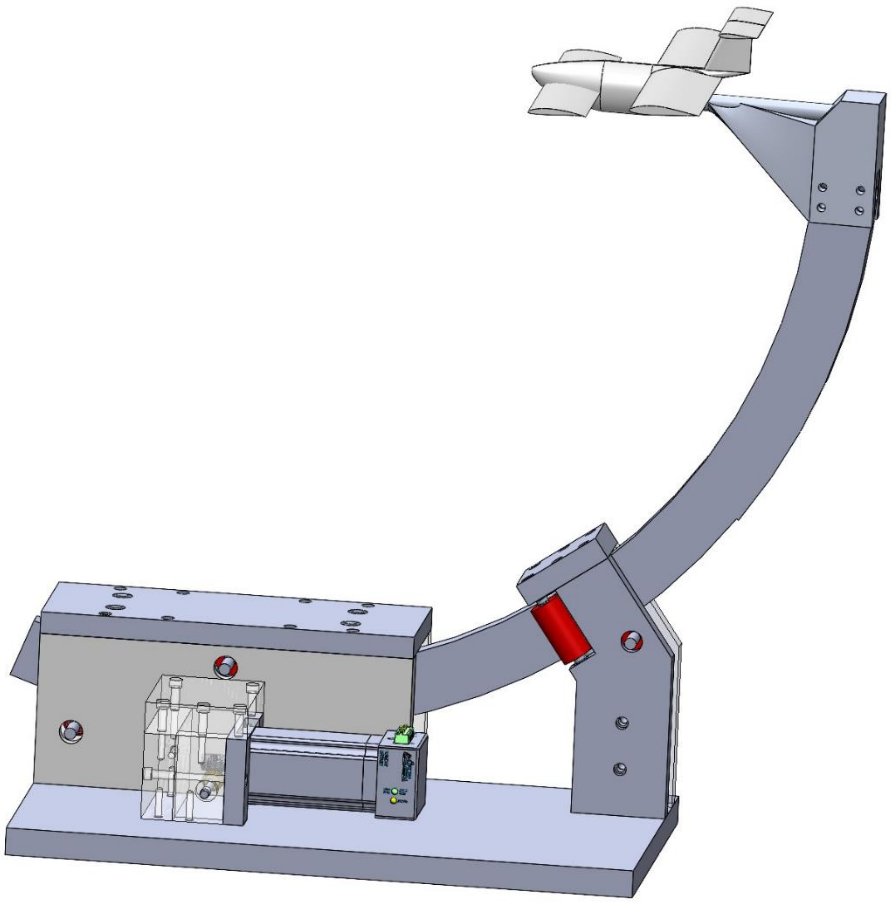


Figure 26: Wind Tunnel Setup

G 5. Operation

G 5.1 Start-up

1. Ensure that the receiver is powered on by connecting the wire coming out of the power limiter to the 'Batt' channel on the receiver while the battery is connected, and the red arming plug is armed. A red LED should light up when connected.

2. Remove the wire coming out of the power limiter from the ‘Batt’ channel then connect it to channel 3 (throttle channel). Make sure all connections are secure and all wires face the right way. (polarity is correct).
3. Power on the transmitter.
4. When the beeping ceases and a long sound plays, the airplane is powered on and ready to fly.

G 5.2 Pre-Flight Check List

1. Battery/Transmitter Voltage (plane and controller)
    a. Making sure that the battery is charged, and the transmitter is receiving power
2. Check Surfaces
    a. Making sure that all butterflies are tightly secure and there are no cracks or disturbances on plane’s surface
3. Check Airframe
    a. Making sure that the plane is structurally sound before take-off
4. Check Propeller
    a. Make sure that the propeller is secure on the plane
5. Check Landing gear
    a. Make sure that the wheels can move freely, and they do not wobble when moving
6. Check Motor
    a. Make sure it is getting power and can spin freely
7. Check Servos
    a. Check all servos to make sure they are moving in the right direction

8. Check Center of Gravity
    a. Balance the plane with all the components

For further information, use the pre-flight checklist available via this link.

G 5.3 Flight Control

A certified Academy of Aeronautics (AMA) pilot should fly the plane. The plan was to ask a pilot at the competition to fly. For flights/test flights here in Tallahassee, contact the Seminole R/C club for assistance, including for a pilot or finding a runway.

G 5.4 Shutdown (Including Emergency Shutdown)

When plane is completely stationary, switch off the remote and then remove the red arming plug before disassembling the plane. For information regarding disassembly, read the operation manual written by T508 (Geometric Team).

In case of an emergency, there are 2 methods to shut down the plane. If the plane is flying, it is recommended that the "thrust kill switch" on the remote is pressed. It is located left to the screen (as shown in figure 1 above). Following this, the pilot should still be able to glide the plane to the ground with control surface movement. Even if that is not possible, the geometry of the plane should allow it to glide to the ground.

If the plane is on the ground (including after thrust kill and glide mentioned above), the red arming plug placed in the bottom tail of the plane, in the first tapered section of the fuselage, should be removed. This would stop the current flow. Following this, the plane should be safe to be examined closely.

G 6. Troubleshooting

As the manual was written before the flight, the following issues and troubleshooting methods are based on the design and integrations, and possible errors that could arise during the flight.

G 6.1 Controller and Receiver

Issue: The controller is not syncing with the receiver, even though the right procedure is followed.

Solution: The most likely reason is that the controller is set to the wrong receiver frequency. Use the frequency knob in the top center of the controller to set it to the left most channel setting, which is related to our receiver. More information can be found on the controller manual here.

G 6.2 Servos and Control Surfaces

A manual for the KST X-10 Wing servos we used can be found here. A link to the belt used can be found here.

Issue: Servo does not rotate the amount commanded using the controller.

Solution: The servo neutral position is incorrect. Connect the servo to the trust channel (as that allows for easier control while adjusting the neutral position). When the controller is at the 50% input position, the servo should be at neutral. This can be checked by using a servo head. If not adjust the servo head so that it is at neutral position. (Make sure to do the same with the control surface to servo connection method used later in the project).

Issue: The belt slips from the gears

Solution: With the help of the geometric team, design gears with small adjustments to the standard GT2 gear pitch diameter and pressure angle found here. Then connect a gear to a servo and a another to a rotational axis. Initially try to just rotate the gear with the belt. Make sure that enough pressure is applied where the belt is on the gear and the belt has enough tension. Then run the servo and see if the gear rotates well. Adjust the bearing locations inside the control surface to adjust the tension of the belt. When there is negligible slip of the belt, there is enough tension.

G 6.3 Validation

Issue: There are small open gaps in the wind tunnel model printed, which could affect the airflow and give invalid data.

Solution: Use "China Clay" and/or tape available in the wind tunnel lab to cover those gaps. They are specifically designed to fill those gaps and not give invalid data. Make sure not to use an excessive amount that would change the geometry of the model.

G 7. Recommended Improvements

The following are some recommended design changes that we recommend for the future projects. These are based on data collected during the wind tunnel test and based on difficulties we had during the design stage.

G 7.1 Recommended Design Changes

It is recommended to connect all wing sections via dove tails. Initially considered for structural integrity, the dove tails provide the best from fit between sections. Pieces connected with dove tails are aligned better, with less inconsistency in the creases. Structural support wasn't considered an issue as there are two spars in the canard and main wings, and one in the tail. It is also important to keep wiring in mind and leave enough place for wires to fit through easily. One print did not have wire holes, and when reprinted the gap was barely wide enough to allow the wire to pass and made it difficult to pull through the entire piece. Landing gear that was rounded at the connection to the fuselage was designed, but constraints from the machine shop prevented its use. This design technique is still recommended, it just needs to be submitted ample time before flight testing.

There is the possibility that the turbulence and vortices produced by the propeller could affect the wings of the plane, especially the main wing. A possible solution is to put the propeller at the back and make the plane a "push plane". However, it is important to keep the center of gravity in the right range based on the design (just in front of the main wing for our wing layout). Furthermore, the rudder and the tail will have to be redesigned to perform effectively. Another possible design is to have 2 smaller propellers, one on each main wing. A gear system will be required to transfer power from one motor into 2 propellers, with at least one axis translation using gears.

G 8. Further Reading

We Recommend the books and articles mentioned in the appendix A for further reading, as a guide in designing a R/C plane. The book by Lennon can be used as a guideline for general design, as it goes into detail about typical R/C plane design requirements. We used the book by Anderson for general aerodynamic calculations such as lift and drag, and longitudinal stability calculations. For roll and yaw stability, refer to the book by Sadraey. We highly recommend that book for the entire design process, as that follows a systems engineering approach to aircraft design. Also, refer to the pilot's handbook regarding setting up control surfaces and their motion.

Appendix G I : Resources

Repository links

- Complete OneDrive access
- Aerodynamic Calculations
- Reference Material

If there are any issues accessing these links, contact Adrian Moya (am16bg@my.fsu.edu) or Sasindu Pinto (sp18dy@my.fsu.edu) .

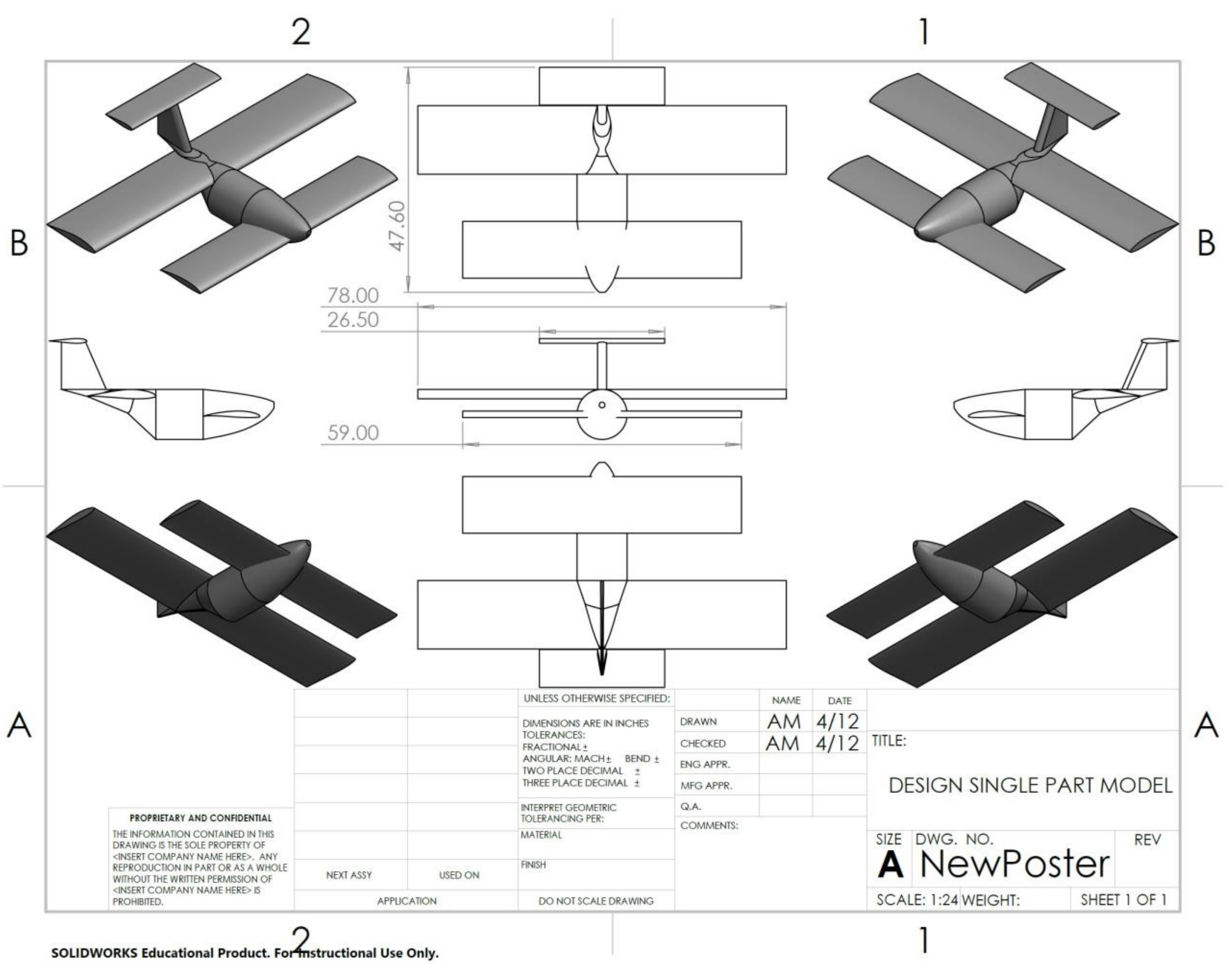
Reference Material

- Anderson, J. D. (2011). Fundamentals of Aerodynamics. In 5. Edition (Ed.). McGraw Hill Publications.
- Lennon, A. (2005). RC Model Aircraft Design. Air Age Media Inc.
- Pilots Handbook of Aeronautical Knowledge. (2017). Federal Aviation Administration.
- Sadraey, M. H. (2013). *Aircraft Design - A systems Engineering Approach.* John Wiley & Suns.

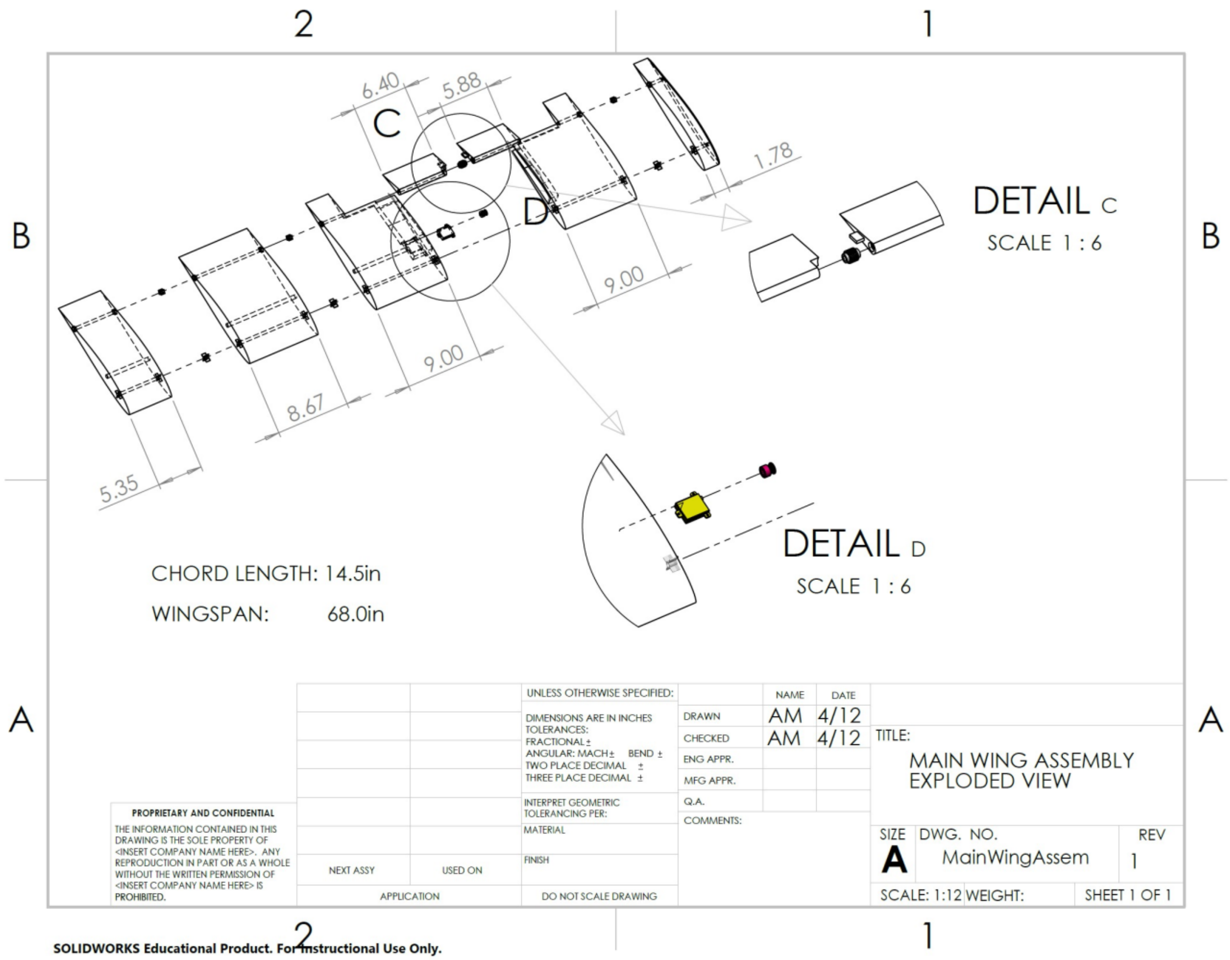
Furthermore, we recommend reading the SAE Aero Design rule book for the relevant year. All these books/papers and the rule book for 2020-2021 can be accessed using the following link to the books folder in T507 One Drive.

Appendix H: Engineering Drawings

H 1: Wind Tunnel CAD



H 2: Main Wing CAD



Appendix I: Calculations

- Note: As mentioned in the disclaimer, these calculations often work together, hence we recommend using them together as some data for calculations come from other files. MATLAB files for these calculations can be found in T507 OneDrive under Aerodynamic Calculations.

Calculations start from the next page.

I 1. CG position determination

Contents


```
clear all;
clc;
close all;
%Center of gravity calculation + componenet placement
%Sasindu Pinto
%All values in US units (in,lbf), unless otherwise specified

%References
%FOA - Fundamentals of Aerodynamics - John D. Anderson
%AD - Aircraft Design, A systems Engineering Approach - Mohhamad H. Sundraey

%profiles
%canard - E214
%aft (main) - E197
%tail - Epller 168
```

Standard Values (at Sea Level)

```
rho_ft=0.0023769;
rho=0.0023769/1728;    %slugs/ft3 / 1728 to get value in inches
```

Mass Values of the components of the plane(lbs)

```
%landing gear back complete = 288 g
%wheel = 65 g
%back base = 181 g
M_motor=1.07;
M_battery=1.29;
M_Prop=0.1875;%0.24
M_shell=10.53%8.92;  %From CAD;
M_total=M_battery+M_shell+M_motor+M_Prop;
M_LandingGear_R=((0.399037/2)+(2*0.1433));    %Rear leanding gear weight
M_LandingGear_F=M_LandingGear_R/2;  %front leanding gear weight
%Total weight of the plane
M_netTotal=M_total+M_LandingGear_F+M_LandingGear_R;
```

```
M_shell =

   10.5300
```

CG Position (Based on CG FBD)

```
%x values
x_motor=1+0.5;
x_shell=25.34;%27.37+5.35; %40.84 %36.42 from assembly
x_battery=9;
x_prop=-0.05;

%(CG x position)
CG_x=(M_battery*x_battery+M_motor*x_motor+M_shell*x_shell+M_Prop*x_prop)/M_total

%y values
y_motor=2.98+1%6.30*0.87-2.04;
y_shell=1.64;%6.30-3.08; %0.66
y_battery=2;

%(CG y position)
CG_y=(M_battery*y_battery+M_motor*y_motor+M_shell*y_shell+M_Prop*y_motor)/M_total
```

```
CG_x =

   21.4136


y_motor =

    3.9800


CG_y =

    1.9005
```

CG with Wheels (Wheel Positions using weight distribution)

```
%front landing gear x vlaue from CG
x_front=10;

%rear landing gear x vlaue from CG
x_backwheel=((2*M_total/10)*x_front)/(8*M_total/10)

%front landing gear x vlaue from leading edge of the plane
x_front_LE=CG_x-x_front
%reas landing gear x vlaue from leading edge of the plane
x_back_LE=CG_x+x_backwheel
```

```
x_backwheel =

    2.5000
```

```
x_front_LE =

   11.4136


x_back_LE =

   23.9136
```

Final CG - with landing gear + no cargo

center to center 18.5 in furthest distance 19.75 in top4+1/8 top distance 4.25in wheel width 1+1/8 wheel diameter 3 in height 12.5 in our height 9.5 in

```
%Height of the landing gear
LGHeight=9.5;

%CG x value
CG_x_wLG=(CG_x*M_total+x_front_LE*M_LandingGear_F+x_back_LE*M_LandingGear_R)/M_netTotal

% Landing gear y values
y_front_LE=12.3*0.87+(LGHeight/4);
y_back_LE=12.3*0.87+(3*LGHeight/5);

%CG y value
CG_y_wLG=(CG_y*M_total+y_front_LE*M_LandingGear_F+y_back_LE*M_LandingGear_R)/M_netTotal
```

```
CG_x_wLG =

   21.3255


CG_y_wLG =

    2.6078
```

Published with MATLAB® R2019b

I 2. Pitch Stability Calculations

Contents


```
clear all;
clc;
close all;
%Stability Calculations + Equilibrium Values
%Sasindu Pinto
%Values in US Units, (in,lbf) :

%References
%FOA - Fundamentals of Aerodynamics - John D. Anderson
%AD - Aircraft Design, A systems Engineering Approach - Mohhamad H. Sundraey
%AT - airfoiltools.com

%profiles
%canard - E214
%aft (main) - E197
%tail - Epller 168

%Load properties of wing profiles
load("E_214_Properties");
load("E197_Properties");
load("Eppler_168");
load("E_668");
```

Known Values

```
rho=0.0023769/1728;    %slugs/ft3 / 1728 to get value in inches

%Chord lengths
Chord_canard=12;
Chord_aft=14.5;   %Main wing
Chord_tail=8;

%Wing spans
Wingspan_canard=49;
Wingspan_aft=68;    %Main wing
Wingspan_tail=26.5;

%Maximum  thickness of each wing (Reference - AT)
thickness_max_canard=Chord_canard*0.111;
thickness_max_aft=Chord_aft*0.1349;
thickness_max_tail=Chord_tail*0.124;

%Velocity conversion to in/s
V_selected_in=25*17.6;

%Dynamic pressure in inches (Reference - FOA)
q=0.5*rho*V_selected_in^2;
```

```
%Aspect Ratio (Reference - FOA)
AR_canard=Wingspan_canard^2/(Chord_canard*Wingspan_canard);
AR_aft=Wingspan_aft^2/(Chord_aft*Wingspan_aft);
AR_tail=Wingspan_tail^2/(Chord_tail*Wingspan_tail);

%Characteristic Length for Lift (Reference - FOA)
S_canard=Chord_canard*Wingspan_canard;
S_aft=Chord_aft*Wingspan_aft;
S_tail=Chord_tail*Wingspan_tail;

%Characteristic Length for Drag (Reference - FOA)
T_canard=Chord_canard*thickness_max_canard;
T_aft=Chord_aft*thickness_max_aft;
T_tail=Chord_tail*thickness_max_tail;

%AoA = 5 deg, based on aero preformance (Reference - AT)
CL_canard=1.1167;  %at AoA
CL_aft=0.887;     %at AoA
CL_tail=0;

%AoA = 0 deg, (Reference - AT)
CL_canard_0AoA=0.6;
CL_aft_0AoA=0.35;
CL_tail_0=0;

%from Stability_File2 - CG positions
CG_x=21;%21.6;%21.6365;%28.3787%39.7086;
CG_y=1.9;%2.5889;
M_total=14;%13.62; %12.3 rounded up to 13;

%canard position from the CAD file
x_c=CG_x-(2.62+(0.25*Chord_canard));
y_c=5.71-CG_y;

%aft position from the CAD file
x_a=24.63+(0.25*Chord_aft)-CG_x;
y_a=CG_y-(1.43);

%tail position from the CAD file
x_t=35.53+4.1+(0.25*Chord_tail)-CG_x;
y_t=10+CG_y;

%canard L/D (Reference - AT)
L_c=E214_Prop(1:73,2)*q*S_canard;
D_c=E214_Prop(1:73,3)*q*T_canard;

%aft L/D (Reference - AT)
%L_a2=E197_Prop(1:73,2)*q*S_aft;
%D_a2=E197_Prop(1:73,3)*q*T_aft;
L_a=E197_Prop(1:73,2)*q*S_aft;
D_a=E197_Prop(1:73,3)*q*T_aft;
%tail L/D (Reference - AT)
L_t=Eppler_168(1:73,2)*q*S_tail;
D_t=Eppler_168(1:73,3)*q*T_tail;
```

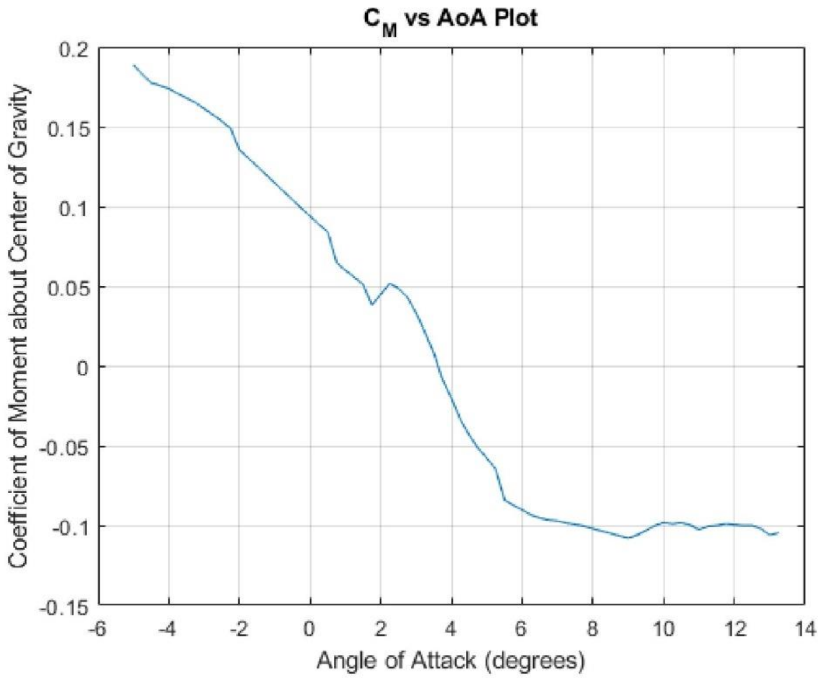
```
%moments (Reference - AT)
M_AC_C=E214_Prop(1:73,5)*q*S_canard*Chord_canard;  %canard
M_AC_M=E197_Prop(1:73,5)*q*S_aft*Chord_aft;  %main
%M_AC_M=E_668(1:73,5)*q*S_aft*Chord_aft;  %main
M_AC_T=Eppler_168(1:73,5)*q*S_tail;  %tail
```

Cm vs AoA plot (Reference - FOA)

```
alphaA=E214_Prop(1:73,1);   %AoA in deg
alphaR=E214_Prop(1:73,1)*pi/180;    %AoA in rad
%alphat=transpose(alpha);   %Tranpose of AoA (used for density plot)

%Moment about CG
M_CG=L_c*x_c + L_c.*(alphaR).*y_c - D_c*y_c + D_c.*(alphaR).*x_c - L_a*x_a - L_a.*alphaR.*
y_a...
    + D_a*y_a - D_a.*alphaR.*x_a - L_t*x_t - L_t.*alphaR.*y_t + D_t*y_t-D_t.*alphaR.*x_t..
.
    + M_AC_C + M_AC_M + M_AC_T;

%Coefficient of Moment about CG
C_M_CG = M_CG./(q*S_aft*Chord_aft);
figure(1)
plot(alphaA,C_M_CG)
title("C_M vs AoA Plot")
xlabel("Angle of Attack (degrees)")
ylabel("Coefficient of Moment about Center of Gravity")
grid on
```



equilibrium values (Reference - FOA)

```
CM_Eq=find(round(C_M_CG,1)==0)   %Equilibrium CM
AoA_Eq=alphaA(32,1) %Equilibrium AoA
CM_at_0=C_M_CG(21,1)     %CM at AoA = 0
C_L_trim=E197_Prop(32,2);    % CL for the main wing at equilibrium

% minimum speed required at equilibrium
V_trim=sqrt(2*M_total/(rho*S_aft*C_L_trim));     %Speed in in/s
V_trim_mph=V_trim/17.6  %Speed in mph
```

```
CM_Eq =

    28
    30
    31
    32
    33
    34
    35
    36
    37
    38


AoA_Eq =
```

```
     3

CM_at_0 =

    0.0939

V_trim_mph =

   10.2904
```

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I 3. Neutral Point Calculations

Contents


```
clear all;
clc;
close all;
%Finding the Neutral Point location
%Sasindu Pinto
%Values in US Units, (in,lbf) :

%References
%FOA - Fundamentals of Aerodynamics - John D. Anderson
%AD - Aircraft Design, A systems Engineering Approach - Mohhamad H. Sundraey
%AT - airfoiltools.com

%profiles
%canard - E214
%aft (main) - E197
%tail - Epller 168

%Load properties of wing profiles
load("E_214_Properties");
load("E197_Properties");
load("NACA_M2_Prop");
load("Eppler_168");
```

Known Values

```
rho=0.0023769/1728;    %slugs/ft3 / 1728 to get value in inches

%Chord lengths
Chord_canard=12;
Chord_aft=14.5;    %Main wing
Chord_tail=8;

%Wing spans
Wingspan_canard=49;
Wingspan_aft=68;    %Main wing
Wingspan_tail=26.5;

%Maximum  thickness of each wing (Reference - AT)
thickness_max_canard=Chord_canard*0.111;
thickness_max_aft=Chord_aft*0.1349;
thickness_max_tail=Chord_tail*0.124;

%Velocity conversion to in/s
V_selected_in=25*17.6;
```

```
%Dynamic pressure in inches (Reference - FOA)
q=0.5*rho*V_selected_in^2;

%Aspect Ratio (Reference - FOA)
AR_canard=Wingspan_canard^2/(Chord_canard*Wingspan_canard);
AR_aft=Wingspan_aft^2/(Chord_aft*Wingspan_aft);
AR_tail=Wingspan_tail^2/(Chord_tail*Wingspan_tail);

%Characteristic Length for Lift (Reference - FOA)
S_canard=Chord_canard*Wingspan_canard;
S_aft=Chord_aft*Wingspan_aft;
S_tail=Chord_tail*Wingspan_tail;

%Characteristic Length for Drag (Reference - FOA)
T_canard=Chord_canard*thickness_max_canard;
T_aft=Chord_aft*thickness_max_aft;
T_tail=Chord_tail*thickness_max_tail;

%AoA = 5 deg, based on aero preformance (Reference - AT)
CL_canard=1.1167;  %at AoA
CL_aft=0.887;     %at AoA
CL_tail=0;

%AoA = 0 deg, (Reference - AT)
CL_canard_0AoA=0.6;
CL_aft_0AoA=0.35;
CL_tail_0=0;

%from Stability_File2 - CG positions
CG_x=32.2919%28.3787%39.7086;
CG_y=3.0959;
M_total=11; %12.3;

%canard position from the CAD file
x_c=CG_x-(9.64+(0.25*Chord_canard));
y_c=5.71-CG_y;

%aft position from the CAD file
x_a=35.5+(0.25*Chord_aft)-CG_x;
y_a=CG_y-(1.43);

%tail position from the CAD file
x_t=54.54+(0.25*Chord_tail)-CG_x;
y_t=15.94+CG_y;

%Distance between mean aerodynamic centers of the canard and the main wing
MAC=x_a+x_c

%canard L/D (Reference - AT)
L_c=E214_Prop(1:73,2)*q*S_canard;
D_c=E214_Prop(1:73,3)*q*T_canard;

%aft L/D (Reference - AT)
L_a=E197_Prop(1:73,2)*q*S_aft;
D_a=E197_Prop(1:73,3)*q*T_aft;

%tail L/D (Reference - AT)
```

```
L_t=Eppler_168(1:73,2)*q*S_tail;
D_t=Eppler_168(1:73,3)*q*T_tail;


%moments (Reference - AT)
M_AC_C=E214_Prop(1:73,5)*q*S_canard*Chord_canard;  %canard
M_AC_M=E197_Prop(1:73,5)*q*S_aft*Chord_aft;  %main

M_AC_T=Eppler_168(1:73,5)*q*S_tail;  %tail
```

```
CG_x =

   32.2919


MAC =

   26.4850
```

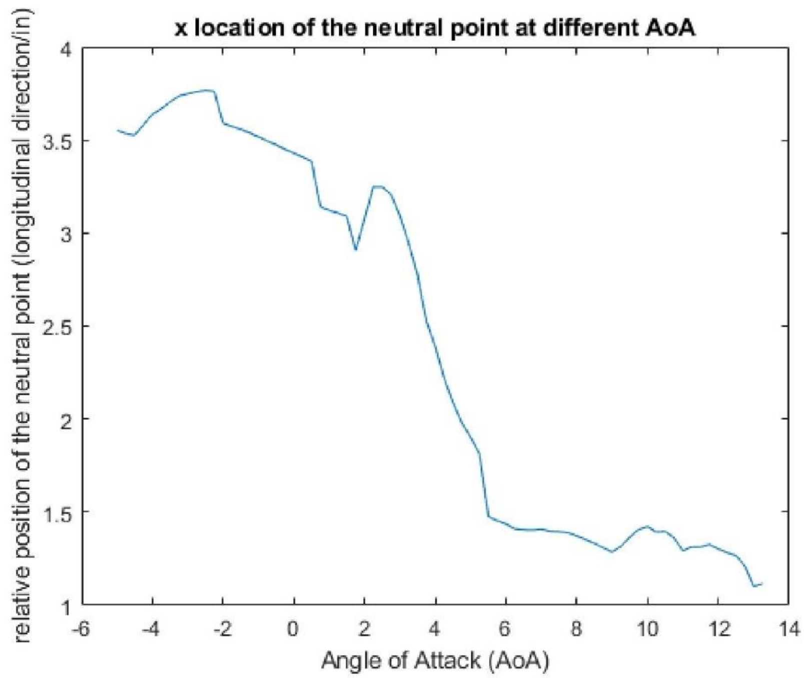
NP plot (Reference - FOA, AD)

```
alphaA=E214_Prop(1:73,1); %AoA in deg
alphaR=E214_Prop(1:73,1)*pi/180; %AoA in rad
%alphat=transpose(alpha); %Tranpose of AoA (used for density plot)

%denominator value of the NP equation
den_x_n=L_c + L_c.*(alphaR) - D_c + D_c.*(alphaR)- L_a - L_a.*alphaR...
    + D_a - D_a.*alphaR - L_t - L_t.*alphaR + D_t-D_t.*alphaR-M_total;

%Neutral Point (NP) Equaitons
x_n=(-1*(L_c*x_c + L_c.*(alphaR).*y_c - D_c*y_c + D_c.*(alphaR).*x_c - L_a*x_a - L_a.*alph
aR.*y_a...
    + D_a*y_a - D_a.*alphaR.*x_a - L_t*x_t - L_t.*alphaR.*y_t + D_t*y_t-D_t.*alphaR.*x_t..
.
    + M_AC_C + M_AC_M + M_AC_T))/(den_x_n);

figure(1)
plot(alphaA,x_n(:,73)) %NP location from CG (behind is positive)
title("x location of the neutral point at different AoA")
xlabel("Angle of Attack (AoA)")
ylabel("relative position of the neutral point (longitudinal direction/in)")
```



equilibrium values for the NP plot

```
trim_x_n=x_n(21,73) %NP location from CG (behind is positive) at 0 AoA
CG_to_NP_Ratio=trim_x_n/(MAC) %CG to NP distance vs MAC ratio - desired range is 10% to 15
%
```

```
trim_x_n =

    3.4294


CG_to_NP_Ratio =

    0.1295
```

Stability Margin

```
S_Margin=x_n(21,73)/Chord_aft;  %for canard planes - upto 25%
S_Margin2=x_n(21,73)/(x_a+x_c);
```

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I 4. Elevator Dimensioning/Operation Calculations

Contents


```
clear all;
clc;
close all;
%Control Surface Calculations - Elevator
%Sasindu Pinto
%All values in US units (in,lbf), unless otherwise specified

%References
%FOA - Fundamentals of Aerodynamics - John D. Anderson
%AD - Aircraft Design, A systems Engineering Approach - Mohhamad H. Sundraey
%AT - airfoiltools.com

%profiles
%canard - E214
%aft (main) - E197
%tail - Epller 168
```

Known Values

```
rho=0.0023769/1728;    %slugs/ft3 / 1728 to get value in inches

%Chord Lengths
Chord_canard=12;
Chord_aft=14.5;%14.5;
Chord_tail=8;
%15.8257
%Wingspans
Wingspan_canard=49;
Wingspan_aft=68%;75;
Wingspan_tail=26.5;

%Maximum thicknesses (Reference - FOA, AT)
thickness_max_canard=Chord_canard*0.111;
thickness_max_aft=Chord_aft*0.1349;
thickness_max_tail=Chord_tail*0.124;

%Characteristic Length for Lift
S_canard=Chord_canard*Wingspan_canard;
S_aft=Chord_aft*Wingspan_aft;
S_tail=Chord_tail*Wingspan_tail;

%Characteristic Length for Lift in ft
S_canard_ft=Chord_canard*Wingspan_canard/144;
S_aft_ft=Chord_aft*Wingspan_aft/144;
S_tail_ft=Chord_tail*Wingspan_tail/144;
```

```
%aft wing surface area (Reference - AD)
SA_aft=Wingspan_aft*Chord_aft;

%Velocity conversion to in/s
V_selected_in=25*17.6;

%Dynamic pressure in inches (Reference - FOA)
q=0.5*rho*V_selected_in^2;

%Aspect Ratio (Reference - FOA)
AR_canard=Wingspan_canard^2/(Chord_canard*Wingspan_canard);
AR_aft=Wingspan_aft^2/(Chord_aft*Wingspan_aft);
AR_tail=Wingspan_tail^2/(Chord_tail*Wingspan_tail);

%Semi-wingspan (Reference - AD)
Wingspan_semi_aft=(70-12.6)/2;
```

```
Wingspan_aft =

    68
```

Elevator Properties (Reference - AD)

```
Elevator_to_Tail_SpanRatio=1;   %ratio between elevator and tail wing span
Elevator_to_TailChordRatio=0.4; %ratio between elevator and tail wing chord
Elevator_def_max=25*pi/180; %max elevator deflection desired

pitch_ang_acc=10;   %deg/sec^2  %angular acceleration of elevation (Ref-AD)
e=0.88  %efficiency - typical value at sea level (Ref - AD)
```

```
e =

    0.8800
```

Elevator Proportions

```
Elevator_span=Elevator_to_Tail_SpanRatio*Wingspan_tail  %elevator span
Elevator_chord=Elevator_to_TailChordRatio*Chord_tail %elevator chord length
S_Elevator=Elevator_chord*Elevator_span;    %elevator surface area

%surface area ratio between tail and elevator
S_ratio_elevator_to_tail=S_Elevator/S_tail;
```

```
Elevator_span =

   26.5000
```

```
Elevator_chord =

    3.2000
```

Elevator Calculations

```
%K=1/(pi*e*AR);
%Inertia_Yaw=
```

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I 5. Roll Stability/Aileron Calculations

Contents


```
clear all;
clc;
close all;
%Control Surface Calculations: Aileron
%Sasindu Pinto
%Values in US Units, (in,lbf) :

%References
%FOA - Fundamentals of Aerodynamics - John D. Anderson
%AD - Aircraft Design, A systems Engineering Approach - Mohhamad H. Sundraey
%AT - airfoiltools.com

%profiles
%canard - E214
%aft (main) - E197
%tail - Epller 168
```

Known Values

```
rho=0.0023769/1728;    %slugs/ft3 / 1728 to get value in inches

%Chord lengths
Chord_canard=12;
Chord_aft=14.5;    %Main wing
Chord_tail=8;

%Wing spans
Wingspan_canard=5049;
Wingspan_aft=68;     %Main wing
Wingspan_tail=26.5;

%Maximum  thickness of each wing (Reference - AT)
thickness_max_canard=Chord_canard*0.111;
thickness_max_aft=Chord_aft*0.1349;
thickness_max_tail=Chord_tail*0.124;

%Coefficient of Lift - AoA at 4.25 deg
CL_Eq_canard=1.0426;
CD_Eq_canard=0.0072;
CL_Eq_aft=0.8171;
CD_Eq_aft=0.0064;
CL_Eq_tail=0.4639;
CD_Eq_tail=0.0070;

%Characteristic Length for Lift (Reference - FOA)
S_canard=Chord_canard*Wingspan_canard;
S_aft=Chord_aft*Wingspan_aft;
```

```
S_tail=Chord_tail*Wingspan_tail;

%aft wing surface area
SA_aft=Wingspan_aft*Chord_aft;

%Velocity conversion in/s
V_selected_in=25*17.6;

%Dynamic pressure (Reference - FOA)
q_selected=0.5*rho*V_selected_in^2;

%Aspect Ratios (Reference - FOA)
AR_canard=Wingspan_canard^2/(Chord_canard*Wingspan_canard);
AR_aft=Wingspan_aft^2/(Chord_aft*Wingspan_aft);
AR_tail=Wingspan_tail^2/(Chord_tail*Wingspan_tail);
```

Aileron Proportions (Reference - AD)

```
%Total aileron span using ratio between main wing and aileron span
Aileron_span_total=0.35*Wingspan_aft %0.2-0.3 desired ratio
Aileron_chord=3;%3.18%0.25*Chord_aft %Aileron chord

%Aileron span with respect fuselage size
Aileron_spanToFuselage_Total=0.6*Wingspan_aft %0.6-0.8 desired ratio

Aileron_span=12.25;%Aileron_span_total/2   %span of one aileron
Aileron_spanToFuselage=15.25;%Aileron_spanToFuselage_Total/2   %positon of the aileron wrt
 fuselage
Aileron_SurfaceArea=Aileron_span*Aileron_chord; %aileron surface area
Ratio_aileronSA_WingSA=Aileron_SurfaceArea/SA_aft %Surface area ratio
```

```
Aileron_span_total =

   23.8000


Aileron_spanToFuselage_Total =

   40.8000


Ratio_aileronSA_WingSA =

    0.0373
```

Aileron Moment Calculations (Reference - AD)

```
%Maximum aileron deflection in rad
AileronDefMax=20*pi/180;

%Minumum aileron deflection in rad
AileronDefMin=8*pi/180;
```

```
tau=0.46;    %for 0.25 chord ratio between aileron and aft wing

%Aileron coefficient of lift
CLa=2*CL_Eq_aft*tau*Chord_aft*(Aileron_chord)/(S_aft*Wingspan_aft);     %per radians

%Aileron coefficient of lift at maximum deflection
CL_aileron=CLa*AileronDefMax

%Aircraft rolling moment
L_Aileron=q_selected*S_aft*CL_aileron*Wingspan_aft;

y_d=0.4*Wingspan_aft*0.5+6.3;    %location of the aileron drag from cg
S_verticalTail=44.83+189.77; %Vertical tail section surface area

S_Total=S_verticalTail+S_tail+S_aft;     %Total tail surface area

%Coeffient of drag from fuselage effecting aileron
CD_R=1.2;    %0.7-1.2 - drag contribution from fuselage

%Steady state(SS) roll rate
P=sqrt(2*L_Aileron/(rho*S_Total*CD_R*y_d^3));

%Moment of inertia from the CAD
Izz=9582.08;    %in longitudinal axis, in inches^2

%Steady state banking angle
Bank_angle=(Izz/(rho*y_d^3*S_Total*CD_R))*log(P^2);
Actual_angle=(round(Bank_angle/pi)*pi-Bank_angle)*180/pi;

%roll rate (rate at which the aircraft rolls)
P_rate=P^2/(2*Bank_angle)
```

```
CL_aileron =

   1.7024e-04


P_rate =

  -8.7473e-05
```

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I 6. Yaw Stability/Rudder Calculations

Contents


```
clear all;
clc;
close all;
%Control Surface Calculations - Rudder
%Sasindu Pinto
%Values in SI Units, (m,N) unless otherwise specified

%References
%FOA - Fundamentals of Aerodynamics - John D. Anderson
%AD - Aircraft Design, A systems Engineering Approach - Mohhamad H. Sundraey
%AT - airfoiltools.com

%profiles
%canard - E214
%aft (main) - E197
%tail - Epller 168
```

Known Values

```
rho=0.0023769/1728;    %slugs/ft3 / 1728 to get value in inches
rho_SI=1.225;   %density in SI

Weight_Plane = 14;
%Chord lengths
Chord_canard=12;
Chord_aft=14.5;   %Main wing
Chord_tail=8;

%Wing spans
Wingspan_canard=49;
Wingspan_aft=68;    %Main wing
Wingspan_tail=26.5;

%Maximum  thickness of each wing in US units (Reference - AT)
thickness_max_canard=Chord_canard*0.111;
thickness_max_aft=Chord_aft*0.1349;
thickness_max_tail=Chord_tail*0.124;

%Characteristic Length for Lift in SI
S_canard=Chord_canard*Wingspan_canard/(39.37*39.37);
S_aft=Chord_aft*Wingspan_aft/(39.37*39.37);
S_tail=Chord_tail*Wingspan_tail/(39.37*39.37);

%Characteristic Length for Lift in US units
S_canard_ft=Chord_canard*Wingspan_canard/144;
```

```
S_aft_ft=Chord_aft*Wingspan_aft/144;
S_tail_ft=Chord_tail*Wingspan_tail/144;


%Velocity conversion to m/s
V_selected=25/2.237;

%Dynamic pressure in SI (Reference - FOA)
q=0.5*rho*V_selected^2;

% tail height in US units
Tail_h_span=10;

% Aircraft cross sectional area (area felt by a cross wind)
Aircraft_Side_area=(3444.42+7.23+6.18)/(39.37*39.37);

%Fuselage drag for crosswing (Reference-AD)
C_D_fuselage_side=0.8;   %Typical value for fuselage side drag (0.6-0.8)

%Typical coefficients for rotation (Reference - AD)
d_c=1;
C_n_beta=0.1     %1/rad
C_n_R=-0.08      %1/rad
C_y_beta=-0.6    %1/rad
C_y_R=0.15       %1/rad
```

```
C_n_beta =

    0.1000


C_n_R =

   -0.0800


C_y_beta =

   -0.6000


C_y_R =

    0.1500
```

Rudder Design Proportions (Reference - AD)

```
%Space above rudder
Space_top=1.5; %3 in for 30 deg elevator deflection + extra space for errors
space_bottom=1.5;
Span_rudder=Tail_h_span-Space_top-space_bottom; %Rudder span
SpanRatio=Span_rudder/Tail_h_span  %%Rudder vs tail span ratio
ChordRatio=0.3   %Desired rudder vs tail chord ratio (Ref- AD)
```

```
Rudder_Chord=ChordRatio*Chord_tail/39.37;    %Rudder chord in SI
Rudder_Chord_in=Rudder_Chord*39.37;
S_rudder=Rudder_Chord*Span_rudder/(39.37);  %Rudder surface area in SI
```

```
SpanRatio =

    0.7000


ChordRatio =

    0.3000
```

Cross Wind Control (Reference -AD)

```
%avg wind speed in Lakeland,FL is 9.6 mph, rounded up to 10 mph
Cross_V_expected=30/2.237;   %in SI

%Force due to cross wind on the plane (Reference -AD)
F_Wind=0.5*rho_SI*Cross_V_expected^2*Aircraft_Side_area*C_D_fuselage_side;

%angle between the forward direction (desired) and cross wind
beta_wind=atan(Cross_V_expected/V_selected);

%Net Speed
V_T=sqrt(Cross_V_expected^2+V_selected^2);

%sigma - thrust to V_T angle
%beta- rudder deflection

%Using symbolic toolbox to solve for sigma and beta
syms beta sigma

eqn1 = 0.5*rho_SI*V_T^2*S_aft*Wingspan_aft*(C_n_beta*(beta_wind-sigma)+C_n_R*beta)+(F_Wind
*d_c*cos(sigma)) == 0;
eqn2 = 0.5*rho_SI*Cross_V_expected^2*S_rudder*Aircraft_Side_area == 0.5*rho_SI*V_T^2*S_aft
*(C_y_beta*(beta_wind-sigma)+C_y_R*beta);

sol = solve([eqn1, eqn2], [beta,sigma]);

u1_Sol = vpa(sol.beta)
u2_Sol = vpa(sol.sigma)

%Rudder deflection expected to account for the cross wind
Rudder_def = u1_Sol*180/3.1416

%The angle the plane land at for a 10mph cross wind
sigma_req = u2_Sol*180/3.1416
```

```
Warning: Unable to solve symbolically. Returning a numeric solution using <a
href="matlab:web(fullfile(docroot, 'symbolic/vpasolve.html'))">vpasolve</a>.
```

```
u1_Sol =

0.22150987746034262199768404765363


u2_Sol =

0.85806809538951246907132675540926


Rudder_def =

12.691551420569668945627428246006


sigma_req =

49.163565434846016180557300730095
```

Landing Performance (Reference - FOA)

```
%time spent to get down to runway
landing_time=31.37/(V_T*sind(5)*1.467);

%horizontal distance traveled during that time
landing_distance_approach=V_T*cosd(5)*1.467*landing_time;

%deceleration of the plane
deceleration=31.3669/Weight_Plane;

%time to come to a stop
time_V_zero=25*1.467/deceleration;

%distance traveled
distance_traveled=25*1.467*time_V_zero-0.5*deceleration*time_V_zero^2
```

```
distance_traveled =

  300.1696
```

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I 7. Performance Calculations

Contents


```
clear all;
clc;
close all;
%Take off speed and thrust calculations
%Sasindu Pinto
%All values in US units (in,lbf), unless otherwise specified

%References
%FOA - Fundamentals of Aerodynamics - John D. Anderson
%AD - Aircraft Design, A systems Engineering Approach - Mohhamad H. Sundraey

%profiles
%canard - E214
%aft (main) - E197
%tail - Epller 168

%Known constants
rho_ft=0.0023769;
rho=0.0023769/1728;    %slugs/ft3 / 1728 to get value in inches
```

Take off Speed Required

```
Weight_Plane=14;%13.62; %12.316 % Max weight of the plane (rounded up to next whole number
)

%Chord Lengths
Chord_canard=12;
Chord_aft=14.5;%14.5;
```

```
Chord_tail=8;
%15.8257
%Wingspans
Wingspan_canard=49;
Wingspan_aft=68%;75;
Wingspan_tail=26.5;

%Aspect Ratios (Reference - FOA)
AR_canard=Wingspan_canard^2/(Chord_canard*Wingspan_canard);
AR_aft=Wingspan_aft^2/(Chord_aft*Wingspan_aft);
AR_tail=Wingspan_tail^2/(Chord_tail*Wingspan_tail);

%Characteristic Length for Lift
S_canard=Chord_canard*Wingspan_canard;
S_aft=Chord_aft*Wingspan_aft;
S_tail=Chord_tail*Wingspan_tail;

%Characteristic Length for Lift in ft
S_canard_ft=Chord_canard*Wingspan_canard/144;
S_aft_ft=Chord_aft*Wingspan_aft/144;
S_tail_ft=Chord_tail*Wingspan_tail/144;

%Coefficient of Lift - AoA = 5 %deg, based on L/D plots
CL_canard=1.1174;
CL_aft=0.8925;
CL_tail=0.6417;

CL_canard_0AoA=0.6;  %at AoA = 0
CL_aft_0AoA=0.35;   %at AoA = 0
CL_tail_0AoA=0;   %at AoA = 0

%Coefficient of Lift - AoA at 3.125 deg
% CL_Eq_canard=0.93595;
% CD_Eq_canard=0.00675;
% CL_Eq_aft=0.68385;
% CD_Eq_aft=0.00605;
% CL_Eq_tail=0.34155;
% CD_Eq_tail=0.00785;

%Coefficient of Lift - AoA at 4.25 deg
CL_Eq_canard=1.0426;
CD_Eq_canard=0.0072;
CL_Eq_aft=0.8171;
CD_Eq_aft=0.0064;
CL_Eq_tail=0.4639;
CD_Eq_tail=0.0070;
```

```
Wingspan_aft =

    68
```

Take off speed (minimum required) (Reference - FOA)

```
%denominator_q=(CL_canard*S_canard)+(CL_aft*S_aft) + (CL_tail*S_tail);
denominator_q=(CL_aft*S_aft);
q=Weight_Plane/denominator_q;
V=sqrt(q*2/rho)
V_mph=V/17.6    %Take off speed in mph
```

```
V =

  152.0908


V_mph =

    8.6415
```

Thrust converstions

```
lbs_thrust=3452/454;
thrust_lb=lbs_thrust*32.174
```

```
thrust_lb =

  244.6358
```

Thrust from tests

```
Thrust_From_test1=6.916*32.17
Thrust_From_test2=thrust_lb*32.17
```

```
Thrust_From_test1 =

  222.4877


Thrust_From_test2 =

   7.8699e+03
```

Thrust Required (Reference - FOA)

```
V_selected_in=25*17.6;    % selected 25 mph takeoff speed in in/s
V_selected_ft=25*1.467;   % takeoff speed in ft/s
q_selected=0.5*rho_ft*V_selected_ft^2; % corresponding dynamic pressure
q_selected_in=0.5*rho*V_selected_in^2; % corresponding dynamic pressure (in)
S_takeoff=100; %ft
```

```
%acceleration required (minimum), ft/sec^2
a_ft=V_selected_ft^2/(2*S_takeoff)
t_takeoff=sqrt(2*S_takeoff/a_ft)    %takeoff time
Thrust_req=Weight_Plane*V_selected_ft/t_takeoff % minimum thrust required
```

```
a_ft =

    6.7253


t_takeoff =

    5.4533


Thrust_req =

   94.1539
```

Reynolds # Calculations (Reference - FOA)

```
mu=3.734*10^(-7) %viscosity
Re_aft=(rho_ft*V_selected_ft*S_aft_ft)/(mu); %Re # for main wing
Re_canard=(rho_ft*V_selected_ft*S_canard_ft)/(mu) ; %Re # for canard
Re_tail=(rho_ft*V_selected_ft*S_tail_ft)/(mu) ; %Re # for tail wing
```

```
mu =

   3.7340e-07
```

Drag Calculations - Skin Friction (Reference - AD)

```
C_f_aft=0.074/(Re_aft^(1/5));    %skin friction drag coef. for aft
C_f_canard=0.074/(Re_canard^(1/5));    %skin friction drag coef. for canard
C_f_tail=0.074/(Re_tail^(1/5));    %skin friction drag coef. for canard
D_f=2*q_selected*C_f_aft*(S_aft) + 2*q_selected*C_f_canard*(S_canard) ...
    + 2*q_selected*C_f_tail*(S_tail); % skin friction drag
```

Drag Calculations - Profile (Reference - FOA)

```
D_canard = CD_Eq_canard*q_selected*S_canard_ft; %Canard drag
D_aft = CD_Eq_aft*q_selected*S_aft_ft; %Main wing drag
D_tail = CD_Eq_tail*q_selected*S_tail_ft; %Tail wing drag
```

Drag Calculations - Induced (Reference - AD) (Reference - FOA)

```
e_lowmid=0.6;    %low/mid wing efficiency
e_high=0.8;      %high wing efficiency

%canard induced drag coefficient
Cd_i_canard=CL_Eq_canard^2/(pi*e_lowmid*AR_canard);
%main wing induced drag coefficient
Cd_i_aft=CL_Eq_aft^2/(pi*e_high*AR_aft);
%tail wing induced drag coefficient
Cd_i_tail=CL_Eq_tail^2/(pi*e_high*AR_tail);

D_i_canard=Cd_i_canard*q_selected*S_canard_ft; %canard induced drag
D_i_aft=Cd_i_aft*q_selected*S_aft_ft; %main wing induced drag
D_i_tail=Cd_i_tail*q_selected*S_tail_ft; %tail wing induced drag

%Total drag of the plane
D_Total= D_f + D_canard + D_aft + D_tail + D_i_aft + D_i_canard +D_i_tail
```

```
D_Total =

   27.9164
```

Lift Calculations - Equilibrium (Reference - FOA)

```
%Lift produced by each wing at equilibrium
L_canard=CL_Eq_canard*q_selected*S_canard_ft;
L_aft=CL_Eq_aft*q_selected*S_aft_ft;
L_tail=CL_Eq_tail*q_selected*S_tail_ft;


L_total_Eq=L_canard+L_aft+L_tail    %Total Lift
```

```
L_total_Eq =

   16.8407
```

Lift Calculations - Takeoff (Reference - FOA)

```
%Lift produced by each wing at equilibrium
L_canard_to=CL_canard*q_selected*S_canard_ft;
L_aft_to=CL_aft*q_selected*S_aft_ft;
L_tail_to=CL_tail*q_selected*S_tail_ft;

L_total_to=L_canard_to+L_aft_to+L_tail_to    %Total Lift

thrust_net=Thrust_From_test1-D_Total;
```

```
L_total_to =
```

18.5727

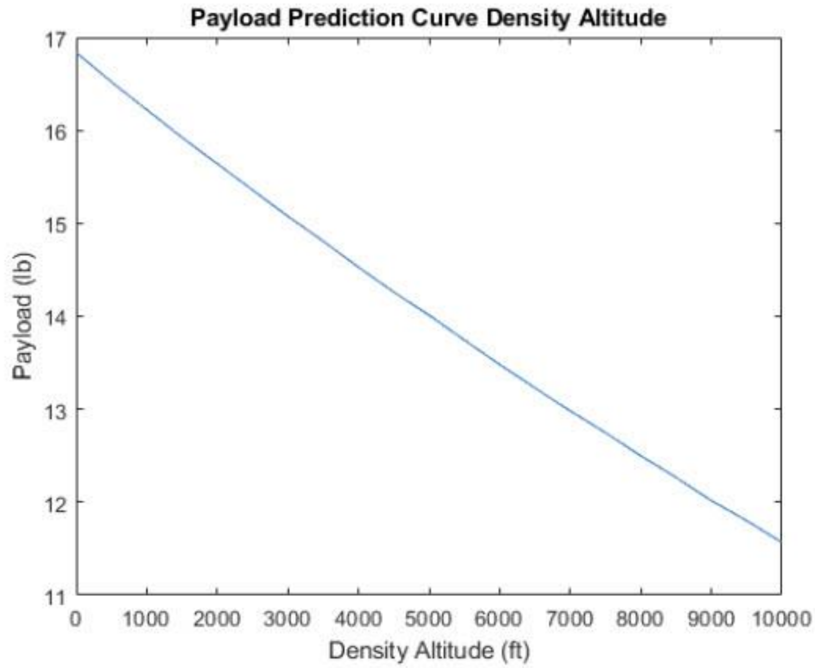
Lift Calculations - ZeroDeg (Reference - FOA)

```
%Lift produced by each wing at equilibrium
L_canard_0=CL_canard_0AoA*q_selected*S_canard_ft;
L_aft_0=CL_aft_0AoA*q_selected*S_aft_ft;
L_tail_0=CL_tail_0AoA*q_selected*S_tail_ft;

L_total_0=L_canard_0+L_aft_0+L_tail_0   %Total Lift
```

```
L_total_0 =

    7.7473
```

Payload Prediction (Reference - FOA, Rule book)

```
pressure=[101.3, 99.4, 97.6, 95.8, 94.1, 92.4, 90.7, 89.1, 87.4, 85.8, ...
    84.3, 82.7, 81.1, 79.6, 78.1, 76.7, 75.2, 73.8, 72.3, 71, 69.6]; %in KPa
altitude=[0:500:10000];
%altitude_transpose=transpose(altitude)
p=pressure.*(10^3).*0.020885434273039; % in lb/ft^2
density=p./(1716.49*518.67); %in slug/ft^3
W_prediction=(CL_Eq_aft*S_aft_ft+CL_Eq_canard*S_canard_ft+...
    CL_Eq_tail*S_tail_ft).*(0.5.*density.*(V_selected_ft^2));
%w_trans=transpose(W_prediction);
plot(altitude,W_prediction)
xlabel("Density Altitude (ft)")
ylabel("Payload (lb)")
title("Payload Prediction Curve Density Altitude")
%Final Plot was done in Excel
```



Properties at takeoff (Reference - FOA)

```
%Acceleration
acceleration_to = (Thrust_From_test1-D_Total)/(Weight_Plane);
%time to get to 25 mph
time_req_acc = V_selected_ft/acceleration_to;
%distance travelled
distance_travelled = V_selected_ft^2/(2*acceleration_to);
```

Flying altitude properties (assuming 400 ft from the start)

```
%Climb time
time_climb=(400-distance_travelled)/(V_selected_ft*cosd(5));
%Altitude
altitude=V_selected_ft*sind(5)*time_climb;
```

Ground effect calculations

```
%Thrust in N
thrustN=222.6358*4.44822;
%Velocity in m/s
V_inSI=25/2.237;

mass_flow_rate=thrustN/V_inSI;  %mass flow rate, in kg/s

%Properller properties in SI units
```

```
pitch_in_meters=10/39.37;
diameter_in_meters=18/39.37;

%Time taken for one revolution
time_one_rot=pitch_in_meters/V_inSI;
%Angular velocity
angularVel=2*pi/time_one_rot;
%Mass flowrate during takeoff
mass_flow_rate_to=thrust_net*4.44822/V_inSI;
```

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Appendix J: Risk Assessment

J 1. Project Hazard Assessment

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

INTRODUCTION

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

PROJECT HAZARD ASSESSMENT POLICY

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

PROJECT HAZARD ASSESSMENT PROCEDURES

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

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

a. Performing periodic laboratory visits to prevent the development of unsafe practice.
b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.
c. Assigning a safety representative to assist in implementing the expectations.
d. Etc.

8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor: Shayne McConomy	Phone #: 850 410-6624	Dept.: ME	Start Date: 11/1/2020	Revision number:1
Project: T507 SAE Aero Design Competition East – Aero Propulsions			Location(s): Senior Design Lab	
Team member(s): Sasindu Pinto, Noah Wright, Cameron Riley, Michenell Louis-Charles, Adrian Moya			Phone #: 850-300-1546	Email: sp18dy@my.fsu.edu

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Thrust Test: Connecting Components	Senior Design Lab	Cameron Riley	Electrical components malfunctioning and shocking someone	Connect the battery at the end Use ESC and power limiter	Rubber Gloves	N/A	HAZARD:3 CONSEQ: Moderate Residual: Medium	•A written Project Hazard Control, approved by the PI. A copy sent to the Safety Committee. •A second worker must be present •Limit the number of authorized workers
Propeller Attachment	Senior Design Lab	Michenell Louis-Charles	Propeller is not secured	Use plyers to tighten bolts	Safety Glasses	N/A	HAZARD:2 CONSEQ: Negligible Residual: Low	•Safety controls are planned by both the worker and supervisor. •Proceed with supervisor authorization.

Powering Motor	Senior Design Lab	Noah Wright	Propeller hitting someone	Clear test area	Safety Glasses	N/A	HAZARD:3 CONSEQ: Significant Residual: Med High	•A written Project Hazard Control, approved by the PI. A copy sent to the Safety Committee. •A second worker must be present •Limit the number of authorized workers
Deconstruct Testing Materials	Senior Design Lab	Cameron Riley	Live wires with the propeller still connected	Disconnect battery first	Gloves & Glasses	N/A	HAZARD:2 CONSEQ: Minor Residual: Low Medium	•Safety controls are planned by both the worker and supervisor. •A second worker must be present •Proceed with supervisor authorization.
Wind Tunnel Test	Florida Center for Advanced Aero-Propulsion	Michenell Louis-Charles	Wind Tunnel Malfunction	AME supervisor proctoring test, Wind Tunnel Fail-Safe System	Safety Goggles	N/A	HAZARD:2 CONSEQ: Minor Residual: Low Medium	•Safety controls are planned by both the worker and supervisor. •A second worker must be present •Proceed with supervisor authorization.

J 2. Project Hazard Control

Project Hazard Control- For Projects with Medium and Higher Risks

Name of Project: SAE Aero Design – Aero Team		**Date of submission:** 12/04/2020
Team member	**Phone number**	**e-mail**
Sasindu Pinto	850 300 1546	sp18dy@my.fsu.edu
Noah Wright	310 463 7149	Ntw16@my.fsu.edu
Cameron Riley	407 913 1485	Cameron1.riley@famu.edu
Adrian Moya	305 587 8054	Am16bg@my.fsu.edu
Michnell Louis-Charles	321 337 5137	Michenell1.louischar@famu.edu
Faculty mentor	**Phone number**	**e-mail**
Dr. McConomy	850 410 6624	smcconomy@eng.famu.fsu.edu

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

While attaching the propeller, the system was turned off. When the equipment was being connected, rubber gloves were worn. Safety goggles were worn while powering on the motor from a safe distant with the remote. The power was then disconnected first as the parts were disassembled.

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

If someone was shocked by equipment: First-aid if necessary, Contact Medical Services
If someone was cut by the propeller: First-aid if necessary, Contact Medical Services

List emergency response contact information:

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

Name	Phone number	Faculty or other COE emergency contact	Phone number
Yamuna Peiris	+94714050190	Dr. McConomy	850 410 6624
Kelly Keith	714 686 6226	FSU Police – Emergency Management	850 644 1234
Deona Riley	407 430 3142		
Zulyn H.-Moya	786 326 8258		
Edeline Dardignac	407 914 3910		

Safety review signatures

Team member	Date	Faculty mentor	Date

[illegible]	12/1/20	Dr. McConomy	
N Wright	12/1/20		
C Riley	12/1/20		
Adrian Moya	12/1/20		
[illegible]	12/1/20		

Report all accidents and near misses to the faculty mentor.