University of California, Merced

AIAA DBF Team at UCM

January 2015

UCMERCED

Contents

Aircraft Name: Kupplung

1 Executive Summary

This report qualifies the conjoined work efforts of the University of California, Merced students in conjunction with the AIAA resources. The purpose of this team is to create an aircraft that not only meets the effective design parameters, but also does so within the competition environment. This team has faced many hurdles, seeing as this is the first competition of its kind for the club, let alone the school. These hurdles narrowed down the team members over time and those who remain at this point find themselves truly dedicated. The ultimate goal of the team is to produce an aircraft that is competition worthy.

1.1 Design Summary

The overall intent of the design process was to create an aircraft that has the capability to satisfy all the mission requirements and gain the highest scores. There were countless conceptual designs that went into deciding on a final idea for our initial prototype taking into account weight, maximum speed, and carrying capacity as the main components of a successful aircraft.

1.2 Mission Requirements

For this competition there were a total of three missions to be completed. Since there were multiple missions, it was important to weigh the impact of each mission into the design of our aircraft. The designs the team ended up using prevailed heavily with the most lightweight (and ultimately, energy efficient) and aerodynamic versions. Since the missions would require a total of 20 minutes or more of flight time, the greatest amount of effort was placed into these specific qualities. The following details are of each mission and the requirements.

1.2.1 Mission 1

Mission 1 dedicates a conventional speed test on how many laps the aircraft can complete in a four minute time limit. Points were awarded equivocally based on the the following equation.

$$M1 = 2\frac{NumberLapsFlown}{MaxNumberLaps}$$

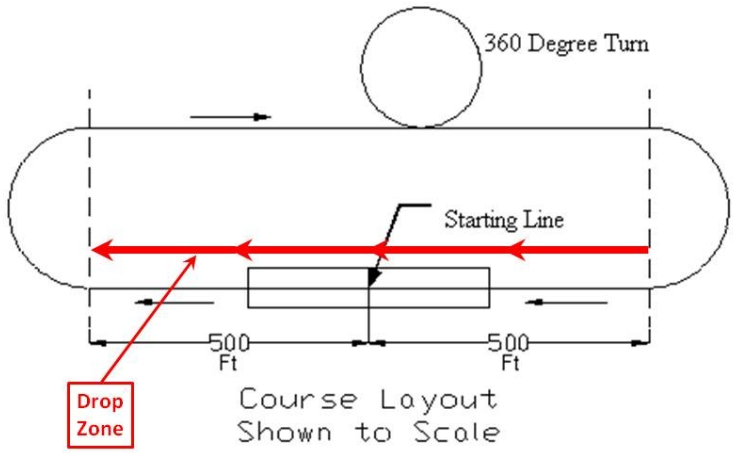

Figure 1: Drop Zone Diagram, courtesy AIAA

1.2.2 Mission 2

The mission begins with a "flight ready" airplane in position with empty open hatches. Payload for mission 2 will be added and prepared, as to simulate flight conditions. The ground crew must leave the area, upon leaving the time will be halted to verify that the airplane is secure. After doing so the time will restart, and mission 2 payload will be interchanged with that of mission 3. Tech inspection prior to ground mission will determine the maximum amount of wiffle balls used in the payload for mission 3. The airplane will be secured and prepared to simulate flight conditions again. Ground team leaves the designated loading area. Stoppage in time will be given to ensure security of the aircraft. The allocated time to complete Ground Mission is 5 minutes. The mission scoring is as follows:

$$GS = \frac{FastestLoadingTime}{LoadingTime}$$

Failure to complete ground mission will result in a score of GS=0.2 for intermediate scoring purposes.

1.2.3 Mission 3

Mission 3 consisted of a Sensor Package Transport Mission in which the aircraft is force to carry extra weight as it performs three laps. The payload weighs 5 pounds, and has specific dimensions, and thus the team focused the design around an aircraft that has the room to not only house the payload, but also takeoff and land with it on board. This heavily restricted the style of body and the length of the tail of the aircraft.

1.2.4 Mission 4

The goal of mission 4 is to take-off within the given field length, while carrying an external release mechanism that will drop Champro 12" wiffle balls within a defined drop zone to validate a single lap. Constraints for the mission include ensuring that all support equipment and fairings are exposed to air from 3 sides minimum. During flight the aircraft will release 1 ball to count towards the overall scoring, releasing more than 1 ball will invalidate that current lap. No other equipment from the aircraft may fall during mission 4. The figures below depict the wiffle ball, and the designated drop zone. With mission scoring being:

$$M3 = 6\frac{NumerLapsFlown}{MaxLapsFlown}$$

A successful landing must occur to receive a scoring result.

1.2.5 Mission Scoring Summary

A team's overall score will be given by the use of their Written Report Score, Total Mission Score and Rated Aircraft Cost using the following formula:

$$Score = WrittenReportScore * \frac{TotalMissionScore}{RAC}$$

The Total Mission Score is given by the product of the Ground Score, being GS and Flight Score, represented by FS.

$$TotalMissionScore = GS * FS$$

Where the flight score is the sum of the individual flight scores of the given missions:

$$FlightScore = FS = M1 + M2 + M3$$

The RAC score is a function between the empty weight and complexity of the aircraft given by:

$$RAC = EW * NServo$$

The empty weight of the aircraft will be taken after each of the respective missions. Where

$$EW = Max(EW1, EW2, EW3)$$

The EWn is the weight after removing the payload post flight.
NServo score is derived by the total number of servos used on the aircraft. The following are all examples of servos that will be counted to the score.

- Conventional R/C Servos
- Speed Controllers
- Electric motors (when not used for propulsion)
- Solenoid Actuator
- Electric Relay

Flight Course/Lap: The direction of the flight course (see figure below) will be determined by a Flight Line Judge. The course is situated and geared to be the safest iteration in order to bring no harm to individuals.

1.3 Mission Regulations

The Ground Mission is the only mission that may completed at the discretion of the team, or when time permits. Where as for the three flight missions must be completed in chronological order, it is not allowed to proceed to the next mission without receiving a valid score from the previous mission. The aircraft that will be present at the competition must be capable of successfully completing all the required missions. A mandatory wing tip load test will be conducted on the aircraft, it must pass the test by meeting the largest payload loading intended for the specific mission. The tech inspection will be aware of any failures and will not allow the aircraft to fly. For mission 2 and 3 the aircraft will enter the assembly area empty.

There is a time constraint of 5 minutes to be able to mount the payload and make last checks on the aircraft system to ensure it is ready for the upcoming mission. After time has passed the team will not have the opportunity to alter the aircraft in any way.The RC receiver must be able to be turned on externally there is no allocated time to open any compartment to connect the receiver. The only ones that have access to the staging box are the assembly crew member, pilot assistant and pilot. Aircraft will use ground rolling take-off technique with a limit of 60 ft.The first upwind turn on the first lap of each mission will occur after passing the turn judge, he will be in charged of the signal of raising a flag . The Flight Judge has the authority to require turns to be made by the aircraft to remain in a safe visual control range at their discretion. In order to receive any score for each mission, the aircraft must successfully land and avoid extensive damage to itself.

1.4 System Performance

The final weight of the aircraft design was about 8 pounds and 5 ounces. This included the weight of the battery and all existing electronics. The final design is capable of carrying a block with dimensions of 10 x 5.5 x 4.5 inches and design capabilities of being able to drop a single wiffle ball. This is the team's inaugural DBF appearance, and we feel that the final design submitted will be able to adequately demonstrate proficiency in all mission requirements.

2 Management Summary

During Summer 2014, the team leads began recruiting members in order to compose a team of dedicated members who were willing to commit to the project. The team began with 19 members who were interested, however as time progressed, various members decided they did not have the necessary time for the project and they left the team. The team consisted of members with a strong aerodynamic background and others without such experience. Disregarding any previous experience that members have, the members were enthusiastic and had many ideas as to how the plane was to be designed and constructed. The team as a whole had never worked on a competition that simulated industry related tasks, and all were eager to be at the forefront and be the first DBF team at our respective chapter.

2.1 Team Organization

In order to have organization, the team lead assigned sub leaders to overview certain aspects of the design and construction to insure their fulfillment. In charge was the previous Chair of the student charter. Where they would be responsible of all aspects of the plane, and along with input of the two sub leads known as Operation Engineers, dived the design process. One sub lead was in charge of the manufacturing and building of the aircraft components. The other was in charge of the electronics and flying of the aircraft. With sub sections being given to the members. The members were encouraged to join all sections and gain as much experience as possible in order to grow their skill sets and prepare them for real world applications when the time arises. See Figure 2.

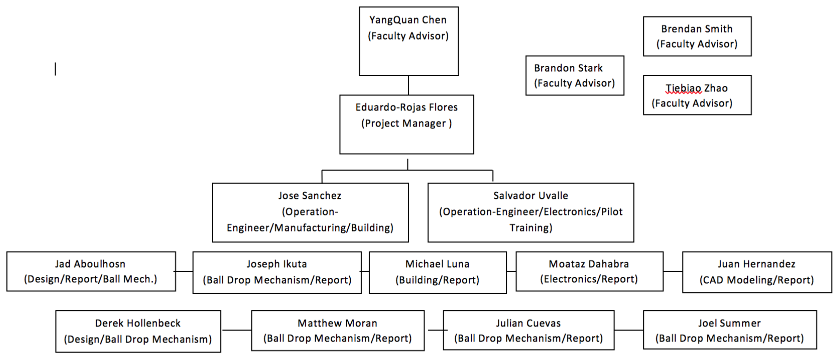

Figure 2: Organizational Chart of Team Members' Responsibilities

2.2 Organizational Chart

To complete the project and give every member an opportunity to participate, each member was allowed to work on whatever portion they desired. Team members were always under the supervision of either the team leader or one of the sub-leaders. During the design process, the entire team provided input, gathered all the relevant ideas, and determined the appropriate implementations.

2.3 Organizational Graph

The team was limited on resources and tools. With the help of the team leaders, team members were exposed to all aspects of construction of a plane and the best methods to facilitate construction. Proper tool use was also taught to members that did not have any experience. At some points during the duration of the project, members collaborated to facilitate implementation of ideas.

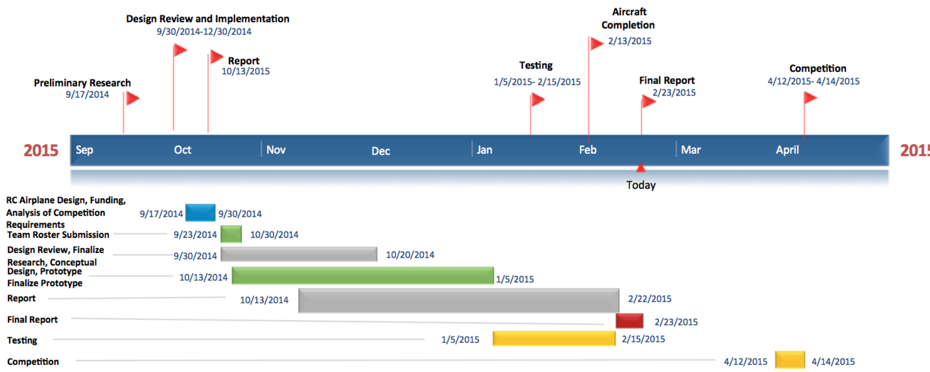

Figure 3: Organizational Chart of Team Members' Responsibilities

2.4 Gantt Chart

In order for the team to reach each milestone throughout the competition timeline. The team adhered to Milestone/Gantt to properly detail the proposed dates of completion for aspects of the design, build and initial flights of the aircraft. Thus reducing the chances of falling behind schedule and elongating the completion of vital components of the aircraft. There were mandatory weekly meetings that will overview the completion of that week's tasks, and could be implemented moving forward to assist the team. Outside altercations caused minor delays, while in other occasions a specific section was completed prior to our proposed date. With constant progression from the members made the overall process run smoothly.

2.5 Cost Assessment

See Table 1 on the next page.

3 Conceptual Design

3.1 Design Constraints

There were multiple design constraints which the aircraft had to meet. There were constraints that constrained design such as the following: the aircraft could not be a rotary wing or lighter-than-air configuration, the motor had to be propeller driven and electrically powered, unmodified, and commercially available, the batteries used to power the motor had to be commercially available NiCad or NiMH batteries and shrink-wrapped or otherwise protected over all electrical contact points, and the propulsion system battery pack could not

	Item	Price
1	Receiver (1)	11.99
2	Batteries (2)	91.98
3	Propellers (1)	9.99
4	Wooden Rods (4)	3.92
5	Wooden Rods 3/8” 4’ (2)	1.96
6	Aluminum Rods (3)	17.97
7	Balsa Airfoils (5)	7.5
8	Balsa Thin (3)	5.97
9	Balsa Thick(3)	8.97
10	Plywood (6)	35.94
11	Balsa (3)	5.97
12	Motor (1)	62.99
13	Servos (7)	153.93
14	Esc (1)	29.99
15	Screws	25.41
16	Landing Gear (1)	6.99
17	Wood Glue (1)	6.99
18	Super Glue (2)	7.98
19	Monokote (3)	38.97
20	Tape (1)	5.99
21	Servo Extensions (4)	27.96
22	Wires (4)	3.96
23	Nose Cone	3.96
24	U Brackets (Copper) (2)	1.00
25	U Brackets (Aluminum) (2)	0.58
26		
27	Subtotal	577.89
28		
29	8.25 Percent Tax	47.67
30	Total	625.56

Table 1: Table of Cost Analysis

weigh more than 2 lbs.

The constraints that were in place for every mission were the following:

- The aircraft must take off without any external assistance.
- No components of the aircraft could fall off during flight.
- The Takeoff Gross Weight (TOGW) is less than 55 lbs.
- The take off length limit is 60 ft.
- The aircraft’s battery packs must not be recharged.

Of the missions to be performed, only missions 2 and 3 had notable constraints. In mission 2, the Ferry Flight, the payload had to be properly secured internally, with no part of the payload exposed to the outside. In mission 3, the Sensor Drop, however, required the payload to be secured externally. "Externally secured" was defined as a minimum of three sides exposed to air when viewed from three sides. Also, all supporting equipment had to be secured externally to the aircraft.

Because of the constraints in place, this required that the fuselage be larger in order to accommodate for the internal payload. The consequence of enlarging the fuselage increased the weight. In order to counter this, the wings built were longer and wider in order to provide the maximum lift possible, as well as to use the power more efficiently in flying the aircraft.

The team concluded that the plane must be able to carry the required payload, as well as be able to record sufficient amount of laps around the track in order to score highly on each mission. Since scoring in each respective mission was directly proportional to the speed of the aircraft as well as number of laps completed, it became apparent that in order to succeed, power efficiency and speed were going to be very important factors.

3.2 Introduction to Design

After analyzing the flight missions, and understanding the flight requirements within the context plane limitations the design process of the aircraft became more and more defined. During the design process, the team was faced mostly with overcoming hurdles that most teams would have resolved in previous competitions. Members and ranking officers all had (in most regards) the same levels of knowledge in aircraft design. This learning process happened, therefore, on all levels of management, as well as within the hierarchies of the dedicated work process.

3.3 Initial Concepts

There were several fuselage and wing designs proposed by the team. However, due to various crucial disadvantages, many of these designs were scrapped. While considering plane designs, the focus was on several factors: power efficiency, speed, weight of the structure, structural integrity, cost efficiency, and durability. The conclusion was that meeting these criteria was crucial to effective operation at competition. From the proposed criteria the determination was that the best design to achieve this would be the conventional wing design.

The team's final decision was that a conventional, medium, camber wing design which was best able to meet the aforementioned criteria. This wing design was primarily chosen due to it being the simplest wing design, making it easy to construct and manufacture as well as being cost-efficient. This would

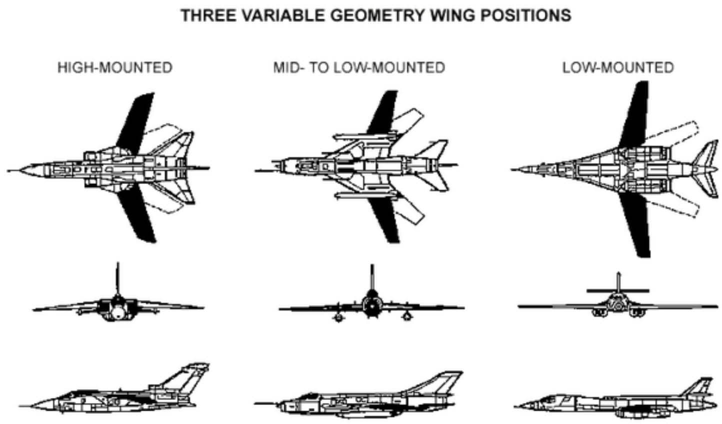

Figure 4: Three Variable Geometry Wing Positions

allow multiple construction iterations for the team to select the most feasible one for flight. Moreover, the specifically medium length was chosen due to it being lighter in weight, while still being durable enough to support the weight of the fuselage, as well as provide the necessary lift for the payloads in various missions.

3.4 Wing Placement Configurations

The first wing placement considered for the aircraft was a high wing placement mounted on top of the fuselage. Having a high wing mount fundamentally changed the aircraft design, because this allowed the landing gear to be placed on the fuselage, relieving the wings of significant stress during takeoff and landing. The advantage of a high wing aircraft was more apparent within the context of controlling the aircraft since the centre of gravity would be below the wing. Other advantages were greater lift and lower stall speed. The challenges presented, however, from a high wing placement were the wing will induce more drag, the aircraft would be less sensitive to changing directions due to the greater stability, and that it was structurally heavier compared to a low wing. Because of the higher lift and easier control for the pilot, the high wing design was selected.

The alternative wing placement that was considered was a low wing placement mounted beneath the fuselage. This is favored in many large aircraft for military and commercial use. The low wing mount gives a lower center of gravity, located above the wing. The advantages of this is better takeoff performance because the forward area of the aircraft tends to be smaller, there would be less induced drag, the tail would tend to be lighter, and the aircraft would tend to

Figure 5: Landing Gear Wide-bottomed ”U” Shape

be more maneuverable. The challenges of this configuration are in the fact that the aircraft would need more runway to takeoff and to land, and that it is less stable and therefore much more difficult to control.

3.4.1 Rectangular Wing Conventional

The only conventional design considered was a rectangular wing that is top mounted. The rectangular wing design is easy to build and simple enough to still be considered a light wing. This wing design is also known as the “Hershey Bar” wing because it looks similar to the candy bar. This style of wing can handle a sensible amount weight and travel at a sensible speed. The big drawback of this design is that it cannot do anything exceptionally. The design is meant to do things averagely and for the purposes of this competition it should work well due to the different task that the aircraft must accomplish.

3.5 Landing Gear Configurations

For such an aircraft to properly land without breaking apart on impact, there was the need for a well sorted landing gear system. Analysis on how real aircraft that have similar constraints as these go about landing showed that when an aircraft that needs to carry most of its weight under the wing area is designed, the generic method has them have two wheels up front with a tail wheel for the back, like a Cessna.

For the front two wheels, a 1/8” thick aluminium landing gear bent in a wide-bottomed “U” shape was employed. Two axles along with corresponding

Figure 6: Rear Landing Gear Wheel, with custom steel piece

nuts were used to attach the wheels to the landing gear. The back tail wheel was a custom piece made from steel and bent in a way that would allow it to act as a leaf spring. Connected, a simple wheel was attached and fastened to the custom steel piece.

The tail dragger landing configurations was considered. The tail dragger-landing configuration is composed of two main gear units. One is located near the center of gravity and supports most the aircrafts weight and a second unit on the rear of the fuselage. The major attraction to this design is its simplicity. Also, the units are lightweight and can be encased in streamline fairings to minimize their drag. Furthermore, the aircraft is tilted to a large angle of attack giving it more altitude, which helps generate a greater lift, and decreases the distances needed for takeoff and landing of the aircraft. However, this configuration has one huge drawback, which are its handling characteristics. The design can be unstable due to the fact that the planes center of gravity is located behind the two main gears. Also, if one wheel touches before the other during landing the aircraft has a tendency to veer of in the direction of that wheel. Despite these liabilities the team felt this landing configuration should work will given the tasks at hand.

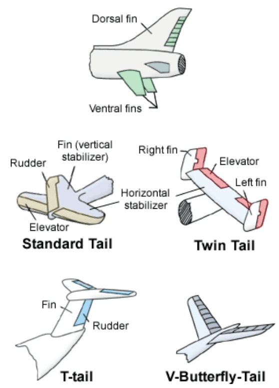

Figure 7: Various Tail Designs

3.6 Tail Configurations

Several tail configurations were considered for the plane. The four that seemed the most promising were as follows: a twin-tail configuration, or a T-tail configuration.

A Twin-tail configuration would provide additional rudder area without building a large single tail. This also adds a measure of redundancy, wherein if one rudder is damaged, the other will remain functional. On the other hand, a T-tail would move the rear vertical surfaces and rudder away from the disturbed airflow coming from the wings. This allow additional stability during pitching movements. However, the design would be prone to a deep stall, making the aircraft unstable in flight. In addition, the tail would need to be made stiff in order to make it strong enough to handle the forces generated by it. A tail with both ventral and dorsal fins was also considered, but was dropped due to the lack of materials needed to reinforce the fin for landing.

A conventional tail was ultimately finalized for the plane due to several design choices. One was for clearance, not only for the landing gear but for the wiffle balls deploying from the dropping mechanism. Having no ventral fin allowed not only for additional clearance and reduced the need for more expensive materials, it also allowed for the unique steering system for the plane when taxiing, as discussed previously. Compared to the other tail designs, it was also the least time and material intensive to construct.

3.7 Selection Validation

To ensure that the selected rectangular wing aircraft with a conventional tail was a possible design that met the competitions requirements, the team built a prototype from balsawood and plywood. The goal of this prototype was to test several design configurations before deciding to make them final. The team was concerned that the weight of the aircraft was not light enough and the battery and motor combination would not create enough lift for the airplane to take of and stay in the air. The team was also concerned that the tail dragger-landing configuration would cause problems due its handling liabilities and lack of an experience pilot.

3.8 Sensor Drop Configurations

In Mission 3, the payload-dropping mechanism and the wiffle balls combined were approximately 3 lbs, and would be mounted below the plane. This is most ideal mounting location, as it does not change the center of gravity significantly, and gives clearance for the payload to drop. Any other mounting location would have resulted in increased weight due to the modifications needed or risk damaging the plane, as well as offsetting the center of gravity significantly. The balls (estimated to be about 2.4 oz each), will be aligned along the length of the plane. Three different configurations for the drop mechanism were considered.

In consideration of the sensor drop mission, most challenges resided in developing a sensible ball mechanism that was simple and yet still effective. Given the several design constraints presented by the DBF rules, the ball mechanism designs were always under construction, and being adjusted. As a team, the design of a mechanism that was able to deploy at least one ball timely, and accurately in order to ensure the necessary trajectory, was crucial.

The final design, composed of wood, plastic, and a servo, proved to be relatively simple. A servo-actuated hinge held a bent rod that positions the wiffle ball against the bottom of the aircraft. The servo will be mapped to the controller as a single function that actuates the servo forward and thus allowing gravity to finish the work from there.

3.9 Fail Safe

The transmitter fail safe has been programmed in accordance with the required rules of the AIAA DBF competition. The receiver and the transmitter failsafe are programmed within their own software. The failsafe is enabled when the transmitter becomes out of range. The mechanical motor failsafe will consist of a power switch that is installed on the YEP 60 esc, separate from the BEC, to allow us to work on the electronics with the motor and motor esc completely off. This allows worry free work, and the simulation of how all channels would work while the throttle is applied. The switch will be mounted to the top of the engine compartment outside of the plane, far from the propellers. The ESC will also be programmed to start slowly and not too quickly, increasing safety.

4 Prototype Design

This section details the various aspects of design that the team faced through development, both theoretically and physically as they progressed through construction of the aircraft.

4.1 Design Methodology

The approach that proved to be the most efficient in the design process was an iterative design process to maximize the total flight score. This allowed continuous improvement on specific points of the aircraft through creating, observing, and testing prototype airframes.

4.2 Design Process

The conceptual design was formulated through a variety CAD models that proved the specific design to be the most structurally sound and that it met the criterion that were defined by the DBF guidelines. More in depth analysis came from various prototypes that gave a general model of what it would take to create a lasting aircraft. Prototype aircraft served to give a flight analysis, with most aspects being documented to make the necessary improvements. This process allowed for the creation of a final airframe design. The team's commitment to the competition and continuous effort to increase the productivity of the aircraft. Continuous effort to manufacture main components, frequent updates on a working solid model, and the loyalty of the team allowed for prototypes to be built within a time span of two to three weeks. This opened up opportunities for a multiple flight and component testing which provided necessary data and feedback to be used in furthering the next design iteration. When dealing with an aircraft, performance characteristics are heavily dependent on each other. This negatively affected the design process, in that it made it nearly impossible to increase performance in one area without affecting performance in another negatively. Many studies were performed by sizing various aspects of the aircraft. Weight was the most important factor when assessing the overall performance of the aircraft in these studies.

4.3 Aircraft Characteristics

During the gathering of ideas for the first prototype, the team focused on a design that would give us high amounts of lift while also retaining a relatively simple shape so that when production commenced, it would be easy to make many parts for the aircraft. Every decision made for the design was first run through all the members and even some of the universities faculty.

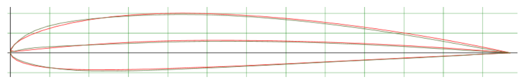

Figure 8: Projected Models of the NACA2411-IL (Green) and DF102-IL (Red)

4.4 Airfoil Selection

The airfoil is arguably the most important component to the plane. While looking for an airfoil that would satisfy our needs, the team had to take into account other characteristics that also affected the selection such as the force of drag, how stable the aircraft would be, and how much lift it would induce. Since what was needed most resembles an asymmetrical airfoil with max camber on top, it wasn't too difficult to find a suitable airfoil for this application. Either way, the use ofa website known as Airfoil Tools, which has 1629 airfoils in it's database with a chalk load of information, allowed the team to finally settle on two airfoil designs (NACA2411-IL) and (DF102-IL).

These airfoils had good characteristics of lift coefficient when compared to the angle of attack needed. The aforementioned website is also provided us a calculator which allowed the calculation needed to modify Reynold's numbers to accurately model plots which they also had on site. This is denoted by the comparison of C_l and α with a Reynold's number of 500,000, shown on the next page, in Figure 7.

As the graph indicates, at a favorable angle of attack of fifteen degrees, a lift coefficient of nearly 1.5 would occur from both airfoils, which means it will affect the take-off performance in a positive manner. Based solely on this figure, the decision was made to use the DF102-IL airfoil.

Figure 8 (on the next page) shows the C_M vs α (Moment Coeff., vs. Angle of Attack) and Figure 9 (on the next page), the C_L vs C_D (Lift Coeff. vs Drag. Coeff.), respectively. These graphs further confirmed the team's suspicions that the DF102-IL model was the most efficient one to go by. After reviewing the data on the graphs, construction began to reproduce these airfoils in the lab.

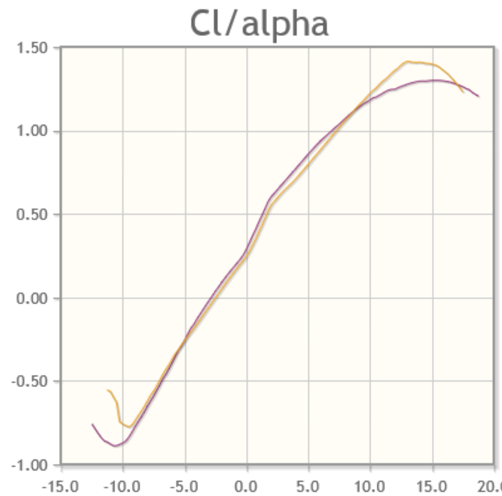

Figure 9: Projection of DF102-IL (tan) and NACA2411-IL (red) in C_l and α

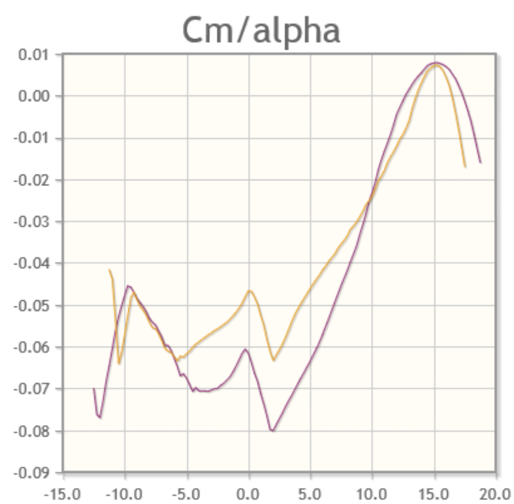

Figure 10: Projection of DF102-IL (tan) and NACA2411-IL (red) in C_m and α

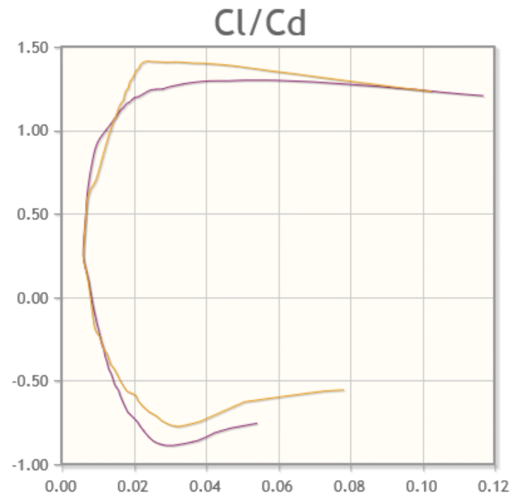

Figure 11: Projection of DF102-IL (tan) and NACA2411-IL (red) in C_L vs C_D

5 Detail Design

Table 2 displays the main dimensions of the aircraft. These dimension parameters came primarily from the prototype, specifically from the wing and fuselage structures. Table 3 contains the all the parameters that define the aerodynamics surfaces of the aircraft. These two tables give a starting point for the design process.

5.1 Dimensions and Parameters

	Length (in)	Width (in)	Height (in)
Wing	81.5	11	1.25
Aircraft	46	81.5	12

Table 2: Aircraft Dimensional Parameters

This table shows the main dimensions of the aircraft body and wing. The selection of these specific sizes was the result of both theoretical lift and testing as a result of the ability for the team to create new designs within a span of two-three weeks worth of hours.

	Airfoil	Span (in)	Chord (in)	Area (in^2)	Max Thick. (in)	Asp. Ratio
Wing	Conv. Med Camber	81.5	10.75	6.26	0.25	7.58
V Stabil.	Flat Plane	10	2.25	0.16	0.25	4.44
H Stabil.	Flat Plane	24	2.25	0.38	0.25	10.67

Table 3: Aerodynamics Surface Dimension Parameters

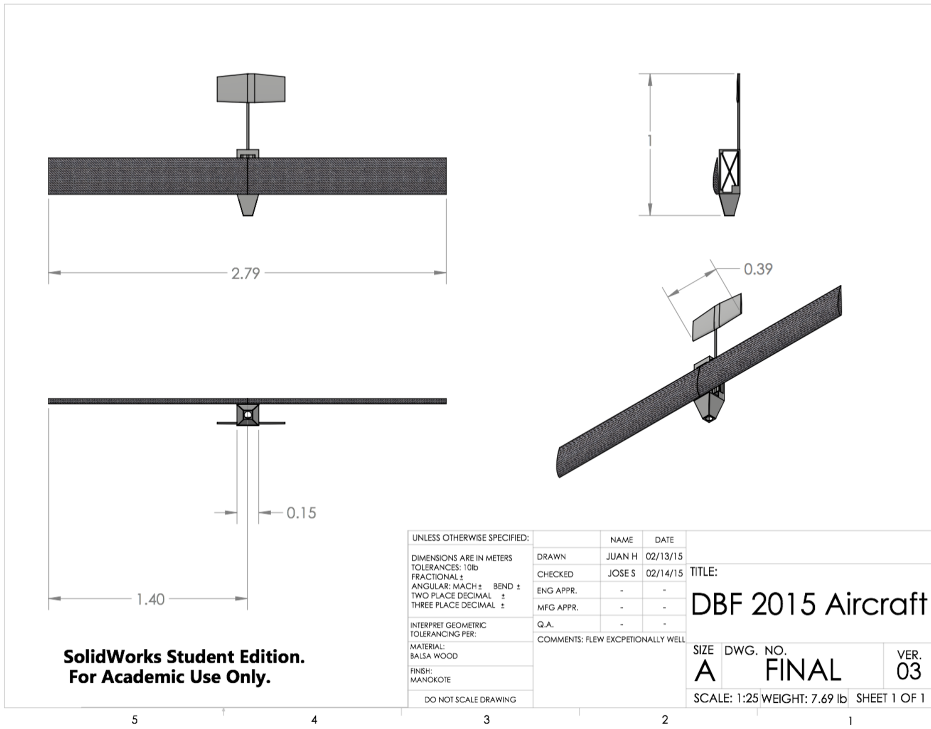

Figure 12: 3-View of the Aircraft in Solidworks

5.2 CAD Drawing Diagrams

See Figure 11. Note, the tail on this drawing is not the tail of the final aircraft. Due to time constraints, the team did not replicate the final product in this 3-view.

5.3 Structural Characteristics

During the design process the aircraft was modeled on engineering design paper and later in the SolidWorks program. There was use of a combination of physical and computational analysis for the aircraft testing for stress, strain, and bending. A combination of these two analysis was used to get a better idea of the "real life" effects that our aircraft will experience during the competition.

Even though the built-in finite analysis (FEA) tools in SolidWorks are very powerful they have some underlying flaws. SolidWorks simulation assumes that assembly of parts is continuous and therefore doesn't take into account the gluing and human error associated with such (in addition to the different weights of such materials like the glue). Depending on the quality of the gluing and and

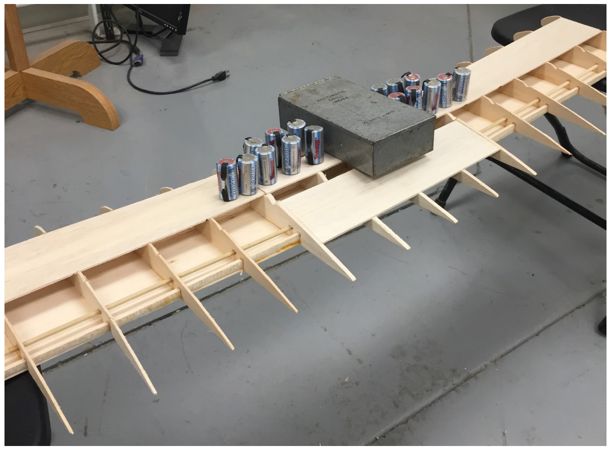

Figure 13: In-lab Wing Stress Test

cutting our expected values from FEA might be significantly off from the true value. Moreover, the team utilized a thin plastic covering of MonoKote for the wings and exterior body of the aircraft. This MonoKote cover was not incorporated in the SolidWorks simulation because it is so thin that SolidWorks won't recognize it as a solid member. Nevertheless, the SolidWork simulations were able to give an idea of the properties and aerodynamics of the aircraft.

When fully constructed and loaded the airplane weighed roughly six pounds. The wings were required to support their own weight plus the weight of the entire plane. In the physical stress analysis calculations of the maximum weight of the wings were found to be 10.068 lbs when concentrated upon the center of gravity. This was roughly five times stronger than the estimated two pound distribution load when the aircraft is in the air. This gave a great safety and confidence ratio for the construction of the final aircraft while complying with acceptable factors of safety.

See Figures 11 and 12.

5.4 Servo Selection

The servo selection was based on two criterion. The first being performance, and the second, durability. For the plane, it was decided that high speed Turnigy servos were to be used. The speed of the servo is about .13 of a second with torque of up to 3kg. The fast response time of the servo reduces input lag between the user and the plane, and it also makes the plane much more agile since it is able to react much faster to user inputs. Also, it is very important to have fast servos on planes that will be using gyroscopes, because when a

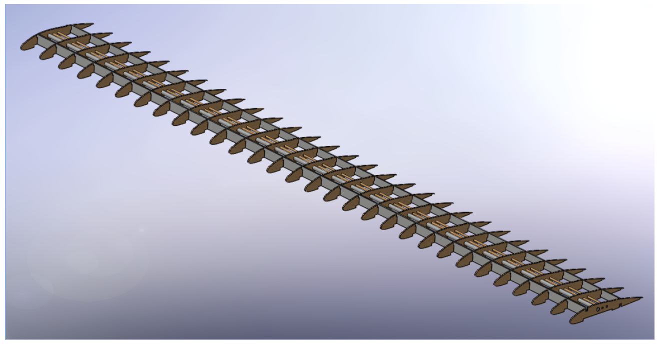

Figure 14: CAD Wing Model

gyroscope sends a command, it needs a servo to quickly react to it. The 3 kg of torque may seem like overkill to most people, but in all actuality it is not. It provides a good overhead against strong winds that can cause servos with minimum torque to stall mid air. The durability part of our selection includes going with the Turnigy brand metal gears.

Turnigy has been known to provide one of the best servos out there in the RC world, on a budget. Research has been done on the servos and they have great centering performance and hold their position with accuracy. Metal gear servos were a must when it comes to high torque applications. From the team experience, plastic geared servos usually strip out mid flight due to sudden torque increase, and also do not survive crashes such as metal geared counterparts. Plastic gears also expand and contract with temperature increase/decrease, which creates variation that we are avoiding. A consistent system is the best system, and the more efficient it becomes.

The servos proved to be more than adequate in the tests. They centered well, were fast, and survived many crashes and were still in 100 percent operation. No gears stripped during any crash. Two servos were lost during construction due to burning out. There was no proper mechanical trim applied to two aileron servos, causing them to stall trying to spend further through their range of motion while the mechanical setup itself limited them, causing the brushed motors within the servos to heat up and melt the brush contacts, essentially frying the servos. It was an important lesson, because it allowed the team to properly set the servo travel rates that do not exceed the mechanical limitation of the servos, avoiding servo stress and burnouts.

5.5 Electronic Speed Controller and BEC Selection

The selection of the electronic speed controller, was based on efficiency, features (such as Governor control, timing, PWM and data logging) and durability. The 60 Amp YEP esc was the best option based on 3 criterias. YEP has some of the best ESC capacitors on the market. Not only that, but when it comes to PWM modification, and Governor control, YEP ranks on top for all three. Their capacitors can handle high bursts of current over what they are originally rated, making them very reliable incase any electrical issues occur (the ESC will not burst into flames due to electrical resistance/backfire).

A lot of the ESCs on the market have capacitor issues resulting in ESCs bursting into flames such as Castle Creation ESC's, however YEP esc's are known not to have such issues. YEP ESC's also provide data logging (current draw and fluctuations, allowing us to find the most optimal throttle settings). Their soft start options are also one of the smoothest on the market, and the PWM control for motors is excellent. It provides a very customizable power system experience. Also they provide timing control of brushless motors, which in turn allows the team to fine tune exactly how much energy the motor should be drawing.

The YEP ESC was extremely efficient in testing. It does not gain heat which means that no energy is lost through heat, and that most of the electricity is going through to the airplane. With the ESC program card, one can easily shut off breaking functions, set the PWM/Motor frequency, and adjust the throttle range exactly how much it is needed to be. It is a very simple and easy to use ESC in this regard. It was also paired with a seperate BEC to provide power to the servos from the smaller battery pack. The BEC was rated at 3-4 amps to provide ample current flow with no risk of overheating.

5.6 Receiver Selection

For the receiver and transmitter system, it was decided that the Spectrum DX7 would be used. Spectrum is one of the most reliable and known Rx/Tx manufacturers. DX7 was chosen specifically for it's ability to use 7 channels. The need of the extra 3 channels to use as toggles for features on the plane (such as dropping the balls, switching between power modes, etc..). The receiver that was chosen was a spektrum DSMX 6CH receiver with the option to buy a satellite and hook it up to it. A satellite is an extension that functions for a receiver, allowing us to be more flexible with our electronics placement. Not only that, but most satellites function as an extra antenna, allowing a more reliable connection to be made between the receiver and the transmitter.

The DX7 also works best with DSMX receivers, since the frequency hopping feature of DSMX can be utilized by both the receiver and transmitter. Frequency hopping provides protection from any interference. Since at the day of the competition there will be many different radios present, frequency hopping will be a safe measure from any possible interference by the many radios present.

The radio and receiver combo worked perfectly. In the test flights, there were no range issues present at all. The user input was received with no lag, there were no servo jitters present and the whole system was glitch free. The servos and servo signal splitters also worked rather well with system, producing no issues. The electronic system was sound and smooth. Range tests were conducted, and the effective range was more than 500ft, more than enough for the competition to safely take place without any range worries. The transmitter provided all the flight control settings and functions that were needed, and it managed to do it with a rather simple and easy to use user interface. The only setup issue present was setting up the flaps, due to using signal wire splitters to two servos. However the issue of getting the to move the servos at the same rate was fixed with mechanical trimming and properly aligning the servos with each other perfectly, so that travel distance becomes the same.

5.7 Weight and Balance

With a 5-pound payload for the sensor package flight, and a model that weighed 6 pounds, ready to fly including all electronics and flight battery, there was a total of an 11 pound max flying weight. With 624 watts of power available, a power loading of 56 watts per pound could be available. This was more than adequate to fly the model, as long as enough wing area is present. The center of gravity will be right under the wings. This resulted in a much more maneuverable plane since the weight is directly under the plane, not producing any drag or what is known as "reaction lag". This also allowed for stable and very predictable flight characteristics.

5.8 Flight Performance

Researching Ni-MH battery cells, the 5000mah size gives the best cost efficiency as far as energy Density versus Weight and Amp-draw capacity. The battery cells used weigh about 60 grams each, and can be discharged at up to 40 amps. According to the contest rules, the battery can weigh no more than 2 pounds or 908 grams. This would allow enough weight for 12 cells, plus enough weight reserved for wire leads and a connector along with a smaller 4 cell 4200mah NIMH battery pack reserved for the electronic systems. These cells put out about 1.2 volts per cell under normal loads, so that only gives us 14.4 volts under load from a 12-cell pack. Just a bit over a 4-cell 5000mah Li-Po battery. 14.4 volts at 40 amps gives a maximum available power of 625 watts.

With a 5-pound payload for the sensor package flight, and a model that weighs 6 pounds, ready to fly including all electronics and flight battery, a 11 pound max flying weight is present. With an 11 pound maximum flying weight, we chose to go with a wing loading of about 30 ounces per square foot fully loaded. 11 pounds is 176 ounces, and 176 divided by 30 would require a wing area of approximately 5.8 square feet or 845 square inches. This airfoil performs best with aspect ratios of 10 or more, so a wing that had a 92 inch wingspan with an average chord of 9.2 inches would have the required area. Tapering the wings at the tip concentrated most of the lift to the center half of the wing, and increases the overall efficiency of the wing. A stab with approximately 15 - 18 percent of the wing area works well, and a rudder with 10 - 12 percent of the wing area is typically sufficient for good yaw control. This would give a required stab area of around 130 to 140 square inches and a rudder area of 85 to 100 square inches. A fully symmetrical airfoil with a thickness of 5 - 6 percent works well for tail surfaces. Earlier it was figured that 625 watts of power was available from the battery pack. Pulling 40 amps of current from a 5000mah pack will give about 6 minutes of full throttle flight time, and about 12 minutes of flying at 2/3 throttle during cruise flight.

5.9 Mission Performance

6 Manufacturing Plan and Processes

Throughout the conceptual design process many different materials and manufacturing techniques were considered. The goal set was to assemble the lightest aircraft possible while still fulfilling the payload requirements for the flight and landing mission sections. By considering different manufacturing options, the best option was picked to create a very light aircraft quickly and allow quick iterations of the design.

6.1 Manufacturing Process and Techniques

The manufacturing process selection is vital because it can significantly reduce the weight of the aircraft resulting in a higher flight score. The manufacturing choices available to the team were limited due to lack of equipment and capability. The two main manufacturing techniques considered for the competition were balsa wood and carbon fiber composites.

6.2 Balsa Wood

Balsa wood was the main material used in constructing the wings and tail of the airplane. Balsa wood has low density and thus lightweight, but has the best strength-to-weight ratio of any readily available material, allowing for a minimized weight for the airplane which allowed for the best power-to-weight ratio, while still being able to withstand all the stresses the aircraft will encounter. Balsa wood is also easy to work with while being relatively inexpensive, giving the best value out of the material.

Manufacturing techniques for balsa wood depend highly on its low density to attain a light structure. Balsa has a poor strength to weight ratio compared to carbon composites, but its lightweight will allow it to complete the missions in the competition more easily. Also, balsa wood is strong enough to handle the different payloads seen at the aircraft's small scale. Lastly, balsa wood is easy to work with and cheap therefore, many iterations of complex structures can be built quickly and proficiently.

6.3 Plywood

Birch plywood was the material used to construct the nose and the fuselage of the airplane. Similar to balsa wood, birch plywood is an easy to handle lightweight wood, and has a excellent strength-to-weight ratio. Plywood is a stiffer material that can be used in area where the stresses were too great for balsa wood to handle. The panel shear of plywood is double that of solid timber, allowing the fuselage to withstand the shear stress which would be faced from the landing gear and wings during flight. Because of the stiffness of plywood, the shape would not deform, and this will allow the payload to be secured without damaging the fuselage. Plywood was also used for manufacturing due to its low density. Plywood is slightly heavier than balsawood but it is also stronger. Therefore, it was used for the fuselage structure to make it more durable since the payload will be placed in it. Plywood is slightly harder to work with then balsawood but is still easy enough to work with and does not require much experience.

6.4 Carbon Fiber Composites

Carbon fiber composites have similar properties to steel with the weight of plastic. Its strength to weight ratio makes it an appealing choice. For the purposes of this competition, carbon fiber composites are stronger than necessary. This material is also more difficult to work with because a mold is required of the initial structure and for complex structures machinery is needed to place the carbon fiber over the mold to acquire the targeted shape. Due to the reasons given, carbon fiber composites were not used in the building of the aircraft.

6.5 Wing Construction

The wings were built using balsa wood which was wrapped in a layer of Monokot after construction. The airfoils were designed with an initial airfoil that was used to trace the airfoil design on the balsa wood. The airfoils were cut and fined tuned by hand with the perimeter being sanded by hand. A two piece support frame for the airfoils was built, and connected to the airfoils using superglue. A three piece shell was built, one piece on top of the airfoils, one piece at the bottom of the the wing, and another at tail of the wing, and glue to the airfoils. The wing was then Monokot all around.

The wing was built using balsawood and was then covered by a thin sheet of Monocot. Box cutters were used to cut out 1/8 in. thick airfoils. Next, a rotary sander was used to make the edges smooth. Then, more precise adjustments were made to the airfoils using a metal file. Subsequently, the airfoils were glued together using wooden glue on two long slotted pieces of wood. Lastly, the trailing edge and the top and bottom balsawood wrap supports were glued onto the wings. The trailing edge is used to ensure the shape of the airfoils remain intact. Wood glue was used to glue the joints due to its high strength and low weight. Monocot was then placed along the ribs of the wing using a hot iron. The hot iron shrinks the Monocot to guarantee a durable, tight, and even skin for the wing.

6.6 Backbone Construction

The backbone consisted of a seven foot hollow aluminum rod with holes added to it for weight reduction. Such a backbone provided simplicity, weight specifications, and strength capabilities. An aluminum rod has a tensile strength of about 500 MPa lies under the safety restrictions and performs very well for its weight per tensile strength ratio.

6.7 Fuselage Construction

The fuselage was constructed of birch plywood. The fuselage consisted of two structures, the nose and the body. The body was used to store the batteries and payload. A simple box was measured, cut, and glued together. The nose was constructed in a similar way and shaped like a pyramid. The nose was attached to the body with a latch that could be opened with the rotor placed on the tip

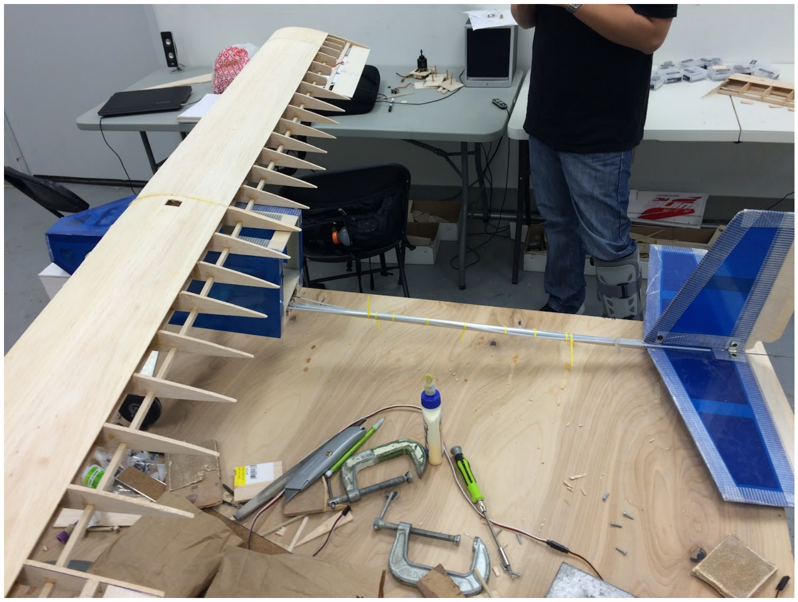

Figure 15: Wing Design in Progress

of the nose. In order to minimize weight, part of the body were removed, and were Monokoted over.

The fuselage was constructed using plywood. Plywood is light but stronger than balsawood making it an excellent choice for the construction of the fuselage. A router was used to cut four pieces of plywood precisely. The four pieces were sanded down to make the edges smooth. The four pieces of plywood were glued together using wood glue to form a box-shaped fuselage. The fuselage has a $\frac{1}{2}$ in. aluminum rod going through which attaches it to the rest of the plane. The fuselage was than completely covered in Monocot using the hot iron.

6.8 Ball Mechanism Construction

In Mission 3, several different configurations for the drop mechanism were considered. Initially, a rotating exposed housing was considered, where the balls would be held above the aluminum rod supporting the majority of the plane. This would have reduced the need for ground clearance for take-off. This was dismissed due to the weight and complexity of the design. Another design explored was a vertical launching mechanism placed on top of the plane. It would have also reduced the need for ground clearance, weighed less than the previous design, and be less complex. The idea also was dismissed due to the danger of the balls causing a catastrophic failure by hitting the tail. A similar idea with

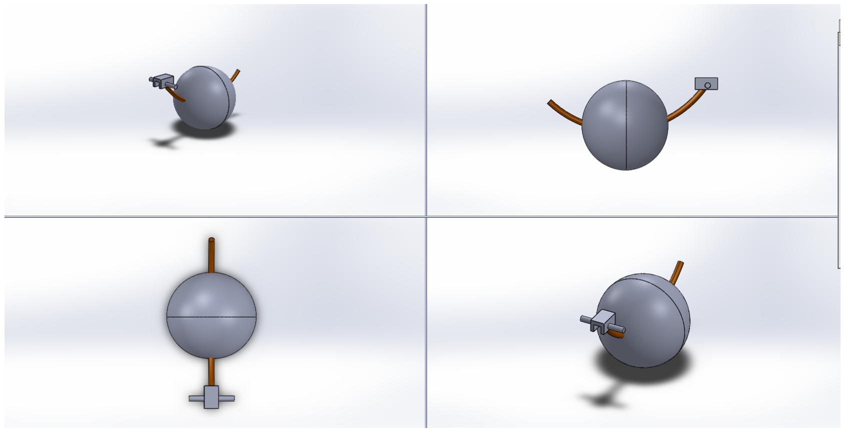

Figure 16: CAD Ball Dropper

a bottom mounted exposed cage that dropped the balls via a rotating rod.

In the end, a design that carries one ball was chosen (detailed below). The reasoning for this was its simplicity, as it only requires one channel from the controller to function, thus requiring little programming. The payload-dropping mechanism and the wiffle ball combined will be mounted underneath the plane. This is most ideal mounting location, as it does not change the center of gravity significantly, and gives clearance for the payload to drop. Any other mounting location would have resulted in increased weight due to the modifications needed or risk damaging the plane, as well as offsetting the center of gravity significantly. The ball (estimated to be about 2.4 oz) and the drop mechanism (estimated to be about 8 oz) will be aligned along the length of the plane.

The initial concept of the mechanism chosen was a hinged, curved rod that will hold the ball in place at almost any orientation while in the air. The bar would rotate via a servo connected to the rod via a metal wire similar to those used in connecting servos to control surfaces. When the bar is rotated fully downward, air drag and gravity will cause the ball to drop to the ground.

To ease assembly, some changes were made in the design of the actual real-world mechanism. Instead of one solid piece, the hinge was made from several components of readily available materials. By doing so, the construction of the hinge was made relatively simple. Small sheets of plywood of about 0.125" thickness were cut-out and measured. The two sections of plywood hold the 0.25" wood rod are held in place via a cut-out section of the main plywood board and epoxy. The length and height of the two sheets of plywood are approximately 1" x 2", respectively. The plywood rod that acts as the main rotating component measures approximately 3.125" in length.

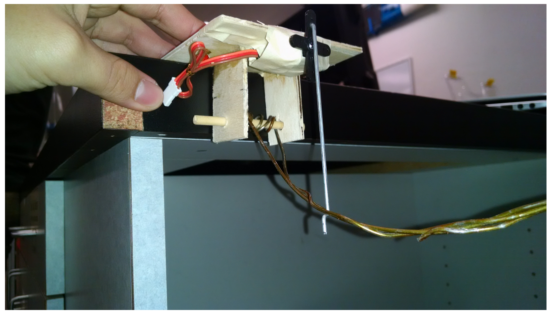

Figure 17: CAD Ball Dropper

The construction/procurement of the hinged rod proved to be somewhat labor and time intensive, so an alternative was used in its place. Hanger wire, coiled around the rod in the hinge, is used to hold the ball instead of a solid, bent rod. Hanger wire (made of steel) was chosen due to its combination of ductility, stiffness, and availability. The wire itself is held by another metal wire, connecting the hanger wire to the actuating servo. The servo is mapped to the controller and is a single function action.

The mechanism's dimensions (without the hanger wire "rod"): are as follows: 3.125"(length) x 3.75"(width) x 2.125"(height). The wire reaches out from the rotating wood rod in the hinge at a length of approximately 9 inches (measured from end of wire while bent to the hinge). The placement of the mechanism will be towards the front of the plane with the bent wire pointing towards the tail. This will allow wind to push the ball towards the end of the rod while allowing gravity to it towards the ground.

6.9 Milestone Chart

7 Testing Plan

The team maintained a consistent testing schedule. Due to the ability to rapidly prototype new design concepts, there were multiple tests conducted throughout the year. The sections below detail the capacities of the tests, as well as the how they were conducted.

7.1 Testing Schedule

Test flight schedules are assigned to be at everyday saturday of the week. During test flights, members were required to do preflight checks and make sure all electronics are properly placed in their respective positions in order to avoid loss of communication with the plane, or electronics to become loose enough to cause a crash. They then performed a hardware check to make sure that all moving mechanisms move smoothly with no interruption in their movement, to avoid a crash that may be cause due to hardware failing or restricted movement. The members are then instructed to go over the movements of the ailerons and flaps along with the rudder to make sure that no channels or movements are reversed. If any channels are reversed, our electronics team fixes the channel reverse issues. The final check is making sure all wires are properly set, tied down, and plugged, and that the batteries are fully charged and are strapped down securely.

7.2 Flight Testing

Flight tests were conducted over an area that provided a ground that was soft enough to absorb energy from a crash so that damage is kept to a minimum when and if the plane the crashes. The flight test ground that was chosen had long grass, and extremely soft dirt. Long grass allows the plane to slow down in it's crash before it hits the ground, while absorbing some of the energy before impact. The soft earth allows the plane to crash comfortably and absorbs most of the energy from the crash, keeping the damage to an extreme minimum. The take of route was by the field on a road, a deserted area in Merced, California. No people or cars were present, which made it an extremely safe area to conduct flight tests for the first time on a aircraft of this size/caliber. The pilot had a lot of room to work with, the road stretched a long distance which provided ample distance to take off and landing. The criterion for flight testing were based on three main criteria and 3 minor criterion.

The three major criterion were:

- Landing Performance
- Takeoff Performance
- Relative flight Stability

The three minor criterion are:

- Flight System Response
- Relative Flight Time
- Maximum Speed

Relative to the report, the final aircraft test were within expected ranges. It performed well when it taken to the flight system response. The servos

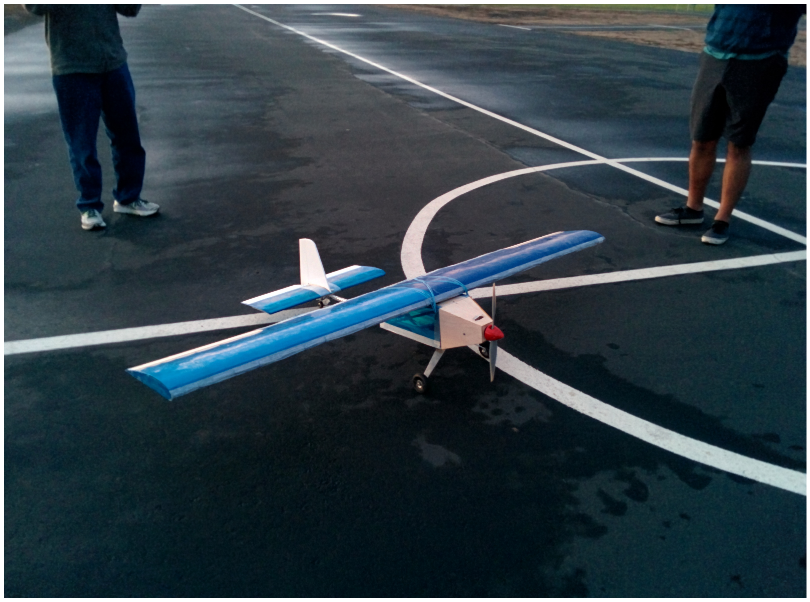

Figure 18: Flight Testing

responded quickly to user input, the transmitter had plenty of range, takeoff was smooth, and landing was smooth. Flight time was close to what was predicted, 4 minutes of full throttle flight (about a minute down from what was predicted initially in the flight performance section).

7.3 Taxiing Testing

Taxing testing was performed in the test flight area. Taxing consisted of testing how the plane handles on sharp rudder turns, and the maximum speed that the plane can handle on turns before it tips. During taxing the pilot tested tested how well the plane handles sharp turns.

There were a few tip overs that occurred due to high speed sharp turns on the rudder, but that was expected. The plane was also taxid at full throttle without any wings to make sure that all wheels are working rather well, and to make sure that even at high speed landings and takeoffs, the wheels will not come loose and that the rudder wheel can handle all the stress that is applied upon it without giving up. The plane failed a few times, however during the final run (relative to this report), the wheels were perfectly functional without any giving up. All wheel bearings were tightened up and reinforced so that no wheels can slide during take off or simply just taxing around.

Figure 19: Flight Testing

7.4 Tests Performed

Three flight tests were conducted, and are described below.

Test 1: The first test flight was conducted at a test flight field. The plane was taxid around in the field so that the pilot could acquire a proper feel of the plane handling ability and available power on tap. The plane was aligned the plane straight on the takeoff road. The road was paved smoothly with no pot holes present. When the pilot applied full throttle for take off, the plane took off straight, and then it started to bank left and crashed in the field.

The initial fuselage was designed to be the weak point of the craft so that it can save the wings and other more complicated parts of the plane that are more complex. As a result, the wings were in perfect working order. The crash was recorded for later analysis in the lab. When the video was analyzed by the electronics and airfoil team, it was determined that the ailerons were not big enough to control the plane, and there was not enough servo travel to allow the pilot to compensate for the unwanted left bank.

The second test flight was conducted in the same area, under the similar circumstances and weather. It was conducted by the same pilot to avoid any pilot error due to not flying the model before. The plane was set in the ground in preparation for takeoff. All pre-flight checks were done. The pilot applied full throttle to the plane however during takeoff the plane slide to the left and crashed into the ground before lift off. The crash was recorded and then reviewed the same day.

While reviewing the craft, the team observed loose ends on the take off system of the plane (Landing gear, rudder control wheel), and it was noticed that the front landing gear wheels had a loose bearing and the rudder control wheel rod was bent. It was then realized then that better wheel bearings must be used to prevent wheel slippage and a much thicker and reinforced rudder

Figure 20: Wing Testing

control wheel rod. It was then observed that the wings were too heavy, which resulted in a very long takeoff distance. A wing was then rebuilt with weight in mind with a better weight/strength ratio.

The third flight was the first successful flight that was attempted. The same pilot was present and area to fly in, but different weather. The winds were at approx. 15mph. After pre-flight checks the pilot applied full throttle for take off. The plane took off in a straight line without much adjustment from the pilot. It was flown for about 5 minutes on before it was landed.

The battery retained about 60 percent of its total charge, which was above expectation. The pilot provided good feedback, and according to the pilot, the aircraft was very responsive, flew rather stable, and had a good amount of power on tap.

7.5 Wing Structural Testing

The wing was held at both ends and weight was added to the center. The final design was able to hold the weight of the plane and the block along with a few more battery packs. It was determined that no further testing was required as the plane would not weigh anymore than all the weight added to it. The first design however, was tested by adding battery cells to it and broke after about 10 pounds. From this it was concluded that the first design is able to carry the weight of the plane however, it would not be able to carry the wooden block.

7.6 Backbone Structural Design

The backbone did not undergo specific testing as the weight of the tail was not very high. The aluminum rod was difficult to bend therefore it was determined it would not be a weak point. We used a thinner aluminum rod to decrease the weight however, after a small crash, the rod bent completely out of shape and it was decided that we would lighten the thicker one by drilling holes through it. Even with the holes, it still proved to be stronger than the thinner rod.

7.7 Ball Mechanism Testing

The ball mechanism, once constructed, was tested by holding it at several orientations (0, 30, 45, 75 degrees) with a blow dryer pushing air towards it to simulate flight. This was done to mechanically verify that the design will work. With the servo at rest, the ball would not fall off until oriented at approximately 100 degrees. With the servo fully actuated the ball falls off with the plane level only when drag acts upon the ball, which will be present when the plane is in actual flight. A slight electronic modification had to be made to the servo so that it could fully actuate to complete the rotation.

7.8 Propulsion Testing

The propulsion system was tested by fully charging the battery and running the motor at full power. With the first battery we chose, the motor was not functioning as expected. Then, the team obtained a different battery of higher voltage and amperage and tested again. With the second battery, the motor was very strong and provided a lot of thrust.

7.9 Motor Mounting Testing

The only test done to see if the motor mount was adequate was running the motor at full power and then inspecting the mount to see if it was damaged. The motor mount was properly secured and therefore proved to suffice.

7.10 Landing Gear Testing

To test the landing gear, the plane was simply dropped from various heights to simulate regular landing or rough landings. the plane was dropped with its takeoff weight from a maximum height of 2 ft. It was determined that 2ft was sufficient height as anything higher would most likely damage the plane and we wouldn't be landing from anything higher than 2 ft unless some sort of failure occurred.

8 Performance Results

The following section details the technical aspects of the tests conducted. All hardware information is listed according to ratings by the manufacturer, and the details involving the performance of the aircraft in flight were reported on by the members who attended the various tests.

8.1 Subsystem Performance

The Cobra motor, Turnigy servos and designed ball dropping mechanism were all tested before mounting on the plane. Once mounted and connected, the servos were tested to see if the correct servo range settings were used and if they were able to move their respective components with proper torque and speed. It was important to make sure that there was enough proper servo travel and torque to ensure that no servo stalling would occur in mid air with wind resistance present. Also, mechanical servo adjusting and trimming was necessary to ensure proper servo travel for ailerons, flaps, rudder, and elevator. This would insure that there is enough control for the pilot to move the plane as desired during flight. The electronics all work really well with each other.

There was no electronic interference between the servos and the receiver and the BEC provides ample power for the servos to function at full power. The YEP 60 ESC also provides more than enough amperage and remains very cool to the touch, which means that the electronic system was working at maximum efficiency. The receiver provided all functionality needed, the transmitter provided more than adequate range needed for the size of the airplane.

The motor remained cool to the touch which meant that there was no over amperage draw, meaning the prop is not too big for the motor size. The battery also remain cool to the touch, and with the flight times that were achieved, it shows that the electronic system was working relatively close to maximum efficiency.

8.2 Propulsion System

The propulsion system was designed to be efficient and with power on tap. It was made to draw only 600 watts on full power while providing ample thrust power. This allows for power to be present, yet efficiency to be present since not many watts are being pulled causing minimal energy to be wasted to heat. This also allows ample flight time at full throttle for the quick lap mission, and a lot of flight time to be reserved for cruising around and dropping the payload. The electronic and mechanical setup is as follows:

Looking at the motor, the Cobra 3525/12 turning an APC 14x7E prop will give the following performance numbers on 12 NiMH Cells or 14.4 volts.

- Volts – 14.4
- Amps – 40
- Watts – 570
- RPM – 7320
- Thrust – 105 ounces
- Pitch Speed – 50 MPH

Using a bigger propeller and a motor with higher torque allows the system to pull more voltage and less amps, which then in turn gives the power of lower voltage but higher current draw of systems, but with much more power efficiency. Pairing this motor up with a Yep 60 amp ESC, and using a 50 amp fuse in line with the battery to protect everything and meet the rules of the competition. This power system will get us 56 watts per pound at the highest weight condition and about 100 watts per pound for the lightly loaded and unloaded flights.

8.3 Structures

The performance of the planes structures during testing varied during stages of development. The plane was able to hold up structure in certain areas of the design and forced changes because of failures in other areas like the backbone. During testing we experienced a failure in the backbone when one of the wheels came off of the landing gear. This failure lead to a design change by increasing the thickness of the rod we were using as the backbone. Other failures included a redesign of the fuselage due to crash impact when the plane stalled under a test flight. We added in a truss like design that added support against shearing. Even after the crash the nose cone held structural integrity along with the mounts holding the motor in place.

The overall wing design held up after the crash as well and proved to be resistant against deflection under flight and loading. The final design of the tail changed slightly with a decrease the backbone distance bringing the tail closer to the fuselage. Refer to the section 3.6 for the tail configuration. This helped with balance and reduced the moment the tail presented being farther back along the backbone of the plane. The ailerons surface area was also increased to improve handling and control. With this change the structure of the ailerons held up under test flight. The landing gear was altered slightly from the original design by adding a collet with a locking screw since we experienced a failure that led to the backbone breaking as mentioned earlier. The overall design of the landing gear held up during testing and proved to be better after adding the solution just mentioned.

8.4 Aerodynamics

Observing the performance of the aircraft during the test flights, the aerodynamics in general were able to be observed.

The cone covering the shaft is a general store bought item that is already aerodynamically stable. Going on behind that the rest of the cone leading up the fuselage the motor is being fed cool air through a ram air induction section. This section helps cool the motor substantially during testing. Before the ram air was added we noticed a significant heat soak problem so adding the ram air solved that problem. This section measured in at two square inches in area.

The fuselage was constrained by the wooden block that is needed to participate in one of the missions. As a result it is cubic-rectangular in shape, however while in flight we did not notice any problem with the design of the fuselage.

The wings, as mentioned in the explanation behind the airfoil, where designed for maximum lift while at cruising speeds. The aircraft then, due to the wing design, was able to take off from the runway in less than sixty feet. Seeing as that is the major constraint for getting the aircraft into the air we saw it as a success.

Going on with the flight tests we were noticing that the tail section of the aircraft was dropping during flight. To improve the flight characteristics to a more favorable style of air stability, the horizontal tail section was improved with max lift airfoil design very similar to the main wing design. After that modification the aircraft stayed stable during all flight tests after that.

8.5 Aircraft Flight Performance

The plane on its first successful sustained flight test did well. It was able to take off while traveling at 8 mph in about 6 seconds. While in flight, the plane had sufficient rudder and elevator control from the tail. However, it was noted by the pilot noted that the ailerons did not provide enough deflection for a suitable roll rate, so they were modified with additional surface area after the test to compensate for this. The landing gear was reinforced with better bearings for this test, as it had initially caused the plane to swerve when taxing last flight test.

The aircraft performed well in flight. It remained relatively stable due to its hefty weight and has a good amount of response due to the adjustment

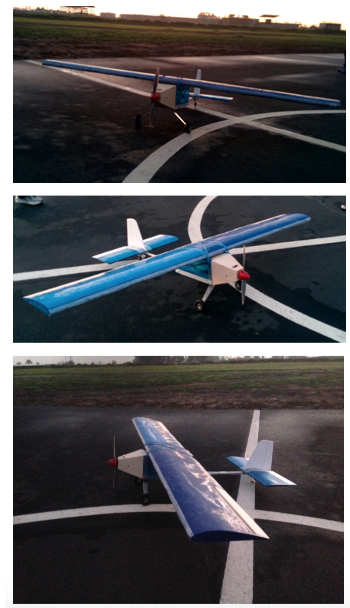

Figure 21: Aircraft 3-View after Construction

of a higher than normal servo travel rate and higher mechanical travel after flight number one. The plane flew for about 5 minutes with about 60 percent of battery capacity left. This meant that the plane has a roughly about 15 minutes of flight time capability, about the same time that was predicted, which also means that the powertrain is extremely efficient. The servos and the receiver had no notable user input lag, and the motor remained cool to the touch. The BEC had no electronic distortions which kept all electronics relatively stable, no servo jitters and the like. All electronics remained cool to the touch, which meant that all electronic systems are efficient.

8.6 Aircraft 3-View Live

The following image is a final representation of the aircraft as it stood on the report creation date. See Figure 21.