CESSNA/ONR STUDENT DESIGN/BUILD/FLY COMPETITION

An AIAA Student Activity

Last update 5/25/00

1999/00 Contest Report

by Greg Page

The Fly-Off for the 1999/00 Cessna/ONR Student Design/Build/Fly competition was held the weekend of April 15-16 at Cessna Aircraft Field in Wichita, Kansas. Teams from 28 universities had aircraft in attendance. All of the teams who submitted the required written reports attended the fly-off with aircraft, a "first" for this year and a 100% increase in the number of teams flying over last year.

I'd like to extend a special welcome to our foreign entrants, two teams from Middle East Technical University in Turkey, one team from Universita' degli Studi,La Sapienza,di Roma Italy, and two teams from Queen's University in Canada. All of the teams had to contend with "typical" (ie. windy) Kansas spring weather and even a light shower on Saturday morning. Even with the changing weather conditions the flight line was never empty for more than a few minutes, as most teams made several flight attempts during the weekend.

Utah State University became our first repeat winner in the contest history, by combining their "best written-report" score of 93.88 with a moderate cost of 6.14 and exemplary flights of 15, 15 and 14 liters for a final net score of 672.72, and a check for $2500.

Second place and $1500 went to the Oklahoma State University #2, the Ditch Witch, who combined a written score of 84.84, a cost of 6.37 and flights of 14, 14 and 16 liters (the highest single flight score) for a net score of 586.09.

Third place and $1000 went to the University of Illinois with a written score of 89.50, a cost of 6.34 and flights of 12, 12 and 13 liters totaling 522.32.

The Utah State University "Best Written Report" is posted here on this web site.

Detailed scoring for the written reports, best 3 sorties flown, and final results are listed below. (Note that a "flight" score of .01 was assigned to teams who did not achieve a scoring flight simply to get Excel to rank them according to their written scores and costs. No flights "scored" at less than 1 liter flown.)

The contest would not have been the resounding success it was without the help of many people too numerous to list here. I do want to especially thank Cessna Aircraft Company and the Office of Naval Research for their financial support and the AIAA Foundation and the Academy of Model Aeronautics for their sponsorship. Special thanks go to our hosts at Cessna for volunteering their weekend time to officiate at the contest

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I'd like to once more congratulate all of this years participants and thank you for making this another successful and fun competition. Draft rules for the 2000/01 DBF competition should be up on the contest web site in less than month, so keep checking in. All of the DBF judges and sponsors thank you for your participation and look forward to seeing you again next year.

Team	Written	Cost	Flights			Total
Utah State Unavailable	93.88	6.14	15	15	14	672.72
Oklahoma State #2	84.85	6.37	14	14	16	586.09
Illinois Unavailable	89.50	6.34	13	12	12	522.32
Georgia Tech	91.67	5.40	8	8	12	475.31
Oklahoma State #1	85.75	6.01	8	10	10	399.50
San Diego	64.38	5.38	12	8	12	382.90
USC	85.88	6.15	8	8	8	335.12
Queen's #1	88.75	5.17	8	5	5	308.99
Cal Poly San Luis Obisbo	89.38	5.59	3	4	4	175.87
La Sapienza	68.00	8.60	6	6	6	142.33
West Virginia	74.88	4.83	3	3	3	139.52
VirginiaTech.	82.37	3.90	1	3		84.48
East Stroudsburg	69.53	5.30	2	2	2	78.71
United States Military Academy	63.88	5.73	2	2	3	78.03
New Mexico	60.79	6.64	2	2	4	73.24
MIT	82.06	4.58	2			35.84
Texas/Austin	82.67	10.19	2			16.23
Miami University	74.90	9.88	1			7.58
Central Florida	76.50	100.00	2			1.53
Queen's #2	82.88	4.61	0.01			0.18
Arizona	87.00	5.12	0.01			0.17
Syracuse	84.33	5.40	0.01			0.16
Cleveland State	81.50	6.62	0.01			0.12
Middle East Tech (Hazerfen)	77.45	6.43	0.01			0.12
Wichita State	77.08	7.02	0.01			0.11
Middle East Tech (ETI)	72.95	7.86	0.01			0.09
Clarkson	78.75	8.64	0.01			0.09
Buffalo	39.43	7.07	0.01			0.06

Again this year the on-site contest judges would like to recognize the efforts of all the participants by way of a number of "Special" awards, based on each teams "unique contribution" to the 1999/00 fly-off. This years judges special awards, in no particular order, are:

2000 ONR/Cessna/AIAA Foundation Design/Build/Fly

Special Awards

In order of the random draw

University of Illinois: Best Scale Award for modeling a CG4 World War II Troop Transport Glider.

METU/Hazerfen - Anatolian-Craft: Sponsors Heritage Award for the best imitation of a Cessna 170.

University of California, San Diego: Heritage Award, Jet Division, for the best imitation of a ME-262.

Cleveland State University: Life above the sea Award for teaching a manta ray to fly.

University of Buffalo: Truth in labeling Award for a plane that flew like its name, i.e. like a buffalo. It meandered off the runway and layed down on the prairie.

University of Arizona: The Borg-Warner Award for fatigue testing gear boxes.

Georgia Institute of Technology: Truth in Labeling Award # 2 for their name - Plan B.

Massachusetts Institute of Technology: Green Peace Award for finding a way to produce air pollution with an Electric motor.

University of Texas at Austin: Navy Carrier Arrival Award for meeting the runway with the greatest vertical speed.

METU/ETI: Rebuilder Award for the greatest number of major rebuilds in a single competition. Presented with an Alchemy citation for turning a large part of their red airplane into silver while turning a large part of their sponsor's gold into splinters.

Oklahoma State University # 2: The What's in a Name? Award for keeping the Ditch Witch out of the ditch - this year.

Cal Poly San Luis Obispo: The NASCAR Award for the most decals on a tail.

University of Central Florida: The Government Procurement Award for the highest rated cost.

University of Southern California: The Heritage Award, propeller division, for the best impression of a Gee Bee Racer.

Clarkson University: The Aeroelasticity Award for the best demonstration of a previously unknown degree of freedom in flight.

Universita' degli Studi, La Sapienza, di Roma: The Vida, Vida, Vida Award for the most enthusiastic signal of time to turn.

East Stroudsburg University: The Dual Mission Award for combining the characteristics of an F-18 and a Caribou.

Miami University: The Sidewinder Award for maintaining the greatest angle between the longitudinal axis of the airplane and the flight path.

Wichita State University: The Norm Abramson Award for the best display of precision woodwork.

West Virginia University: The Twiggie Award for the most anorexic body for their entry, "Wing on a Stick".

Oklahoma State University: The State Farm Good Neighbor Award for intentionally crashing their plane rather than endangering the spectators.

Utah State University: The Humble Pie Award for making the contest organizers eat their words about "No Repeat Winners".

New Mexico: The Lucy in the Sky Award for the best flying diamond.

Combined Queens # 1 and # 2: The Wake the Dead Award for the loudest hotel party.

Virginia Polytechnic and State University: The Training Flight Award for a good takeoff followed by a landing and a landing and a landing and a landing .... with a special Kangaroo Citation for the highest hop.

United States Military Academy: The Colorblindness Award for steadfastly maintaining that their orange airplane was a Grey Hog.

Syracuse University: The Hoover Award for the best vacuum cleaner with special notice of the most spectacular explosion of an impeller.

Queen's University # 1: The Restraint Award for confining all their 360 degree turns to the horizontal plane rather than the vertical plane this year.

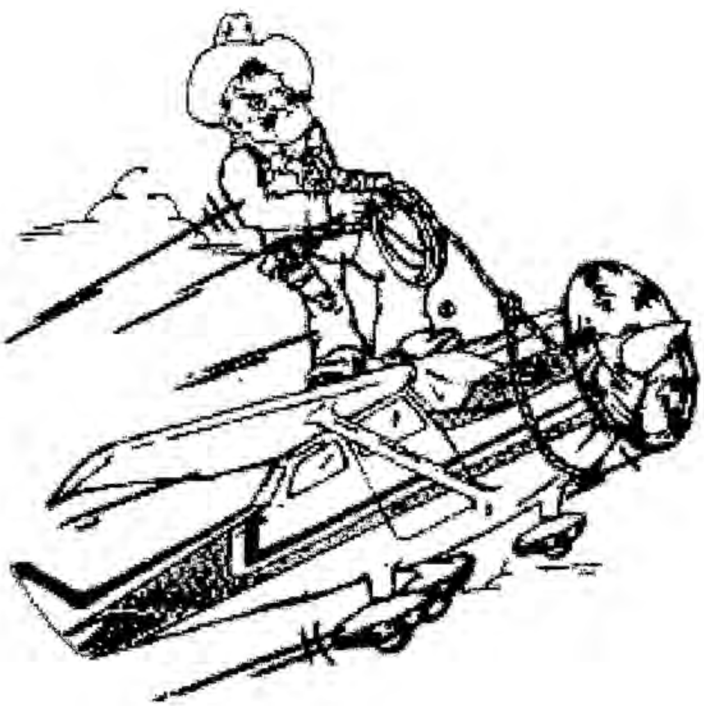
Queen's University # 2: The Poulan Weed Eater Award for trimming the greatest area of Kansas prairie with a propeller.

And finally,

Chris Bovais: The Greatest Ratio of Bladder to Brain as evidences by his ability to stand on the flight line all day with only one short potty break.

Cessna/ONR Student Design/Build/Fly Competition

OSU Team #2
Flight Factory



Design Report – Addendum Phase

Oklahoma State University
April 10, 2000

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1. Lessons Learned

1.1 Prototype Testing

Over the past few weeks since the proposal phase the OSU Flight Factory was able to test fly our prototype aircraft. This proved to be highly beneficial for verifying the performance characteristics of our design and providing the data needed to modify our design to be as competitive as possible for the contest.

1.1.1 Taxi Test

Our first test was a taxi test in a large parking lot. This was done to check the propulsion system while in the aircraft as well as the ground handling characteristics. This taxi test showed that the steering worked extremely well, but pulled a little to the left. The aircraft's wide main gear spacing allowed it to be turned at high speeds without any worry of tipping the plane. The nose wheel brake did not work as well as expected. While the stopping power of the brake was excellent, the hydraulic system was not setup correctly to give both free spinning and full stopping modes.

1.1.2 First Test Flight

Our first test flight was conducted on Friday March 24th at the Ditch Witch facility in Perry, Oklahoma. The runway at Ditch Witch is paved and will most likely simulate the contest site. We began by conducting a complete pre-flight inspection of the aircraft. Once all controls and components were checked, the motor was run up to verify the correct installation and operation of the propulsion systems. The first test flight was performed without payload and a take-off weight of 25.5 pounds. The test pilot, pointed the aircraft into the wind and accelerated to take-off speed. The aircraft accelerated slower than expected and took off in over 100 feet. The aircraft slowly climbed for about 5 seconds at full power and then began to sink. Since is was apparent that the aircraft would not fly, the pilot set the plane down in a nearby field. Due to the lack to climbing ability the plane came down rather hard and broke the bottom wing loose from the fuselage.

After studying the flight video and noticing the nose high characteristics of the airplane, additional wing calculations were performed to determined that the wing incidence angles were about 6 degrees too low. From the acceleration characteristics of the first test flight the Flight Factory also chose to increase the thrust for the next test flight by increasing the propeller diameter.

1.1.3 Second Test Flight

After the repairs and corrections were made the OSU Flight Factory was ready to fly again. This second test flight was much more successful than the first. With the corrected incidence angle and increased power the aircraft took off in 72 feet and climbed very well. The pilot spent the remainder of this flight trimming the control surfaces to achieve straight and level flight. The pilot found that once the aircraft was properly trimmed it was a little sluggish in the roll mode, but otherwise flew very well. A picture from this flight is seen in Figure 1.1.

1.1.4 Third Test Flight

The third test flight was used to simulate contest missions, check battery endurance, and determine sortie times for the loaded and unloaded configurations. The Flight Factory placed 2 liters of water in the aircraft and setup the contest flight course. Due to the increase in power, it was expected that the endurance would drop well below the endurance needed to complete 3 scoring sorties. The aircraft took off with 2 liters, take-off weight of 29.9 pounds, in 85 feet. The pilot had no problem turning around the pylons or performing the 360 degree turn. The flight time for this sortie was 75 seconds, which is very close to what the Flight Factory had predicted. Then the payload was removed from the aircraft and 2 empty laps were flown without incident in a time of 134 seconds. During the second scoring sortie it became apparent that the battery power was dwindling and the pilot chose to make the final turn a few hundred feet short in order to get the plane back to the runway before batteries gave out. The total flight time for this mission was 3 minutes 35 seconds.

Next, a fully charged battery pack was placed in the plane and a payload of 3 liters was added. Since a 2 liter payload was unable to make 2 scoring sorties, only 1 scoring sortie and 1 empty sortie was attempted. The airplane took-off within 100 feet and flew as expected. A summary of Lessons Learned from the prototype aircraft is found in Table 1.1.

1.2 Final Contest Aircraft versus Proposal Design

1.2.1 Aerodynamics and Configuration Group

Knowing the flight characteristics of the prototype aircraft the aerodynamics group was able to make a few minor corrections final contest aircraft. The results of the first test flight caused an inspection of the airfoil characteristics due to the lack of climbing ability and nose high flight pattern. The bottom wing for the first test flight was mounted at negative 3 degrees. After additional research it was discovered that the current wing incidence was creating a large amount of drag during take-off and causing the plane to cruise nose up. Setting the bottom wing incidence at plus 3 degrees would significantly reduce drag and allow the aircraft to take-off more readily.

Additional analysis of the decalage also revealed the top wing's incidence should be one degree less than the bottom instead of one degree more. The prototype had a decalage of plus 1 degree to the bottom wing and was causing uneven lift distribution between the top and bottom wing. Since the top wing's angle of attack was too high with respect to the bottom wing, the top wing was carrying more than half the lifting load. This uneven - distribution causes inefficient wing operation. This problem was corrected by having a decalage of negative 1 on the final contest aircraft.

The Flight Factory discovered that to achieve proper CG location the fuselage needed to be slightly longer since the prototype was tail heavy. This increase in fuselage area in front of the CG would create instability in yaw direction. Thus, the vertical tail area was increased by making it 2.5 inches taller. The prototype was not unstable in yaw, but the slight increase in drag of a larger tail was worth the risk of instability.

The flight test showed that the aircraft had no problem pitching up or down, but needed full elevator deflection to do so. The aerodynamics team was worried that in a dive there would be a lack of tail volume, so the elevator chord was increased from 1.5 inches to 2.5 inches.

1.2.2 Propulsion Group

The actual performance data of the propulsion system came exceptionally close to the estimated values of the various desired propulsion parameters. The *Excel* spreadsheet and *MathCad* documents used to calculate such outputs as thrust, RPM and endurance were remarkably accurate at estimating such values given a specific battery pack, motor and propeller. However, even though the initial propulsion system performed in the manner that was it was designed, the selected Astro-Flight Cobalt 640 motor was unable to handle the increased power output needed at a lowered endurance level. The Astro-Flight Cobalt 640 was simply inadequate to handle the load. Consequently, the Astro-Flight Cobalt 661 motor was chosen to take the 640's place on the contest plane. This modification suitably matched the power requirements needed for our efficiency and load handling.

As a consequence of using another motor, a different propeller that matched these changing parameters was needed to power the plane. The chosen propeller was a 20 x 12 prop with hollow blades fabricated from unidirectional and bi-directional carbon fiber and epoxy. This preference was selected due to its high performance in addition to its lightweight and strength.

1.2.3 Structures Group

After the flight tests, the structures group determined that the aircraft was extremely strong and durable because of the carbon fiber construction methods. This was proven by the easy repair of the aircraft after the crash during the first test flight. Knowing that every pound taken out of the airplane structure would increase our payload capacity as well as decrease Rated Aircraft Cost (RAC), the structures group made number of construction method changes to reduce the empty weight of the aircraft. In addition to weight savings, their were a couple of configuration changes to various parts of the aircraft to optimize overall performance.

Wing:
The carbon fiber used on the prototype airplane had a 'wet' side and a 'dry' side. The dry side needed an additional layer of adhesive to prevent the carbon fiber from becoming starved for resin. A new type of carbon fiber was found that does not require this layer of adhesive and will save a significant amount of weight on the wings of the final contest aircraft.

Fuselage:
The honeycomb used between the layers of carbon fiber in the prototype fuselage was replaced with a foam core for the final aircraft. Due to the nature of honeycomb, a layer of adhesive must be used between the honeycomb and carbon fiber regardless of the type of carbon fiber used. Once again, this was additional weight in the fuselage that could be taken out by changing to a different material. While the honeycomb was stronger, the foam core

should be sufficiently strong to do the job. The sides of the fuselage and the bulkheads contained a foam core, while the bottom of the fuselage was 2 layers of carbon fiber. This method proved easier than attempting to bend the foam core from the sides to the bottom of the fuselage since the blue foam tends to break when bent around a sharp corner.

The fuselage for the final contest aircraft was initially made about 1 foot longer than necessary. Since center of gravity (CG) needed to be properly located with in the fuselage, this gave the Flight Factory the flexibility of assembling all critical components of the aircraft and then cutting the fuselage to length for correct CG and payload location. Calculations for this length were performed for the prototype, but the lack of exact manufacturing techniques prevented the aircraft balance from being perfect. This new method will allow the exact fuselage length to be found.

Since the new contest strategy was to perform only two scoring sorties, this meant the availability of more power over a shorter period of time that could be delivered by the motor. This increase in power would allow the aircraft to carry more weight than the prototype. Taking this into consideration, the fuselage was designed to carry 6 liters of water, with the capability of adding a 7th liter in case the aircraft was able. The sixth bottle would lay horizontally atop the bottom wing. The seventh bottle would lay atop the sixth bottle, but would stick out above the top of the fuselage. Another set of fuselage lids was manufactured to fare the seventh bottle inside the fuselage, and would be placed on the plane in a time of need.

Stabilizers:

Since white foam is approximately half the density of blue foam, the horizontal and vertical stabilizers were made from white foam instead of blue foam on the final contest aircraft. The prototype tail section proved to be over designed on strength and was also tail heavy. Switching to white foam not only reduced the overall weight of the aircraft, but helped correct the tail heavy tendencies of the prototype.

End Struts:

The end struts were modified to fit the new incidence angles of the wings. Since the end struts are the supporting members for the top wing, the angle at which they attach to the wings determines the decalage. Also, the kevlar on the outside of the end struts was trimmed from covering the entire outside, to just a strip matching up with the top and bottom wings. These strips of kevlar provide a very durable surface for the wing bolts to attach through the end struts to the wings.

Center Strut:

While performing a wing lift load of our prototype aircraft at full weight, it was determined that the top wing may not be strong enough under a high g-loading. Thus, a center strut made from a single steel wire was added to the center of the top wing. This wire was very lightweight and would transfer the force of the lifting load on the top wing into the bottom of the fuselage, where the wire was attached.

Motor Mount:

The overall size and shape of the motor mount performed in a desirable fashion. However, we found that the motor produced more vibration than expected so the motor was attached to the aluminum mount through a piece of rubber on each side. The prototype had the motor mount attached with rubber to the fuselage, but not the motor to the mount.

Landing Gear:

The rubber wheels used on the prototype aircraft proved to have too much rolling resistance. For this reason roller blade wheels were chosen for the main gear of the final aircraft. The harder roller blade wheels will reduce ground friction and decrease take-off distance.

The shoe in the nose wheel brake was given 2 O-Rings instead of one, which helped seal the hydraulic fluid inside the brake system and increased braking power. A bleed screw was added to the brake system to aid in the removal of unwanted air from the hydraulic line. Additionally, the prototype nose gear was prone to bend during a hard landing. In order to strengthen the nose gear, the diameter of the aluminum shaft was increased. A side view of the final aircraft can be found in Figure 1.2.

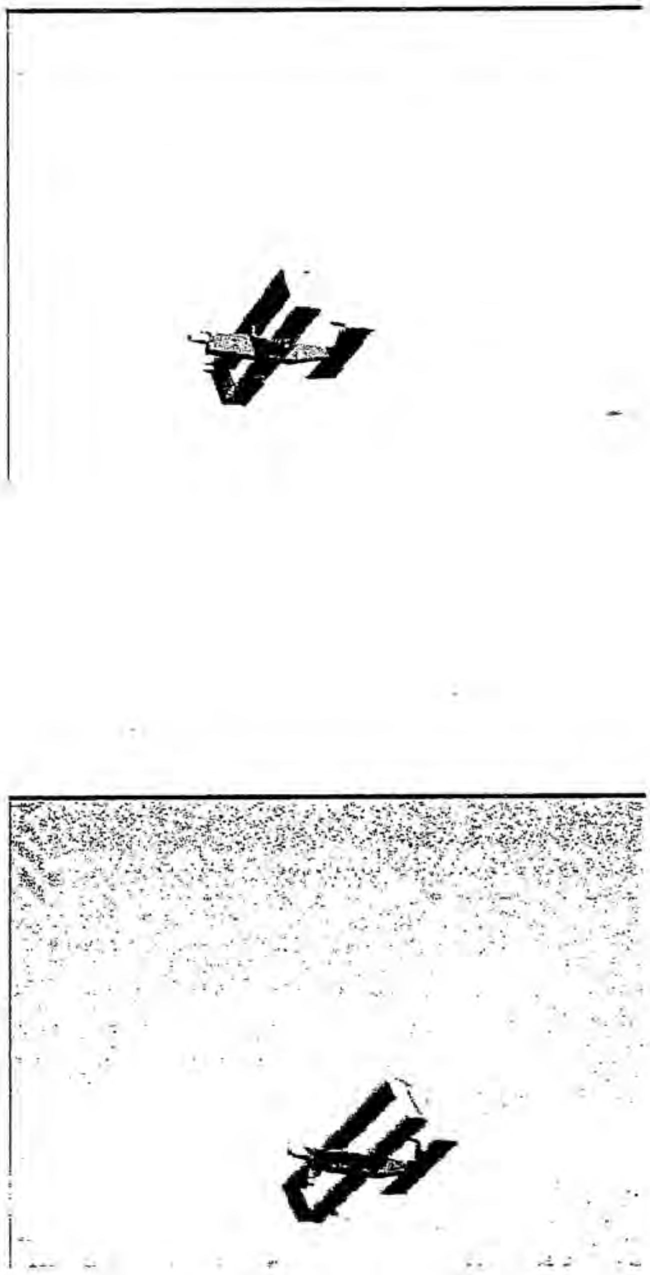


Figure 1.1: Prototype First Successful Flight

LESSONS LEARNED

	Prototype Test	Rating	Problem Description	Proposed Solution
Taxi :	Steering	Very Good	None	None
	Braking	Fair	Insufficient stopping power	Fix brake shoe
Flight 1:	Take-Off	Poor	Over 100 feet	Adjust Wing Incidence & Increase Power
	Climb	Poor	Did not climb	Increase Power
	Turn Left	-	-	-
	Turn Right	-	-	-
	Straight & Level Flight	-	-	-
	Descent	-	-	-
	Landing	-	-	-
	Sortie Flight Time	-	-	-
	Power	Poor	Insufficient Power	Increase Propeller diameter
Flight 2:	Take-Off	Very Good	None	None
	Climb	Very Good	None	None
	Turn Left	Fair	Insufficient Roll Power	Increase Aileron size
	Turn Right	Fair	Insufficient Roll Power	Increase Aileron size
	Straight & Level Flight	Good	None	None
	Descent	Good	None	None
	Landing	Good	None	None
	Sortie Flight Time	-	-	-
	Power	Very Good	None	None
Flight 3:	Take-Off	Very Good	None	None
	Climb	Very Good	None	None
	Turn Left	Fair	Insufficient Roll Power	Increase Aileron size
	Turn Right	Fair	Insufficient Roll Power	Increase Aileron size
	Straight & Level Flight	Very Good	None	None
	Descent	Good	None	None
	Landing	Good	None	None
	Sortie Flight Time	Very Good	None	None
	Power	Very Good	None	None

Table 1.1 - Summary of Lessons Learned from Prototype aircraft

2. Aircraft Cost

2.1 Final Competition Rated Aircraft Cost

The rated aircraft cost for the final competition aircraft is very important since it directly affects the score. To achieve the highest overall score the Flight Factory attempted to reduce RAC while reaping a high flight score.

Initially the Flight Factory planned on three, five liter scoring sorties within each ten minute mission. After flight testing it became apparent that our design needed too much power to achieve the endurance needed for three scoring sorties. At this point the strategy was to perform 2 scoring sorties with as much payload as possible. The wing area was left the same since increasing it would penalize our RAC. Instead more power was added to lift the extra weight without any more wing area. This power was delivered by increasing the propeller diameter since this did not hurt the RAC.

The final competition aircraft has two wings, each with a chord of .92 feet and a span of 6.98 feet. This results in a total wing area of 12.84 square feet. Since this area is distributed over 2 wings, the RAC receives a penalty of $100 dollars. Inlcuding both wings at $200 and the wing area at $1027.2, the total RAC for the wings is $1227.20.

The single fuselage is 5.83 feet long with one horizontal and one vertical stabilizer. With a cost penalty of $100 per fuselage and $80 per foot, the final RAC for the fuselage is 566.40. The vertical stabilizer cost $100 and the horizontal costs $200. There is also a basic charge of $100 for the tail section. This results in a combined RAC for the fuselage and tail section of $966.40

The propulsion system consists of 1 motor, 1 propeller and 36 battery cells. The motor and the propeller each cost $100 dollars for a propulsion system RAC of $200. The cells have an RAC of $60 a each, for a total battery pack RAC of $2160. The propulsion battery pack is by far the most expensive component of our aircraft in terms of RAC.

The aircraft control system uses 6 servos to control all operations of the airplane. There is a servo for each aileron, one for the elevator, one for the rudder, one for brakes, and another for steering. Each servo has a RAC of $20 and the flight systems have basic charge of $100. This results in a total flight systems RAC of $220.

All components together, excluding the payload and propulsion batteries, weigh 15.1 pounds. At $100 per pound, the cost for the aircraft empty weight is $1510. When these parameters are applied to the Rated Aircraft Cost calculation, the OSU Flight Factory's final competition aircraft RAC is $6.2836(thousands).

A complete breakdown and calculation of the final competition aircraft's RAC is found in Table 2.1. A breakdown of Rated Aircraft Cost for each of the airframe dependant parameters is found in Figure 2.1. As seen in the figure, the number of cells, aircraft empty weight, and the wing area make of 77% of the total RAC. Keeping the wing area low decreased the cost in 2 ways. There is a direct penalty for wing area, and the smaller wings have less weight.

The Flight Factory feels that this is a competitive RAC for the amount of payload the airplane is capable of ferrying during a 10 minute mission.

RATED AIRCRAFT COST

Airframe Dependent Parameters

# cells= 36	Projected Wing Area (sq. ft.)= 12.84
# engines= 1	Length of fuselage (ft)= 5.83
# propellers= 1	# Vertical Surfaces= 1
# Wings= 2	# Horizontal Surfaces= 1
#servos= 6	Empty Aircraft Weight (lbs)= 15.1
# fuselages= 1	

Coefficient	Description	Supplied Cost Model	Value
A	Manufacturers Empty Weight Multiplier	$100/lb	$100 /lb
B	Rated Engine Power Multiplier	$1/watt	$1 /watt
C	Manufacturing Cost Multiplier	$20/hour	$20 /hour
MEW	Manufacturers Empty Weight	Actual airframe weight, lb., without payload or batteries	15.1 (lbs)
REP	Rated Engine Power	# engines*50A*1.2V/cell*#cells	2160 (Watts)
MFHR	Manufacturing Man Hours	MFHR = SWBS hours	130.7 (hrs)
		WBS 1.0 Wing(s):	
		5 hr/wing	10.0 (hrs)
		+4 hr/sq ft Projected Area	51.4 (hrs)
		WBS 2.0 Fuselage and/ or pods:	
		5 hr/body	5.0 (hrs)
		+4 hr/ft of length	23.3 (hrs)
		WBS 3.0 Empenage:	
		5 hr (basic)	5.0 (hrs)
		+5 hr/Vertical Surface	5.0 (hrs)
		+10 hr/Horizontal Surface	10.0 (hrs)
		WBS 4.0 Flight Systems:	
		5 hr (basic)	5.0 (hrs)
		+1 hr/servo	6.0 (hrs)
		WBS 5.0 Propulsion Systems:	
		5 hr/engine	5.0 (hrs)
		+5 hr/propeller or fan	5.0 (hrs)

Rated Aircraft Cost, $ (Thousands) = (A*MEW + B*REP + C*MFHR)/1000

Rated Aircraft Cost, $ (Thousands) = $6.2836

Table 2.1 - Final Competition Aircraft's Rated Aircraft Cost

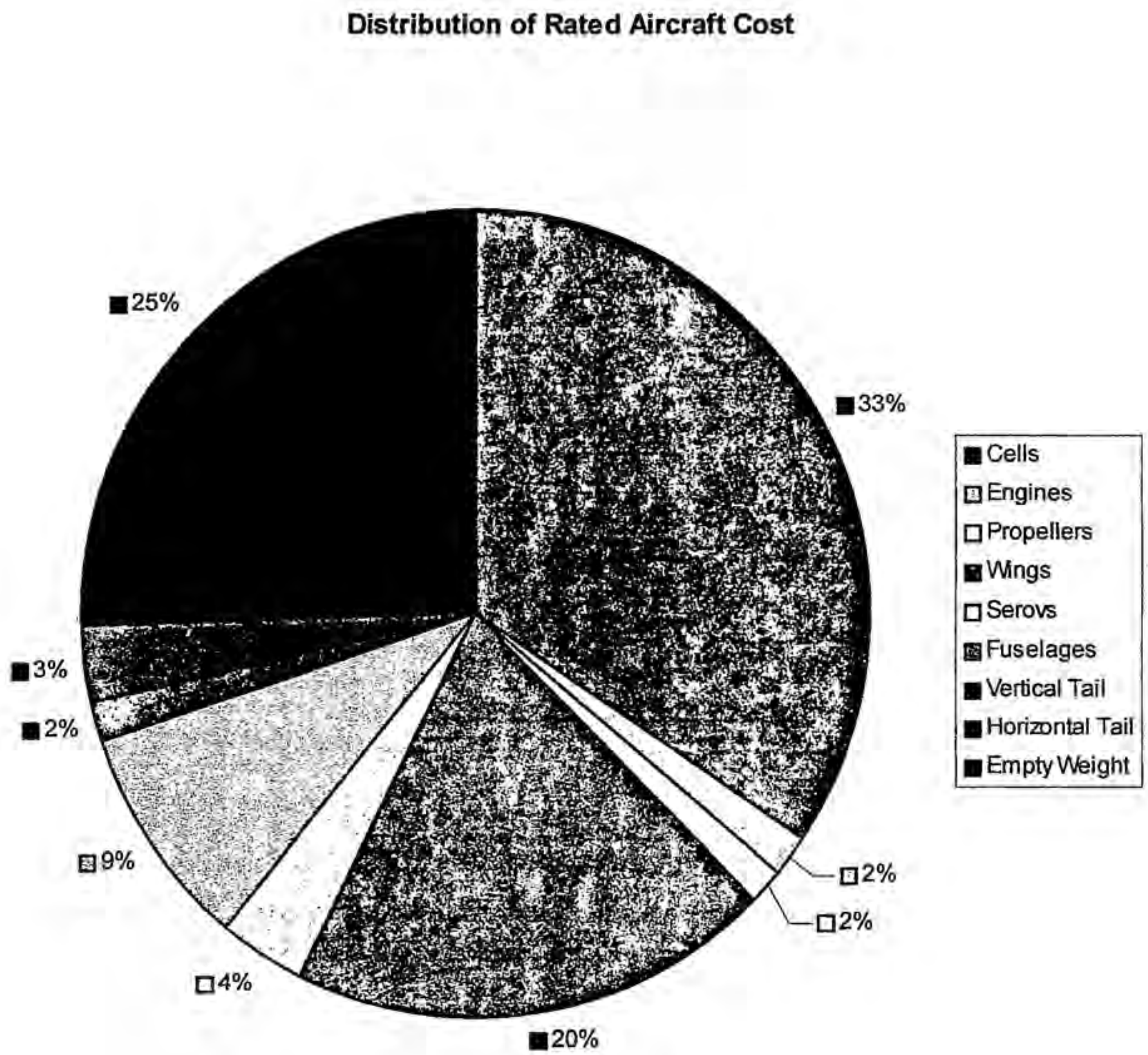
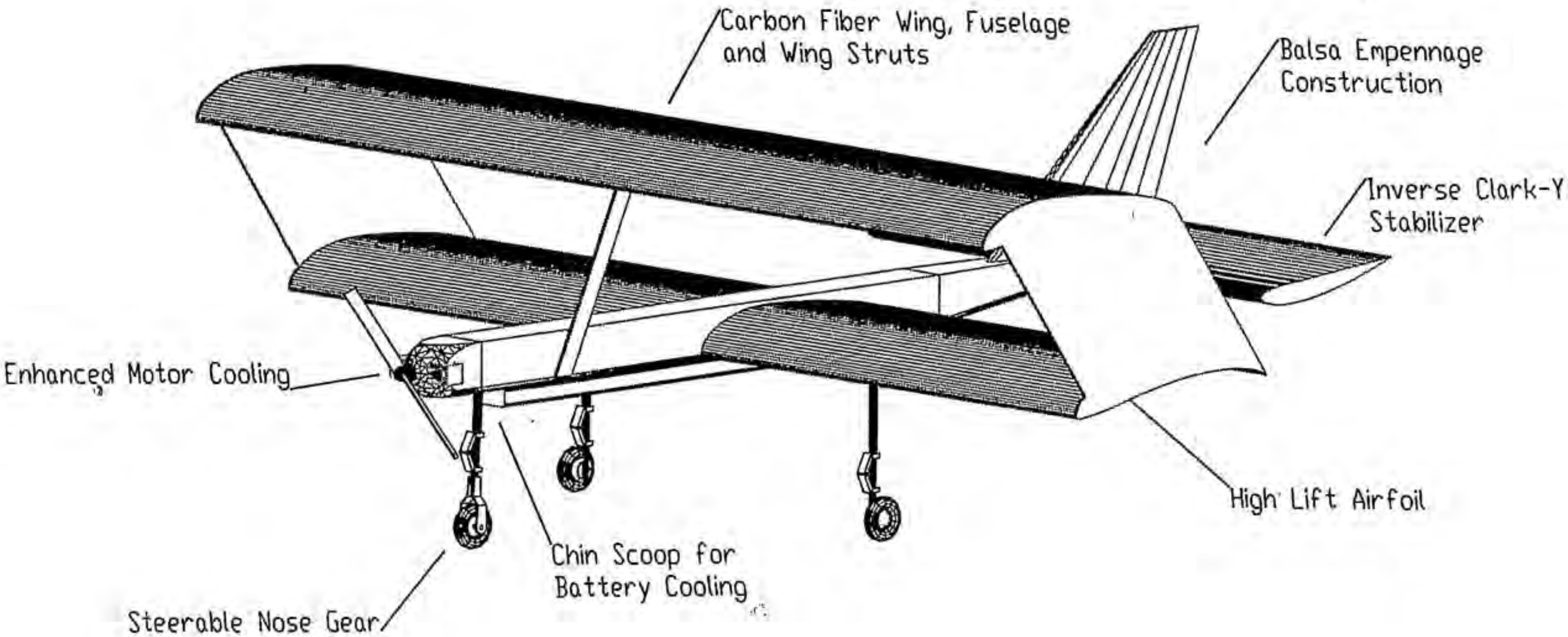


Figure 2.1: Distribution of Rated Aircraft Cost

2000 Cessna/ONR Student Design/Build/Fly Competition

Proposal Phase

"The Hammerhead"
Special Features



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1 Executive Summary

1.1 Development Process

Oklahoma State University's O.R.A.N.G.E. A.B.I.S.S team adopted an active development process for the Cessna/ONR Design/Build/Fly 2000 Competition. The approach taken to derive the final configuration was systematic, as to expedite an efficient convergence to a competitive aircraft.

Much research was conducted in the field of remotely piloted aircraft in order to advance the learning curve. Propulsion research, as well as aerodynamic wind tunnel testing, was conducted and evaluated. Current periodicals, the Internet, and other publications were consulted in the process. Various material construction techniques were also investigated. Historical data was readily accessible within the Oklahoma State University Mechanical and Aerospace Engineering Department.

During the conceptual design phase, the team brainstormed and generated innovative ideas. The ideas presented were not criticized, but presented freely. This allowed equal and objective design input from every member on the team, regardless of background or academic level. As the design process progressed, the conceptual sketches were further interpreted and analyzed. The team members reviewed the ideas and established figures of merit for each concept configuration including, but not limited to, construction feasibility, cost, performance, and durability. Practical considerations drove the design for this conceptual approach.

As the conceptual process developed, a Score Evaluation Spreadsheet was developed with the design. The spreadsheet developed by the Aerodynamics Group incorporated Rated Aircraft Cost, numerous performance parameters, and strategy from previous years contests. The spreadsheet evolved to be "all encompassing" in the preliminary stage, including general configuration parameters ranging from monoplane versus biplane to efficiency factors. Rated Aircraft Cost was included to determine score based upon a particular configuration. Thus, numerous configurations could be analyzed, and trends for these configurations could be compared in order to optimize for the highest possible score. Theoretically, an aircraft was developed to attain the highest score possible.

In addition to developing the conceptual ideas and the Score Evaluation Spreadsheet in parallel, practical issues were considered as well. Although the conceptual ideas would be easy to construct, the basic ideas might not generate the best possible score. Conversely, the developed Score Evaluation Spreadsheet might generate the optimal score, but might not be feasible with current construction technology. Therefore, a transition between the theoretical and conceptual ideas had to be established.

As the design process transitioned to the preliminary stage, the conceptual drawings were analyzed in further detail. In this stage, basic sizing was completed for various components. A consequential score evaluation and trade study was completed to observe the relation between score and resultant performance parameters. Wind tunnel modeling was performed in this phase in order to obtain data for the detail design phase.

In the detailed design phase, more in depth work was accomplished as to the actual performance sizing of the aircraft. The sizing of control surfaces, determination of control rates, and center of gravity analysis was addressed in this design phase. The Propulsion Group finalized selection of the motor, prop, and batteries to be used. The Structures Group decided upon appropriate construction methods to be used for the specific aircraft components and materials.

A systematic design process was employed to expedite the system of evolvement. The process included **conceptual, preliminary, and detail design** stages. Tasks were chronologically organized into these three groups to efficiently derive a final product.

1.2 Design Tools Overview

The selection of design tools was based upon appropriateness for the task, previous experience, and individual proficiency.

Conceptual Design Tool:

- Microsoft Excel

Microsoft Excel was used as the driving force to create a design for score optimization. The Score Evaluation Spreadsheet was the paramount tool in the design process.

Preliminary Design Tools:

- UIUC Airfoil Database
- Martin Hepperle's Airfoil Analysis Web page
- MotoCalc
- Microsoft Excel
- MathCAD

The UIUC Airfoil Database contains a plethora of airfoil profile sections. The coordinates from this database were inputted into AutoCAD to generate the airfoil sections used in the drawings. Martin Hepperle's Airfoil Analysis Webpage was utilized in conjunction with the UIUC Airfoil Database to attain preliminary design data for performance.

MotoCalc was used primarily by the Propulsion Group as a database to conduct research on motors and battery options. This software was used mainly in the preliminary design phase. Microsoft Excel was used in conjunction with MathCAD to size aircraft components and control surfaces. In addition, excel models of DC motor operations were created.

MathCAD was utilized for more rigorous mathematical modeling and complex equations, such as stability calculations and control sizing. Excel was used to expedite data reduction from wind tunnel testing, and to incorporate the Rated Aircraft Cost within the Score Evaluation Spreadsheet.

Detail Design Tools:

- AutoCAD
- Microsoft Excel

AutoCAD was used to produce basic construction drawings, as well as spawn 3D rendered views of the finished prototype to allow checking of all major interfaces. AutoCAD was used throughout the various phases of the design process.

Microsoft Excel was also used as a detailed design tool for the primary purpose of sizing landing gear for allowable stresses. The spreadsheet format allowed for various loads and angles of impact to be accounted for in the sizing of landing gear.

Additional Design Aids:

In addition to the above computational software, other published references were inquired as well. For detail design of the biplane configuration, Aircraft Design: A Conceptual Approach by Daniel P. Raymer served as a useful tool. The Propulsion Group benefited from Astroflight's published Electric Motor Handbook by Robert Boucher.

Technical references also provided useful help and advice. Dr. Andrew S. Arena, Jr. in the Oklahoma State University Mechanical and Aerospace Engineering Department aided with technical advice. Joseph Conner, engineering graduate student, helped in setting up the wind tunnel experiments and provided useful knowledge of electric propulsion and model airplane techniques. Brian Vermillion, president of Advanced Racing Composites, supplied information and background on composite construction, which was very useful in the conceptual phase of design.

1.3 Preliminary Budget

A preliminary budget was constructed to maintain a running balance and to efficiently and effectively remain within budget. The budget is based on historical estimated costs. The projected budget is as follows:

Prototype Preliminary Budget

Consumables

Description	Quantity	Price	Total
2 oz Thin CA	3		$16.97
2 oz Med CA+	2	$5.99	$11.98
Aerosol Activator	1	$4.99	$4.99
Epoxy	2	$7.99	$15.98
Knives & Blades	5	$1.50	$7.50
Dremel Accessories	1	$10.00	$10.00
Sandpaper	2	$4.00	$8.00
Spirit Glider	1	$73.97	$73.97
Plotter Paper	1	$20.00	$20.00
Vacuum Bagging	1	$40.00	$40.00
Tape	2	$40.00	$40.00
Total			**$249.39**

Mechanical and Electrical

Description	Quantity	Price	Total
Motor	1	$225.00	$225.00
Gear Box	1	$50.00	$50.00
Speed Controller	1	$130.00	$130.00
Propellers	3	$40.00	$120.00
Batteries	35	$8.00	$280.00
Wiring and Connectors	1	$20.00	$20.00
Servos	8	$30.00	$240.00
Solder	1	$3.00	$3.00
Piezo Gyros	2	$130.00	$260.00
Receiver Batteries	1	$20.00	$20.00
Total			**$1,348.00**

Construction Materials

Description	Quantity	Price	Total
Balsa	1	$25.00	$25.00
Other Wood	1	$20.00	$20.00
C/F Prepreg/sq ft	90	$7.20	$648.00
Blue Foam	1	$40.00	$40.00
Monokote	2	$12.99	$25.98
Sullivan Tires	5	$8.00	$40.00
Aluminum	1	$70.00	$70.00
Misc. Landing Gear	1	$40.00	$40.00
Control Horns	10	$0.50	$5.00
Hinges	5	$1.50	$7.50
Push Rods	6	$0.50	$3.00
Total			**$924.48**

Total Cost
Initial Prototype $2,522

Final Design Projected Budget

Consumables

Description	Quantity	Price	Total
2 oz Thin CA	3		$16.97
2 oz Med CA+	2	$5.99	$11.98
Aerosol Activator	1	$4.99	$4.99
Sandpaper	2	$4.00	$8.00
Vacuum Bagging	1	$40.00	$40.00
Tape	2	$40.00	$40.00
Total			**$121.94**

Mechanical and Electrical

Description	Quantity	Price	Total
Motor	1	$225.00	$225.00
Gear Box	1	$50.00	$50.00
Speed Controller	1	$130.00	$130.00
Propellers	2	$40.00	$80.00
Batteries	35	$8.00	$280.00
Wiring and Connectors	1	$20.00	$20.00
Servos	8	$30.00	$240.00
Total			**$1,025.00**

Construction Materials

Description	Quantity	Price	Total
Balsa	1	$25.00	$25.00
Other Wood	1	$20.00	$20.00
C/F Prepreg/sq ft	90	$7.20	$648.00
Blue Foam	1	$40.00	$40.00
Monokote	1	$12.99	$12.99
Sullivan Tires	5	$8.00	$40.00
Aluminum	1	$60.00	$60.00
Misc. Landing Gear	1	$15.00	$15.00
Control Horns	10	$0.50	$5.00
Hinges	5	$1.50	$7.50
Push Rods	6	$0.50	$3.00
Total			**$876.49**

Total Cost
Final Prototype $2,023

Estimated Travel Expenses

Description	Quantity	Price	Total
Van Rental	1.5	$225.00	$225.00
Motel	4.5	$55.00	$495.00
Total			**$720.00**

Total	
Cost	$5,265

2 Management Summary

2.1 Team Architecture

The team consists of students ranging from freshman to graduate students, and is divided into three groups: Aerodynamics, Propulsion, and Structures. A Marketing group was also established to support funding. A chief engineer was selected for the team to facilitate organization and communication. Team members were surveyed by Dr. Arena, the team advisor, and were then allocated into the three subgroups based upon technical background and personal interests. These three subgroups are guided by a respective group lead. The three subgroups were further subdivided into smaller sections, depending upon anticipated complexity of tasks. The team structure is outlined in the following diagram:

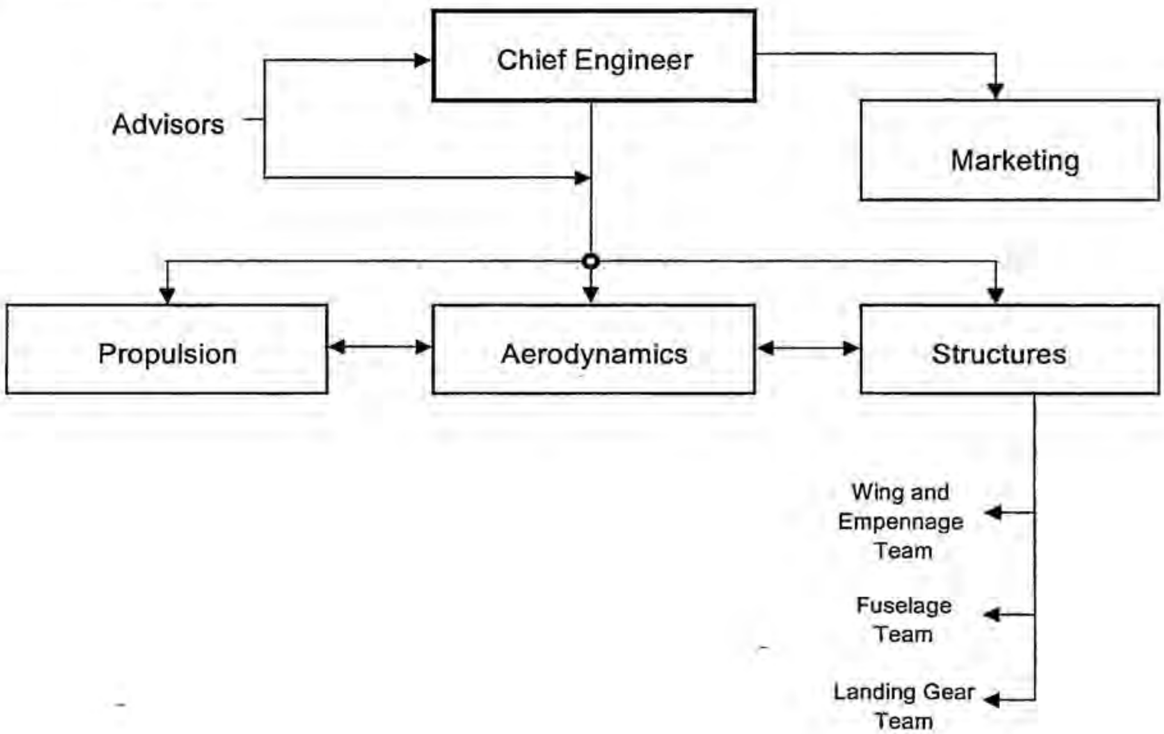


Figure 2.1 Team Architecture Diagram

An active managerial approach was implemented to expedite communication between each technical group. Although each member is appointed to a specific group, the member is not confined to that specific group, and interdisciplinary activity is encouraged. For instance, the Aerodynamics Group is highly encouraged to be adequately involved with the Structures and Propulsion Groups. This approach expedites communication on the overall project, and results in a more refined final product.

2.2 Management Structure

With the architecture of the team clearly defined, the management structure of the team can be further outlined. Each team member, as stated above, was appointed to their respective task based on experience and personal preference.

The Aerodynamics Group made up approximately one-fourth of the team. This group is primarily responsible for configuration design, performance calculations, weight and balance, and stability and control. They have accomplished detailed wind tunnel testing on various configurations and have also been very instrumental in structural development, primarily with the construction of the wings.

The Propulsion Group also consists of approximately one-fourth of the team. This group is responsible for battery, motor, and propeller selection and testing, and the interfacing between each component. The Propulsion Group is actively involved with the Aerodynamics Group in correlating performance requirements and limitations. This group is also involved with the Structures Group to facilitate an agreement on motor-fuselage interfacing, battery arrangement, and battery placement.

The Structures Group comprises the remaining members of the team. This group has been conducting research on design and construction methods, including component matching, interfacing, and composite lay-up techniques. Connection points and interfacing was of primary concern of this group. Due to the large spectrum of the Structures Group, it is further subdivided into Landing Gear and Brakes, Wing and Empennage, and Fuselage subgroups.

The Landing Gear and Brakes Subgroup is primarily concerned with the design and construction of the ground handling systems. Therefore, members with the most efficient machining skills were appointed to this subgroup. The Wing and Empennage Subgroup is responsible for the construction of their respective components and is instrumental in determining the layout of the internal configuration and the controls system. The Fuselage Subgroup held the responsibility of fuselage layout, along with propulsion and wing integration. Initially, these team members constructed a "practice plane" model to acquire the necessary proficiency.

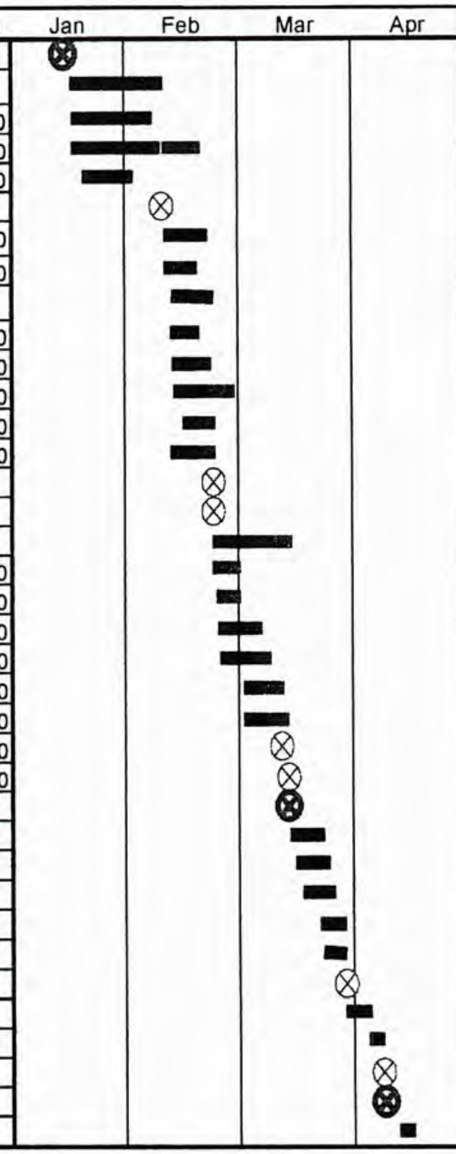
Each of the above groups is led by an assigned Group Lead. The Group Leads are responsible for facilitating communication between the groups and establishing efficient and paralleled tasks for each group member. These tasks are assigned through the Milestone Chart in Figure 2.2. The Milestone Chart helped to facilitate schedule control among the groups so that each group member knew the major elements and at what time these elements were to be completed. The group leads could then plan their group work accordingly.

The Chief Engineer leads the project as a whole. This person is involved in coordinating, scheduling, ordering, and maintaining communication between the groups. Not only does the Chief Engineer coordinate the team, but also holds involvement in every aspect of the design, including, but not limited to, Aerodynamics, Propulsion, and Structures.

The Chief Engineer plays an intricate part in all the groups by maintaining configuration control. As all team members design and construct the airplane in parallel, communication is essential in configuration control. E-mail, FTP, phone lists, and regular team meetings are the primary forms of communication.

Figure 2.2 details the anticipated progress of the design stages. Major contest deadlines are depicted, as are internal deadlines.

	Start	Finish	Actual Finish
Project Kickoff	1/17/00		
Conceptual Design Stage			
Conceptual Brainstorming	1/17/00	2/6/00	2/7/00
Preliminary Research	1/17/00	2/7/00	2/18/00
Score Evaluation Spreadsheet Design (Configuration)	1/19/00	2/7/00	2/2/00
Configuration Freeze - Progress Report 1	2/7/00		
Preliminary Design Stage	2/7/00	2/16/00	2/16/00
Score Evaluation Spreadsheet Design (All Encompassing)	2/7/00	2/18/00	2/18/00
Detail Design Stage			
Detail Design - Aero and Structures Internal Design	2/9/00	2/18/00	2/18/00
Aero Detail Design - Airfoil/Sizing/Stability	2/10/00	2/16/00	2/19/00
Propulsion Testing - Battery/Motor/Prop Previous Year Setup	2/10/00	2/21/00	2/28/00
Structures - Detail Design Components	2/14/00	2/17/00	2/21/00
Construction Drawings	2/9/00	2/19/00	2/21/00
Construction Drawings Due - Progress Report 2	2/21/00		
Prototype Design Freeze	2/21/00		
Structures - Experimental Testing/Construction	2/21/00	3/7/00	
Construction Preparation	2/21/00	2/22/00	3/1/00
Cut Molds	2/22/00	2/24/00	3/2/00
Carbon Fiber Layup and Detail	2/24/00	3/3/00	3/9/00
Final Construction	3/2/00	3/5/00	3/11/00
Systems Integration	3/3/00	3/7/00	3/12/00
Prepare Phase 1 Proposal	3/3/00	3/8/00	3/13/00
Proposal Due Internally	3/8/00		3/10/00
Progress Report 3 - Prototype Rollout	3/8/00		3/13/00
Phase 1 Proposal Due COB	3/13/00		
Flight Test and Performance Evaluation	3/13/00	3/17/00	
Aero/Structural/Propulsion Modification of Prototype	3/14/00	3/19/00	
Final Design Work	3/17/00	3/23/00	
Detail Drawing Modification	3/20/00	3/27/00	
Addendum Report Preparation Internal	3/22/00	3/27/00	
Final Design Freeze	3/27/00		
Final Design Construction	3/27/00	4/6/00	
Final Design Flight Test/Contest Practice	4/6/00	4/10/00	
Aircraft Grounded	4/10/00		
Addendum Due AIAA COB	4/10/00		
Cessna/ONR International Contest	4/14/00	4/16/00	



Scheduled Time
Actual Time
Internal Deadline
Contest Deadline

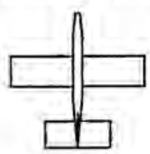
Figure 2.2 Milestone Chart Showing Planned and Actual Timing of Major Elements

3 Conceptual Design

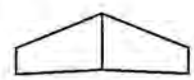
3.1 Alternative Concepts Investigated

To achieve the design most suited for the established mission, it was necessary to review and critique multiple aircraft configurations. These alternatives were considered and narrowed down by a variety of factors that will be discussed. The aircraft configurations considered were as follows:

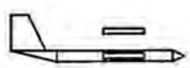
- Standard Monoplane



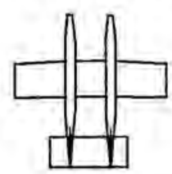
- Flying Wing



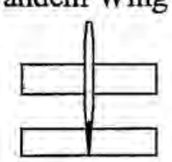
- Biplane



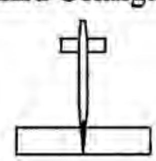
- Dual Fuselage Monoplane



- Tandem Wing



- Canard Configuration



The standard monoplane configuration of a single fuselage, single wing, standard tail aircraft is simple and has been proven historically to be safe and stable.

The biplane configuration of a standard fuselage with two wings, one above the other, allows for increased lift with lower drag due to a higher aspect ratio for each wing.

The tandem wing configuration consists of a standard fuselage and two wings, one located substantially forward of the other. In this configuration, one wing can act as the stabilizing airfoil, allowing removal of the horizontal tail surface.

The flying wing configuration, the lifting airfoil acts as the fuselage and horizontal-stabilizing surface. This design eliminates the need for vertical and horizontal tail surfaces and streamlines the aircraft, increasing the overall drag characteristics.

The dual fuselage configuration incorporates a standard wing design with two fuselages mounted side by side. This configuration is most often used with two engines, one at the nose of each fuselage, and with two vertical surfaces mounted independently on each fuselage.

The canard configuration can be used with multiple fuselage and wing designs. The canard replaces the horizontal tail surface with a similar controlling surface mount forward of the main lifting wing. This design is primarily used where the elimination of wing stall is desired.

For an overview of the cost and score performance of each configuration, see Figure 3.1 at the end of Section 3.

3.2 Design Parameters Investigated

Primary design parameters were investigated during the conceptual design phase to determine which had the most significant impact on the Figures of Merit (FOM). These design parameters are as follows:

- Amount of water to be carried
- Payload configuration and access
- Wing loading
- Airfoil selection
- Power loading
- Aspect ratio
- Wing geometry
- Number of wings
- Number of fuselages
- Number and location of motors
- Number and location of batteries
- Landing gear configuration
- Braking and steering
- Component cooling
- Material selection
- Fuselage length

The amount of water to be carried was affected directly by the selected wing and power loading and the aspect ratio of the wing. Proper matching of these components is essential to assure takeoff in 100 feet and to maximize flight score.

Payload access had to consider such things as wing configuration and fuselage shape. Rapid access to payload for loading and unloading was necessary to maximize the number of sorties in a mission during the competition. Different options considered were a detachable nose and tail to pull out the water bottles, a top hinged hatch with and without the bottles attached to the hatch, and replaceable pods attached to the fuselage. Different configurations for the bottles included laying the bottles on their side and upright in the fuselage. Different bottle sizes were investigated for the two different configuration possibilities.

Airfoil selection was one of the most important considerations in the design phase. The right airfoil was required to optimize the lift needed for the intended mission. For the competition, an airfoil with a high lift to drag ratio throughout the angle of attack range was desired due to the takeoff requirement. The higher this ratio, the more weight the aircraft can lift with no penalty in drag or power.

Wing geometry plays an important role in the aerodynamic performance. A tapered wing effectively approaches the ideal lift distribution of an elliptical wing without the added difficulty of constructing the elliptical shape. This, however, produces unfavorable stall characteristics compared to that of a constant-chord wing. A rectangular wing stalls at the root first leaving some aileron effectiveness. This, along with the ease of construction of a constant-chord wing, led to the use of a straight, rectangular geometry.

Multiple wing designs must be considered due to span limitations placed on the design. Aspect ratios less than three can have very poor drag qualities, which can lead to a variety of limitations. To counter this, multiple wings can be used. This results in larger wing area for limited spans, retains high aspect ratio, and preserves efficiency and drag qualities.

Multiple fuselages must be considered to blend the placement of multiple engines and tail surfaces if necessary. More than one fuselage may be desired if loading requirements require a long fuselage. A dual fuselage design would allow more cargo room while maintaining a reasonable fuselage length.

The number of motors required is primarily determined by the availability of a motor that can provide sufficient power and also by the efficiency of the configuration. Multiple motors may be desired for smaller prop usage or location restrictions. The motor location is critical due to the effects of prop-wash and motor-out handling qualities of the aircraft. Restrictions in motor placement must be considered such as ground clearance and structural attachment.

The number of batteries required depended upon the power required from the battery pack. Since the battery pack weight is limited to five pounds, it was decided that the power density of the batteries was an important parameter to consider when selecting the type of battery to use. Battery incorporation into the design was critical to assure that the aircraft fell into the CG limitations and that adequate cooling could be accomplished. Payload locations had to be decided in conjunction with battery location and the effect of heat generated from the battery packs on surrounding components.

During a mission, several takeoffs and landings must be executed. Therefore, it was decided that the landing gear configuration, which directly affects the ground handling of the aircraft, was an important parameter to consider. Tricycle, bicycle, and tail dragger configurations were all considered in the conceptual design. Shock absorbers such as oleo strut, spring or torsion bar, cantilevered gear, and rubber were investigated to minimize the landing impact on the airframe.

The competition missions are limited to ten minutes with a starting point for each takeoff. With this time restraint, brakes would allow the aircraft to stop faster during landing rollout. Also, it will allow the plane to stop before the takeoff starting point, saving precious time and possibly preventing the need to return to the starting point after landing. Commercial brakes were considered as well as a self-manufactured design. Steering was determined to be an important factor because it would allow a faster return to the starting line if the line was passed. Nose gear steering, differential braking, and pure rudder were all ideas investigated.

Component cooling was necessary in two major places, the motor and the batteries. The cooling air must come from either the prop-wash or the in-flight airflow. Using the prop wash for cooling will supply cooling air proportional to the loads being drawn while the in-flight airflow will not suffice while operating in ground conditions.

Material selection was an important design consideration due to limitations of certain materials. While balsa and Monokote construction are lightweight and easy to construct, they limit the use of complex airfoils and fuselage designs. The use of lightweight metals provides strong structures but increase weight significantly. Composite construction using fiberglass or carbon fiber are expensive and difficult to work with, but allow very complex and rigid designs.

3.3 Figures of Merit Employed

The following are the Figures of Merit that were used in the consideration of different design configurations:

- Flight score
- True aircraft cost
- Ease of construction
- Payload access
- Propulsion capabilities
- Handling qualities

The primary Figure of Merit was flight score. However, all the above Figures of Merit were considered in achieving a reliable and safe design while maximizing score.

The Rated Aircraft Cost was used to eliminate designs that would incur large penalties in cost due to multiple fuselages, multiple vertical and horizontal tail surfaces, excessive wing area, and number of motors.

The true aircraft cost was used in a similar manner to the rated aircraft cost. The true aircraft cost reflected actual budget requirements of the design.

Ease of construction was used to ensure that the final design would be within the manufacturing abilities of the team and to ensure that a time consuming, complex design was avoided due to time constraints.

Payload access was also a major concern due to the high turn around time desired. The final design must have easy access to the payload to ensure that complications do not arise in the payload removal or addition to the airplane between sorties.

Propulsion capabilities were evaluated for the conceptual designs to ensure that the potential for multiple motor configurations existed if deemed necessary by the propulsion team.

Handling qualities are of the most important considerations in the design phase. Ground handling is included among these qualities. If the aircraft is uncontrollable, the design mission cannot be accomplished. While certain designs may be extremely efficient, if handling qualities are marginal, the risk of aircraft loss is high. Aircraft handling is a safety issue and should be treated as such.

3.4 Analytical Methods

In conjunction with the conceptual design stage, analytical design had to be performed to find the optimum configuration that would maximize the final flight score. This entailed the overall optimization of the aircraft by varying certain parameters, which included such things as wing loading, maximum power required, endurance, and cost factor. The entire spreadsheet was set up to show the results for aircraft carrying two to eight liters of water.

First, basic dimensioning equations were derived to size different parts based on a varying design payload. Power requirements were then derived based on the predetermined component sizes, the gross takeoff weight of the aircraft, and maximum takeoff distance. Efficiencies for the propulsion system were then determined from historical sources and assisted in determining the required battery power for required system performance. The power required for the desired cruise speed was then calculated, and by estimating course length, the predicted number of laps possible for minimum endurance was determined. Set limits for current flow removed any configurations that exceeded a 50 Amp current flow to prevent system damage and to preserve safety.

The aircraft cost factor was determined from the given equations supplied in the contest rules. The estimated sizing, weight, and component number along with the battery, motor, and propeller requirements to arrive at the final, factored cost for the aircraft. The predicted score was then calculated based on the endurance, range, number of liters carried, and the aircraft cost factor and was varied with wing loading for optimization. A graph showing the optimal score versus liters of water based on wing loading can be found in Figure 3.2. The predicted score is derived independently of the report score and is only used as a comparison tool to aid in the selection of the overall aircraft configuration.

A flowchart located in Figure 3.3 shows a simplified logic tree of the score evaluation spreadsheet. Inputs include such things as the number of components installed, wing loading, coefficient of lift and drag, weight (gross takeoff and empty), take off distance, lap time, battery cell type and number of cells, maximum allowable current, and aircraft efficiency factors. Once these inputs are identified, a Visual Basic macro was used to vary and plot wing loading to find the maximum score versus number of liters. The optimal wing loading can then be loaded into the spreadsheet along with other parameters to accurately determine the final approximation.

The calculations were tested for accuracy by using the aircraft configuration data from previous years and comparing the theoretical performance data to actual recorded information. Adjustments were made accordingly in areas where error was excessive.

3.5 Configuration Selection

The final configuration was made with the use of Figure 3.4 and the score evaluation calculations. The final configuration consisted of the following characteristics:

- Biplane wing design
- Single, slender fuselage
- Single vertical and horizontal tail surfaces
- Tricycle landing gear
- Single motor
- Lower cowling battery arrangement

The primary reason the biplane design was decided upon was to maximize wing area while maintaining a reasonable aspect ratio along with the optimized wing loading.

The single, slender fuselage was selected to minimize drag, have easy and fast accessibility to the payload, and to increase the longitudinal and lateral moments of inertia to assist in oscillation damping.

The tail configuration of one vertical and one horizontal surface provided the required trim while minimizing the cost factor and drag.

The tricycle landing gear was preferred to a tail-dragger configuration for stability in ground handling. The gear location was determined to prevent tipping in taxiing and gusty wind conditions.

The single motor configuration was chosen based on the availability of a motor that provided the required power and minimization of score loss due to the cost factor. It also blended well with the single fuselage selection and provided thrust along the centerline of the aircraft.

The battery pack was arranged with the cells laid side-by-side in series. This configuration was necessary for the cells to be stored in the battery cowling located beneath the fuselage. The purpose for storing the cells beneath the fuselage was threefold. First, removing the batteries from within the fuselage allowed for more compact bottle spacing and a more compact fuselage. Second, storing the batteries outside the fuselage kept heat generated by the batteries away from the rest of the system. Third, storing the cells in the battery cowling meant the center of gravity of the plane could be fine-tuned easily by shifting the battery pack within the battery cowling.

Overall, it is felt that this is an efficient and competitive design that will be within the capabilities of the team to design and construct while meeting the basic mission requirements.

Aircraft Configuration	Factored Cost (Dollars)	Estimated Score
Standard Monoplane	5404.29	21.26
Biplane	6181.50	24.26
Tandem Wing	6308.42	23.78
Flying Wing	5037.50	20.35
Dual Fuselage Monoplane	7223.41	15.59
Canard Monoplane	5404.29	21.26

Figure 3.1 Aircraft configuration versus factored cost and estimated score

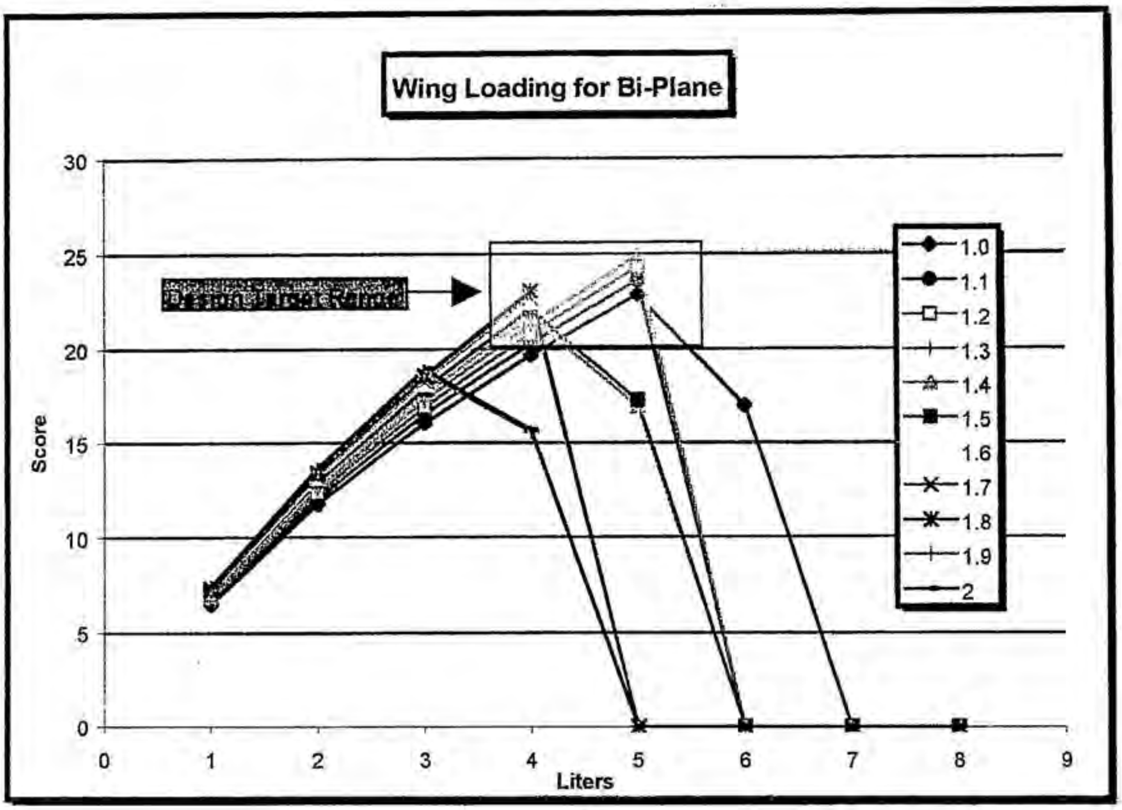


Figure 3.2 Score versus number of liters for varying wing loadings.

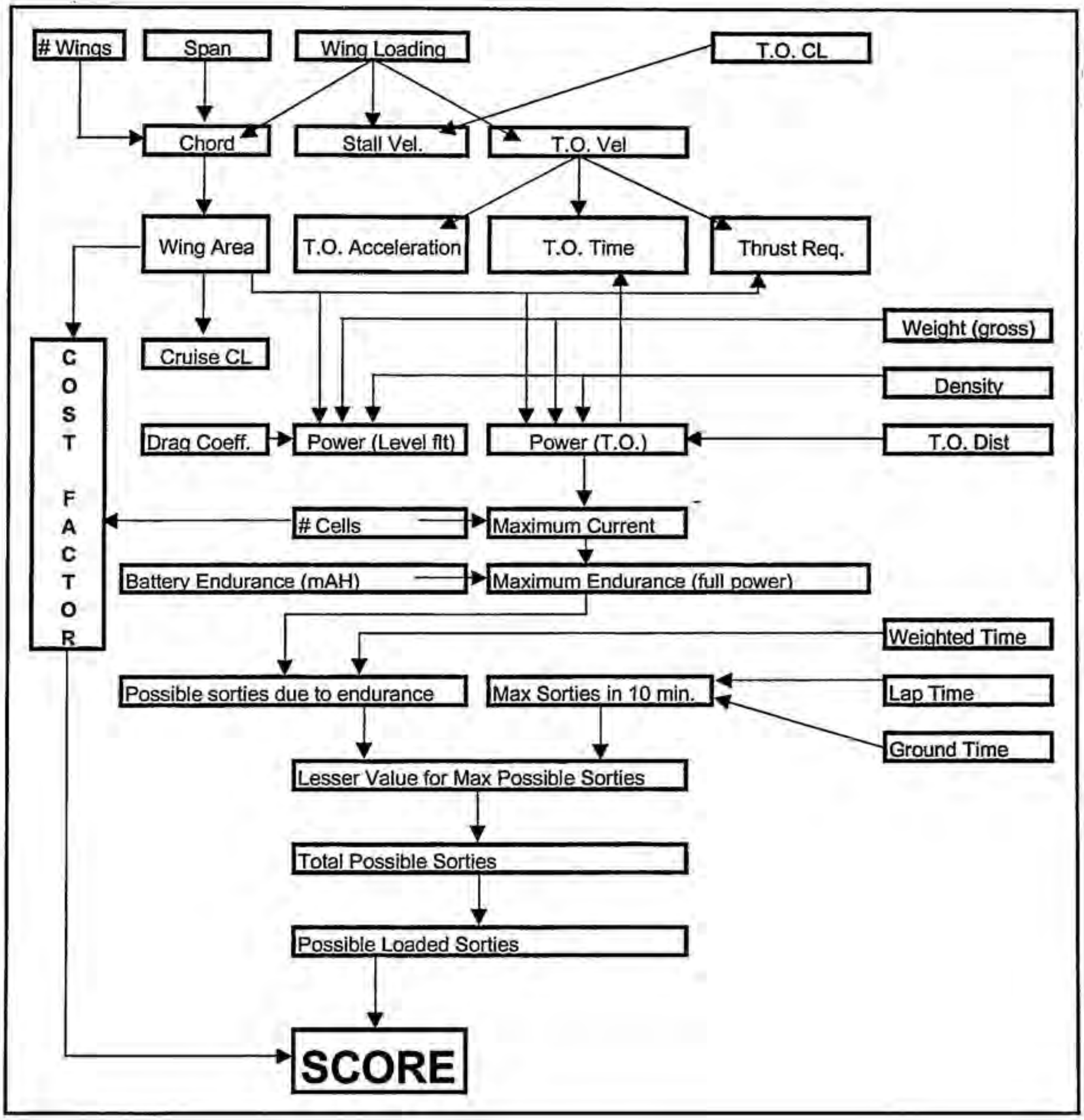


Figure 3.3 Score evaluation spreadsheet flowchart

Figures of Merit	Weight Factor	Standard Monoplane	Biplane	Tandem Wing	Flying Wing	Dual Fuselage	Canard
Rated Aircraft Cost	0.3	4	3	4	5	2	4
True Aircraft Cost	0.1	4	3	2	1	1	4
Ease of Construction	0.05	5	3	3	4	1	5
Payload Access	0.1	5	4	4	2	3	4
Propulsion Capabilities	0.05	4	5	4	3	3	3
Aerodynamic Stability	0.2	4	5	3	1	4	5
Efficiency w/ Span limitations	0.1	3	5	5	3	3	4
Take Off Limitations	0.1	3	5	4	3	4	2
Totals	1	3.050	3.150	3.050	2.650	2.050	2.950

Figure 3.4 Figures of Merit Ranked

4 Preliminary Design

During the preliminary design phase, the aerodynamic shape, structural layout, and power characteristics were better outlined and sized to be suitable for the competition objectives. Preliminary layout drawings of the plane were presented in this stage.

4.1 Design Parameters Investigated

Design parameters were investigated during the preliminary design phase. These design parameters are as follows:

- Aspect ratio
- Wing loading
- Number of Wings
- Power loading
- Volumes of tail
- Fuselage configuration
- Payload configuration
- Landing gear configuration

The aspect ratio of a monoplane design was insufficient for the wing area needed. A reasonable aspect ratio was obtained by adding another wing. By taking advantage of the full wing span allowed (seven feet), and using the chord of 20 inches determined by the score optimization spreadsheet, the resulting aspect ratio for each wing was 4.19.

Wing loading was chosen to optimize the score. The score optimization spreadsheet was utilized again to plot different wing loadings versus number of liters carried. Given the wing area chosen above, the best wing loading was 1.3.

Fuselage configuration is directly related to the payload amount to be carried. The payload is one-liter cylindrical bottles of any dimension, which must be accessible for easy removal and replacement. However, fuselage length needed to be minimized to maximize score. In addition to payload arrangement being a primary concern, aircraft stability and drag due to cross sectional area were vital concerns in the fuselage arrangement.

Landing gear type and wheel size was determined through ground handling characteristics and impact absorption characteristics. In designing the landing gear, weight, impact load, and drag had to be considered. The predicted weight for the team's aircraft ranged from 25 to 35 pounds loaded. The goal was to design the gear to be as light as possible while maintaining sufficient strength to withstand the loads. Several different types of shock absorbers were investigated including oleo, spring shocks, and rubber shocks. The figures of merit in the design of the shock absorbers were ease of manufacture, reliability, and weight required.

Various landing gear configurations were researched and trade studies conducted to find the optimal configuration to accommodate our design needs. The designs considered were tail-dragger, tricycle, and bicycle configurations. The Aerodynamics Group was consulted as to the possible impact of varying designs on the handling qualities during landing. These considerations were incorporated into the figures of merit. The method of steering for the aircraft is specific to each landing gear configuration, therefore, it will be determined by the configuration selected.

4.2 Figures of Merit Detailed

The Aerodynamics Group performed trade-off studies to obtain simultaneous optimization of component spacing.

The recommended separation between the two wings of a biplane is one chord length, but analysis showed the gap could be reduced to 14 inches without significantly decreasing the efficiency. Numerically, the efficiency dropped from .67 to .6. See Figure 4.5. The top wing was placed as close to the bottom wing as possible in order to decrease the moment of inertia and profile area.

While historical research indicated that stagger in biplane wings was only for increased pilot visibility, the Aerodynamics Group found several reasons to include a positive stagger in the design. First, when the top wing is staggered forward it is at a slightly larger relative angle of attack due to decalage and stalls before the bottom wing. This produces a nose down pitching moment because the aft wing is still generating lift, and the plane will naturally recover from the stall. Second, the stagger allows favorable center of gravity location. A trade-off between decalage effects and moving the landing gear as far aft as possible resulted in a stagger of 10 inches. With the CG three inches in front of the lower wing spar, the odd number of liters can be centered on the CG. In the zero-stagger configuration, the middle bottle would have to be placed on top of the lower wing spar. The tight fuselage sizing would not allow for this without the addition of a structurally and aerodynamically undesirable "bubble" for the bottle. The bubble would complicate payload removal hatches, and it would form an unnecessary protrusion in the case that four liters was deemed optimal.

From the Score Evaluation Spreadsheet, it was determined that the five liters of water would be the optimum payload with possibilities of increasing that number after testing. It was determined that the smallest frontal area possible was the most desirable trait because it would minimize form drag. Laying the bottles lengthwise in the fuselage could attain a small frontal area. The decision between oblate and prolate fuselage depended upon the dimensions of the one-liter bottles. A trade study in optimizing the drag versus fuselage length was performed and it was determined that 3.5" X 7" bottles, which were readily available, were optimal for transporting the cargo. This bottle size led to a prolate shaped fuselage of approximately seven feet.

The shape of the fuselage was determined from concepts such as a round balsa stringer, round carbon fiber, and square carbon fiber or wood (see Figure 4.1). The square carbon fiber shape was chosen for the team's configuration because of ease of manufacturing, durability, and ease of loading and unloading (see Figure 4.2). Carbon fiber was chosen over wood because of greater strength and stability

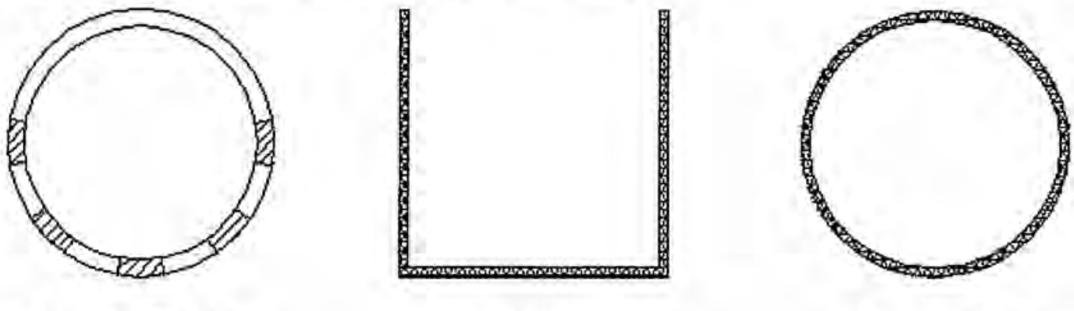


Figure 4.1 Examples of fuselage cross-sections

As this year's competition requires a series of loaded and unloaded sorties, quick removal and insertion of the payload are critical factors that affect the shape of the fuselage. Film from last year's competition was analyzed to find the fastest way to load and unload payload. The top hatch that flipped up giving access to the payload inside the fuselage and the removable nose cone or tail cone proved to be among the slowest of the methods observed. The fastest way incorporated a removable hatch on top of the fuselage connected to the payload that could be replaced with an identical hatch containing no bottles for the unloaded sorties.

After an extensive research, literature, historical data review, and consultation with the Aerodynamics Group, the landing gear configuration chosen was the tricycle configuration for its ground stability, takeoff performance, and landing stability. Tail dragging was primarily eliminated as a configuration possibility due to the tendency to ground loop as a result of the center of gravity being located behind the main struts. The bicycle configuration was not chosen because of the reduced handling qualities while on ground. Figure 4.3 is a decision matrix summarizing the results.

The height of the landing gear was dependent upon the size and mounting of the propeller and the amount of clearance desired for the propeller. A clearance of one inch below the propeller when the nose gear was fully compressed and the main gear was fully uncompressed was chosen as the minimum clearance to protect the motor and prop. Also, the spacing of the gear was considered to prevent tipping of airplane in cross winds. From references and historical data, a distance of one-third the wing span was found to be the ideal spacing of the gear to prevent tipping in high winds while on the ground. This distance correlated to fourteen inches from centerline of the fuselage to the main strut of the landing gear.

Three primary configurations for the shock absorbers were considered and analyzed for use in the landing gear. These configurations were oleo, rubber, and springs. Oleo shocks were investigated and found too complicated to manufacture, hard to repair, and their reliability was highly dependent on the quality of manufacturing. Given the limited machining ability of the Structures Group members, it was determined that oleo shocks carried a high risk of incorrect manufacturing. The Rubber shock absorber was heavily weighed against the spring shock but eliminated due to the potential for increased size and drag due to the large volume required for expansion of the rubber. The spring shock was chosen because of its simple design and reliability. It was also believed that this design would prove simple and fast to manufacture. (Figure 4.4)

Preliminary loads for landing were calculated from design specifications provided by the Aerodynamic Group and used in conjunction with a 1.5-g factor of safety. A spreadsheet was made by inputting different diameters of rod and tubing and calculating the stresses incurred by the worst case side loading. From the diameter and stress spreadsheet, materials were chosen based on their yield strength and density. Aircraft grade aluminum 6061-T651 was chosen for the strut material due to the high strength and lower density versus other aircraft grade aluminum and steels.

Nose gear steering was chosen as the best method of steering because of reliability, time savings, and ease of use for pilot. Differential braking of the main gear was not incorporated for steering to simplify ground controls. Instead, the main gear brakes will actuate simultaneously while utilizing the nose wheel for steering.

The brake design chosen was designed by students at OSU and manufactured by the Structures Group. The decision for in-house manufacturing of the braking system was driven largely by the lack of availability of small scale hydraulic braking and/or the prohibitive cost of such a system. The brake design incorporates a hydraulically actuated internal drum brake. The hydraulics will be controlled through servos and master cylinders located within each wing on easy-access panels.

4.3 Analytical Methods Detailed

The Aerodynamics Group created a series of MathCad programs to assist in the iteration of sizing calculations. The program began with wing analysis and worked through to the tail calculations. A 10% factor of safety was incorporated into the resulting dimensions of the surface controls.

Mounting the landing gear on the wings instead of the fuselage was a limiting factor. For a tricycle setup, the recommended placement of the gear is 15° aft of the CG to eliminate a tipping tendency during ground handling. The gear was mounted on the lower wing spar located at the quarter chord with the CG two inches behind the leading edge of the lower wing.

4.3.1 Wing Surface and Control Sizing

The ailerons were sized by setting an initial span and control power. The desired deflection was set at 15°. Robert C. Nelson's Flight Stability and Automatic Control provided a curve showing the relation between the flap effectiveness parameter, τ, and the ratio of control surface area to lifting surface area. This curve was regenerated in Microsoft Excel to obtain a specific equation. This equation was then input into the MathCad Sizing program. The effectiveness was calculated and then the ratio could be solved. Now the required area was known and divided by the initial span to get the corresponding aileron chord length. If the chord was unreasonable, the initial span was changed and the process was repeated. With the addition of velocity and estimated moment of inertia about the roll axis, the corresponding lift and torque were solved, which ultimately gave a roll rate. This process was repeated until a desirable roll rate was achieved. Figure 4.6 shows the roll rate versus control power.

4.3.2 Tail Surface and Control Sizing

With the center of gravity positioned at 3 inches forward of the main gear, the wing moments were found. An initial tail volume was estimated and the neutral point and static margin located. The Cmcg of the tail needed to counter the wing was determined. Then the tail area was found. See Figure 4.7. A wing angle of attack giving a favorable cruise lift coefficient was input. Then, the tail incidence angle was set at to trim the plane with 0° of elevator deflection. Because of the tail sizing needed for trim, the static margin increased to 30%. This value is higher than for typical planes, but was necessary and acceptable for the design. Again, 10% was added to the elevator size for a margin of safety.

An inverted Clark-Y airfoil gave desirable lift coefficients and decreased drag for the incidence angle used. The vertical tail area was calculated using a historical tail volume coefficient found in the AIAA text by Raymer. For the rudder, the maximum deflection was set and the effectiveness was given a value. Then the ratio and $Cn\beta$ were found which determined size. The effectiveness was adjusted to get a $Cn\beta$ value comparable to ones found for existing aircraft. The final rudder dimensions fell into the recommended value of 30-35% of the vertical tail. Aerodynamic balancing of the rudder was based on the recommended 25% value found in textbooks and existing aircraft.

An NACA 0009 airfoil was chosen for the vertical tail because of its symmetry and thin profile. The surface was swept back for aesthetics and to attain a longer moment arm for the aerodynamic center.

4.3.3 Fuselage Contribution

The pitching moment caused by the fuselage was calculated by hand and found to be insignificant. This arises because the area of the fuselage is small compared to that of the wings. Although fuselage effects were found to be negligible, the Structures Group was continuously consulted regarding the interfacing of components and the feasibility of construction. Connecting points will be smoothly flared to reduce drag.

4.3.4 Weight and Balance

The batteries were used to fine-tune the CG. A weight and balance spreadsheet, Figure 4.10, calculated the necessary location of the battery pack.

Figure 4.8 and Figure 4.9 show the results of the surface and control sizing.

The analytical methods employed by the Structures Group varied from the basic physics of force analysis to spreadsheets used to calculate approximate stresses in bodies. Basic force analyses were performed on the action of landing and decelerating to find the relative landing forces. These forces were placed into the spreadsheet with dimensional approximations to size and select the materials for construction. The landing forces were also used to size the springs required for the shock absorbers.

Figures of Merit	Weight Factor	Round Balsa Stringers	Round Carbon Fiber	Square Wood/ Carbon Fiber
Ease of Strength Analysis	0.05	2	4	4
Weight	0.25	3	4	3
Ease of Manufacture	0.3	2	2	4
Aerodynamic Shape	0.15	4	5	3
Real Cost	0.05	2	2	3
Ease of Loading/Unloading	0.2	1	3	4
Totals	1	2.35	3.25	3.55

Figure 4.2 Fuselage configuration decision matrix

Figures of Merit	Weight Factor	Tricycle	Tail Dragger	Bicycle
Weight	0.15	1	3	2
Ground Stability	0.15	5	1	3
Drag	0.1	2	3	4
Take off Performance	0.2	4	2	1
Ease of Construction	0.1	3	4	1
Landing Stability	0.3	5	3	1
Totals	1	3.7	2.6	1.75

Figure 4.3 Landing gear configuration decision matrix

Figures of Merit	Weight Factor	Oleo/Pneumatic	Spring	Rubber
Ease of Manufacture	0.4	2	5	4
Reliability	0.35	2	4	5
Expected Weight	0.25	3	4	3
Totals	1	2.25	4.4	4.1

Figure 4.4 Shock absorber design decision matrix

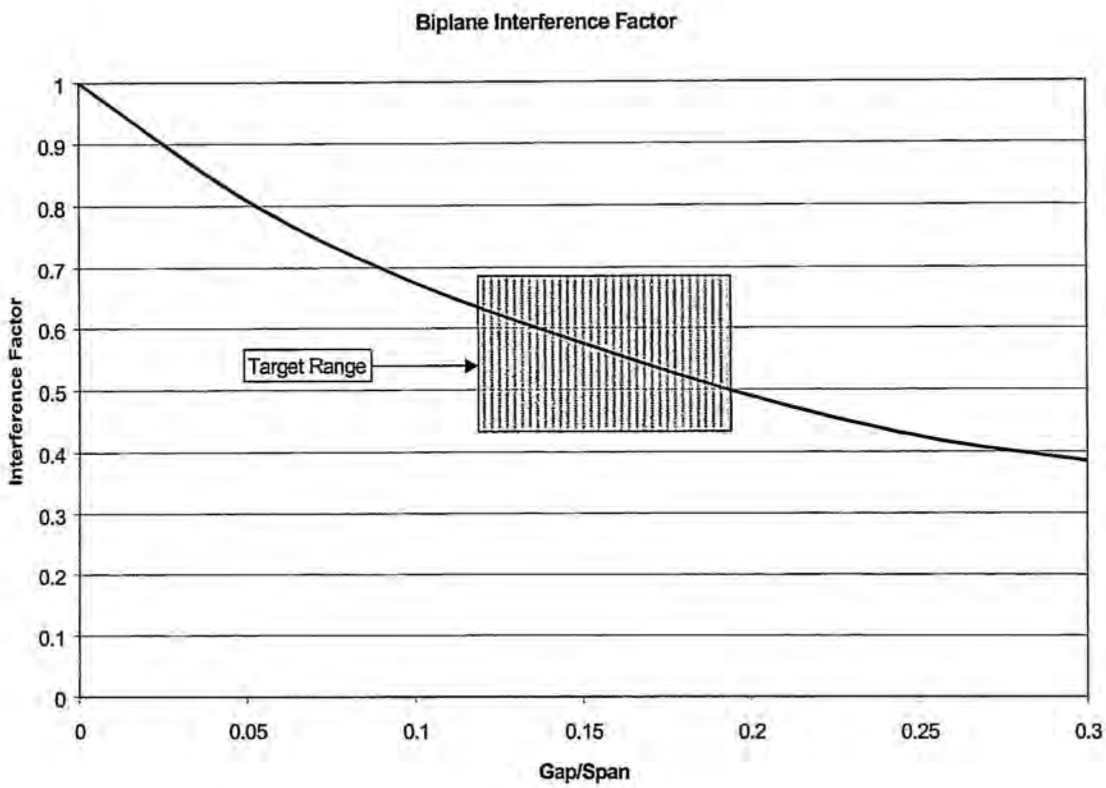


Figure 4.5 Biplane Interference Factor

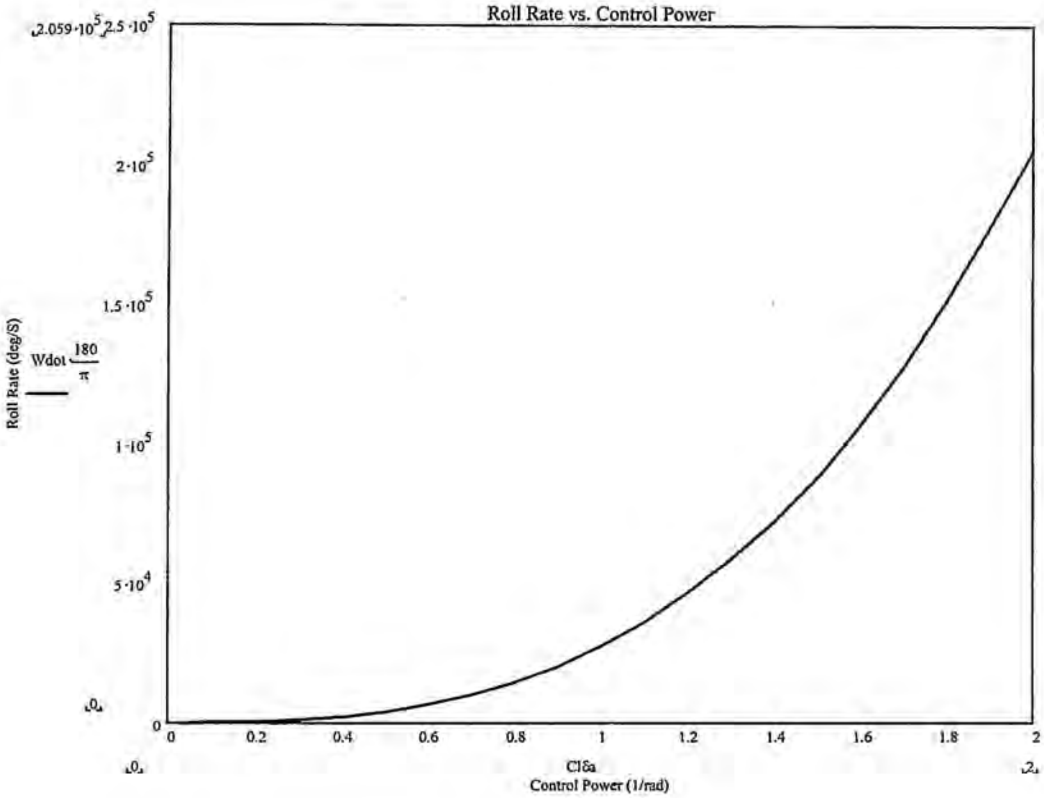


Figure 4.6 Roll Rate versus Control Power

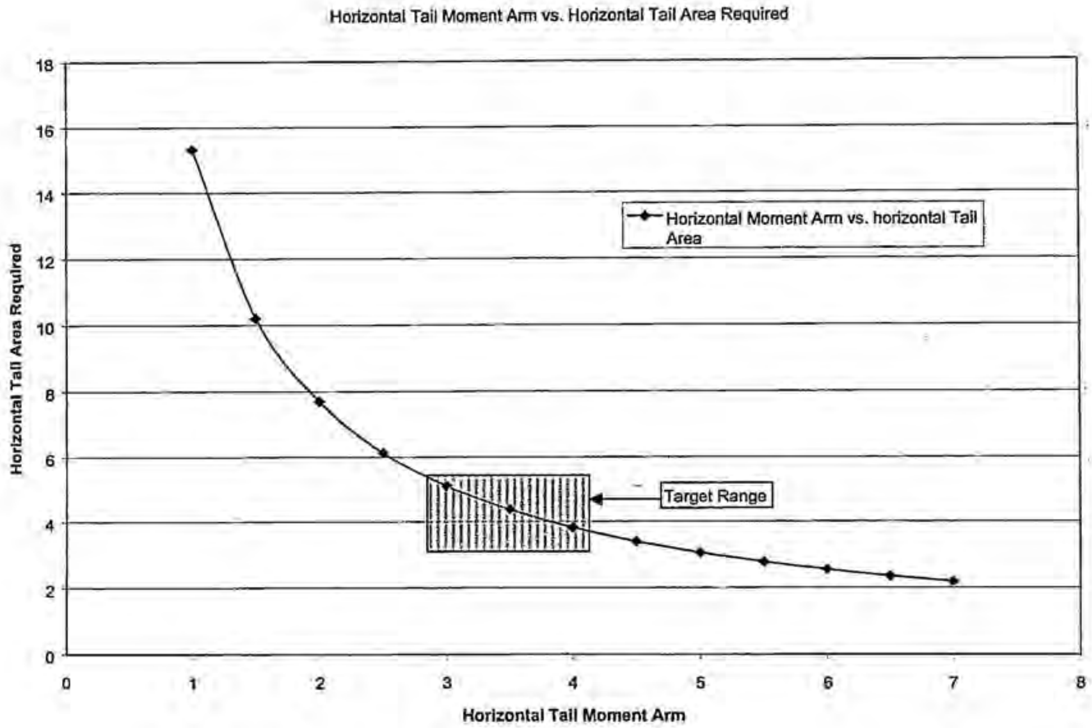


Figure 4.7 Horizontal Tail Moment Arm versus Horizontal Tail Area Required

	Horizontal	Elevator	Wing	Aileron	Vertical	Rudder
Chord (in.)	13.83	2.51	20.00	4.42	12.00	-----
Span (in.)	41.48	41.48	84.00	1.50	14.40	14.40
Area (sq. ft.)	4.38	0.72	11.67	0.55		
Flap effectiveness		0.308		0.136		
Servo deflection (degrees)		20.0		39.8		32.0
Servo force (lbs.)		0.848		0.848		0.848
Force (lbs.)		0.434		0.757		6.606

Figure 4.8 Component Sizing

Neutral Point	8.054
Static Margin	0.303
Tail Volume	0.8
Roll Rate (deg./sec)	53.465
Outer Edge Aileron Position (ft.)	3.5
Inner Edge Aileron Position (ft.)	2.0
Rudder Deflection (deg.)	15.0
Cn	0.030
CnB	0.187
Cnr	0.019

Figure 4.9 Sizing and Stability Calculations

Component		oz.	moment arm	Datum Dist.	moment
motor/gear box	1	12.5	-32.5	7.5	5.86
controler	1	3	-28	12	2.25
mount	1	7	-31	9	3.94
prop	1	3	-34	6	1.13
batteries	1	80	-3.4	36.6	183.00
front fuselage	1	4.64	-17	23	6.67
Aft fuselage	1	4.16	25	65	16.90
Horz tail	1	16	42	82	82.00
Vert tail	1	8	45	85	42.50
Spar	1	2.5	3	43	6.72
Bottle 1	1	38.2	-3	37	88.34
Bottle 2	1	38.2	-11	29	69.24
Bottle 3	1	38.2	-19	21	50.14
Bottle 4	1	38.2	12.5	52.5	125.34
Bottle 5	1	38.2	20.5	60.5	144.44
Upper Wing	1	32.08	-7	33	66.17
Lower Wing	1	3.2	3	43	8.60
End Plate	2	1	-2	38	2.38
Reciever	1	1.13	26	66	4.66
Gyro	2	1	26	66	4.13
Batteries	1	3.17	28	68	13.47
Elevator Servo	2	1.58	42	82	8.10
Rudder Servo	1	2	42	82	10.25
L. Aileron Servo	1	1.58	3	43	4.25
R. Aileron Servo	1	1.58	3	43	4.25
NWS Servo	1	2	-28	12	1.50
Nose Landing Gear	1	0.65	-27	13	0.53
Main Landing Gear	2	1.25	3	43	3.36
Brakes Assy	2	4	2	42	10.50

Weight--->					
Weight--->	384.0 oz.	Moment Sum	960.09	Payload Fraction	
	24.0 lbs.	Datum Sum	960.05	Wb/Wa-->	0.49737

1) Moment sum is a sum of all individual moments
2) Datum sum is the distance from the datum to the CG multiplied by the total weight
3) When the 2 match, the aircraft is centered about the CG location

Note: Datum is located 40 inches forward of CG location which is 2 inches aft of the lower wing leading edge.

Figure 4.10 Weight and Balance

5 Detail Design

5.1 Performance Data

5.1.1 Take-Off Performance

Take off performance was directly related to the power provided by the Propulsion Group. For the gross take off weight of the aircraft, enough power had to be provided for the aircraft to lift off within 75% of the maximum take off distance of one hundred feet. This limit was predetermined to ensure that a take off with less than maximum power could be accomplished. Based on a power of approximately eight hundred watts, it was determined that the aircraft could meet or exceed this limitation.

5.1.2 Handling Qualities

Considering the competition location, it was determined that the aircraft must be designed to handle gusty wind conditions. This required that the ailerons and rudder deflect quickly and sufficiently to counter unstable wind conditions, and the control sizing to be such that roll and yaw performance were good but controllable with standard servo actuators.

The stall characteristics of the aircraft were also of primary concern. Handling at high angles of attack under loaded conditions require that the wings have stall characteristics that would help prevent a spin in the event that the aircraft entered a stalled condition. Several steps were taken to eliminate bad stall characteristics:

First, the wing shape was considered. A tapered wing could be used to provide a more elliptical lift and increase aircraft efficiency but would cause the wing to stall very uniformly, giving the pilot very little reaction time before spin entry. A rectangular wing decreases the overall lift and efficiency of the aircraft but when entering a stall, the root of the wing stalls first and spreads outboard over the wing, reducing the rate of stall and giving the pilot more control in the preliminary stages of the stall. Therefore, the rectangular wing was selected from a safety standpoint.

Next, to assist in stall recovery, the decalage angle, or the difference in incidence angle of the wings relative to each other was researched. Using analytical and wind tunnel test data discussed in Section 5.3, it was found that a decalage angle of negative one degree (the top wing at one degree lower incidence angle than the bottom wing) would allow the top wing to stall approximately five degrees before the bottom wing. The top wing was staggered ten inches forward of the bottom wing with the CG located three inches forward of the bottom wing's quarter chord. When the top wing stalls, the lift of the bottom wing is located aft of the CG and caused a forward pitching moment about the CG forcing the nose down and assisting in the stall recovery.

As each mission requires a series of loaded and unloaded sorties, a significant amount of the gross weight will be removed during parts of each mission. This could cause the CG to shift due to the weight change. However, the payload will be loaded symmetrically around the CG to negate a CG shift during loading and unloading.

5.1.3 G-Loading Capability

As gusty wind conditions were expected due to the competition location, the accelerations that the aircraft could encounter in gusty wind conditions could easily exceed 2.5G's. Therefore, a reasonable G-loading limitation of 4G's was placed on the aircraft for safety of flight. This was determined to be reasonable based on the construction methods and materials selected for construction. All structural elements were sized according to the 4G maximum load.

A single piece spar assembly was designed into the lower wing and fuselage in which the main landing gear is mounted. This provides a structure to absorb excessive G-load that could be experienced during rough landings. With the high G factor of safety designed into the spar, the landing gear was designed with a 1.5G load capacity. This ensures that in the event of a structural failure in the landing gear, the wing will not collapse and cause further damage. The length or the spar was dependent upon the historical data and research conducted for the optimal landing gear placement. As previously stated, the length from the centerline of the fuselage to main gear strut is fourteen inches.

5.1.4 Range and Endurance

In reviewing the mission requirements it was determined that since range was constant endurance should be the primary focus. Based on loading conditions, power requirements, power efficiencies and battery limitations, various calculations were performed to maximized endurance through battery selection. For the design range of five liters of water, a full power endurance of 6.5 minutes was predicted. This decreases approximately 20% for each additional bottle carried.

5.1.5 Payload Fraction

To keep the payload fraction high, several measures were taken to reduce structural weight:

1) Landing gear was manufactured from scratch to save weight over prefabricated landing gear.
2) For greater strength, foam cores would be left in some carbon fiber sections of the aircraft. Beaded white polystyrene was selected over blue extruded

polystyrene as form material for the carbon fiber, as white is half the density of the blue.

3) Carbon fiber was selected as the main construction material for its high strength to weight ratio.
4) Since the vertical and horizontal tails do not see large forces they will be constructed of a balsa structure and Monokote covering. This provides an adequate structure with a very light weight.

The final payload fraction was determined to be 41%.

5.2 Component Selection and Systems Architecture

5.2.1 Propulsion System

The propulsion system required optimizing the overall system performance through component matching. If these components are not properly matched and overall efficiency is not optimized, then the overall performance of the system suffers. The components of the propulsion system include the batteries, the motor, and the propeller. Each of the propulsion system components was commercially available as required by contest rules.

In developing the battery pack, a spreadsheet was used to maximize power density given the five-pound limit per pack. Types of batteries considered were Sanyo 2800, Sanyo 3000, and SR 2500. The battery that provided the maximum overall score possible was the Sanyo 3000 mAh cell. Figure 5.6 compares the score versus liters carried of the various types of batteries tested. The Sanyo 3000 mAh cell satisfied the power requirements, held to the current limit, and provided the flexibility to increase the number of liters carried by the aircraft. Using the Sanyo 3000mAh battery resulted in a 25-cell battery pack.

The motor was chosen based on the maximum power required as determined by the Aero-Controls group. Only a few companies manufacture electric motors suitable for the requirements of the system. Motor manufacturers considered were Aveox and Astroflight. Ultimately, the motor with the best efficiency that could meet our needs was chosen. Brushless motors were considered, however, it was discovered that the inefficiency introduced into the system by the controller for brushless motors negates the efficiency gained by choosing brushless over brush motors.

Commercially available custom windings were also considered, but they were deemed unnecessary for anticipated operating conditions. The motor best suited for the desired performance was the Astro Cobalt 40 8T#20 motor with a 3.1:1 gearbox. The gearbox was used to reduce the number of revolutions per minute of the propeller, hence, producing the desired thrust.

An analysis was performed to match a propeller to the system based on experimental data. The propeller that provided the highest takeoff thrust and best efficiency was selected for use. Using equations that described the performance of several different propellers in terms of C_T, C_P, thrust, and efficiency, a spreadsheet was developed to aid in selecting the propeller that helps optimize overall performance. Figure 5.7 through Figure 5.9 show the resulting data. Takeoff thrust requirements were considered first, then cruise thrust, and then efficiency. The propeller with 0.7 pitch-to-diameter ratio best suited our needs. The takeoff thrust provided by this propeller was 8.7 pounds. The cruise velocity attainable with this propeller was 57 feet per second.

Maintaining maximum possible overall efficiency in the propulsion system was critical. In an attempt to reduce losses in the system, tests were conducted on last year's system using a dynamometer to determine the impact of cooling schemes. Cooling the batteries had no impact on the overall performance of the propulsion system. However, cooling the motor had a significant impact on the overall efficiency of the motor. With this in mind, fins were developed to help dissipate heat away from the motor, thereby helping maintain higher efficiency during operation. As seen in Figure 5.10 and Figure 5.11, the thrust and power increased by approximately seven percent. The endurance also increased by approximately 15 seconds.

The propulsion system consisted of an Astro Cobalt 40 8T#20 motor with a set of cooling fins attached directly to the motor to expedite cooling. The motor used a 3.1:1 gearbox to drive an APC propeller with a 0.7 pitch-to-diameter ratio. One battery pack consisting of 25 Sanyo 3000mAh cells and weighing less than five pounds served as the power source of the system.

5.2.2 Landing Gear and Braking System

The landing gear was manufactured in-house and consisted of a tricycle design with a hydraulic braking system located on each of the main gear hubs. The nose landing gear is steerable which alleviates the need for differential braking. The steerable nose wheel is supported within a yoke and centered on the nose wheel strut (see Figure 5.12). The main wheels consist of the braking device in the center of the wheel that is attached to the main strut (see Figure 5.13). The landing gear struts consist of spring shock absorbers pinned into a wooden block mounted at the end of the wing spar (see Figure 5.14). The insertion of the strut through the wing and into the spar also acts a securing device for holding the wings in place.

The drum style braking system uses water as the working fluid and consists of a master cylinder, pressure hose, wheel cylinder, brake shoe and hub. The master cylinder for each wheel hub brake is located on an access panel behind each main strut in the wing. This panel also provides access to the aileron control servo. The brake hydraulic lines are connected together through a pressure line running through the fuselage to ensure that the brakes will have equal pressure actuation regardless of any discrepancies in the control servos or master cylinders.

5.2.3 Aerodynamics

As discussed before, the Selig 1223 airfoil was selected primarily on its high lift to drag ratio. It was the primary reason for the use of composite materials due to its complex design. The 1223 demonstrated excellent qualities from wind tunnel tests that have confirmed published data of the airfoil.

Wing area was determined through the score evaluation and was sized to maximize score. This led to a wing loading of 1.3 and a total wing area between the two wings of 22.6 square feet.

Tail volume was designed by summing the moments of the wing, fuselage and tail. Due to the high forward pitching characteristics of the wings, an inverted Clark Y airfoil was used for the horizontal tail to decrease drag at the incidence angle of negative six degrees required to stabilize the aircraft at cruise. Refer to Figure 5.3 for the C_M versus α plot.

The vertical tail was sized to achieve the C_{nB} of 0.187, approximately that used by larger general aviation aircraft. The rudder was sized in the same manner to give a C_{nr} of 0.019. This was deemed adequate to control the aircraft in yaw in gusty wind conditions.

5.3 Wind Tunnel Testing

In order to validate performance data for the Selig 1223 airfoil, and to study the effects of the airfoil in the biplane wing configuration, it was decided to construct a one third scale wing set in order to perform flow visualization and determine lift and drag with the use of a force balance. The wings were mounted so the decalage angle between the wings could be varied and the assembly could be varied from an angle of attack of negative thirteen to positive thirty. This allowed a study of the stall characteristics of the airfoil when in the monoplane and biplane configurations and the effects of the wings on each other. This also allowed flow visualization to determine the proper decalage angle in which the top wing would stall at a slightly lower angle of attack to increase stall recovery and stability.

Tests were performed at a Reynolds number of 400,000 and a velocity of 85 ft/s. Resulting data for lift and drag from the force balance used during the study can be found in Figure 5.1 and Figure 5.2. Some flow visualizations were accomplished at slower velocities and Reynolds numbers to study variances in the stall characteristics at lower Reynolds numbers. This data proved to be invaluable in the flow visualization alone and showed that with the wings spaced 75% of a chord length apart, very little lift was lost due to interference. It also showed that, at 30 degrees angle of attack, the effects of the top wing prolonged the full stall of the lower wing to a Reynolds number of half that of the test number. Evaluation of this data determined the decalage angle of the top wing to be set at negative one degree. A slight loss in the maximum coefficient of lift was suffered but was deemed to be a necessary trade off for improved stall safety. Pictures showing wind tunnel setup and operation can be found in Figure 5.4 and Figure 5.5 respectively.

5.4 Sizing and Configuration

Basic empty weight	17.5 lbs.
Payload weight	11.5 lbs.
Gross TO weight	29 lbs.
Payload fraction	0.40
Gross TO weight wing loading	1.3
Aspect ratio for each wing	4.19
Total Wing area	22.6 ft^2
Wing span	7 ft
Mean aerodynamic chord length	1.67 ft
Wing stagger	10 inches
Wing Separation	14 inches
Number of Servos	8 Servos
Final Configuration RAC	$6181.50
Final Configuration Estimated Score	24.26

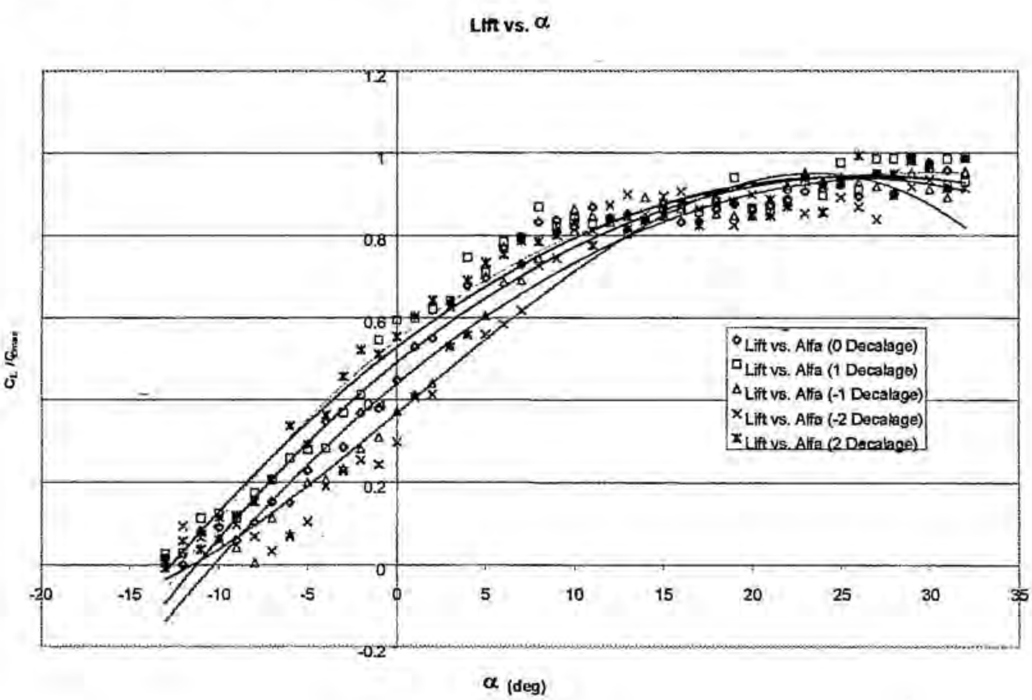


Figure 5.1 C_L versus α

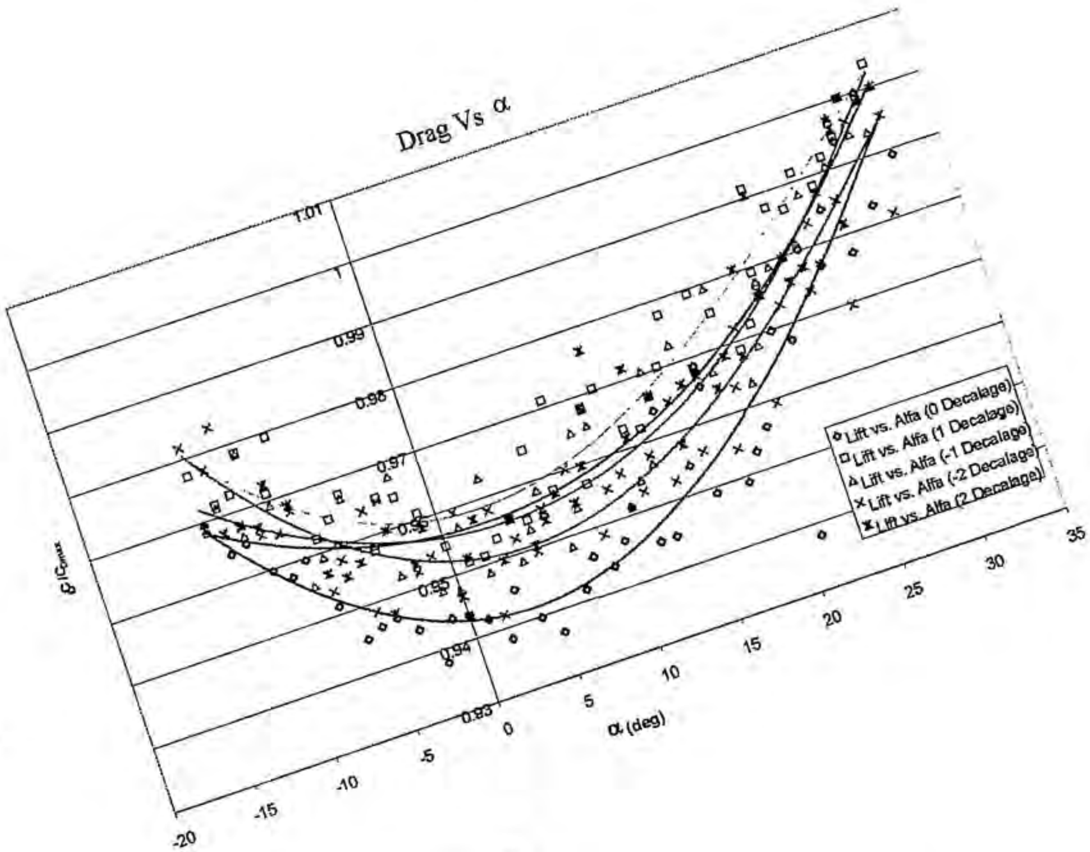


Figure 5.2 C_D *versus* α

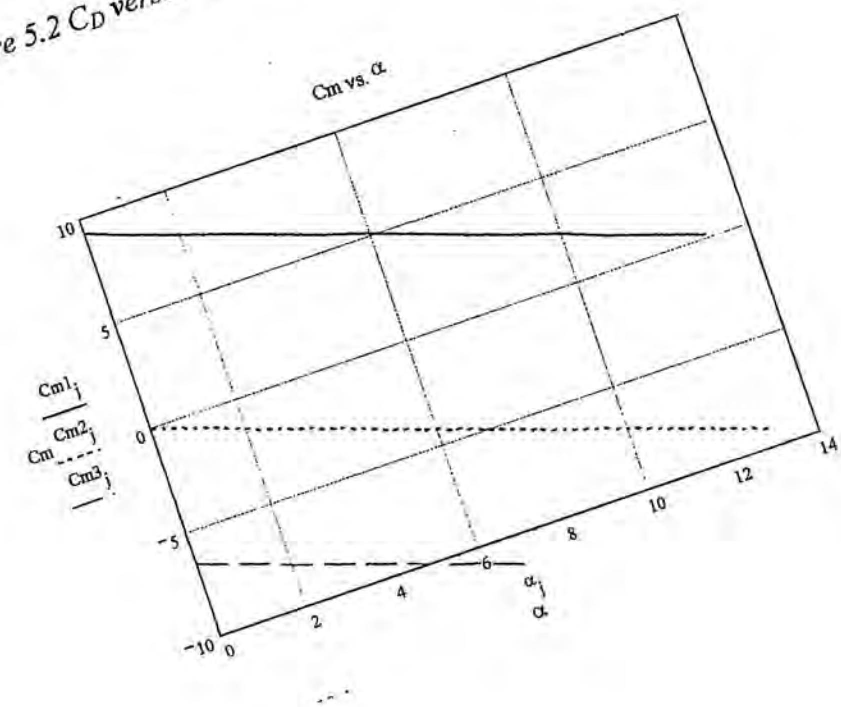


Figure 5.3 C_m *Vs* α

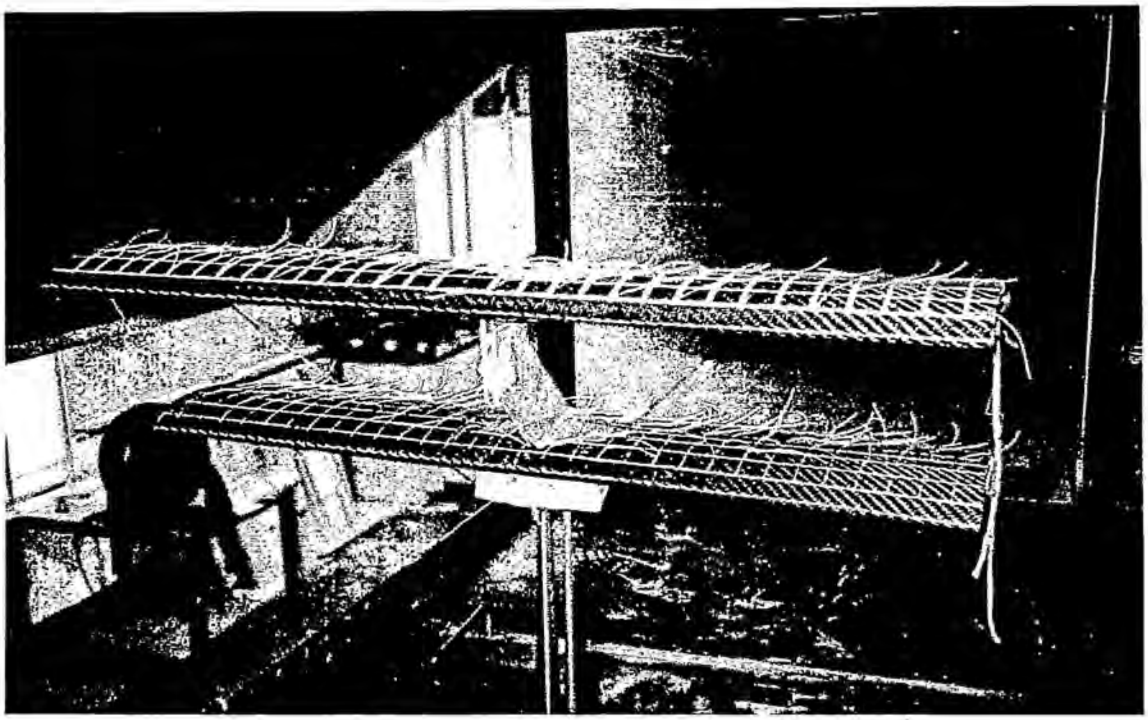


Figure 5.4 Wind tunnel test setup

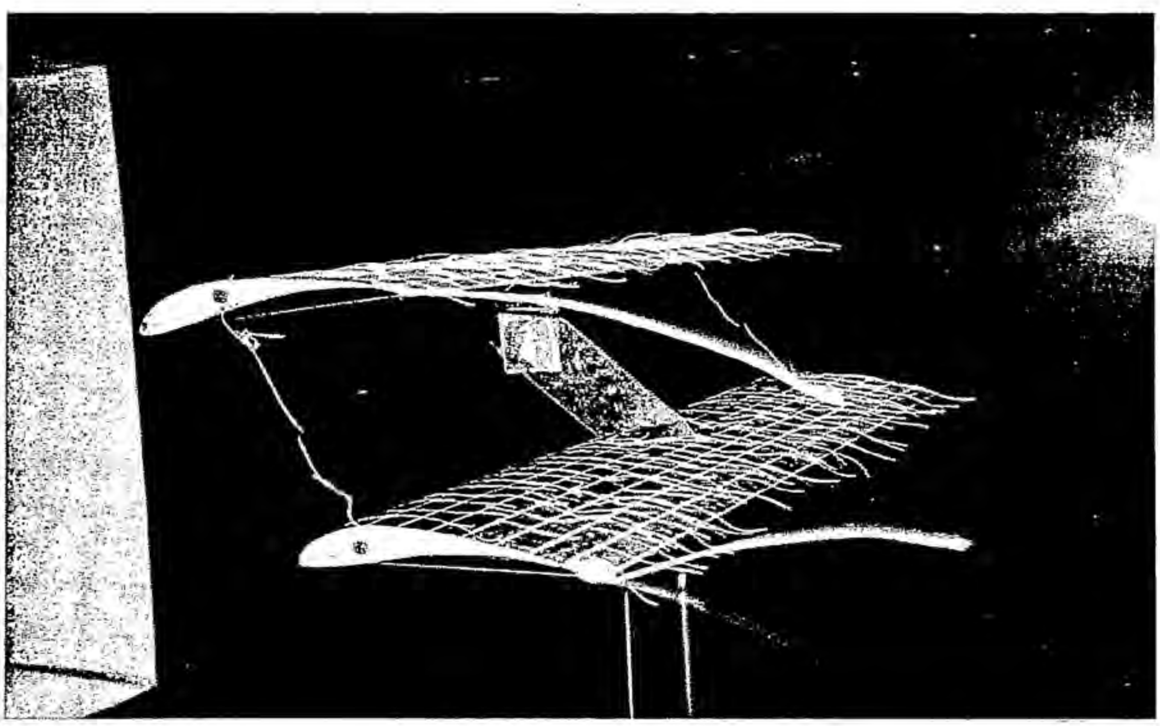


Figure 5.5 Wind tunnel testing in progress

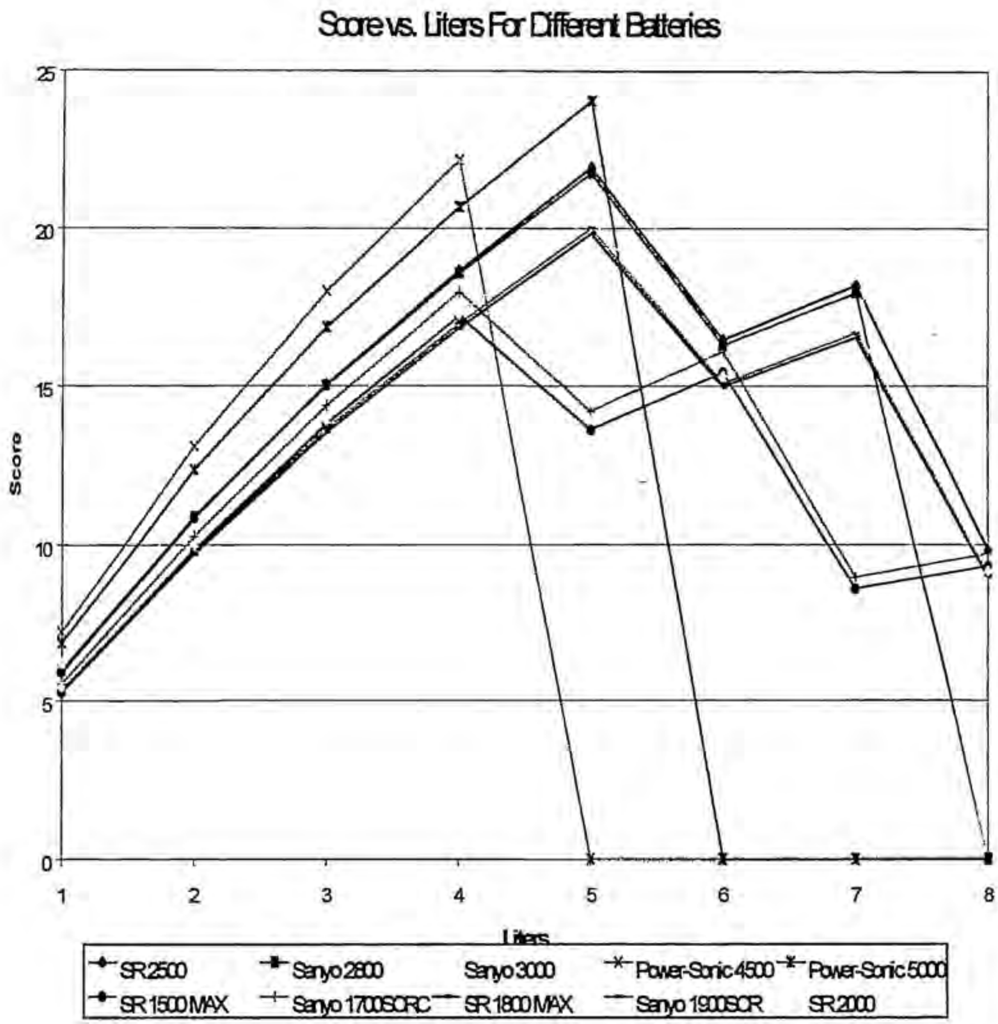


Figure 5.6 Score vs. Liters with Different Batteries

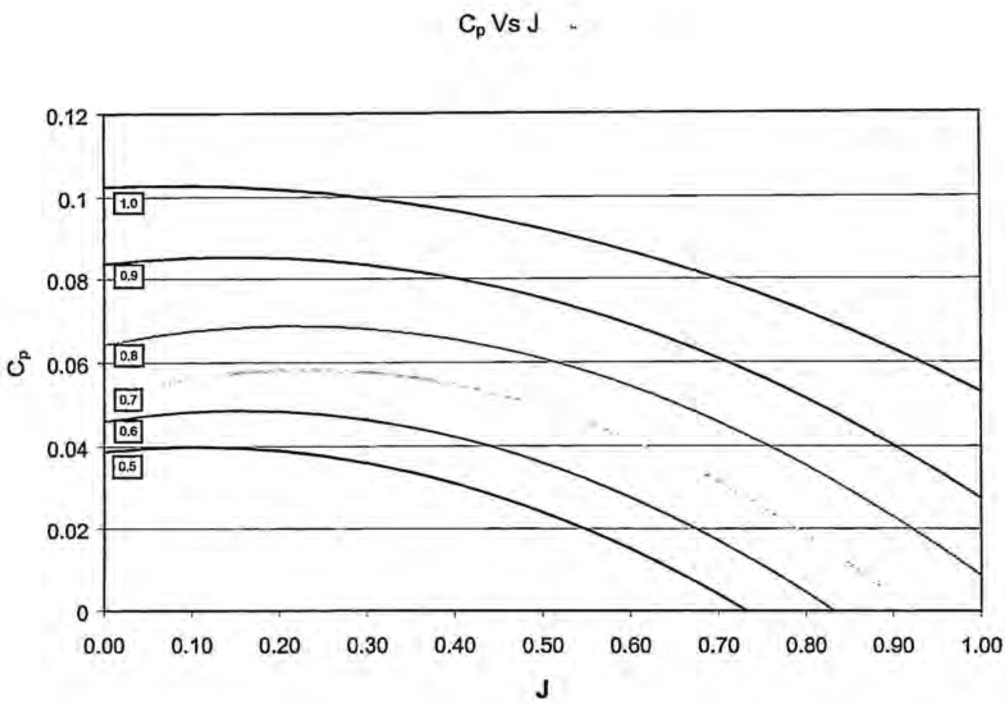


Figure 5.7 C_P vs. J

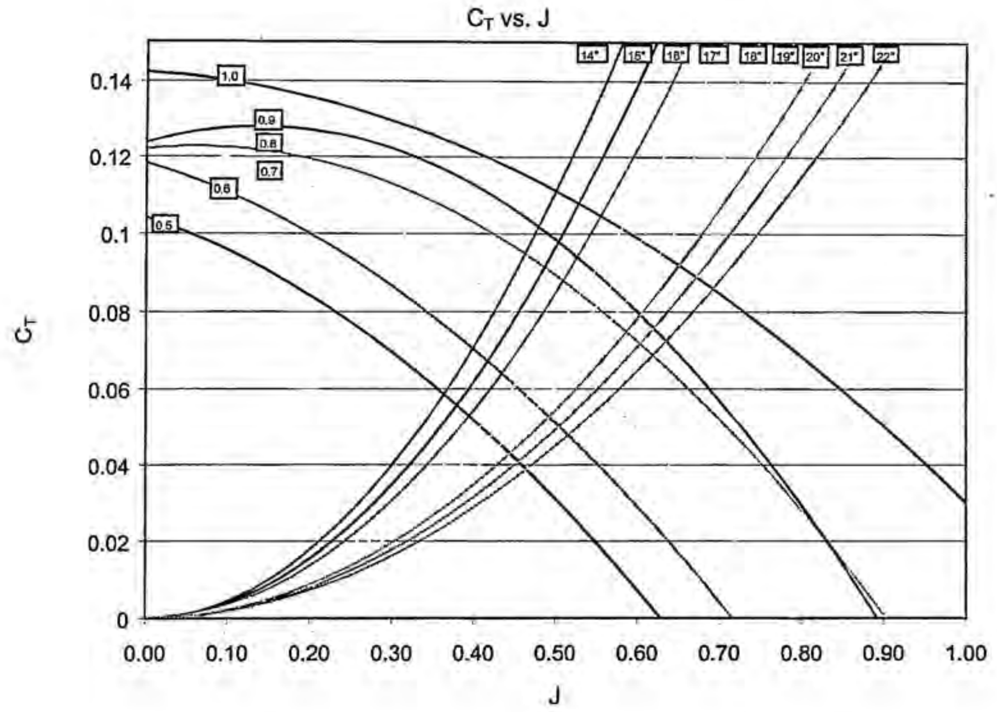


Figure 5.8 C_T vs. J

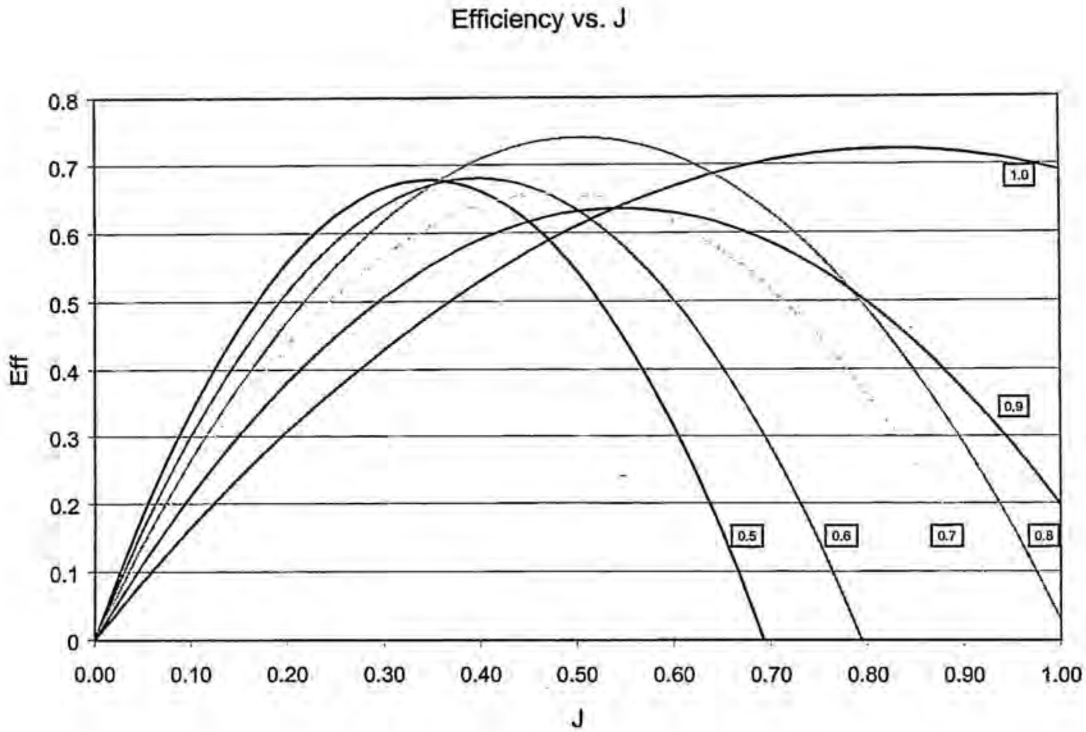


Figure 5.9 Efficiency vs. J.

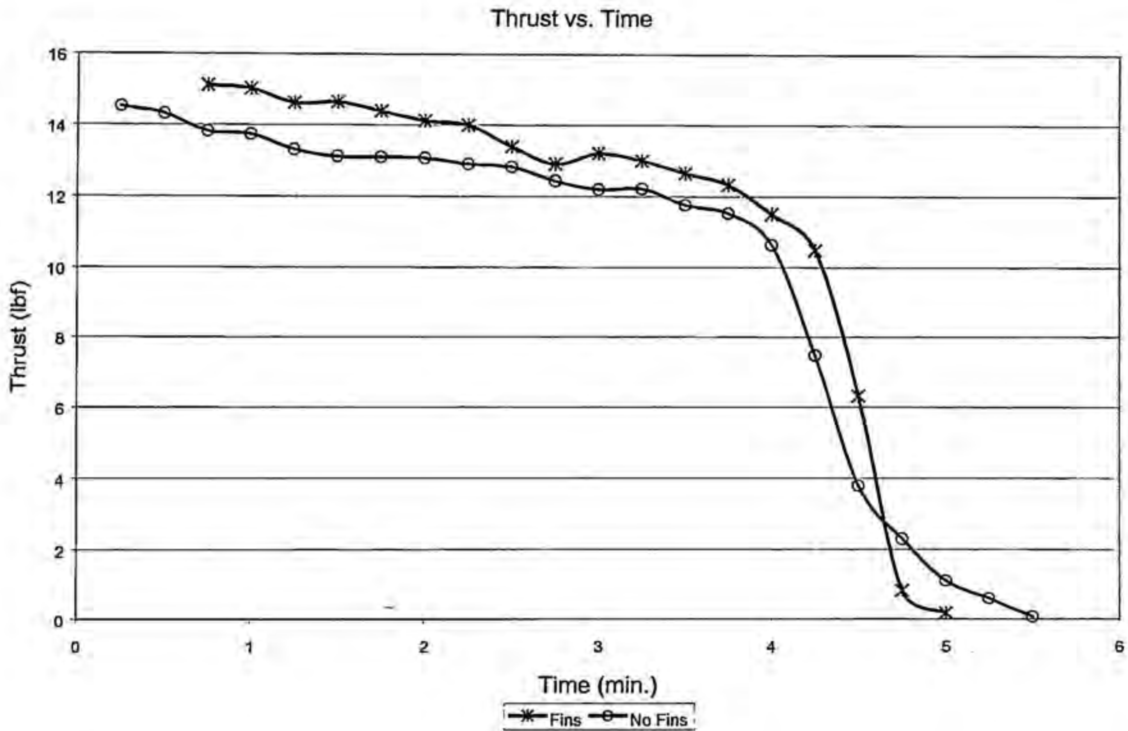


Figure 5.10 Thrust vs. Time

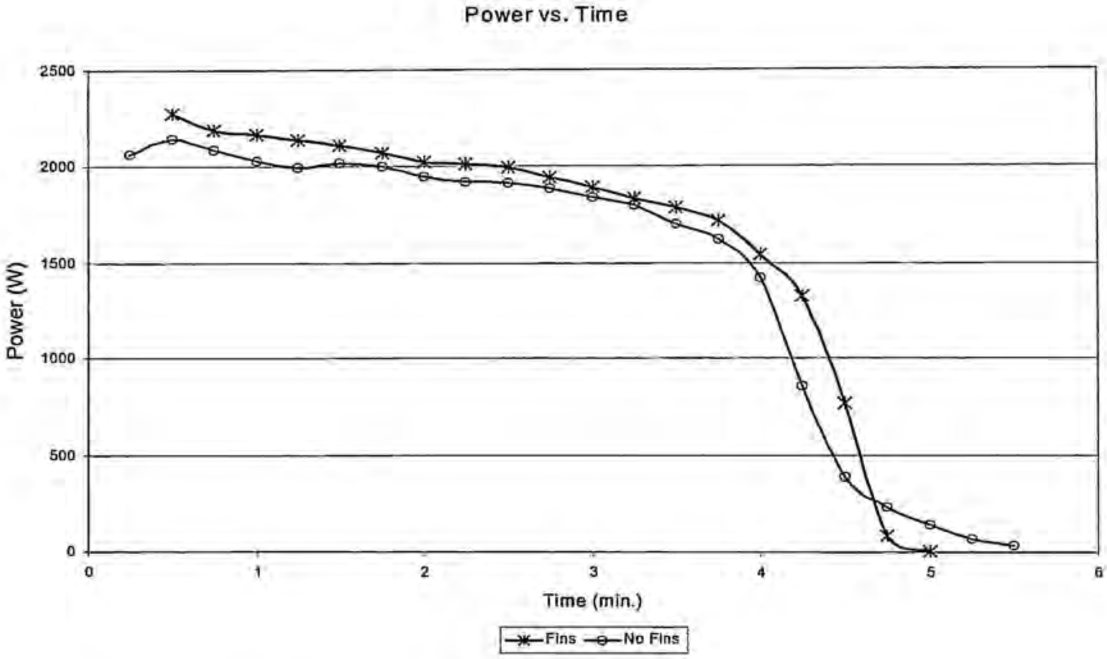


Figure 5.11 Power vs. Time

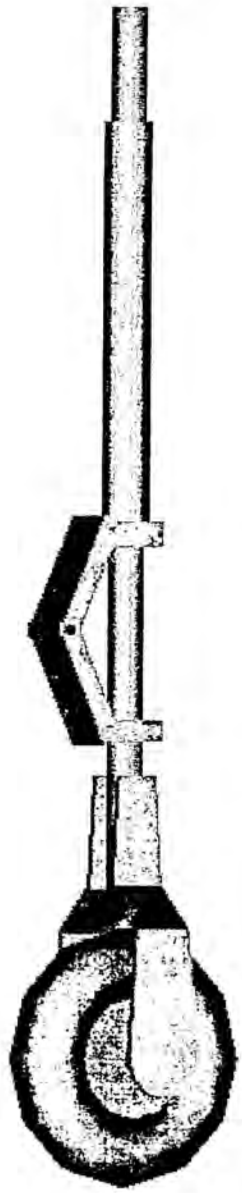


Figure 5.12 Nose Wheel 3D View

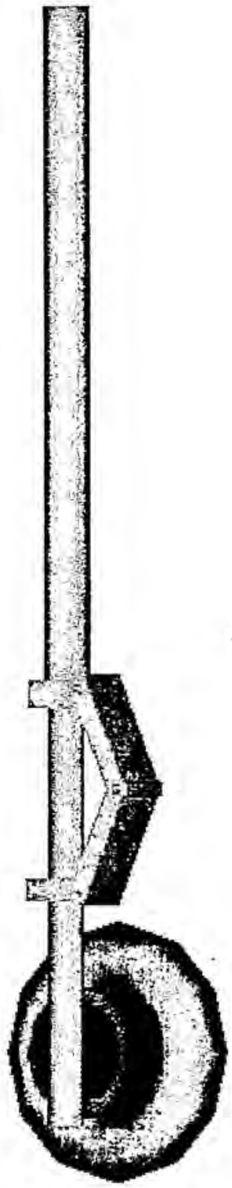


Figure 5.13 Main Wheel 3D View

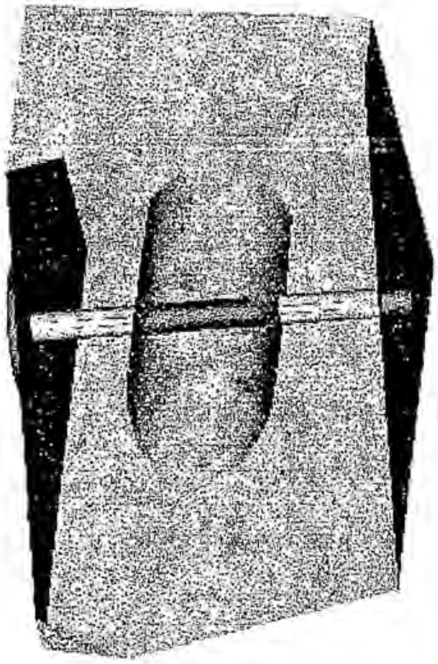


Figure 5.14 Main Strut Mounting Block 3D Cut-Away View

6 Manufacturing Plan

6.1 Manufacturing Processes Investigated

The processes considered for the manufacture of the aircraft centered on the following materials:

- Balsa wood and Monokote™
- Carbon fiber and Kevlar™
- Aluminum

The first process considered, which involved primarily balsa wood and Monokote, was thought to be the most common method of constructing small-scale aircraft. The wings of the aircraft would be formed by cutting thin ribs from sheets of balsa, gluing the ribs to a central spar (or to multiple spars if extra support were needed) and coating the structure with Monokote. The horizontal and vertical stabilizers would be constructed in the same manner as the wings. The fuselage would consist of thin balsa sheets forming a box structure, with several balsa longerons running the length of the fuselage for support. Small pieces of plywood or pine would be used for high-stress components such as the motor mount, landing gear blocks, and fuselage doublers. Thus, an aircraft constructed using this process would consist primarily of a balsa wood frame covered with Monokote, with plywood or pine adding extra strength to critical areas.

The second process, which involved primarily carbon fiber and Kevlar, was considered as a means to produce a much more durable and streamlined aircraft. This method would consist of laying up pre-preg carbon fiber over foam molds for the fuselage, wings, and stabilizers. Kevlar would be used to reinforce high-stress areas such as the motor mount and component attachment locations.

The third process, which involved only aluminum, was known to be common in larger aircraft. Fabrication using aluminum would involve careful machining of individual parts, followed by riveting the parts together. The strength provided by aluminum would allow this aircraft to be essentially a hollow shell.

Finally, a combination of the above three options was considered as a fourth potential manufacturing process. This process would consider each component of the plane (i.e., wings, fuselage, and stabilizers) individually, and the best material for each component would be selected.

6.2 Figures of Merit

The figures of merit used to screen competing concepts were the following:

- Strength to weight ratio of materials
- Availability of materials
- Cost of materials
- Required skill levels
- Required time of construction
- Ability to produce desired profiles

The composite materials possessed the best strength to weight ratio. An addition of a foam core increased the second moment of inertia, giving even higher strength. White polystyrene foam was found to have approximately half the density of blue insulation foam.

Although the availability of materials was essential, it did not restrict the team's choice of manufacturing processes since all of the materials under consideration were readily available. Monokote and large sheets of balsa could be easily ordered from hobby shops. Carbon fiber and Kevlar were available from nearby composite manufacturers. Aluminum sheets could be purchased at local hardware stores.

Cost of materials was an important consideration, but it did not completely restrict use of the more expensive materials (carbon fiber and Kevlar) since funding was available in the form of sponsorship from local businesses. Also, one manufacturer of composite products was willing to sell materials to the team at no profit, which made composite materials much more affordable.

The necessary skill levels associated with each manufacturing process limited the feasibility of some processes. For example, all members on the team had some experience with machining aluminum, but few possessed the expertise to machine all parts of the aircraft from aluminum.

Required time of construction was a concern because less than three weeks were available for constructing the prototype after construction drawings were complete, and even less time was available for constructing the final aircraft after flight testing the prototype.

The ability to produce desired profiles had the highest impact on the manufacturing processes selected. The only material that would allow the production of sophisticated high camber airfoils and a streamlined fuselage was carbon fiber. In contrast, balsa wood would permit few curved surfaces on the aircraft, and aluminum would be difficult to machine to an exact profile. Achieving desired component profiles was extremely important to the team due to the impact this would have on the aircraft's overall performance in flight.

The figures of merit were incorporated into a decision matrix as seen in Figure 6.2. This provides a general view of the individual characteristics of each material considered. The most suitable material for each aircraft component was then selected while maintaining an acceptable balance for interfacing materials.

6.3 Assemblies of the Final Design

After carefully considering each figure of merit described above, it was decided to produce the aircraft using a combination of different materials and manufacturing processes.

6.3.1 Wings and Spar

A carbon fiber skin with a white polystyrene beaded foam core was used for the wings. A template of the Selig 1223 airfoil was constructed and used in conjunction with a commercially available foam cutter to ensure precise shaping of the foam wing cores. The ailerons were attached to the lower wing using a gapless hinge to prevent airflow disruption. A carbon fiber wing spar was rigidly attached to the fuselage. The lower wing simply slides onto the wing spar and is held in place by the landing gear, as described below. A carbon arrow shaft is inserted aft of the main carbon fiber spar in the lower wing, through the fuselage, to act as a torsional secondary spar. The upper wing is attached to the aircraft by end struts and a center strut, made of a carbon fiber foam carbon fiber sandwich. The end struts are bolted in place with nylon bolts. The center strut is epoxied to the upper wing and bolted to the fuselage for easy removal.

6.3.2 Fuselage

The fuselage was constructed out of carbon fiber, with Kevlar and wood inserted to reinforce high-stress areas. Foam was used to obtain the desired fuselage profile. After the carbon fiber had cured over the foam molds, the foam was extracted to allow for the placement of the payload. Wooden bulkheads were then added to the fuselage for both torsional and bending strength.

6.3.3 Motor Mount

An aluminum motor mount was constructed and bolted to a Kevlar firewall in the fuselage. It was formed from a single piece of aluminum sheet that was cut and bent in place. It was then secured together with rivets.

6.3.4 Landing Gear and Brakes

The landing gear and brakes were constructed of aluminum. The main gear was supported by a small block of pine embedded at the endpoints of the spar. This block of wood was also utilized in the attachment of the lower wing. A quick release pin secures the gear and wing into the spar while allowing easy removal of the lower wing for shipping purposes. Kevlar reinforcements were added to the nose gear and fuselage junction.

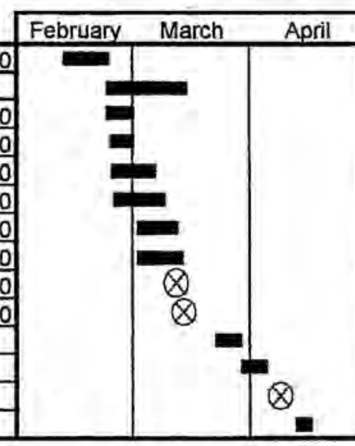
6.3.5 Empennage

The vertical and horizontal stabilizers were constructed of balsa wood and Monokote. As described above, these were formed by cutting thin ribs from sheets of balsa, gluing the ribs to a central spar, and coating the structure with Monokote. This significantly reduced the weight and resultant moment of the stabilizers, as compared with a carbon fiber and foam core buildup. The spars of the vertical stabilizer extend into the rear of the tail and then are epoxied in place. The horizontal tail has a carbon arrow shaft spar that extends through the rear of the fuselage. It is then epoxied to the rear of the fuselage.

6.4 Manufacturing Milestone Chart

The construction of the prototype began on February 22 and was completed on March 13. The following milestone chart illustrates the construction process graphically.

Construction Drawings	2/9/00	2/19/00	2/21/00
Structures - Experimental Testing/Construction	2/21/00	3/7/00	
Construction Preparation	2/21/00	2/22/00	3/1/00
Cut Molds	2/22/00	2/24/00	3/2/00
Carbon Fiber Layup and Detail	2/24/00	3/3/00	3/9/00
Final Construction	3/2/00	3/5/00	3/11/00
Systems Integration	3/3/00	3/7/00	3/12/00
Prepare Phase 1 Proposal	3/3/00	3/8/00	3/13/00
Proposal Due Internally	3/8/00		3/10/00
Progress Report 3 - Prototype Rollout	3/8/00		3/13/00
Detail Drawing Modification	3/20/00	3/27/00	
Final Design Construction	3/27/00	4/6/00	
Aircraft Grounded	4/10/00		
AIAA International Contest	4/14/00	4/16/00	

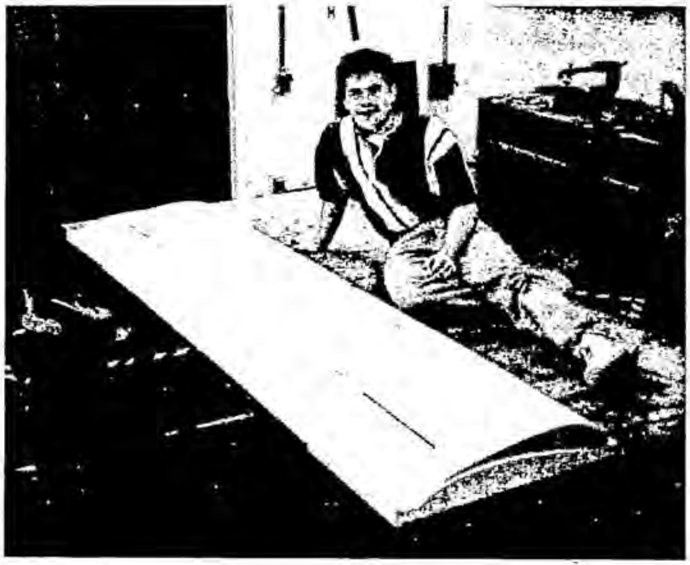


Scheduled Time
Actual Time
Internal Deadline ⊗

Figure 6.1 Manufacturing Milestone Chart

Figures of Merit	Weight Factor	Balsa Wood and Monokote	Carbon Fiber and Kevlar	Aluminum
Strength to Weight Ratio	0.2	4	5	3
Availability of Materials	0.05	5	3	4
Cost of Materials	0.05	5	2	3
Required Skill Levels	0.15	5	2	2
Required Time of Construction	0.2	4	5	2
Ability to Produce Desired Profiles	0.35	2	5	3
Totals	1	3.55	4.3	2.7

Figure 6.2 Material Decision Matrix



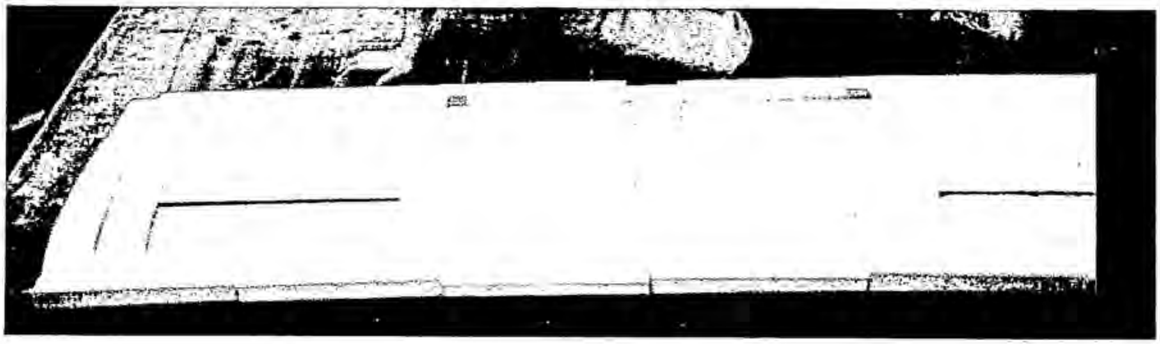
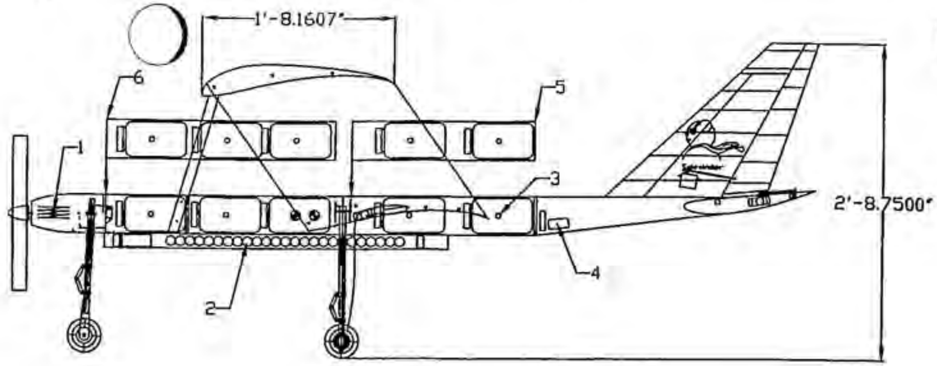
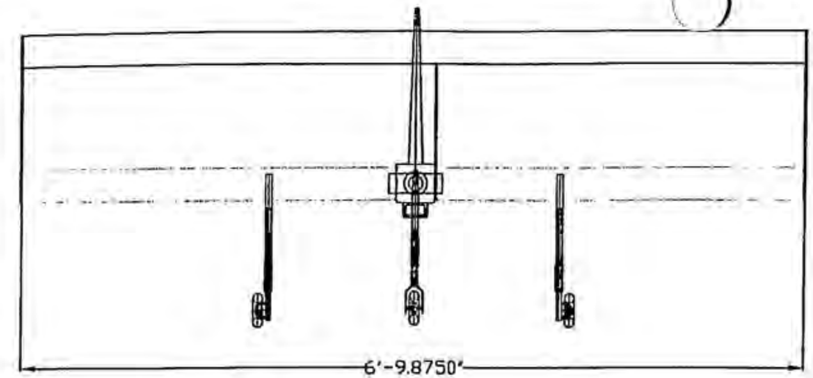
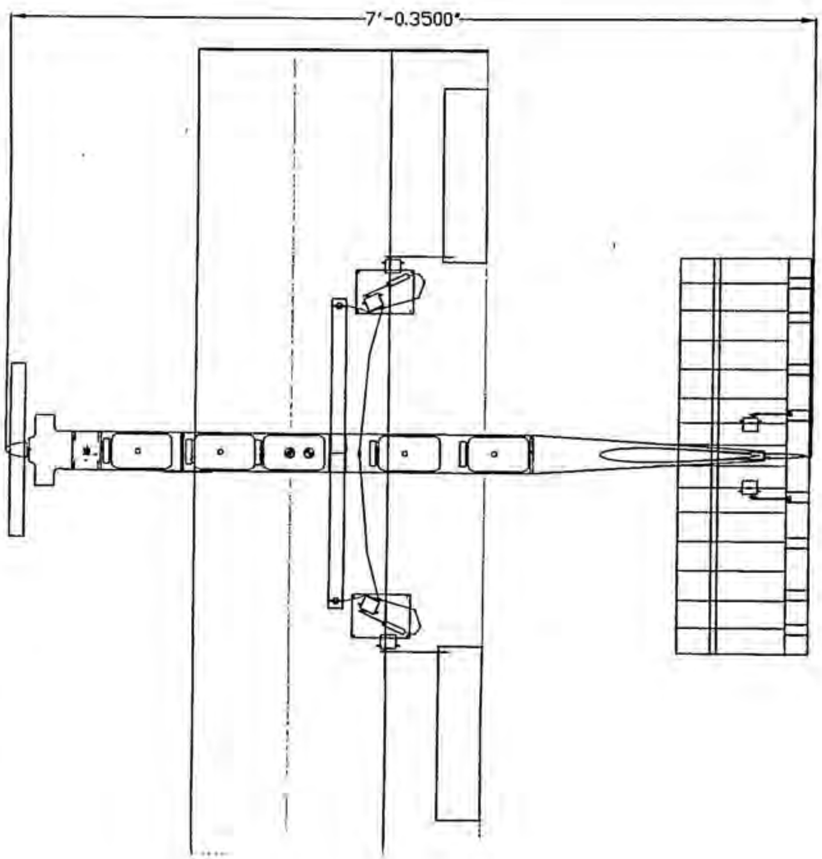


Figure 6.3 Lower Wing Foam Core Lay-up







1. Cooling Fins attached to Motor
2. Battery Pack
3. Water Bottle
4. Reciever and Systems Batteries
5. Aft Hatch
6. Forward Hatch

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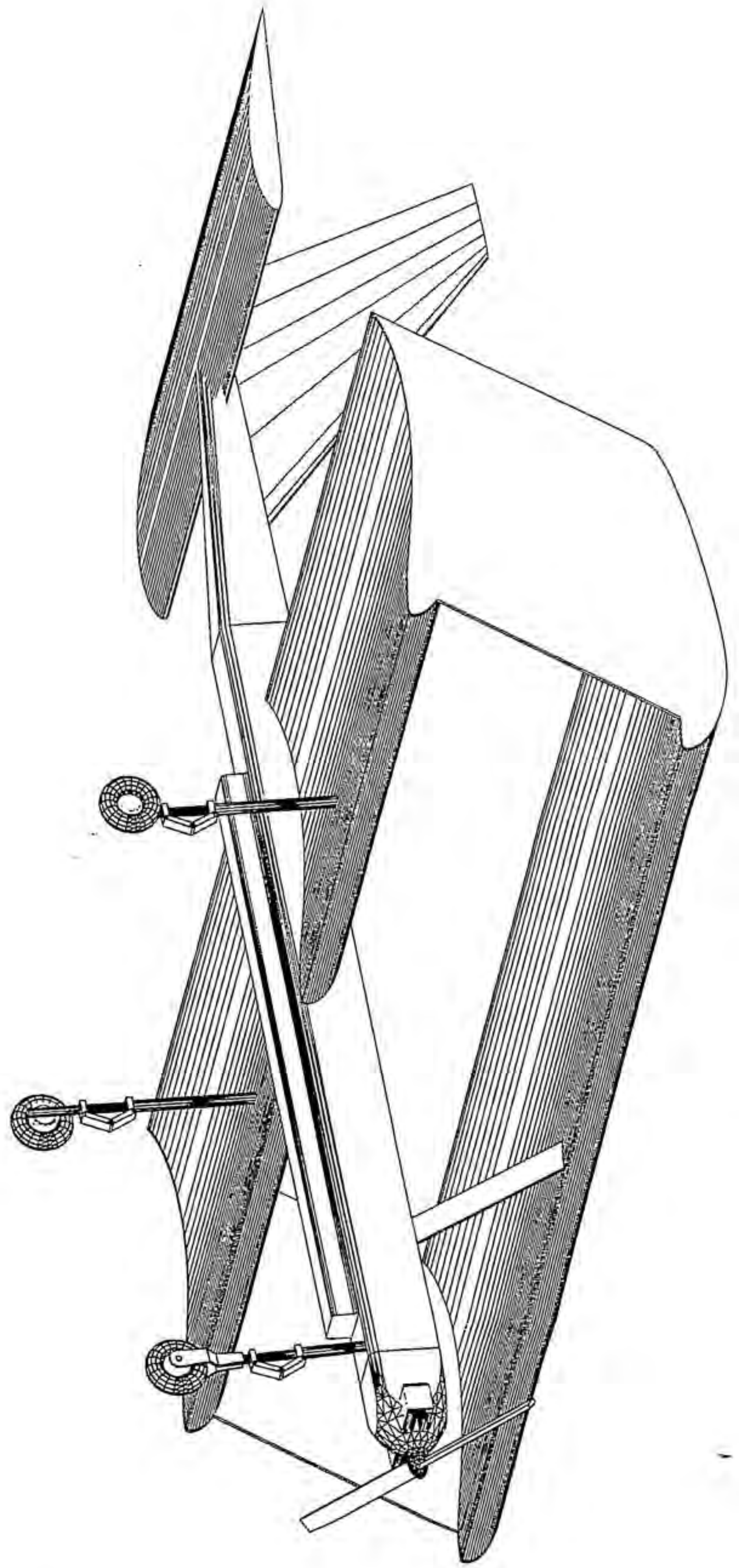

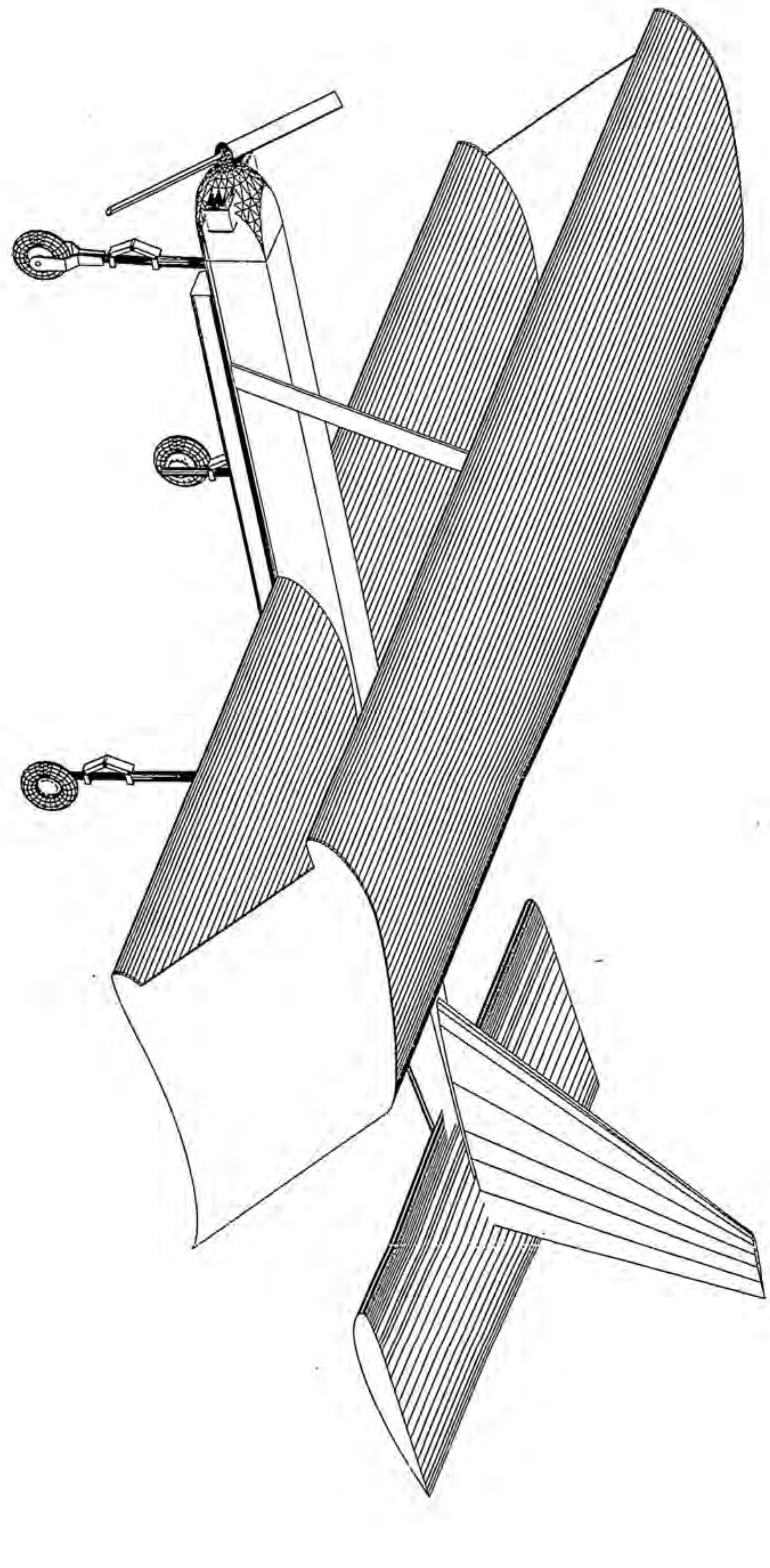

2000 Cessna/ONR Student Design/Build/Fly Competition

Addendum Phase

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7 Lessons Learned

After completion of prototype construction, the team took the opportunity to perform extensive flight tests. This testing allowed any arising problems to be solved and modifications to be made to the aircraft before construction of the final aircraft.

7.1 Aerodynamics Group

7.1.1 First Flight

The first flight occurred on the afternoon of March the twenty-fourth. The aircraft, along with ballast to correct the center of gravity, was approximately seven pounds overweight, forcing the first flight to take place with the equivalent of three liters of water on board. The aircraft lifted off smoothly into a 15-knot quartering crosswind and climbed slowly to altitude. After completion of one lap around the pattern, the flight was brought to an end by landing the aircraft into the wind. During final approach, the aircraft came close to hovering and touched down with an approximate 10-foot landing roll.

Observations made during this flight highlighted two things. First, the Selig 1223 airfoil performed better in the bi-wing design than initially determined. This was determined by calculating the coefficient of lift from the stall speed and known weight of the aircraft during the flight. Since the aircraft came close to hovering during approach, the approximate wind speed could be used as the stall speed. Second, the parasite drag of the aircraft was much higher than predicted. The known power of the flight was used along with the approximate cruise speed and weight to estimate the parasite drag of the aircraft. This allowed the aircraft to fly at very low airspeeds but prohibited the aircraft from attaining adequate cruise velocities.

7.1.2 Second Flight

The second flight of the day was performed with a larger propeller producing an increase in performance while validating data from the previous flight. In this flight, various turns along with straight and level flight were accomplished. On the base leg to landing, propulsive power was lost and an engine-out landing was performed short of the runway. No damage was done to the aircraft, to the amazement of the cows sharing the field.

7.1.3 Lessons Learned

Aside from the drag and propulsion discoveries, data from both flights showed the stability and control of the aircraft was as predicted with one exception. Slight pitching difficulties were initially encountered, which were corrected by trimming the elevator and shifting the angle of the thrust line by two degrees. The vertical center of gravity was higher than the thrust line and resulted in a pitching up moment. Angling the motor down slightly placed the thrust line through the center of gravity, correcting the pitching problem and reducing the amount of nose-down trim needed. Roll and yaw response was reported to be excellent with rudder and aileron controls coordinated and provided excellent handling in turbulent conditions.

7.1.4 Changes Made

Based on the data gathered from the test flights, further analysis was performed to minimize drag and weight while maximizing lift and score (See Figure 7.1 and Figure 7.2). This information led to two major changes and a few minor ones. First, the wing area was reduced by 25 percent. In doing this, the overall volume, thus the weight, of the wings was decreased exponentially while lift was decreased linearly (See Figure 7.2). This also decreased the drag created by the wings due to surface area. Second, much effort was focused on devising a lay-up method for the carbon fiber that would produce a smooth finish. The surface finish on the prototype aircraft's wings was very rough, and combined with the area of the wing, created higher than acceptable drag. Other minor changes included decreasing the horizontal tail sizing proportionally with the wing. Also, a thinner, symmetrical airfoil was used in place of the inverted Clark Y airfoil originally selected, as the pitching moment of the Selig 1223 airfoil was not as great as expected.

7.2 Propulsion Group

7.2.1 First Flight

From previous unsuccessful take-off attempts, it was determined that a higher propulsion power was required. A larger propeller was mounted to the motor for the second flight. With the larger propeller the plane was able to take off and climb successfully, but power was still insufficient to produce adequate flight speeds.

7.2.2 Second Flight

During the second flight the same propulsion configuration was successfully used although the motor was damaged from the increased current drawn required from the larger propeller. Additional test flights were terminated since enough information had been collected to refine the prototype aircraft.

7.2.3 Changes Made

In order to increase power capacity, the AstroFlight Cobalt 640 motor has been replaced with an AstroFlight FAI 660 motor for the final plane. The FAI 660 motor is rated to 60 Amperes, where the Cobalt 640 can only handle 30 Amperes. The Cobalt 661, 662, 690 and Cobalt 691 were also considered as replacements for the Cobalt 640, but these motors could not handle current in excess of 35 Amperes. The FAI 660 was also the most efficient option with a 25-cell battery pack. Only AstroFlight motors were considered because speed controllers and connections had already been purchased to match their motors.

Propeller size was increased from the original design for the reasons discussed above. The propeller diameter was increased by 13 percent. This increased the static thrust of the propulsion system by 40 percent. The increase in thrust along with the reduction of wing area will result in an increase of the flight velocity of the aircraft.

The number of cells in the battery pack was not changed, but the battery pack configuration was modified from the original design. Instead of placing the batteries side-by-side in one long row, the batteries were placed side-by-side in two rows and then stacked, one row on top of the other. This allows the batteries to be shifted from the front or the back of the aircraft in order to adjust the aircraft's center of gravity. The revised battery configuration also reduces the amount of support that has to be used on the pack, therefore reducing the overall pack weight.

7.3 Structures Group

After the flight testing of the prototype, several modifications were made to the aircraft structure to improve the physical characteristics. Final AutoCAD drawings of the items that differ from the preliminary designs have been made and are included at the end of this report.

7.3.1 Fuselage

The design of the final fuselage was similar to that of the prototype with the major modifications being a decrease in the overall length and an increase in the depth of the battery cowling.

Changes in construction procedures were aimed towards making the exterior surfaces as smooth as possible. This was accomplished by placing Plexiglas against the fuselage surfaces during the curing process of the carbon fiber. The decrease in fuselage length paired with the refined construction resulted in a weight savings of approximately one pound.

As designed, the fuselage can hold five bottles lying horizontally or eight bottles standing vertically with a different hatch cover. Separate fairings were constructed to enclose the bottles in the horizontal and vertical positions.

7.3.2 Wings and Tail

As mentioned above, changes to the wing and tail included a wing and tail area reduction of 25 percent and the use of a symmetrical horizontal stabilizer. A smoother surface was accomplished on the wings by creating a hard female mold from foam and diluted spackle. The spackle prevented the structure of the foam from being translated into the finish of the carbon fiber and reduced the surface roughness significantly. The elevator hinge was replaced by a piano-style gapless hinge, like that of the ailerons, to help reduce drag.

7.3.3 Landing Gear and Brakes

Taxi tests performed by the aircraft showed that the purchased main gear springs were less stiff than advertised by the manufacturer. New, stiffer, smaller diameter springs replaced the initial springs before flight-testing.

During flight testing, the torque arms for the landing gear used on the prototype were found to have too much torsional play. In addition, after hard landings, the torque arm attachments that were press fit onto the struts were prone to twisting. A new design to keep the strut assembly aligned was created for the final aircraft. Using a key in the inner strut that slides within a slot in the outer strut, alignment was retained without the use of torque arms (See refined AutoCAD drawings). The new design reduced weight and drag associated with the torque arms and simplified the manufacturing process.

With the new smaller diameter spring installed into the main gear, a smaller diameter strut could be machined to encase the spring. This smaller main gear, as well as the new design for strut alignment, reduced the weight of each strut by approximately ¼ pound.

The nose strut assembly worked well, but it was determined that the spring-loaded gear was not needed. This enabled a wire design to be used which provides a smaller frontal area, simplifies steering, and has the ability to deflect back on ground rolling impacts (i.e. potholes).

The landing gear worked as designed in taking the loads encountered during landing and taxiing. The lower nose strut bent under an excessive load during an off-field landing, showing that the lower struts would give prior to wing and fuselage damage occurring.

Overall, the design of the landing gear and brakes worked very well. The main gear spring struts took all of the impact on landing as anticipated and the main gear brakes worked well in stopping the aircraft within a limited area. The final aircraft will keep the brakes as an option, with installation dependent on the required strategy.

7.4 Impact of Design Changes

7.4.1 Manufacturing Techniques and Time Factors

Building and flying a prototype aircraft proved to be invaluable in all aspects of the design phase. A summary of the design changes made are as follows:

- Wing area reduced by 25%
- Horizontal tail area reduced and changed to symmetrical airfoil
- Fuselage and wing finished refined
- Torque arms replaced by key/slot design
- Nose strut replaced with wire spring gear
- Thrust line shifted 2 degrees
- Astroflight FAI 660 series motor replaced 640 series motor
- Battery cowling size increased
- Battery pack changed from single row to double row
- 9.5 lb. weight reduction from prototype to final design

As the final aircraft was built, the processes used in manufacturing were refined based on lessons learned while building the prototype aircraft. Modifications made to various subsystems within the aircraft, as described above, saved on materials and time, while the experience of building the prototype enabled the final aircraft to be built to a higher standard of quality and reduce construction time from one month to one week.

7.4.2 Budget

The true cost of the final aircraft is illustrated in Table 7.1. As seen, the difference between the projected and actual costs is quite significant. This is mostly due to insufficient experience with carbon fiber handling and construction techniques. Experimentation with the carbon fiber and associated techniques led to increases in the budget of the final design.

Throughout the semester, the team has taken an active marketing approach, successfully recruiting the required sponsorship. In addition to the 1200 dollars allocated by the University, the team has raised approximately 4000 dollars in sponsorship. Although the actual budget expanded significantly, the costs were offset by surpassing the original funding goal. This not only allowed the team to complete the final aircraft, but also to purchase spare parts for the Competition.

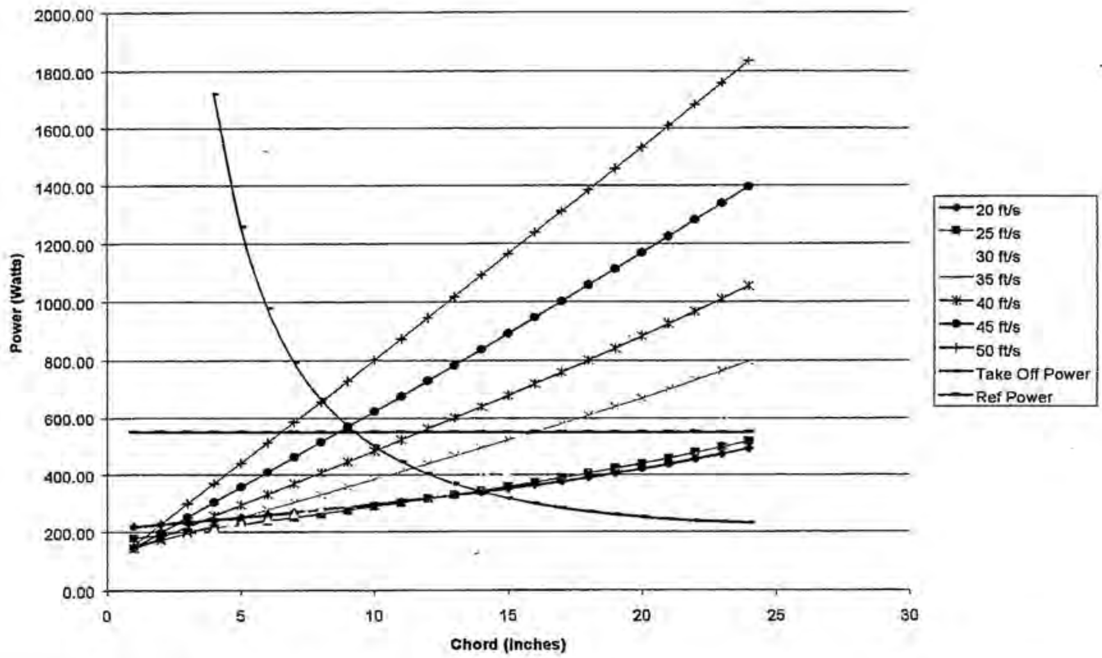

Figure 7.1 Power Required versus Chord Length for Varying Velocities

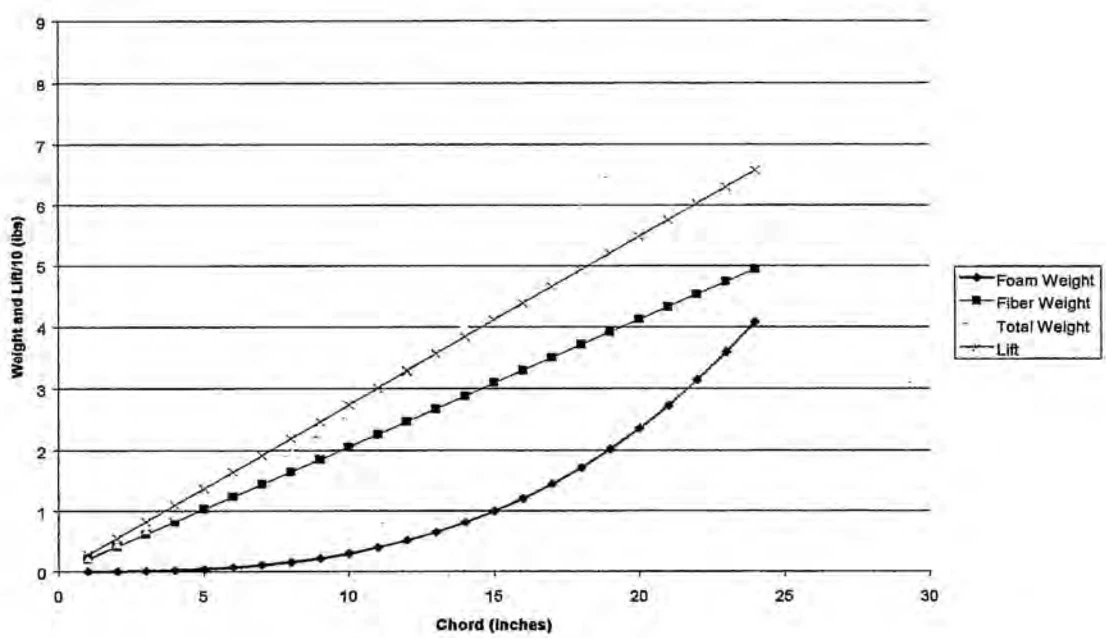

Figure 7.2 Chord Length Effect on Weight and Lift

Table 7.1 Projected and Actual Costs of Competition Aircraft

Consumables

Description	Quantity	Price	Projected Cost	Actual Cost
CA glue	3	$4.90	$14.70	$8.49
Epoxy	5	$1.97	$9.85	$3.94
Sandpaper	2	$4.00	$8.00	$5.53
Bagging Film	19 yd	$1.75	$33.25	$45.50
Breather	8 yd	$3.13	$25.04	$37.50
Perf Release	5 yd	$3.50	$17.50	$24.50
Non Perf Release	11 yd	$5.25	$57.75	$73.50
Chromate Sealant	3 roll	$4.50	$13.50	$22.50
Miscellaneous	1	$20.00	$20.00	$45.00
Total			**$199.59**	**$266.46**

Mechanical and Electrical

	Quantity	Price	Projected Cost	Actual Cost
Motor	1	$275.00	$225.00	$550.00
Speed Controller	1	$130.00	$130.00	$180.00
Propellers	2	$40.00	$80.00	$125.00
Batteries	35	$8.00	$280.00	$262.50
Wiring and Connectors	1	$20.00	$20.00	$57.99
Servos	8	$30.00	$240.00	$112.94
Total			**$975.00**	**$1,288.43**

Construction Material

	Quantity	Price	Projected Cost	Actual Cost
Wood	1	$25.00	$25.00	$17.00
C/F Preprg Twill	90 sq ft	$7.20	$648.00	$900.00
C/F Preprg Uni Tape	17	$3.00	$51.00	$90.00
Kevlar	3 sq ft	$11.97	$35.91	$119.70
Foam	1	$40.00	$40.00	$30.72
Arrow Shafts	4	$5.00	$20.00	$35.00
Monokote	1	$12.99	$12.99	$25.98
Sullivan Tires	5	$8.00	$40.00	$24.00
Roller Blade Wheels	2	$5.00	$10.00	$10.00
Bearings	9	$2.00	$18.00	$24.99
Springs	7	$1.25	$8.75	$10.52
Aluminum	1	$60.00	$60.00	$43.00
Nose Landing Gear	1	$22.95	$22.95	$22.95
Push Rods	6	$0.50	$3.00	$8.00
Miscellaneous	1	$15.00	$15.00	$29.71
Total			**$1,010.60**	**$1,391.57**

Total Cost by Category

	Projected	Actual
Consumables	$199.59	$266.46
Mechanical and Electrical	$975.00	$1,288.43
Construction Material	$1,010.60	$1,391.57
Total	**$2,185.19**	**$2,946.46**

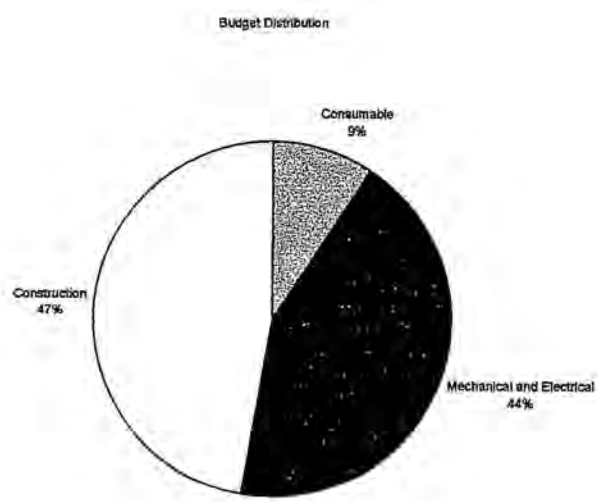

Figure 7.3 Budget Distribution Chart

Figure 7.4 Prototype Aircraft During First Take-Off

Figure 7.5 Competition Aircraft During First Flight

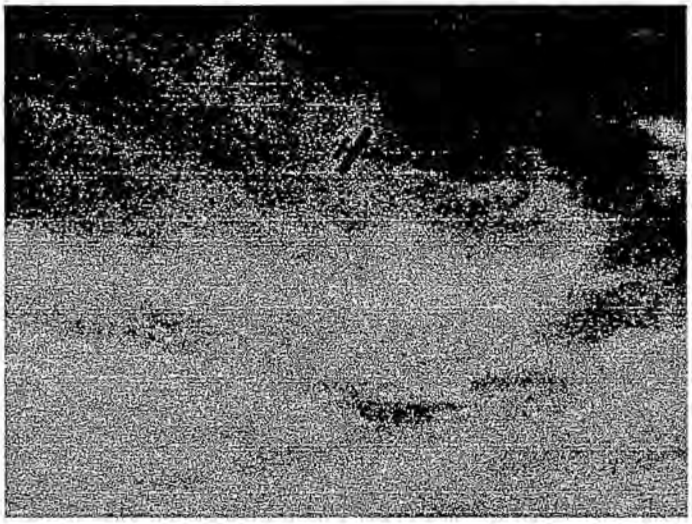

Figure 7.6 Competition Aircraft Climbing During First Flight

8 Aircraft Cost

The total Rated Aircraft Cost for the ORANGE ABISS aircraft is $6,016. The break down of this cost is shown in Table 8.1. See Figure 8.1 for a percentage breakdown of the cost per section.

8.1 Manufacturer's Empty Weight

The total Manufacturer's Empty Weight for the competition aircraft is 15.2 pounds. This amounted to $1,520 or 25.3 percent of the total Rated Aircraft Cost. A slight increase in weight was obtained from the use of carbon fiber construction over balsa wood construction, but was necessary to achieve the durability and complex wing structure desired. A slight increase in weight was obtained from the addition of a custom made landing gear that was both rugged and tuned to the performance of the aircraft. Weight was minimized in the area of the tail by utilizing balsa wood and Monokote construction. Wing weight was minimized by using polystyrene foam as a wing core. This foam is half the density of the typically used blue foam.

8.2 Rated Engine Power

In this design, one motor was determined capable of providing the power required for all phases of flight. This minimized the rated cost of this section to $1,500, or 24.9 percent of the overall RAC. Twenty-five of the batteries that gave the optimum propulsion configuration could be used within the five-pound limit, helping to maintain a low cost factor. Both of these factors were considered and played a part in the decision of the final configuration to maximize score.

8.3 Manufacturer's Cost

This section was determined to be the most important and weighed very heavily in final design considerations. The final RAC of this section totaled to $2,996 and 49.8 percent of the total cost. It is broken into the following five sections:

1) Wing(s)
2) Fuselage and/or Pods
3) Empennage
4) Flight Systems
5) Propulsion Systems

8.4 Wing(s)

This section was broken into the number of wings and the total wing area. This was found to be the most expensive part of the Manufacturer's Cost and was a major consideration during the design phase. The wing area was matched to the power available deemed necessary and the ability to meet the short field take-off requirements. The wing area was also optimized to allow versatility and minimize the cost while maintaining high lift capabilities. Due to the wing area required to achieve the mission, it was decided that the performance increase associated with the bi-wing design offset the increased cost. This was done for two reasons. First, the aspect ratio could be much higher with a bi-wing design, increasing overall wing efficiency; and second, it allowed the volume of the foam core to be lessened, reducing the total wing weight considerably.

8.5 Fuselage and/or Pods

The goal of the fuselage design was to minimize frontal area and create a streamline structure. To meet these goals, the bottles were placed longitudinally into the fuselage. While this increased the payload bay length from other designs considered, the fuselage was kept short by strategic placement of such things as the battery pack, servos and controllers.

8.6 Empennage

In this category, sizing was not an issue in the cost factor, only the number of components. With the engine and fuselage configuration, there were no stipulations that required a non-standard tail design. Therefore, single vertical and horizontal tail surfaces of the appropriate sizing were designed to accomplish the stability required.

8.7 Flight Systems

This section consisted only of the number of servos used. For the competition aircraft's configuration, seven servos were required, with two of those being optional. One servo was used on each individual aileron to allow differential operation and trimming. With the use of aerodynamic balancing, only one servo was selected for rudder control with a separate servo for nose wheel steering. This allowed the steering rates to be changed using the control radio without affecting rudder control or deflection. One high torque servo was selected to control the elevator. The two remaining servos are high torque servos that operate the braking system, one for each master cylinder.

8.8 Propulsion System

The two focal areas of this section were the number of motors and the number of battery cells to be used. After determining the power requirements, research showed that a single motor could provide the required power. Based on the motor performance, power requirements and strategy, the optimum battery cell was selected. The optimization of the batteries was based on its performance, real world cost and weight. Once selected, the maximum number of cells was determined by the maximum five-pound battery pack weight. For the competition aircraft, 25 cells of the 3000 maH batteries were used.

Table 8.1 Rated Aircraft Cost

Coef.	Description	Value
A	Manufacturers Empty Weight Multiplier	$100 / lb.
B	Rated Engine Power Multiplier	$1 / Watt
C	Manufacturing Cost Multiplier	$20 / hour
MEW	Manufacturers Empty Weight	15.2 lb.
$MEW	(A * MEW) / 1000	$1.520 (thousands)
REP	Rated Engine Power	
	# engines	1
	# cells	25
	(# engines * 50A * 1.2V/cell * # cells)	1500 Watts
$REP	(B * REP) / 1000	$1.500 (thousands)
MFHR	**Manufacturing Man Hours**	
WBS	Work Breakdown Structure	
WBS #1	Wing	
	# wings	2
	projected area	17.5 ft^2
	(5 hr./wing + 4 hr./ft^2 projected area)	80 hr.
WBS #2	Fuselage	
	# bodies	1
	length	5.7 ft
	(5 hr./body + 4 hr./ft length)	27.8 hr.
WBS #3	Empennage	
	# vertical surfaces	1
	# horizontal surfaces	1
	(5 hr. + 5 hr./vert.surf. + 10 hr./horiz.surf.)	20 hr.
WBS #4	Flight Systems	
	# servos	7
	(5 hr. + 1 hr./servo)	12 hr.
WBS #5	Propulsion Systems	
	# engines	1
	# propellers	1
	(5 hr./engine + 5 hr./propeller)	10 hr.
MFHR	Σ WBS hours	149.8 hrs.
$MFHR	(C * MFHR) / 1000	$2.996 (thousands)
RAC	**Rated Aircraft Cost**	
	(A*MEW + B*REP + C*MFHR) / 1000	**$6.016 (thousands)**

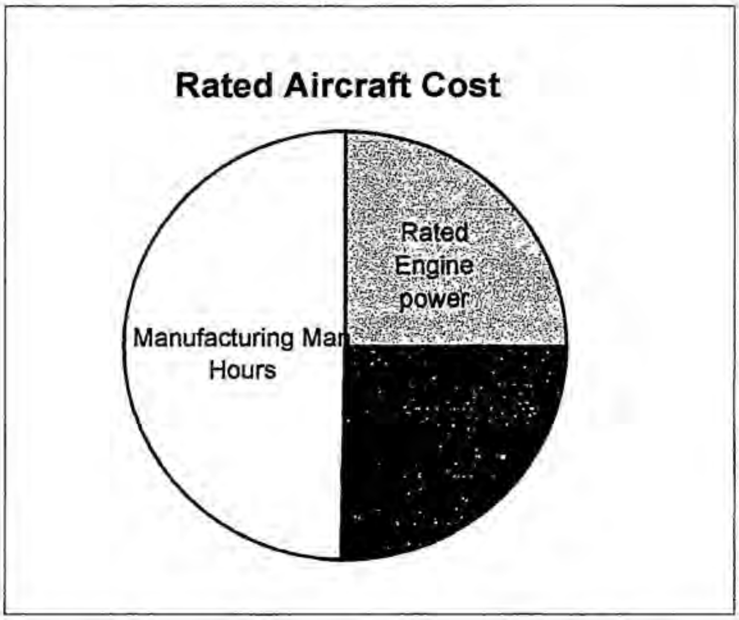

Figure 8.1 Rated Aircraft Cost Percentage Per Section