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EML4551-2

Team 513: SAE Aero Design

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Abstract

Radio controlled (RC) airplanes provide a way to push the boundaries of airplane design. The Society of Automotive Engineers (SAE) Aero Design competition is an event for college students that challenge them with designing an RC airplane fit to carry out a task. In 2020, the competition wants teams to build a short takeoff and landing airplane. We met these requirements by designing an airplane that can carry a size five soccer ball, one pound of cargo, and takeoff within 100 feet. The design features a 6-foot wing that slides through the fuselage and a 3D printed internal structure and external skin. A unique swinging hatch allows for front-loading the cargo bay. The team's 5.5-foot-long, 15-pound airplane is mostly constructed out of light weight PLA filament, a 3D printing material. This material is 50% less dense than regular PLA filaments. The lightweight filament reduces the total weight of the airplane to increase its performance. 3D printing also allowed the team to create the airplane in modular parts. Modular parts make it easier to repair and assemble than a traditional RC airplane. Our focus at competition was to showcase this innovative approach to design and manufacture an RC airplane with as much additive manufacturing as possible.

Keywords: 3d printing, additive manufacturing, aeronautics, design.

Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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FSGC	Florida Space Grant Consortium
SAE	Society of Automotive Engineers

Chapter One: EML 4551C

1.1 Project Scope

The objective of this project is to design and manufacture a 3D printed remote controlled (RC) airplane that complies with all rules and regulations for competing in the regular class of the Eastern SAE Aero Design competition. The team is tasked with manufacturing the airplane out of as much 3D printed material as possible and to take off within the designated runway while carrying the predetermined cargo. A comparison of the pros and cons of a 3D printed plane to planes that are manufactured out of other materials will be conducted throughout the duration of the project.

The team assigned to this project is comprised of seniors majoring in Mechanical and Electrical Engineering at the FAMU-FSU College of Engineering who will complete the project up to the point of building a prototype and attending the competition in the spring. The following section defines the scope for the project.

1.1.1 Project Description

The objective of this project is to design and manufacture a 3D printed remote controlled (RC) airplane that complies with all rules and regulations for competing in the regular class of the SAE Aero Design East Competition. .

1.1.2 Key Goals

In this section, details for a successful 3D printed airplane in the Eastern SAE Aero Design competition are listed. All the goals below were chosen to comply with the SAE Aero. Design rules book. Per the rules book, the airplane is expected to be able to successfully take off and land from a short runway while transporting multiple forms of cargo. The following key goals were determined:

- The plane's primary construction material is 3D printed filament.
- The plane can take off within the designated runway length.
- The plane can land within the designated landing area.
- The plane can operate effectively while carrying the designated payload.
- The plane has an easily accessible cargo area that minimizes loading and unloading time.
- The plane is easily controllable while in flight.
- The plane can withstand environmental conditions.
- The plane may be printed on a standard FFF 3D printer.
- The plane is affordable in relation to comparable off-the-shelf models.
- The plane is easily transportable by parts or as a whole.
- The plane is easy to assemble for a moderate level hobbyist.
- The plane can easily be repaired using modular construction.

1.1.3 Market

The airplane is designed for competitive purposes in the SAE Aero Design East competition. The airplane will be judged by officials based on its performance and adherence to the rules, which will be translated into a score and ranked against other teams.

However, upon completion of the project the RC airplane community may desire to learn about the design and manufacturing process of a 3D printed RC airplane. The following markets were identified for the airplane: The primary, secondary, and tertiary markets are the SAE Aero

Design competition judges, the team members, and the 3D printing community, respectively. The quaternary market is the RC model airplane community. Overall, the airplane has the potential to show the aerospace industry how 3D printing may be used for applications that were previously discounted.

1.1.4 Assumptions

The expected outcome of this project is to compete at the SAE Aero Design East competition. The following assumptions were made regarding the design and use of the RC airplane:

- The airplane will fly under earth conditions like gravity, temperature and pressure.
- The airplane will be mainly used for competition purposes.
- The airplane will adhere to all 2020 SAE Aero Design East rules.
- The airplane will be remotely operated by only one person.
- The airplane will be constructed of modular pieces.
- The airplane does not have to be 100% 3D printed.
- Electronics such as servo motors and batteries will be purchased off the shelf rather than custom made.
- Purchasable prefabricated parts will be used where applicable.
- The airplane will be able to fly under normal weather conditions.

1.1.5 Stakeholders

The stakeholders for this project are the team sponsor and advisor: Dr. McConomy, Dr. Shih, and Dr. Hooker. The team sponsor and advisor have dedicated their time to ensure that the team has all resources, materials, and guidance to produce a successful 3D printed remote controlled airplane that is competition ready. Moreover, the team's sponsor, and advisor have applied for a grant from the Florida Space Grant Consortium (FSGC). Therefore, the FSGC is a stakeholder invested in the success of the team's project. The sponsor, advisor, and team will continue seeking additional funding sources. Outside of the contacts provided, the team will communicate with the Seminole RC Club as well as personnel in the College of Engineering machine shop for additional mentoring.

1.2 Customer Needs

The customers' needs are paramount to the design of the RC airplane. However, the airplane is built for the purpose of competing in the SAE Aero Design competition; therefore, the customers are the judges of the competition. The judges of the competition operate according to the rule book for the event; thus, the rule book will be regarded as the primary customer. Within the rule book are guidelines and design constraints pertaining to the airplane (SAE International, 2020). These constraints were gathered from the rule book and are referred to as the customer statements, while the team's conclusions of each will be referred to as the interpreted need. The gathered information from the rule book is presented below in Table 1.

Table 1

SAE Rule book Customer Needs Interpretation

Question/Prompt	Customer Statement	Interpreted Need
General Aircraft Requirements	Competing designs are limited to fixed wing aircraft only.	The aircraft has fixed wings.

	All aircraft must be flyable at their designated empty center of gravity position on the submitted 2D aircraft drawing.	The aircraft can fly with no payload and the center of gravity mark is marked on the airplane.
	The aircraft gross take-off weight may not exceed fifty-five (55) pounds.	The aircraft is fifty-five pounds max.
	The aircraft's wingspan cannot exceed 120in.	The wingspan of the aircraft is limited to a maximum of 120in.
	All aircraft must be controllable in flight.	The aircraft is controllable when it is operated.
	The aircraft may not rely solely on aerodynamic control surfaces for ground steering.	The aircraft turns through other means other than the aerodynamic control surfaces when on the ground.
	The aircraft must be identified with school name, mailing address and email address	The aircraft has school name, mailing address, and email address on it.
	The team numbers must be at least 3 inches height	The team number is at least 3 inches in height and is visible on the outside of the aircraft.
	The aircraft must only be powered by the motor on board the aircraft.	No other internal and/or external forms of stored potential energy can be used besides the motor.
	All powered aircraft must utilize either a spinner or a rounded model aircraft type safety nut.	The propeller is secured with a nut that is designed to secure the propeller.
	Metal propellers are not allowed.	Metal propellers are not used.
Materials Requirements	The use of lead is strictly prohibited.	Lead will not be used anywhere on the aircraft.
	The use of fiber-reinforced plastics is prohibited. This includes duct tape.	Fiber-reinforced plastic and adhesives will be not used on the aircraft.
Materials Requirements	Elastic materials such as rubber bands shall not be used to retain the wings or payloads to the fuselage.	Elastic materials will not be used to retain the wings or payloads to the fuselage.

	The aircraft must be propelled by a single electric motor.	The aircraft's thrust is provided by one electric motor.
	The aircraft must be powered by a commercially available Lithium-Polymer battery pack.	The batteries are purchased and operate on Lithium-Polymer technology.
	The aircraft must use a 2019 V2 or newer version 1000-watt power limiter from Neumotors.com.	The power limiter sold by Neumotors.com will be used on the aircraft.
Electronics Requirements	The use of 2.4GHz radio control system is required and must have a functional fail-safe system.	The fail-safe system will disable the aircraft if connection is lost between the radio and the aircraft and only 2.4GHz frequency will be used.
	The Battery pack for the radio must have a minimum capacity of 1000 mAh, enough to safely drive all the servos.	The number of servos and potential current drawn will be taken into consideration when choosing the battery pack.
	The radio system's battery pack must be controlled by a clearly visible and properly mounted on/off switch on the external surface of the aircraft.	A means to toggle the aircraft's power supply will be clearly visible and accessible on the aircraft.
	All batteries in the aircraft must be positively secured so that they cannot move under normal flight loads.	The internal electrical components remain secured during takeoff, flight, and landing.
Payload Requirements	The payload cannot contribute to the structural integrity of the airframe, meaning, the airframe must be able to fly without the payload installed.	The aircraft is structurally sound and can fly without the payload.
	All static payload must be secured with metal hardware that penetrates all payload plates.	Metal hardware penetrates and secures the payload to the aircraft.
	The cargo may not be exposed to airstream at any point in flight.	The cargo is not exposed to the airstream during flight.
	Tape, Velcro, rubber bands, container systems and friction systems alone may not be used to	The use of tape, Velcro, rubber bands, container systems, and

Payload Requirements	retain the support assembly and/or payload plates.	friction systems are not used to support assembly or payload.
	Only one cargo bay is allowed.	The aircraft will have one cargo bay.
	The length of the cargo bay must be detailed on the drawing for technical inspection.	The drawings of the aircraft show the length of the cargo bay.
	The team must supply their own payload plates.	The payload plates are designed and manufactured by the team for the aircraft.
	The spherical payload must be an unmodified size 5 soccer ball.	The airplane can carry an inflated soccer ball as its payload.
	The cargo bay must accommodate a minimum of 1 soccer ball.	The cargo bay can hold at least 1 soccer ball.
	All payload must be unloaded within 2 minutes to be scored.	The cargo can be unloaded with ease from the aircraft.
Mission Requirements	The aircraft must remain on the runway during the take-off roll.	The aircraft is in contact with the ground during takeoff.
	The take-off distance limit is 100 ft.	The aircraft can become airborne within the prescribed take-off distance.
	The distance from the initial start before the turn is 400 ft.	The aircraft can maintain controlled flight for the minimum distance from initial start before turning.
Mission Requirements	Touch-and-go landings are not allowed and will be judged as a failed landing.	Aircraft can land and remain in consistent contact with the ground during landing.
	The landing distance limit is 400 ft.	Aircraft can land within the prescribed landing distance.
	The use of one (1) helper to hold the aircraft for take-off is allowed.	An individual may assist the aircraft for its initial take off.

Note: All items in the customer statement column were acquired from reference (SAE International, 2020).

The team also consulted the team's advisor, Dr. Shih, and the class instructor/sponsor, Dr. McConomy, for additional needs and constraints which are shown in Table 2. Dr. Shih did not provide any additional needs or constraints. He advised to the team to ensure that the airplane/aircraft followed the rules of the competition.

Table 2

Advisor and Sponsor Customer Needs Interpretation

Question/Prompt	Customer Statement	Interpreted Need
To Dr. McConomy: "What is the project scope?"	The RC airplane must be printed from 3D printed material.	The airplane is printed with 3D printing material.
To Dr. McConomy: "How much of the airplane needs to be 3D printed?"	The airplane must be primarily 3D printed.	The airplane is as 3D printed as possible.
To Dr. McConomy: "What additional requirements does the project have besides competing in the competition"	Be innovative. 3D printing has already been done, so make it better.	Innovation will be a priority while designing and manufacturing the airplane.
To Dr. McConomy: "What should our performance goals be?"	Carry the minimum payload that is required by the competition. Focus on innovation.	The team will select one area of the competition to excel in.

Table 1 outlines the customer statements that were pulled from the SAE Aero Design rule book; these customer statements were interpreted by the team. Many of the customer needs contained metrics and constraints that must be followed in order to be compliant with the rule book. Therefore, many of the interpreted needs may seem to detail solutions for several aspects of the airplane but are necessary to the team's success at competition. A few notable physical constraints from the customer needs are that the airplane cannot weight over 55 pounds and it may not have a wingspan great than 120 inches. In addition to this, the airplane may only utilize a single electric motor to provide thrust, but there is no limitation to the make or model of the motor. Table 2 outlines the customer statements and interpreted needs that were obtained from the team's advisor and sponsor through several in person meetings. Questions were transcribed through in person meetings so that a conversation could result in a thorough understanding of the customer needs. The team found it notable that the team's sponsor wanted the airplane as 3D printed as possible and that it was only of interest to carry the bare minimum payload during the competition.

1.3 Functional Decomposition

To gain a better understanding of the nuances of designing an R/C airplane, the team completed a functional decomposition. The team collaborated to create the functional decomposition utilizing their knowledge of physics and RC airplanes. This collaboration occurred as a team brainstorming session using a whiteboard to transcribe ideas. First, the major systems were identified by considering what the airplane must do fundamentally; that is to takeoff, land and maintain flight all while carrying the designated payload. These fundamental tasks were identified as the major systems of the airplane. The minor systems were then identified based on the actions required to carry out the major functions. Highlights of the minor systems include the need to accelerate, generate lift, maneuver in flight, and carry a payload. Figure 1 displays the hierarchy chart created from functional decomposition. A higher resolution version of Figure 1 is included in Appendix B. In the second row of the figure, the major functions can be seen. In the subsequent rows, the minor functions are shown.

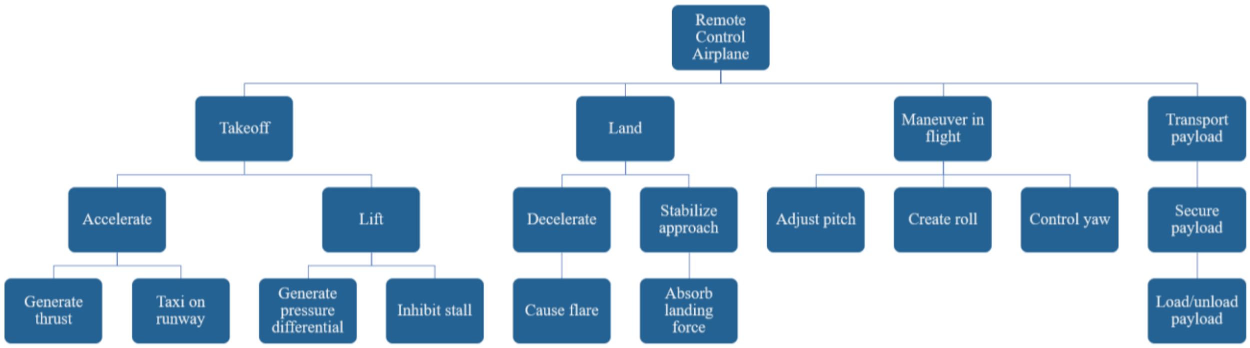


Figure 1. Functional Decomposition Hierarchy.

The functional decomposition was created based on the major functions that all aircrafts must accomplish — takeoff, land, fly and carry the designated payload. Each primary function was broken down into minor functions that detail what the major functions must satisfy on a fundamental level. In order to takeoff, it is necessary to accelerate, which is done by generating thrust. The other subfunction included within taking off is the creation of lift which is done by generating a pressure differential through airflow. Furthermore, it is necessary to inhibit a stall during takeoff to avoid an immediate crash landing. Accelerating is also necessary to taxi the airplane to runway. The next major function, landing, is accomplished by decelerating and stabilizing the airplane's approach towards the ground. Decelerating occurs by utilizing the airplane's control surfaces to cause flare during the landing approach. Flare is defined as raising the nose of the airplane which causes the airplane to go into a controlled descent. Ultimately, the airplane slows down enough for a safe landing. Stabilizing the plane is necessary to land the airplane because the airplane needs to slow down in a controlled manner in order for the landing gear to gently touchdown on the ground. Consequently, it is necessary for the landing gear to absorb the impact force of the airplane on the ground, so that the airplane does not experience excessive impact forces. Next, flying requires the airplane to maneuver while in the air, which is done by using the control surfaces to change the pitch, roll, and yaw of the plane. Finally, the last major function, transporting payload, is done by flying from point A to point B. For safety reasons, it is imperative that the payload is secured within the cargo bay; it is critical that the cargo bay is easily accessible so that the user may unload and load payloads with ease.

Once the team identified the major and minor functions, the cross-reference table was created to relate the major functions to the minor functions. The relationships between the functions can be seen in Table 3 below.

Table 3

Functional Decomposition Cross Reference Table

		Major Functions				
Minor Functions	Related Customer Needs	Maneuver in Flight	Land	Takeoff	Carry Payload	Ranking
Accelerate	1, 2, 3, 5, 6, 7, 8, 9	X	X	X	X	1
Generate Thrust	1, 2, 5, 6, 7, 8, 9	X	X	X	X	2
Taxi on runway	3, 4, 5, 8		X	X	X	9
Lift	1, 2, 3, 4, 6, 7, 8, 9	X	X	X	X	3
Generate pressure differential	1, 5, 8	X	X	X	X	4
Inhibit stall	1, 3, 4, 8, 9	X		X	X	7
Decelerate	3, 5, 9		X			12
Cause flare	1, 2, 3, 6, 7, 8		X			13
Stabilize approach	1, 4, 5, 9	X	X		X	8
Absorb landing force	2, 4, 6, 7, 8, 9		X		X	9
Adjust pitch	1, 3, 5, 8	X	X	X	X	6
Create roll	1, 3, 8	X				14
Control yaw	1, 3, 8	X		X		11
Secure payload	1, 2, 4, 5, 6, 7, 8, 9	X	X	X	X	5
Load/unload payload	1, 2, 4, 5, 6, 7, 8, 9		X		X	10
Ranking		3	1	4	2	

Table 3 above shows how several of the minor functions may relate to more than one major function. For example, the minor function “stabilize approach” was compared against each column of major functions and an “X” was applied to each column where that action was found necessary to satisfy any of the major functions. The process of landing the airplane requires execution of a landing pattern, otherwise known as the approach. Therefore, an “X” was placed in the “Maneuver in Flight” and “Land” columns. The third “X” was marked in the

"Carry Payload" column because the airplane needs to remain stable during flight with the additional weight.

The X's in each column and row were tallied to create a ranking system: more X's correlate to a higher ranking, with 1 being the highest placement and therefore the most important. "Land" and "Accelerate" were ranked number one for major and minor functions, respectively. Taking off was found to be the least important major function as it does not heavily rely on many aspects of the airplane to leave the ground. Landing was found to rely and require more minor functions of the airplane and its dynamics. For instance, to land the airplane velocity, stability, and resistance to impact forces are all critical to a controlled and safe landing. Accelerating was ranked number one because it is required for all the major functions; it is necessary to maneuver in the airplane in flight, generate additional thrust during adverse landing situations as well as ensuring the airplane has enough airspeed to takeoff with the designated payload.

The interpreted customer needs were examined and cross referenced against the minor functions to establish a connection between the physical actions of the airplane and the objectives of the project. For example, the deceleration minor function relates to customer needs of electronics, mission requirements, and innovation. The deceleration of the airplane is controlled by throttle and control surfaces, which are in turn controlled by the electronics. Deceleration is critical for a safe landing which satisfies the mission requirements. The team is exploring unique methods for decelerating the airplane; therefore, it satisfies innovation.

The functional decomposition will act as a guide for the team as the engineering and design of the airplane begins. It is important that the team references the functional decomposition to ensure that all of the minor functions of the airplane are satisfied to successfully accomplish the major functions of the project.

1.4 Target Summary

The targets and metrics for the airplane were determined from the SAE Aero Design Competition rule book and outside resources. The rule book outlines specific targets that the airplane must meet, including maximum and minimum constraints; since these targets must be strictly followed to be compliant with the rules, they were taken verbatim from the rule book (SAE International, 2020). Additional targets and metrics were created to accompany the lowest level subfunctions from the functional decomposition. These targets and metrics were determined from outside resources that explore airplane aerodynamics and electrical components. The team researched successful RC airplane designs in combination with published articles and textbooks to determine many of the targets for the team's airplane (Anderson, 2016) (Nicolai & Carichner, 2010). The same methodology was utilized for the electronics, which were also benchmarked against available products by using supplier catalogs (RC Airplanes, 2019). The team understands that these targets and metrics may evolve as the design of the airplane develops; it is also likely that additional targets and metrics will become evident as time progresses. In Table 4 below, the functions are outlined and matched with the targets and metrics required to compete in the SAE Aero Design Competition.

Table 4

Mission Critical Targets

Function	Metric	Target
	Major Function: Lift	
Structure	Gross takeoff weight	Less than 55 lbs
Generate pressure differential	Wingspan	60 - 120 in
Generate pressure differential	Coefficient of lift	Greater than 1.0
	Major Function: Accelerate	
Generate Thrust	Force	10 lbf

Abiding by the rules of the competition, the mission critical metrics of the airplane are the wingspan, gross take-off weight, coefficient of lift, and the thrust requirement. Each of these variables are dependent on each other and must balance as a system to achieve a successful takeoff, flight, and landing. Keeping the wing span of the airplane to less than 10 ft, the gross take-off weight less than 55 lbs, and obtaining a lift coefficient greater than 1.0 are taken to be the mission critical targets. These targets, along with the thrust force, of the airplane are interdependent as the weight of the plane dictates the minimum values of the other targets. These targets are critical to the airplane generating enough lift to the leave the ground. The wingspan and the maximum weight targets of the plane are dictated by the rule book. The thrust force and the coefficient of lift targets were determined through external resources, such as textbooks about aerodynamics (Anderson, 2016). The coefficient of lift target was found through aerodynamic resources that deem a coefficient of lift to be greater than 1.0 necessary to generate enough lift to generate a positive upward net force (Anderson, 2016). The thrust force was determined with information from published papers and will be compared against verification tools such as the program DriveCalc. The published papers dictate the amount of thrust necessary for takeoff given the drag and weight of the airplane.

A full catalog of targets, including the accompanying validation methods and tools, is found in Appendix C. To validate the targets above as well as the additional targets found in Appendix C, different validation tools were found to be necessary. The tools for validation can be divided into two groups: simulation testing and physical testing. Simulation testing entails utilizing programs such as MATLAB, SOLIDWORKS, and xlfr5 (a low Reynolds number aerodynamics simulator) to model and predict the physical capabilities of the airplane. Many of aerodynamic targets may only be validated through simulation as it is unrealistic to test and validate them through physical experimentation. For many of the targets, the team will be able to compare the simulation results to the physical capabilities of the model. The physical capabilities will require physical validation tools. These tools entail using rulers, protractors, scales, voltmeters, etc. in combination with various testing apparatuses. For example, the thrust of the engine with a given propeller will be calculated through DriveCalc, and it will be compared against the physical measurement utilizing a force gauge. Ensuring that the targets set by the rule book are accurately measured is critical to the team's success at competition as they must be strictly followed and validated to be considered compliant.

1.5 Concept Generation

Once the team reached the stage of concept generation, the agenda of weekly team meetings was adjusted to allow for devoted brainstorming time to generate concepts. By relating the major and minor functions, established from the functional decomposition, the team was able to generate possible solutions that would satisfy the minor functions of the airplane, such as, the wing shape, wing orientation, tail style, fuselage style, material selection, landing gear style, and battery selection. The team broke down the main aspects of the airplane into various categories so that solutions to each aspect of the airplane could be developed independently. This was done so that the team could develop a broad spectrum of possible airplane designs. The team developed different solutions to each category in several different ways. Most of the solutions were obtained from airplane design textbooks and online resources. From the textbooks, it was found that biomimicry could be used in reference to wing selection, as an elliptical wing is modeled after the wings of a bird (Simons, 2015). In addition to this, the team was free to develop their own unique solutions to each component category. Table D-1 in Appendix D shows the team's initial component configuration chart that was developed to show possible solutions for each category.

It was found that Table D-1 was too large and too specific for the initial concept generation. With the 17 categories that were developed, and the various solutions within each category, the total number of possible airplane configurations was over 2 trillion. Therefore, the team went back to the original component configuration chart to reduce the number of categories and solutions. The team eliminated categories that were found to be too specific for the current stage of design and development. For example, how the modular pieces of the plane were going to be fastened together was deemed to be determined after the airplane takes its initial shape. Solutions to each category were also eliminated based on their feasibility and/or if the solution was fit for satisfying the project objective. For example, several aileron and flap configurations were eliminated due to their complexity and their minimal advantages versus simpler designs. Table 5 below is the condensed component configuration chart depicting the main and critical aspects of the airplane via a concept generation chart. Each component is depicted for reference in the figures of Appendix D.

Table 5

Concept Generation Chart

3D Material	Landing Gear	Wings	Wing Location	Aileron/Flaps	Fuselage	Tail
PLA	Tricycle with Front Wheel	Elliptical	Low Wing	Plain	Flying boat	Conventional
ABS	Tricycle with Tail-Wheel	Tapered	Mid Wing	Split	Double booms	T-Tail
LW-PLA	Four Wheels	Rectangular	High Wing	Slotted	Subsonic	Cruciform
					High Capacity Subsonic	Triple
						Twin
						Boom
						High Boom

Table 5 was utilized to develop the list of 100 concepts located in Appendix D as Table D-2. These concepts were developed through a combination of two methods: a typical morphological chart method and the crap shoot method. The first 50 concepts were developed by the team by drawing 50 unique lines through Table 5 in order to generate 50 unique concepts (morphological method). The second 50 concepts were generated utilizing the crap shoot method from Table 5. This was accomplished in Excel by using the random function. This function was implemented so that only one solution from of each column was selected at random, leading to 50 random airplane solutions. Once the team had generated 100 concepts, it was of interest to select 5 medium fidelity concepts and 3 high fidelity concepts. This was done as a team, where the team went through and analyzed each of the 100 concepts. The team eliminated concepts that were not feasible to the team's success at competition and/or were not feasible to manufacture. Once these concepts were eliminated, the team members individually went through the remaining concepts and applied their knowledge of aerodynamics, design, and material science to identify medium and high-fidelity concepts. The high-fidelity concepts were chosen because they were found to be the best combination of solutions to complete tasks at competition.

Concept 1.

Concept one is a medium fidelity concept that features wings of an elliptical shape with a low location on the fuselage, tricycle landing gear with only one front wheel, split ailerons and flaps, double booms fuselage, and a boom tail. This concept would be printed from a PLA material which, due to a lower temperature, is easier to print and can print in better detail. The elliptical shaped wings are efficient in every flight regime, such as subsonic that the team's airplane falls under. They provide a relatively large area of a wing and constant lift distribution across the span of the wing. This reduces wing loading and improves the airplane's ability to maneuver. Locating the wings low on the fuselage increases the cargo carrying capabilities as it minimizes the used volume in and around the fuselage. For instance, the support spar for the wing can run through the fuselage, below the cargo area. The tricycle configured landing gear with the singular wheel at the front is a common design amongst most conventional passenger planes. The benefit of the singular wheel location depends on the center of mass location and the desired landing orientation and approach. The reason for the split ailerons is that they give the plane more redundancy in case of a failure for control, less wing loading during flying, and better control of roll and yaw. The split flaps control the airplane laterally by giving it increased lift and drag, depending on the location on the wing. The double boom fuselage has a nacelle, which is a type of a housing that can hold the engine or equipment of an aircraft. The tail shape is forced to be a boom tail due to the use of double boom fuselage. This is characterized by its connection to the wings through connections that run lengthwise to the wings. It is used because the fuselage does not go all the way back to the horizontal stabilizer which is optimal at keeping the plane flying straight. It has a significant benefit when it comes to the accessibility of the cargo; it also reduces the fuselage weight as the fuselage is often smaller in a double boom design.

Concept 2.

Concept two is a medium-fidelity concept that is made of Light Weight (LW) PLA; this material uses foaming technology, which can make parts up to 65% lighter when compared to normal PLA. The specific strength of a material is the material's strength divided by its density. This property is a crucial factor in aerodynamics because the material must be able to handle significant loads while also being lightweight. LW-PLA has a higher specific strength than regular PLA, which makes it a better option regarding weight and strength. Some of the concerns with this material are that it requires high printing temperatures, which cannot be reached by most of the 3D printers that the team has at their disposal. In addition, we will have to test different settings to achieve the desired tolerances and material properties.

For landing gear, this concept will use a tricycle with tail-wheel that allows the plane to naturally sit at a positive angle of attack and will keep the propeller further off the ground. A tail wheel is beneficial because the plane can generate a higher lift at low speeds but is disadvantageous because the positive angle of attack increases drag, which decreases acceleration. If the acceleration is decreased, then the velocity is also decreased, so whenever the control surfaces are used, they will generate smaller lifting forces due to the lower traveling velocity. The tail-wheel landing gear is commonly used in bush planes due to their high thrust and low weight, but both two characteristics do not apply to cargo planes. Bush planes and gliders have a tail-wheel instead of a nose wheel because having two larger front landing gear assemblies is sturdier than one. Furthermore, having a tail-wheel will avoid a tipping moment, that will help lift the plane nose during taking off.

Concept 2 also features wings of an elliptical shape with a mid location on the fuselage. Aerodynamically, the elliptical platform is the most efficient as it has the lowest induced drag and constant spanwise lift distribution. However, elliptical wings are the hardest to manufacture. This concept also features a high capacity subsonic fuselage as well as a tripletail. The tripletail is also not easy to manufacture and is therefore not commonly used in modern planes.

Concept 3.

Concept three is a medium fidelity concept that shares the same manufacturing material and landing gear as concept two; therefore, the first and second paragraphs from concept two also apply to concept three. This concept is different because it features a tapered wing design. For a tapered wing, the chord is varied across the span to approximate the elliptical wing lift distribution, without negatively affecting the wing's manufacturability and efficiency. The tapered wing is an efficient wing that is easier to manufacture than an elliptical wing. This concept also features a high wing location that creates a pendulum effect that helps to stabilize the plane and in turn makes it easier to control while in flight. This concept has a triple tail and a flying boat fuselage. Flying boat fuselages are typically used with floats to land on the water. Since the competition runway is on concrete, there is no benefit to use this type of fuselage, but it can be modified to work as a land-based fuselage that increases the cargo area volume without significantly increasing drag. The overall combination of its components makes it a medium fidelity concept.

Concept 4.

Concept four is a medium fidelity concept comprised of a rectangular wing with a high fuselage wing location, tricycle landing gear with the singular wheel in the front, slotted flaps, a flying boat fuselage, and a boom tail. The concept will also be primarily constructed out of LW-PLA. Light weight PLA is significantly less dense than normal PLA; therefore, it is a viable material to construct the airplane as weight is a primary concern. The tricycle configured landing gear with the singular wheel at the front is a common design amongst most conventional passenger planes; however, it is not commonly used for smaller cargo planes where the singular wheel is in the back of the plane. The benefit of the singular wheel location depends on the center of mass location, the desired landing orientation and approach, as well as, other airplane characteristics. The rectangular wing is known to be one of the least efficient wing designs, but it is the easiest to design and manufacture. A boom tail results in different flight dynamics over a conventional tail as it is often larger than a conventional airplane tail; it also opens the option for placing the propulsion system directly behind the fuselage. A slotted flap has large benefits over other flaps as it has gap between the flap and the wing. This gap introduces a new boundary layer that attaches to the flap and in turn increases lift and decreases drag.

Concept 5.

Concept five is a medium fidelity concept that is comprised of rectangular wings with a mid-fuselage wing location, four-wheel landing gear, split ailerons and flaps, a high capacity subsonic fuselage, and a boom tail design. The four-wheel landing gear has four wheels on the ground which adds stability to the aircraft while on the ground, but they increase the weight and drag of the airplane. Rectangular wings were picked for this design which are the easiest to manufacture. These wings do not provide the most efficient lift when compared to the other wing shapes. Split flaps and ailerons do provide extra lift; however, at the cost of additional drag. Determining the length of the flaps and ailerons split can be beneficial if done correctly. The high capacity subsonic fuselage design is energy efficient and aerodynamic. A high boom tail design has two longitudinal booms that provide additional lift and increase the control and stability of the airplane. The filament that the plane will be made from is LW-PLA, it benefits were discussed in the previous concepts.

Concept 6.

The first high-fidelity concept features tapered wings with a low fuselage wing location, tricycle landing gear with tail wheel, plain ailerons and flaps, a flying boat fuselage, and conventional tail as depicted below in Figure 2.

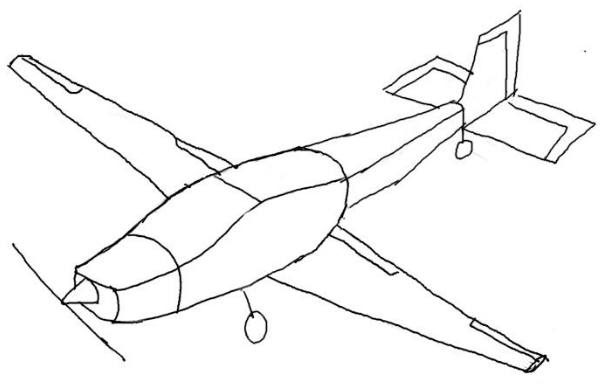


Figure 2. High fidelity, concept 6 sketch.

First, the tricycle landing gear with a tailwheel design features two wheels near the center of gravity and a smaller wheel in the back under the tail. The advantage of this style is that the fuselage and wings are angled upwards due to the smaller back wheel, thus adding a positive angle of attack to in turn increase the lift that is generated during takeoff. These are typically found on smaller airplanes because the takeoff and landing distances are relatively short, similar to the team's competition constraints. Tapered wings were picked because their lift characteristics are a compromise between elliptical and rectangular wings but are easier to manufacture than elliptical wings. The lift distribution for tapered is better than rectangular wings, but not as good as elliptical wings. Plain ailerons and flaps were picked because they are easy to design and manufacture and offer high lift advantages. The flying boat fuselage have a built-in incident angle of attack; furthermore, this design is useful because they are built to carry cargo which is the essence of the competition. Finally, a conventional tail provides good stability and control with a very low structural weight. This is beneficial to the project because low weight airplane is desired. The material used to construct the plane is light weight PLA. This material is significantly less dense compared to other filaments available on the market, which will ensure a lighter plane that will be able to carry additional cargo.

Concept 7.

The second high fidelity concept features rectangular wings with a high fuselage wing location, tricycle landing gear with tail wheel, plain ailerons and flaps, a flying boat fuselage, and a conventional tail as depicted below in Figure 3.

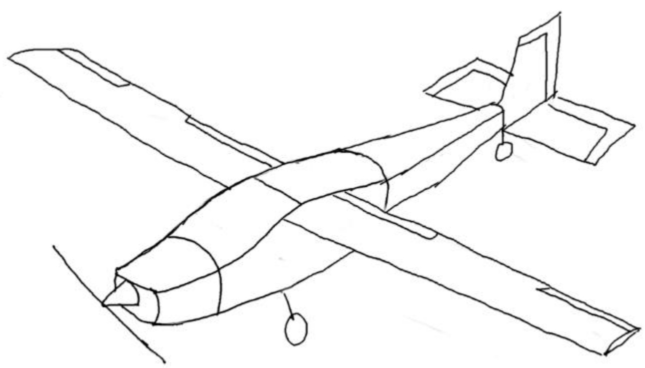


Figure 3. High fidelity, concept 7 sketch.

The concept will also be primarily made from light weight PLA. This material is less dense compared to other filaments available on the market and as advantageous for reasons explained previously. This concept features two wheels in the front and a smaller wheel in the back under the tail. As explained previously, one advantage of this is that the wings have an increased angle of attack due to the smaller tail wheel causing the tail to be closer to the ground than the front fuselage. These are mainly used on slower planes which is appropriate for our competition because there is a limited runway distance for takeoff and landing. The rectangular wing is known to be one of the least efficient wing designs, but it is the easiest to design and manufacture. High position wings provide increased stability during flight as the planes center of mass will be below its center of lift. Plain ailerons and flaps were picked because they are high lift devices and are easy to design and manufacture. The flying boat fuselage optimizes the aerodynamic surfaces to provide enough space to carry large amounts of cargo, which is the essence of the competition. This concept also features a conventional tail that provides good stability and control with a very low structural weight, which ensures a lighter airplane.

Concept 8.

The third high fidelity concept features elliptical wings with a mid-fuselage wing location, tricycle landing gear with front wheel, plain ailerons and flaps, a flying boat fuselage, and a boom tail as depicted below in Figure 4.

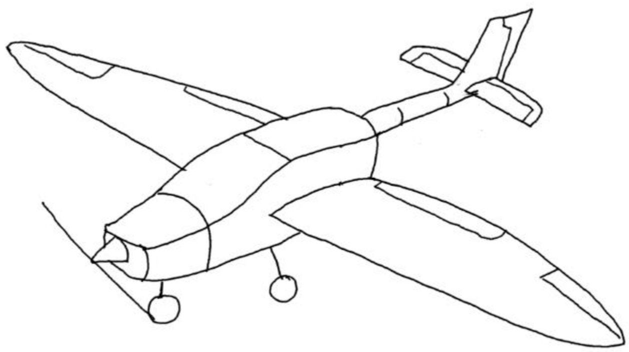


Figure 4. High fidelity, concept 8 sketch.

The airplane would be printed using light weight PLA material, which is beneficial for reasons discussed previously. The elliptical wings produce maximum constant lift distribution over the span of the wings, thus making them the most efficient wing shape. Elliptical wings are known for being difficult and expensive to manufacture due to changing chord length, but 3D printing increases the feasibility of manufacturing the wings. By locating the wings mid-way on the fuselage, the streamline efficiency is increased at the cost of reduced structural strength. Plain ailerons and flaps are high lift devices which will aid in completing the objective of a short takeoff and landing. Additionally, the landing gear configuration of a front wheel tricycle provides improved directional stability while taxiing on the runway compared to the other configurations. The flying boat fuselage combined with a boom tail optimizes the aerodynamic surfaces by minimizing the weight of the airplane while still providing enough cargo space. The combination of this fuselage and tail design allows for more cargo to be carried.

Conclusion

The high and medium fidelity concepts were selected based on the advantages and disadvantages the components have when combined as a system. The high fidelity concepts were chosen because they were found to be the best combination of solutions to be successful at competition while minimizing the overall complexity. Several of the medium fidelity concepts were found to over complicate the design of several aspects of the plane with minimal benefits. As mentioned, some component-based advantages were cancelled out when combined thus reducing the overall fidelity of the concept. Moving forward, the team will evaluate the high and medium fidelity concepts to arrive at a single concept that will be selected as the most feasible and optimal airplane design.

1.6 Concept Selection

After the team generated 8 different concepts for the airplane, it was of interest to determine which of the 8 concepts was the most suitable for the team's success at competition. In order to do this a concept selection process was conducted in a three-step process. The first step was to create a house of quality (HoQ), seen below in Figure 5. The HoQ benefits concept selection by providing the team a method of relating the customer requirements into quantifiable design variables.

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Row #	Weight Chart	Relative Weight	Customer Importance	Column #	1	2	3	4	5	6	7	8	9	10
				Direction of Improvement	▼	▲	▲	◇	▲	◇	▼	▼	▼	▼
				Functional Requirements / Customer Requirements (Explicit and Implicit)	Weight(Lb)	Thrust (lbf)	Lift (lbf)	Drag (lbf)	Acceleration (ft/s^2)	Weight Distribution (lbf(x))	Wingspan (in)	Time to Unload Cargo (sec)	Price ($)	Manufacturing Time (sec)
1		16%	10	Fly	●	●	●	●	●	▽	●	▽	▽	○
2		10%	6	Carry Payload	●	●	●	●	●	●	○	○	▽	○
3		8%	5	Takeoff Distance	●	●	●	●	●	▽	●	○	○	●
4		8%	5	Landing	●	●	○	●	●	▽	▽	▽	○	●
5		8%	5	Cost	▽	●	▽	▽	○	○	○	▽	●	○
6		15%	9	3-D Printed	●	▽	▽	▽	●	○	●	●	●	●
7		10%	6	Flight Stability	○	▽	●	●	○	●	●	●	▽	○
8		10%	6	Payload Accesibility	▽	▽	▽	●	○	●	▽	●	▽	●
9		16%	10	Safety	●	●	▽	▽	○	○	○	●	○	▽
				Technical Importance Rating	700	629	464.5	590.3	638.7	409.7	554.8	535.5	345.2	509.7
				Relative Weight	13%	12%	9%	11%	12%	8%	10%	10%	6%	9%
				Weight Chart										

Figure 5. House of Quality Chart (HoQ).

The first step in the HoQ process is to identify customer expectations and requirements, which can be explicit or implicit. From reading the rule book and communicating with our customer, the two most important requirements are that the plane must be able to fly, and it must operate in a safe manner. These two requirements score 10 on a scale from 1-10. The next most important requirement was identified to be that the plane must be 3-D printed since the team's customer clearly stated that this is of utmost importance. Flight and safety scored slightly higher than the 3-D printing requirement because the plane could participate in the competition without being primarily 3-D printed, but it cannot participate if it's unsafe.

Carry a payload, payload accessibility, and flight stability were set at 6 out of 10. These requirements were weighted in this manner as they are the main capabilities of the airplane that are evaluated during competition. Furthermore, cost, landing, and takeoff distance were set at 5 out of 10 as they are not as critical to the team's success at competition. However, cost is a moderately important factor in the project because registering for competition costs more than half of the budget, and the traveling cost is also high; therefore, most of the budget is not available for the airplane itself. Reaching the desired takeoff distance and landing were set at 5 because the competition points are moderately based on these two requirements.

After determining the importance of each customer requirement, engineering parameters (functional requirements) were determined as means to relate the customer needs into quantifiable variables. Each engineering parameter is strongly, moderately, and weakly related to one or more customer requirements. A direction of improvement of each engineering parameter was established in order to make it evident whether it was of interest maximize or minimize each parameter. A key depicting the use of these parameters is at the top of Figure 5.

The main takeaways from the HoQ process are that weight, thrust, acceleration, and drag are the most critical engineering characteristics that will yield maximum customer satisfaction. The weight of the airplane was found to be the most important parameter as it directly relates to the safety, the takeoff distance, the amount of cargo that can be carried, and the takeoff and landing distance of the airplane; as discussed previously, these are the customer requirments that are most critical to the team's success at competition. Driving the weight of the airplane down will allow the airplane to carry additional cargo, and takeoff and land in a shorter distance. The weight is also directly related to the safety of the airplane as a lighter airplane inherently will have less momentum and less risk involved in the event of a crash. Thrust, acceleration, and drag are very close to weight in the importance rating (approximately 12%). This was expected as all these parameters are strongly related to one and another. For example, if the overall drag of the airplane is increased, then an increase in thrust is necessary as the airplane must be able to maintain the same degree of acceleration to reach to necessary takeoff velocity. The least important factor was found to be cost. The team's main expenses, not related to the competition, are mainly driven by the cost of 3D printing the airplane. As the team has secured a filament sponsor, this was not found to relate to many of the other customer needs.

After the HoQ was created and analyzed, the most important engineering parameters from it were extracted. The top engineering parameters were placed into a Pugh chart as the selection criteria. The use of a Pugh chart was of interest during concept selection as it enables the team to use to the most important engineering characteristics to weigh the various concepts against a datum. The goal of the Pugh chart is to narrow the number of concepts down to a few viable concepts that are competitive against the datum. While creating the pugh chart it was found that some of the top engineering parameters in the HoQ are insignificant to the concept selection process. These parameters were thrust and acceleration, which were not found to be viable parameters to weigh the various concepts that the team generated; this is because the same motor, battery and propeller combination will be implemented among all of the concepts. The use of the same propulsion system combination is driven by the customer and competition requirements that constrains the power supply to the airplane. The 8 concepts that were generated by the team is summarized below in Table 5.

Table 5

Concept Generation Summary

#	3D Material	Landing Gear	Wings	Wing Location	Aileron/Flaps	Fuselage	Tail
1	PLA	Tricycle front	Elliptical	Low	Split	Double boom	boom
2	LW PLA	Tricycle tail	Elliptical	Mid	Plain	High capacity subsonic	Triple tail
3	LW PLA	Tricycle tail	Tapered	High	Split	Flying boat	Triple tail
4	LW PLA	Tricycle front	Rectangular	High	Slotted	Flying boat	Boom
5	LW PLA	Four wheels	Rectangular	Mid	Split	High capacity subsonic	Boom
6	LW PLA	Tricycle tail	Tapered	Low	Plain	Flying boat	Conventional
7	LW PLA	Tricycle tail	Rectangular	High	Plain	Flying boat	Conventional
8	LW PLA	Tricycle front	Elliptical	Mid	Plain	Flying boat	Boom

Although there is a column for flaps in Table 5, which is a high lift device typically used on Short Takeoff and Landing (STOL) aircraft, the team determined this is a feature that would significantly increase the complexity of the build and thus was eliminated from the concept selection criteria moving forward. Instead, the team will generate enough lift through airfoil and wing selection. From Table 5, concept 7 was selected as the datum for the first Pugh chart iteration because it is the most generic airplane design amongst all of the concepts; therefore, it was of interest to compare the pros and cons of the more unique and complex concepts to a typical aircraft. One of the team's concepts was chosen as the datum because 3D printed model aircraft are not commercially available. Additionally, the constraints of the competition are new and unique; therefore, there are not any previous designs to compare against.

The Pugh chart seen below in Table 6, shows the initial Pugh chart that was constructed with the remaining 7 concepts. Each concept was weighted against the datum utilizing the concept selection criteria. This process was conducted for each concept where a '+' deems that the concept performed better than the datum in that selection criteria area, consequently, a '-' means that the concept preformed worse than the datum

Table 6

Initial Pugh Selection Chart

		Concepts						
Selection Criteria	**Concept 7**	**1**	**2**	**3**	**4**	**5**	**6**	**8**
Weight	DATUM	+	-	-	S	S	+	+
Drag		+	S	-	S	-	S	+
Wingspan		+	+	+	S	S	+	+
Time to Unload		+	-	S	S	-	+	-
Manufacturing Time		-	-	+	S	S	+	-
Cost		-	+	S	+	+	S	+
# of pluses		4	2	2	1	1	4	4
# of minuses		2	3	2	0	2	0	2

The various selection criteria were utilized in the following manner. A '+' was given to a concept in the weight selection criteria if it was found that the concept could be lighter than the datum. A '+' was given to a concept in the drag selection criteria if the concept was found to have less drag than the datum. A '+' was given in the wingspan selection criteria if it was found that the concept could generate efficient lift. A '+' was given in the in the time to unload selection criteria if it was found that the concept could potentially decrease the total time to unload the cargo. A '+' was given in the manufacturing selection criteria if the concept was found to be less complex than the datum. Similarly, a '+' was given in the cost selection criteria if the concept was found to be less expensive than the datum.

From Table 6, it was found concept 4 was very similar to the datum as the only difference was the landing gear configuration. It earned a '+' over the datum because the boom tail can be purchased rather than 3D printed, which will drive the cost of the airplane down. It remained a viable solution for the next Pugh chart. Concept 2 was found to have minimal advantages over the datum; the elliptical wing made it advantageous because of its lift efficiency but is known to be more difficult to manufacture. Additionally, the location of the wing on the concept is not optimal for quickly unloading the cargo as its support spar would run directly through the fuselage. For these reasons, concept 2 was eliminated. Concept 5 was also eliminated as its only difference from the datum was its landing gear. The four-wheel landing configuration was found to greatly increase the drag of the airplane over the datum's tricycle configuration; therefore, it was eliminated as a viable concept. The remaining concepts (1, 3, 4, 6 & 8) performed noticeably better than the datum and remained viable solutions for the next Pugh chart. Concept 6 was found to perform the best against the datum and was deemed the new datum for the final Pugh chart, seen below in Table 7.

Table 7

Final Pugh Selection Chart

		Concepts			
Selection Criteria	**Concept 6**	**1**	**3**	**4**	**8**
Weight	DATUM	+	-	S	+
Drag		+	-	-	+
Wingspan		S	S	-	S
Time to Unload		S	-	+	-
Manufacturing Time		-	S	+	-
Cost		-	S	S	+
# of pluses		2	0	2	3
# of minuses		2	3	2	2

Utilizing the same method as in the initial Pugh chart, two additional concepts were eliminated using the final Pugh chart. Concept 3 was eliminated because of its weight and its tail design. The triple tail design will add unnecessary weight and complexity to the overall design. Additionally, its high wing design poses the same unloading problem as the mid wing design. Concepts 1 and 8 were deemed lighter than the datum because of their boom tail and elliptical wing; however, each of these component designs adds a great deal of complexity to the design. Concept 4 should be eliminated because of its rectangular wing which increases drag and weight while decreasing its lift efficiency in comparison to a tapered wing. However, concept 8 should also be eliminated due to its mid wing location, which significantly impedes its ability to carry cargo due to the wing support spar being required to run through the cargo area. Concept 4 will replace concept 8 going forward. Therefore, the concepts chosen for analysis in the Analytical Hierarchy Process (AHP) were 1, 4, and 6.

AHP is a pairwise comparison between the criteria that was deemed to be necessary to the success of the project by providing the team a means to check for selection bias. By comparing the criteria based off one another (ex: wingspan vs drag, time to unload vs drag, etc.) the team was able to determine which criteria is more important. After determining the relative importance of the criteria, each column is totaled and then normalized. It is important that the sum of each column in the normalized comparison matrix is 1; this is a simple check to ensure the normalization was done correctly. Furthermore, the normalized criteria of each row are summed up to yield the criteria weight. After determining the criteria weight; matrix math is used to determine the consistency. To find the weighted sum vector take the weighted numbers and multiple them by the criteria weight. After completing this for every criterion; the consistency index is found which is done by taking the average consistency, subtracting the number of criteria (6), then dividing by one less than the number of criteria. This final value gives yields the consistency index. After the consistency index is determined, it is necessary to find the consistency ratio; this is found by dividing the consistency index by the RI value (the RI is given based off the number of criteria). Finally, if the consistency ratio is less than 0.1; then the process was not biased in during the evaluation of the criteria. If it is above 0.1, the criteria weights were biased. The results of this process and weights of the criteria is shown below in Table 8.

Table 8

AHP Criteria Weights and Consistency Check

	Weighted Sum Vector	Criteria Weight	Consistency (Con)
Drag	2.840	0.369	7.697
Wingspan	1.387	0.212	6.554
Time to Unload	0.607	0.097	6.268
Weight	1.044	0.156	6.711
Manufacturing Time	0.962	0.143	6.739
Cost	0.159	0.024	6.591
Avg Con: 6.760	Con Index: 0.152	Con Ratio: 0.122	Consistent?: **No**

From this table, the criteria weights in the middle column of the table can be seen. It was found that the drag of the airplane is the most important criteria amongst the other criteria, with the least important criteria being cost. As previously discussed, the cost is not of great importance as most of the airplane cost lies within the materials to manufacture the airplane. It also can be seen that the criteria consistency check was deemed slightly biased, as it yielded "No" on the consistency check. This is likely due to the extensive research the team has conducted on what parameters of an airplane are most important. This research likely biased the team when the comparison chart was made, as subconscious favoritism became apparent by the end of the selection process.

With the criteria weights and importance known, AHP was conducted for each criteria and chosen concepts from the final Pugh chart. The chosen concepts were concept 1, 4, and 6.

The final ranking matrix for the concepts is shown in below in Figure 6. All other tables and figures produced from AHP are found within Appendix E.

[Final Rating Matrix]^T			
Selection Criteria	Concept 1	Concept 4	Concept 6
Drag	0.480	0.115	0.405
Weight	0.405	0.115	0.480
Wingspan	0.260	0.106	0.633
Time to Unload	0.260	0.106	0.633
Manufacturing Time	0.091	0.455	0.455
Cost	0.574	0.140	0.286

X

Criteria Weights {W}	
	Weight
Drag	0.369
Weight	0.212
Wingspan	0.097
Time to Unload	0.156
Manufacturing Time	0.143
Cost	0.024

=

	Alternative Value
Concept 1	0.355
Concept 4	0.162
Concept 6	0.483

Figure 6. Final Rating Matrix Determination

Referencing Figure 6, the method for calculating the final alternative value is done by multiplying the transpose of the final rating matrix with the criteria weights. Thus, using AHP concept 6 would be considered the winner. Despite a failed consistency check on the overall weight of the selection criteria, the individual selection criteria and concept selection matrices yielded a passed consistency check. Taking this into account, the team agreed with the results of the selection process and chose concept 6, sketched previously in Figure 2, as the designated winner. This concept has the highest potential to yield mission success at competition because its combination of low tapered wings, flying boat fuselage, and conventional tail maximizes lift and drag efficiency while carrying cargo that can be easily accessed.

1.8 Spring Project Plan

For the Team's Project plan for the next semester (Spring 2020), the students planned their course of action and how to proceed with the airplane design so that it is completed by the competition deadline. A full Gantt chart is shown in Appendix F where there are deadlines set for tasks, deliverables, and milestones to be completed by the team members. Each task is assigned to a team member, listed with the part or component it corresponds to, and the category it falls under. Figure 7 below provides a visual summary of the milestones for this project.

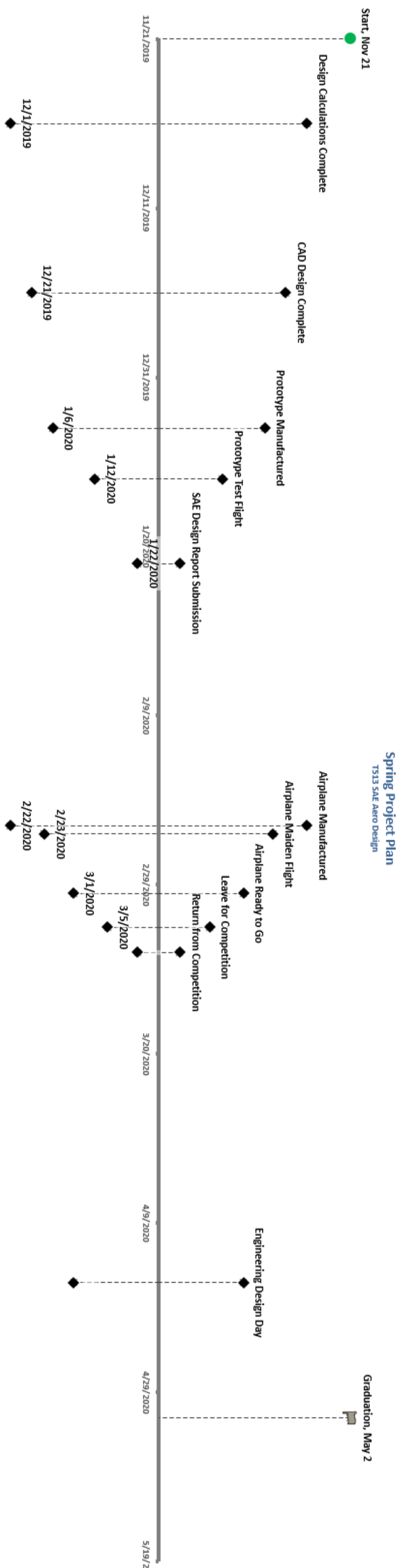


Figure 7. Visual Timeline of Project Milestones

Currently, the final calculations are near completion (11/22/19). It is estimated that the CAD design of the airplane will take approximately 30 days for completion. It is estimated that it will take 42 days to 3D print all of the parts using one LulzBot 3D printer. The students must account for enough time to print test parts, prototype, and assemble the final airplane. The assembly of the plane will take approximately 24 days including test flights at the Seminole RC field. In regards to competition preparation, the plane will have to be in flying condition and all SAE competition deliverables must be submitted. A full Gantt chart containing milestones and deliverables is shown in Appendix F.

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Mission Statement

Team 513 is committed to ensuring a positive work environment that supports professionalism, integrity, respect, and trust. Every member of this team will contribute a full effort to the creation and maintenance of such an environment in order to bring out the best in all of the team as well as this project. All members will seek to excel in fulfilling the requirements for the academic course and the SAE Aero Design competition.

Team Roles

Each team member is delegated a specific role based on their experience and skill sets. The roles are described as follows:

Aeronautics/3D Printing Engineer - Nestor Aguirre:

The responsibility of the aeronautics and 3D printing engineer is to perform in both areas to combine them properly, so they work harmonically and successfully. This role includes the study and analysis of the best design for aerodynamic and structural components while being aware of manufacturing the 3D printed components and understanding their limitations and advantages as the building material. They will explore new designs and building techniques to combine both fields. They will make sure that the manufacturing and the aerodynamic design engineers are both in constant communication and heading towards the same goal.

Aeronautics Engineer/Financial Advisor – Leah Evans:

The Aeronautics Engineer will manage the team, develop a project plan, timeline for the project and delegate tasks among group members according to their skill sets The aeronautics engineer oversees designing, developing, and testing the aerodynamic components implemented in the project, such components include the fuselage and the control surfaces. They are responsible for confirming these components adherence to all SAE Aero Design competition rules to remain eligible for competing. Additionally, they must maintain communications with the electronics, CAD, and 3D printing engineers to ensure the components integrate as a functional system.

The financial advisor manages the budget and maintains a record of all credits and debits to project account. Any product or expenditure requests must be presented to the advisor, whom is then responsible for reviewing and analyzing equivalent/alternate solutions. They then relay the information to the team and if the request is granted, order the selection. A record of these analyses and budget adjustments must be kept in an organized document. They also assist the team in exploring fundraising options and acquiring sponsorship. This team member also owns the team calendar and assists in organizing, planning, and the setting up of meetings.

3D Printing Engineer – David Litter:

The 3D printing engineer is responsible for ensuring all CAD files are printed promptly and correctly. They will work closely with the CAD owner and organizer to make sure that all parts fit together correctly, can be printed, and determines the best settings for printing. They keep all relevant documentation in an organized manner and communicate with other team members to ensure the components integrate as a functional system. In addition, they are responsible for keeping a record of all correspondence between the group and 'minutes' for the meetings

Electrical Design Engineer – Hebert Lopez:

The electrical design engineer oversees designing, developing, and testing the electrical circuit to be implemented in the project. The electrical design engineer must pick the appropriate components, build the circuit, test it, and make sure it complies with the SAE Aero Design competition rules to remain eligible for competion. The electrical design engineer oversees designing a specific aspect of the project. In this case, they will design the electrical circuit to be used in the project. They will also assist in establishing dimensions and characteristics that follow the regulations established for the competition. They will keep all design documentation in an organized manner and communicate with other team members to ensure the components integrate as a functional system.

This team member is also the web master. The web master is in charge of managing the team's web page content, such as uploading the necessary documents and pictures.

Electronics Test Engineer – Martina Kvitkovičová:

The electronics test engineer is responsible for identifying, designing, and testing of the components needed for a successful parts integration into the final project design. They will ensure that all the parts that are acquired and ordered will be used to build a prototype and later the final product. Additionally, they will assist with confirming the 3D printed airplane components meet the specific needs and guidelines for a successful takeoff, flight, and landing. The final product will be fully tested for proper component functionality and system performance. They will keep all test documentation in an organized manner and communicate with other team members to ensure the components integrate as a functional system.

CAD Engineer – Zachary Silver:

The CAD Engineer will manage the team, develop a project plan, timeline for the project and will delegate tasks among group members according to their skill sets. They will also finalize all documents and provide input on other positions where needed. The CAD Engineer is responsible for promoting teamwork. If a problem arises, the team leader will act in the best interest of the project. They will keep the communication flowing between the team members, the sponsor, and the advisor. They take the lead of organizing, planning, and the setting up of meetings.. Finally, they are responsible for keeping the team on track with the project and its set timeline.

The CAD Engineer also directs the main assembly of the project in the designated CAD program. They must create a file naming convention and ensure that it is followed by all of those that create CAD files. They must also retrieve files from other group members and ensure that there is a back of up of the files in a location where everyone on the team has access to the files. They must communicate with the 3D printing engineers to ensure that parts are physically feasible to 3D print.

Other Duties:

Team members must at minimum complete the tasks as assigned to their role, but they are not confined to their role and are encouraged to share input for the project. Each person on the team will be treated as an equal. As the project progresses, some roles may become less active. Those member's efforts will be refocused to assist with other team member's responsibilities. Future roles include, but are not limited to, webmaster, report editor, and social planner.

Communication

For daily communication the team will use the messaging app, GroupMe. Basecamp will be the primary form of project management. Basecamp is primarily web based, but team members are strongly encouraged to download the mobile app. Team members are required to use the message board on Basecamp for pitching project ideas and sharing feedback. Messages directed at a specific team member, such as using the '@' feature for direct notification, require response from the team member within 4 hours during daytime hours (10am – 10pm). Additionally, Basecamp will have the home link to the team OneDrive folder where all documents will be stored and shared. Email will be a secondary form of communication for issues not being time sensitive. Invitations to milestone meetings, such as advisor and sponsor meetings, will be sent via Outlook meeting invite. Team members must respond to these invitations within 24 hours.

Each group member must have a working email for the purposes of communication and file transference. Members must check their emails at least twice a day to check for important information and updates from the group. Although members will be initially informed via Basecamp, meeting dates and pertinent information from the sponsor will additionally be sent over email; therefore, it is very important that each group member checks their email frequently.

If a meeting must be cancelled, an email must be sent to the group at least 24 hours in advance. Any team member that cannot attend a meeting must give an advanced notice of 24 hours informing the group of their absence unless it is known that the team member cannot make the set meeting due to a scheduling conflict (work or class). Rationale for a team member's absence will be appreciated but is not required if the reason is personal. Repeated absences in violation with this agreement will not be tolerated.

Team members are required to submit their assignments on time. If a team member requires assistance to complete their assignment they are expected to reach out for help. Team members who do not submit their assignment within two days of the expected delivery date will be referred to external sources such as Dr. McConomy and Dr. Hooker for inhibiting the project's success.

Attendance Policy

Attendance will be recorded at all team meetings upon the start of the meeting. Team members who are more than 30 minutes late to the meeting will be considered absent and are responsible for providing snacks for the following team meeting Invitations to meetings will be sent through Microsoft Outlook and must be responded to within 24 hours. If a team member is unable to attend a meeting, at least a 24-hour notice must be given prior to the start of the meeting must be given to the team by changing their meeting invite status to "decline" and posting in the GroupMe chat. In the case of an emergency, such that less than a 24-hour notice is given, notice must be given as soon as possible and the reason for missing will be noted. Examples of acceptable emergency reasons for absences include major health issues, car troubles, family emergency, jury duty, or pet emergency/veterinary ER visit. Other reasons will be addressed on a case by case basis. In the event that a team member is on vacation or out of town during the time of a meeting they are expected to alert the team of their expected absence and if it is possible, they must skype or call into the meeting. The team will seek external support from Dr. McConomy and Dr. Hooker for disciplinary action after 2 absences per semester. Team members who fail to complete their tasks will also be considered for disciplinary action by external support. Team members must be aware that the aforementioned disciplinary action may affect their grade on the project. The team reserves the right to ask for external support without the consent of a team member's knowledge.

Team Dynamics

The students will work as a team while allowing one another to make any suggestions or constructive criticisms without having the fear of being embarrassed. If any member on this team finds a task to be too difficult, it is expected that the member will ask for help from the other team members. If any team member feels they are not being respected or taken seriously, that member must bring it to the attention of the team or team leader to resolve the issue. We shall not let emotions dictate our actions. Everything the team does is for the benefit of the project and together everyone will strive to make the project successful.

Ethics

Team members are required to be familiar with the NSPE Engineering Code of ethics as they are responsible for their obligations to the public, the client, the employer, and the profession. There will be stringent following of the NSPE Engineering Code of Ethics.

Dress Code

Team members may wear casual attire for all team meetings and working events. Proper personal protective equipment (PPE) must be worn when in the lab or machine shop as required by the task and location at hand. Casual attire is acceptable for advisor meetings. In person meetings with the sponsor(s) and additional officials of significance will require team members to come in business casual attire. All group presentations will be given in business casual or business formal and will be decided by the team at least 24 hours prior to the presentation. Acceptable forms of business casual attire include khakis and a tucked in polo shirt, or slacks and a blouse. Acceptable forms of business formal attire include a suit and tie, or dress pants and a blazer.

Weekly and Biweekly Tasks

Meetings with the advisor will be held biweekly on Fridays at 2pm in Dr. Shih's office located in the AME building. Team meetings will be held every week and will be posted on Basecamp; invitations will be sent to all attending all of the team members via Microsoft Outlook. During said meetings, ideas, project progress, budget, conflicts, timelines and due dates will be discussed. All members are expected to participate in meeting discussions. In addition, tasks will be delegated to team members during these meetings. It is expected that team members attend all the meetings and repeated unexcused absences will not be tolerated.

Decision Making

All team members will take part in the decision-making process, which will follow the decision-making guidelines. Should ethical/moral reasons be cited as a dissenting reason, then the ethics/morals shall be evaluated as a group and the majority will decide on the plan of action. If the group is equally divided during a decision, then the team's advisor will be included to break the tie. In this situation, both sides will be given a chance to explain their rational to the advisor before a decision is made. Individuals with conflicts of interest should not participate in decision-making processes, but do not need to announce said conflict. It is up to team member to act ethically, for the best interests of the group, and the goals of the project. Achieving the goal of the project will be the top priority for each group member. Below are the steps to be followed for each decision-making process:

- Problem Definition – Define the problem and understand it. Discuss among the group.
- Tentative Solutions – Brainstorm possible solutions. Discuss among the group to determine the most plausible solutions.
- Data/History Gathering and Analysis – Gather necessary data required for implementing tentative solutions. Re-evaluate tentative solutions for plausibility and effectiveness.
- Selected Solution – The group picks a single solution to pursue with just rational and support.
- Design – Design the selected solution for the product and construct it. Re-evaluate for plausibility and effectiveness.
- Test and Simulation/Observation – Test design for selected solution and gather data. Re-evaluate for plausibility and effectiveness.
- Final Evaluation – Evaluate the testing phase and determine its level of success. Decide if design can be improved and if time/budget allows for it.

If the team, or a team member, acquires new information about the selected solution to show that it is no longer a viable solution, then the team will reconvene to re-evaluate the solution at hand. A vote will reoccur on whether the original selected solution should continue to be implemented into the product. If two solutions to a problem are both considered to be viable options by the team, then they may both be pursued for seven days. On the seventh day, the team will reconvene and choose a single solution to continue to pursue based on the provided rationale and evidence.

Conflict Resolution

In the event of discord amongst team members the following steps shall be respectfully employed:

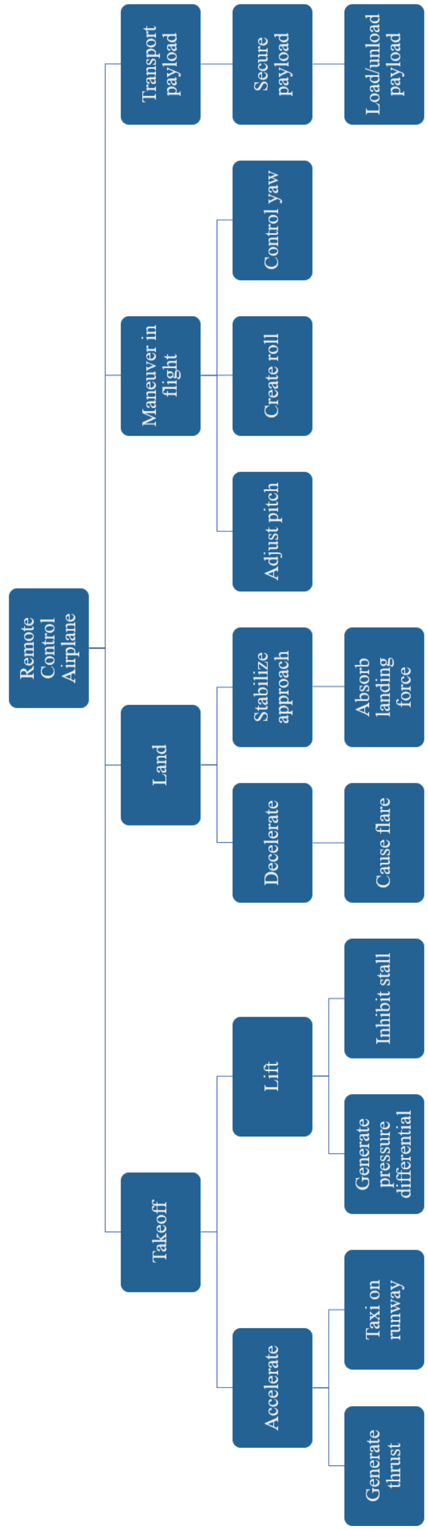
- Each team member is invited to provide justification for their solution. During this time, the team member may or may not invite other team members to participate in their justification. Team members must respect a team member's decision to speak freely without being interrupted.
- A meeting with the advisor or the course instructor will be booked for all team members to attend. The advisor or the course instructor will facilitate the resolution to the conflicts.
- Administration of a vote, if needed, favoring majority rule.
- In the event of a tied vote, the advisor or course instructor will be the deciding vote. Or if agreed upon by the entire team, a coin flip will decide.

Statement of Understanding

By signing this document, the members of Team 513 agree to all Code of Conduct above and will abide by the code of conduct set forth by the group.

Name	Signature	Date
Leah Evans		01/09/2020
Zachary Silver		01/09/2020
David Litter		01/09/2020
Martina Kvitkovičová		1/10/2020
Hebert Lopez	Hebert López	1/10/2020
Nestor Aguirre	Nestor Aguirre	1/10/2020

Appendix B: Functional Decomposition



Appendix C: Target Catalog

Function	Metric	Target	Method of Validation	Tools for Validation
Accelerate				
Generate Thrust	Force	10 lbf	Experimental	Force Gauge/ Scale
	Propeller Size	14in - 18in	Physical Experiment and Computations	Test sized propellers to determine maximum thrust and compare against DriveCalc prog ram
	Electric Motor Rating Kv Ratting	390 Kv Rat ing	Given by Manufacture	Manufacture Validated
	Electric Motor Maximum Power	950W	Experimental	Apply current and measure voltage with a voltmeter
	Propulsion System Ba ttery Voltage	22.2 V	Experimental	Voltmeter
Taxi on Runway	Angular Steering for Front Wheel	-60° to 60°	Experimental	Attach to front wheel, test total rotation, and record time
Apply Throttle	Velocity for Takeoff	30 mph	Theoretical Calculations	MATLAB, PropCal 3. 0
	Ground Distance for Takeoff	Less than 100 ft	Theoretical and Experimental	MATLAB and flight testing
	Propulsion system battery capacity	4000 mAh	Given by manufacturer	Manufacturer Validate d
	Propulsion System battery duration	10 minutes	Theoretical Calculations	Determined by current drawn by propulsion system
	Power limiter top limit	1000 W	Competition Requirement	Manufacturer Validated

Lift				
Generate Pressure Differential	Angle of Attack	2-5 Degrees	Database Comparative Analysis	xlfr5
	Coefficient of Lift	Greater than 1.0	Theoretical Calculations	MATLAB
	Coefficient of Drag	Less than 1.0	Theoretical Calculations	MATLAB
	Wingspan	60 – 120 in	Experimental and Theoretical Calculations	Prototyping, Solid works simulations, and MATLAB
	Wing Loading	10 –20 oz/ft^2	Finite Element Analysis	MATLAB, SOLIDWORKS Simulation
Structure	Gross-take-off weight	Less than 55 lbs	Theoretical Calculations, Physical Experimentation	SOLIDWORKS Simulation, digital scale
Inhibit Stall	Stall Speed	Greater than 30mph	Theoretical Calculation	MATLAB simulation
	Stall Angle of Attack	Greater than 25 Degrees	Experimentation	Flight testing and XLFR5
Decelerate				
Reduce throttle	Velocity for Landing	Less than 30mph	Theoretical calculations and experimentation	MATLAB, Prop Calc 3.0, testing motor and flight testing
Engage Flaps	Time to deploy	1 Second	Experimental	Stopwatch
	Angle of flaps	0°- 30°	Computer simulation	SOLIDWORKS Simulations
Stabilize approach				
Absorb Landing Force	Force	2x Weight (lbf)	Theoretical	MATLAB and FEA

Maneuver in Flight				
Servo Motors	Servo Motor Angular Speed	0.17 sec per 60 degrees	Given by Manufacture	Manufacturer Validated
	Angular Pitch Position	-60° to 60°	Experimentally Test	Attach to control surface, test total rotation, and record time
	Angular Roll Position	-60° to 60°	Experimentally Test	Attach to control surface, test total rotation, and record time
	Angular Yaw Position	-60° to 60°	Experimentally Test	Attach to control surface, test total rotation, and record time
Secure Cargo				
Load/Unload Payload	Time	2 Minutes	Human	Load/unload payload from cargo area with hands
Carry Payload	Force	5 lbf	Experimental	
	Radio System Battery Current Capacity	1000 mAh	Rule Requirement	Manufacturer Validated
	Radio System Battery Time Duration	6 min	Theoretical Calculations	Determined by current drawn by controller
Controller				
Radio Control System	Wavelength Frequency	2.4 GHz	Competition Requirement	Manufacturer Validated
	Electronic speed controller continuous current	85 A	Given by Manufacturer	Manufacturer Validated

Appendix D: Concept Generation

Table D-1

Concept Generation Extended Component Table

Modular Connections	3D Materials	Propeller Size	Propeller Pitch	Number of Blades	Landing Gear	Landing Gear Mechanism	Landing Gear Suspension	Wings	Wing Location	Wing Orientation	Aileron/Flaps	Motor	Fuselage	Electronics add ons	Battery	Tail
Compression	PLA	Large Prop	Large Pitch	2 Blade	Tricycle with Front Wheel	Fixed	Fixed	Elliptical	Low Wing	Uniform Leading Edge	Plain	Low kv Rating	Flying boat	Speed Densor	High Battery Capacity	Conventional
Formfit	ABS	Small Prop	Small Pitch	3 Blade	Tricycle with Tail-Wheel	Retractable	3D Printed Flexible	Tapered	Mid Wing	Swept	Split	High kv Rating	Double booms	Gyroscope	Low Batter Capacity	T-Tail
Glue	LW-PLA			4 Blade	Four Wheels		Metal Fleible	Rectangular	High Wing		Slotted		Symmetric from side view	Camera	Higher Ampacity	Cruciform
Fasteners	TPU				Ski-Plane		Shocks	Inverted			Fowler		SubSonics	Illumination	Appropriate C rating	Dual
Japanese glue free joints	PP							Winglets			Double-Slotted Fowler		Super Sonic	Extra Battery		Triple
T-joint glued form fit								Triangular			Junkers		High capacity sub sonic	Special Speed Controller		V
Soldering											Gouge		High manurability super sonic			Inverted V
											Fairey-Youngman					Inverterd Y
											Zap					Twin
											Krueger					Boom
											Gurney					High Boom
											Leading Edge Droop					Multiple-plane tail
											Handley-page					

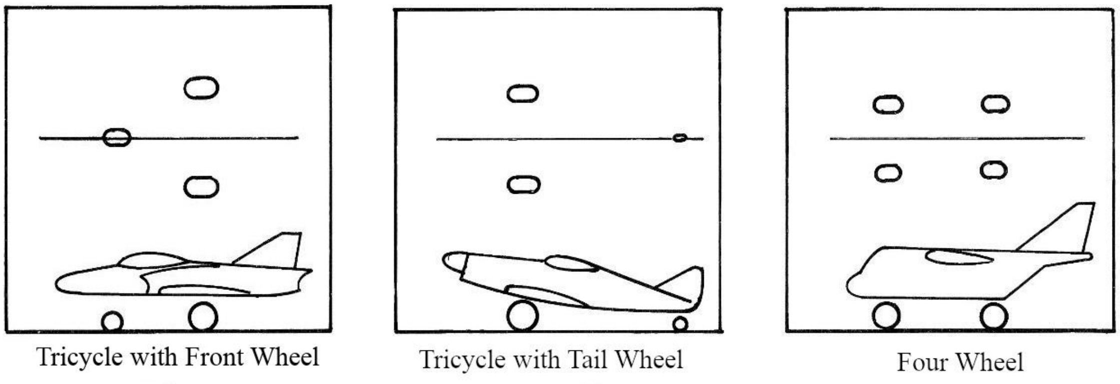


Figure D-1. Landing gear configurations (Özgen, 2015).

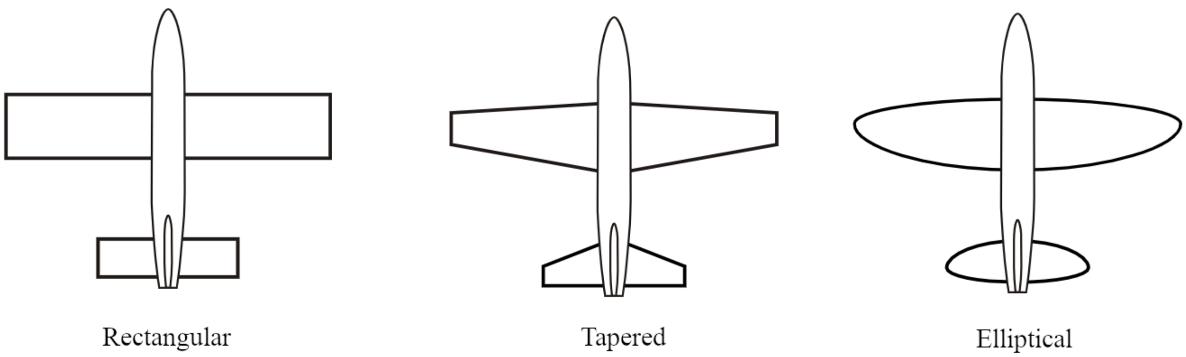


Figure D-2. Wing shape (Wing Configuration, 2019).

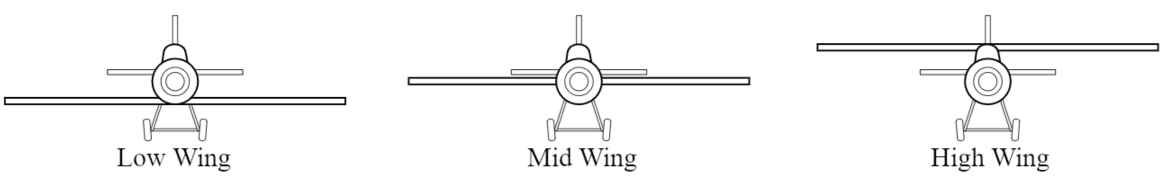


Figure D-3. Wing shape (Wing Configuration, 2019).

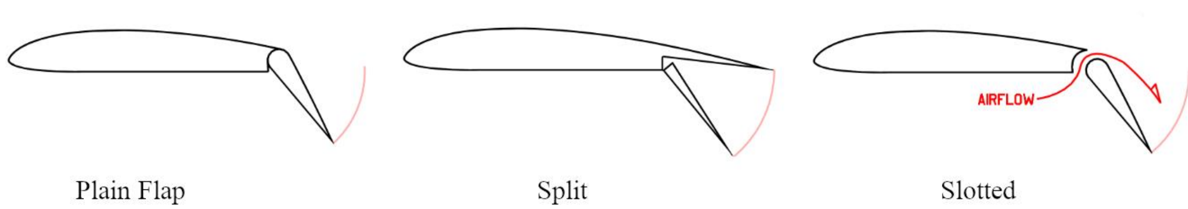


Figure D-4. Flap style (Flap (Aeronautics), 2019).

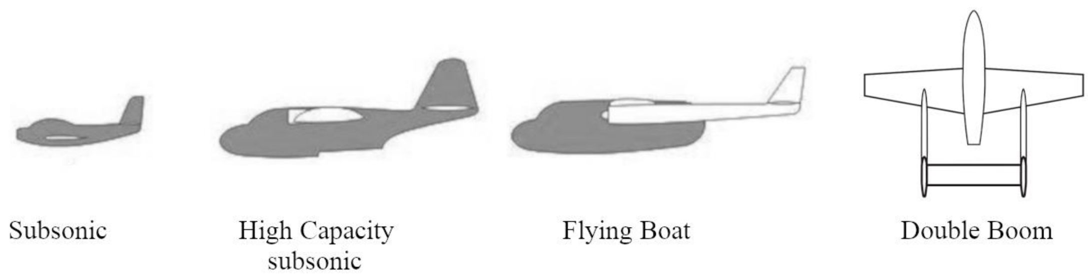


Figure D-5. Fuselage style (Fuselage , 2019).

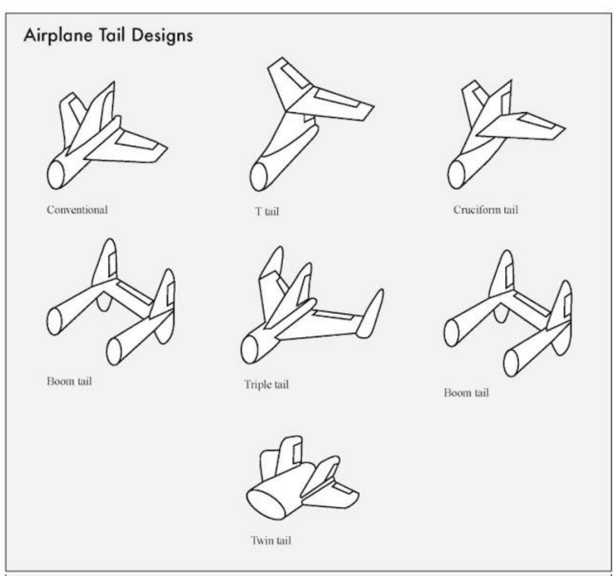


Figure D-5. Airplane tail configurations (Flight: Tail Designs, n.d.).

Table D-2

100 Generated Concepts

Concept #:	3D Materials	Landing Gear	Wings	Wing Location	Aileron/Flaps	Fuselage	Tail
1	PLA	Tricycle with Tail-Wheel	Elliptical	Mid Wing	Plain	High Capacity Sub Sonic	Boom
2	ABS	Four Wheels	Rectangular	Mid Wing	Slotted	Flying boat	High Boom
3	ABS	Tricycle with Tail-Wheel	Tapered	High Wing	Split	SubSonics	T-Tail
4	PLA	Tricycle with Front Wheel	Elliptical	Low Wing	Split	Double booms	Boom
5	PLA	Four Wheels	Elliptical	Mid Wing	Split	Double booms	Triple
6	LW-PLA	Tricycle with Tail-Wheel	Tapered	Low Wing	Slotted	Double booms	Triple
7	ABS	Tricycle with Front Wheel	Tapered	Low Wing	Split	Double booms	T-Tail
8	LW-PLA	Tricycle with Tail-Wheel	Tapered	Mid Wing	Slotted	High Capacity Sub Sonic	Triple
9	PLA	Tricycle with Tail-Wheel	Tapered	Mid Wing	Slotted	SubSonics	Triple
10	LW-PLA	Four Wheels	Rectangular	Mid Wing	Split	High Capacity Sub Sonic	High Boom
11	ABS	Tricycle with Tail-Wheel	Rectangular	High Wing	Slotted	Double booms	Twin
12	PLA	Four Wheels	Elliptical	High Wing	Plain	Double booms	T-Tail
13	LW-PLA	Four Wheels	Rectangular	Low Wing	Split	Flying boat	Cruciform

14	PLA	Tricycle with Tail-Wheel	Tapered	Low Wing	Slotted	Flying boat	Boom
15	LW-PLA	Tricycle with Front Wheel	Elliptical	Mid Wing	Slotted	Double booms	Boom
16	PLA	Four Wheels	Elliptical	Low Wing	Slotted	High Capacity Sub Sonic	Conventional
17	ABS	Four Wheels	Elliptical	Low Wing	Slotted	SubSonics	Conventional
18	ABS	Tricycle with Front Wheel	Elliptical	Mid Wing	Split	Flying boat	T-Tail
19	ABS	Tricycle with Tail-Wheel	Rectangular	Mid Wing	Split	High Capacity Sub Sonic	Triple
20	LW-PLA	Tricycle with Tail-Wheel	Rectangular	Mid Wing	Split	Double booms	T-Tail
21	LW-PLA	Tricycle with Tail-Wheel	Tapered	High Wing	Plain	Flying boat	Conventional
22	PLA	Tricycle with Front Wheel	Tapered	High Wing	Slotted	Double booms	Boom
23	LW-PLA	Tricycle with Tail-Wheel	Elliptical	Mid Wing	Split	High Capacity Sub Sonic	Triple
24	PLA	Four Wheels	Rectangular	High Wing	Slotted	Flying boat	Cruciform
25	PLA	Four Wheels	Tapered	Low Wing	Split	Double booms	Twin
26	ABS	Tricycle with Front Wheel	Tapered	High Wing	Slotted	Flying boat	Conventional
27	ABS	Four Wheels	Rectangular	High Wing	Split	SubSonics	Cruciform
28	ABS	Four Wheels	Rectangular	High Wing	Plain	High Capacity Sub Sonic	Boom
29	PLA	Tricycle with Tail-Wheel	Elliptical	Mid Wing	Split	Flying boat	T-Tail

30	LW-PLA	Tricycle with Front Wheel	Elliptical	Low Wing	Split	High Capacity Sub Sonic	Cruciform
31	PLA	Tricycle with Tail-Wheel	Rectangular	Low Wing	Slotted	Flying boat	Conventional
32	ABS	Four Wheels	Elliptical	Low Wing	Split	Flying boat	T-Tail
33	PLA	Four Wheels	Elliptical	Low Wing	Split	Flying boat	T-Tail
34	PLA	Tricycle with Tail-Wheel	Rectangular	Mid Wing	Split	SubSonics	T-Tail
35	PLA	Tricycle with Front Wheel	Tapered	High Wing	Split	Flying boat	Boom
36	LW-PLA	Tricycle with Tail-Wheel	Tapered	Low Wing	Split	Flying boat	Boom
37	ABS	Four Wheels	Tapered	High Wing	Plain	Flying boat	T-Tail
38	LW-PLA	Tricycle with Front Wheel	Tapered	Low Wing	Plain	SubSonics	Conventional
39	LW-PLA	Tricycle with Front Wheel	Rectangular	Mid Wing	Plain	High Capacity Sub Sonic	High Boom
40	LW-PLA	Tricycle with Tail-Wheel	Tapered	Low Wing	Plain	High Capacity Sub Sonic	Twin
41	PLA	Tricycle with Front Wheel	Rectangular	Mid Wing	Plain	High Capacity Sub Sonic	Cruciform
42	ABS	Four Wheels	Tapered	High Wing	Split	Flying boat	T-Tail
43	LW-PLA	Tricycle with Tail-Wheel	Tapered	Mid Wing	Slotted	Double booms	Twin
44	ABS	Tricycle with Tail-Wheel	Elliptical	Low Wing	Split	SubSonics	Conventional
45	PLA	Tricycle with Tail-Wheel	Rectangular	High Wing	Plain	Double booms	T-Tail

46	ABS	Tricycle with Front Wheel	Elliptical	Mid Wing	Split	Double booms	High Boom
47	LW-PLA	Tricycle with Front Wheel	Tapered	Mid Wing	Slotted	Flying boat	Conventional
48	LW-PLA	Tricycle with Front Wheel	Rectangular	Mid Wing	Slotted	Double booms	T-Tail
49	LW-PLA	Tricycle with Tail-Wheel	Elliptical	High Wing	Plain	Flying boat	Triple
50	LW-PLA	Four Wheels	Tapered	High Wing	Split	Flying boat	High Boom
51	LW-PLA	Four Wheels	Tapered	High Wing	Split	Double booms	Cruciform
52	ABS	Tricycle with Front Wheel	Rectangular	Mid Wing	Slotted	Flying boat	High Boom
53	LW-PLA	Tricycle with Tail-Wheel	Rectangular	Low Wing	Plain	Double booms	High Boom
54	PLA	Four Wheels	Elliptical	High Wing	Split	Flying boat	Triple
55	PLA	Four Wheels	Tapered	High Wing	Plain	Flying boat	Twin
56	LW-PLA	Tricycle with Front Wheel	Elliptical	Mid Wing	Slotted	SubSonics	T-Tail
57	PLA	Four Wheels	Rectangular	High Wing	Plain	Flying boat	Cruciform
58	PLA	Tricycle with Front Wheel	Rectangular	Low Wing	Slotted	Double booms	High Boom
59	PLA	Four Wheels	Rectangular	Low Wing	Split	Flying boat	Twin
60	LW-PLA	Tricycle with Tail-Wheel	Rectangular	Low Wing	Slotted	Flying boat	Conventional
61	LW-PLA	Tricycle with Front Wheel	Rectangular	High Wing	Slotted	Flying boat	Boom
62	PLA	Tricycle with Tail-Wheel	Elliptical	Mid Wing	Split	High Capacity Sub Sonic	Twin

63	ABS	Tricycle with Front Wheel	Tapered	High Wing	Split	High Capacity Sub Sonic	Triple
64	ABS	Tricycle with Front Wheel	Tapered	Low Wing	Plain	SubSonics	Cruciform
65	LW-PLA	Tricycle with Tail-Wheel	Rectangular	High Wing	Plain	Flying boat	Conventional
66	PLA	Tricycle with Front Wheel	Rectangular	Mid Wing	Plain	SubSonics	Conventional
67	LW-PLA	Tricycle with Front Wheel	Elliptical	Low Wing	Split	Double booms	Twin
68	LW-PLA	Tricycle with Front Wheel	Elliptical	Mid Wing	Plain	Flying boat	Boom
69	LW-PLA	Tricycle with Tail-Wheel	Elliptical	Mid Wing	Plain	High Capacity Sub Sonic	Triple
70	LW-PLA	Tricycle with Tail-Wheel	Tapered	High Wing	Plain	Flying boat	Triple
71	LW-PLA	Tricycle with Tail-Wheel	Elliptical	Low Wing	Plain	SubSonics	Cruciform
72	PLA	Tricycle with Tail-Wheel	Rectangular	High Wing	Slotted	High Capacity Sub Sonic	Cruciform
73	LW-PLA	Tricycle with Front Wheel	Elliptical	Low Wing	Slotted	Double booms	Boom
74	LW-PLA	Four Wheels	Tapered	High Wing	Split	Double booms	High Boom
75	ABS	Four Wheels	Tapered	High Wing	Split	Flying boat	High Boom
76	PLA	Tricycle with Tail-Wheel	Rectangular	High Wing	Split	Flying boat	Boom
77	PLA	Tricycle with Front Wheel	Tapered	High Wing	Slotted	SubSonics	Conventional
78	LW-PLA	Tricycle with Tail-Wheel	Tapered	Mid Wing	Split	Flying boat	Twin

79	ABS	Tricycle with Front Wheel	Tapered	Low Wing	Split	SubSonics	T-Tail
80	LW-PLA	Tricycle with Front Wheel	Tapered	Low Wing	Plain	High Capacity Sub Sonic	Cruciform
81	PLA	Tricycle with Front Wheel	Elliptical	Mid Wing	Split	High Capacity Sub Sonic	T-Tail
82	PLA	Tricycle with Tail-Wheel	Tapered	High Wing	Split	Flying boat	Twin
83	ABS	Four Wheels	Rectangular	High Wing	Split	High Capacity Sub Sonic	Triple
84	PLA	Four Wheels	Rectangular	High Wing	Slotted	Flying boat	T-Tail
85	ABS	Four Wheels	Tapered	Mid Wing	Split	SubSonics	Boom
86	ABS	Tricycle with Tail-Wheel	Rectangular	Mid Wing	Slotted	High Capacity Sub Sonic	High Boom
87	ABS	Tricycle with Front Wheel	Tapered	High Wing	Plain	Flying boat	High Boom
88	PLA	Tricycle with Tail-Wheel	Tapered	Mid Wing	Slotted	Double booms	T-Tail
89	LW-PLA	Four Wheels	Tapered	High Wing	Slotted	High Capacity Sub Sonic	Cruciform
90	LW-PLA	Tricycle with Front Wheel	Rectangular	Low Wing	Split	Double booms	High Boom
91	PLA	Tricycle with Tail-Wheel	Tapered	Mid Wing	Plain	SubSonics	Twin
92	ABS	Tricycle with Front Wheel	Tapered	Mid Wing	Plain	High Capacity Sub Sonic	T-Tail
93	LW-PLA	Four Wheels	Rectangular	Mid Wing	Plain	Double booms	T-Tail
94	ABS	Tricycle with Front Wheel	Rectangular	Mid Wing	Split	Double booms	Triple

95	LW-PLA	Four Wheels	Tapered	Mid Wing	Plain	Double booms	Cruciform
96	PLA	Tricycle with Front Wheel	Rectangular	Mid Wing	Split	Double booms	Twin
97	LW-PLA	Four Wheels	Tapered	Low Wing	Plain	Flying boat	Triple
98	ABS	Tricycle with Tail-Wheel	Rectangular	High Wing	Slotted	SubSonics	Conventional
99	ABS	Four Wheels	Rectangular	Low Wing	Split	Double booms	Cruciform
100	ABS	Tricycle with Tail-Wheel	Elliptical	High Wing	Slotted	High Capacity Sub Sonic	High Boom

101. Modified Draco airplane
102. Modified PZL Wilga airplane
103. Modified Cessna 337 airplane
104. Modified Piper Super Cub airplane
105. Modified Zenith CH-750 airplane
106. Modified M28 Skytruck airplane
107. Modified STOL UC-1 Twinbee airplane
108. Modified Northrop 1929 Flying wing airplane
109. Modified Northrop XP-56 airplane
110. Modified Knapp Lil Cub airplane

Appendix E: Analytic Hierarchy Process

Table E-1

Criteria 1 – Drag

	Weighted Sum Vector	Criteria Weight	Consistency (Con)
Concept 1	1.460	0.480	3.044
Concept 4	0.346	0.115	3.010
Concept 6	1.230	0.405	3.033
Avg Con: 3.029	Con Index: 0.015	Con Ratio: 0.028	Consistent?: **Yes**

Table E-2

Criteria 2 – Weight

	Weighted Sum Vector	Criteria Weight	Consistency (Con)
Concept 1	1.230	0.405	3.033
Concept 4	0.346	0.115	3.010
Concept 6	1.460	0.480	3.044
Avg Con: 3.029	Con Index: 0.015	Con Ratio: 0.028	Consistent?: **Yes**

Table E-3

Criteria 3 – Wingspan

	Weighted Sum Vector	Criteria Weight	Consistency (Con)
Concept 1	0.790	0.260	3.033
Concept 4	0.320	0.106	3.011
Concept 6	1.946	0.633	3.072
Avg Con: 3.039	Con Index: 0.019	Con Ratio: 0.037	Consistent?: **Yes**

Table E-4

Criteria 4 – Time to Unload

	Weighted Sum Vector	Criteria Weight	Consistency (Con)
Concept 1	0.790	0.260	3.033
Concept 4	0.320	0.106	3.011
Concept 6	1.946	0.633	3.072
Avg Con: 3.039	Con Index: 0.019	Con Ratio: 0.037	Consistent?: **Yes**

Table E-5

Criteria 5 – Manufacturing Time

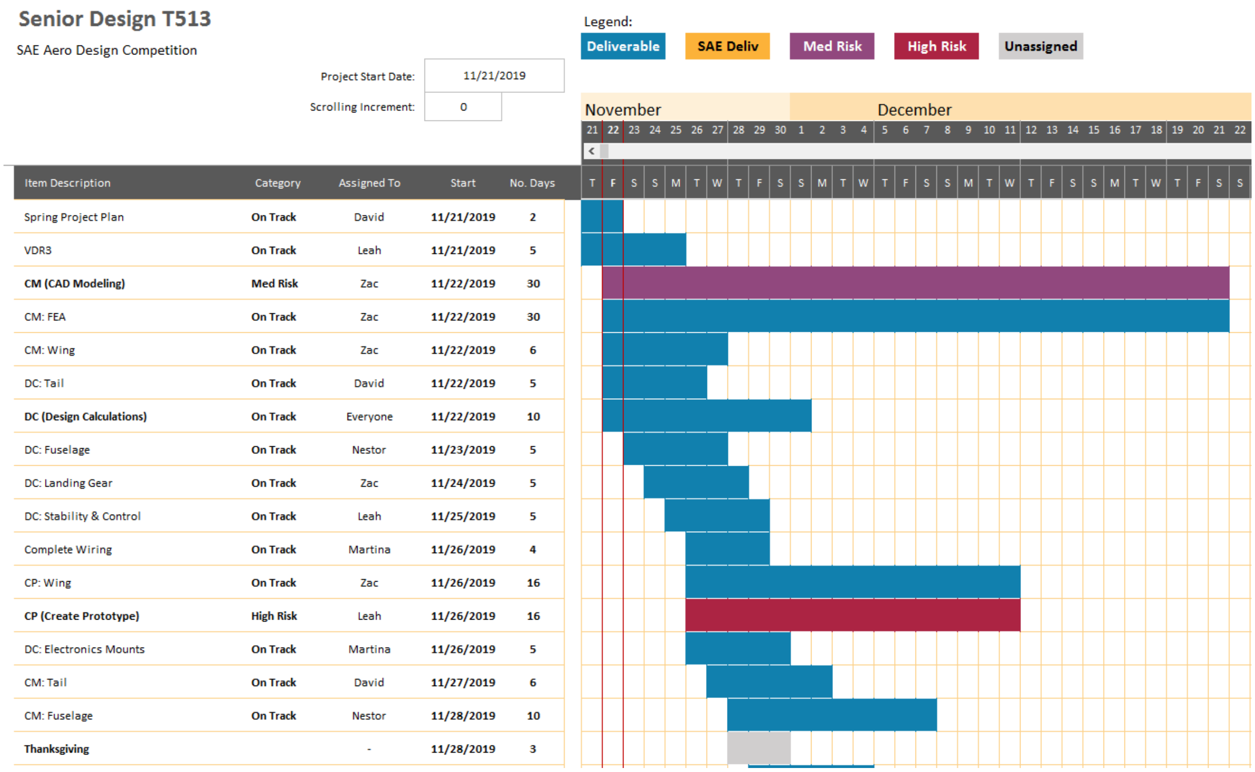
	Weighted Sum Vector	Criteria Weight	Consistency (Con)
Concept 1	0.273	0.091	3.000
Concept 4	1.364	0.455	3.000
Concept 6	1.364	0.455	3.000
Avg Con: 3.000	Con Index: 0.000	Con Ratio: 0.000	Consistent?: **Yes**

Table E-6

Criteria 6 – Cost

	Weighted Sum Vector	Criteria Weight	Consistency (Con)
Concept 1	1.853	0.574	3.230
Concept 4	0.427	0.140	3.049
Concept 6	0.897	0.286	3.133
Avg Con: 3.137	Con Index: 0.069	Con Ratio: 0.132	Consistent?: **No**

Appendix F: Spring Project Plan



Item Description	Category	Assigned To	Start	No. Days
Spring Project Plan	On Track	David	11/21/2019	2
VDR3	On Track	Leah	11/21/2019	5
CM (CAD Modeling)	Med Risk	Zac	11/22/2019	30
CM: FEA	On Track	Zac	11/22/2019	30
CM: Wing	On Track	Zac	11/22/2019	6
DC: Tail	On Track	David	11/22/2019	5
DC (Design Calculations)	On Track	Everyone	11/22/2019	10
DC: Fuselage	On Track	Nestor	11/23/2019	5
DC: Landing Gear	On Track	Zac	11/24/2019	5
DC: Stability & Control	On Track	Leah	11/25/2019	5
Complete Wiring	On Track	Martina	11/26/2019	4
CP: Wing	On Track	Zac	11/26/2019	16
CP (Create Prototype)	High Risk	Leah	11/26/2019	16
DC: Electronics Mounts	On Track	Martina	11/26/2019	5
CM: Tail	On Track	David	11/27/2019	6
CM: Fuselage	On Track	Nestor	11/28/2019	10
Thanksgiving		-	11/28/2019	3

Figure F-1. Gantt Chart Part 1

Senior Design T513

SAE Aero Design Competition

Project Start Date: 11/21/2019

Scrolling Increment: 16

Thanksgiving		-	**11/28/2019**	**3**
CM: Landing Gear	**On Track**	Leah	**11/29/2019**	**6**
CM: Electronics Mounts	**On Track**	Hebert	**12/1/2019**	**5**
Engineering Ring Ceremony	**Goal**	-	**12/3/2019**	**1**
CP: Tail	**On Track**	David	**12/7/2019**	**8**
CP: Fuselage	**On Track**	Leah	**12/9/2019**	**5**
DR: Performance Analysis – Takeoff/Lift	**Low Risk**	Leah	**12/9/2019**	**3**
DR (Design Report)	**Low Risk**	-	**12/9/2019**	**44**
Final Exams	**Goal**	-	**12/9/2019**	**5**
CP: Landing Gear	**On Track**	Nestor	**12/10/2019**	**2**
CP: Electronic Mounts	**On Track**	Martina	**12/11/2019**	**1**
Fall Break		-	**12/13/2019**	**24**
DR: Test and Integration	**Low Risk**	Leah	**12/16/2019**	**5**
DR: Loads and Environments, Assumption:	**Low Risk**	Heb	**1/3/2020**	**4**
DR: Performance Analysis – Flight Maneuv	**Low Risk**	Martina	**1/6/2020**	**2**
DR: Performance Analysis - Thrust	**Low Risk**	Nestor	**1/6/2020**	**3**
First day of classes	**Goal**	-	**1/6/2020**	**1**

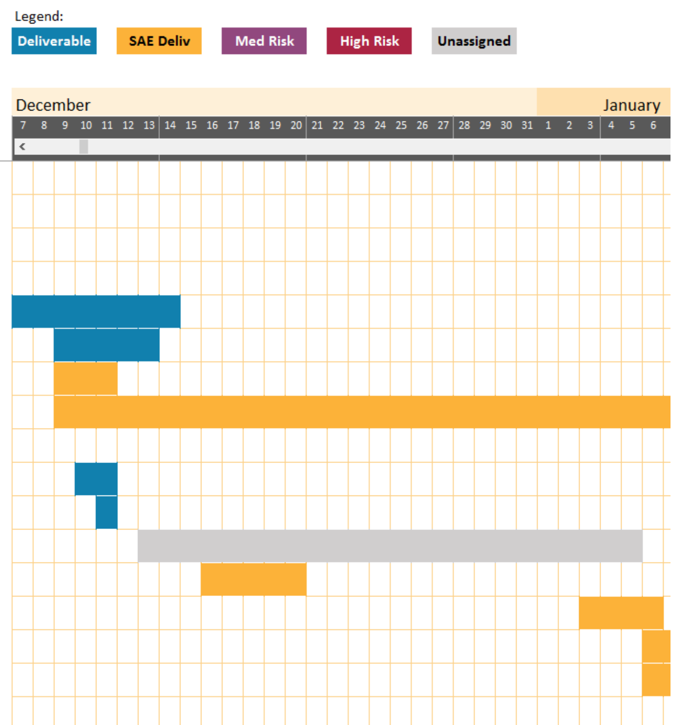


Figure F-2. Gantt Chart Part 2

Senior Design T513

SAE Aero Design Competition

Project Start Date: 11/21/2019

Scrolling Increment: 38

DR: Performance Analysis – Takeoff/Lift	**Low Risk**	Leah	**12/9/2019**	**3**
DR (Design Report)	**Low Risk**	-	**12/9/2019**	**44**
Final Exams	**Goal**	-	**12/9/2019**	**5**
CP: Landing Gear	**On Track**	Nestor	**12/10/2019**	**2**
CP: Electronic Mounts	**On Track**	Martina	**12/11/2019**	**1**
Fall Break		-	**12/13/2019**	**24**
DR: Test and Integration	**Low Risk**	Leah	**12/16/2019**	**5**
DR: Loads and Environments, Assumption:	**Low Risk**	Heb	**1/3/2020**	**4**
DR: Performance Analysis – Flight Maneu\	**Low Risk**	Martina	**1/6/2020**	**2**
DR: Performance Analysis - Thrust	**Low Risk**	Nestor	**1/6/2020**	**3**
First day of classes	**Goal**	-	**1/6/2020**	**1**
Test Prototype	High Risk	Leah	**1/7/2020**	**5**
DR: Performance Analysis – Static & Dyna	**Low Risk**	Zac	**1/10/2020**	**5**
DR: Design Layout & Trades	**Low Risk**	Hebert	**1/13/2020**	**5**
DR: Performance Analysis - Stability	**Low Risk**	David	**1/13/2020**	**3**
PA: Fuselage	**On Track**	Zac	**1/13/2020**	**16**
PA (Print Airplane)	**Low Risk**	-	**1/13/2020**	**42**
DR: Manufacturing	**Low Risk**	Zac	**1/14/2020**	**3**

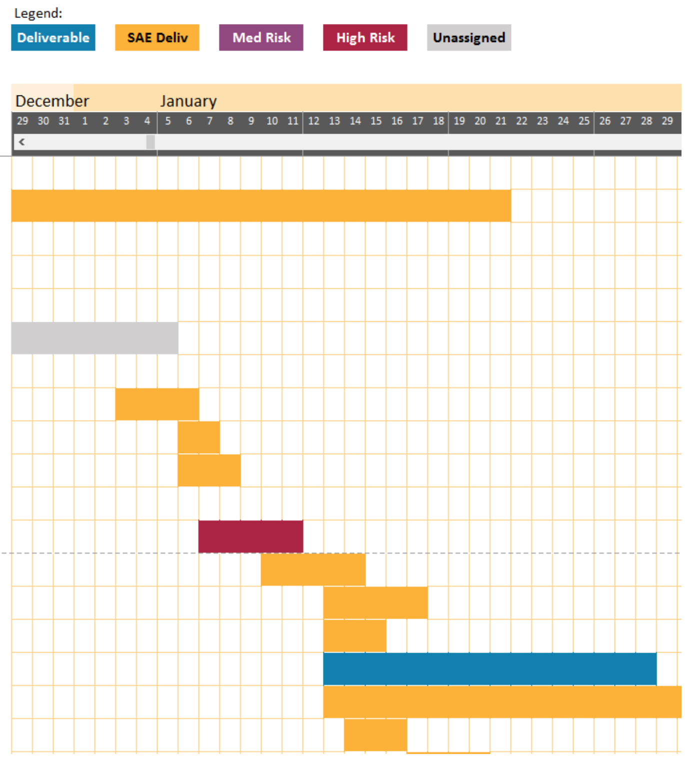


Figure F-3. Gantt Chart Part 3

Senior Design T513

SAE Aero Design Competition

Project Start Date: 11/21/2019

Scrolling Increment: 55

DR: Performance Analysis – Static & Dyna	Low Risk	Zac	1/10/2020	5
DR: Design Layout & Trades	Low Risk	Hebert	1/13/2020	5
DR: Performance Analysis - Stability	Low Risk	David	1/13/2020	3
PA: Fuselage	On Track	Zac	1/13/2020	16
PA (Print Airplane)	Low Risk	-	1/13/2020	42
DR: Manufacturing	Low Risk	Zac	1/14/2020	3
2D Drawing	Low Risk	Zac	1/17/2020	4
Tech Data Sheet	Low Risk	Hebert	1/17/2020	4
DR: Conclusion & Review	Low Risk	Leah	1/20/2020	3
Martin Luther King, Jr. Day		-	1/20/2020	1
STEM Career Fair		-	1/28/2020	1
PA: Wing	On Track	David	1/29/2020	16
A (Assembly)	High Risk	-	1/30/2020	23
A: Wings	High Risk	Zac	1/30/2020	2
PA: Tail	Med Risk	Zac	2/13/2020	6
A: Fuselage	High Risk	Leah	2/14/2020	4
A: Landing Gear	High Risk	Nestor	2/17/2020	4
A: Electronics	High Risk	Martina	2/18/2020	3

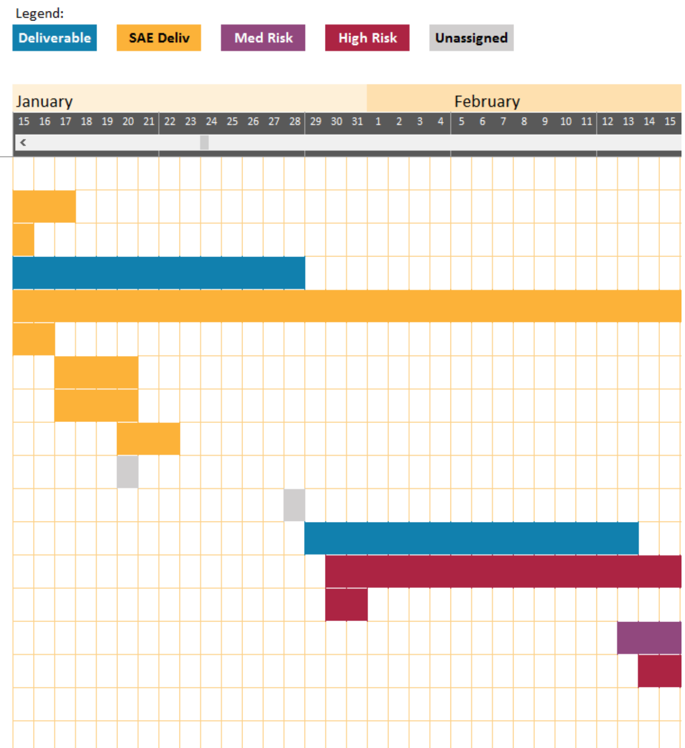


Figure F-4. Gantt Chart Part 4

Senior Design T513

SAE Aero Design Competition

Project Start Date: 11/21/2019

Scrolling Increment: 83

Task	Status	Assigned	Start	Days
Martin Luther King, Jr. Day		-	1/20/2020	1
STEM Career Fair		-	1/28/2020	1
PA: Wing	On Track	David	1/29/2020	16
A (Assembly)	High Risk	-	1/30/2020	23
A: Wings	High Risk	Zac	1/30/2020	2
PA: Tail	Med Risk	Zac	2/13/2020	6
A: Fuselage	High Risk	Leah	2/14/2020	4
A: Landing Gear	High Risk	Nestor	2/17/2020	4
A: Electronics	High Risk	Martina	2/18/2020	3
PA: Miscellaneous	Med Risk	David	2/19/2020	4
A: Tail	High Risk	David	2/20/2020	2
Maiden Flight	High Risk	Leah	2/22/2020	2
Airplane Adjustments	On Track	-	2/24/2020	7
Prepare for Competition		Zac	3/1/2020	5
SAE Competition	High Risk	-	3/5/2020	4
Spring Break		-	3/14/2020	9
Engineering Design Day		-	4/16/2020	1
Final Exams		-	4/27/2020	5

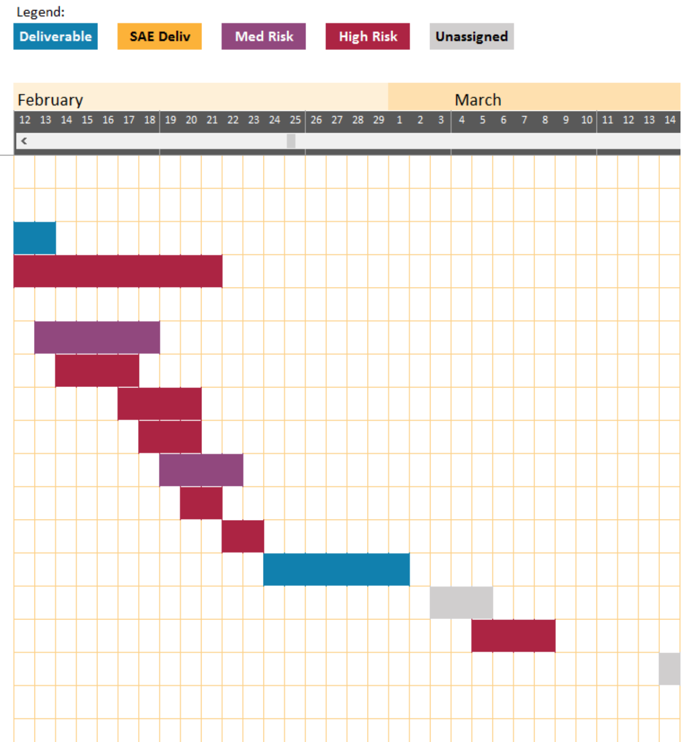


Figure F-5. Gantt Chart Part 5

Senior Design T513

SAE Aero Design Competition

Project Start Date: 11/21/2019

Scrolling Increment: 114

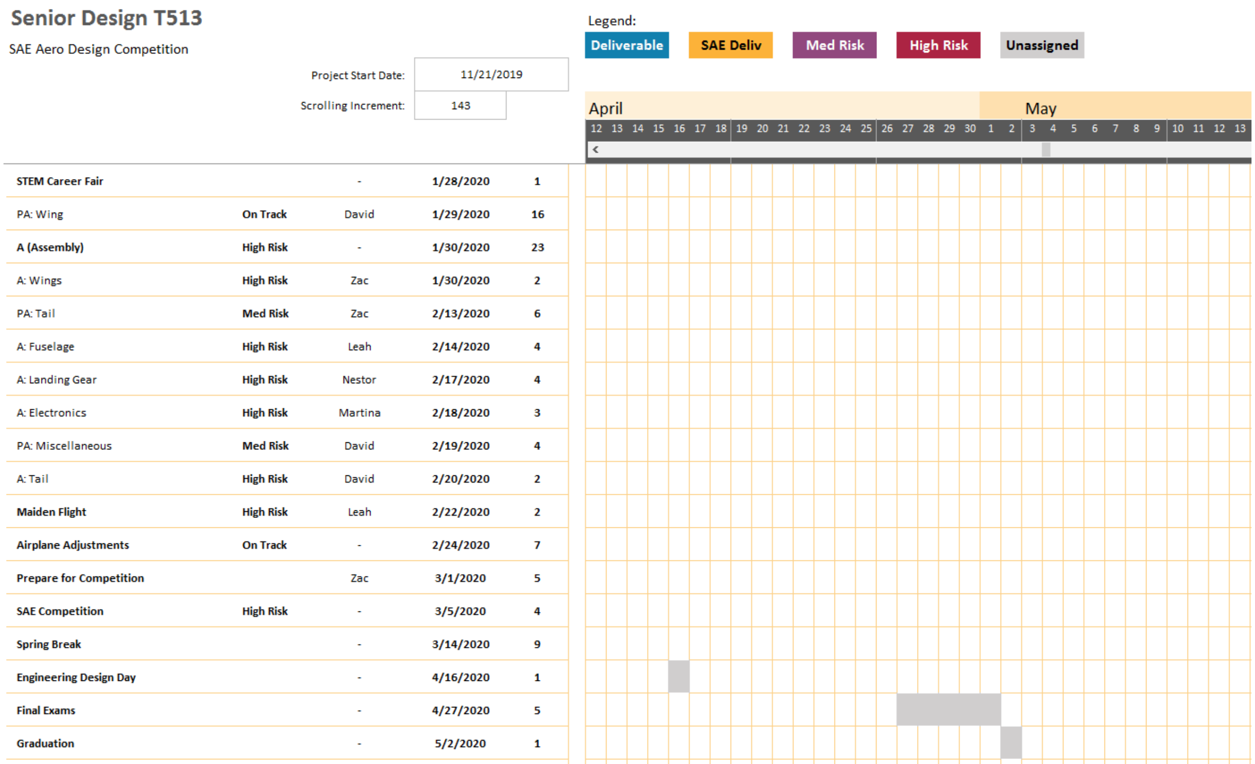
Legend: Deliverable | SAE Deliv | Med Risk | High Risk | Unassigned

March | April

14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14

STEM Career Fair		-	**1/28/2020**	**1**
PA: Wing	**On Track**	David	**1/29/2020**	**16**
A (Assembly)	**High Risk**	-	**1/30/2020**	**23**
A: Wings	**High Risk**	Zac	**1/30/2020**	**2**
PA: Tail	**Med Risk**	Zac	**2/13/2020**	**6**
A: Fuselage	**High Risk**	Leah	**2/14/2020**	**4**
A: Landing Gear	**High Risk**	Nestor	**2/17/2020**	**4**
A: Electronics	**High Risk**	Martina	**2/18/2020**	**3**
PA: Miscellaneous	**Med Risk**	David	**2/19/2020**	**4**
A: Tail	**High Risk**	David	**2/20/2020**	**2**
Maiden Flight	**High Risk**	Leah	**2/22/2020**	**2**
Airplane Adjustments	**On Track**	-	**2/24/2020**	**7**
Prepare for Competition		Zac	**3/1/2020**	**5**
SAE Competition	**High Risk**	-	**3/5/2020**	**4**
Spring Break		-	**3/14/2020**	**9**
Engineering Design Day		-	**4/16/2020**	**1**
Final Exams		-	**4/27/2020**	**5**
Graduation		-	**5/2/2020**	**1**

Figure F-6. Gantt Chart Part 6



Senior Design T513

SAE Aero Design Competition

Project Start Date: 11/21/2019

Scrolling Increment: 143

Legend: Deliverable, SAE Deliv, Med Risk, High Risk, Unassigned

STEM Career Fair		-	1/28/2020	1
PA: Wing	On Track	David	1/29/2020	16
A (Assembly)	High Risk	-	1/30/2020	23
A: Wings	High Risk	Zac	1/30/2020	2
PA: Tail	Med Risk	Zac	2/13/2020	6
A: Fuselage	High Risk	Leah	2/14/2020	4
A: Landing Gear	High Risk	Nestor	2/17/2020	4
A: Electronics	High Risk	Martina	2/18/2020	3
PA: Miscellaneous	Med Risk	David	2/19/2020	4
A: Tail	High Risk	David	2/20/2020	2
Maiden Flight	High Risk	Leah	2/22/2020	2
Airplane Adjustments	On Track	-	2/24/2020	7
Prepare for Competition		Zac	3/1/2020	5
SAE Competition	High Risk	-	3/5/2020	4
Spring Break		-	3/14/2020	9
Engineering Design Day		-	4/16/2020	1
Final Exams		-	4/27/2020	5
Graduation		-	5/2/2020	1

Figure F-7. Gantt Chart Part 7

Appendix A: APA Headings (delete)

Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

See publication manual of the American Psychological Association page 62

Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 1 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.

Figure 1. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 1

The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

Level of heading	Format
1	**Centered, Boldface, Uppercase and Lowercase Heading**
2	**Flush Left, Boldface, Uppercase and Lowercase**
3	***Indented, boldface lowercase paragraph heading ending with a period***
4	***Indented, boldface, italicized, lowercase paragraph heading ending with a period.***
5	*Indented, italicized, lowercase paragraph heading ending with a period.*

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