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T508: SAE Aero Design - Geometric Integration

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Abstract

The team's project is to design and build a radio-controlled plane to compete in the Society of Automotive Engineers (SAE) Aero Design contest. The plane must take off in under 100 feet while carrying a regular size five soccer ball and one pound weight. Two senior design teams took part in the project, with our team overseeing the structural design of the plane. We worked with the propulsion and aerodynamic calculations made by the aero propulsion team to design a structurally sound plane that can achieve flight. With most RC airplanes being build using materials like foam and balsa wood, our plane stands out in being 3D printed. Additive manufacturing is a very uncommon way to build these planes. Most RC pilots find printing filament to be far too heavy and stick with the typical construction materials to build their planes. To combat this increase in weight, a filament that foams when exiting the printer nozzle was used. Another unique feature of our plane is an extra set of wings known as canards. These were added to create more lift to help the plane achieve take off. These wings have no control surfaces on them, and serve solely to create more lift. The plane is estimated to weigh 14.6 pounds when fully loaded with cargo, and to be able to take off in under 60 feet.

Keywords: LW – PLA, Canards, RC Airplane, 3D Printing

Disclaimer

Due to COVID-19 the team was unable to physically attend the competition. Regardless of this, the plane was still designed and built within competition rules regarding size and building material. One of our sponsors the Seminole RC Club also graciously offered to help in conducting a test flight. This test will be done in Tallahassee with the plane carrying the same cargo load and the attempting the same flight path that would have been required at the competition.

Acknowledgements

Team 508 would first like to thank the Florida Space Grant Consortium for providing the necessary funding for this project. All competition registry and building materials were bought with this financial support so without them this project would not be possible.

The team would also like to thank our advisor Dr. Hruda, as well as Team 507's advisor Dr. Shih. The advice given for both the structural and aeronautic design greatly helped in building this plane. We hope that next year's teams can maintain these professional relationships to again help in completing this project.

We would also like to thank those who provided the materials and resources for constructing our plane. The ColorFabb LW-PLA bought through MatterHackers was the most used filament in printing the plane. Without this filament there would be no chance of our plane taking off. The FAMU – FSU College of Engineering Machine shop also provided materials for building the landing gear. We want to thank them for using this material along with the material bought from OnlineMetals to machine the requested parts of the plane.

Finally the team wants to thank the many individuals and organizations who also supported us throughout the project. Leah Evans and Zachary Silver from last year's Aero Design Competition project helped by giving guidance to solve many design and construction problems both our teams faced. We would also like to thank Eric Adams from FSU's Innovation Hub for providing printing advice along with additional printers and filament. Lastly we want to thank the Seminole RC Club for their design advice and help in conducting a test flight. Everyone mentioned on this page has helped make this project possible, and the team will forever be thankful for them.

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Notation

CAD	Computer Aided Design
CG	Center of Gravity
FAMU	Florida Agricultural and Mechanical University
FRP	Fiber Reinforced Plastic
FSU	Florida State University
LW-PLA	Lightweight Polylactic Acid
PLA	Polylactic Acid
RC	Radio Controlled
SAE	Society of Automotive Engineers

Chapter One: EML 4551C

1.1 Project Scope

There are two teams that are assigned to this project. Team 507 is overseeing the design and building of the plane's propulsion and control systems, while Team 508 is in charge of planning and fabricating the geometrics of the aircraft. The following sections layout the scope of Team 508's part of constructing the plane for the competition.

1.1.1 Project Description

The objective of this project is to design and manufacture a remote control plane within the rules and regulations of the SAE Aero Design East competition. The plane will primarily be 3D printed. It will be able to take off and land carrying a size five soccer ball and a one pound box weight. After landing these must be unloaded in under one minute.

1.1.2 Key Goals

This section details the team's goals in successfully achieving the objective described above. These goals were chosen to meet the requirements of the competition as well as to create a unique and operable RC plane. The objectives of the team are listed below.

- The majority of the plane's structure is 3D printed
- The plane meets all competition design requirements so it can compete
- The team stays within budget while building the plane, and acquires additional funds if necessary

- The plane can take off and land on the competition runway
- The plane can carry a size five soccer ball and one pound box weight
- The cargo of the plane can be loaded and unloaded in under one minute
- The plane can operate in high winds and other undesirable conditions
- The plane can be securely transported to and from the competition
- The plane can be easily assembled once all parts are built/bought
- The appointed controller will have no trouble in flying the plane

1.1.3 Markets

There are a variety of different markets similar to our project that may take interest in the results of our design. First and foremost are RC plane hobbyists. As of now most RC aircrafts are made from materials like foam and balsawood. They may be great materials from a functional stand point, but the RC plane market may take interest in our project because 3D printing can aid in the construction and personalization of the planes. Instead of carving pieces from foam or wood, 3D printing the plane would allow the owner to create more complicated and precise designs in a CAD program, then print the parts and assemble them.

A secondary market for our project would be toy companies. Instead of developing molds in the traditional fashion, molds could be 3D printed. This would make the design of the mold easier to change, in that the it could be changed in a design program then re-printed. Parts of more complicated toys could be printed themselves too.

Military contractors would also be a primary market for our project. One of the primary needs of our plane is that it needs to carry specified cargo. UAVs are already used in the U.S. military mainly from a surveillance and attack standpoint, but in adopting certain aspects of our design, they can also be used to deliver critical supplies to personnel in combat zones. 3D printing these UAVs could also increase their ability to interchange parts and create attachments for tactical elements. Also, using 3D printing material may lower the cost of building the UAVs. That way if one is lost or shot down by the enemies, the cost isn't as great.

Delivery services such as UPS, FedEx, and the USPS would also be a primary market. These companies could use small cargo carrying UAVs to deliver packages. Especially with the emergence of the Urban Air Mobility field, these companies could use 3D printed models similar to our project to deliver goods in both rural and densely populated areas. This again may lower material costs, and make redesigning or changing parts of the UAVs easier.

1.1.4 Stakeholders

Some of the stakeholders invested in Team 508's project are the FAMU – FSU College of Engineering, our sponsor Dr. McConomy, Team 507's faculty advisor Dr. Shih, Team 508's faculty advisor Dr. Hruda, and additive manufacturing companies. The company out team purchases printing filament from specifically will be a stakeholder.

The additive manufacturing company we purchase our printing filament from is the key stakeholder in our project because the success of a 3D printed RC aircraft could help to promote 3D printing within the UAV and aviation industry. 3D printing is already a technique used in the development of small UAVs, however the parts made in this fashion are generally not used for structural purposes. As noted in the key goals section, additive manufacturing will be one of the main focuses in building our aircraft. If the team can successfully design a plane with 3D printing filament, the additive manufacturing industry may greatly benefit from the project.

The FAMU – FSU College of Engineering is also a stakeholder in our project, specifically the Mechanical Engineering department. In many ways our team and our plane will be representing the department and the college in general. The team behaving in a professional manner at the competition, as well as the plane performing in a satisfactory manner can help Dr. McConomy establish relationships with companies who could become future Senior Design sponsors.

Both Team 507 and 508's faculty advisors are stakeholders in our project too. They are both volunteering time and resources to each of their teams. With Dr. Shih being the director of the Aero – Propulsion, Mechatronics and Energy (AME) program, and Dr. Hruda heading the additive manufacturing course at the

college, our performance can help bring recognition to both professors' programs.

1.1.5 Assumptions

Certain assumptions will be safe to make in designing the aircraft. These expectations involve the plane itself as well as how the competition will operate. These assumptions are listed below.

- The plane will abide by all SAE Aero Design competition rules
- The plane will be designed for competition not private use
- Longevity is not a priority. The plane is designed mainly for the competition flight
- The majority of the plane will be 3D printed
- The plane will consist of multiple parts with a maximum length of 9 inches due to the printers being used
- The team has access to three Lulzbot printers
- When possible, multiple parts will be printed in one queue on a printer
- The plane will not have to fly in the rain
- When possible, parts will be bought/borrowed not built. This applies mainly to the propulsion system and not the structure of the plane
- The plane will be able to fly in a cross wind
- The plane will be flown at sea level conditions. This applies to gravity, altitude, air pressure, etc.
- The plane will be flown by a trained, non – biased pilot
- Minimal assembly will take place after unloading the plane at the competition
- The design and build of the aircraft will be an iterative process

1.2 Customer Needs

With our project being part of a competition, the contest rules and regulations are the main needs the team has to meet. In speaking with Dr. McConomy who is serving as our team's sponsor, he also made suggestions involving the design of the aircraft. Some of these ideas will serve as customer needs as well. During a team meeting the competition rules pertaining to the plane's geometrics and the suggestions from Dr. McConomy were discussed to determine their engineering interpretations and how they will apply to our part of the aircraft. The tables below show the decisions that were made to meet the needs of the project. In Table 1, the customer needs brought from the rule book are shown. The rules are grouped by how they apply to the design of the plane. They then each have the team's interpretation of the rule.

Table 1.
Customer Needs from the SAE Rulebook.

Rule Book Section:	**Statement:**	**Need Interpretation:**
General Aircraft Requirements	Each team's plane must have its university name, mailing address, email address written on it with 3" minimum font size	The plane will have the required information written on it in 3" font.
General Aircraft Requirements	The team number assigned by SAE must be written on both sides of the wings and both sides of a vertical surface in 3" font.	The plane's identification number can be visible from all angles.
General Aircraft Requirements	All planes must have fixed wings.	The aircraft's wings are fixed to its body.
General Aircraft Requirements	The plane must be flyable at the empty CG point marked on the plane	The plane can fly with no cargo on board.

General Aircraft Requirements	Gross take-off weight must not exceed 55 pounds.	The plane weighs 55 pounds or less.
General Aircraft Requirements	All planes must have a safety nut mechanism.	The plane has a safety nut for the propeller.
Geometric Design Requirements	The wingspan must have a maximum length of 120 inches.	The wingspan is at or below 120 inches.
Geometric Design Requirements	The aircraft cannot rely on flight control systems for ground steering.	The plane has a ground steering mechanism.
Geometric Design Requirements	Cargo hold must fully enclose the mission's required cargo.	No cargo is visible when the plane is flying.
Geometric Design Requirements	The cargo must not contribute to the structure of the plane.	The plane is structurally sound when empty.
Materials Requirements	Metal propellers are not allowed.	The propeller is made of a material other than metal
Materials Requirements	The use of lead is strictly prohibited.	No lead is used in making the plane.
Materials Requirements	FRP composites like duct tape can't be used in any part of the plane.	No sections of the plane are made or secured with FRPs.
Materials Requirements	Rubber bands can't be used in securing the wings or payload.	Retaining the wings or payload does not depend on rubber bands.

Materials Requirements	Tape, Velcro, rubber bands, containers, and friction alone can't be used to secure the box load.	Other methods are used in securing the box load.
Flight Mission Requirements	The plane must take-off in less than 100 ft.	The plane has 100 feet to achieve flight.
Flight Mission Requirements	The cargo consists of a size 5 soccer ball and payload plates.	The plane can take off and complete the needed flight pattern carrying this cargo.
Flight Mission Requirements	Each team has two minutes to achieve take-off. As long as the plane remains in the required take-off boundary, multiple attempts are allowed.	Multiple take-off attempts are allowed with the allotted two minute time period and if the plane has remained within the 100 ft take-off boundary.
Flight Mission Requirements	One helper can be used in assisting the plane's take off.	One team member can help the pilot get the plane to achieve take-off
Flight Mission Requirements	The team is given one minute to unload the plane after the flight is complete.	Design the fuselage to where all cargo can be unloaded in less than one minute.

In analyzing Table 1, it can be seen that many of these customer need interpretations will serve as constraints in how the plane must be designed. These needs must be carefully considered in designing the aircraft to make sure it qualifies for the competition. Table 2 shows the needs noted in the team's meeting with Dr. McConomy. In this table the first column lists the questions the team asked Dr. McConomy, and second lists his response to each question. In the same manner as Table 1, the third column lists the team's engineering interpretation of the statement.

Table 2.
Sponsor Needs

Question/Prompt:	Statement:	Need Interpretation:
Are the rules the only things we should see as customer needs?	The rules should be seen as the bare minimum. This is a contest so we are trying to impress judges.	Find innovative ways to build the plane that will stand out at the competition.
How much of the plane must be 3D printed? Meaning where are other materials allowed?	3D printing material must be the primary material used. Other materials must only be used where deemed necessary.	The plane's main building material is 3D printing filament. Other materials are only used when needed.
If possible, is sponsorship from other companies and organizations outside of the college allowed?	Sponsorship is allowed. It will help in funding aspects like material and transportation.	Pursuing outside sponsorship is okay.
Are there any specifications we need to follow in regards to electric components?	Reduce wires as much as possible as electrical components are dead weight	Use as few wires as possible.

These customer need interpretations will be used to help make the plane meet its full potential. To do well at the competition, the plane has to do more than just qualify for the contest. Research needs to be done to find innovative building methods and features to catch the eye of the judges, while still obeying the rules of the competition. We mustn't overdo it but, in finding ways to make a qualifying and original aircraft, our team can represent the school proudly at the competition.

1.3 Functional Decomposition

After the customer needs were found and the project scope was created, the team made the project's functional decomposition. This was done by each team member creating their own hierarchy chart through integrating the customer's needs with the basic concepts of creating an operable RC plane. When each member had their own chart, a meeting was held to discuss the similarities and differences between the charts that were created. We then combined the best aspects of our charts, and added any other additional parts we found necessary. The team's final hierarchy chart is shown in the figure below, and can also be found in Appendix B.

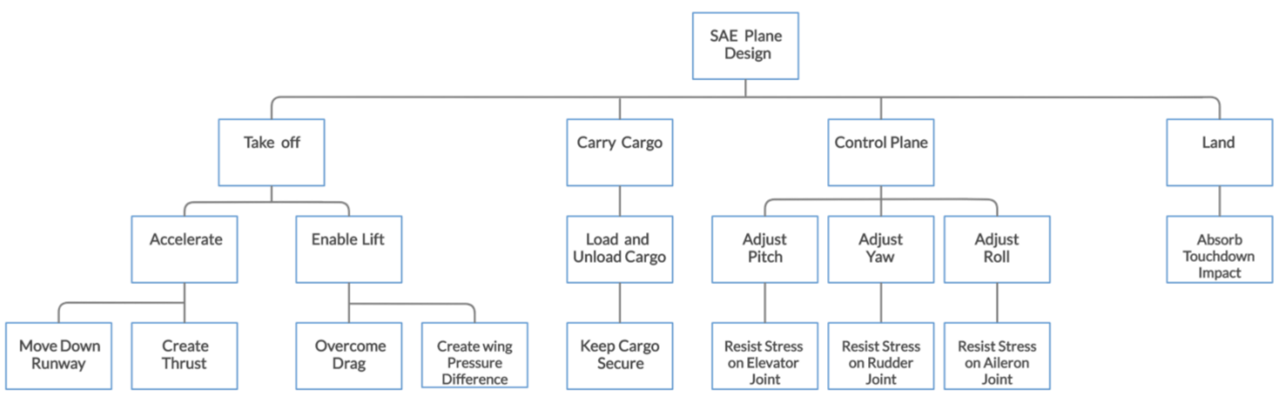


Figure 1. Functional decomposition hierarchy chart.

In Figure 1, the first row of functions will serve as the major functions of the plane. These were chosen since taking off, controlling the plane in flight, and landing are basic functions of an RC plane, and transporting the payload is part of the competition requirements. Each of these major functions were then broken down into their respective minor functions. The minor functions are the things that need to be accomplished to meet the major functions' needs. As seen in Figure 1, taking off is broken down into two separate branches. The plane must accelerate to create the needed thrust and travel down the runway. It must also enable lift through overcoming the drag force it's experiencing, and by creating the proper pressure difference around the airfoils. Once take-off has been accomplished, the pilot must be able to control the plane. This will be done by making sure the pilot can adjust the pitch, yaw, and roll of the plane when necessary. When this is done, the joints of the elevators, rudder, and ailerons must all be able to withstand the stress they will endure. Transporting the payload has minor functions that will have to be met as well. In order to comply with our customer needs, the aircraft's fuselage will need to be designed for easy access to the cargo. This will allow the team to load and unload the cargo in the time allotted. It is also essential that the cargo is secured within the aircraft's body. Movement of the cargo could cause the center of gravity of the aircraft to shift and make controlling the plane difficult for the RC pilot. Finally, the landing function has a minor function that will need to be met. The pilot must first align the plane with the runway and steadily decrease its altitude using the plane's steering systems. But when touchdown occurs, the landing gear will have to absorb the impact of the plane hitting the ground. These major and minor functions all contribute to the success of the project.

After the major and minor functions were defined, a cross reference matrix was created. The table is shown below.

Table 3.
Functional Decomposition Cross Reference Table.

		Major Functions:				
Minor Functions:	Customer Needs:	Take off	Control Plane	Transport Cargo	Land	**Minor Function Ranking:**
Enable Lift	1, 2, 3, 4, 6	X	X		X	1
Overcome Drag	1, 2, 3, 4, 6	X	X			2
Create Wing Pressure Difference	1, 2, 3, 4, 6	X	X		X	1
Accelerate	2, 3, 4, 6, 8	X	X	X		1
Move Down Runway	2, 3, 4, 6, 8	X	X	X		1
Create Thrust	2, 3, 4, 6, 8	X	X	X		1
Adjust Roll	6, 8		X	X	X	4
Withstand Stress on Aileron Joint	6, 8		X	X	X	
Adjust Yaw	2, 6, 8		X	X	X	3
Withstand Stress on Rudder Joint	2, 6, 8		X	X	X	3
Adjust Pitch	4, 6, 8	X	X	X	X	2
Withstand Stress on Elevator Joint	2, 6, 8	X	X	X	X	3
Load and Unload Payload	1, 2, 3, 4, 6			X		3
Keep Payload Secure	1, 2, 3, 4, 6	X		X	X	1
Absorb Touchdown Impact	4, 6		X	X	X	4
Major Function Ranking:		4	1	3	2	

The table seen above is our group's functional decomposition cross reference matrix. It displays how many minor functions and customer needs are applied to each of our major functions. We used this chart to determine which of the major functions is of highest importance. This table has all of the minor functions listed in the first column, and has the major functions listed in the first row. This allows the major and minor functions to be compared against one another. If it was found that a major and minor function were in relation, an 'X' was placed at their row and column. As seen above, columns with more "X's" are ranked of higher importance as more minor functions pertain to them. For example, since decelerating and controlling the plane relate to one another, an X was put in that cell. Similarly, absorbing touchdown impact and take-off do not apply to each other, so there is no X in that cell. To rank the priority of the major functions, the number of X's were counted for each major function. The function with the most X's was considered the highest priority, and the function with the least amount of X's was considered the lowest priority. It was found that controlling the plane is the highest priority and taking off is the lowest priority.

To rank the minor functions, the customer needs were also taken into consideration. To do this, they were each assigned a number. The rulebook sections from Table 1 were numbered one through four, and the questions from the conversation with Dr. McConomy in Table 2 were numbered five through eight. If any of these customer needs applied to a minor function, the assigned number was put in that minor function's customer needs cell. For instance, it was found adjusting roll met needs six and eight. To rank the minor function priority, each of their customer needs and major function applications were totaled. In doing this, it was found that many minor functions tie in priority ranking. This is shown in the final column of Table 3. This means that these groups of minor functions must be treated with the same priority level.

The team agrees with what is shown in Table 3, which shows that the control of the airplane should be treated with the highest priority. This is because this function will have a great impact on the other major and minor functions of the project. The flight mission requires that the plane takes off, completes the needed flight path, then lands. But even if the correct acceleration and airfoil pressure differential is created, lack of control over the pitch of the plane on the pilot's part may lead to the plane never getting off the ground. Similarly if the pilot can't steer the plane correctly during the flight or when trying to land, the aircraft can easily crash. The team also has to consider that the plane will be carrying the required cargo, and make sure that the plane can be controlled when carrying the payload and when empty.

The team is also satisfied with how the minor function rankings turned out. All of the highest priority minor functions revolve around a successful take off. This does fall under control of the plane, and if the aircraft can't get off the ground, then none of the other minor functions will come into play. The second and third highest ranking minor functions are related more to controlling the plane in flight along with loading and unloading the payload. As stated, sustained control of the plane is the team's number one priority. The team also needs to put a considerable amount of thought into how the cargo hold is constructed to ensure that it can be loaded and unloaded within the allotted time. The minor functions for landing the plane ranked least priority. If the plane is able to get off the ground, and we meet the needs relating to keeping control over the plane, the pilot should have minimal issues in landing it. Regardless of ranking, each major and minor function has been created to serve a specific purpose. To have the highest chance of building a working aircraft that will impress the judges at the competition, the team must be sure that the aircraft is capable of all of these functions.

1.4 Target Summary

The targets and metrics for our project were made using the SAE Aero Design Competition rulebook to keep the plane within the competition requirements, as well as outside research to give the plane the best chance to succeed in the contest. We used the rulebook to specify maximum wing span, maximum total plane weight, and other constraints required by the competition. The rest of our targets and metrics were made from the project functional decomposition and other ideas. Team 507 has made calculations in MATLAB about what the ideal thrust, angle of attack, and how much lift will be needed for our plane to achieve flight. Both teams have conducted research on RC plane design and have gone to many outside sources for advice. This includes team sponsors like the Seminole RC Club, and the printing supervisors at the FSU Innovation Hub. Seen below in Table 4 is our team's targets and metrics we find most critical to being able to build an effective aircraft.

Table 4.
Critical Targets and Metrics.

Function:	Metric:	Target:
Overall Structure	Total Flight Weight	Less than 55 lbs.
Create Wing Pressure Differential	Wingspan	Less than 120 in.
Create Wing Pressure Differential	Printing Error Tolerance	± 0.02 in.
Absorb Touchdown Impact	Landing Gear Impact Force	At most 22.8 lbf

Considering our mission and build requirements outlined in the SAE Aero Design Competition rule book along with our functional decomposition, our team picked out four critical targets and metrics. Our first critical target and metric pertained to the overall structure for our aircraft. Based on SAE's design requirements, our metric was total aircraft weight, and the target is to be less than 55 pounds. This is a critical target because any aircraft outside of SAE's design requirements will not pass the preflight inspection and will be unable to compete. To validate this metric the plane must be weighed with a scale before the competition. Our second and third critical target and metric stem from the function for a wing pressure difference. Wing pressure differences are essential to the success of our project because high pressure on the bottom of the wing creates the force necessary to lift the aircraft off of the runway. This is a mission critical function as our aircraft needs to take off and complete a pre-determined flight path. As noted in Table 4, this function has two targets and metrics. The first target and metric was taken from the SAE Aero Design competition rule book which specifies that our aircraft must have a wingspan of no larger than 120 inches. In validating this metric, the plane must be designed with a much shorter wingspan using SOLIDWORKS, and measured after the parts are printed. The second target and metric came from the need for our aircraft to be 3D printed within a certain error tolerance as the printers will not be one hundred percent accurate. Our team determined an error tolerance of ± 0.02 inches was appropriate based on the advice given by printing supervisors at the Innovation Hub, as well as the error calculated using a calibration cube. Our final critical target and metric is for the landing gear to absorb the touchdown impact of landing. Based off of the current target weight of the plane (20 lbs.), the plane's landing gear would need to be able to handle an impact force of at least 22.8 lbs. This may change depending on if the weight of the plane changes. If the landing gear cannot absorb the touchdown impact, a good flight may be ruined by a crash landing.

Appendix C lists all the targets the team must meet. It also shows each target's validation method and the tools these methods require. Depending on what aspect of the plane the targets apply to, different validation tools and processes will be needed. With our team's responsibilities focusing on the geometric aspects of the plane, many of the target validation methods will require physical measurement tools and procedures. For example, a ruler is needed to ensure 3D printed parts stay within our defined error tolerance and loading the aircraft within the time limit requires practice and a timer. Some targets will need simulation tests to make the correct aerodynamic calculations. This will mean working with Team 507 to combine the geometric needs of the plane and their aerodynamic calculations. Although we can simply measure the wingspan of the plane with a tape measure, we will need to work with Team 507 to make sure the wings create the correct amount of lift. This will involve things like MATLAB simulations. It should be noted that the current targets and metrics are not set in stone. As the design process continues, our teams may come across the need to change the validation methods, metrics for certain targets, and even add and drop targets all together.

1.5 Concept Generation

To generate the possible design concepts for our project, the team first had to find the different physical aspects of aircrafts that could be designed to meet the targets and metrics of the project. This was done through reading RC airplane design manuals, studying actual aircrafts, and simply brainstorming as a group. In doing this the team came up with ten airplane features that needed to be considered. Once the main aspects were defined, the group then had to find the different ways these features are built. The most feasible ones were then kept and as a potential way to construct that part of the plane. The ten airplane features along with their respective design options are shown below in Table 5. The design components are also shown in Appendix D with pictures to get a better idea of how they look and operate.

Table 5.
Project Concepts.

Printing Material	Wing Design	Wing Profile	Landing Gear	Tail	Propeller Location	Fuselage	Flaps	Ailerons	Winglets
LW-PLA	Elliptical	High	Tricycle	Conventional	Front	Subsonic	Plain	Frise	Grantz
PLA	Rectangular	Mid	Taildragger	T-tail	Rear	Supersonic	Split	Differential	Whitcomb
	Tapered	Low		Cruciform		HC Subsonic	Slot		None
	Rect./ Tapered			None		HM Supersonic	None		
	Delta			Twin tail		Flying Boat			
				Boom tail		Hypersonic			

After creating the table, it was used to create 100 possible designs for the plane. Multiple methods were used to do this. First we found real planes like Cessnas and Long EZs that RC planes can be modeled after, and created our own conceptual designs with the options from Table 5. Once we had these designs, the morphological chart method was used by changing only certain aspects of the first designs to get different ones. After both these methods were used, we were still short of 100 concepts. This meant the crap shoot method had to be used. This was done by putting all possible plane concept in an Excel graph, then programming it to select one option from each aircraft feature. The team then had to go through the list and edit/eliminate different concepts based on if certain ones overlapped or just weren't feasible. For example, if the program put elliptical wings and any sort of winglet in a concept, either the wings or the winglets had to be changed. Once all the concepts were generated, a meeting was held with Team 507 to combine our conceptual ideas and pick the best ones. These were chosen through finding which ones were the most practical to build, yet still met the targets and metrics of the project.

Concept 1.

Concept 1 is the team's first high fidelity concept. It's propeller is located at the front of the plane, has a flying boat fuselage with the tricycle landing gear formation, and is built with the high wing profile with a conventional tail. The wings of this plane are built using a combination of the rectangular and tapered wing design, and have the Grantz style winglets. It is shown in the figure below.

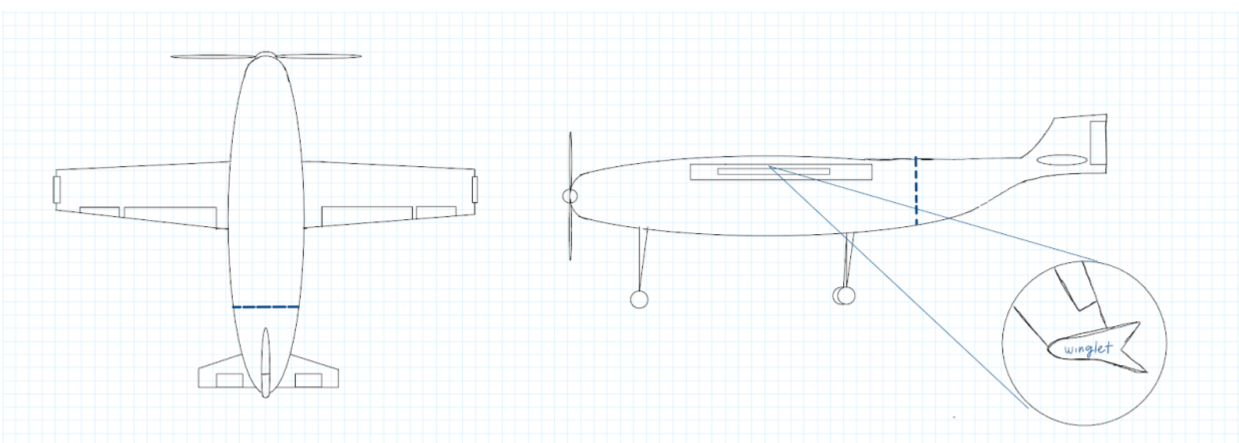


Figure 2. High fidelity Concept 1 drawing.

The tricycle landing gear was chosen because it will be easier for the plane to taxi to the runway with a single wheel in the front instead of the back. The flying boat fuselage is used since it is a common fuselage for cargo carrying aircrafts. The rectangular and tapered wing combination set at a high profile was selected because having wings designed in this shape is a good way to get the efficiency of elliptical wings yet in a more buildable layout. Elliptical wings can be very hard to construct, especially when it comes to 3D printing. A rectangular and tapered wing combination will help to create the necessary lift, yet still keep the wings printable. These wings also have flaps and ailerons for steering, and for increasing the lift and drag of the plane when needed. Grantz style winglets were also chosen. Winglets reduce the drag the plane experiences from the vortices created by the wings. A conventional style tail was selected for this plane because it is simple to build yet is still good in keeping control of the plane. Finally, this first concept would be built using light weight PLA (LW-PLA) printing filament. This material is great for building aircraft because it is not as dense as normal PLA, making it much lighter than the usual printing filaments. Even though it is not as dense, the team has done strength tests comparing the two materials that shows LW-PLA is still a valid option for building the plane in terms of the stress it will endure during flight. One thing that needs to be taken into account is that this is a foaming material. This means that if the temperature and fan settings of the printer are not correct, the material may foam incorrectly, causing the part to become warped.

Concept 2.

Concept number 2 is our team's second high fidelity concept. It is shown in the figure below.

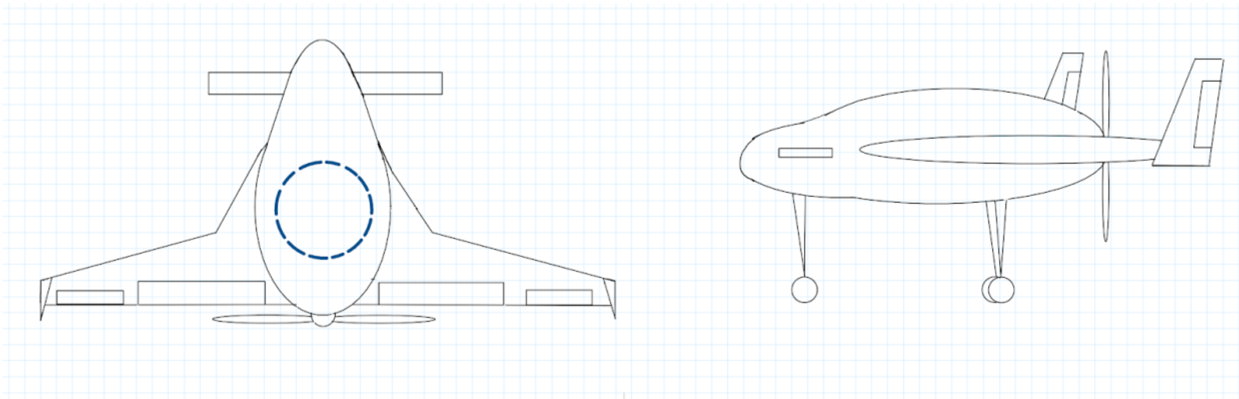


Figure 3. High fidelity Concept 2 drawing.

This concept has a subsonic fuselage, with the motor and propeller placed in the rear of the aircraft, eliminating a traditional tail or boom. The plane has mid profile delta wings as well as canards placed at the front of the plane. Both of these sets of wings create the lift needed for the plane to fly. The canards are also used to keep the plane from stalling. These wings are placed at a higher angle of attack than the delta wings. This means that they will stall before the main wings. When this happens, the nose of the plane falls forward, and the plane will stop stalling when the correct pressure differential in airflow is recreated around the wings. This means that in theory, this plane can never stall completely and fall out of the sky. Concept 2 will also have tricycle landing gear along with ailerons and flaps for the same reasons mentioned in Concept 1. This plane also has winglets, except these winglets will be Tipsails. Tipsails need to be used because these winglets have rudders, and with no tail on this plane, the rudders in the tipsails will be needed to control the yawing motion of the plane. Like Concept 1, LW-PLA is used as the printing filament. This will again help keep the plane as light as possible without drastically affecting the strength of the building material.

Concept 3.

Concept 3 is the team's last high fidelity concept. In essence, it can be seen as a combination of a lot of the features from Concepts 1 and 2. It's pictured in Figure 4.

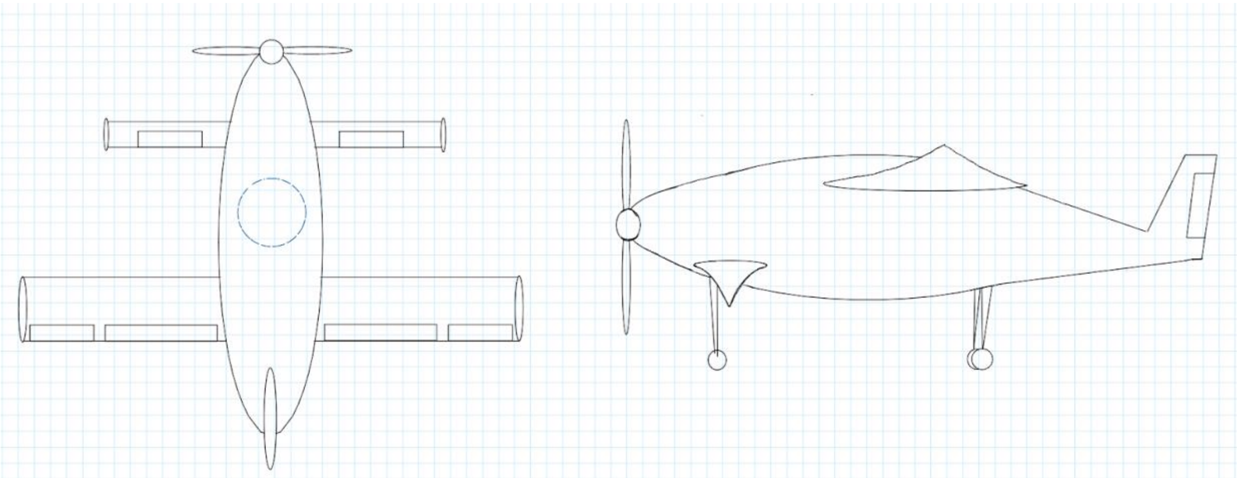


Figure 4. High fidelity Concept 3 drawing.

As with the last two concepts, Concept 3 is built with LW-PLA, tricycle landing gear, along with flaps and ailerons. All these features will be used for the same reasons mentioned earlier. This concept also uses a front propeller and has a flying boat fuselage to act as a cargo plane like in Concept 1. The plane has a high wing profile like in Concept 1, except this time rectangular wings are used. This wing design is the easiest to print, and will allow more innovative connection methods to be used in connecting the parts of the wings. Rectangular wings do however put the most stress on the root of the wing, so reinforcements may be necessary. Concept 3 also has canards to create more lift and keep the plane from completely stalling. Grantz winglets are used on both the canards and the main wings to reduce drag. The winglets on the canards will be pointing down to direct the vortices created by those wings away from the main wings. This is so the airflow for the main wings doesn't get disrupted by the canards. The winglets for the main wings will be pointed upwards as usual. Concept 3 has a tail but with just the rudder portion. The rudder is needed to control the yawing motion of the plane, but since canards are used, there's no need for any horizontal wings on the tail of the plane.

Concept 4.

Concept 4 is the team's first medium fidelity concept. This concept is shown in the following figure.

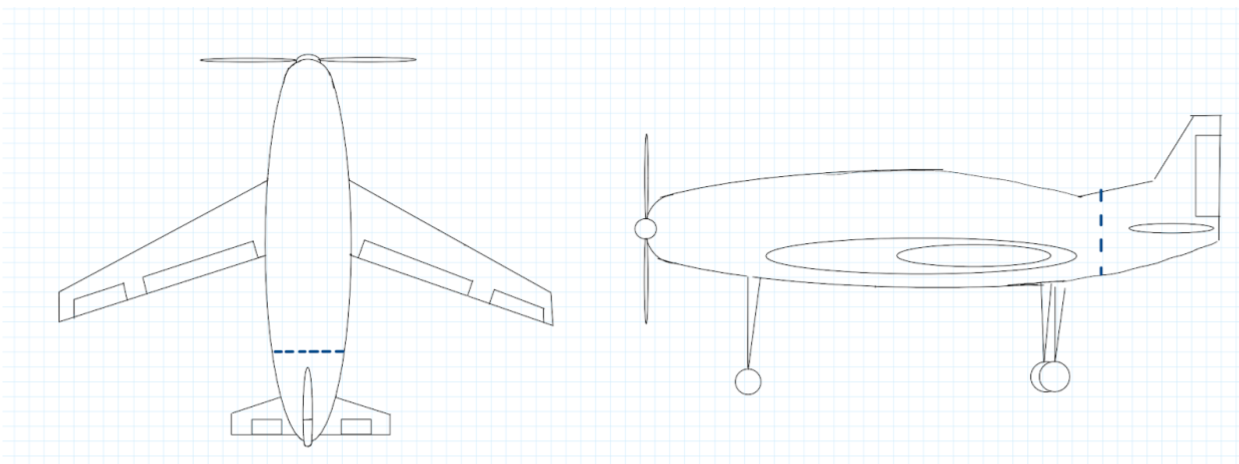


Figure 5. Medium fidelity Concept 5 drawing.

In this concept, the plane once again has a front propeller, flying boat fuselage, as well as flaps and tricycle landing gear. It has a low wing profile with tapered wings. Tapered wings come very close to the efficiency of elliptical wings, yet are still easier to print. They also don't require the reinforcements that rectangular wings sometimes need. Concept 4 also has the Grantz winglets to reduce the drag on the wings. The flaps and ailerons are used in the design as well to steer the plane and increase lift or create drag when necessary. A conventional tail is also in this design for it being simple yet still being able to keep control of the plane. Unlike the previous designs, this plane is built using PLA. Even though PLA is heavier than LW-PLA, LW-PLA can only be used in certain printers. There are more printers on campus that our team has access to that can use PLA. Also, PLA is less likely to warp since it doesn't foam like LW-PLA. This means that parts could be finished at a faster pace, and there is a better chance of getting the plane finished before the competition.

Concept 5.

This concept is our team's second medium fidelity concept. It will be built with LW-PLA and will include rectangular wings. This plane includes a high wing profile and a tricycle landing gear configuration. It will have a conventional tail, and will also have a front propeller. This plane will have a flying boat fuselage to ensure that all the plane's payload can be carried efficiently. The plane also has flaps and ailerons to help control the plane in flight. This plane does not include winglets on its design. A picture of this concept can be seen below.

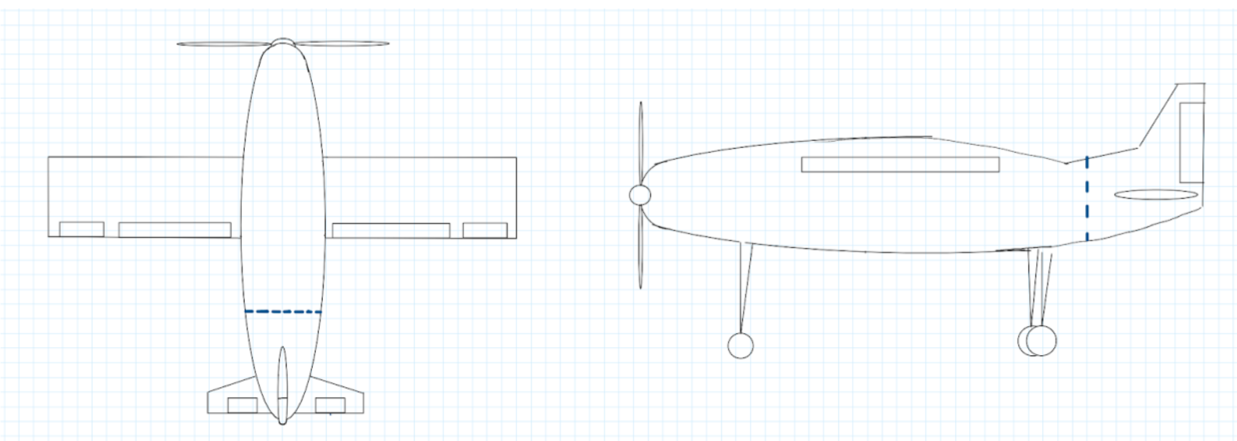


Figure 6. Medium fidelity Concept 5 drawing.

Concept 6.

This concept is our team's third medium fidelity concept. It will use LW-PLA and elliptical wings as this wing type is the most efficient in generating lift across the wing. This plane has a low wing type with a tricycle landing gear configuration. This design includes a conventional tail type and a front propeller. This plane includes a subsonic fuselage which is able to hold the specified load given by SAE competition rules. This design uses flaps and ailerons in a way to control the plane in flight. This plane design will not include winglets on it. A sketch of this design can be seen below.

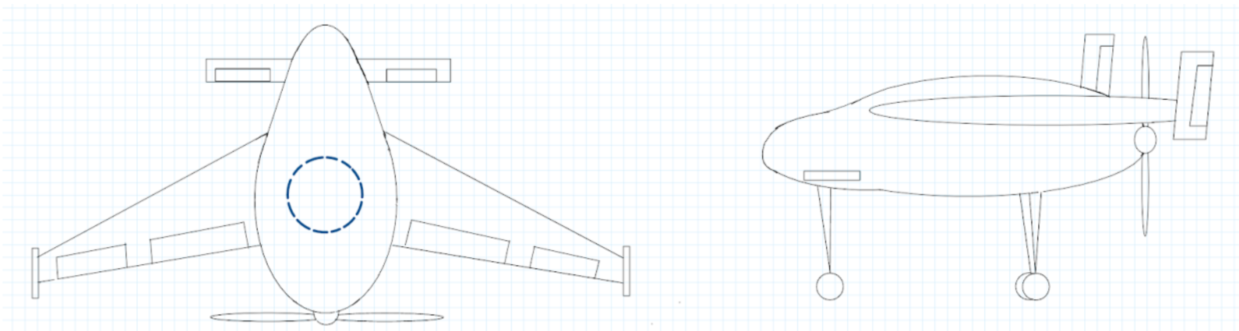


Figure 7. Medium fidelity Concept 6 drawing.

Concept 7.

This concept is our team's fourth medium fidelity concept. It will use PLA as its building material. It has tapered wings, and will include canard wings for the same reasons mentioned in previous designs. The design includes a high wing profile and will use a tricycle landing gear configuration. This plane will not have a tail since it has a rear propeller. The fuselage will be a supersonic fuselage and it will include split flaps. The plane includes ailerons and flaps for steering, lift, and purposes. The tip sails will act as winglets to minimize the vortices, and control the yawing motion of the plane. The figure below depicts this design.

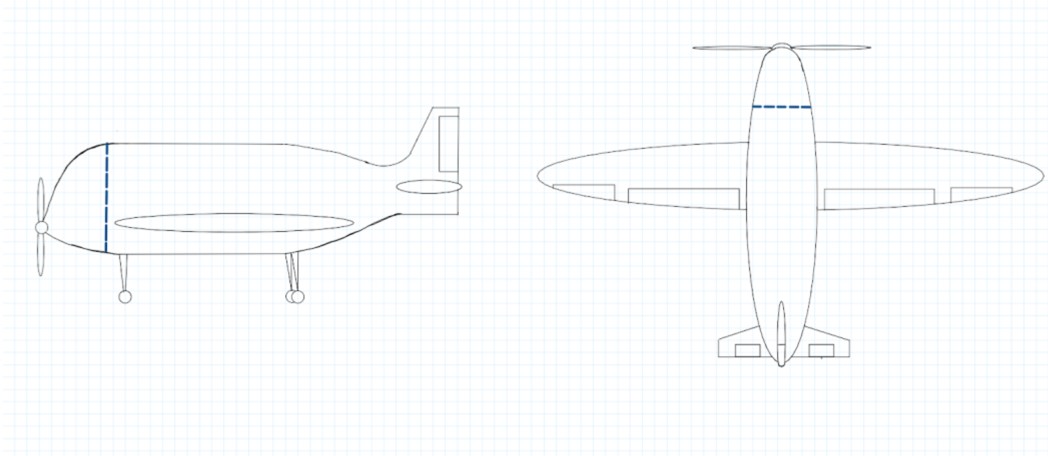


Figure 8. Medium fidelity Concept 7 drawing.

Concept 8.

Concept 8 is our team's final medium fidelity concept. The concept involves using PLA as its material as it will be able to be printed faster so that we can keep within the deadline. The plane also includes tapered wings as that will increase the aspect ratio leading to the aircraft to gain more lift. The plane uses a high wing profile and will use a tricycle landing gear layout as it will be more efficient for take-off. The plane has a T-tail configuration so the high wings don't affect the air flowing over the tail. Concept 8 also has a front propeller. The plane uses a flying boat fuselage layout as it is more efficient for carrying cargo. This design also uses plain flaps as they will be able to reduce the needed take off speed. Ailerons are also used for steering purposes. This plane design does not include winglets and can be seen in the image below. Concept 8 is shown in the figure below.

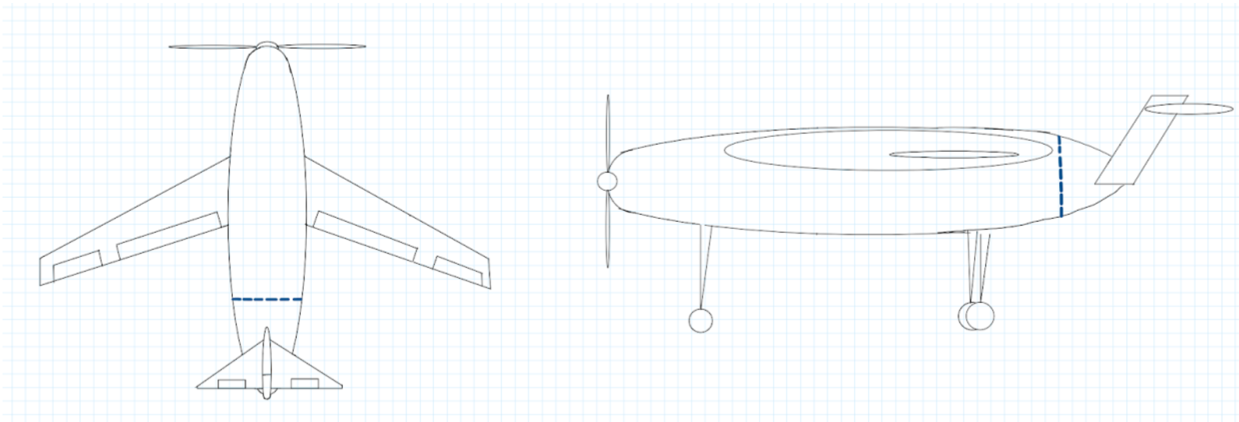


Figure 9. Medium fidelity Concept 8 drawing.

The table below is a summary of the features chosen for each fidelity concept. As mentioned in the Targets Summary chapter. it should be noted that with whatever fidelity concept the team goes with, changes in the design may be made throughout the design process. The team may find that some design concepts aren't feasible, or even find better ways to design certain aspects of the plane.

Table 6.
Medium & High Fidelity Concepts.

No.	Printing Material	Wing Design	Wing Profile	Landing Gear	Tail	Propeller Location	Fuselage	Flaps	Ailerons	Winglets
1.	LW-PLA	Rect./Tapered	High	Tricycle	Conventional	Front Propeller	Flying Boat	Plain	Differential	Grantz
2.	LW-PLA	Delta & Canards	High	Tricycle	None	Rear Propeller	Subsonic	Slot	Differential	Tip Sails
3.	LW-PLA	Rectangular & Canards	High	Tricycle	Rudder w/ no wings	Front Propeller	Flying Boat	Slot	Differential	Grantz
4.	PLA	Tapered	Low	Tricycle	Conventional	Front Propeller	Flying Boat	Slot	Differential	Grantz
5.	LW-PLA	Rectangular	High	Tricycle	Conventional	Front Propeller	Flying Boat	Slot	Differential	None
6.	LW-PLA	Elliptical	Low	Tricycle	Conventional	Front Propeller	Subsonic	Plain	Frise	None
7.	PLA	Tapered & Canards	High	Tricycle	None	Rear Propeller	Supersonic	Split	Differential	Tip Sails
8.	PLA	Tapered	High	Tricycle	T-tail	Front Propeller	Flying boat	Plain	Frise	None

1.6 Concept Selection

The first chart the team made for selecting our be concept was a Binary pairwise Comparison chart. The chart is shown in the figure below.

Table 7.
Binary Pairwise Chart

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

This chart is used to rank our design features by comparing the importance of each feature directly to each other. In the column furthest to the left, all of our designs major functions are shown. As the row continues to the right, it is being compared to the columns going downward in sequential order. For example, in column 3, row 2, the function of stability is being compared to the center of gravity being in front of the center of pressure of the plane. The feature we find to be more important will be marked with a 1 and the feature it is being compared with will then be marked with a 0. So with our prior example, we found having our center of gravity in front of our center of pressure to be more important than our plane's stability. We ended up concluding that the plane’s center of gravity being located in front of the center of the pressure is the most important feature about this design. We concluded this by adding up all the values in the row and it ended up being greater than every other row making it the most important feature of the plane. Carrying the minimum cargo load required was deemed the second most valuable feature while the material of the plane, and the plane being easy to load and unloaded being the 2 least valuable features of the planes.

This next chart is our house of quality chart. This chart is used as a planning matrix that is built to show how customer requirements relate to the methods companies can use to achieve these requirements. This chart is a primary tool used in the quality function development in order to help facilitate group decision making. In this chart we used mission critical targets, customer needs, and corresponding weight factors. The chart is shown below, with the highlighted grey parts pertaining to our group as they have to do with geometric factors of our airplane.

Table 8.
House of Quality Chart.

Units		lbf	lbf	lbf	degrees	ft/s	ft/s^2	degrees	seconds	lbs	ft/s^2	psi	psi
Customer Requirements	**Importance Weight Factor**	**Lift**	**Drag**	**Thrust**	**Max Angle of Attack**	**Stall Speed**	**Acceleration**	**Control Surface Movement**	**Loading/ Unloading Time**	**Weight**	**Deceleration**	**Joint Strength**	**Material Strength**
1. Material	1		1							9		9	9
2. Stability	6	9	3	3				9					
3. CG in front of CP	10	9	3	9	9	9		9		3			
4. Meet takeoff/landing requirements	7	9	3	9			9				9		
5. Wingspan meets restrictions	7	9	3		3	3		1				3	3
6. Sufficient Power	5	1	1	3			3	3		1	1		
7. Maneuverability	4				3	3		9		3		3	1
8. Light Weight	6	3		3			3			9	3		
9. Touch-down Impact	2							3		3	9	9	9
10. Ground Controls	7							1					
11. Carry the Minimum Cargo Load Required	8	9		3			3		9	9	3	9	9
12. Easy to Load/Unload	1								9	3		3	
Raw Score		365	96	228	123	123	120	215	81	191	128	135	124
Relative Weight %		18.92	4.98	11.82	6.38	6.38	6.22	11.15	4.20	9.90	6.64	7.00	6.43
Rank Order		1	11	2	6	6	10	3	12	4	8	5	9

In this chart, any section that is left blank is deemed not important. Any section with a 1 in it is deemed relatively unimportant, sections with a 3 are deemed somewhat important, and any section with a 9 is considered highly important. The improvement direction row on the top of the chart indicates which feature is exceeding expectations, meets requirements, or can be improved. Using the weighted values, we were able to determine the importance of our characteristics given. This leads to the weight of the plane being our team's most important characteristic.

Our initial Pugh Chart was created with the concepts which ranked higher than 6.75 on the Binary Pairwise Comparison chart. These concepts were compared against last year's design (our datum) in terms of the highest priority customer requirements defined in the House of Quality.

Table 9.
Pugh Chart 1.

		Concepts							
		High			Medium				
Selection Criteria	**2021 Competition Entry**	1	2	3	4	5	6	7	8
Lift	DATUM	+	+	+	-	-	+	-	-
Thrust		S	S	S	S	S	S	S	S
Control Surface Movement		+	+	+	+	S	+	S	S
Weight		-	S	-	-	-	S	-	S
Joint Strength		+	+	+	+	+	+	+	+
# of pluses		3	3	3	2	1	3	1	1
# of S's		1	2	1	1	2	2	2	3
# of Minuses		1	0	1	2	2	0	1	1

For the first selection criteria, lift, a plus was given to the concept if it would produce more lift than the datum. Next a plus was given to a concept if it would produce more thrust than the datum. Similarly for control surface movement and joint strength, a plus was given if the concept had more control surface movement or joint strength. For weight, a plus was awarded to a concept if it weighed less than last year's design. Minuses were given to concepts which had less lift, thrust, control surface movement, or joint strength than the datum. Concepts higher in weight than the datum were also given a minus. An 'S' was awarded to concepts for which the selection criteria would be the same as the datum.

Concepts which included canards, such as concepts two, three, and six were awarded pluses for lift. This is because canards eliminate the need for a downward force on the tail to push the nose of the plane up. Instead, the canards on the front of the plane provide the lift needed to push the nose up. This means that the net lift generated by the plane is higher than that of an aircraft without canards. Concept 1 was awarded a plus for lift because of the use of a high lift airfoil and because we included flaps and longer wingspan than the datum. Concepts four, five, seven, and eight were given minuses because their design would mean a reduction in lift compared to last year's design. In terms of thrust, all eight concepts were given an 'S' to indicate that the thrust would be the same as the datum. The amount of thrust produced will be the same for all concepts because our teams plan on using the same motor, propeller and battery used on the 2020 competition entry. This also means that there will be no variation in the thrust produced between our generated concepts. For control surface movement, concepts one, two, three, and six were awarded pluses because they all would have an increased wing area from the datum. As a result, the control surface areas would also be increased making it an improvement from the datum. In terms of weight, none of the eight concepts would be an improvement from the datum. Concepts two five and eight would have weights estimated to be similar to the datum and as a result, were awarded an 'S' . Concepts one, three, four, five and seven were given minuses because of their flying boat fuselage which would be an increase in material. In addition to the added weight of a larger fuselage all of these concepts would also require additional servos to power the additional control surfaces. Concepts two and six were given an ‘S’ because they are inherently more compact designs as they do not have a tail or boom. These concepts would require less material to build even with the addition of canards. Finally, all eight concepts would have an improvement in joint strength as our teams are planning on using stronger servos to power the control surfaces than what were utilized on the datum.

From the eight concepts compared in this initial Pugh Chart, concepts one, two, three and six were the highest ranking for improvements from the datum with three pluses each. Concept two was chosen as the datum for the next Pugh Chart because it had no minuses and two criteria which were the same as the datum. It should be noted that concept six had the same totals as concept two however, concept two was chosen as the datum because of the complexity of building a delta wing.

For our second Pugh Chart, concepts one, three and six were compared against our new datum, concept two. Similarly to the preceding Pugh Chart, pluses, minuses, and ‘S’s were awarded to the concepts using the same criteria defined above. It should be noted that on our second Pugh Chart, all three designs were ranked equally for four out of the five selection criteria. This means that the variation in ranking came down to each concept’s lift rating. Concept one was given a minus for lift because of the lack of canards. This means that the net lift produced by the aircraft would be lower than that of the datum due to the downward force produced by the tail. Concept six was also given a minus because of its reduction in wing surface area caused by a swept back wing instead of a delta wing. Finally, concept three was awarded a plus because of the high wing surface area produced by the combination of the rectangular canards and main wings. The second Pugh Chart is shown below.

Table 10.
Pugh Chart 2.

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

AHP charts are used in the analytic hierarchy process to help in organizing and analyzing complex decisions. Ultimately, these charts will give values of efficiency for concepts and characteristics. We found these by comparing each design's characteristics to each other and noting which design will fulfill this characteristic better. The charts used in conducting the AHP process are shown in Appendix E, with the final rating matrix and its alternative values shown below.

Table 11.
Final Rating Matrix.

Selection Criteria	Concept 1	Concept 3	Concept 6
Lift	0.243	0.669	0.088
Thrust	0.333	0.333	0.333

Concept	Alternative Value
Concept 1	0.292
Concept 3	0.411

Control Surface Movement	0.236	0.110	0.654
Weight	0.260	0.633	0.106
Joint Strength	0.333	0.333	0.333

Concept 6	0.297

This matrix was used to calculate the final values by multiplying the transpose of the final rating matrix to the criteria weights. In doing this, we came to the conclusion that concept 3 is the best design for our project. A bar to better portray the rankings of the concepts is shown below.

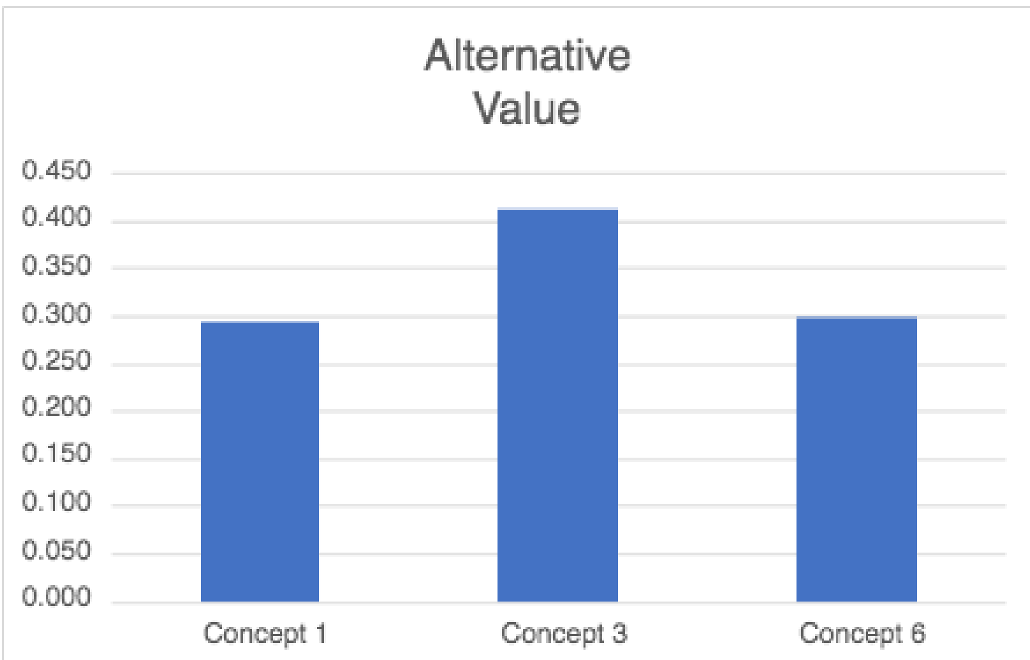


Figure 10. Alternative Value bar graph.

Concept 3’s highest ranking characteristics is its ability to generate lift, and that its weight will be less than the other planes. We determined this design will give us the highest chance of successfully performing our mission due to its canards and wings keeping the plane in flight without stalling, its flying boat fuselage holding the specified cargo, and the design allowing easy access to load and unload the payload.

1.7 Spring Project Plan

The figure below shows the team's spring project plan. Parts of the project worked on over winter break are also a part of the figure to show the work done in between semesters.

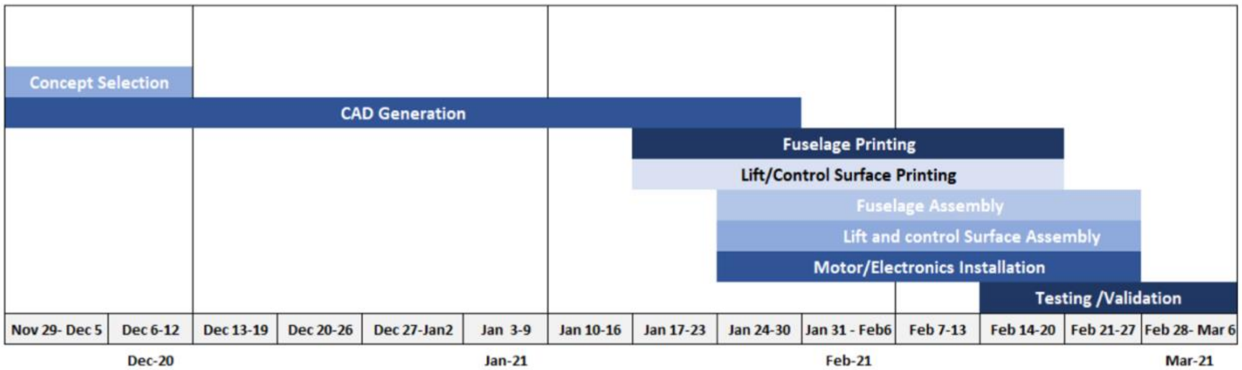


Figure 11. Winter break and spring semester project plan.

Chapter Two: EML 4552C

2.1 Restated Project Definition and Scope

There are two teams that are assigned to this project. Team 507 is overseeing the design and building of the plane's propulsion and control systems, while Team 508 is in charge of planning and fabricating the geometrics of the aircraft. The following sections layout the scope of Team 508's part of constructing the plane for the competition.

2.1.1 Project Description

The objective of this project is to design and manufacture a remote control plane within the rules and regulations of the SAE Aero Design East competition. The plane will primarily be 3D printed. It will be able to take off and land carrying a size five soccer ball and a one pound box weight. After landing these must be unloaded in under one minute.

2.1.2 Key Goals

This section details the team's goals in successfully achieving the objective described above. These goals were chosen to meet the requirements of the competition as well as to create a unique and operable RC plane. The objectives of the team are listed below.

- The majority of the plane's structure is 3D printed
- The plane meets all competition design requirements so it can compete
- The team stays within budget while building the plane, and acquires additional funds if necessary
- The plane can take off and land on the competition runway

- The plane can carry a size five soccer ball and one pound box weight
- The cargo of the plane can be loaded and unloaded in under one minute
- The plane can operate in high winds and other undesirable conditions
- The plane can be securely transported to and from the competition
- The plane can be easily assembled once all parts are built/bought
- The appointed controller will have no trouble in flying the plane

2.1.3 Markets

There are a variety of different markets similar to our project that may take interest in the results of our design. First and foremost are RC plane hobbyists. As of now most RC aircrafts are made from materials like foam and balsawood. They may be great materials from a functional stand point, but the RC plane market may take interest in our project because 3D printing can aid in the construction and personalization of the planes. Instead of carving pieces from foam or wood, 3D printing the plane would allow the owner to create more complicated and precise designs in a CAD program, then print the parts and assemble them.

A secondary market for our project would be toy companies. Instead of developing molds in the traditional fashion, molds could be 3D printed. This would make the design of the mold easier to change, in that the it could be changed in a design program then re-printed. Parts of more complicated toys could be printed themselves too.

Military contractors would also be a primary market for our project. One of the primary needs of our plane is that it needs to carry specified cargo. UAVs are already used in the U.S. military mainly from a surveillance and attack standpoint, but in adopting certain aspects of our design, they can also be used to deliver critical supplies to personnel in combat zones. 3D printing these UAVs could also increase their ability to interchange parts and create attachments for tactical elements. Also, using 3D printing material may lower the cost of building the UAVs. That way if one is lost or shot down by the enemies, the cost isn't as great.

Delivery services such as UPS, FedEx, and the USPS would also be a primary market. These companies could use small cargo carrying UAVs to deliver packages. Especially with the emergence of the Urban Air Mobility field, these companies could use 3D printed models similar to our project to deliver goods in both rural and densely populated areas. This again may lower material costs, and make redesigning or changing parts of the UAVs easier.

2.1.4 Stakeholders

Some of the stakeholders invested in Team 508's project are the FAMU – FSU College of Engineering, our sponsor Dr. McConomy, Team 507's faculty advisor Dr. Shih, Team 508's faculty advisor Dr. Hruda, and additive manufacturing companies. The company out team purchases printing filament from specifically will be a stakeholder.

The additive manufacturing company we purchase our printing filament from is the key stakeholder in our project because the success of a 3D printed RC aircraft could help to promote 3D printing within the UAV and aviation industry. 3D printing is already a technique used in the development of small UAVs, however the parts made in this fashion are generally not used for structural purposes. As noted in the key goals section, additive manufacturing will be one of the main focuses in building our aircraft. If the team can successfully design a plane with 3D printing filament, the additive manufacturing industry may greatly benefit from the project.

The FAMU – FSU College of Engineering is also a stakeholder in our project, specifically the Mechanical Engineering department. In many ways our team and our plane will be representing the department and the college in general. The team behaving in a professional manner at the competition, as well as the plane performing in a satisfactory manner can help Dr. McConomy establish relationships with companies who could become future Senior Design sponsors.

Both Team 507 and 508's faculty advisors are stakeholders in our project too. They are both volunteering time and resources to each of their teams. With Dr. Shih being the director of the Aero – Propulsion, Mechatronics and Energy (AME) program, and Dr. Hruda heading the additive manufacturing course at the

college, our performance can help bring recognition to both professors' programs.

2.1.5 Assumptions

Certain assumptions will be safe to make in designing the aircraft. These expectations involve the plane itself as well as how the competition will operate. These assumptions are listed below.

- The plane will abide by all SAE Aero Design competition rules
- The plane will be designed for competition not private use

- Longevity is not a priority. The plane is designed mainly for the competition flight
- The majority of the plane will be 3D printed
- The plane will consist of multiple parts with a maximum length of 9 inches due to the printers being used
- The team has access to three Lulzbot printers
- When possible, multiple parts will be printed in one queue on a printer
- The plane will not have to fly in the rain
- When possible, parts will be bought/borrowed not built. This applies mainly to the propulsion system and not the structure of the plane
- The plane will be able to fly in a cross wind
- The plane will be flown at sea level conditions. This applies to gravity, altitude, air pressure, etc.
- The plane will be flown by a trained, non – biased pilot
- Minimal assembly will take place after unloading the plane at the competition
- The design and build of the aircraft will be an iterative process

2.2 Results

After selecting the most desirable concept, the CADing and printing of the plane began. The drawings for the plane and landing gear showing all dimensions can be found in Appendix G. The assembled RC plane is shown in the figure below.

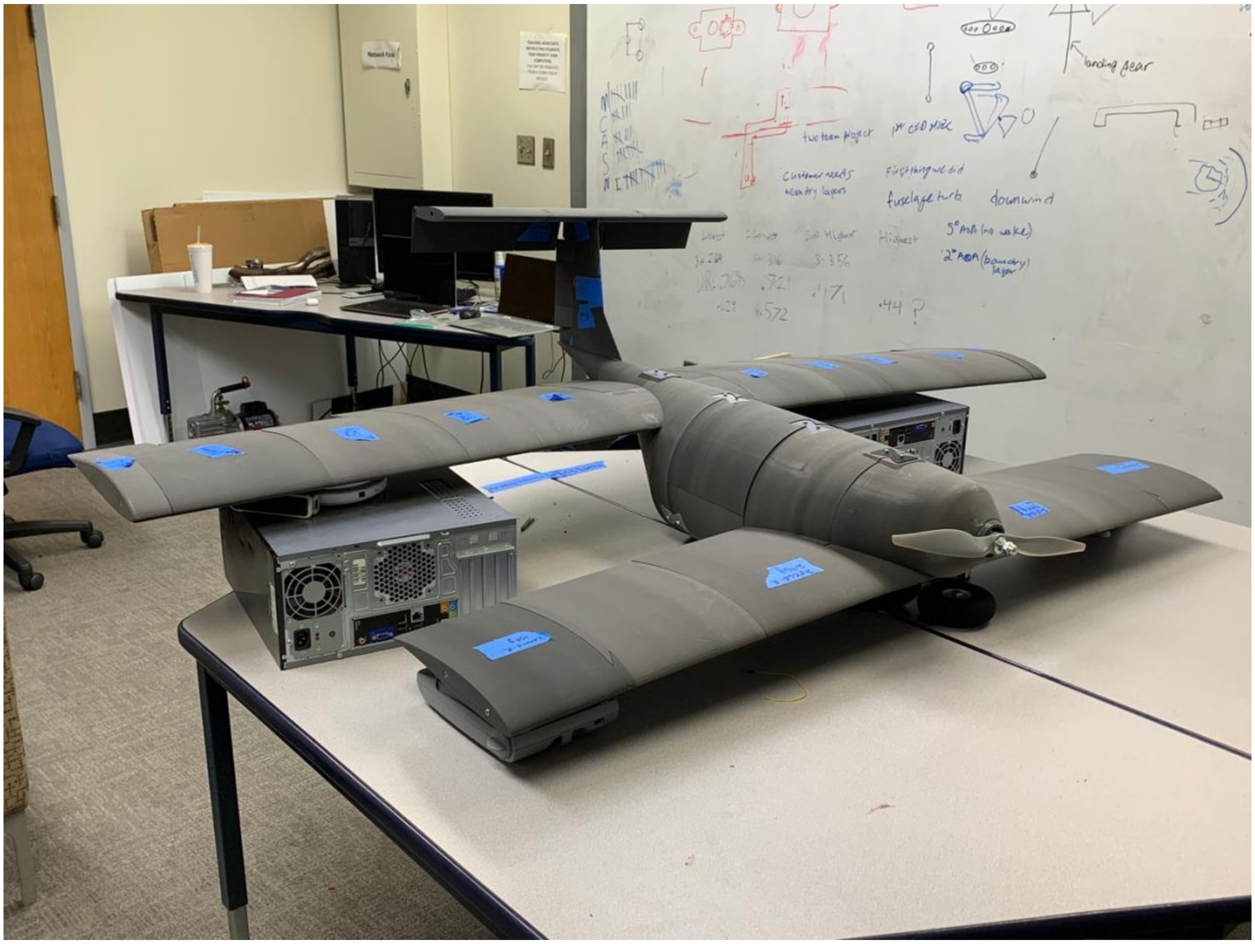


Figure 12. The assembled competition plane.

2.3 Discussion

Our plane nicknamed “The Golden Goose” has the tricycle landing gear setup. It is not attached in the above figure to keep the plane from rolling off the table. All lifting surfaces rectangular in shape. The main wings have a high wing profile and a set of ailerons for maneuverability. The front canards have a low wing profile and no control surfaces. The end piece of both canards is also attached using a dovetail joint to explore the use of woodworking in building the plane. The end piece slides onto the middle piece and is held in place due to the forward motion of the plane. Originally, there was supposed to be no horizontal tail, with the elevators placed on the canards. However to increase the stability of the plane, a T-tail was added with the elevators placed on this horizontal surface. All lift surfaces are assembled and attached to the fuselage with spars. A spar is a rod running the length of a wing, through the fuselage, and into the opposite wing. The spars are secured by screwing end caps on the ends of the wings to compress the modular pieces of the wings together.

The fuselage is assembled using a combination of dovetails and bowties. Bowties are separate pieces printed out of PLA that are screwed in place. To attach two pieces of the fuselage, one end of the bowtie is screwed onto the first piece of the fuselage, and the other end is screwed into the next piece of the fuselage. One to three bowties were used at each connection point. Dovetail joints were again used in connecting pieces of the fuselage. An example of each of these connection methods is shown in the following figure.

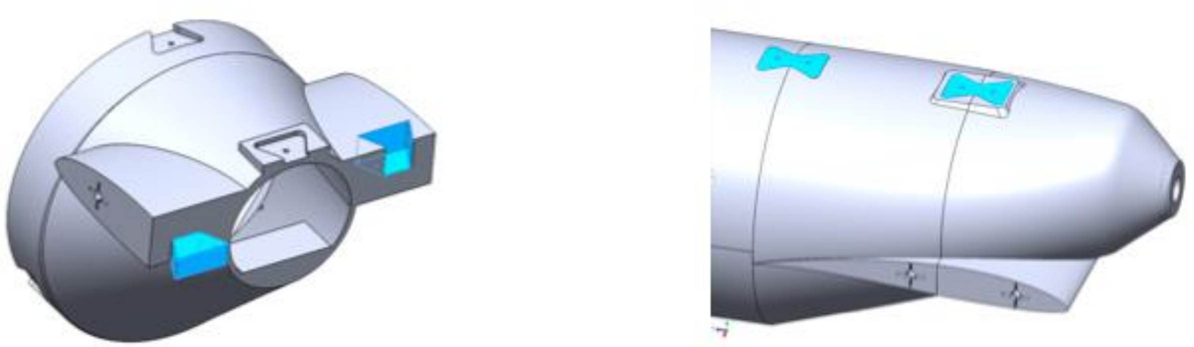


Figure 13. Assembling methods for the fuselage.

The size 5 soccer ball and one pound box weight are held inside the fuselage. To load and unload the cargo, the top part of the fuselage is removed. This is shown in the figure below.

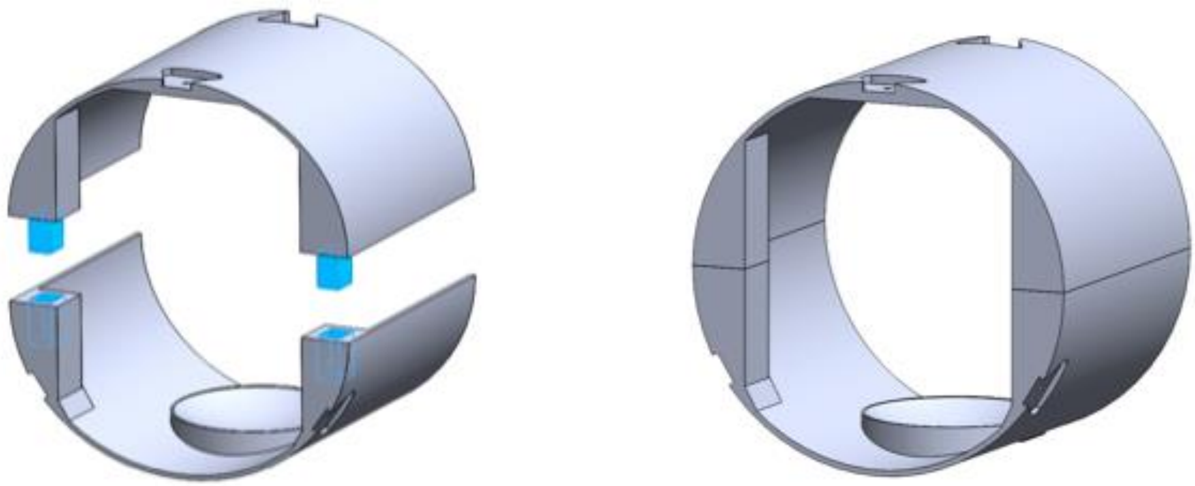


Figure 14. How to get to the cargo hold.

This part of the fuselage is held in place using two bowties on the top of the plane as well as the two dowels highlighted in blue. To get inside of the plane, the two bowties of the top part of this section are removed. This section is then lifted off of the plane. The soccer ball sits on the round part of the bottom of the fuselage. The box weight is secured behind the soccer ball in the next section of the plane shown below.

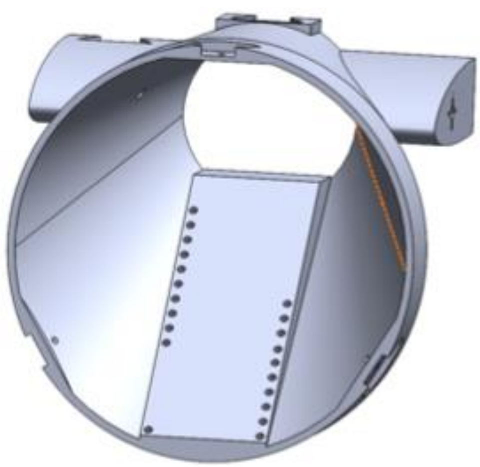


Figure 15. Location of the box weight inside the fuselage.

The box weight is held in place using two screws. There are multiple locations to place the weight so the CG can be adjusted if necessary. The box weight should be loaded before the soccer ball as it is much harder to access with the ball in the way.

2.4 Conclusion

In building the plane, the structural prints were finished in time to assemble the plane before Engineering Day. Even though the team had to withdraw from the competition, the plane was still built within competition rules. The wingspan does not exceed the 120 inch limit. The weight of the plane is 14.6 pounds, which is well within the 55 pound constraint. No FRP's were used and both the LW-PLA and PLA filaments contain no carbon fiber. We are using a typical plastic propeller instead of the forbidden metal one. If the team were to have taken part in the test flight of the competition, we expect that the place would have passed all inspections.

2.5 Future Work

The teams are now working on wiring the plane. We are also trying to get approval from FSU PD to conduct a full test flight. If this flight is approved, it will take place on April 19th. Seminole RC Club members have graciously offered to help with this. We are planning to meet with a member to get the wiring up to his standards so he can fly the plane with the motion controls he is used to. If the flight is not approved in time, no full test flight will be done. The validation tests will have to be done with the plane not leaving the ground. If it comes to this a set of tests will be worked out with Dr. McConomy. The teams are hoping the test flight will be approved, but still planning to have the plane done in time to do a validation test with Dr. McConomy on the 16th when it is officially due.

Appendices

Appendix A: Code of Conduct

Mission Statement

In working together in a professional and effective manner, Team 508 will be committed to meeting all of the requirements of our Senior Design project. We will strive to represent the values of the FAMU - FSU College of Engineering by being dedicated to operating efficiently, staying organized, and functioning with a businesslike attitude throughout the entire design and build process. When finished, we desire that our final results represent the knowledge we have acquired at the college. Our goal is to make our unique design stand out at the competition, and we hope to leave the college proud of what we were able to accomplish.

Team Roles

Each team member will serve as a Co-Design Engineer. In doing so, they will be responsible for contributing to the development of CAD models and drawings, and all necessary calculations associated with the overall project design. The team members will also have their own individual areas of the project that they will take charge of. They will be assigned as follows:

Lauren Chin: *Lift and Control Surfaces Engineer, Meeting Coordinator, & Co-Design Engineer*
The Lift and Control Surfaces Engineer will be in charge of designing the best ways to build and connect all lift and control surfaces. The Meeting Coordinator is responsible for taking meeting minutes and distributing them to team members. They are also responsible for scheduling all team member only meetings in conjunction with the Project Manager.

Joseph Figari: *Fuselage/Payload Engineer, Co-Design Engineer, & Financial Officer*

The Fuselage/Payload Engineer is in charge of designing the fuselage of the plane, and making sure it meets all the requirements regarding securing the propulsion system and payload. The Financial Officer is in charge of keeping the project within budget. When necessary they are in charge of drafting proposals for more funding.

Jacob Pifer: *Project Manager, Manufacturing Engineer & Co-Design Engineer*

The Project Manager is the point of contact for the team and is responsible for submitting all team assignments. The Project Manager is also responsible for ensuring the team stays on task and on schedule in order to complete the project within the allotted time. The Manufacturing Engineer is responsible for the materials research associated with the project, and for determining the ideal fabricants to complete the final design. The Manufacturing Engineer is also responsible for making sure all designed parts are printable, and operating the 3D printers. They must also queue and pick up any parts printed at FSU's Innovation Hub.

Note: These are each team members' **official** roles. It does not excuse members from assisting others in areas of the project outside of their assigned responsibilities. Other tasks may arise during the project duration, so the above roles also do not prohibit team members from taking on more obligations. Additional tasks will first be completed on a volunteer basis. If no one volunteers, the Project Manager will decide who must complete the task. The decision will be based on each team members' workload, including their own.

Communication

Our team group chat "Write Bros. 2.0" will be the main way group members communicate outside of class and meetings. When a message is sent from a group member relaying information, all others should at least "like" the message to show it has been read. Obviously if a response is necessary, group members should respond. If a message only involves some group members, those members should be tagged in the message. Those who are not tagged should still read the message and respond if necessary. Email is another acceptable way to communicate, but should be used for sending important documents, completed assignments, and other things of this nature. The group chat should be the main form of casual communication between group members. Team members should send verification that they have received and read a message or email within 24 hours of the message being sent.

Basecamp will be another way team members communicate. It will act as a central hub for communication between Dr. McConomy and team members, as well as the interaction between Team 507 and 508. This includes sharing important documents and scheduling meetings. Team members should frequently check Basecamp for any important information or schedule changes.

There will be mandatory group meetings following the dismissal of the Senior Design lecture Tuesdays and Thursdays within the time period of 3:30pm to 7:45pm. Zoom will be the main way meetings are held. Note that team members should be available for meetings at 3:30pm on Tuesdays and Thursdays regardless of the start time of Senior Design lecture. Any additional team meetings will be scheduled during the following time slots by the Meeting Coordinator and Project Manager:

Monday: 11:00 am - 8:00 pm

Tuesday: 9:00 am - 7:45 pm

Wednesday: 10:00 am - 8:00 pm

Thursday: 9:00 am - 7:45 pm

Friday: 10:00 am - 8:00 pm

Saturday: 10:00 - TBD

Sunday: TBD

***Meeting times can be rescheduled due to holidays, emergencies, or acceptable unforeseen circumstances.**

All group members will be notified a minimum of 24 hours before a scheduled meeting via Basecamp and/or the group chat. In the case of necessary meetings outside of the scheduled time slots, group members should still make every effort to attend. Sponsor and advisor meetings will be scheduled by the Project Manager and may be scheduled at any time, including outside of the above schedule. The Project Manager and Meeting Coordinator will be in frequent contact to schedule, cancel, or move team meeting times.

The Meeting Coordinator will take detailed notes and minutes of each meeting and distribute them via email and/or Basecamp within 24 hours of the meeting's end. **All team members should still be taking their own detailed notes during every team meeting even though the Meeting Coordinator will be sending notes to the team afterwards.**

All team members should find a quiet room with low potential for distractions or disruptions to attend Zoom meetings, especially meetings with sponsors, advisors, and Dr. McConomy present. Distractions include roommates/family members, pets, silly posters, or anything else that would make it hard to concentrate on the meeting content. The preferred meeting area for each member would be a well-lit and quiet room with no roommates or pets, and a wall in the background that is as bare as possible. Should a team member encounter a problem which requires them to momentarily leave a Zoom meeting, they will excuse themselves in a polite and professional manner to resolve the problem, then return as quietly as possible. If a team member is disconnected from a Zoom meeting due to bad internet connection, the team member will notify the team via the group chat and call the Project Manager or Meeting Coordinator in order to continue participating in the meeting. The rest of the team will notify all other parties involved in the meeting to explain the current situation and ensure they understand why that team member is no longer visually present. The team member who was cut out should continuously try to reconnect to the Zoom session even while on the phone.

Any documents or files related to project meetings should be shared with the entire team even if the document/file is team member specific. Files will be shared via FSU email and/or uploaded to Basecamp. The files should be labeled using the class file naming convention. All team members should be copied on any emails to sponsors, advisors, or Dr. McConomy.

For joint team meetings, Teams 507 and 508 will communicate through GroupMe. The same rules regarding responding and replying to messages will apply in this group chat. Weekly group meetings will be held through Zoom and scheduled on Basecamp. A One Drive folder will be used to hold any documents pertaining to both teams.

Dress Code

Whether online or in person, good hygiene is expected from group members during team meetings. This means showered, hair brushed, and all other ethical hygiene basics. Depending on the type of meeting, Group members will have different dress code requirements. These requirements are as follows:

Presentations: Business Casual

For presentations, group members should wear a clean white/neutral colored button-down shirt, a suit with no tie along with dress pants and dress shoes. Members should of course be practicing good hygiene as mentioned above. For Zoom meetings, dress pants and shoes are not mandatory since only the top half of each member will be in frame. In the case of in-person meetings, members always need to wear the dress pants and dress shoes. This would be preferred in all meetings but, required in any in person meetings.

Advisor/Professor Meetings: Casual Dress

For advisor and professor meetings, casual dress is allowed. This is defined as any outfit you would wear to a normal class meeting at COE. When it comes to hygiene, please practice good hygiene when meeting in person. For online meetings, it is up to each member as they will be in separate houses and rooms.

Sponsor Meetings: Business Casual

For sponsor meetings, members should dress business casual by wearing clean, neutral button-down shirts without a tie. Neutral polos and blouses are okay as well. Good hygiene will again be practiced. The rules mentioned above regarding the type of meeting (online or in-person) and when dress pants and shoes are needed apply here as well.

<u>Team Members Only:</u> Casual Dress

For these meetings team members can dress casual. However they should still look presentable. This means they should be wearing clean, appropriate attire. Good hygiene is of course still required.

Attendance Policy

Meetings will be scheduled within the agreed upon time-slots to make attendance easy. Once a meeting time is agreed upon all members are expected to be present, except in the case of emergencies. As mentioned above in the Communications section, meetings will be scheduled with at least 24 hours' notice. During the meeting, attendance will be kept by the Meeting Coordinator. Excessive and unexcused absences are both considered Code of Conduct Violations. For this Code of Conduct, excessive absences are defined below.

- One or more excused absence per week for three weeks straight
- Two or more unexcused absences in two weeks

This will be the baseline for what constitutes "too many absences". If agreed upon by the group, an absence can be struck from team member's absence count.

Absences can be a nuisance to group activity but are sometimes necessary as we are all senior engineering students and balancing heavy workloads in preparation for graduation. Last minute absences require at least 24 - 48 hours' notice to the Project Manager. Any employed team member should send the team their weekly schedules for the team to plan meetings and divide work. Team members who miss meeting will be updated on the progress and decisions made during the meeting as soon as possible. In the event of an unexpected absence due to sickness, a death in the family, or other extenuating circumstances, the team member must notify the team. If it is a private matter, they can tell only the Project Manager if they wish. For planned absences, a week in advance warning is required. If you are going to be late to a meeting, you must notify the group within the 10 minutes leading up to the meeting, or the first ten minutes of the meeting (20 minutes total).

Even if a group member has an excused absence, they are still responsible for any tasks assigned to them. If this team member is unable to complete their tasks within the allotted time, they will notify the Project Manager. When needed, the remaining group members will divide the work that still needs to be completed.

At the start of the semester you are given 1 vacation day and you are given one more on the 7th week of the fall semester. These vacation days will allow you to submit an assignment 1 day late. You must notify Dr. McConomy 24 hours before the due date that you are using the vacation day. If any vacation days are left over by the end of the fall semester you can either use them on 10 points extra credit for attendance and participation, or they can roll over to the spring semester. If a team member must use a vacation day, the group must also be notified.

Assignment Completion and Submission

All group work will be submitted by the Project Manager in the format required by Dr. McConomy. Any files shared between group members will also be named and formatted using the file naming convention required by Dr. McConomy. Each group member is required to finish the assigned tasks agreed upon when the assignment is given. All group members must agree that the assignment is finished before it is submitted. Unless agreed upon by the group, no further changes will be made to the assignment during the last hour before the deliverable is due. For example, if an assignment is due at 5pm, no one is allowed to change the document after 4pm, unless the group is notified and finds it necessary. The entire team must be notified of any changes made to a deliverable after it has been deemed "complete". Upon completion and submission, the final document will be uploaded to Basecamp.

Team Disputes

Any disputes between team members will first be brought to the Project Manager. Team disputes include problems involving finishing assignments, lack of communication, or other project disruptions. The parties involved must schedule a private meeting with the Project Manager to discuss the issue, by contacting them outside of the main group chat. If the issue cannot be resolved, the matter will then be brought to an advisor and/or Dr. McConomy. The parties involved must then follow the mediator's verdict.

Code of Conduct Violations

Code of Conduct violations will follow the disciplinary tier system below:

- **First Offense:** Verbal warning from the group

- **Second Offense:** Verbal warning from the group
- **Third Offense:** Private meeting with the Project Manager
- **Fourth Offense:** Private meeting with the Project Manager
- **Fifth Offense:** Signed document stating the group member recognizes their actions as Code of Conduct violations brought to Dr. McConomy by the team member and the Project Manager

Depending upon the magnitude of the situation, the group can excuse the offense or skip different tiers of the system. This must be done with a majority vote from the parties not involved. To uphold each group members' right to privacy, the Project Manager will keep track of team members' Code of Conduct violations.

Changes to the Code of Conduct

Any recommended changes made to the Team 508 Code of Conduct must first be brought to the entire team. After the proposition is explained to the team a vote will be taken. A majority vote is needed for the changes to be made. The Project Manager will then make the proposed changes to the official copy of the Team 508 Code of Conduct.

Statement of Understanding

By signing this document on January 12, 2021 the members of Team 508 agree to the conditions, policies, and consequences it details.

Lauren Chin

Joe Figari

Jacob Pifer

Appendix B: Functional Decomposition

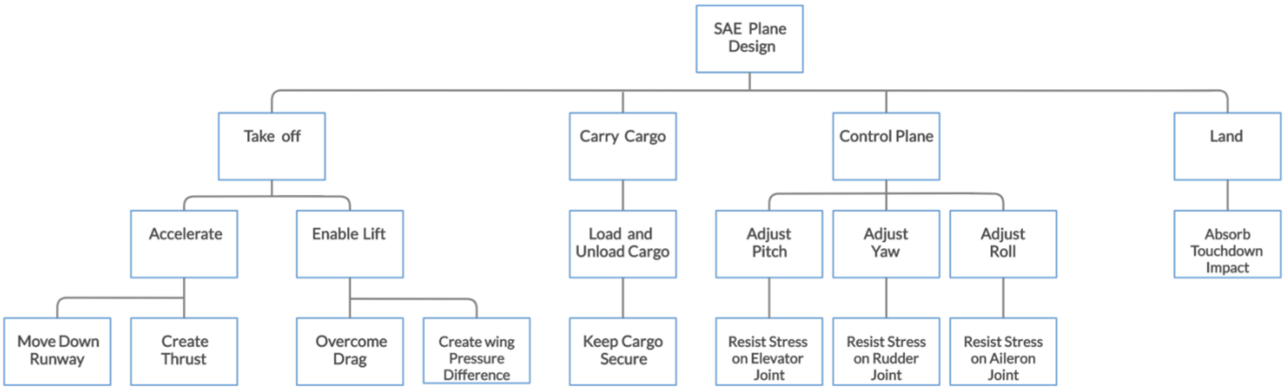


Figure 16. Tricycle (left) and Taildragger (right) landing gear (Ozgen, 2015).

Appendix C: Target Catalog

Table 12.
Full Catalog of Project Targets and Metrics.

Function:	Metric:	Target:	Validation Method:	Validation Tools:
Accelerate				
Generate Thrust	Take-off Distance	Less than 100 ft.	Theoretical Calculations and Test Flights	Use measuring tools to find take-off distances of each of the test flights
	Propeller Size	12 in. – 18 in.	Experiments	Measure amount of thrust created using different propellers with weighing scale and motor
Move Down Runway	Front Wheel Steering	-60° to 60° range of motion	Experiments	Measure range of motion of front wheel and the stability of the aircraft at extreme angles
Enable Lift				
Create Wing Pressure Differential	3D Printing Dimensional Error Tolerance	± 0.02 in.	Physical Measurements	Use calibration cubes to compare SOLIDWORKS dimensions to printed dimensions
	Wingspan	Less than 120 in.	Theoretical Aerodynamic Calculations and Physical Measurements	MATLAB and tape measure
Overcoming Drag	Drag at Connection Points	Minimize Number of Printed Parts	Experiments and Theoretical Aerodynamic Calculations	MATLAB and prototypes
Overall Structure	Total Flight Weight	Less than 55 lbs.	Theoretical Calculations and Physical Measurements	Weighing scale
Load and Unload Payload				

Overall Plane Cargo	Weight	6 lbs.	Experiments and Theoretical Calculations	Weigh competition weights, motor, battery, etc.
Keep Payload Secure	Weight	2 lbs.	Competition Requirement	Weighing scale
Unload Payload	Time	Less than one minute	Competition Requirement	Conduct time trials
Plane Control				
Withstand Stress Applied to the Aileron Joint	Pounds per Square Inch (psi)	Maximum Applied Stress of 2500 psi	Experiments and Theoretical Aerodynamic Calculations	Material strength tests, MATLAB, and SOLIDWORKS Simulations
Withstand Stress Applied to Rudder Joint	Pounds per Square Inch (psi)	Maximum Applied Stress of 2500 psi	Experiments and Theoretical Aerodynamic Calculations	Material strength tests, MATLAB, and SOLIDWORKS Simulations
Withstand Stress Applied to Elevator Joint	Pounds per Square Inch (psi)	Maximum Applied Stress of 2500 psi	Experiments and Theoretical Aerodynamic Calculations	Material strength tests, MATLAB, and SOLIDWORKS Simulations
Servos Overpower Flight Forces	Torque	Greater than 67 oz. · in.	Experiments and Theoretical Aerodynamic Calculations	MATLAB
Land				
Absorb Touchdown Impact	Force	750 lbf.	Theoretical Calculation	MATLAB and SOLIDWORKS simulation

Appendix D: Concept Generation

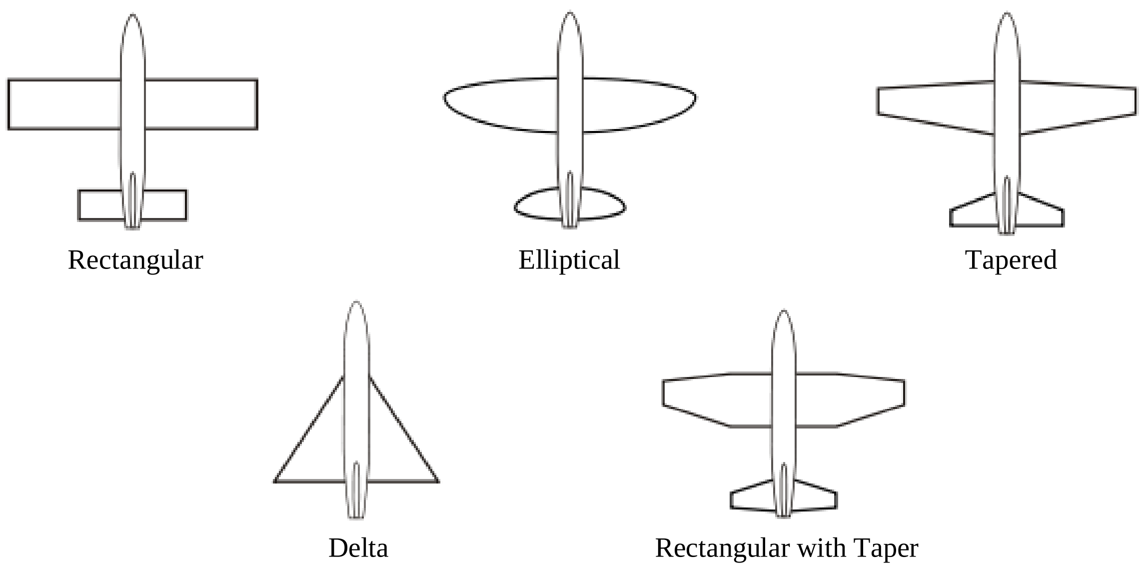


Figure 17. Possible wing designs (Wing Configuration, 2020).

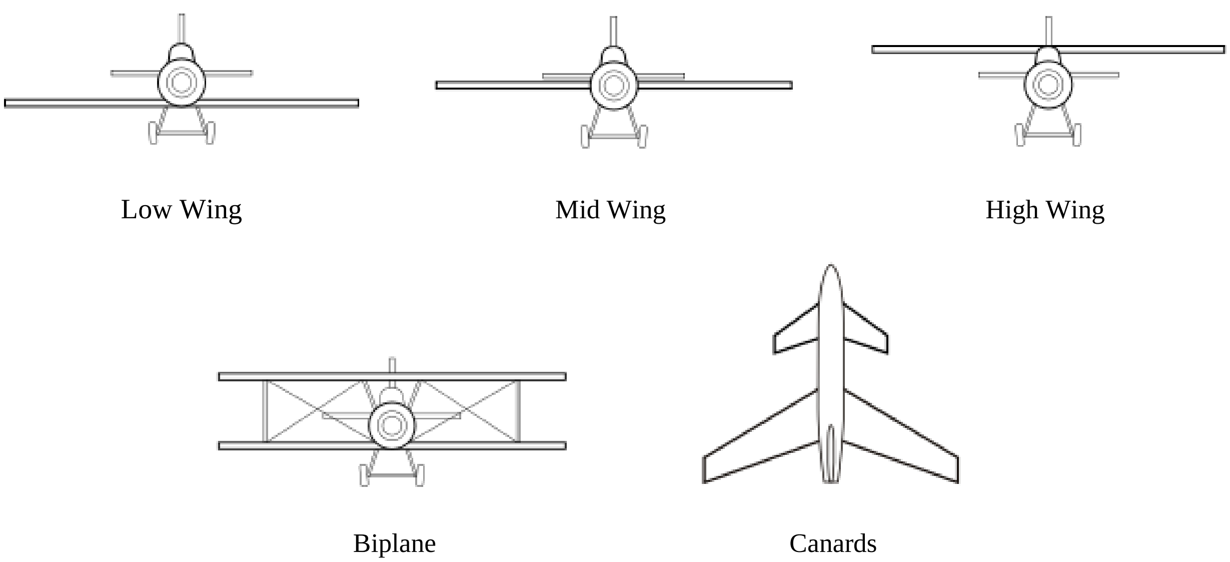


Figure 18. Possible wing profiles (Wing Configuration, 2020).

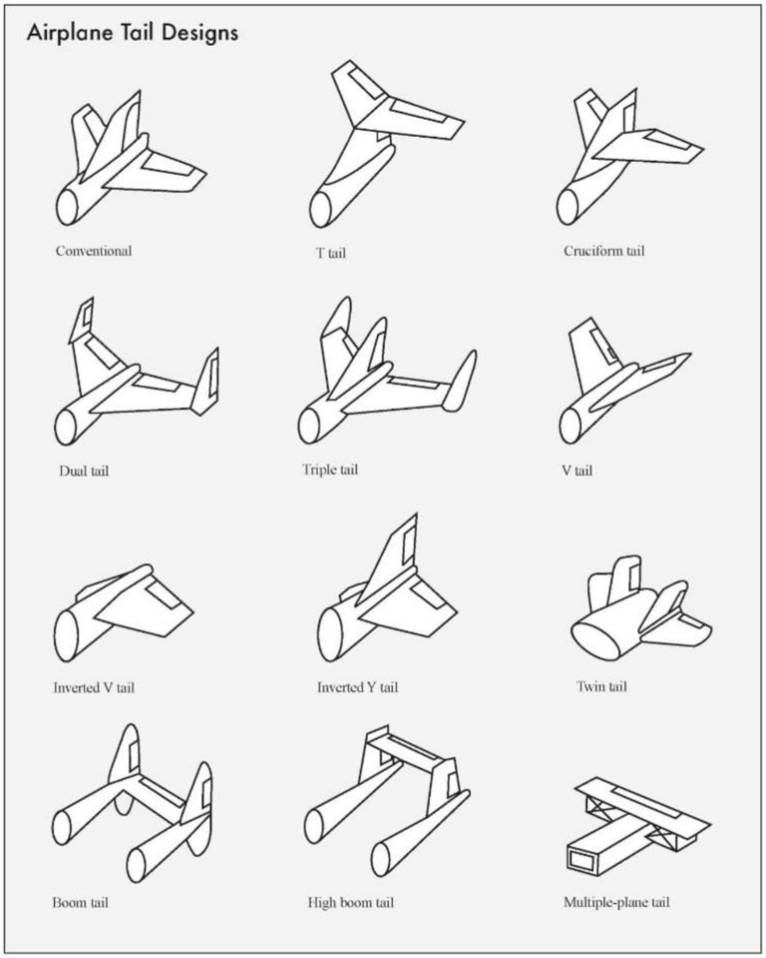


Figure 19. Possible tail configurations (Tail Designs, n.d.).

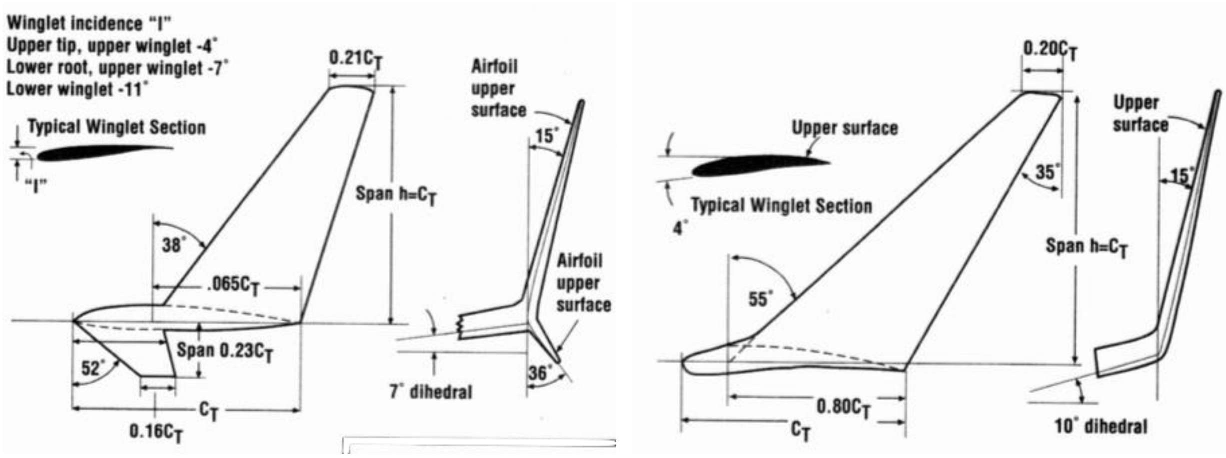
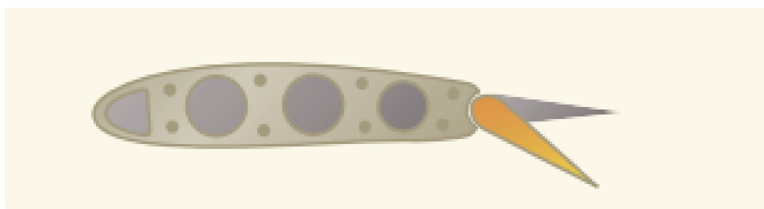
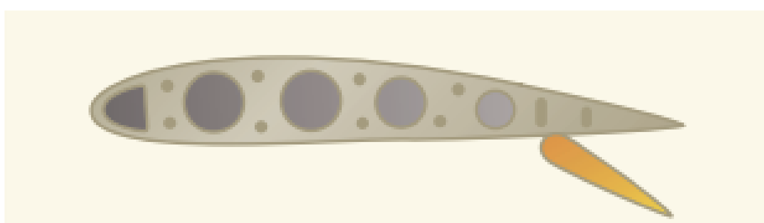


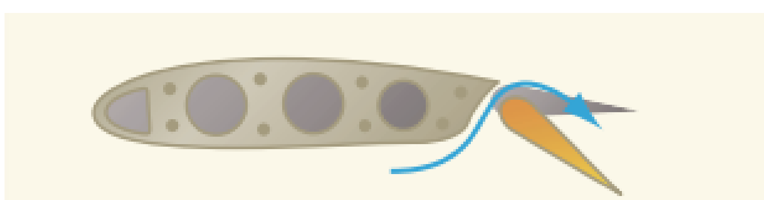
Figure 20. Whitcomb (left) and Grantz (right) Winglets (Lennon, 1996).



Plain Flaps



Split Flaps



Slot Flaps

Figure 21. Types of flaps (Aircraft Structure, n.d.).

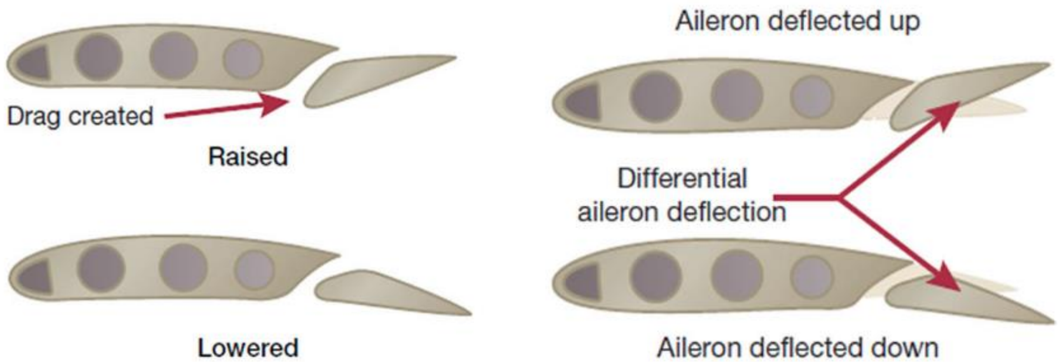


Figure 22. Frise (left) and Differential (right) ailerons (estaff, 2014).

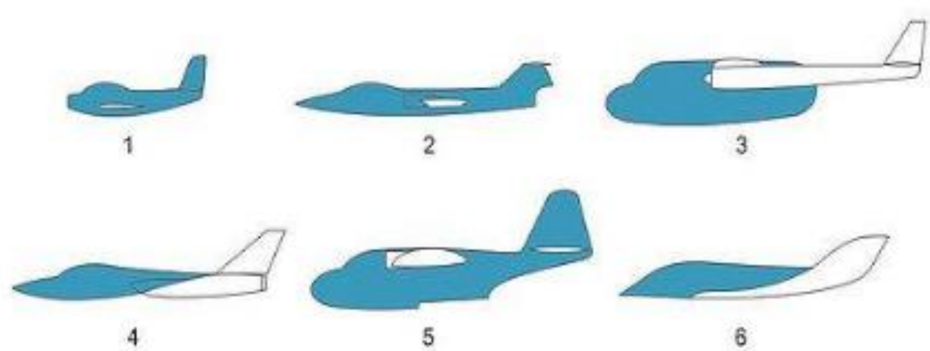
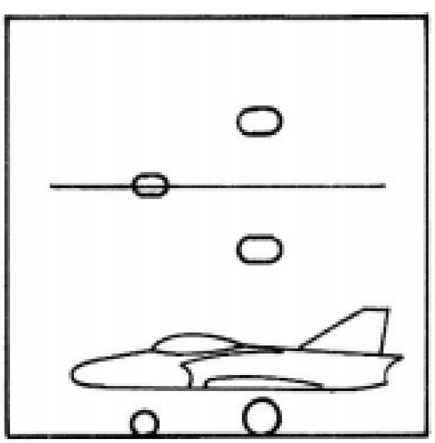


Figure 23. Types of model plane fuselages: (1) Subsonic, (2) Supersonic, (3) High capacity subsonic, (4) High-maneuverability subsonic, (5) Flying boat, (6) Hypersonic



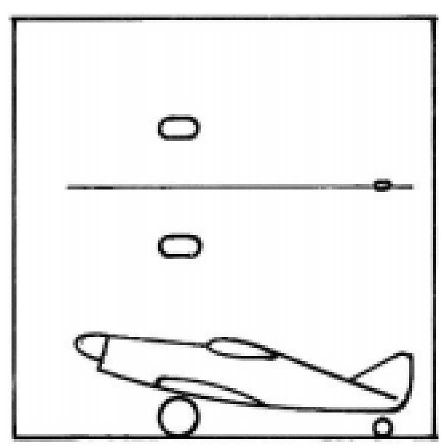


Figure 24. Tricycle (left) and Taildragger (right) landing gear (Ozgen, 2015).

Table 13.
100 Project Concepts.

No.	Printing Material	Wing Design	Wing Profile	Landing Gear	Tail	Propeller Location	Fuselage	Flaps	Ailerons	Winglets
1*	LW-PLA	Rect./Tapered	High	Tricycle	Conventional	Front Propeller	Flying Boat	Plain	Differential	Grantz
2	LW-PLA	Rect./Tapered	High	Tricycle	Conventional	Front Propeller	Subsonic	Split	Frise	Whitcomb
3	LW-PLA	Rect./Tapered	High	Tricycle	Conventional	Front Propeller	HC Subsonic	Slot	Differential	Whitcomb
4	LW-PLA	Rect./Tapered	High	Tricycle	Conventional	Front Propeller	HM Subsonic	None	Differential	Whitcomb
5*	LW-PLA	Delta & Canards	High wing	Tricycle	None	Rear Propeller	Subsonic	Slot	Differential	Tip Sails
6	PLA	Rectangular	High	Taildragger	Conventional	Front Propeller	Subsonic	Split	Frise	None
7	PLA	Rectangular	High	Tricycle	None	Double Propeller	Subsonic	None	Differential	None
8*	LW-PLA	Rectangular & Canards	High	Tricycle	Rudder w/ no wings	Front Propeller	Flying Boat	Slot	Differential	Grantz
9	LW-PLA	Rectangular	Canard	Tricycle	T-tail	Rear Propeller	Subsonic	Plain	Frise	None
10	PLA	Delta	Mid	Tricycle	None	Rear Propeller	Subsonic	None	Differential	None
11	LW-PLA	Tapered	Mid	Tricycle	Cruciform	Front Propeller	Super sonic	None	Frise	Grantz
12	PLA	Rectangular	High	Tricycle	Conventional	Front Propeller	Hypersonic	Spit	Frise	Tip Sails
13	LW-PLA	Rectangular	Biplane	Taildragger	Conventional	Front Propeller	Hypersonic	None	Differential	None
14	LW-PLA	Elliptical	High	Tricycle	Boom Tail	Front Propeller	Subsonic	None	Differential	None
15	LW-PLA	Tapered	High	Tricycle	Conventional	Front Propeller	HC Subsonic	Slot	Differential	None
16	PLA	Delta	High	Tricycle	None	Rear Propeller	Subsonic	None	Differential	Tip Sails
17	LW-PLA	Tapered	High	Tricycle	T-tail	Front Propeller	Subsonic	Slot	Frise	None
18	LW-PLA	Rect./Tapered	Low	Tricycle	Conventional	Front Propeller	Supersonic	Split	Frise	Grantz
19	PLA	Rectangular	High	Taildragger	Cruciform	Front Propeller	Hypersonic	None	Frise	Whitcomb
20	LW-PLA	Tapered	Low	Tricycle	Cruciform	Front Propeller	HM Supersonic	None	Differential	None
21	LW-PLA	Tapered	Low	Tricycle	Cruciform	Front Propeller	Hypersonic	None	Differential	Grantz
22*	PLA	Tapered	Low	Tricycle	Conventional	Front Propeller	Flying Boat	Slot	Differential	Grantz
23	PLA	Elliptical	Biplane	Taildragger	Cruciform	Double Propeller	Hypersonic	Split	Frise	None

24	PLA	Rect./Tapered	Mid	Tricycle	Boom tail	Double Propeller	Subsonic	Plain	Differential	None
25	PLA	Tapered	Biplane	Tricycle	Boom tail	Double Propeller	HM Supersonic	Plain	Differential	Tip Sails
26*	LW-PLA	Rectangular	High	Tricycle	Conventional	Front Propeller	Flying Boat	Slot	Differential	None
27	LW-PLA	Rect./Tapered	Mid	Taildragger	Triple tail	Double Propeller	Supersonic	Slot	Frise	None
28	LW-PLA	Tapered	Biplane	Tricycle	Conventional	Double Propeller	Supersonic	Slot	Frise	None
29	LW-PLA	Rect./Tapered	Low	Taildragger	Triple tail	Double Propeller	HM Supersonic	None	Differential	Whitcomb
30	LW-PLA	Rectangular	Low	Taildragger	None	Front Propeller	HM Supersonic	Slot	Frise	Tip Sails
31	LW-PLA	Rectangular	Biplane	Tricycle	Conventional	Double Propeller	Flying boat	Split	Frise	Tip Sails
32	LW-PLA	Elliptical	Biplane	Taildragger	Twin tail	Double Propeller	Subsonic	None	Frise	None
33	PLA	Elliptical	High	Tricycle	Conventional	Double Propeller	Flying boat	Plain	Differential	None
34	PLA	Rect./Tapered	Mid	Tricycle	Triple tail	Double Propeller	Hypersonic	None	Differential	Grantz
35	PLA	Rectangular	Mid	Tricycle	Twin tail	Rear Propeller	HM Supersonic	None	Differential	Tip Sails
36	LW-PLA	Rect./Tapered	Mid	Taildragger	Conventional	Front Propeller	HC Subsonic	Slot	Differential	None
37	LW-PLA	Elliptical	Biplane	Taildragger	Twin tail	Rear Propeller	Subsonic	Plain	Differential	None
38	LW-PLA	Tapered	High	Tricycle	T-tail	Front Propeller	Flying boat	None	Differential	Tip Sails
39	PLA	Rectangular	Biplane	Taildragger	Twin tail	Rear Propeller	Hypersonic	Slot	Frise	Tip Sails
40	LW-PLA	Rect./Tapered	Mid	Taildragger	Cruciform	Double Propeller	HC Subsonic	Plain	Frise	Tip Sails
41	PLA	Rectangular	Low	Taildragger	Twin tail	Rear Propeller	HM Supersonic	None	Frise	Whitcomb
42	LW-PLA	Tapered	Mid	Tricycle	T-tail	Rear Propeller	HM Supersonic	Split	Frise	None
43*	LW-PLA	Elliptical	Low	Tricycle	Conventional	Front Propeller	Subsonic	Plain	Frise	None
44	LW-PLA	Tapered	Low	Tricycle	Triple tail	Rear Propeller	Flying boat	Slot	Differential	Tip Sails
45	LW-PLA	Tapered	High	Taildragger	T-tail	Rear Propeller	Hypersonic	Split	Frise	None
46	PLA	Elliptical	High	Tricycle	Conventional	Rear Propeller	Flying boat	Plain	Differential	None
47	LW-PLA	Rect./Tapered	Low	Tricycle	Boom tail	Rear Propeller	Flying boat	None	Frise	None
48*	PLA	Tapered & Canards	High	Tricycle	None	Rear Propeller	Supersonic	Split	Differential	Tip Sails
49	LW-PLA	Tapered	High	Taildragger	Cruciform	Front Propeller	Flying boat	Slot	Frise	Tip Sails
50	LW-PLA	Elliptical	Low	Tricycle	Boom tail	Rear Propeller	Supersonic	Plain	Differential	None
51	PLA	Rectangular	Mid	Tricycle	Twin tail	Rear Propeller	HM Supersonic	None	Differential	Tip Sails

52	PLA	Rect./Tapered	Mid	Taildragger	Triple tail	Double Propeller	Supersonic	Split	Frise	Grantz
53	PLA	Tapered	High	Taildragger	Conventional	Front Propeller	HC Subsonic	Slot	Frise	Tip Sails
54	LW-PLA	Tapered	Biplane	Taildragger	Cruciform	Front Propeller	HM Supersonic	Plain	Differential	Tip Sails
55	LW-PLA	Rectangular	Mid	Taildragger	Twin tail	Front Propeller	Hypersonic	None	Frise	Grantz
56	LW-PLA	Rect./Tapered	Mid	Taildragger	Conventional	Rear Propeller	Flying boat	None	Differential	None
57	PLA	Elliptical	Low	Tricycle	Cruciform	Double Propeller	Flying boat	None	Differential	None
58	LW-PLA	Elliptical	High	Taildragger	Cruciform	Front Propeller	HM Supersonic	None	Differential	None
59	PLA	Tapered	Mid	Tricycle	Conventional	Double Propeller	Flying boat	Plain	Frise	Tip Sails
60	LW-PLA	Elliptical	Biplane	Taildragger	Boom tail	Rear Propeller	Hypersonic	Split	Frise	None
61	PLA	Tapered	Low	Tricycle	Boom tail	Front Propeller	Supersonic	Slot	Frise	Grantz
62	PLA	Elliptical	Mid	Tricycle	Triple tail	Front Propeller	HM Supersonic	Split	Differential	None
63	PLA	Tapered	Low	Tricycle	Triple tail	Rear Propeller	HC Subsonic	None	Frise	Whitcomb
64	LW-PLA	Rect./Tapered	High	Taildragger	Conventional	Rear Propeller	HC Subsonic	Slot	Differential	Grantz
65	LW-PLA	Tapered	Biplane	Tricycle	Conventional	Front Propeller	Subsonic	Slot	Frise	Whitcomb
66	LW-PLA	Rectangular	Mid	Tricycle	Cruciform	Double Propeller	Flying boat	Split	Frise	Tip Sails
67*	PLA	Tapered	High	Tricycle	T-tail	Front Propeller	Flying boat	Plain	Frise	None
68	PLA	Rectangular	Mid	Tricycle	Conventional	Rear Propeller	Flying boat	None	Frise	None
69	PLA	Rect./Tapered	Biplane	Tricycle	Boom tail	Rear Propeller	Subsonic	Slot	Differential	Tip Sails
70	LW-PLA	Rectangular	Biplane	Tricycle	T-tail	Front Propeller	Supersonic	Split	Frise	Tip Sails
71	PLA	Tapered	Biplane	Taildragger	Conventional	Rear Propeller	HM Supersonic	Plain	Differential	None
72	LW-PLA	Rectangular	High	Tricycle	Twin tail	Double Propeller	HC Subsonic	Plain	Differential	Whitcomb
73	LW-PLA	Rectangular	High	Tricycle	Boom tail	Front Propeller	Hypersonic	Plain	Frise	Whitcomb
74	LW-PLA	Rect./Tapered	Low	Tricycle	Triple tail	Double Propeller	Supersonic	None	Frise	None
75	PLA	Rectangular	Biplane	Taildragger	Cruciform	Rear Propeller	HC Subsonic	None	Differential	Grantz
76	PLA	Tapered	Mid	Tricycle	T-tail	Rear Propeller	Supersonic	Plain	Frise	Grantz
77	LW-PLA	Elliptical	Mid	Taildragger	Triple tail	Double Propeller	Subsonic	None	Differential	None
78	LW-PLA	Rectangular	Low	Taildragger	Conventional	Double Propeller	HC Subsonic	None	Differential	Whitcomb
79	PLA	Rectangular	High	Taildragger	Triple tail	Double Propeller	Supersonic	Plain	Differential	Grantz

80	LW-PLA	Elliptical	Low	Tricycle	T-tail	Double Propeller	Flying boat	Plain	Frise	None
81	PLA	Elliptical	Low	Taildragger	Boom tail	Double Propeller	HC Subsonic	Split	Differential	None
82	LW-PLA	Rect./Tapered	Mid	Taildragger	Twin tail	Double Propeller	Hypersonic	Split	Differential	Tip Sails
83	LW-PLA	Elliptical	High	Tricycle	Triple tail	Rear Propeller	Supersonic	Plain	Differential	None
84	PLA	Tapered	High	Tricycle	Conventional	Front Propeller	Supersonic	None	Differential	Grantz
85	LW-PLA	Rectangular	Low	Taildragger	Twin tail	Rear Propeller	Hypersonic	Plain	Frise	Whitcomb
86	PLA	Rectangular	High	Taildragger	Boom tail	Double Propeller	Subsonic	Plain	Differential	Whitcomb
87	PLA	Tapered	Mid	Tricycle	T-tail	Rear Propeller	HM Supersonic	Plain	Frise	Whitcomb
88	LW-PLA	Elliptical	Low	Taildragger	T-tail	Double Propeller	Flying boat	None	Differential	None
89	LW-PLA	Rect./Tapered	Mid	Tricycle	Cruciform	Double Propeller	HM Supersonic	Plain	Frise	None
90	LW-PLA	Rect./Tapered	Low	Tricycle	Cruciform	Rear Propeller	Flying boat	None	Differential	None
91	LW-PLA	Rect./Tapered	Low	Tricycle	Boom tail	Double Propeller	Hypersonic	None	Frise	Grantz
92	PLA	Rect./Tapered	Biplane	Taildragger	Boom tail	Front Propeller	Flying boat	None	Frise	Whitcomb
93	PLA	Elliptical	Low	Tricycle	Triple tail	Front Propeller	Subsonic	Plain	Frise	None
94	LW-PLA	Rect./Tapered	High	Taildragger	Conventional	Rear Propeller	Supersonic	Split	Frise	Whitcomb
95	LW-PLA	Elliptical	High	Taildragger	Cruciform	Front Propeller	Flying boat	None	Differential	None
96	LW-PLA	Rect./Tapered	Low	Tricycle	Twin tail	Front Propeller	HC Subsonic	Slot	Frise	Tip Sails
97	PLA	Rectangular	High	Taildragger	Twin tail	Front Propeller	Subsonic	Slot	Frise	Whitcomb
98	LW-PLA	Elliptical	Mid	Taildragger	T-tail	Double Propeller	HC Subsonic	Plain	Frise	None
99	PLA	Rect./Tapered	Biplane	Tricycle	Triple tail	Front Propeller	HC Subsonic	Slot	Differential	Tip Sails
100	LW-PLA	Rect./Tapered	Mid	Taildragger	Conventional	Front Propeller	Subsonic	Plain	Differential	None

Appendix E: AHP Charts

Table 14.
Development of a Candidate set of Criteria Weights.

	Lift	Thrust	Control Surface Movement	Weight	Joint Strength
Lift	1.00	0.33	3.00	9.00	9.00
Thrust	3.00	1.00	3.00	9.00	9.00
Control Surface Movement	0.33	0.33	1.00	5.00	3.00
Weight	0.11	0.11	0.20	1.00	0.11
Joint Strength	0.11	0.11	0.33	9.00	1.00
Sum	4.56	1.89	7.53	33.00	22.11

Table 15.
Normalized Criteria Comparison Matrix for Table 13.

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

Table 16.
Consistency Check for Table 13.

{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Con = {Ws}/{W} Consistency Vector
1.911	0.490	3.899
2.802	0.230	12.184
0.796	0.140	5.683
0.149	0.040	3.720
0.478	0.100	4.780

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

Table 17.
Lift Comparison Matrix.

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

Table 18.
Normalized Criteria Comparison Matrix for Table 16.

	Concept 1	Concept 3	Concept 6	Criteria Weight
Concept 1	0.231	0.226	0.273	0.243
Concept 3	0.692	0.677	0.636	0.669
Concept 6	0.077	0.097	0.091	0.088
Sum	1.000	1.000	1.000	1.000

Table 19.
Consistency Check for Table 16.

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

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

Table 20.
Thrust Comparison Matrix.

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

Table 21.
Normalized Criteria Comparison Matrix for Table 19.

	Concept 1	Concept 3	Concept 6	Criteria Weight
Concept 1	0.333	0.333	0.333	0.333
Concept 3	0.333	0.333	0.333	0.333
Concept 6	0.333	0.333	0.333	0.333
Sum	1.000	1.000	1.000	1.000

Table 22.
Consistency Check For Table 19.

{Ws}=[C]{W} Weighted Sum Vector		
1.000	{W} Criteria Weights	Con={Ws}/{W} Consistency Vector
1.000	0.333	3.000
1.000	0.333	3.000

λ Average Consistency	CI Consistency Index	CR Consistency Ratio
3.00000	0.00000	0.00000

Table 23.
Control Surface Movement Comparison Matrix.

	Concept 1	Concept 3	Concept 6
Concept 1	1.00	3.00	0.20
Concept 3	0.33	1.00	0.20
Concept 6	3.00	5.00	1.00
Sum	4.33	9.00	1.40

Table 24.
Normalized Criteria Comparison Matrix for Table 22.

	Concept 1	Concept 3	Concept 6	Criteria Weight
Concept 1	0.231	0.333	0.143	0.236
Concept 3	0.077	0.111	0.143	0.110
Concept 6	0.692	0.556	0.714	0.654
Sum	1.000	1.000	1.000	1.000

Table 25.
Consistency Check for Table 22.

{Ws}=[C]{W} Weighted Sum Vector		
0.697	{W} Criteria Weights	Con={Ws}/{W} Consistency Vector
0.320	0.236	2.959
1.912	0.110	2.898

λ Average Consistency	CI Consistency Index	CR Consistency Ratio
2.92716	-0.03642	-0.07004

Table 26.
Weight Comparison Matrix.

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

Table 27.
Normalized Criteria Comparison Matrix for Table 25.

	Concept 1	Concept 3	Concept 6	Criteria Weight
Concept 1	0.231	0.217	0.333	0.260
Concept 2	0.692	0.652	0.556	0.633
Concept 6	0.077	0.130	0.111	0.106
Sum	1.000	1.000	1.000	1.000

Table 28.
Consistency Check for Table 25.

{Ws}=[C]{W} Weighted Sum Vector		
0.790	{W} Criteria Weights	Con={Ws}/{W} Consistency Vector
1.946	0.260	3.033
0.320	0.633	3.072

λ Average Consistency	CI Consistency Index	CR Consistency Ratio
3.03871	0.01936	0.03723

Table 29.
Joint Strength Comparison Matrix.

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

Table 30.
Normalized Criteria Comparison Matrix for Table 28.

	Concept 1	Concept 3	Concept 6	Criteria Weight
Concept 1	0.333	0.333	0.333	0.333

Concept 3	0.333	0.333	0.333	0.333
Concept 6	0.333	0.333	0.333	0.333
Sum	1.000	1.000	1.000	1.000

Table 31.
Consistency Check for Table 28.

{Ws}=[C]{W} Weighted Sum Vector		
1.000	{W} Criteria Weights	Con={Ws}/{W} Consistency Vector
1.000	0.333	3.000
1.000	0.333	3.000

λ Average Consistency	CI Consistency Index	CR Consistency Ratio
3.00000	0.00000	0.00000

Table 32.
Final Rating Matrix.

Selection Criteria			
Lift	Concept 1	Concept 3	Concept 6
Thrust	0.243	0.669	0.088
Control Surface Movement	0.333	0.333	0.333
Weight	0.236	0.110	0.654
Joint Strength	0.260	0.633	0.106

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

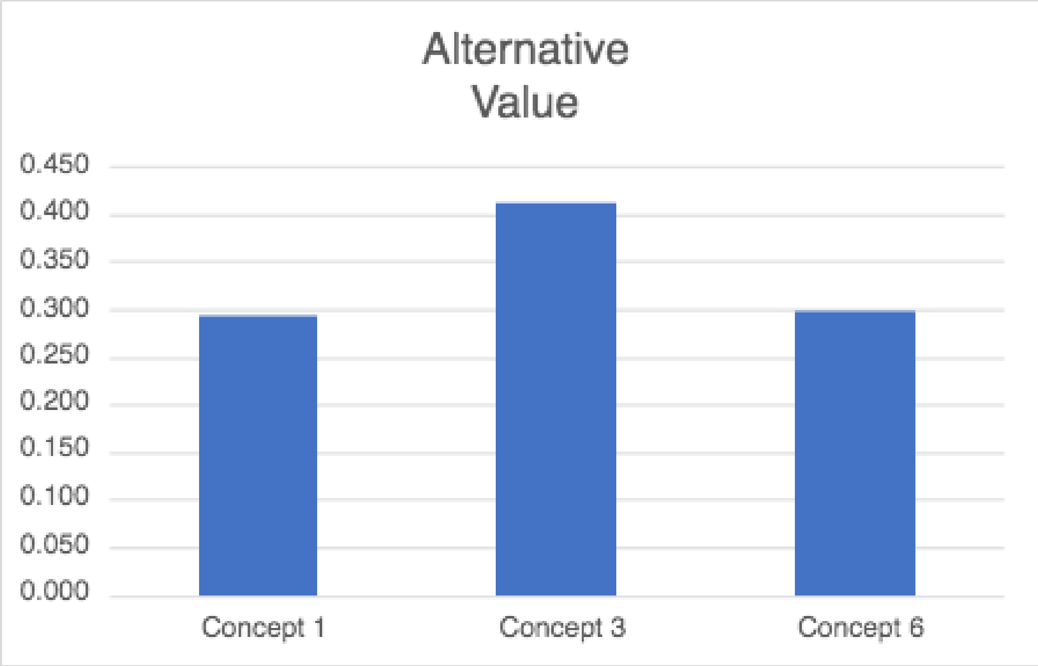


Figure 25. Concept selection alternative value bar graph.

Appendix F: Operation Manual

1.1 Project Overview

The team's project is to design and build a radio-controlled plane to compete in the Society of Automotive Engineers (SAE) Aero Design contest. This is an international competition that challenges students to build a plane that can carry a designated payload and complete a required flight path. The plane must take off in under 100 feet while carrying a regular size five soccer ball and one pound weight. Two senior design teams took part in the project, with our team overseeing the structural design of the plane. We worked with the propulsion and aerodynamic calculations made by the aero propulsion team to design a structurally sound plane that can achieve flight.

With most RC airplanes being build using materials like foam and balsa wood, our plane stands out in being 3D printed. Additive manufacturing is a very uncommon way to build these planes. Most RC pilots find printing filament to be far too heavy and stick with the typical construction materials to build their planes. To combat this increase in weight, a filament that foams when exiting the printer nozzle was used. Another unique feature of our plane is an extra set of wings known as canards. These were added to create more lift to help the plane achieve take off. These wings have no control surfaces on them, and serve solely to create more lift. The team also explored using different woodworking methods to assemble the plane. This helped in decreasing the amount of glue, nuts and bolts, and other typical assembly materials. The plane is estimated to weigh 14.6 pounds when fully loaded with cargo, and to be able to take off in under 60 feet. This manual explains how the plane was built and the correct ways to assemble and use it. It will focus on the geometric structure design of the plane that our team oversaw.

1.2 Disclaimer

Due to COVID-19 the team was unable to physically attend the competition. Regardless of this, the plane was still designed and built within competition rules regarding size and building material. One of our sponsors the Seminole RC Club also graciously offered to help in conducting a test flight. This test will be done in Tallahassee with the plane carrying the same cargo load and the attempting the same flight path that would have been required at the competition.

2. Additive Manufacturing

Section 2 describes how the parts of the plane were designed and printed. The filament used to build the plane was ColorFabb's lightweight polylactic acid (LW-PLA). This filament foams when leaving the nozzle, causing a decrease in the density and weight of the print. Through tests and advice from previous teams, it was found that printing each part at 235°C with a flow rate of 60% resulted in a print that was far lighter than prints done using normal PLA.

2.1 CADing a Part

When designing parts of the plane, the printability of the parts must always be considered. Parts must be designed to meet the needs of the design while at the same time falling within the constraints of the printer. There are many things that must be kept in mind when CADing parts. These include making sure the print can fit on the printing bed, figuring out if it needs supports, and much more. All parts must be CADed to where there is at least one printing orientation that makes failure unlikely. For example, in printing parts of the airplane's wings, it is tempting to position the part in the same horizontal orientation it will be attached to the plane. This however would cause the print to fail or require lots of supports. For this print it would be much better to set the part on its side printing the length of the wing part upward. This would allow the part to be printed on a flat face with no overhangs requiring supports. In designing parts to have at least one printing orientation that won't require supports, this will save both time and material in printing the part.

Even though it is best to avoid the use of supports, it is sometimes necessary to implement them. When this is the case, the part should still be oriented to where the least amount of supports are needed. This will decrease print time, material usage, and chances of failure. It is advised that a z – offset of 0.25 mm be used. This will ensure the supports can adhere to the print and serve their purpose but are still fairly easy to remove.

2.2 Slicing a Part

To print the parts the team mainly used the two Lulzbot Taz 6 printers in the senior design lab. There are also two more available for project use at FSU's Innovation Hub on the main campus. Any smaller prints made from normal PLA were sent to the Innovation Hub to print on their small DREMEL printers all students have access to. To slice prints, the team used the Cura by Lulzbot program. The settings the team used were based on the settings recommended by last year's team. Some modifications were made to things like temperature and infill, but the majority of the settings remained the same.

To slice a part, the CAD file must first be saved as an STL file. It is important to make sure that the resolution settings for saving these files are set high to keep the parts as smooth as possible. To do this, click the "options" tab that comes up when saving as an STL and increase the resolution to its maximum setting.

After the STL file has been created, import it into the Cura program. After that put the part in its correct orientation and adjust the print settings as needed. Each print may have slightly different settings. Some parts may require changes in infill settings or the need for rafts. This is explained more in section 6. Once the settings are finalized, it is best to put the part on “layer view” and check each layer of the print to make sure no issues will arise during printing. If there are any questions or issues don’t print. With how big these prints need to be it is best to either modify the settings or make changes to the CAD than waste time and filament. For more complicated or longer prints, it’s sometimes best to do smaller test prints first. This will often show if changes need to be made without wasting dozens of hours of print time.

After the settings are finalized save the new gcode to a thumb drive. This file must then be reopened on a notepad program and slightly edited. With LW-PLA being a foaming material, the dimensions of the print will not be as accurate as expected. Even worse the expanding material can cause the nozzle of the printer to clog. To counteract this, the flow rate must be changed without effecting the rest of the settings. This is done by searching for the ‘M221’ commands in the gcode. There are normally only two of these commands but different prints may have more. In each of these commands change the ‘S100’ to ‘S60’. This will reduce the flow rate to 60% without affecting the rest of the print settings. The file must then be resaved and transferred to the SD cards for the printer being used.

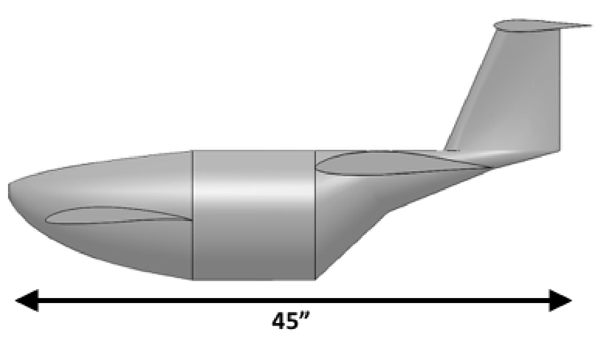
2.3 Printing a Part

After the gcode has been edited and saved on the SD card, insert the card into the printer and turn it on. Before a print is started, make sure there is enough filament on the roll being used. In Cura, an estimate is given as to how much filament will be used. With the flow rate being changed the estimated weight is a little under double what the print will actually weigh. To see if there is enough filament on the roll, weigh the roll and subtract the weight of the plastic filament roll. This roll weights 230 grams. If there isn't enough filament, either open a new roll or be prepared to pause the print and switch rolls at some point in the print. The printers are not equipped to pause on their own so it would have to be done manually. Once a roll of filament is chosen, heat the nozzle up to around 200°C and insert and load the filament until it smoothly oozes from the nozzle.

Once the printer is loaded press the button on the printer and scroll down to 'printer from SD'. Find the file you plan to print and select it. The printer will then go through the auto level procedure. While it's doing this it's important not the mess with the printer bed or change any settings in the printer. Once the auto leveling procedure is finished the print will begin. It's important to watch the first layer and make sure there's no issues. When satisfied with the print, close the printer cover door and wait for the print to finish.

3. Component Description

These sections are about the different modules of the plane. The figures below show a full assembly of the plane from the top and side view with dimensions.



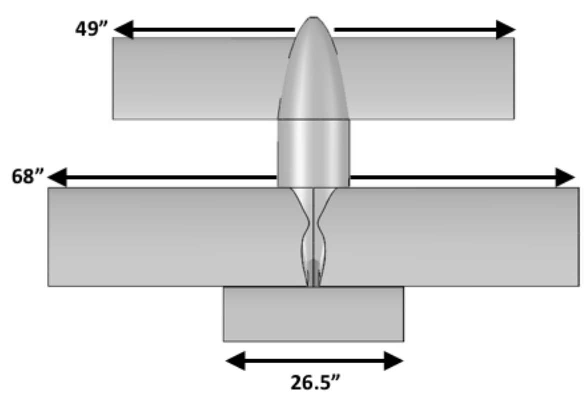


Figure F-1. Side and top view of the plane with dimensions

3.1 Canards

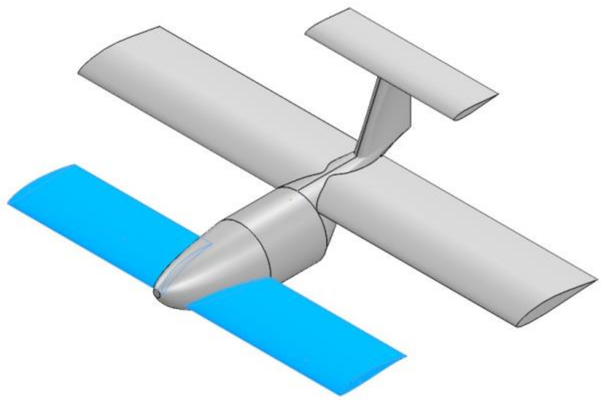


Figure F-2. Canards of the plane highlighted in blue

A set of canards was added to the front of the plane. These are rectangular wings with a low profile. This was done to increase the amount of lift the plane experiences. The canards have no control surfaces, and are only there to create more lift. The canards are made from six LW-PLA pieces, with two aluminum spars also being used to help in assembling the canards. These wings are made using the Eppler 214 airfoil. This airfoil has a lower stall angle than the main wings. This means the canards will stall before main wings. If stalling were to occur, this will result in the nose of the plane falling forward, realigning the plane and causing the needed airflow over the wings to occur, keeping the plane in flight. This means that in theory the plane will never stall to point where it falls and crashes.

The team explored new assembly methods in building the canards. For a proof of concept test, the last two pieces of the canards on either side of the plane are assembled using a dovetail joint, with the male end on the outer piece. The outer portion is slid in from the front meaning it will be held in place due to the plane moving forward.

3.2 Main Wings

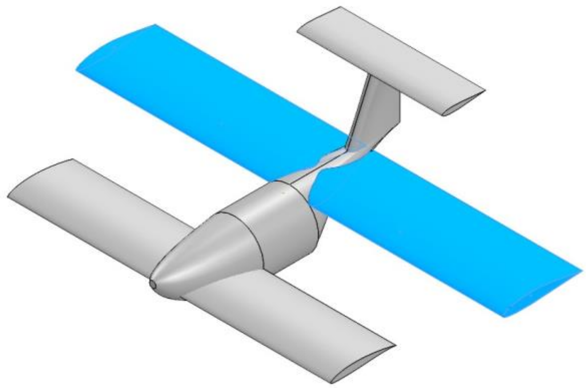


Figure F-3. Plane's main wings highlighted in blue

The main wings of the plane are made from a total of ten pieces. These are rectangular wings with a high wing profile. Eight pieces are anchored to the plane and two are the ailerons on either side of the plane. These wings are made using the Eppler 197 airfoil which has a higher stall angle than the canards, allowing the stall prevention described in the previous section. The main wings are assembled in a method slightly different than the canards. Pieces are still slid onto the canards, however there are no woodworking techniques used in compiling the pieces. Instead the final pieced on the wings act as end caps in beings attached through screws. The spars for these wings are threaded and screws are used to keep the end caps in place. This keeps the pieces in place through compression, keeping the wings fully assembled during flight.

The ailerons of the wings rotate about the back spar of the wings. To control the ailerons, a belt and gear system is used. Both the servo motor and aileron have their own gears, with a belt wrapped around them. The servo gear and belt raise and lower the aileron upon command, controlling the motion of the plane.

3.3 Fuselage

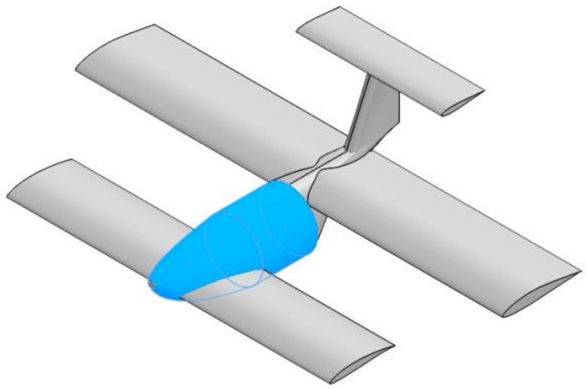


Figure F-4. Fuselage of the plane highlighted in blue

The fuselage of the plane consists of six sections. The first two sections are where the motor, battery, and other electronics are secured. These sections are attached with two PLA bowties. The next section is where the soccer ball and box weight are secured. This section is made from two pieces that can be detached by unscrewing the top bowties and lifting the top piece from the plane. The last pieces are secured with bowties and dowels, with the final piece having the dowels to secure the T-tail.

3.4 T-tail

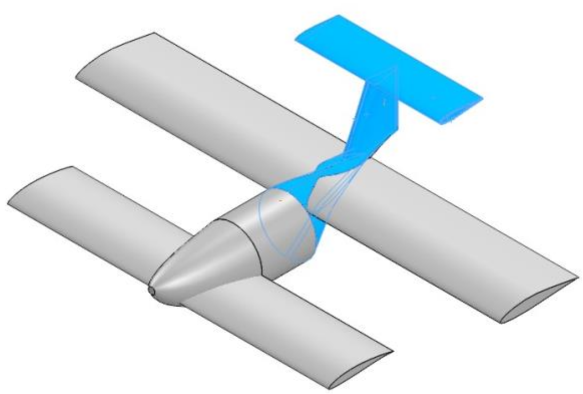


Figure F-5. The T-tail of the plane highlighted in blue

The T-tail is made from five non-moving pieces along with the elevators and rudder. The vertical pieces are attached to the plane and to each other using glue and dowels. The horizontal section is attached using the dovetail joints in a similar manner to the canards. Both the rudder and elevators rotate about a spar just like the ailerons do. A belt and gear system is also used to control the surfaces.

3.5 Landing Gear

Figure F-6. Front landing gear (left) and rear landing gear (right).

The landing gear for the plane is made using the tricycle layout. The back two wheels have no control surfaces and are attached using bolts and screws. The front wheel is attached using two clamp collars, with one outside and one inside the plane. This wheel is free to move and is controlled by a servo in the front of the plane. This gives the plane the ability to be steerable when moving on the ground.

4. Integration

The following sections explain how to assemble the plane. Each section has a step by step list of instructions description in how the modular parts of the aircraft should be connected.

4.1 Fuselage

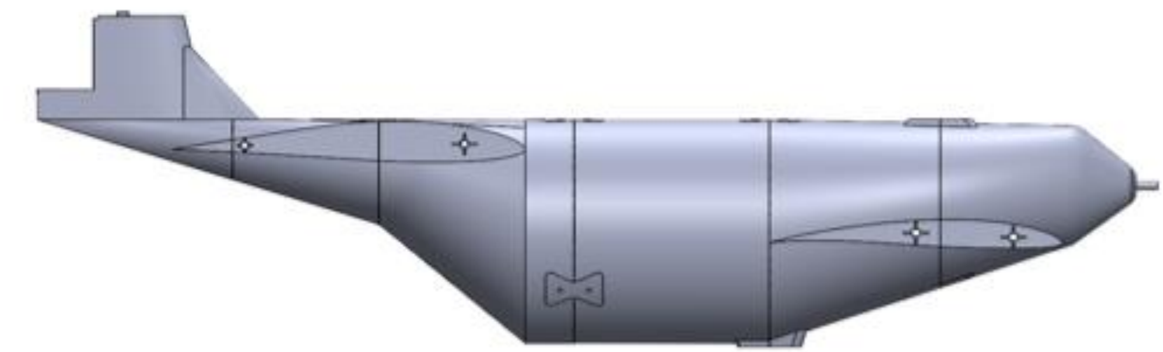


Figure F-7. Assembled Fuselage.

1) Take the nose of the plane and attach the motor using the motor mount. First connect the motor to the motor mount, then insert the combination into the slot on the front of the nose with the shaft for the propeller sticking out of the nose. The mount then needs to be screwed into the four brass threads that must be soldered into the gap for the motor mount. The best way to solder these in place is by placing the threads on the soldering iron to heat them up then lightly press them into a pilot hole extruded into the nose. After they are in place use four #8-32 bolts to secure the motor mount.
2) After the motor mount is in place, attach the rear canard piece that houses the battery and front wheel of the plane. Do this using two bowties. In using the bowties, the same soldering method described in step 1 must be used to put the brass threads in their needed

location. After the threads are in place, insert the bowties in their respective locations and screw them in with the #8-32 bolts.

3) After the rear canard piece is in place insert the battery box into its supports to prepare for the wiring that must take place. Then insert the front wheel into its hole then tighten the two shaft collars when the wheel shaft is at the correct height. Then connect the servo motor to the wheel shaft.

4) The two pieces of the cargo bay must then be connected using bowties and the same process described above. Two bowties will connect the bottom piece of the cargo bay to the fuselage and one will connect the top piece.

5) Once the cargo bay is assembled, attach the first main wing mounts. This is done using bowties to connect the front piece to the cargo bay, then bowties and dowel/glue combinations for the final two pieces. Make sure the sections on the wing mount for each of these pieces are all aligned with each other.

4.2 Canards

Figure F-8. Assembled canards (top) and main wings (bottom)

1) To connect the canards first slide the two 0.25” diameter spars through their respective holes in the fuselage. Try and make it to where there is about the same length of spar on either side of the plane.
2) Connect the first cross connecter to the side of the plane. After this slide the first section of the wing onto the spars and connect it to the fuselage using the crosses.
3) To connect the next two pieces first connect them using the dovetail joint by sliding the outer section onto the middle section. After this slide both sections onto the spars.
4) Once all sections are on the spars use two #10-24 screws to compress all the pieces in place. Repeat this entire process for the other canard wing.

4.3 Main Wing

1) Follow the first two steps from the canard section. When the part holding the servo is reached, attach the servo to its mount inside of the wing.
2) Slide the ailerons into place on the back spar. After this attach the servo and aileron gear using the belt.
3) Attach the remaining portions of the wings using the crosses then screw the end caps into place using #10-24 bolts.

4.4 Tail

Figure F-9: Assembled T-tail

1) Attach the bottom vertical portion of the tail to the dowels on the fuselage using glue. Slide the rudder spar into place once this is complete. After this put the servo and top vertical portion of the tail in place using the dowels.
2) Slide the middle horizontal section on to the vertical part using the dovetails. Then slide the other horizontal sections with their respective servos into place using the dovetails.
3) Insert the 0.25” and 0.1875” spars into their locations and attach the elevators to the tail. The 0.25” spar goes on the front of the horizontal tail and the 0.1875” spars are used for the rudder and back section of the horizontal tail. Use the #10-24 bolt for the 0.25” spar and the #6-32 bolt for the 0.1875” spar to secure the horizontal portions of the tail.

5. Operation

When operating the plane, it is best that it is done by a seasoned pilot who has an AMA license (Academy of Model Aeronautics). Each one will have their own methods in getting the aircraft ready to fly, but they will each follow a general process. The following steps should always take place:

1) If not flown at the competition, the pilot from the RC Club will most likely want to test all electronics the night before or many hours before the flight time. If you are participating in the competition, it is best to do these tests yourselves. Make sure the controller and receivers are connecting, and that all servo motors are getting current. If not, check the wiring to make sure everything is correct. Do this WITHOUT the propeller attached. If the propeller were to hit someone by accident, this will most likely cause a serious injury. It is best to remove the red arming plug after this if not at the runway already.
2) Once the controls have been tested, align the plane in the direction you plan for it to take off and clear the runway of any other objects. Some pilots take further precaution and secure the plane in place using a rope and stake attached to the plane to inhibit it from moving when doing controls tests.
3) Mount the propeller to the propeller shaft. Use a wrench if necessary to make sure the safety nut is secure.
4) If it has been removed, insert the red arming plug. Once again make sure the controller connects to the receiver and test the motor and all control surfaces.

5) Have all people stand behind the plane. If some sort of stake and rope system was used to keep the plane in place, remove it.
6) Begin the test flight. Be sure to stay alert and follow any commands from the pilot. Keep an eye on the plane as well. If for some reason the pilot were to lose control of the plane follow his directions in staying clear of the crash.
7) After the plane has landed remove the red arming plug. With the circuit broken in doing this, the plane is now safe to pick up and move.
8) In this case the cargo of the plane must then be unloaded. To do this, unscrew the top bowties of the cargo portion of the fuselage. If the piece of the plane then take out the cargo. Once its removed place the piece of the fuselage back in place and screw the bowties back in.

6. Troubleshooting

6.1 Printing Issues

3D printing using LW-PLA can be very tedious. The filament is far more susceptible to printing issues than more common filaments, and the team had to find ways to solve the various obstacles that arose. Below are some of the common problems the team had to deal with, along with the solution the team implemented.

6.1.1 Plate Adhesion

Prints remaining stuck to the plate was a common issue the team dealt with. If the first layer of the print did not properly adhere to the plate, the print would eventually begin to curl, resulting in a warped print. The team approached this problem in a couple of ways. A quick solution was to use a common glue stick to apply glue to the plate before the print started. This would help with relatively short prints, but if a much longer print was taking place, curling would still eventually occur. The best way to solve this problem was to use a raft. A raft is a layer of filament printed on to the bed that the actual print will be printed on top of. It adds time and filament usage to a print, but solved the curling problem the team was dealing with. It's important to use a good z-offset setting when queuing a raft. If the offset is too short, it will be nearly impossible to remove the raft without damaging the print. It was found that an offset of 0.35mm kept the print adhered to the bed and was able to be removed without damaging the print.

6.1.2 Warping

Warping occurred in other ways other than plate adhesion. With LW-PLA being a foaming filament, the prints had to be done in a controlled environment. Even the slightest changes in the ambient temperature or air pressure could cause the print to foam too much, creating a warped print. To solve this problem printers were placed in enclosures. To further control the printing conditions, the doors of the enclosures were taped up once the print started. This kept the prints running in a controlled environment, reducing the chance of a failed print.

6.1.3 Stringing

Stringing was a minor issue that the team had to deal with when printing. Stringing is when the printer continues to extrude filament when traveling from one point to another and drifting over areas where no layers are supposed to be printed. This leads to lose strings of filament piling up in different areas. There unfortunately was no real solution to this problem. It did not interfere with the print but did need a fair amount of post processing to clean up. Usually, the stringing can be removed by hand or using pliers to grad big clumps of the material that are hard to reach. The stringing usually didn't cause issues in how the print was to be used but did add dead weight to the print. This should be heavily considered since the plane needs to be made as light as possible.

6.1.4 Ghosting

Ghosting is when the printer plate vibrates when moving along the y-axis bars. This began to happen with one printer later on in the project. Replacing the bearings in the best way to fix this issue. A more temporary fix is to clean and lubricate the bars the bed slides on. To do this, first clean the bars using an alcoholic sanitizer wipe. After that apply a small amount of PTFE grease to the bars and spread along the length of the bar. If this problem occurs and the bearings are not replaced, this quick and easy fix will most likely need to be done several times throughout the semesters.

7. Project Recommendations

7.1 Sponsorships

The previous year's team started a relationship with Tallahassee's Seminole RC Club. This club offered great insight in helping us with our project. The members are well experienced in building RC planes, and are more than happy to give advice in designing the plane. Next year's team should maintain this relationship. Make time to be a part of their club meetings to give updates on the design to get their opinion on the plane. Plan trips out to the air fields to meet members in person and get some hands on learning in designing the plane. This can help in getting a better idea in how to build different aspects of the plane you may have questions on. Hopefully next year the team can attend the SAE competition, but if not the club can conduct the test flight for the team. It will be very helpful to contact the club early on and the project, and continue to build the relationship up to the test flight.

If buying filament directly for ColorFabb, contact them about a sponsorship. The team spoke with them and a discount was offered, but due to shipping time and product availability we had to buy the filament from a different distributor. Contact ColorFabb early, and speak with Dr. McConomy about buying the filament in time for it to ship.

7.2 Working with the Aero Propulsion Team

This was the first year there were two separate teams working on one project. It took time to get used to it, but we eventually felt like one big team. In this team being focused on the structural design of the plane, many of the first stages of the project were spear-headed by the other team. It is important that the geometric team still be a part of this stage of the design. Help with the research, calculations, and simulations done to help in designing the plane. It is also prudent to make sure the printers in the lab are operable, and the team knows how they work long before official printing is to begin. Do simple test prints to make sure you know how to operate the printers and to figure out your preferred print settings for the filament you choose to use. If this were to be put off until it's time to start printing parts of the plane, any printer issues that could have been fixed earlier would be wasting possible printing time.

7.3 College Resources

Innovation Park and the FSU main campus are full of resources that can help in designing and building the plane. The team should establish a good relationship with Eric Adams at FSU's Innovation Hub. Eric in in charge of the 3D printing done at the Hub, and is a wealth of knowledge when it comes to additive manufacturing. He can help in teaching you the basics of running printers and giving advice in how to fix the different problems that can occur when 3D printing. If possible he can even provide access to another TAZ printer. Getting to know Eric will be great for completing the project.

The AME Building next to COE can also be helpful in designing the plane. The aero propulsion team was able to do a wind tunnel test with a small prototype of the plane. It helped in proving that the calculations and simulations done in designing the plane were correct. It also gave better imagery in seeing how the airflow over different horizontal surfaces could affect one other. If you know graduate students or professors who are a part of AME, speak with them about doing a wind tunnel test. It will help in designing the plane and provide great images for presentations.

In picking the filament to use in building the plane, conduct different strength tests to see how possible choices compare to one another. The team did three-point bending tests and torsion tests with Dr. Campbell in the COE materials lab. This helped in showing more reasons to use LW-PLA than its weight properties alone. Dr. Campbell was more than willing to help with these tests, so contact him early on to conduct them. The tests the team did were mainly to compare filaments themselves. It may be good to test different infill patterns as well. This will help in finding the best filament and infill combination possible for your project.

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