University of California, Berkeley

Airbears Team Report

AIAA Design, Build, Fly Competition

Tuesday march 1st, 2011

Contents

1.0 EXECUTIVE SUMMARY

The Airbears team is a small unit composed of eight undergraduates: two seniors, two juniors, three sophomores, and one freshman. The team's main aeronautical design experience comes from recreational RC flying. Due to the small team size and low resource budget, the airplane focuses on simplicity, affordability, and manufacturing efficiency. As such, the design combines a powerful motor with a compact body, meeting both the carrying capacity and size objectives.

A three-part 60" wingspan is stored along with the multi-sectioned fuselage in the suitcase; all parts can be assembled and deployed within a five minute time frame. The current prototype plane performs particularly well at the target objective, towing payload, and can carry up to 0.5 pounds with excellent performance and reasonable speeds of 25 mph. The flight electronic components are concentrated in the nose of the aircraft, leaving ample room directly underneath the center of lift of the aircraft which allows the aircraft to maintain stability under loading condition. The prototype of the aircraft has four control surfaces: two ailerons, an elevator, and a rudder; however, the final aircraft will forego the rudder. The added rudder for the current prototype is a safety measure in case the aircraft experiences unexpected yaw or torque-roll effects.

The prototype aircraft was constructed using readiboard foam boards for its affordability and ease of construction. The foam boards proved to be sufficiently strong to handle the amount of forces experience by the fuselage and more importantly by the wing. Furthermore, by constructing the aircraft out of foam boards the weight of the aircraft can be minimized.

Given the considerations mentioned above, the Airbears team was able to successfully construct and test fly the second prototype aircraft. The aircraft met our initial design parameters and proved to be very inexpensive to build. The following chapters of this report will detail the development of the aircraft developed specifically for the 2011 Design, Build, Fly competition.

2.0 MANAGEMENT SUMMARY

2.1 Team Management

The Airbears team is composed of three team lead and five sub-teams: Power system, Computer Aided Design (CAD), Wing, Fuselage and Tail. Each sub-team was responsible for designing and constructing its respective part under the supervision of the team lead. The composition of each group is shown in the tree structure below:

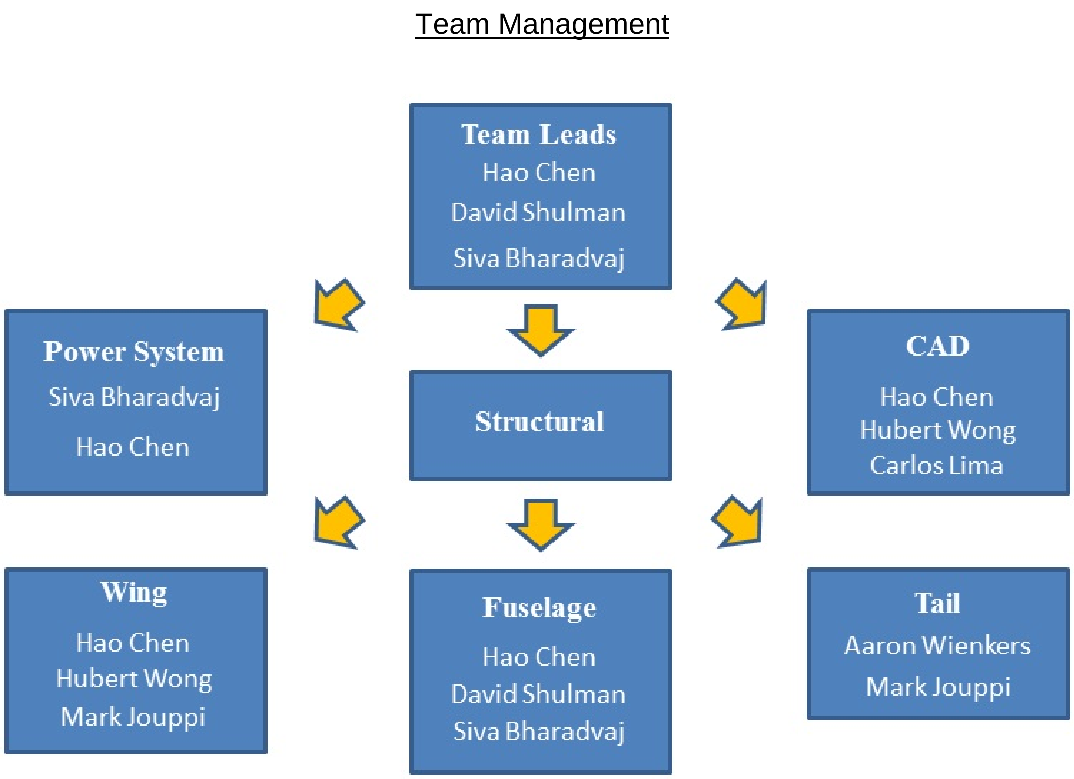


Figure 1. Team Management Tree

The team leads conducted the conceptual design of the aircraft based on a list priorities optimized for the performance parameters as well as team capability. Based on their concepts, the sub-teams performed in-depth design and analysis of their respective parts, followed by material acquisition and construction of a prototype. The Wing team was responsible for airfoil selection, actuator placement, mechanisms for rapid wing assembly, and construction. Similarly, the Tail team shared many of the same responsibilities, albeit focused on the tail section. The power system team had to determine the appropriate propeller, motor, Electronic Speed Controller, and battery combination to achieve the optimal lift vs. speed ratio for the payload and speed flight missions. The team with the most responsibility was the Fuselage team. It had to plan for the exact placement of the flight electronics, and payload (golf balls, steel plate) for the correct center of gravity while keeping the plane aerodynamic. Every sub-team utilized CAD drawings as well as common shared tools and building material to minimize construction costs and enhance the team's ability to adjust to prototype changes. Meanwhile, the team leads monitored and work closely together to ensure a smooth integration of the various sections of the aircraft.

2.2 Airbears Gantt Chart

Since the Airbears is a relatively small and inexperienced team, it was critical for the team to work with a developed schedule in mind so that the project stays on track. Therefore a Gantt chart detailing the entire development of the aircraft from design to final flight testing was created.

Airbears Gantt Chart

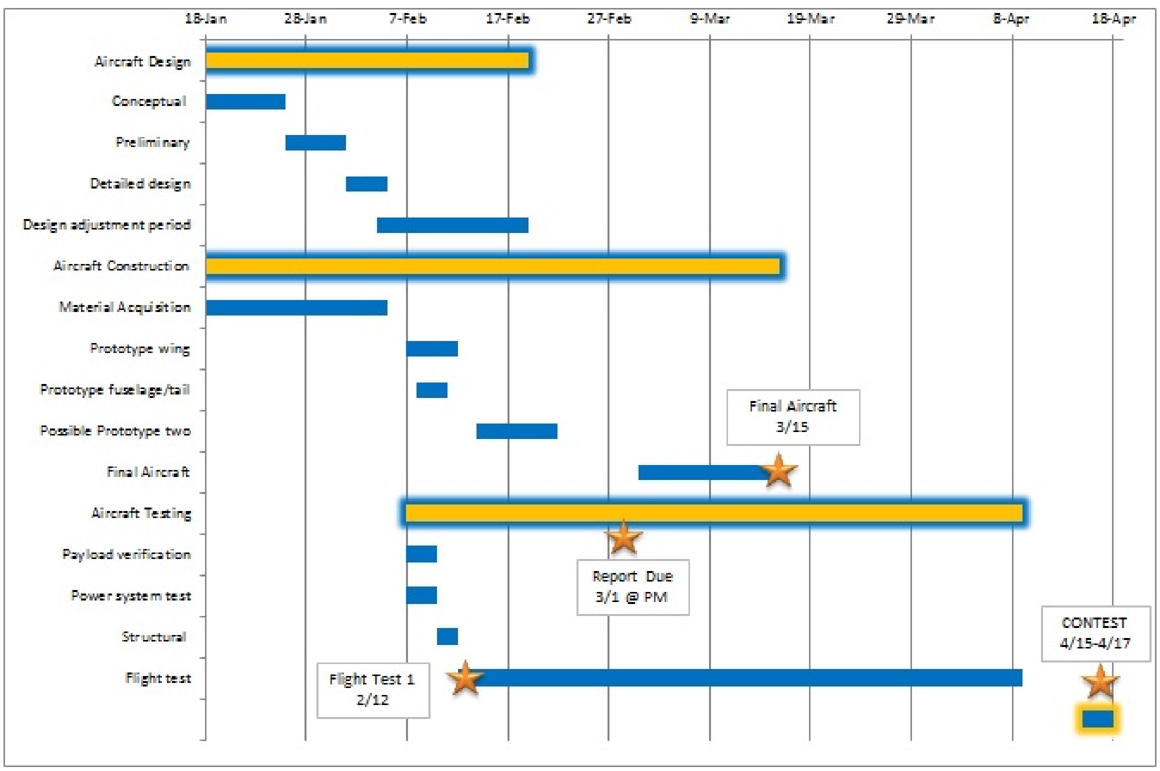


Chart 1. Aircraft Development Gantt Chart

3.0 CONCEPTUAL DESIGN

The plane design was dictated both by the size/weight restrictions and the mission requirements given in the competition guidelines.

3.1 Competition Guidelines

The competition is comprised of three missions contributing to the total score, each with different weighted values: Mission 2 is worth three times as much as Mission 1 and Mission 3 is worth twice as much as Mission 1. The total score for an individual team is shown by the equation below:

$$Total\ Score = \frac{Written\ Report\ Score * (Score_{Mission\ 1} + Score_{Mission\ 2} + Score_{Mission\ 3})}{\sqrt{Max(Empty\ Weight_{Mission\ 1}, Empty\ Weight_{Mission\ 2}, Empty\ Weight_{Mission\ 3})}}$$

In order to generate the best possible score, this equation was optimized with all exogenous variables removed, i.e. those based on the performance of other teams. Values for speed and empty weight, the latter of which was assumed to be constant, were determined by examining similar designs, as well as by taking data on several prototypes.

General Aircraft Requirements

- Battery pack(s) maximum weight limit is 3/4 lb.
- The complete UAV flight system must fit in a commercially produced suitcase meeting airline carry-on bag.
  - Carry-on must not exceed 45 linear inches as shown in diagram. No single dimension can exceed 22"
  - The case must include the complete "flight" system consisting of the aircraft, propulsion battery, and all required parts and tools to assemble a flight ready aircraft.
- All payloads must be secured sufficiently to assure safe flight without possible variation of aircraft cg during flight.
- All payloads must be carried fully internal to the aircraft mold lines.

General Mission Specifications

- Assembly/flight line crew is limited to pilot, observer and 1 ground crew who will be the assembler/launcher/retriever. The aircraft assembly must be performed by the single ground crew member as would be typical of a single soldier portable system.

- The UAV system (including pre-installed payload when flying Mission 2) will be brought to the staging box inside the carry-on bag.
- Upon entering the staging box the single ground crew member will assemble and flight check the aircraft (prior to being called to the flight line).
  - The assembly and checkout must be completed in less than 5 minutes.
  - There is no work allowed on the aircraft after the 5 minute assembly and checkout time.

Mission 1: Dash to critical target

This mission involves the plane flying as many laps as possible over a 4 minute time limit. Scoring is done by comparing all teams to each other; the team with the most laps sets the benchmark and will receive a score of 1, with all other teams receiving a fraction of that score:

$$Score_{Mission\ 1} = \frac{Number\ of\ Laps}{Maximum\ Number\ of\ Laps}$$

Mission 2: Ammo Re-Supply

This mission demands that the plane fly 3 laps with a steel bar payload of certain dimensional constraints. Although the team selects the actual dimensions of the bar, it must be a minimum of 3” wide and 4” long. This mission is scored based on individual performance; it is the ratio of the payload weight to the flight weight without resepect to other teams:

$$Score_{Mission\ 2} = \frac{Payload\ Weight}{Flight\ Weight}$$

Mission 3: Medical Supply Mission

This mission has the plane fly 3 laps once again, but this time with a payload of golf balls whose quantity is chosen by the team. As in the first mission the score is a function of all teams' performances, with the highest number of golf balls setting the perfect score:

$$Score_{Mission\ 3} = \frac{Number\ of\ Golf\ Balls}{Maximum\ Number\ of\ Golf\ Balls}$$

3.2 Design Requirements

Given both the general and specific mission requirements, some qualitative conclusions were reached about design and performance goals. Not only must the plane be quick and simple to assemble, but must also fit within a suitcase of the specified dimensions. In addition, it was necessary to maximize certain flight capabilities, as determined by the mission objectives:

- **Mission 1:** maximize speed to achieve most laps possible
- **Mission 2:** maximize carrying capacity for high-density weight
- **Mission 3:** maximize carrying capacity for low-density weight

In order to maximize the total score, several different design configurations were considered and the weights of the different missions were taken into account. Since all factors are interdependent, we decided to focus foremost on maximizing the carrying capacity of high-density weight, which means maximum structural integrity and towing thrust capacity.

3.3 Solutions, Concepts, and Configurations

3.3.1 Aircraft Configuration

Airbears started with a very clear first goal. To build a plane that could successfully fly every mission. Our early concept sketches favored a flying wing design with a compartment on top of the aircraft for loading the payload. We initially believed that a flying wing would give us a stable platform to compete from. Most of our team was inexperienced in building RC aircraft. As such, we consulted several RC hobbyists and engineers about the flying wing and learned quickly that construction of the flying wing airfoil would be more difficult that we first imagined.

After getting these expert opinions, the team leads met up to discuss the benefits and drawbacks of using the more exotic flying wing design as opposed to a conventional design. Falling back on our original goal of building a plane that would successfully compete in all missions, we settled upon a pusher prop conventional aircraft design. We sought design inspiration from existing portable UAVs such as the AeroVironment RQ-11 Raven.

3.3.2 Fuselage

To carry high-density weight, the fuselage does not have to be particularly large. Rather, it must be very structurally sound and able to handle large amounts of pressure. It must also be able to hold the weight in a central area so that the center of gravity does not set the plane off balance. In addition to strength and balancing the center of gravity, there is also a length constraint on the fuselage imposed by the size of the suitcase. For these reason, the fuselage was designed to be detachable into two pieces and minimalistic in size. When assembing the fuselage together, the front and rear pieces are joint using multiple wooden rods which also serve as rubberband pegs that hold the wing to the fuselage.

3.3.3 Wing/Tail

A few wing configurations were considered. These considerations include high wing, low wing, mid wing, bi-wing, and delta wing. The common factor that they all share is that the wing will have multiple pieces in order to maximize the lift of the aircraft. However, as easy of construction/assembly and stability are essential to our design, we opted for the high wing configuration since it offers the maximum stability and lift.

As for the design of the tail section, the team initially considered a fuselage and boom held together with a carbon pin configuration. The reason was that it allowed for easy assembly and disassembly. The team also selected the conventional perpendicular vertical/horizontal stablizer configuration. Once again, this selection was based on the fact that the team aimed at constucting the most simple yet effective aircraft for the contest. Other exotic configurations such as the T or V tail were considered. However, since the perpendicular stabilizer configuration has a proven track and the most common and easy to implement, it was selected for final implementation.

3.3.4 Power System

The power system was design using an open sourced power system combination software readily available to RC hobbyists. The power system includes the propeller, motor, speed controller, and battery. It is important to design the power system as a single entity because all of the components are interdependent. The design begins with an estimation of the final aircraft weight. After which an appropriate propeller was chosen for an given amount of thrust and pitch speed. Once the propeller is established, the power system team tracked backwards through the motor and battery selection. The speed controller selection was the most simple because of the given 20 Amp current limit.

4.0 PRELIMINARY DESIGN

4.1 Power system Trade Offs

Realizing that we could not support our original design payload with the battery current limits, we considered a new design approach starting with a “rule of thumb” for aircraft performance. This rule of thumb estimates the flying characteristics of an aircraft based on the power to weight ratio of the motor (shown in Table 1). Our team captain suggested an aircraft with trainer characteristics, so we settled on a desired power to weight ratio of 65 watts per pound. This was the basis for our preliminary design. The propeller and motor were designed appropriately using the online power system selection tool.

Table 1: General RC Aircraft flight characteristics based on power to weight ratio[1]

Watts/pound	Flight characteristics
< 50	Lightweight, slow flyers
50 – 80	Trainers, powered gliders, park flyers
80 - 120	Sport flying, basic/intermediate acrobatics
120 – 180	Serious acrobatics, pattern flyers, scale EDF jets

Given our desired flight characteristics, we were able to write an equation relating the weight of the aircraft to the power required from the battery:

$$(\text{Aircraft weight})(\text{Power to Weight ratio}) = \text{Watts} = (\text{Battery Voltage})(\text{Battery Current})$$

We then estimated the approximate weight of our aircraft: about 1 to 1.5 pounds for the plane, 0.75 pounds for the battery packs, and 1 to 1.5 pounds for the payload (the golf balls or steel bar). This settled to a maximum weight of about 3.5 pounds. Plugging this into our equation, we determined the aircraft would require 228 watts to fly as we desired. This imposed a requirement on the battery pack to be able to supply 228 watts without breaching the 20 amp current limit. This can be easily determined using an electrical power equation:

$$P = IV$$

We substituted the power requirement of 228 watts for P and a maximum current draw of 18 amps for I to find that the battery must supply at minimum an average of 12.7 volts. Noting the limitations on battery type specified in the contest rules, our team settled on NiMH batteries rather than NiCd batteries as NiMH batteries have a higher energy density per cell than NiCd batteries.

[1] http://www.rc-airplane-world.com/watts-per-pound.html

The battery chemistry of NiMH batteries provides 1.2 volts nominally per cell. Thus, at least 11 cells in series would be required to produce the 12.7 volts necessary to drive our aircraft. We searched battery pack vendors for different configurations of battery packs (weight per cell, number of cells, milliamp hours per cell, and discharge capacity). Finally, we settled on two NiMH configurations (shown in Table 2). With the voltage and power known, we were able to calculate the anticipated current draw. Then, assuming constant current draw, we calculated the approximate flight time with each battery pack.

Table 2: Theoretical battery optimization

Config. #	Number 1.2V cells	Capacity (mAh)	Aircraft Weight (lb)	Power to Weight (W/lb)	Total battery weight (lb)	Nominal voltage (V)	Current Drawn (A)	Flight Time (min)
1	11	1700	3.50	65	0.732	13.2	18.1	5.62
2	12	1500	3.50	65	0.652	14.4	16.6	5.41

Theoretically, battery configuration 2 provided 9% increased nominal voltage, 8.3% reduced current draw, and 11% reduced weight with only 4% reduced flight time as compared with configuration 1. We chose the 12 cell, 1500 mAh configuration to power our aircraft for the competition.

4.2 Airfoil

The wing sub-team considered three different airfoils. The first one is the NACA 138012; it is a good airfoil for flight up angle of attack of 10 degrees. (Figure 2) However, the difficulty with the NACA airfoil is the construction of the wing. It is unlike a flat bottom clark y airfoil and may be hard to prototype given our capabilities. As mentioned before, the clark y airfoil is also a good because of the flat bottom. However because of the flat bottom its lift coefficient and aerodynamic qualities aren't as great as the NACA 138012, but practical and sufficient for our purposes. The final airfoil considered was the MH30, which is a thinner airfoil of around 8% thickness. Although it is a thin airfoil, it has decent lift capabilities with flaps that are roughly 20% of the chord. It is good for Re= 150,000 and above which is our range. It is designed for higher speed flight b/c of its low thickness and drag-- which will be great for the speed run. Given these consideration, the prototype aircraft was built using a clark Y airfoil with a constant chord length of 8 inches since it is the easiest to construct and most practical.

Angle of Attack/ Lift Coefficient Characteristics for NACA 138012

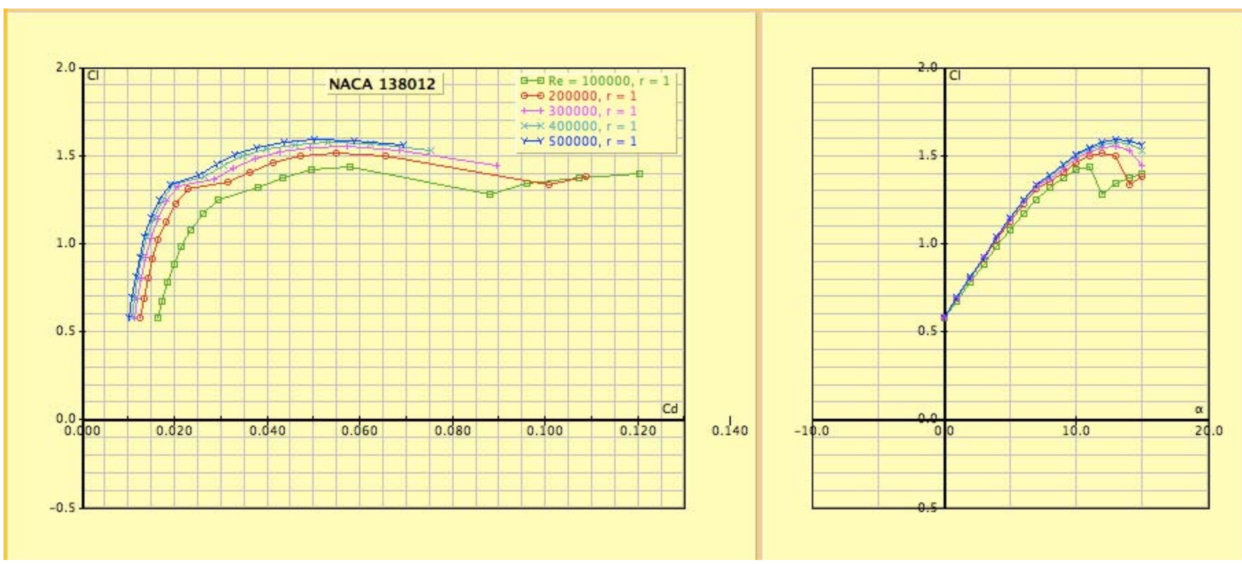
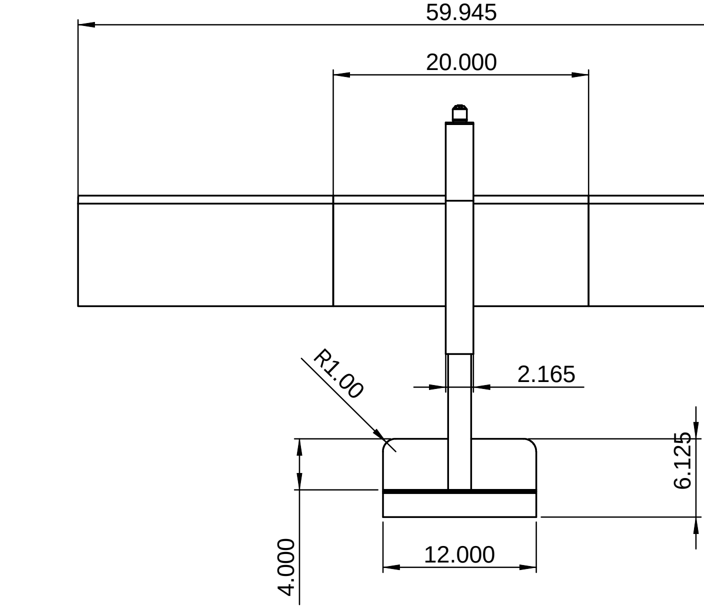
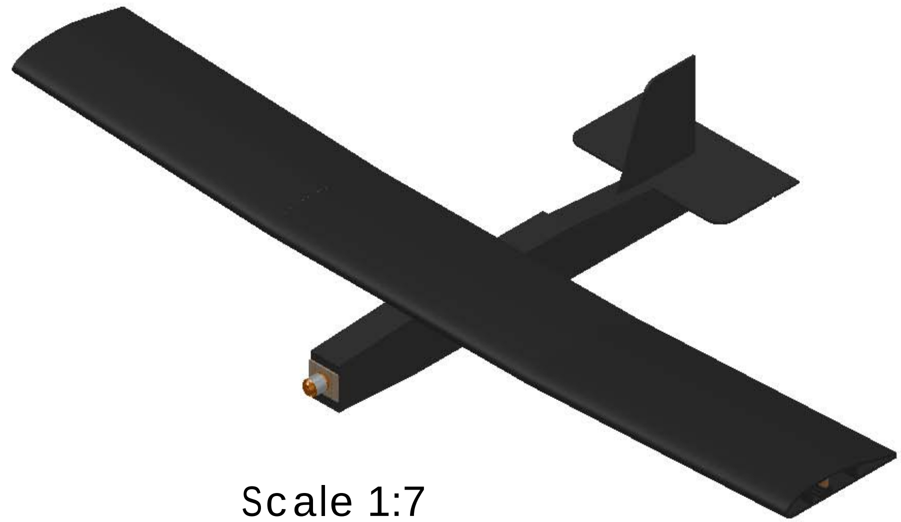


Figure 2. NACA 138012 Angle of Attack/Lift Coefficient

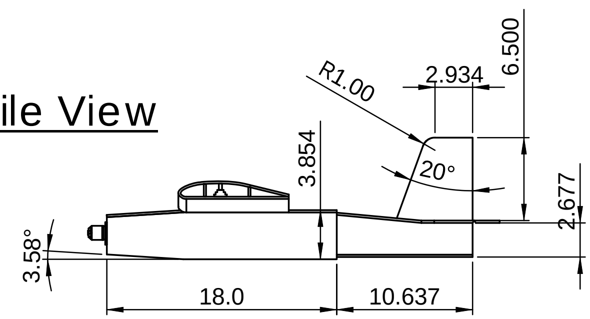
Bottom View

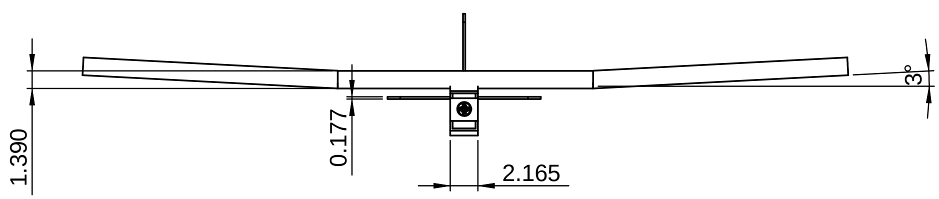




Scale 1:7
Isometric

Profile View

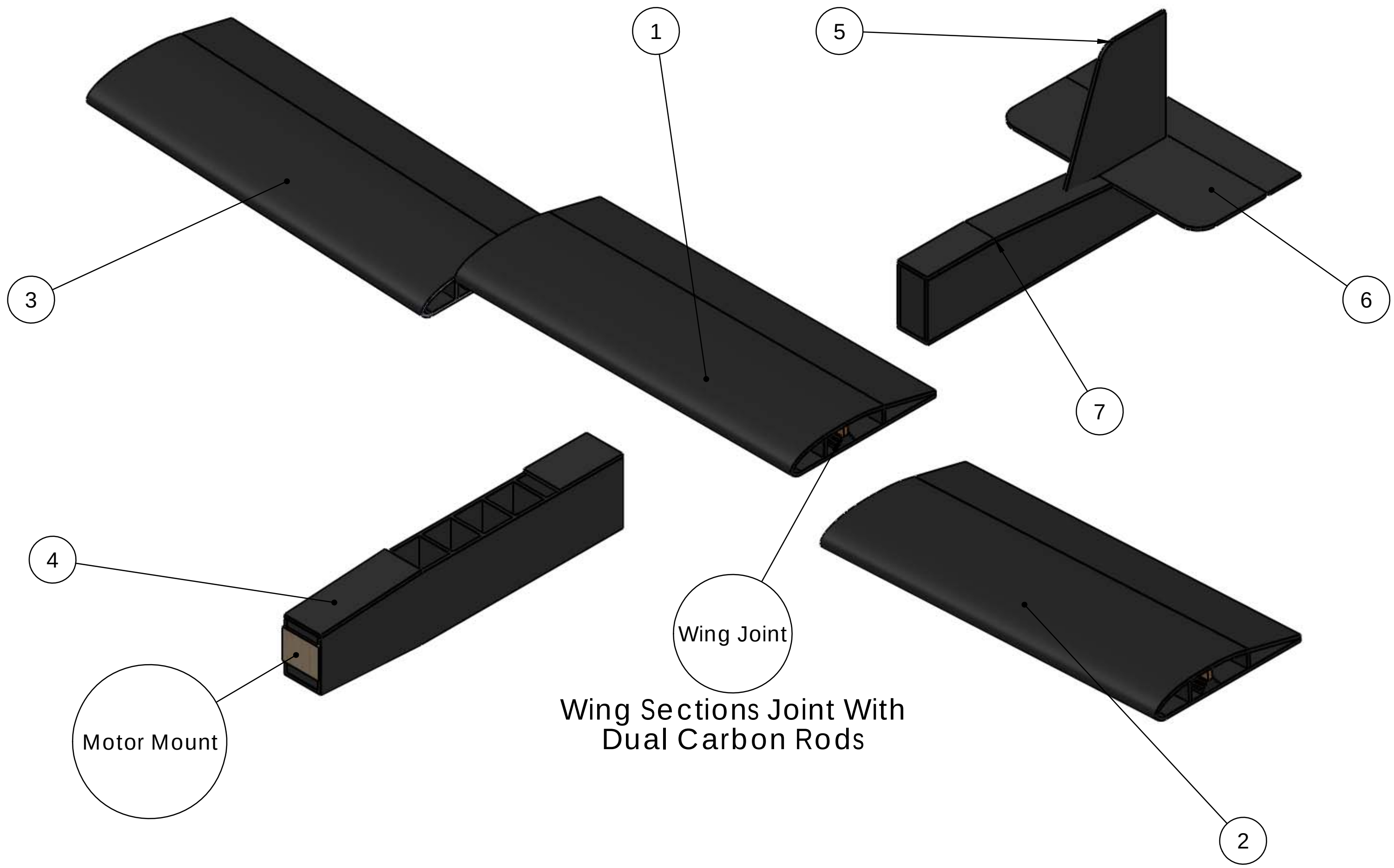




Front View

U.C. Berkeley AirBears

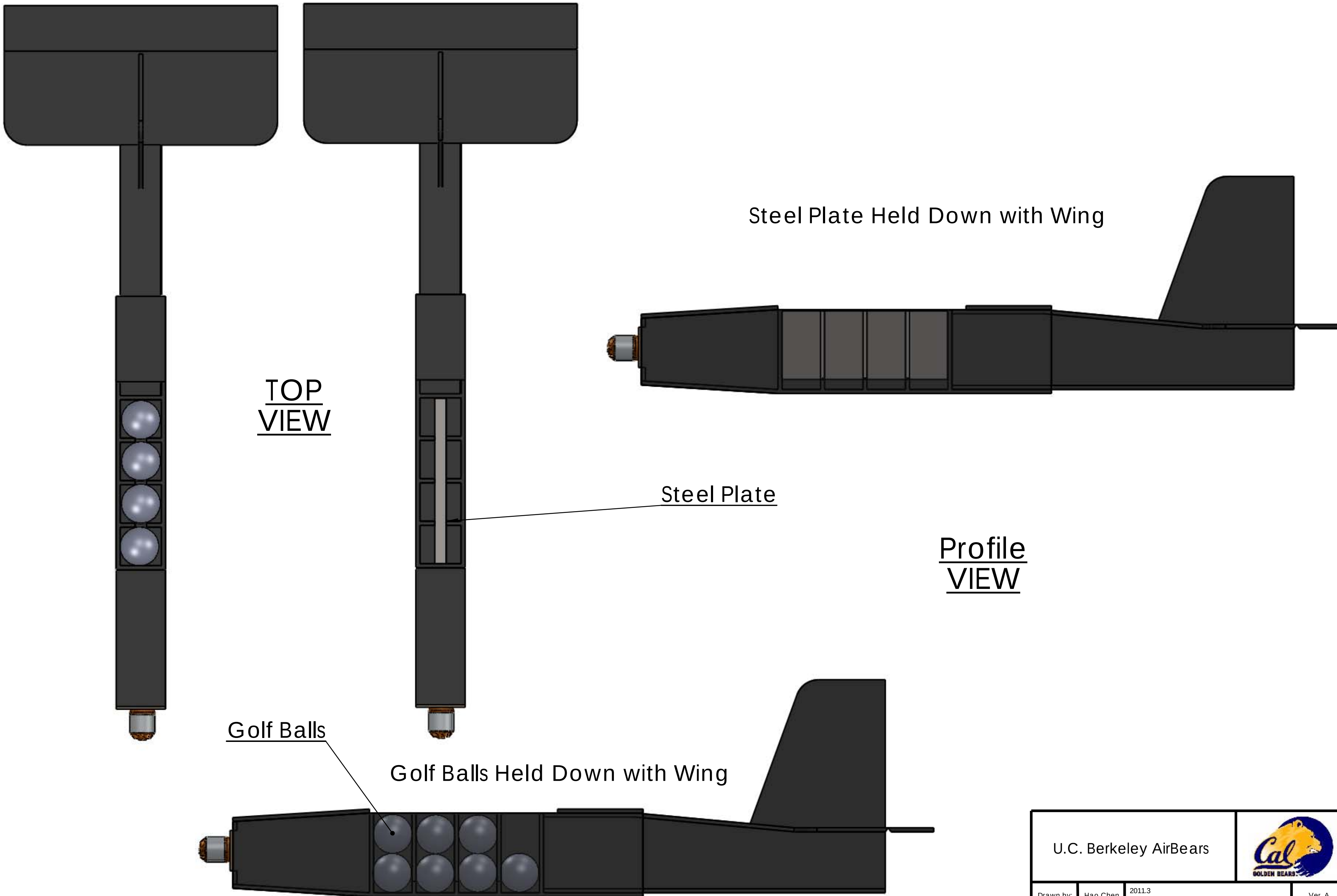
Drawn by:	Hao Chen	2011.1 Three View	Ver. A
Unless specified, all dimensions are in inches.			Third Angle
SCALE:10 Unless Specified		SHEET 1 OF 3	



Wing Sections Joint With
Dual Carbon Rods

ITEM NO.	PART NUMBER	Material	QTY.
1	wing_main	Rediboard Foam	1
2	wing panel left	Rediboard Foam	1
3	wing panel right	Rediboard Foam	1
4	fuse front portion	Rediboard Foam	1
5	Vertical Stab	Rediboard Foam	1
6	Horizontal Stab	Rediboard Foam	1
7	Fuse Rear Portion	Rediboard Foam	1
9	fuse rear portion	Rear section of the Fuselage	1

U.C. Berkeley AirBears			
Drawn by: Hao Chen	2011.2	Exploded View	Ver. A
Unless specified, all dimensions are in inches.			Third Angle
SCALE 1:10 Unless Specified		SHEET 2 OF 3	



U.C. Berkeley AirBears			
Drawn by:	Hao Chen	2011.3 Payload Strategy	Ver. A
Unless specified, all dimensions are in inches.			Third Angle
SCALE 1:4 Unless Specified		SHEET 3 OF 3	

6.0 MANUFACTURING PLAN AND PROCESSCES

One of the main goals of this project was design and construct a well performing aircraft simply. To that respect some rigidity and appearance was sacrificed and the readiboard foam board was chosen to be the main construction material. Not only is the readiboard easy to cut and sand, it is also much faster to construct because there is practically no down time for waiting for the glue to dry.

The construction material of the entire plane was mainly the readiboard readily available at Dollar Tree stores. The only parts of the aircraft that is not constructed out of the foam board are the motor mount, control horns and the wooden pegs for holding the wing down to the fuselage. Because the aircraft is constructed out of the foam board, the tools required to build this aircraft is very minimal. Tools such as X-acto knives and fabric glue were used for the majority of the build.

6.1 Fuselage

The fuselage of the prototype aircraft was constructed out of readiboard foam boards due to the material's relatively high strength for how light it is. Initially, the team considered making a balsa wood fuselage, but opted for the foam as it would lead to a faster, easier build process. After a model of the fuselage was created in Solid Works, the team marked sections of the foam to be cut out according to the specifications from the computer model. The foam sheets were cut with an x-acto knife. Fabric glue was used to attach the pieces of foam together. After one side of the fuselage is glued to the bottom of the fuselage, pieces of bulkheads were added both to strengthen and serve as compartments for holding the golf balls. Since the fuselage is a two piece design, extra precaution was taken to make sure that the rear piece fits into the front piece in a snuggly fashion. Finally, Velcro pieces were added to the interior of the fuselage to ensure that all flight electronics such as the radio receiver, speed controller, and battery do not move in flight.

6.2 Tail

We initially created the tail out of a carbon-fiber rod connected to a foam horizontal stabilizer and elevator. However, our first prototype with this design flew poorly. It is suspected that the first prototype had problems with its center of mass and torque. The tail section was redesigned and built out of foam in a process similar to how the fuselage was made. For added insurance, a rudder servo was installed in the second prototype in order to counter any adverse roll or yaw effects. The team cut out sections of foam in the tail to install servos that would control the elevator and rudder. Holes were drilled through the bulkheads of the rear portion to allow servo connector wires to reach the receiver located at the front portion of the aircraft fuselage.

6.3 Wing

The wing consists of three pieces; a center piece and two outer pieces that connect to the middle at a 3 degree dihedral (see pictures). Each piece was constructed out of the same readiboard foam material. The technique used to bend the foam to conform to the shape of the airfoil was to peel off the paper that's attached to the side of the foam that will be the inside of the wing. This allows the foam to foam smoothly over the ribs of the wing without creasing. First, the supporting ribs of the wing were cut out of foam in the shape of the airfoil. Once done, slots for the main spar (spruce wood) of each section of the wing were cut. Once the foam ribs were prepped, four pieces of 1/8th inch blasa ribs were cut for wing connection in order to house the housing of the connection rods that will be inserted in between each section to keep the wing pieces together. Once complete, the ribs (foam and wood) along with the connection rod housing were carefully glued down to each section of the wing. In the end, the foam is curved around these supporting pieces and the desired airfoil forms. After the main structure of the wing was created, ailerons had to be installed in the two outer wing pieces. Sections were cut out of the foam wing from the two extremes of the wing piece and foam structured ailerons were built out of the cutouts and reattached back onto the aircraft. A servo was installed in each outer wing piece for the aileron control. The servo wires are then routed to the interfaces of the wings and ready to be attached when the wing sections are fitted together.

The team opted to use skids for landing, which were attached to the bottom of the fuselage and on the sections of the wing closest to the ground.

7.0 TESTING PLAN

Testing began as soon as various components of the aircraft were completed. The objective of testing was to determine the operable range of loading for the structural systems, the power and heat output for the motor and battery, and the effectiveness of the control surfaces.

7.1 Structural Systems

The largest portion of the aircraft is the three piece wing, which spans 60 inches. Wing loading tests were conducted in a controlled manner by securing the wingtips and loading progressively more weight at the lift center of the wing.

7.2 Motor and Battery

Battery current draw and power was measured by running the motor detached from the plane. We also estimated the battery life by examining the charge of the battery after a known flight time.

8.0 PERFORMANCE RESULTS

The first prototype of the airplane exhibited pronounced banking problems, which were most likely due to the propeller-tail proximity. This original design was a pusher-configuration, which resulted in the tail being only 6 inches behind the motor. The fluid motion generated by the propeller blades produced a torque on the horizontal stabilizer, causing the plane to naturally bank to the right. After seeing the same problem after several testing iterations, it was decided that the design would have to be slightly modified. The main change to the aircraft was the position and direction of the motor, which was changed from pusher to tractor. Once this was done, the plane's banking problem was entirely resolved. However, another issue that emerged was the plane's pitch; it had a natural tendency to point upwards and begin stalling. After the motor was re-angled at a slight downward angle, the plane flew much better and now has good hands-free gliding characteristics.

8.1 Structural Systems

Ultimately the wing was able to support 6.5 lbs, which is roughly 3.7 g given the 1.75 lb plane weight.

8.2 Control Surfaces

The plane was observed to travel a distance of 277 feet in 12 seconds on the first run, and then the same distance in 9 seconds on the second run. It was also able to make a full turn of 20 ft diameter.

Figure 3. Prototype in Flight