FLORIDA INTERNATIONAL UNIVERSITY

EML 4905 Senior Design Project

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REQUIREMENT FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

SAE BRAZIL AERODESIGN COMPETITION

25% Report

Andres Cardenas

Arjav Patel

Nestor Paz

Advisor: Professor George Dulikravich

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Andres Cardenas, Arjav Patel and Nestor Paz and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

Nestor Paz	Andres Cardenas	Arjav Patel
Team Leader	Team Member	Team Member

Dr. George Dulikravich

Faculty Advisor

Table of Contents

LIST OF FIGURES

List of Tables

Abstract

The SAE Aero Design Brazil is an international engineering competition sponsored by SAE International that will hold its 16^{th} edition in Sao Jose Dos Campos, Brazil from 30 October to 2 November. The purpose of the competition is to design, manufacture and fly a radio controlled (RC) airplane able to carry as much payload as possible within the restrictions set by SAE. The competition attracts engineering teams from all over the world, and encourages them to design original and efficient aircraft.

The team will be participating in the competition and representing FIU under the name PanthAir Cargo. Special emphasis will be placed on the engineering theoretical and experimental calculations. The team will try to design an aircraft as light as possible in order to lift as much payload possible while respecting all design restrictions. Computer assisted design (CAD) software packages like Solid Works and ANSYS will be used to aid the design of the aircraft. Finite element analysis will be performed on the structure of the airplane using ANSYS in order to assure the aircraft is kept inside a safe yet light design. Tradeoff studies will be conducted on many parameters of the aircraft like the configuration of the wings. The software modeFRONTIER will be used to optimize this configuration in order to obtain maximum drag and minimum lift. Wind tunnel tests will be conducted on the final prototype in order to confirm any analytical data.

The team will design the optimal aircraft for this competition while keeping low any manufacturing and material costs. The team has found an excellent RC airplane pilot within the current FIU student body. He has attended our team meetings, and offered his expertise from his own experience perspectives. It is the team's intention to take our pilot with us to the competition in Brazil.

The team will also be seeking sponsors in order to reduce the out of pocket expenses for each member.

1. Introduction

1.1 Problem Statement

The problem statement is to design and build a remote control airplane capable of competing on an international level within a given set of rules and parameters. The event is sponsored by the Society of Automotive Engineers (SAE). The organization changed its name in 2006 to SAE International to reflect the increasingly international character of its activities. According to their website [4], they have more than 138,000 engineers and related technical experts in the aerospace, automotive and commercial-vehicle industries. Their core competencies are life-long learning and voluntary consensus standards development. SAE International's charitable arm is the SAE Foundation, which supports many programs including the Collegiate Design Series. The SAE Aero Design Series falls under that effort.

SAE International hosts three Aero Design series competitions a year. Two are held in the United States the spring and one in Brazil in the fall. Due to FIU’s senior design timeline, the competition that would be appropriate for the team to enter would be the one in Brazil. It is also referred to as the *SAE Brasil Aero Design Competition 2014*.

The competition is divided into three classes: Micro, Regular and Advanced. The class that we would be competing in is the Regular class. This class offers the best chance to compete within our very limited resources. The Regular class also offered the best opportunities to learn and apply sound mechanical and aerospace engineering principles because it does not allow for computer assisted flight controls to be used. Although these types of electronics often help improve the performance of any aircraft, sometimes they can also be used to compensate for design flaws.

The rules allow for the collegiate teams to be comprised of up to 15 members. Obviously, any team having that many people working towards the same goal greatly enhances their chances to succeed. PanthAir Cargo is currently composed of only four members including our pilot.

This competition is governed by a set of rules and regulations that have been included in Appendix 1. According to their rules, in order to succeed a team must perform the following (translated from Portuguese):

- Careful analysis of the competition rules
- Consistent conceptual and preliminary design
- Definition and / or preparation of the design methodology
- Preparation and / or set of analysis tools (calculations)
- Design details
- Construction, construction quality, robustness and reliability of the project
- Preparation and essay development engineering
- Preparation of the report
- Planning and preparation of the oral presentation
- Competition flight

According to the rules, the following should also be considered in order to succeed:

- Seeking sponsorship (financial support)
- Planning
- Effective Leadership
- Teamwork
- Logistics
- Communication skills
- Interpretation of rules and additional documents
- Creativity and Innovation
- Having good sportsmanship

1.2 Motivation

The team seeks to work on a project that would provide the opportunity to come up with innovative ideas and applying them to the field of aerospace engineering. Choosing a design capable of competing in the SAE Brazil Aero Design Competition also provides the following motivations:

- To build an airplane capable of competing in a world class event
- Potential for increased funding for future projects
- Leaving a legacy behind for future students to follow

1.3 Literature Survey

The very first piece of literature that had to be carefully study was the SAE Brazil Aero Design Competition Rules. These rules provide a set of parameters and boundaries from which we would not be allowed to deviate from. These rules are written in Portuguese, which to some degree presented a challenge in trying to determine the correct translation.

Other literature that has been researched is the reports and results from previous universities that have previously competed in *SAE Aero Design Competitions*. There are plenty of proven ideas that can be found in this kind of research as well as ideas that were found not to have been so good. In fact, in some cases bad design ideas led to catastrophic failure and loss of the airplane. As such, a priority has been placed on trying to learn from previous mistakes as much as possible.

Research on aircraft manufacturing techniques has also been done and is also of great importance to us. Considering the small size of the team and that it counts with very limited resources, a major consideration for this design will be to take into consideration the feasibility of manufacturing during the selection of concepts and designs. For example, the team has extensively researched manufacturing the wings using Styrofoam because of the potential savings of time and money.

The engine and propeller combinations are also being researched. It has been found that some of the allowed engines have previously been tested with different propellers in order to determine the best thrust producing combinations. That kind of research alone would have required many of hours of testing. The team is planning on putting together a well performing engine and propeller combination and performing its own test to validate the results.

There is also a lot of literature available for to research the electrical and electronic components of the airplane including the transmitter, receiver, electric servos, on-board battery, battery sensors and wiring. A well performing combination of all of these components is necessary while balancing the weight, size and cost limitations.

Literature is being researched for almost every component of the aircraft including, landing gears, wheels, tires, fuel tank, hinges, hardware and materials. The amount of literature available for researching all the components is almost limitless.

Design literature is also been researched to assist in considering all the different design alternatives. An example of this research is the book “Aircraft Design: A conceptual Approach” Fourth Edition, by Daniel P. Raymer. This is an extremely useful and helpful book when trying to select a design.

2. Project Formulation

2.1 Overview

This project was chosen because of the fact that it afforded the team to become exposed to many aircraft design challenges. Additionally, it was deemed that participating on an international level would be very exciting. The SAE Brazil Aero Design Competition is a world class competition with teams from all over the world attending.

2.2 Project Objectives

The main objective of this project is to design and build a radio-controlled airplane capable of competing in the *SAE Brazil Aero Design Series Competition*. The goal of the competition is to carry as much load as possibly while respecting the competition design parameters and restrictions. The *SAE Brazil Aero Design Series Competition* offers three different categories each one with its own challenges and rules: Micro, Regular and Advanced. The micro class was considered by the team to be too small of a project to be considered as a senior project thesis. The advanced class falls out of the capabilities of the team in terms of money, experience, and eligibility. Therefore, *PanthAir Cargo* decided to design and build an airplane capable of competing in the Regular class. This class will still provide significant engineering challenges as well as a total team effort to succeed.

As shown in the following figure, the aircraft is supposed to take off, fly around an oval imaginary circuit and land. It cannot perform any flight maneuvers or deviate from such circuit. The aircraft has a maximum take off distance of 61m and a landing runaway of 122m. The maximum allowed for take-off is 3 minutes, starting from the moment the judge gives clear signal for take-off.

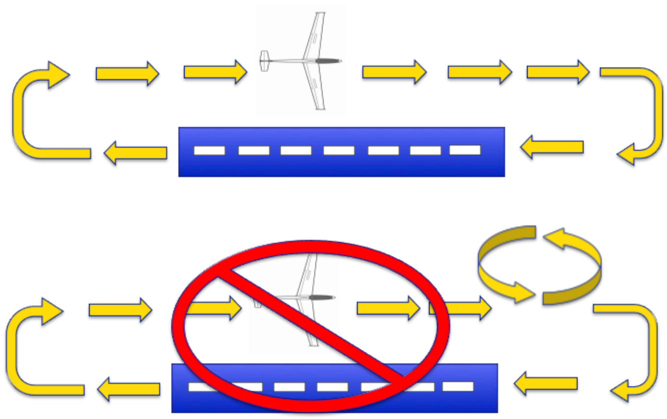


FIGURE 1: Allowed flight pattern for Regular Class

Teams will try to carry as much payload as possible. Points are awarded not only on the load carried but also on the final report, oral presentation and bonus points awarded if certain tasks are completed.

2.3 Design Specifications

In order to compete in the Regular Class of the *SAE Brazil Aero Design Competition*, there are design specifications called for in the rules that would have to be met. For example, the propulsion system is required to be an internal combustion engine capable of running on fuel mixture consisting of 72% Methanol, 10% Nitro methane and 18% oil. More specific information on the engine is included in the Engine Constraints section of this report.

Another major area that has very strict specifications is the cargo bay. A cargo bay needs to be incorporated in the aircraft in order to carry the payload. The cargo bay cannot have a volume of less than 4800 cm^3. It should also be composed of six faces orthogonal to each other independent of their size. It is against the rules to use lead as the material to manufacture the payload. The payload should have a side door in any of its faces and the team should be able to load and unload the aircraft in less than 120 seconds.

There are many other design specifications outlined in the rules. For example, all the structural support connections have to be designed in such a way that they can be easily inspected for security and integrity before and during the competition. Another specification requirement is that all bolts must be secured with self locking nuts.

2.4 Constraints and Other Considerations

2.4.1 Geometric Constraints:

This year, the geometric design restrictions are based on a fixed area of the plan for view of the aircraft. Teams cannot exceed 0.775 m^2 of area on a top view of the aircraft. Minimum geometric requirements for the load compartment as well as restrictions on the engine are given by SAE.

The geometric restriction of the aircraft is based on a maximum plan form view area of 0.775 m^2 as depicted in the figure below:

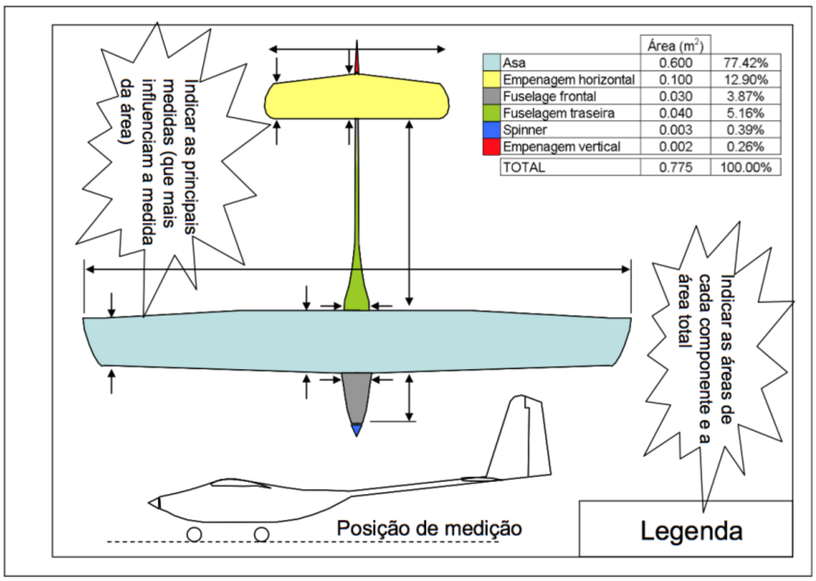


FIGURE 2: Geometric Restrictions

All lift-producing surfaces will be accounted for when calculating the total area even if they are on top of each other. In other words for bi-planes, the areas of both wings will be included in the calculation. The team will try to gain as much wing area as possible by reducing the fuselage area.

The Airplane must not exceed a maximum gross weight of 20kg, including the payload. For this reason, it is critical to reduce the weight of the unloaded aircraft in order to gain as much as possible in payload weight.

Note: Figures 1 and 2 were directly copied from the SAE Brasil Aero Design Rules. See Appendix 1.

2.4.2 Engine Constraints:

The SAE Aero Design competition rules were very clear on the type of engine that can be used in the aircraft. The rules specify that teams can only make use 4 different types of engines and there would be no tampering with the engine, no sort of turbo boost or anything else that would enhance the performance of the engine. The team has to choose from these 4 engines: K&B 6170, OS 61 FX (no longer manufactured), Magnum XLS 61 and OS 55AX. The decision on what propeller and engine combination to use is yet to be made. This decision can be made at a later date after some more research is done on the best engine for our design. After doing some analysis and research on the performance of these engines it was found that it was very similar for the different engines. All of these engines' RPMs range from about 12,000 up to 17,000 at max thrust. Every engine has a break in propeller and a variety of propellers recommended for usage with that particular engine. The usage of different sizes of propellers might be good for an engine in the short term but will definitely kill the engine in the long run. It's like putting the wrong size tires in one's car.

The fuel for the engines will be provided by SAE competition. The fuel consists of 90% ethanol and 10% oil bioethanol. The fuel consists of very biodegradable contents which is not hazardous for the environment.

Propellers are a very important part of any airplane. A great propeller matching up with an engine can give a greater thrust and forward motion more than any other propeller can. Also on the flip side a bad choice in propeller can eat up a whole engine. As mentioned above putting a wrong size propeller is as bad as putting wrong size tires on one's car. Because all the energy that is produced is being lost in trying to pump more energy into making extra bit of motion. Using up 10 times more energy to conjure up maybe 1% more thrust is a waste of energy. That energy can be better used to fly the plane at a steady state. After selecting the best engine for its concept, the team will precede on to select the best propeller size for that given engine.

2.4.3 Cargo Bay Compartment:

The rules require that the cargo bay compartment contain a minimum of 4800 cm3. The compartment has to contain six orthogonal sides, and must not be supported by the payload. It is left up to the teams to be as innovate as they wish as far as where they place the compartment or what dimensions to use in order to obtain the minimum volume. The compartment does have to have one access door in order to replace the payload after the flight, and it must be totally enclosed.

The design and integration of the cargo bay revealed to be the single most important challenge and characteristic for our design. It requires careful considerations to stresses, effects on center of gravity of the aircraft, must hold at least the amount of payload that can be predicted, be readily accessible and must not add a significant amount of weight to the aircraft.

2.5 Discussion

There have been some significant challenges that presented themselves in the course of determining the parameters and constraints that we needed to follow. The team was initially following the rules for the SAE East Aero Design Competition at the beginning of the semester. As a result, the original concept that was being considered was quite different. For example, the team initially considered an electrical motor in the first designs. The geometric requirements were also much different that made a more innovated design to be applied. However, in mid February SAE Brazil published their rules, which need to be followed. The team was hoping they would be similar, but actually turned out to be quite different.

This last minute changing of the rules obviously affected the team’s strategy and meant a delay of a couple of weeks as far as research and designs.

3. Design Alternatives

3.1 Overview of Conceptual Designs Developed

PanthAir Cargo has been considering a number of conceptual designs that are thought would be successful in this competition. Very innovative concepts as well as more conventional concepts have been considered. Some of the concepts and characteristics that must be considered involve different variations of wings, empennage and fuselage combinations.

3.1.1 Major Components

The major components of our design include the cargo bay, wings, fuselage, empennage, engine/propeller, flight control surfaces, electronics and landing gear arrangement.

3.2 Overview of Wing Designs

Probably the most important design characteristic that will affect the performance of the aircraft is the wing design. It requires considering many characteristics such as airfoil design, wing location, dihedral angle and to a very large degree, the manufacturing feasibility of the design.

A desirable characteristic for wing design would be selecting a design that contributes to lateral stability. Such a characteristic is found on aircraft that have their wings mounted up high. Low and mid wing designs do not add to lateral stability.

The dihedral angle is the angle of the wings to the horizontal plane. The addition of an dihedral angle would add to stability, but it also creates a stress concentration point at the center of the two wings which has to be overcome by adding more stiffening and thus more weight.

Our aircraft wing will not be experiencing an supersonic air flows. Thus it is not necessary to consider sweeping them in order to mitigate shock wave effects.

Lastly, it is deemed essential that the wings be capable of being easily manufactured. Given our lack of resources, this is deemed a high priority.

3.2.1 Wing Design Alternatives

The location, angle of incidence and dihedral angle are also important characteristics that affect the performance as well as the stability of the aircraft. Some of the wing concepts considered include:

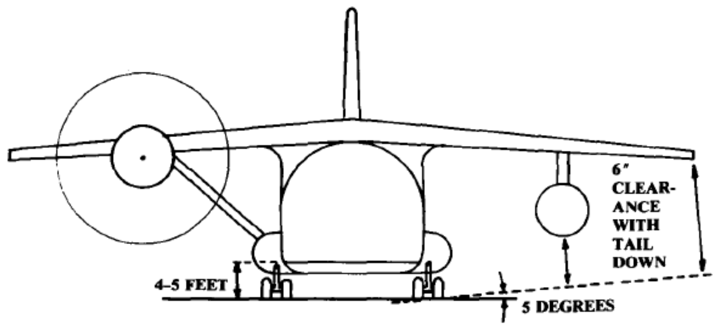


FIGURE 3: High Wing Design

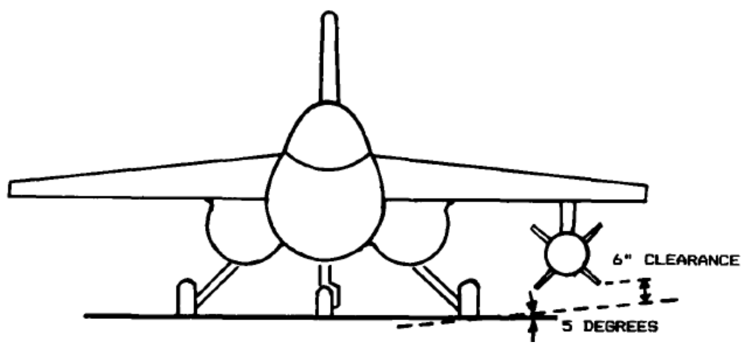


FIGURE 4: Mid Wing Design

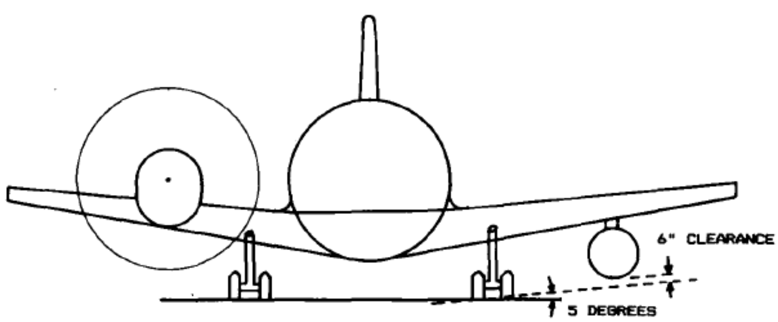


FIGURE 5: Low Wing Design

The wing designs shown above were obtained from research made on wing designs [3].

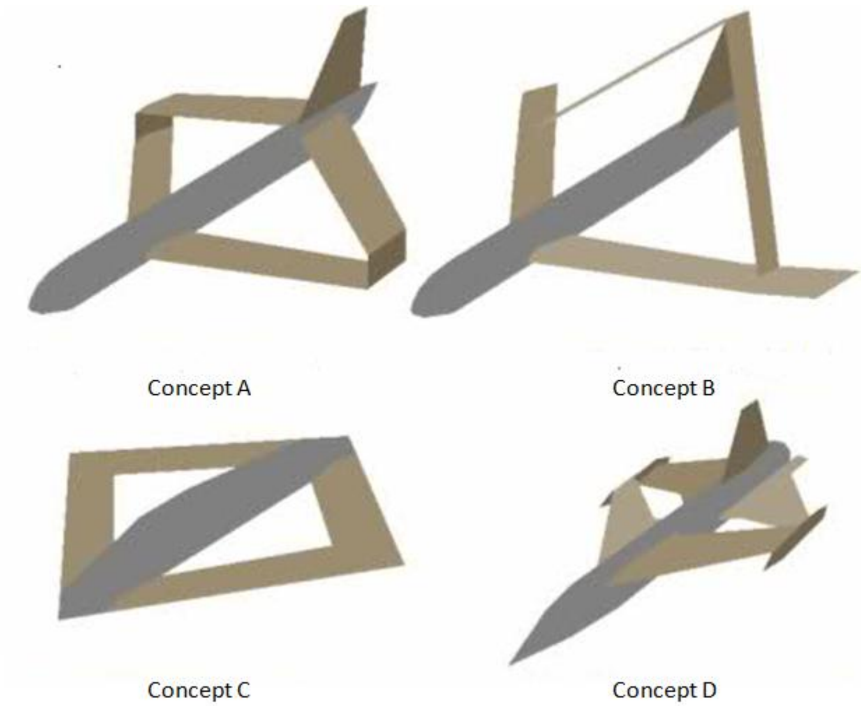


FIGURE 6: Advanced Joined Wings Concepts

The advanced joined wings concepts shown in the figure above were obtained from research made on joined wings [2]. In concept A is a typical box wing configuration. Concept B is a typical joined wing configuration. Concept C is Boeing's fluid wing configuration. Concept D is the D0014's bi-diamond wing configuration.

3.2.2 Airfoil Design Alternatives

The airfoil design characteristics will affect the lift vs the coefficient of drag coefficients. The highest possible lift to drag ratio is a main objective when designing an airfoil. Designing and validating the results of a custom airfoil can be very rewarding both in the knowledge gained as well as in the achieved performance. Therefore, designing our own airfoil was one of the first milestones we set out to do. This is being done using computational fluid dynamic analysis.

Software that is being used to optimize our design includes:

- SolidWorks/Solid Edge
- ANSYS fluent/COMSOL multi physics
- Xfoil/ XFLR5
- modeFrontier

3.3 Empennage Design Alternatives

The empennage of the airplane is an important consideration. There is a variety of empennage design variations that are have been researched and considered including the ones in the following figure:

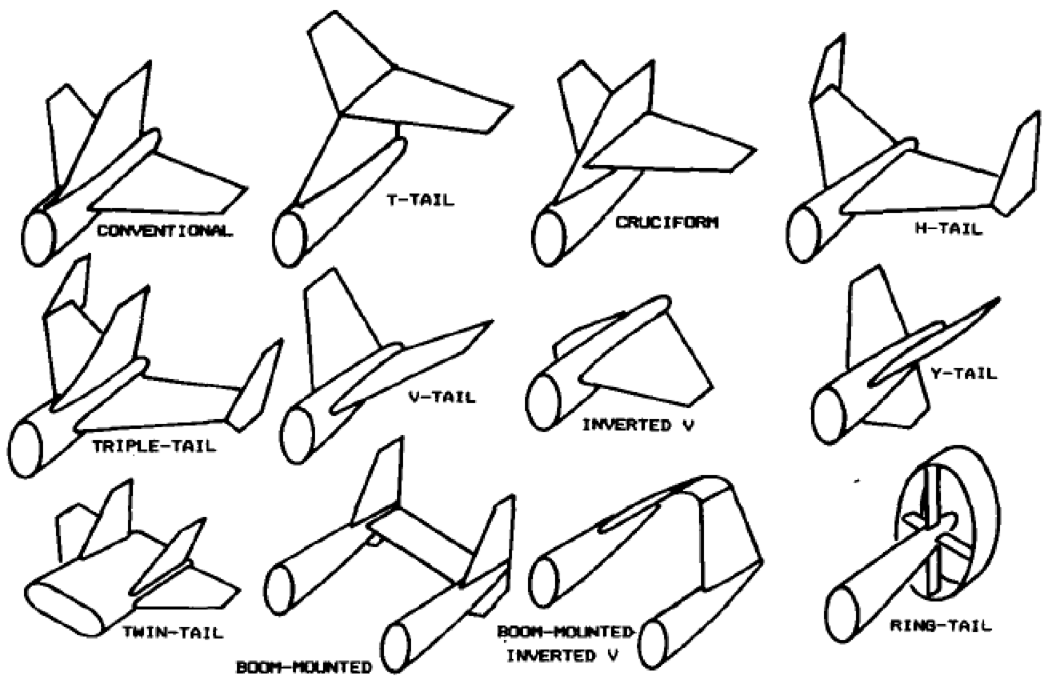


FIGURE 7: Empennage Variations

The empennage or "aft tail" variations shown above were obtained from research made on aft tail configurations [3].

3.4 Engine and Propeller Alternatives

The engine and propeller combination is still being researched. The team has discovered a number of available static and dynamic tests performed on some of the available engines using standard commercially available propellers. Once the research is completed, an engine and propeller combination will be selected using a matrix method similar to the one used for the airfoil selection.

The selected engine and propeller combination will then go through test to validate the expected results.

3.4.1 Engine Fuel Consumption

In order to determine the amount of fuel required for each competition trial, it is necessary to estimate the fuel consumption of the engine/propeller combination. This is also an important consideration in order to then select the appropriate capacity fuel tank.

TABLE 1: Approximate Fuel Consumption Rates for OS Engines

Approximate Fuel Consumption Rates at Full Throttle for the Most Commonly Used Aircraft Engine Sizes

	2-Stroke Glow cu. in	4-Stroke Glow cu. in	2-Stroke Gas cc	4-Stroke Gas cc
0.375 oz/min				25
0.5 oz/min				32
0.75 oz/min	.32	.50	24	
1 oz/min	.40-.46	.70	32	
1.5 oz/min	.60	.90	50	
2 oz/min	.90	1.20	64	
2.5 oz/min	1.20	1.60		
3 oz/min	1.60	2.00		
3.5 oz/min	2.00			

Note that exact consumption rates will vary depending on the fuel:air mixture, type of fuel used, nitro content, prop size, rpm, condition of the engine and atmospheric conditions.

The table above was obtained from research made on fuel consumption [5].

3.5 Fuel System

The team estimates that the aircraft will need to perform for about 2 minutes, and based on the previously discussed fuel consumption rate, would require about 3 oz of fuel. However, in order to allow for possibly having to do a “go around”, it is deemed that twice that amount should be available. Given the fact that the aircraft needs to be as light and small as possible, it is necessary to select a tank that will hold just enough fuel for the performance. Below is an example of a fuel tank that would meet our previously stated criteria:

FIGURE 8: Fuel Tank

The figure above was obtained from research made on fuel tanks [6]. The fuel tank above is an 8 oz capacity fuel tank made by Sullivan. The specifications for it are:

- Capacity: 6oz
- Height: 1.75"
- Width: 2.125"
- Length: 4"

3.6 Flight Control Systems

Flight control systems include the flight control surfaces (ailerons, elevator and rudder) as well as their mechanical and electrical requirements and arrangements. The flight control system research has not been completed.

3.7 Electrical Systems

The electrical system includes the on-board batteries, the batteries monitoring system, the remote control receiver, the electric servos and all the wiring and connections. This system will be designed to be integrated into the finalized aircraft design.

3.8 Landing Gear System

The landing gear system will be greatly influenced by the finalized aircraft design. Below are various alternatives for landing gear system arrangements:

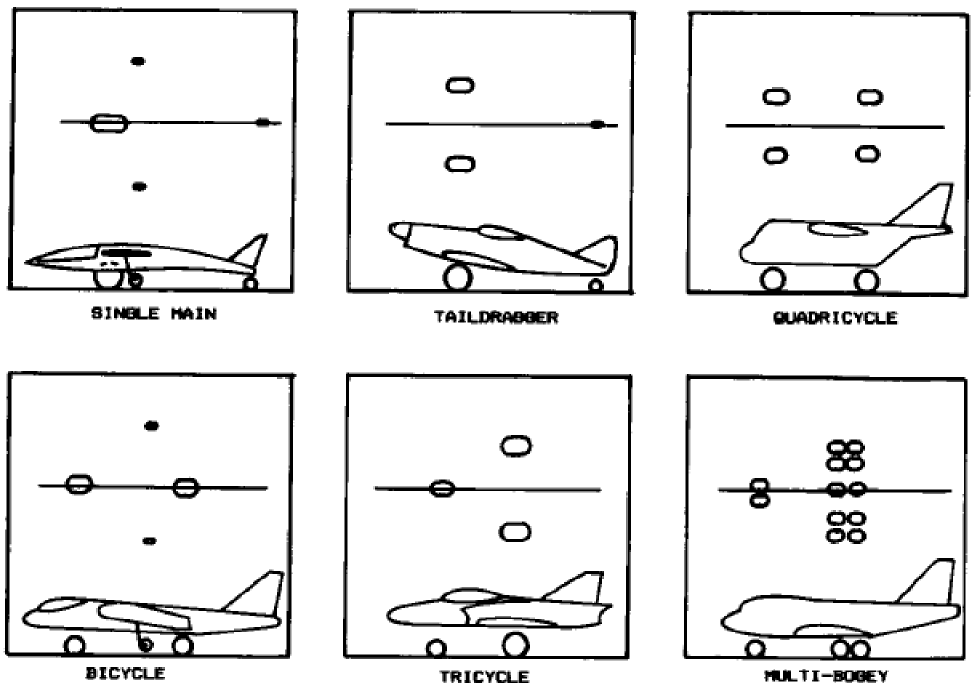


FIGURE 9: Landing Gear Arrangements

The landing gear arrangements shown in the figure above were obtained from research made on landing gear configurations [3].

3.9 Other Alternatives

This section is reserved for other alternatives yet to be considered.

3.10 Feasibility Assessment

Due to the fact that the competition is in Brazil, and that it might be necessary to rely on obtaining the services of a local remote control airplane pilot, the stability of the chosen design was deemed a very high priority. The *PanthAir Cargo* design should be relatively easy to fly in order to mitigate the risk of an accident. Had the competition been local, the risk of using a less stable, but more advanced design such as a box-wing design would have been more acceptable.

Another very important consideration is the manufacturability of a chosen design. Trade off studies will be performed to finalize many of the details. For example, it may be very difficult if not impossible to manufacture an airfoil profile that might have the best aerodynamic characteristics. In which case, perhaps a replacement profile may be used that exhibits acceptable aerodynamic characteristics, but is feasible to manufacture.

3.11 Proposed Design

3.11.1 Prototype System Description

The characteristics that have been decided so far include:

- Top mounted wing
- Front mounted engine with a "Tractor" pulling propeller
- As small as possible fuselage "shade area"
- Conventional tail arrangement
- The use of "winglets"

Below are our first two proposed concepts:

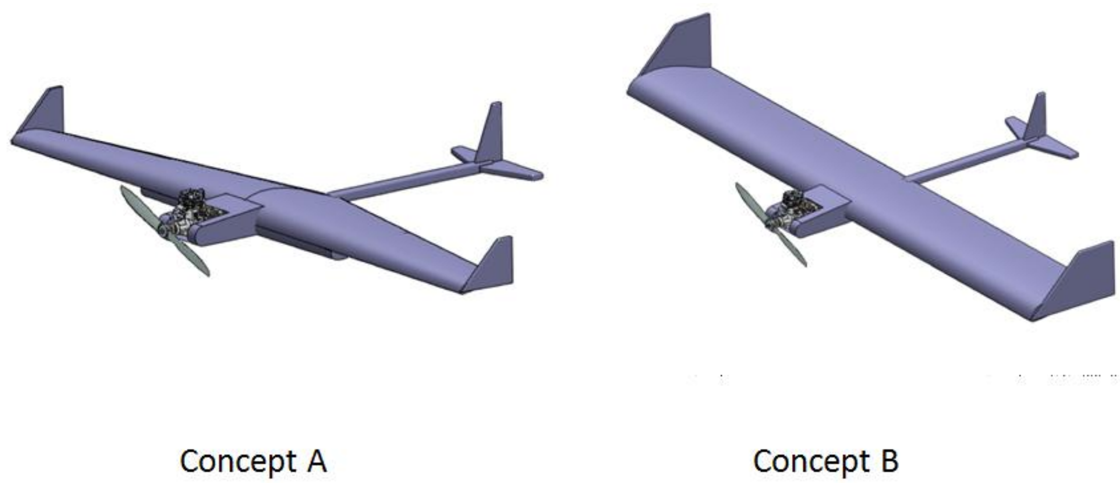


FIGURE 10: Proposed Concepts A and B

In Concept A above, the fuselage was widened to allow for cargo bay to be centrally and laterally located under the wing. In this method, the projected fuselage area was minimized. Access to the payload would be through a side door under the wing. This concept would allow for the use of tapered wings.

In Concept B above, the cargo bay was relocated to the inside of the wings which distributed the payload throughout the entire wing span. This concept was deemed more efficient at allowing the engine propeller thrust to be less obstructed compared to Concept A. It would not be possible nor appropriate to use tapered wings on this concept since the payload is evenly spread. Therefore, a rectangular wing would be necessary, and due to the larger surface area of the wing, a reduced wing span would be necessary.

The team expects to use a “tail dragger” landing gear arrangement for both concepts A and B. By doing so, the wheelbase of the airplane will be increased compared to a tricycle landing gear arrangement. A longer wheelbase contributes to high speed taxing stability.

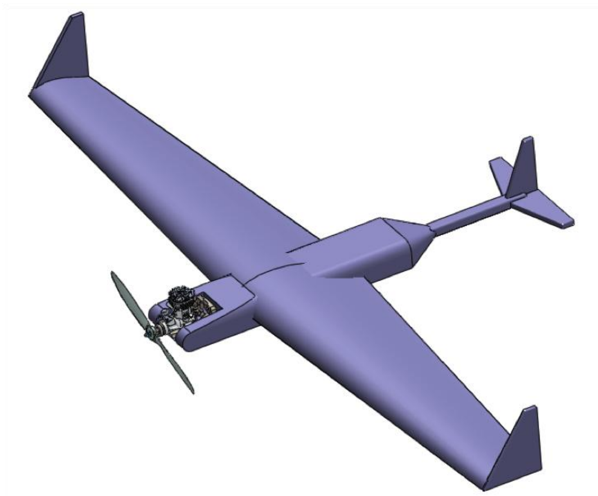


FIGURE 11: Proposed Concept C

A conventional high wing arrangement is illustrated in concept C above. In this concept, the cargo bay would be placed longitudinally in the fuselage. Access to replace the payload would be by removing the wing or through an access door in the back of the fuselage. This arrangement would slightly reduce the overall surface area available for the wing due to increased amount of projected area by the fuselage.

In order to maximize the wheelbase a tail dragger landing gear arrangement is desired. A more conventional tricycle landing gear will make it more difficult to taxi and take off, but it may be necessary to obtain enough ground clearance at the aft end of the fuselage. This detail remains to be determined.

3.11.2 Prototype Structural Design

The team had invested a great deal of time on structural design and analysis of concept B until it became apparent that it wasn't feasible. More details on these analysis are found later on in this report.

The team just switched to concept C the day prior to writing this report. As a result, the structural design and analysis has not been completed yet. However, due the very conventional nature of this design, it is highly unlikely that any structural design concern would not be properly addressed and resolved.

3.11.3 Proposed Wing Airfoil Design

Airfoils that were considered:

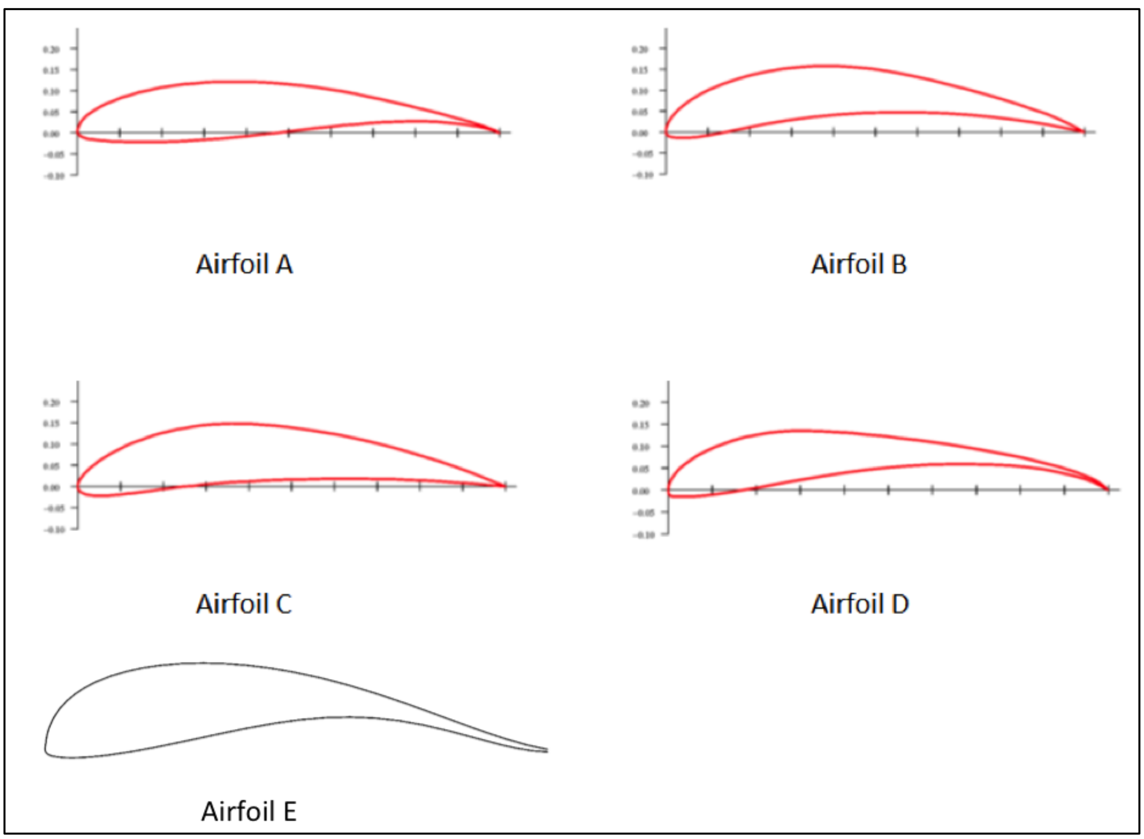


FIGURE 12: Airfoil Shapes

The airfoils shown above were obtained from research made on airfoils for heavy lift cargo planes [1]. Airfoil A is the Wortmann FX 63-137, airfoil B is the Eppler 423, airfoil C is the NACA 8414 and D is the Selig 1223. Airfoil E is the Reddy-LR-007, its a custom-made airfoil created by a student at FIU and optimized for low Reynolds numbers.

An objective method of selecting the design airfoil was deemed necessary since there were various criteria to consider. For example, it is desired to have the best possible aerodynamic performance that would give the best lift to drag ratio. However, there are trade-offs to consider. The best performing airfoils have extremely thin trailing edges that would potentially create areas that may be weaker or more susceptible to damage. Said very long thin trailing edges are also deemed very difficult to manufacture especially given the limited recourses available.

The 5 proposed airfoil designs were evaluated on their aerodynamic performance, strength, and manufacturability. The results of this initial assessment are shown in following table:

TABLE 2: Airfoil Criteria Ratings

	Airfoil Criteria Ratings		
Airfoils	**Excellent = 5, Very good = 4, Good = 3, Fair = 2, Poor = 1**		
	Aero Performance	**Structural Integrity**	**Manufacturability**
	1-5	1-5	1-5
Wortmann FX 63-137	3	3	2
Eppler 423 Airfoil	4	4	4
NACA 8414 Airfoil	3	5	5
Selig 1223 Airfoil	5	2	1
Reddy-LR-007	5	2	1

After this initial assessment, the values obtained from Table 1 were used to calculate weighted relative ratings as shown in table 2. By using this method, the airfoil with the highest rating ratio would be deemed the best choice given our selection criteria.

The Reddy-LR-007 and the Selig 1223 were deemed the best as far as the predicted aerodynamic performance. However, these two airfoils have very long and thin trailing edges that would be more difficult to manufacture relative to the other airfoils. These long and thin trailing edges are also susceptible to damage so they would require special structural considerations. Because of these two concerns, these two airfoils were rated low in the manufacturability and structural integrity categories. However, as the team's research evolves, it is quite possible that good engineering solutions may be found to overcome these concerns, and these ratings may be modified as a result.

TABLE 3: Airfoil Selection

Airfoils	Relative rating number - R (=rating number x weighting factor)			ΣR	Σr	ΣR/r
	Aero Dynamic Performance	Strength	Manufacturability			
	1	2	3	30.00	6	
Wortmann FX 63-137	3	6	6	15.00	6	2.50
Eppler 423 Airfoil	4	8	12	24.00	6	4.00
NACA 8414 Airfoil	3	10	15	28.00	6	**4.67**
Selig 1223 Airfoil	5	4	3	11.00	6	2.00
Reddy-LR-007	5	4	3	12.00	6	2.00

The team was expecting the custom Reddy-LR-007 to be the best choice given the high performance expected; however, once it was analyzed using all the criteria above, it was not going to be the best choice. According to the table above, the best choice would be the NACA 8414 airfoil, followed closely by the Eppler 423 airfoil. As such, our team decided to accept the objective results, and use the NACA 8414 airfoil.

The best performing airfoils scored low mainly due to their rather complex manufacturing requirements. Research is still being conducted on manufacturing techniques before a final assessment and selection is made. The team would still prefer to use the Reddy-LR-007 airfoil if possible.

3.12 Analysis of Concepts

The team has ruled out concept A due to the very high aerodynamic frontal surface area obstructing the thrust generated by the engine and propeller. By obstructing the path of the thrust, the airspeed of the aircraft would be reduced which would be accompanied by a loss of lift.

Concept B has encountered some very challenging engineering stress concerns in having to carry the payload in the wings in a very limited space. In order to make this concept work, the displacement of the wing would have to be minimal to as to not place a load on the payload being carried. Simulations were run using various materials and various loads to determine if this was a feasible concept. The simulations included pulling 5 g's during flight, as well as just over minus 2 g's simulating a hard landing.

The results of these simulations are shown below:

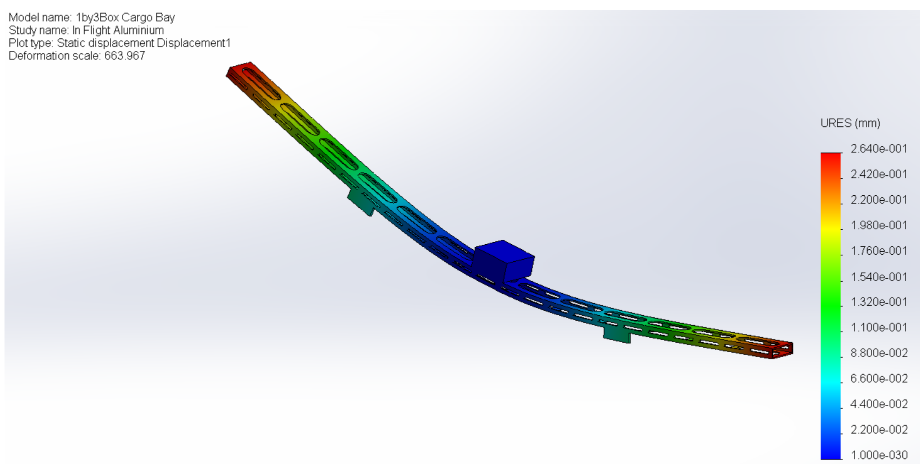


FIGURE 13: In Flight Displacement of Cargo Bay for Concept B

As seen in the figure above, the in-flight displacement at 5gs would be 26.4 mm. In this arrangement, a rectangular channel made out of 6061 aluminum alloy was used for the simulation. It revealed approximately 26.4 mm displacement at the wing tips.

Another simulation was also performed simulating a "hard landing". In this simulation, a hard landing was assumed to take place if the aircraft was dropped from a height of 1 meter.

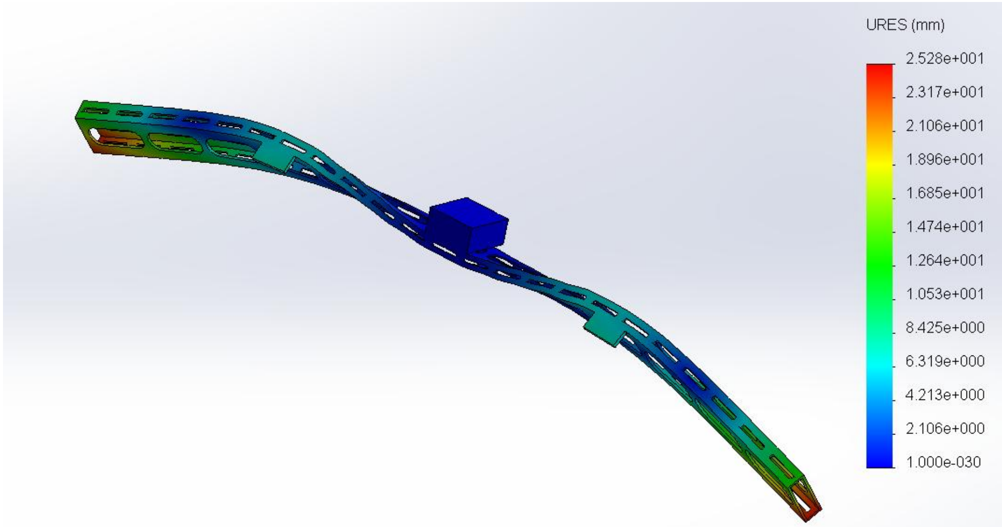


FIGURE 14: Hard Landing Simulation of Cargo Bay for Concept B

As seen in the figure above, a hard landing would cause a displacement of 25.2 mm.

As demonstrated in the 5 G and hard landing simulation, the cargo bay would require a more rigid structure which will continue to add undesirable weight to the aircraft.

Another concern with the design of concept B was that it would be very difficult to make the wing of this concept able to be separated into 2 or 3 pieces for shipping. Having a solid wing this size would have added hundreds of dollars to the cost of our project. Because of these concerns, concept B was also eliminated from any further consideration.

As a result of the analysis of concepts A and B, the team has selected concept C. Trade off studies and simulations are still on-going, but this concept is relatively simpler and more reliable than the previous two. The fuselage size would have to be lengthened enough to accommodate the cargo bay. The landing gears would be attached to the fuselage since that is where most of the weight is. A “tail dragger” landing gear arrangement is deemed the best choice for our application. The wings will have the capability to be separated into 2 or 3 pieces. Wing displacement in this concept is not such a big concern as it was for concept B.

3.13 Discussion

After carefully considering the proposed designs and weighing the pros and cons for each one, the team opted for concept C. Although not as innovative as concepts A and B, concept C was considered to be the best one for meeting our requirements.

PanthAir Cargo's design process is still evolving. However, as previously shown, some characteristics have already been adopted. The team's strategy places priority in the following order:

1. Cost of design
2. Stability of the design
3. Manufacturability of the design
4. Structural Integrity of the design
5. Performance of the design

The reason that performance was placed at the bottom is due to the fact that if any of the previous priorities are not met, performance would not affect the project. Secondly, it is deemed that an experienced pilot in a relatively less capable but stable design will out-perform a less experienced pilot flying a more sophisticated aircraft design.

Although the team is assuming a worst case scenario of having to use an unfamiliar pilot, as of the date of this report, the team has been able to find a fellow FIU student with 6 years of remote control aircraft flying experience to fly our airplane.

4. Project Management

4.1 Overview

In order for this project to succeed, it is essential that major milestones and requirements be identified and accomplished in a timely manner. The major aspects of this project involve the design, manufacture and flight demonstration of an unmanned aerial vehicle (UAV). Some of the milestones and requirements include the preparation and submittal of a flight video as well as a project report to the SAE Brazil Aero Design Competition Committee.

4.2 Breakdown of Project Requirements

The project was broken down into smaller parts such as the research of airfoil shapes, the engine/propeller combination selection, and cargo bay alternatives. Additionally, as classroom tasks became necessary, further taskings were necessary to accomplish requirements such as presentation slides, reports and our team poster.

In addition to the time required to dedicate to research and perform design work, it is also necessary to timely plan for and prepare the required presentations and reports. The amount of time necessary for the latter has proven to be a substantial time investment into this project.

Another task that we had to perform was registering for the competition. This proved to be an extremely difficult process. First, the team had to wait until the date that the registrations were opened on the website to do so. However, it wasn't until then that the information required to register for the event was known. Many personal details were necessary including obtaining passport numbers for each person of the team including our academic advisor. It was also necessary for each member to join SAE International and obtain an ID number. Many emails were exchanged (in Portuguese) trying to clarify all the questions and requirements. The open registration period ended quite abruptly before we were able to gather all the required information. As a result, the team is now on a waiting list for the phase 2 of the registration process.

4.3 Breakdown of Project Task Responsibilities

TABLE 4: Task Assignments

Required Tasks	Designated Member
Reading of the Rules	All
Initial A/C sizing	Nestor
Motor and Prop Selection	Arjav
Airfoil Design Selection	Andres
Airfoil Design Optimization (CFD)	Andres
Cargo Bay Design	Nestor
Cargo Bay Load Stress Simulations	Arjav and Nestor
Empennage Design	Nestor
Fuselage Design	Nestor
Propose Design Concepts	All
Select Design Consept	All
Optimize Design Concept	Andres/Arjav
Cost Analysis	Arjav
Pilot Search	All
Manufacturing Materials Research	Andres
Manufacture Wings	All
Manufacture Fuselage	All
Manufacture Empenage	All
Prepare Reports	All
Team Poster	Arjav
Register for Competition	Nestor
Fuel Tank Selection	Nestor/Arjav
Fuel Tank Integration	Nestor/Arjav
Weight and Balance	Nestor
Thrust Validation Test	All
Drag Validation Test	All
Flight Testing	All
Post Flight Adjustments	All
Flight Practicing	All
Flight Video	All
SAE Report	All
Wing Load Computations	Nestor
Landing Gear Design	Nestor
Flight Control Areas Calculations	Nestor
Flight Control Rigging	Nestor
Selection of Servors	Nestor
Selectlon of Internal Electrical	Arjav
Selection of Radio	Arjav

4.4 Timeline

TABLE 5: Proposed Timeline

Task	2014											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Research												
Literature Survey												
Competition Registration												
Design												
Calculation and Analysis												
Control and Stability												
Computational Fluid Dynamics												
Prototype Construction												
Pilot Selection												
Wind Tunnerl Testing												
Revise												
Report and Drawings to SAE												
Practice Flights												
Design Change Report to SAE												
Flight Video												
Pilot Change Form if Required												
Competition												
Senior Design Report												
Senior Design Presentation												

4.5 Cost Analysis

TABLE 6: Estimated Prototype Costs

Prototype Costs	Amount ($)
Engine	170
Propellers	20
Radio Controller	300
Servos and Electronics	200
Fuel Tank	20
Payload	50
Batteries	100
Manufacturing Materials	150
Landing Gear	30
Flight Control Rigging	25
Operating and Misc	100
Estimated Airplane Costs=	1,165

TABLE 7: Estimated Competition Costs

Competition Costs	Amount ($)
Registration	600
Travel Expenses	1000 per person
Total event cost per person	1,200

TABLE 8: Hours Spent on Project

Individual hours	Hours spent/week	Hours spent this semester
Andres	20	360
Arjav	20	360
Nestor	20	360
Total hours	60	1080

As shown in the previous three tables, this project requires a considerable amount of monetary as well as time contributions from each member if it is to succeed. Unless the team gets a sponsor or funding, the total costs will be distributed among the team members.

5. Analytical Analysis

5.1 Initial Sizing

The maximum amount of projected area of .775 m^2 is the driving geometric factor for the aircraft sizing. In order to arrive at a preliminary aircraft concept design the following assumptions will be made based on historical data:

Tapered ratio: 0.45

Wing root C_{wing}: 0.3048 m

Max Wing Area S_w: 85% of the wings + horizontal tail area

Max Horizontal Tail Area S_h: 15% of the wings + horizontal tail area

Fuselage projected area S_f: 0.0903 m^2

Miscellaneous areas S_m: 0.0645 m^2

The total available area cannot exceed the stated maximum of .775 m^2. Based on the above assumptions the area available for the wings plus the horizontal tail is:

$S_w + S_h$ = Max Area - S_f - S_m = 0.0602 m^2

S_w = .85 * ($S_h + S_w$) = 0.5271 m^2

S_h = .15 * ($S_h + S_w$) = 0.0930 m^2

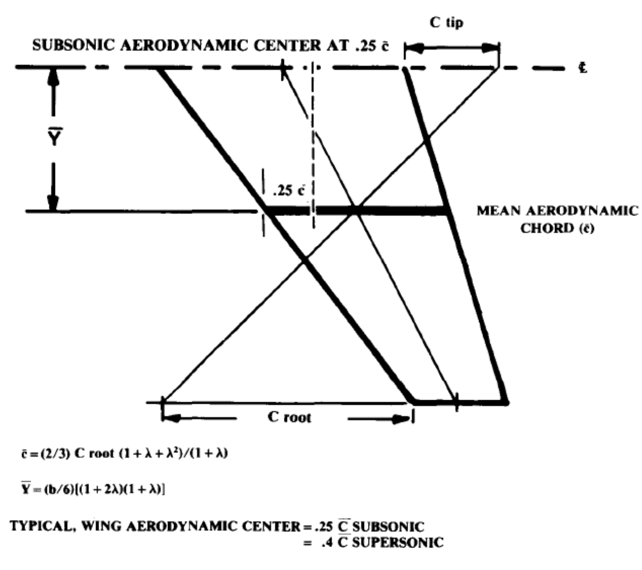


FIGURE 15: Wing Mean Aerodynamic Chord (MAC)

The figure shown above was obtained from research made on wing geometry [3].

In order to estimate the wing span, it is necessary to calculate the mean aero dynamic chord (MAC), of the wing first. The formula for calculating MAC was obtained from the previous figure:

$$\bar{c} = (2/3)\ C\ root\ (1 + \lambda + \lambda^2)/(1 + \lambda)$$

The calculated wing MAC is 0.2316 m

Using the same method, the MAC for the horizontal tail was calculated and resulted in a length of 0.1853 m.

Having the MAC for both the wing and the horizontal tail, their spans, b, can be calculated using the following formulas:

Span for the wing = $b_{wing} = S_w/MAC_{wing}$
Span for the horizontal tail = $b_{ht} = S_{ht}/MAC_{ht}$

Based on the initial assumptions, our estimated wing span will be about 2.277 m and the span of our horizontal tail will be about .5021 m.

The MAC is also important in calculating the center of lift of the wing. Normally the center of lift for a wing is a distance of 0.25 MAC. In this case it comes out to 0.0579m. This becomes a critical dimension for the aircraft because for an aircraft to have longitudinal stability (along the lateral axis), the aircraft's fully loaded center of gravity should be slightly forward of the center of lift. This is also the desired location for the center of gravity for the payload.

The cargo bay doesn't necessarily have to fall on the center of gravity. However, it is essential that the payload does. Our selected concept will have enough flexibility to locate the slightly forward or aft within the cargo bay to adjust for the actual center of gravity once the prototype is finished, and a weight and balance check is performed on it.

All the above calculations were done in an exell spreadsheet and a sample of it is contained in Appendix B.

5.2 Kinematics Analysis

In order to be able to calculate many of the variables for our design such as how much payload can be carried, it is necessary to and often helpful to start with the amount of available power. In this case, the available power comes from the available thurst from the engine and propeller combination, F_{thrust}.

In order for the aircraft to accelerate and maintain the necessary velocity to maintain stable flight, the F_{thrust} must be equal to or greater than the sum of all the opposing forces $\sum F_{opposing}$. The opposing forces are made up by the force necessary to accelerate the mass F_{accel}, the force caused by the wheels friction $F_{friction}$, and the force caused by wind resistance F_{drag}. Or:

$$F_{thrust} = \sum F_{opposing} = F_{friction} + F_{accel} + F_{drag} \qquad (1)$$

For the sake of our calculations, we are assuming the heaviest allowed aircraft mass which is 20 kg. By knowing this amount, it will be possible to calculate the force necessary to accelerate the aircraft for flight once the required velocity V for lift off is calculated. The required acceleration force can be calculated as follows:

$$V^2=V_0^2 +2*a* \Delta x \qquad (2)$$

Where: V= takeoff velocity

V_0 is the initial velocity (zero in this case)

a = acceleration required

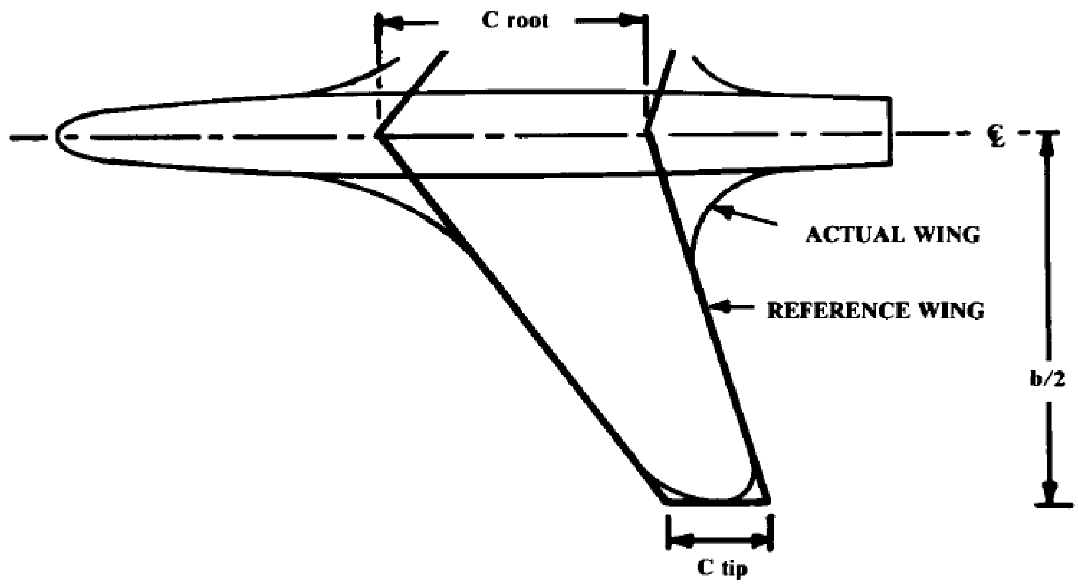
Δx = the required take off distance

By rearranging the equation above, the acceleration can be calculated as follows:

$$a = V^2/(2* \Delta x) \qquad (3)$$

The required velocity V as well as the resulting drag forces can be obtained from wind tunnel testing as estimated based on simulations. The airfoil design will greatly affect these calculations.

Our selected concept C will allow us to use tapered wings which are a good aero dynamic characteristic. Tapered wings also allow for lighter and thinner support supports as the distance from the fuselage is increased. The wings are expected to flex creating a displacement at the tips. The figure below illustrates some of the wing geometry considerations:



S	= REFERENCE WING AREA
C	= CHORD (DISTANCE L.E. TO T.E.)
A	= ASPECT RATIO = b^2/S
t/c	= AIRFOIL THICKNESS RATIO (MAXIMUM THICKNESS/CHORD)
λ	= TAPER RATIO = C tip/C root
b	= SPAN

GIVEN: W/S, A , λ

$S = W/(W/S)$ $\quad b = \sqrt{A \cdot S}$ $\quad C_{root} = 2 \cdot S/[b(1+\lambda)]$ $\quad C_{tip} = \lambda \cdot C_{root}$

FIGURE 16: Wing Geometry

The figure shown above was obtained from research made on wing geometry [3]. According to this source, a good wing taper ratio would be .4 to .5.

Since the team just began to work on concept C after concept B was found not feasible, much of the engineering calculations are still required for the fuselage and wings.

6. Conclusions

The team got off to a difficult start due to the fact it spent a bit more than a month conducting research and design work using the only available rules at that time which were the 2014 SAE East Aero Design Competition rules. Upon the publishing of the 2014 Brazil Aero Design rules, it was realized that our design would be substantially different. For example, it went from electric propulsion to internal combustion, the geometric requirements were substantially changed, and the required minimum cargo bay volume was not even required in the prior rules. All of this resulted in a small shift of our timeline.

One area that the team has dedicated countess hours on is on performing simulations and analysis on the custom FIU airfoil, the Reddy-LR-007. The team could have chosen to use an already researched and proven airfoil, but felt that the experienced gained by conducting our own research would be very valuable. It was also deemed that we might also end up with a better performing airfoil. The team hopes to have the airfoil analysis completed very soon so as to be able to use the obtained data to perform many of the dependent calculations for the entire prototype.

Another obstacle that the team is facing is the possibility of not being able to secure a slot in the competition in Brazil. The available slots were very limited, and the team has not been able to secure one yet. As a result, the team has also considered an alternative plan in the event that it cannot compete. The alternative plan is for the team to continue its research, design, manufacture and fly the prototype while following all the rules. We would then also plan a performance demonstration test flights, and invite a variety of people including our academic advisor to witness the tests and results. We would then compare our results to the published competition results in order to assess our performance.

In spite of the aforementioned challenges, the team is very optimistic about our project. We were able to find an excellent pilot ahead of schedule, and we plan on finishing the construction on schedule.

References

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Appendices

Appendix A: SAE Brasil Competition Rules

The 16th Annual SAE Brasil Aero Design 2014 rules include a total of 104 pages written in Portuguese. The rules may be downloaded from their website: http://www.saebrasil.org.br/eventos/programas_estudantis/aero2014/Regras.aspx

Appendix B: Prototype Initial Sizing Sample Calculations

Calculated span b	93.33964
Cwingroot	12
Cwingtip	5.4
Desired taper ratio λ	0.45
Max Wing Area Sw	851
Calculated wing MAC	9.117241
Calculated Wing Aspect Ratio A	10.23771
Max Hor Tail Area Sht	150.1879
Desired taper ratio λ	0.45
Chortailroot	9.6
Chortailtip	4.32
Calculated ht MAC	7.293793
.25 ht MAC	1.823448
Calculated ht wing span bht	20.59119