CESSNA/ONR STUDENT DESIGN/BUILD/FLY COMPETITION

An AIAA Student Activity

# 1997/98 Cessna/ONR Student Design/Build/Fly Final Scores

The Fly-off for the 1997/98 Cessna/ONR Student Design/Build/Fly competition was completed Saturday 25 April at Westport Airport in Wichita Kansas. The conditions were very challenging due to high and gusting winds but several teams were able to complete the specified mission profile, and many others made noteworthy attempts.

All 17 teams who completed the written report phase of the contest also made the Fly-off and all contestants made at least one flight attempt. This is twice as many teams as made the Fly-off for last year, and is a great sign for the future of the competition. Rules for the 1998/99 competition will be up on the contest web site, and e-mailed to all of this years participants, in a few weeks.

A further sign that the contest has a good future is the press and TV coverage we have obtained for this years competition. The event was noted on the local Channel 3 news, and will be reported in RC Report and Radio Control Modeler.

I would like to personally thank and commend all the students who participated in the contest this year for their efforts. Although the contest was developed by the AIAA Technical Committees, it is for the students. We are very glad to see that you find it to be worth while. I also want to thank our financial

supporters, Cessna and ONR, with a special thanks to our hosts, Cessna Aircraft and the Wichita RC Club, for making this competition possible.

So, without further ramblings, here are the scores for the 1997/98 competition.

| | | |
|---|---|---|
| 1. Univ. of Southern California | 1042.8 | 12 Laps x 86.9 Written |
| 2. Texas A&M | 516 | 6 Laps x 86.0 Written |
| 3. Syracuse University | 162.2 | 2 Laps x 81.1 Written |
| 4. Univ. of Texas, Austin | 138.8 | 2 Laps x 69.4 Written |
| 5. Utah State University | 91.9 | Written |
| 6. University of Illinois, UC | 90.1 | Written (6 laps best attempt) |
| 7. Washington State Univ. | 87.0 | Written |
| 8. Queens University, Canada | 85.6 | Written |
| 9. Oklahoma State Univ. | 82.5 | Written |
| 10. West Virginia | 81.5 | Written (5 laps best attempt) |
| 11. MIT | 79.8 | Written (3 laps best attempt) |
| 12. University of Alabama | 69.5 | Written |
| 13. Virginia Polytechnic Univ. | 67.2 | Written (6 laps best attempt) |
| 14. University of Arizona | 64.1 | Written |
| 15. Univ. of Central Florida | 58.3 | Written |
| 16. Univ. of California, Los Angeles | 55.5 | Written |
| 17. San Diego State University | 47.0 | Written |

(Laps noted as "best attempt" are flights which failed to meet the required criteria for a scored landing.)

Congratulations to all the participants, and we look forward to seeing you again next year.

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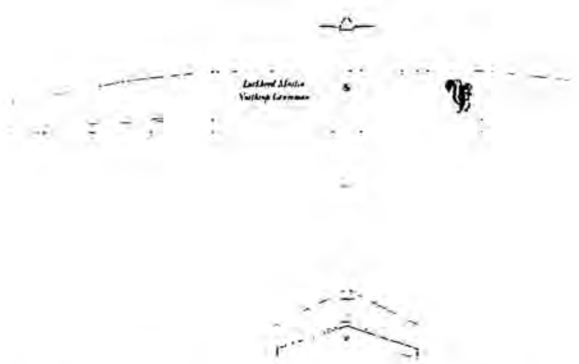
# Design Report - Proposal Phase

March 13, 1998

1997/1998 AIAA Student Design/Build/Fly Competition

PEPÉ

The University Of Southern California



UNDERGRADUATE TEAM MEMBERS

Philip Haworth- Editor, Propulsion
Ryan Romo- Editor, Configuration
Stuart Sechrist- Weight Analysis, Structures
QiHuan Chen- Aerodynamics, S&C
David Sandler- Editor, Mission Performance
Jacob Evert- Conceptual Design
Kevin Helm- Support Equipment
Nathan Palmer- Landing Gear

FACULTY ADVISOR

Dr. Ron Blackwelder

INDUSTRY ADVISORS

Blaine Rawdon- Boeing
Mark Page- All American Racing

SPONSORS

Lockheed Martin Skunk Works
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# 1. EXECUTIVE SUMMARY

## 1.1 Introduction

To solve the problem designed for contestants of the AIAA Student Design/Build/Fly competition, the University of Southern California team chose to divide it into five major areas: Configuration, Aerodynamics, Structures and Weights, Propulsion, and Mission Performance. Configuration focused on the layout of the

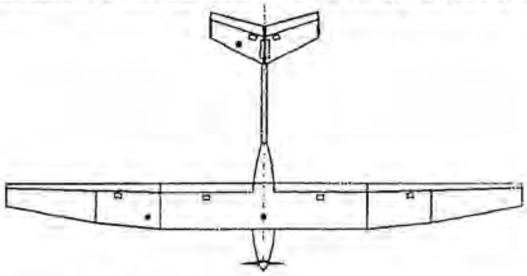


*Figure 1.1 Plan View of Final Design*

aircraft, and drawings and blueprints used in both the design and manufacturing stages of aircraft development. Aerodynamics aimed its efforts to determine the aerodynamic characteristics of the airplane and found suitable airfoils for use in the competition. Weights calculated the weights of materials and payload in the aircraft, located the center of gravity, analyzed the moments and forces of the final configuration, and chose the structural materials to be used in the final construction. Propulsion created the most efficient system to propel the aircraft and chose the best combination of propeller, motor and battery. Mission Performance tied the Aerodynamics, Weights, and Propulsion sections together to provide the complete platform from which different configurations were compared and contrasted.

The final configuration of the aircraft includes a flapped S7012 airfoil, no gearbox, an 8-inch propeller, and 26 Sanyo KR-1700AE batteries. The wing has an area of 5.3 ft² and an aspect ratio of 13. The predicted performance of the 13.77 lb. airplane is 25.3 laps.

## 1.2 Range of Design Alternatives

Multiple design alternatives were considered. Primary design alternatives compared choices of wing, tail, and motor configuration. These alternatives were explored in an attempt to maximize propulsive efficiency and turning performance, minimize construction, mechanical complexity, weight and overall drag, and to maintain stability.

Wing types considered were swept, low wings, anhedral and dihedral configurations. Tail alternatives that were investigated included a V-tail, T-tail, along with different kinds of tailskids. Various motor configurations included alternatives such as using more than one motor, having a pusher propeller, or a more conventional tractor propeller.

Secondary, more detailed design alternatives looked at included payload configurations, wing mounting techniques, and layout of all essential hardware. Different payload configurations examined had variations in location, accessibility, and dimensions. There were three ways considered to mount the wing: a two-piece wing that plugs into the side of the fuselage, a one-piece wing bolted to the fuselage from the top, and a wing that slides into place from front to back. Different layouts of the essential electronics and cargo were based on available space and center of gravity considerations.

## 1.3 Design Tools

The two main design tools used in development of the design were Microsoft Excel spreadsheets and AutoCAD v.14. While still

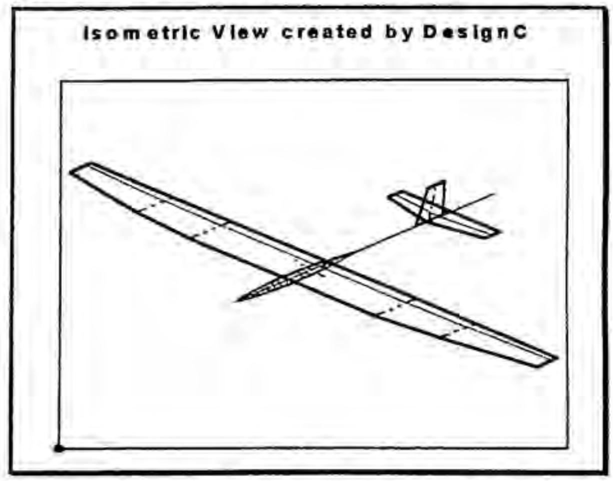


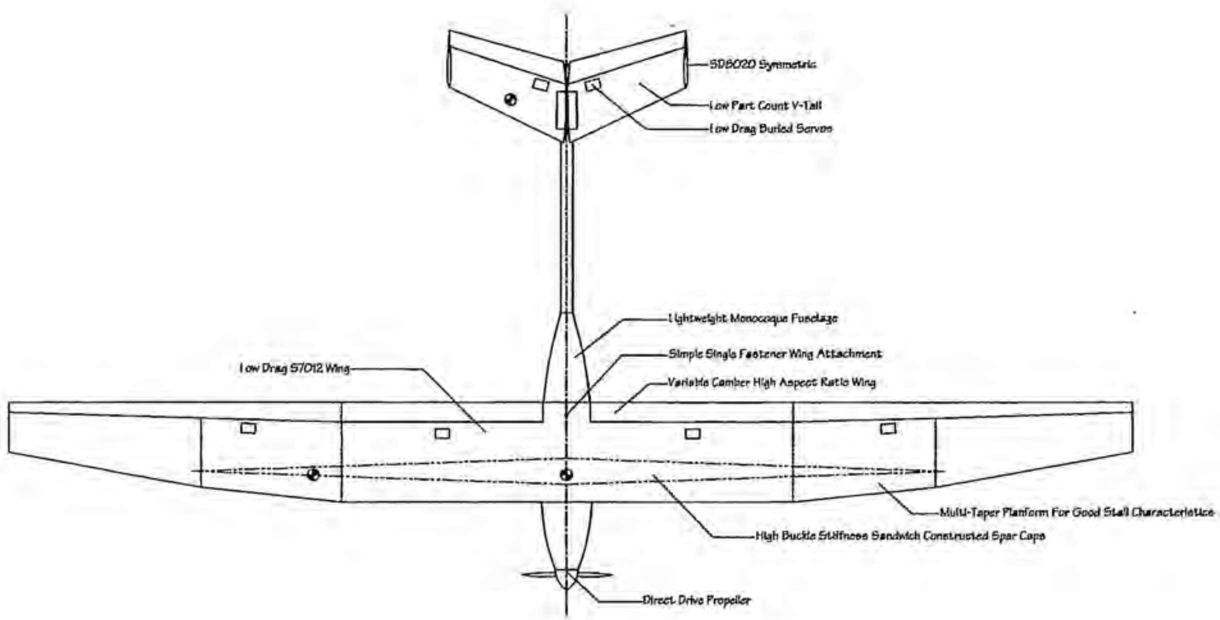

*Figure 1.2 Isometric of Final Design Prior To Inclusion Of V-Tail*

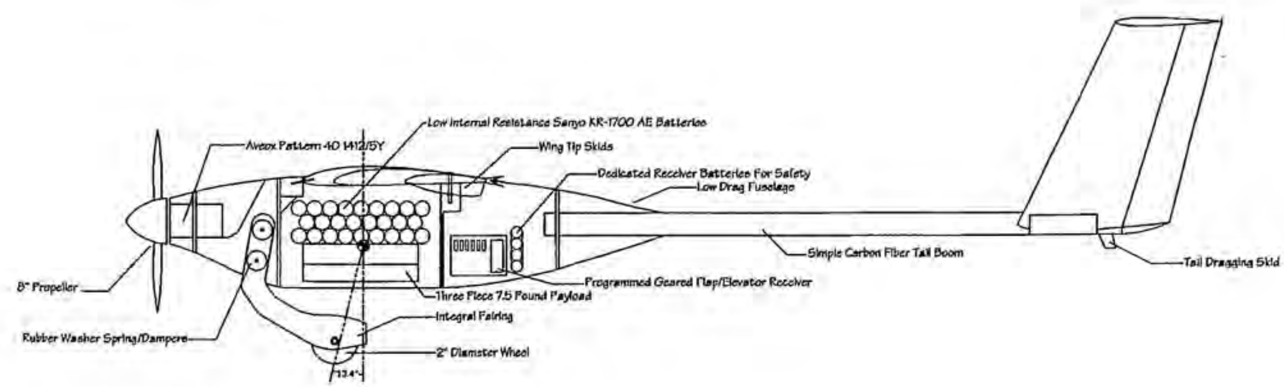
developing concepts for the design, Aerodynamics and Propulsion chose numerous airfoils, batteries, motors, and gearboxes, to examine in the preliminary and detailed stages of development. Weights researched electronic components involved and the materials to be used in the manufacturing process, and began building the code for an Excel spreadsheet. Configuration used AutoCAD to draw preliminary drawings for analysis and adjusted to specific constraints. Mission Performance gathered the equations from the other team divisions to enter in to a spreadsheet designed to connect the spreadsheets from the Weights, Aerodynamics, and Propulsion areas.

The preliminary design connected the completed Excel spreadsheets from each team division

# PEPÉ

The University Of Southern California



through the Mission Performance spreadsheet into a final workbook, after which time various configurations, including variations in wing area, aspect ratio, gearbox, motor, batteries, and airfoils were tested and compared. AutoCAD was used by Configuration and created the drawings of the airplane based of the Excel spreadsheet tests. After the major design characteristics were finalized, Configuration made more accurate drawings (blueprints) to be used in analyzing and manufacturing the design.

In addition to Excel and AutoCAD, the detailed design process enlisted the use of DesignC, a commercially available model sailplane design geometry program, in Excel format, created by Blaine Rawdon. This program was used and developed a 3-D drawing of the complete airplane that was easily modified to adjust the geometry of the wing and tail. Another use of Excel was to calculate specific performance characteristics that included take off performance, range, and endurance. Also, AutoCAD was used extensively to finalize the internal layout of the hardware and provided the schematics from which the plane was manufactured.

# 2. MANAGEMENT SUMMARY

## 2.1 Team Architecture

Management of the team was determined by experience and patterned after a corporation. Two industry professionals, Blaine Rawdon and Mark A. Page, agreed to share their time and knowledge to advise the group, held the roles of project managers and provided essential information and data needed to make the calculations for design. Dr. Blackwelder, who managed the funding, filled the chief financial officer role. He found the sponsors for the USC entry: Lockheed Skunk Works Corporation and Northrop Grumman. Assignments for various design sections (role of associate engineers) of the project were done on a volunteer basis of students, granted according to experience, responsibility and ability.

## 2.2 Design personnel and assignment areas

The responsibilities assigned rested in the 8-student team members. Ryan Romo produced configuration and drawings of the aircraft, while Qi Chen researched airfoils and developed the aerodynamics spreadsheet. Stuart Sechrist did structural testing, wrote the weights and structures spreadsheet, and directed the manufacturing process. Phil Haworth researched batteries, motors, gearboxes, and propellers, and prepared the propulsion spreadsheet. David Sandler connected the different sections together through the mission performance spreadsheet into one workbook. Finally, Nathan Palmer provided landing gear research as Kevin Helm and Jacob Evert researched alternative designs during the conceptual design phase.

Management Architecture

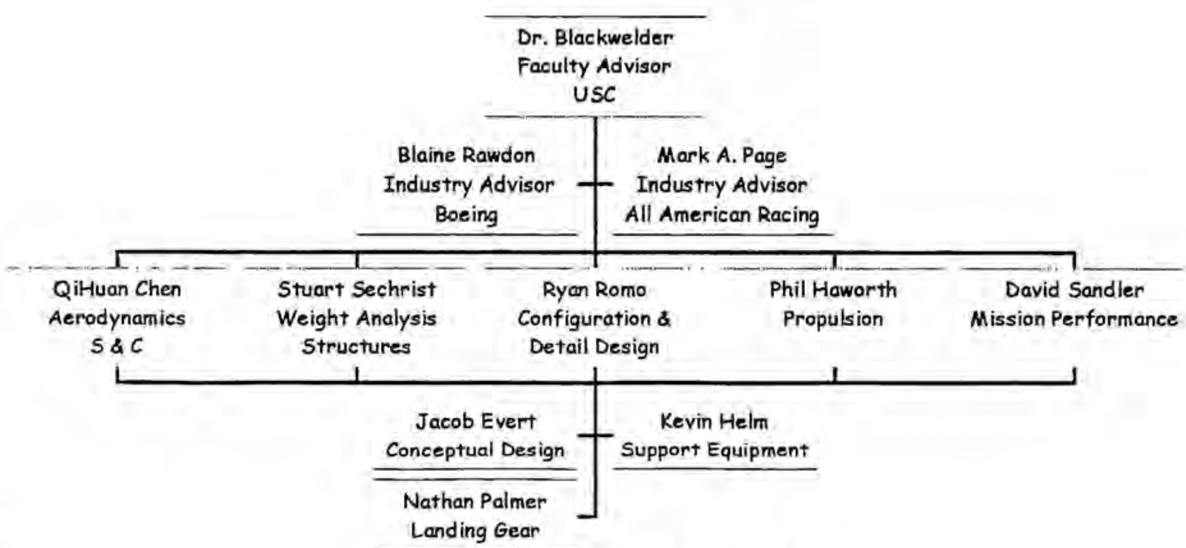
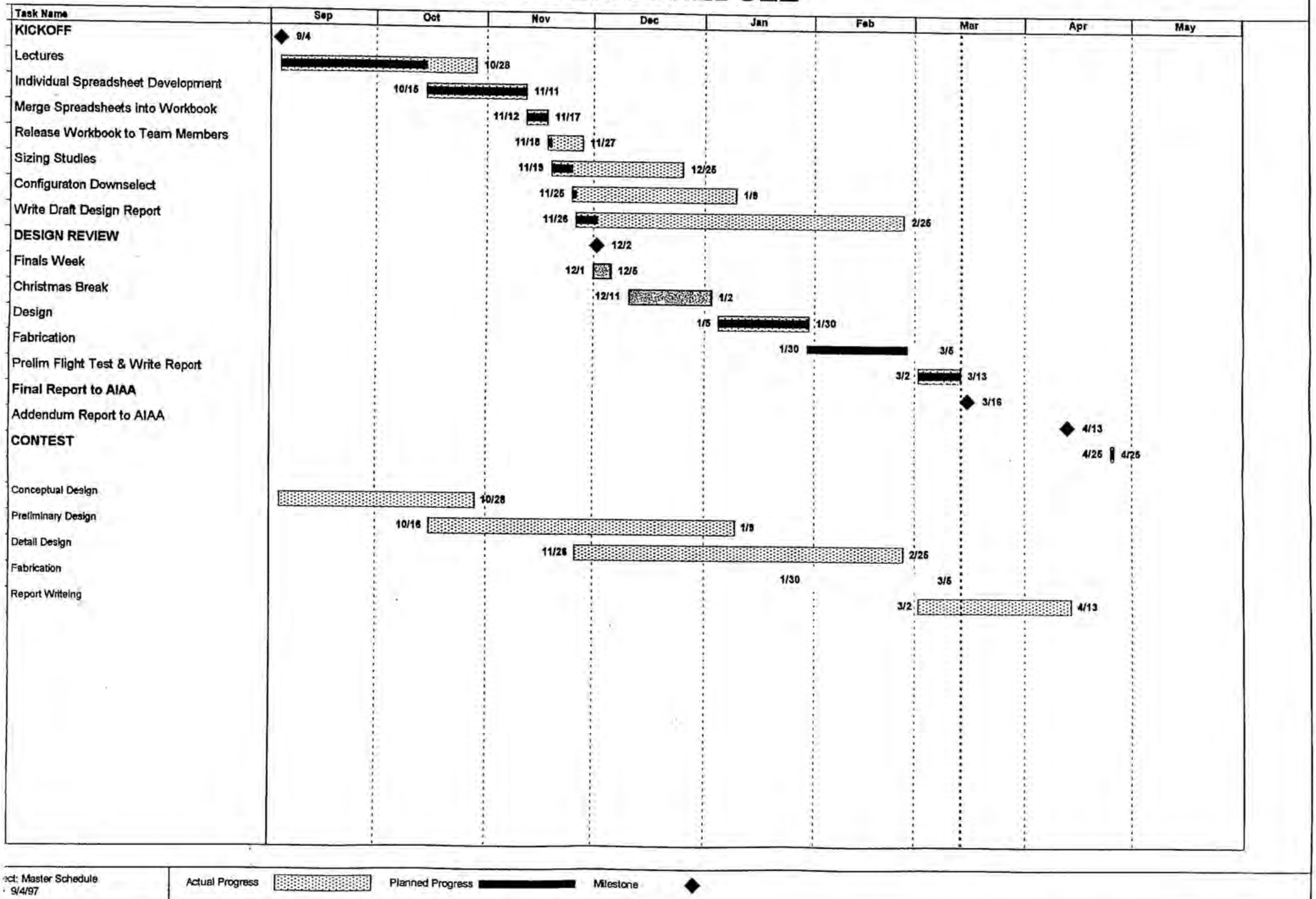



*Figure 2.1 Team Organizational Chart*

# USC AIAA Student Design/Build/Fly Competition

## MASTER SCHEDULE



## 2.3 Management structures

Setting group goals and a loose timeline, determined by the project managers, achieved a schedule control that met AIAA deadlines. Specific items and details of the configuration were addressed weekly as problems and new ideas arose. Most of the important decisions involving the plane were done as a group at weekly meetings. The milestone chart developed by the group is shown in Figure 2.2. Selection of the final airplane from the spreadsheets took longer than expected and held up all progress for several weeks.

# 3. CONCEPTUAL DESIGN

## 3.1 Design Parameters

The goal decided upon by the team was to design a plane with the shortest lap time possible. To achieve this goal, the highest straightaway and minimum turn radius (contributing to a decreased total lap distance) were obtained.

## 3.2 Figures of Merit

It was decided that the six most important variables for this mission were: turn rate, roll rate, weight, Lift-to-drag ratio (proportional to energy efficiency), simplicity of the plane, and flying characteristics. Turn rate determined how sharp the turn was, and is dependent on the load factor and $C_L$ capability. Roll rate is important for entering and exiting the turns quickly and to reduce turn distance. Weight and L/D are important because of affects on the energy consumption rate. Maximizing the L/D ratio and thereby minimizing the drag maximizes the speed of the aircraft as desired.

Time constraints and mission requirements determined that simplicity allowed for the easiest design and manufacturing. If major problems were discovered during testing, there was time to make modifications on the design. Human error is to be a factor in the flying of this airplane, so an aircraft that is easier to handle will put less stress and possible problems in the hands of the pilot, reducing the risk of a mistake during competition. Also, because of the decision to pull up to near stall velocity twice during each lap, stall and recovery characteristics are very important.

### *3.2.1 FOM Rankings*

Agreeing that the turn is the most important part of the mission, the load factor capability (or turn rate) was the feature most important for the plane. L/D was second because the batteries needed to last the whole seven minutes of the race. Next, due to a tight schedule, simplicity was ranked third, which gave the simpler designs an advantage. Roll rate ranked fourth because it has a smaller overall effect on the turn than the first three categories. Flying characteristics was set fifth since it mostly depends on the pilot. Weight was categorized as least important because an accurate depiction of weight could not be determined at this early stage of development.

## 3.3 Analytic Methods Used

The method of gathering ideas for the design of the aircraft was to put <u>every</u> idea on the board. From this pool, each was evaluated and ranked. Evaluations were based on our figures of merits using judgment calls and observation by inspection, and the pool was reduced to six planes

## 3.4 Initial Concepts

Plane A is a biplane; B resembles the Lockheed P-38 with three fuselages and the propulsion unit in the middle; C is a variation on B with an optional middle fuselage and two smaller propulsion units on the outside fuselages; D is a flying wing; E is a traditional, single wing with one motor, airplane; F is a variation of E, but its landing gear is wheels on the wing tips, with a downward bend in the wings for propeller clearance. Refer to Figures 3.1 through 3.6

## 3.5 Rankings

Each plane was ranked for all categories and one was selected. The plane with the lowest totals, plane E, our initial and simplest idea, was focused upon for the rest of the meetings.

### *3.5.1 Turn Rate*

Turning rate, or load factor and $C_L$ capability, will determine how tight the turn will be. All planes except D were able to perform sharp turns; they made use of flaps and similar airfoils. Plane D ranks last because of its short tail arm, while the rest had equal scores in this category.

### *3.5.2 L/D (Energy Efficiency)*

Aspect ratio (Span$^2$/Wetted area) was compared on all the airplanes. Plane A had the smallest wingspan and a large wetted area, and ranked last in the category. Planes B and C were ranked 5$^{th}$ and 4$^{th}$ respectively.

*Figure 3.1 Proposed Biplane Configuration*

*Figure 3.4 Proposed Blended Wing Configuration*

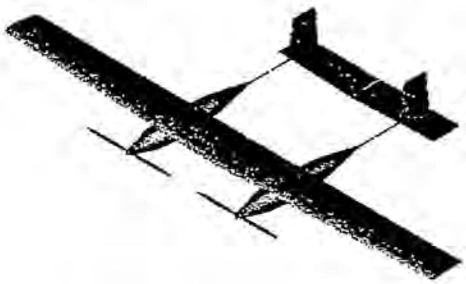


*Figure 3.2 Proposed Double Fuselage Configuration*

*Figure 3.5 Proposed Traditional Airplane Configuration*

*Figure 3.3 Proposed Triple Fuselage Configuration*

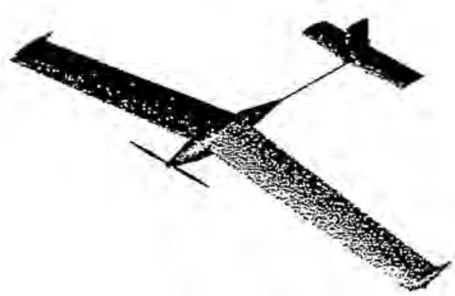


*Figure 3.6 Proposed Anhedral Wing Configuration*

Though they possessed a larger span than A, they also had a larger wetted area than the other planes because of the three fuselages. Plane C ranked better than B because the third middle fuse is optional, reducing the wetted area. Plane D ranked first because it had a large span and a very low wetted area. Planes E and F scored about the same, but since F uses the wing tips as landing gear, the wetted area is a little bit smaller than E.

*3.5.3 Simplicity*

Simplicity was scored by summing up the total number of sub-assemblies required to build for the plane. A had the most parts of the six: fuselage, propulsion unit, two wings, two ailerons, wing struts, vertical tail, rudder, h-tail, elevator, and a main gear, for a total of 12 sub-units. This tied for a rank of 4th. B and C were the most complicated of the six because of integration of three fuselages would prove to be a difficult task, and they consisted of 13 and 12 sub assemblies respectively. D is rather simple, and consisted of a wing, 2 elevons, 1 rudder, 1 propulsion unit, nose gear and a main gear totaling seven and ranking it first. E and F were the next two simplest planes with E having 10 and F having 11 sub assemblies. It was decided that the wing structure for plane F would require a complicated joining system, and so would attaching the wheels to the wing-tips.

*3.5.4 Roll Rate*

Roll rate is important for entering and exiting the turn quickly and it reduced the turn distance. Plane A's shorter wing span allows for an excellent roll rate, which is inversely proportional to wing span, and ranked first amongst the other designs. The other planes are all quite similar with B and C being slower due to mass further away from the center of roll for the plane. Planes E and F will be similar, but slower still, and D is the slowest of them all because of the lack of a tail.

*3.5.5 Flying Characteristics*

Handling qualities are a very important part of the mission since the plane will pull up to near stall twice each lap. Plane A has excellent stall characteristics and ranks first because it recovers nicely due to the high lift. B, C, E, and F all will handle quite well, as the tail will help with pitch damping. Proper center of gravity (c.g.) location also gave each equal static stability. Only plane D did not perform well in this category. The lack of a tail reduces pitch damping, and, being a flying wing, has less predictable stall characteristics.

*3.5.6 Weight*

Weight was difficult to estimate. Because D has the most volume, it was considered to be the heaviest of the group. Following was C because of the two propulsion units, and then came A because of all the bracing required for a bi-plane. B was 3rd because of the extra fuselages, and E was second after F because of its extra weight from the landing gear.

## 3.6 Overall Rating

The rankings concluded that plane E would be the base design. F followed in second, while third and fourth place went to planes A and B. Planes D and C tied for last in the overall category. In following meetings, improvements and small design changes were done to create our current design. The chart below shows each plane and their ratings.

| FOM's | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Turn Rate* | 1 | 4 | 5 | 6 | 2 | 3 |
| *L/D* | 6 | 5 | 4 | 1 | 3 | 2 |
| *Simplicity* | 5 | 6 | 4 | 1 | 3 | 2 |
| *Roll Rate* | 1 | 4 | 5 | 6 | 2 | 3 |
| *Flying Characteristics* | 2 | 3 | 4 | 6 | 1 | 5 |
| *Weight* | 4 | 3 | 5 | 6 | 2 | 1 |
| ***Sum total*** | **19** | **25** | **27** | **26** | **12** | **17** |
| **Overall Ratings** | ***3rd*** | ***5th*** | ***6th*** | ***4th*** | **1st** | ***2nd*** |

# 4. PRELIMINARY DESIGN

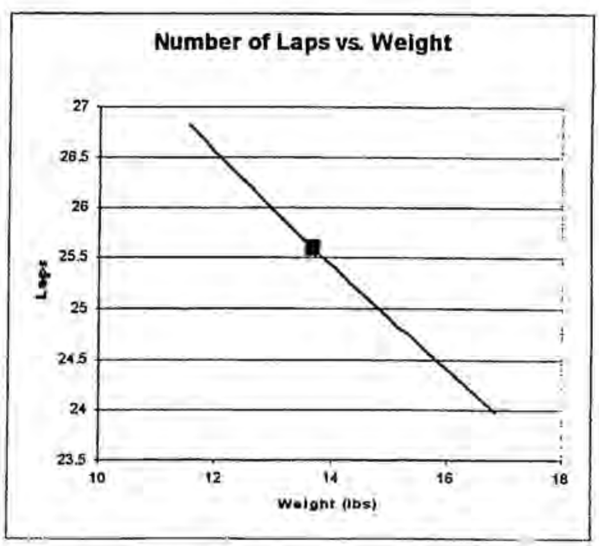



*Figure 4.1 Laps vs. Weight*

| **Weights** | | **Total Weight** | | 13.77 lbs. | | |
|---|---|---|---|---|---|---|
| **Inputs** | | lbs. | | | % of plane | |
| | Cargo | 7.50 | | | 54.48% | |
| | | | | | | |
| Propulsion | Motor from propulsion | 0.6375 | Propulsion TOT | 3.435 | 24.95% | |
| fudgeF | Battery weight | 2.50 | | | | |
| 1 | Wiring | 0.10 | | | | |
| | Speed control | 0.14 | weight of heavyist Avox controller | | | |
| | Prop | 0.06 | | | | |
| | | | | | | |
| Wing | core density lb/ft^3 | 2.25 | Wing TOT | 1.069 | 7.77% | |
| fudgeF | core volume ft^3 | 0.20067774 | Weight w/o spar | 0.740 | 5.37% | |
| 1.1 | Area DesignC in^2 | 763.20 | assume 1.5oz glass | | | |
| | calculated spar wt. | 0.299591311 | | | | |
| | | | *core volume based* | | | |
| | | | *on t/c and span* | | | |
| | | | | | | |
| | | | | | | |
| Tail | core density lb/ft^3 | 2.25 | Tail TOT | 0.053 | 0.39% | |
| fudgeF | core volume ft^3 design | 0.010390 | | | | |
| 1.1 | AreaH DesignC in^2 | ***86.40*** | | | | |
| | AreaV DesignC in^2 | ***86.40*** | | | | |
| | | | | | | |
| | | | | | | |
| Radio | receiver | 0.125 | Radio TOT | 0.813 | 5.91% | |
| fudgeF | servos | 0.5 | | | | |
| 1 | battery? | 0.188 | | | | |
| | | | | | | |
| LandingGear | gear | 0.386497065 | LandingGearTOT | 0.464 | 3.37% | |
| fudgeF | *3% of total plane* | | | | | |
| 1.2 | | | | | | |
| | | | | | | |
| Fuselage | wetted area DESIGNC | 147.5781634 | Fuse TOT | 0.342 | 2.49% | |
| fudgeF | thickness in | 0.02 | | | | |
| 2 | density lb/in^3 | 0.058 | | | | |
| | | | | | | |

## 4.1 Weights

In design of an aircraft, one of the most important factors is the total weight and its minimization because of the limited energy budget and needing to maximize range in a short time. Many of the plane's components were known to have a specific weight, including the radio, batteries, and steel. These known values of the hardware and materials were entered into the Weights portion of the spreadsheet. Excel was then used to test slightly different configurations in order to create the best possible airplane and come to a quick total weight calculation. Figure 4.1 shows the effect of weight on total laps. The result is that a 3.6 % increase in weight decreases the number of laps by 1%. Inputs for this spreadsheet came from geometry calculated by DesignC and other major design criteria such as the airfoil and the type of motor selected. Weights computed by this sheet included the foam core of the airfoils for the tail and wing, different motor weights, and wing spar weight calculation.

After this sheet was completed it was found that results were not as expected. Wing spar weight was not nearly as high as expected, and given different airfoils, the calculated spar weight did not change much. Figure 4.2 shows the effect of aspect ratio on the weight of the wing spar for four different airfoils considered.
Another consideration was a change in performance of the plane due to a weight of plane slightly different than that calculated. Doing this gave an idea of how the plane would perform if the actual weight of the competition aircraft was not the same as the one calculated. A breakdown of components by weight and percentage of total weight is supplied in Table 4.1.

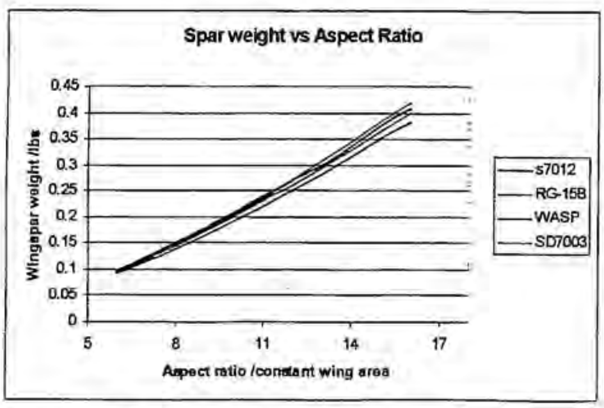



*Figure 4.2 Spar Weight For Given Aspect Ratio*

| Component | Weight in Pounds |
|---|---|
| **Fuselage** | **0.342** |
| **Wing** | **1.269** |
| Wing foam | 0.740 |
| Wing spar | 0.329 |
| Wing servos | 0.2 |
| **Tail** | **0.4405** |
| Tail Foam | 0.53 |
| Tail Boom | 0.1875 |
| Tail servos | 0.1 |
| **Propulsion** | **1.3425** |
| Motor | 0.6375 |
| Wiring | 0.2 |
| Propeller | 0.06 |
| Receiver | 0.125 |
| Battery for Receiver | 0.188 |
| Speed Control | 0.14 |
| **Landing Gear** | **0.375** |
| ***Empty Weight*** | ***3.769*** |
| Payload | 7.5 |
| Batteries | 2.5 |
| ***Total Weight*** | ***13.769 lbs.*** |

*Table 4.1 Weight Breakdown by Component*

## 4.2 Propulsion

### *4.2.1 Propulsion Design Parameters*

The design parameters investigated in the propulsion area of the project were the following: propellers, motors, gearboxes, and batteries. The propeller to be used was an important parameter to be matched to the performance required of the propulsion system. The chosen propeller's Design Advance Ratio should most closely match the actual Advance Ratio achieved in order to provide the most propeller efficiency. The choice of motor is critical for the most torque and power to deliver to the propeller to provide the thrust. Gearboxes were also considered in case the optimum performance characteristics of the propellers and motors operated at different revolutions per minute (r.p.m.). The battery choice needed to be cells that provided the most electrical energy in 2.5 lbs. of cells.

### *4.2.2 Propulsion variables*

The propeller data used to provide the characteristics of each type of propeller configuration was provided in Excel format by Mark A. Page. The specifications for the four motors considered in the final design were provided on the Aveox World Wide Web page. The ratios for the eight gearboxes considered were provided by the Astroflight and Aveox World

Wide Web pages. The statistics for the seven batteries under consideration were provided by ElectriCalc, a commercially available electric propulsion model airplane program purchased from Aveox. All of the statistics were entered into worksheets that were to be referenced by the Propulsion and Mission Performance spreadsheets.

### *4.2.3 Propulsion spreadsheet*

An Excel spreadsheet was created that matched the propeller and the electric propulsion system. It was divided into two halves, one for the propeller inputs and outputs, and the other for the motors, batteries, and gearboxes. The propeller side contained the variable inputs: Design Advance Ratio, number of propeller blades, diameter of the propeller, operating velocity, and the required thrust. The outputs were the torque, rpm and power required, along with propeller efficiency, thrust coefficient, and power coefficient. These outputs were connected to the second half of the spreadsheet by matching the torque and rpm provided by the propeller side to the torque and rpm that the motor-gearbox-battery system needed to provide. With these inputs and constants provided by the specifications of certain batteries, motors, and gearboxes, the following quantities could be determined: voltage, current, battery life, power output, and throttle setting.

### *4.2.4 Findings of Propulsion spreadsheet*

The selected battery pack consisted of 26 KR-1700AE cells. It was discovered that batteries with a higher capacity had a higher internal resistance, and provided less total energy than cells with less capacity and less internal resistance. The increased weight of the higher capacity cells was a driving factor in selecting the lower capacity, lower internal resistance, KR-1700AE batteries.

The maximum current of the system, I=40A, was not a limit approached by any of the design configurations. The maximum voltage, however, was one of the drivers in selecting J, the design advance ratio, and the propeller diameter. As J or propeller diameter decreases, the voltage required to produce the necessary thrust increased.

The advance ratio of 0.833 was chosen because any advance ratio smaller than that would have required a voltage greater 32.5 volts, which is the maximum voltage available with 26 cells. Figure 4.4 shows the effect of Design Advance Ratio on the total number of laps. Of the four advance ratios researched, the optimum was the greatest value without exceeding maximum voltage. Figure 4.5 shows the relationship between total laps and propeller diameter. The propeller diameter of 0.68 ft, or approximately 8 inches, was chosen because it was found to be the peak of the laps vs. propeller diameter curve, and required the

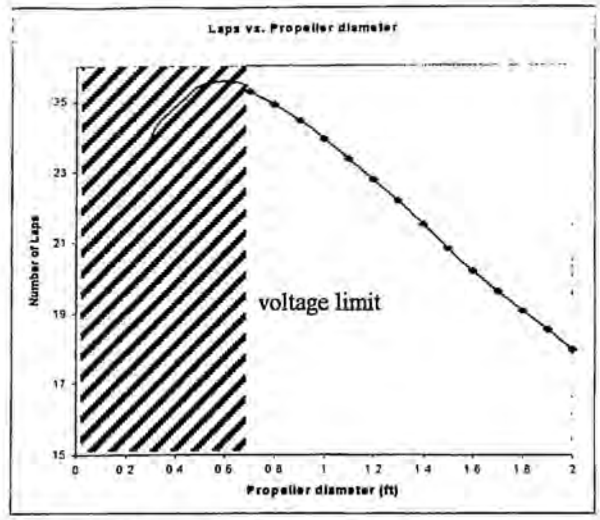



*Figure 4.3 Laps vs. Propeller Diameter*

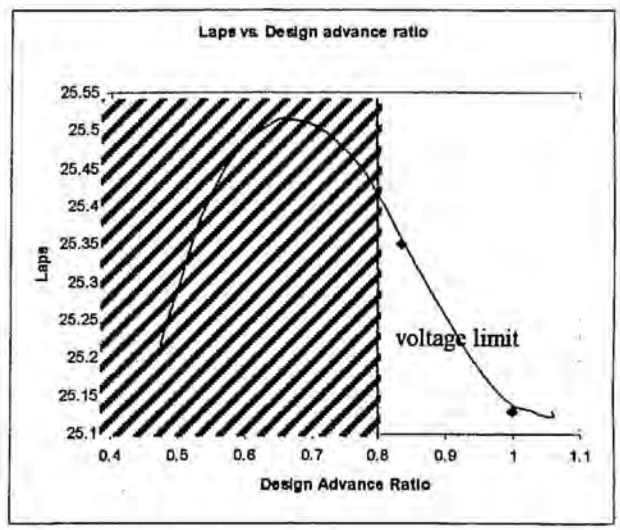



*Figure 4.4 Laps vs. Advance Ratio*

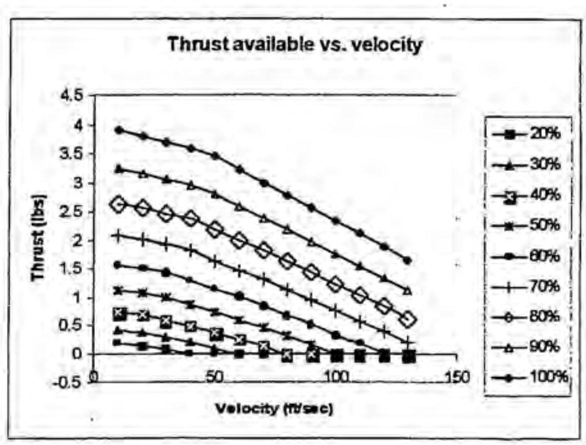



*Figure 4.5 Available thrust vs. velocity*

Propulsion Spreadsheet

## Inputs

| | |
|---|---|
| Velocity (ft/sec) | 120.1355168 |
| Air density (slugs/ft^3) | 0.0023769 |
| Thrust at cruise, lbs | 1.991669761 |
| Blade Count | 2 |
| Design J | 0.833 |
| **Input - Actual J** | 0.661929248 |
| Dprop (ft) | 0.682 |

## Inputs

| | |
|---|---|
| Motor Number | 2 |
| Battery Choice | 6 |
| Gearbox choice | 1 |
| Gear ratio (# : 1) | 1 |

***Actual J (V/nD) =*** ***0.661027***

***Delta J (input-output)=*** ***0.000903***

## Outputs

| | |
|---|---|
| RPM - cruise | 15,989 |
| Power (hp) | 0.534 |
| Torque (ft-lb) | 0.175 |
| Ct -actual | 0.0545 |
| Cp | 0.0440 |
| Prop efficiency | 0.814473468 |

## Outputs

| | |
|---|---|
| Motor Shaft Power (hp) | ***0.534133*** |
| **Motor Torque Req'd (ft-lb)** | ***0.175454*** |
| motor RPM | 15,989 |
| I @ max pwr (amps) | 47.86 |
| I @max eff. (amps) | 6.90 |
| Input Power (hp) | 0.657 |
| Efficiency | 0.814 |
| Batt. Pack Life (min) | 7.36 |
| K1- motor torque constant (ft-lb/amp) | 0.012036 |
| K2- motor RPM constant(RPM/Volt) | 585 |
| I (amps) | ***15.08*** |
| Io (amps) | 0.500 |
| Battery voltage (volts) | 32.500 |
| Ro = armature resistance (ohms) | 0.341 |
| Throttle fraction | 1.00 |
| Voltage (volts) | 32.47 |

| | |
|---|---|
| ***Required Voltage*** | 32.47 |

| | |
|---|---|
| Selected Motor | 1412/5Y |
| Selected Gearbox | no gearbox |
| Selected Battery | KR-1700AE |

# Motor, Gearbox, and Battery Worksheet

## Motors

| | Motor Samples (All are AVEOX motors) | | | |
|---|---|---|---|---|
| Motor Designation for MAIN worksheet | 1 | 2 | 3 | 4 |
| Motor model | 1412/4Y | 1412/5Y | 1415/2Y | 1415/3Y |
| Speed constant (RPM/volt) | 725 | 585 | 1190 | 795 |
| Torque constant(in-oz/amp) | 1.865 | 2.311 | 1.136 | 1.699 |
| Motor resistance (ohms) | 0.065 | 0.105 | 0.02 | 0.05 |
| No load Amps | 0.7 | 0.5 | 1.8 | 1.2 |
| Continuous current | 22 | 17 | 50 | 40 |
| Motor Weight | 0.6375 | 0.6375 | 0.7625 | 0.7625 |
| Length | 0.196666 | 0.196666 | 0.2216666 | 0.2216666 |
| Diameter | 0.1225 | 0.1225 | 0.1225 | 0.1225 |

## Gearboxes

| Gearbox # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Manufacturer | | astro flight | astro flight | astro flight | astro flight | astro flight | astro flight | aveox |
| Description | no gearbox | model 710 | model 711 | model 712 | model 713 | model 714 | model 714 | |
| Ratio (# to 1) | 1 | 3.27 | 4.36 | 3.69 | 3.1 | 3 | 2.7 | 3.7 |

## Batteries

| Battery # | Model Name | Tot. Energy (ft-lb) |
|---|---|---|
| 6 | KR-1700AE | 159644.9 |

| Number for worksheet | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Model Name | N-1700SCRC | KR-1000AEL | KR-1100AEL | KR-1200AE | KR-1400AE | KR-1700AE | RC-2000 |
| Milliamp-hours | 1950 | 1100 | 1200 | 1300 | 1450 | 1850 | 2000 |
| Milliohms per cell | 5.5 | 9.5 | 10.5 | 9.1 | 11.5 | 8.5 | 7 |
| Milliamp-hours per ounce | 1005 | 1155 | 1215 | 1228 | 1326 | 1249 | 1012 |
| Weight | 1.94 | 0.95 | 0.99 | 1.06 | 1.09 | 1.48 | 1.975 |
| Number allowed | 20 | 42 | 40 | 37 | 35 | 26 | 20 |
| Total Batt. mOhms | 110 | 399 | 420 | 336.7 | 402.5 | 221 | 140 |
| Milliohms speed control, etc. | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| power supply resistance | 125 | 414 | 435 | 351.7 | 417.5 | 236 | 155 |
| amp-minutes | 2340 | 2772 | 2880 | 2886 | 3045 | 2886 | 2400 |
| total energy (ft-lb) | 129441.78 | 153338.724 | 159312.96 | 159644.862 | 168440.265 | 159644.862 | 132760.8 |

maximum voltage, or full throttle. It was discovered through the design process that having a gearbox, while reducing propeller rpm and increasing propeller diameter and efficiency, provided neither more nor less laps than gearing the propeller directly to the motor. This was due to the assumed 3% transmission loss due to the gearbox and the gearbox's weight. It was decided that if there were no gain by having a gearbox, there would be an advantage to having no gearbox and a smaller propeller diameter. Figure 4.5 shows the thrust available from the propeller at various velocities at throttle settings from 20% of maximum to 100% of maximum.

## 4.3 Aerodynamics

Aerodynamic characteristics, key to every aircraft, are based on its wing(s), tail, and fuselage dimensions as well as their shapes. The aerodynamics worksheet analyzed various airfoils and determined the aerodynamic characteristics necessary to predict performance when combined with the other worksheets.

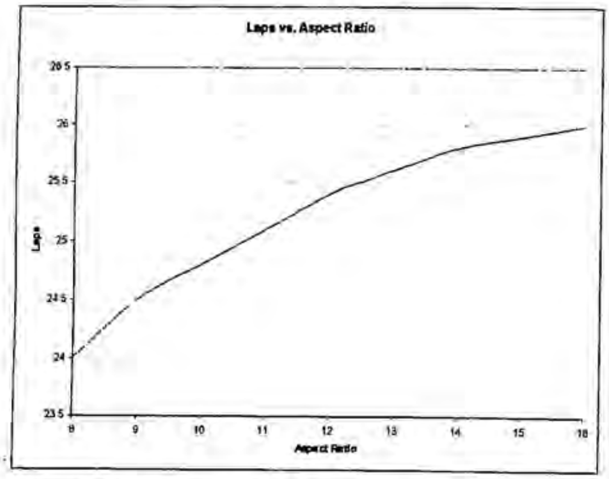



*Figure 4.5 Laps vs. Aspect Ratio*

In this case the task was to create an aircraft which flies at a maximum possible velocity provided the highest bank angle possible for the highest velocity in the turns.

### *4.3.1 Wing*

In designing the wing, it was decided that a low drag/moderate lift airfoil would perform the best for the contest requirements. A low-drag airfoil allowed the airplane to fly through the straight-aways with as much velocity as possible, and a high lift airfoil allowed high bank angles in the turns, reducing the turn radius around the pylons and the time to go around. A trade-off between having a high lift and low drag airfoil was made, even though a high camber airfoil gave the highest lift. However, the higher camber produced the most drag, while a thin low camber airfoil produced the least lift , but also the least drag. The decision was made to have a thin low camber airfoil, to take advantage of its low drag and to add a flap to it to increase its lift characteristics in the turns.

In choosing an airfoil, designs were taken from Dr. Michael Selig's "Summary of Low-Speed Airfoil Data – Volume One". From this resource, airfoils were chosen based on their moderate lift characteristics. These airfoils were then analyzed using Dr. Martin Hepperle's World Wide Web page (http://beadec1.ea.bs.dlr.de), which has an airfoil analysis program. This data was then entered into a spreadsheet designed by the team to analyze the plane. The spreadsheet calculated the lift, induced drag coefficients, total drag of the wing, total drag of the airplane, and the total lift to drag ratio of the airplane. These calculations were made using the assumption that flow over the plane was incompressible. Initial data used for the calculations were the two-dimensional drag and lift coefficients of the airfoils.

The final seven airfoil designs analyzed were the RG15, SD7037, WASP, E387A, K3311, S7012, and the E374. These seven were then analyzed, again using Dr. Hepperle's web page, adding flaps of various sizes (in percent of the airfoil chords), at various deflection angles. This was done in order to determine how adding a flap would affect the lift and drag characteristics of the airfoils. The S7012 had the second highest lift coefficient (1.5 vs. 1.6 - the E387A), the lowest drag coefficient at straight and level flight (.008 vs. .0082 for the next best – the RG15B), and the highest L/D of all the airfoils tested (21.4 vs. 20.6 for the E374B, at the turns). The final aircraft has both ailerons and inboard flaps.

In determining the wing dimensions, many factors were taken into account. First, though it would

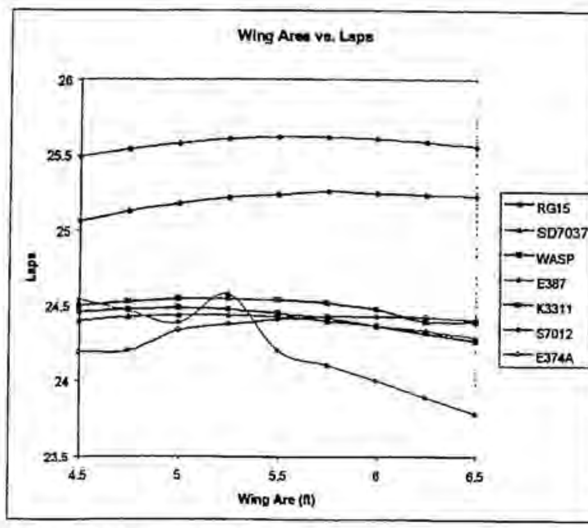



*Figure 4.6 Laps vs. Wing Area*

| CL | Cdo-wing | Cdi | CD-wing | CD-total | L/D-wing | [redacted] | |
|---|---|---|---|---|---|---|---|
| 0.1 | 0.008 | 0.000265144 | 0.008265144 | 0.01420854 | 12.09900245 | | |
| 0.2 | 0.008 | 0.001060577 | 0.009060577 | 0.015003973 | 22.07364981 | | |
| 0.3 | 0.008 | 0.002386298 | 0.010386298 | 0.016329694 | 28.88420918 | | |
| 0.4 | 0.0082 | 0.004242307 | 0.012442307 | 0.018385704 | 32.14837812 | | |
| 0.5 | 0.0088 | 0.006628605 | 0.015428605 | 0.021372001 | 32.40733653 | | |
| 0.6 | 0.0095 | 0.009545191 | 0.019045191 | 0.024988588 | 31.50401516 | | |
| 0.7 | 0.0115 | 0.012992066 | 0.024492066 | 0.030435462 | 28.58068389 | | |
| 0.8 | 0.012 | 0.016969229 | 0.028969229 | 0.034912625 | 27.61550863 | | |
| 0.9 | 0.012 | 0.021476681 | 0.033476681 | 0.039420077 | 26.88438578 | | |
| 1.1 | 0.0125 | 0.032082449 | 0.044582449 | 0.050525845 | 24.67338659 | | |
| 1.2 | 0.013 | 0.038180766 | 0.051180766 | 0.057124162 | 23.44630804 | | |
| 1.3 | 0.0135 | 0.044809371 | 0.058309371 | 0.064252767 | 22.29487266 | | |
| 1.4 | 0.014 | 0.051968265 | 0.065968265 | 0.071911661 | 21.22232576 | | |
| 1.5 | 0.0145 | 0.059657447 | 0.074157447 | 0.080100843 | 20.22723368 | | |
| 1.6 | 1 | 0.067876917 | 1.067876917 | 1.073820313 | 1.498300014 | | |
| 1.7 | 1 | 0.076626676 | 1.076626676 | 1.082570072 | 1.579006018 | | |
| 1.8 | 1 | 0.085906723 | 1.085906723 | 1.091850119 | 1.657600936 | | |
| 1.9 | 1 | 0.095717059 | 1.095717059 | 1.101660455 | 1.734024295 | | |
| 2 | 1 | 0.106057683 | 1.106057683 | 1.112001079 | 1.808223957 | | |
| CL-max 2D | 1.5 | | | | | | |
| | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | RG-15B @300k | SD7037B @300k | WASP @300k | E387A @300k | SD7003 @300k | K3311 @300k | S7012 @300k w/ f |
| CL-max 2D | **1.1** | **1.3** | **1.2** | **1.1** | **1.1** | **1.1** | **1.5** |
| t/c = | 0.0892 | 0.092 | 0.0935 | 0.0906 | 0.0851 | 0.1103 | 0.0875 |
| ***0.1*** | 0.008 | 0.011 | 0.011 | 0.018 | 0.0078 | 0.0118 | 0.008 |
| ***0.2*** | 0.0082 | 0.0105 | 0.0088 | 0.0098 | 0.007 | 0.009 | 0.008 |
| ***0.3*** | 0.0078 | 0.0078 | 0.0083 | 0.0085 | 0.008 | 0.0085 | 0.008 |
| ***0.4*** | 0.0079 | 0.008 | 0.0081 | 0.009 | 0.0085 | 0.0085 | 0.0082 |
| ***0.5*** | 0.0082 | 0.0082 | 0.0092 | 0.0095 | 0.0095 | 0.0092 | 0.0088 |
| ***0.6*** | 0.0094 | 0.009 | 0.01 | 0.011 | 0.015 | 0.01 | 0.0095 |
| ***0.7*** | 0.011 | 0.0098 | 0.011 | 0.015 | 0.012 | 0.0115 | 0.0115 |
| ***0.8*** | 0.0123 | 0.0118 | 0.012 | 0.018 | 0.014 | 0.0118 | 0.012 |
| ***0.9*** | 0.016 | 0.013 | 0.0138 | 0.0121 | 0.018 | 0.0123 | 0.012 |
| ***1.1*** | 0.022 | 0.0158 | 0.015 | 0.018 | 0.022 | 0.013 | 0.0125 |
| ***1.2*** | 0.04 | 0.0182 | 0.0175 | 0.021 | 0.032 | 0.016 | 0.013 |

be ideal for wing to have an infinitely high aspect ratio (AR) and longest span possible, limits are imposed by the structural abilities of available materials. Another factor taken into consideration was shipping. The maximum length allowed by commercial parcel companies is nine feet, so not exceeding that allows for safer, simpler travel of the wing. A third consideration was that it was better to have a low span aircraft for the straight-away segments of the course.

The team imposed an AR of 16, fearing structural instabilities such as flutter and wing bending past it, and the original design had a wing with an aspect ratio of 16, a wingspan of 10.2 feet, and a chord length of 9.1 inches. After some adjustments in the design spreadsheet, it was found that the aspect ratio could be lowered to 13 and the wing span could be trimmed down to 8.3 feet with a chord length of 8.8 inches. The original configuration allowed the plane to perform an estimated 26.1 laps in the seven-minute time limit. The final configuration gave an estimated performance of 25.3 laps. Figure 4.5 shows the effect of aspect ratio on the number of laps. There is no obvious optimum for the aspect ratio. The shorter wing span was favorable because it fit under the 9 feet maximum length limit for packages set by commercial parcel services. This allowed for a single piece wing as opposed to the 2-piece wing required for the 10.2 feet span, which is favorable because of its does not require a joiner setup to connect 2 pieces together.

A joiner would add unwanted weight, canceling the effects of reduced aspect ratio. The lowered aspect ratio was a result of the shorter span length, but even in doing so from the original 16 to 13, the chord length of the wing was essentially maintained. It was necessary to retain a sizable chord length for the structural stability. A longer chord length produces a thicker wing, and thickness adds stiffness.

Figure 4.6 shows the effect of wing area on the number of laps for seven different airfoils. All the airfoils have flat optima, and the S7012 airfoil yields the most laps. Figure 4.7 shows the drag versus velocity curve for the S7012 airfoil at different total airplane weights. Figure 4.8 shows the chosen airfoil shape.

The final part of designing the wing was to configure it. Elliptical wing loading was most preferable but nearly impossible to manufacture. To make the wing loading near elliptical, it was necessary to taper the wing. The tapers were designed to allow the wing to stall near center span as opposed to the tips. Center stall precludes roll-off and ensures downward pitch. If the tips stalled, the task of rebalancing and regaining control of the plane would be entirely up to the pilot, a task that would be extremely difficult at the low altitude and high speeds in which the plane will be flown. It was decided that the wing would have four taper breaks, two on each side of the wing, which allowed three

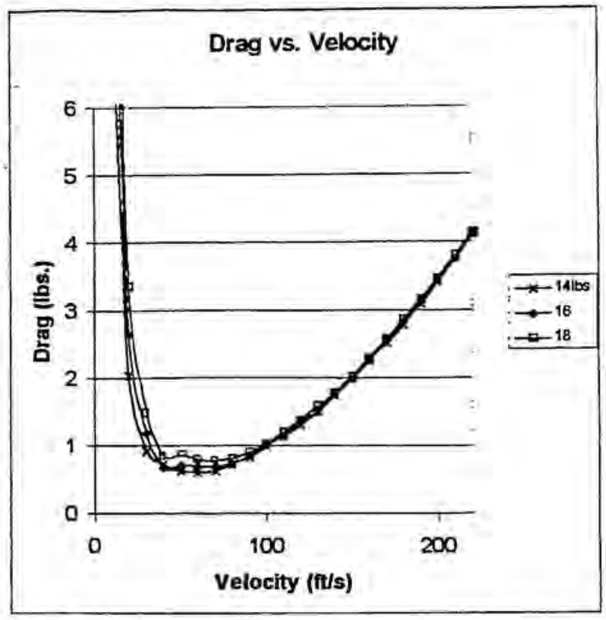



*Figure 4.7 Drag vs. velocity*

panels on each side. The breaks were at 40% and 65% of each side of the wing, measured from the center. The first panel was not tapered while the second panel was tapered from 100% to 85% of the root chord. The wing tip was tapered from 85% to 50% of the root chord. This three-panel configuration on each side allowed for the most favorable wing lift distribution.

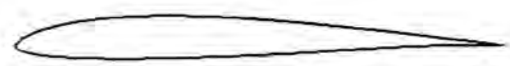


*Figure 4.8 S7012 Airfoil*

### *4.3.2 Tail*

In designing the tail, a symmetric airfoil was chosen because it does not produce lift at zero angle of attack but would produce the necessary upward or downward lift for control with the proper flap deflection. Thus, the symmetric airfoil chosen for the tail was the SD8020, as shown in Figure 4.9. A V-tail configuration was chosen over the more conventional low horizontal – flapped and full flying tail – with a

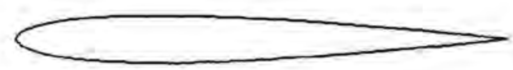


*Figure 4.9 SD8020 Airfoil*

vertical stabilizer and a T-tail configuration because it was simpler than the other configurations. It had two identical sections bonded at a set angle, and in has two surfaces. This is different the other configurations which had three effective surfaces. Also taken into consideration was that a V-tail had the clearance required for ground rolls that the plane would experience due to the single wheel landing gear configuration. A low horizontal would scrape the ground, while a T-tail would clear it but would be difficult and more complicated to implement.

#### *4.3.3 Fuselage*

The fuselage of the aircraft needed to have certain minimum dimensions in order to hold the necessary payload (7.5 lbs. of weight, 2.5 lbs. of batteries, radio receiver equipment and all necessary padding). It was desirable to make the smallest fuselage possible to reduce the drag that it produces, which turned out to be 20% of the overall drag. The box dimensions of the fuselage were 4.25" x 7.00" x 5.25" and were used to design the main cargo sections. The rest of the fuselage was tapered from these dimensions to a 1-inch diameter circle for the tail to be placed into, as well as tapered forward to accommodate the motor.

#### *4.3.4 Stability and Control*

The objectives were to give the pilot a predictable airplane, i.e. high stability and good pitch damping. The static margin was chosen to be 20%mac, while the tail arm was chosen to be one third the wingspan, which is derived from competition sailplane practice. It was decided that 33.2 inches was a good length for the arm because it was relatively short and allowed for a tail that did not require too much structural rigidity. The final tail volume was 0.85 square feet, which translated to a tail span of 27 inches.

The control of the aircraft was thought to be a problem due to the V-tail configuration of the tail, but it was decided that the problem could be resolved by using the mixing capabilities of commercial radio transmitters used for operating model planes, and doing so on the elevator and rudder functions. The flaps of the wings would be the slave control of the elevator function and would also be dependent on the ailerons. Deployed for takeoff, the flaps would follow the ailerons in the turns.

### 4.4 Mission Performance

The mission performance portion of the spreadsheet was designed to utilize all the other pages of the spreadsheet (Weights, airfoil data, etc.) to combine all performance and design aspects into a single airplane. In doing so, various models of aircraft type and their results could be determined and compared.

The different models of aircraft were changed by the input variables. Primary inputs consist of the airfoil data, aspect ratio, wing area, motor, battery and gearbox type. Secondary inputs are the percentage of maximum lift coefficient in the turns, diameter of the propeller, design of the J propeller and fuselage area. Final inputs include the areas of the wheels, struts, tails and the density of the air ($\rho_{Wichita}$=0.0023769 slugs/ft$^3$).

Once all the data inputs have been selected, the spreadsheet is ready to solve for its output variables. The airfoil chosen is run through an iteration process to determine the coefficient of lift in the straightaway and another in the turns. At the same time, the weights page uses all the airplane sizing (wing area, fuselage area, etc.) and powerplants (batteries, motor and gearbox type) to determine the weight of the plane, while the DesignC page uses only the sizing values to picture what the plane will look like. The spreadsheet is designed as a program to run all variables and calculate all outputs based on the input data and their linked equations.

The outputs of the configuration page are positioned into 3 categories: vehicle, propulsion and mission performance. Vehicle performance gives the weight of the plane, all coefficients of lift needed (2-D $C_{Lmax}$, 3-D $C_{Lmax}$, in the turn and in the straightaway), the lift-to-drag ratios in the straightaway and in the turn and the number of g's in the turn. Propulsion performance involves the solution for thrust, propeller and motor rotations per minute, the horsepower of the motor selected, the voltage of the battery (and current running across it), and the percentage of throttle being used. The percentage of throttle is desired to be at, but no greater than 100%. Inputs are adjusted in an attempt to reach this level for a maximum number of laps. This number of laps is produced in the mission performance section. Also shown are the distance and work per lap, propeller efficiency, total energy of the battery, the take-off field length and the airspeed velocity (ft/s). The most valuable number, again, is the number of laps.

The critical elements in determining the maximum number of laps are the combination of the battery, motor and gearbox, along with selecting an airfoil and adjusting its area and aspect ratio. The propeller efficiency is 81.2% and the efficiency of the motor-gearbox-battery system is 81.9%. The total number of complete laps predicted is 25. The average airspeed for the entire mission is 120 feet per second.

## 5. DETAIL DESIGN

### 5.1 Performance Predictions

The overall performance guidelines included an airspeed of 120.1 feet per second, a range of 25.3 laps, a weight of 13.77 pounds and a force of 7.56 g's in the turns.

# *USC AIAA97 Contest Design Spreadsheet*

Enter inputs (red), then Cntrl-b for converged solution

*DESIGNER INPUTS*

| Airfoil # | %CL max(turns) | Sw | ARw | Sh | Sv | Swet fuselage | Wingspan |
|---|---|---|---|---|---|---|---|
| (#1-8) | % | ft2 | n.d. | ft2 | ft2 | ft2 | ft |
| 7 | 85.00% | 5.3 | 13 | 0.60 | 0.60 | 2.00 | 8.300602388 |
| S7012 @300k w/ flap | | | | | not yet DesignC | | |
| **Swheels+frngs** | **Sstruts** | **Dprop** | **Design Jprop** | **Motor type** | **Battery type** | **Gearbox type** | **Rho(S.L.)** |
| frontal ft2 (all) | frontal ft2 (all) | ft | 333,.5,.666,.833.1.000 | (#1-4) | (#1-7) | (#1-8) | slugs/ft3 |
| 0.05 | 0.01 | 0.682 | 0.833 | 2 | 6 | 1 | 0.0023769 |
| | | | | 1412/5Y | KR-1700AE | 1 | |

*Vehicle Performance*

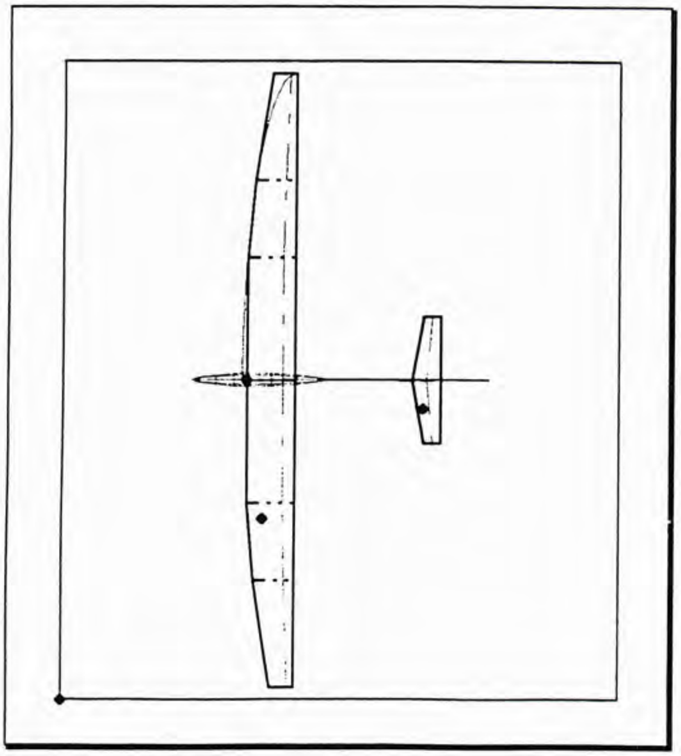
| Weight | CL max -2D | CL max -3D | CL straight | CL turn | L/D straight | L/D turn | n turn |
|---|---|---|---|---|---|---|---|
| lbs | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | g's |
| 13.68 | 1.5 | 1.35 | 0.150 | 1.15 | 10.30 | 21.38 | 7.63 |

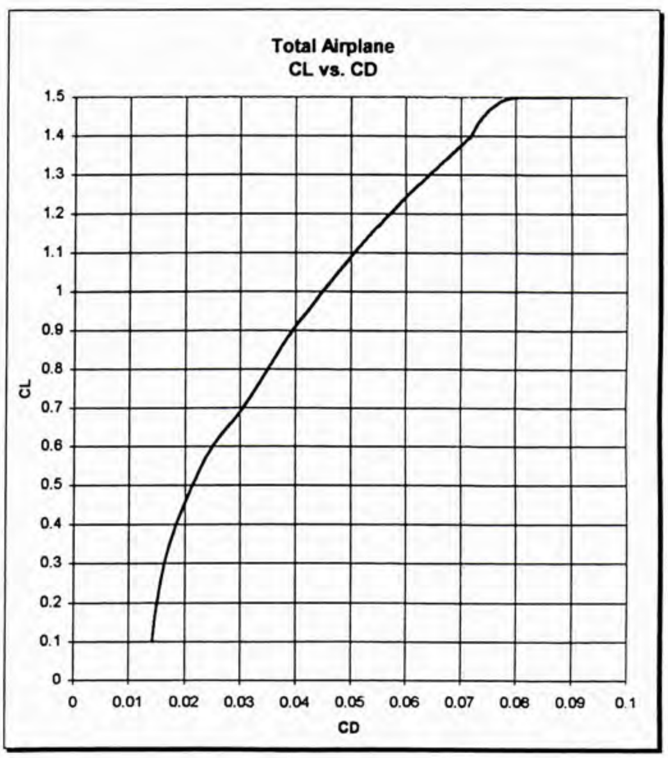
*Propulsion Performance*

| Thrust=avgDrg | Actual J | Prop RPM | Motor RPM | Motor Hp | % Throttle | Voltage V | Current I |
|---|---|---|---|---|---|---|---|
| lbs | n.d. | revs/min | revs/min | shp | %batt voltage | Volts | Amps |
| 1.99 | 0.661 | 15,989 | 15,989 | 0.53 | 99.9% | 32.47 | 15.08 |
| | | | | | (must be<100%) | | **88.69%** |

*Mission Performance*

| Distance/Lap | Work/Lap | Total E-Battery | Prop Efficiency | Mtr+Batt+Gbx η | Total Laps | TOFL | Airspeed V |
|---|---|---|---|---|---|---|---|
| ft | ft-lbs | ft-lbs | % | % | n.d. | ft | fps |
| 1,993 | 3,969 | 159,645 | 81.4% | 81.4% | 25.32 | *TBD* | 120.14 |





*5.1.1 Takeoff Performance*

$$\frac{(Vcli/Vsta)^2 W^2}{g\rho S C_{L\max}\left[T-[D+\mu_r(W-L)]_{avg}\right]} = s_{lo}$$

$\rho$ = density of air
W = weight of airplane = 18 pounds (with 1.3 SF)
g = gravitational acceleration
S = wing surface area = 5.3 ft.$^2$
$C_{L\max}$ = Maximum Lift Coefficient = 1.15
T = thrust = 3.93
D = drag = 1.54
$\mu_r$ = coefficient of rolling friction
$s_{lo}$ = distance to clear 6' obstacle
L = lift
Vcli/Vsta = Climb Velocity / Stall Velocity = 1.2

*Equation 5.1 Takeoff Distance Equation*

The total takeoff distance, including the distance to clear a six-foot obstacle at the end of the runway, is 300 ft. This is the distance calculated for an airplane weighing 18 pounds, or a safety margin of 1.3.

*5.1.2 Handling Qualities*

Handling qualities were integrated directly into the aircraft to reduce the demands placed upon the pilot. To begin with, the aircraft was constrained to a static margin (S.M.) of 20%, the same as sail pilots use, so pilots can adapt to flying the plane. Also, per competition sailplane practice, directional stability ($C_{n\beta}$) was given a value greater than or equal to 0.00201 degrees for low snaking (snake-like movement in the air that is difficult to control). Next, high pitch damping was added through use of a longer tail boom (increased length results in more damping), which helps the plane correct itself in flight when upward gusts strike the tail. Fourth, the airplane utilizes a geared flap to elevator, which increases $C_L$ in the turns to 1.15, helping to prevent stall in the turns designed for a radius of 59.5 feet. Fifth, the $\delta_{elevator_{MAX}}$ (maximum change of elevator) is limited to 85% of the wing's $C_{L\max}$, no matter how hard the pilot pulls on the stick, eliminating worry for the pilot in overchanging the elevator. Sixth, a neutral stick was set for straightaway trim, allowing the pilot to let go of control with the knowledge that the plane is flying true. A seventh parameter applied was to set the plane at maximum throttle for the duration of the flight, including climb and descent. Eighth, full span ailerons were built for a high roll rate to quickly get into the roll angle the plane is designed to fly at. Finally, it was determined that the pilot should actively control bank angle. Therefore, dihedral stability is not a big issue and the dihedral = 0°.

*5.1.3 G Load Capability*

The maximum g load encountered in the turns is 7.63g. For a safety factor of 1.5, the wing spar is designed to withstand a load factor of 11.44g.

*5.1.4 Range and Endurance*

The maximum endurance of the airplane is 3500 seconds (58 minutes) at an average velocity of 50 feet per second. The predicted maximum range of the airplane is 177,380 feet (33.6 miles) at 60 fps.

*5.1.5 Payload Fraction*

**Table of Weight per Section of Aircraft**

| Section | Percentage |
|---|---|
| Steel payload | 54.4 |
| Fuselage | 2.5 |
| Wing | 9.2 |
| Tail | 3.2 |
| Propulsion | 9.8 |
| Landing gear | 2.7 |
| Batteries | 18.2 |
| **TOTAL** | **100.0** |

## 5.2 Component Selection

The final design created with the use of the Excel workbook dictated the component selection. The selected propeller was an 8X6 propeller. The battery pack was one 26-cell, Sanyo KR-1700AE pack. The motor was the Aveox 1412/5Y, and did not require the use of a gearbox. The selected airfoil was the S7012 airfoil with 20% flaps.

## 5.3 Configuration Process

*5.3.1 Selection of Building Materials*

The final design for the University Of Southern California's entry into the AIAA competition was developed over time by weighing, comparing, and discussing all thoughts, ideas and results.

From the beginning a general consensus was formed by the group that the use of composites in construction was to be done in order to achieve a lightweight yet strong design. Composites were used to make a carbon fiber fuselage, Spyder-foam core wing and carbon fiber landing gear provided superb levels of strength while maintaining minimal weight. A high strength to weight ratio was the key factor in the decision to go this route, in addition to ease construction, being easily formed into very difficult shapes, as opposed to balsa wood frames which must be cut to the appropriate shape. Another benefit offered by composites is their reproducibility, often an overlooked benefit. Once a mold has been produced, a piece (such as a fuselage) can be made in about the time it takes for the epoxy (glue) to dry. Besides composites' obvious structural and design benefits, they were chosen based on past experience in competition with them, as attested by annual entries in the SAE Cargo Plane Competition.

The plane's look took shape over many brainstorming sessions, as the basic process consisted of altering and improving a drawing of a plane brought to meetings. Over the course of time, a final design was developed. The preliminary shape was assumed by referencing past competition planes, with slight modifications made for a long and narrow fuselage, chosen for its ability to carry all necessary items without incurring excess drag. With a fuselage set, the rest of the plane was designed.

### *5.3.2 Wing-Fuselage Integration*

The wing was chosen based on spreadsheet calculations, which showed that the Selig S7012 with 20% flaps provided the largest $C_{Lmax}$. Besides the amount of work that went into choosing an airfoil, the structural system of the wing involved structural testing and research. The final design for the wing does not include a conventional spar, rather a carbon fiber and 1/32" plywood lay-up on the upper surface of the wing. This design required much thought into how to connect the wing and the fuselage. Much of the forces from the wing were transferred to the center section, and it was key not to compromise the surface of the wing anywhere near the carbon and plywood spar. The final design called for two dowels that protrude from the leading edge of the wing and are then accepted by two holes in a bulkhead of the fuselage. The final point of restraint for the wing is a bolt towards the trailing edge of the wing that effectively clamps the entire wing assembly to the fuse. This system allows for quick removal of the wing as well as providing access to the interior of the fuselage, preventing the fuselage's aerodynamic shape from being compromised by unnecessary access holes.

### *5.3.3 Landing Gear design*

#### 5.3.3.1 General landing gear configuration

The design of the landing gear was driven by the twin criteria of drag reduction and maximum simplicity, one major criterion. The spreadsheet revealed that cutting landing gear drag in half resulted in another theoretical lap, a significant improvement in performance. Using these criteria, a tricycle landing gear was eliminated because of the drag incurred if left extended and the complexity involved if it were made retractable. Also eliminated was a bicycle configuration because it offered few benefits over a simpler taildragger arrangement. Thus, a taildragger arrangement was decided as the basic layout for landing gear.

#### 5.3.3.2 Number of Wheels

The question of how many wheels to use and their placement remained. Early on, the benefits and drawbacks of a single, centrally mounted wheel were considered. Having a single landing gear in front instead of a conventional taildragger arrangement does away with one wheel and strut, potentially resulting in half the drag. Also, such a system is potentially half as complicated as a two-wheel arrangement. It makes takeoffs and landings more difficult, but the promised simplicity and drag reductions overrode this argument. It was decided to go ahead with the single landing gear concept.

#### 5.3.3.3 Landing Gear Retracts

As it became more defined, the plan for the landing gear underwent several modifications. Originally planned was to have the wheel retract into the rear of the fuselage. After sizing the wheel and the plane more precisely, it was discovered that gear retraction would require a weighty servo system and would be difficult geometrically to retract the gear and strut completely into the fuselage. Retracting the gear but leaving it exposed might have reduced drag compared to leaving it fully extended, but the expected drag reduction was deemed insufficient to justify the weight, complexity, and lack of robustness inherent in such a design. Thus, the decision was made to use a fixed single landing gear with a fairing plus a tailskid.

5.3.3.4 Landing Shock Absorbed by the Gear

At this point shock absorption became an issue. Calculations showed that maximum expected landing

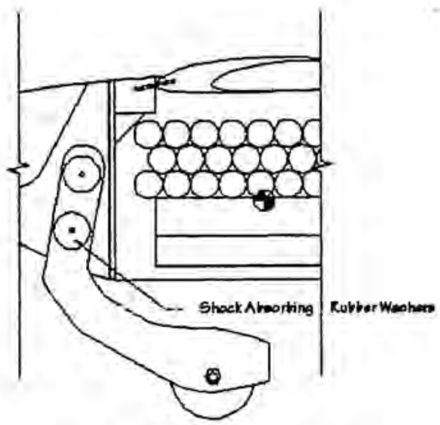



*Figure 5.1 Detail of Landing Gear Shock Absorber*

loads needed to be between 20 and –2 g's, assuming a vertical landing velocity of 4 feet per second (fps). Very rigid carbon fiber strut anchored to the plane with shock-absorbing rubber grommets was used to solve the problem. The strut uses two carbon bars that sandwich a core of light balsa wood. This H shaped strut, created by the sandwich, provided a pocket for both the wheel itself and its attachment to a bulkhead inside the fuselage. The drag of this strut was greatly reduced by applying a balsa faring to the strut and around the wheel, essentially turning the strut into another wing surface, reducing pressure drag.

5.3.3.5 Takeoff and Landing Skids

With a single wheel gear, the problem of stability on landings and takeoff became yet another concern. For takeoffs it was assumed that a skilled pilot could easily control the plane, but landing was not so easily controlled. The solution was to place skids at critical points on the plane and prevent scraping of the wing and tail during landing by placing skids on both tips of the wing as well as on the rear of the tail boom. Then the material for the skids became another design decision. Metal hoops were rejected since they created too much drag and were hefty in weight. The final design called for the skids to be made of circuit board, which is light in weight and creates a considerably less amount of drag than steel rings.

*5.3.4 Tail Boom Design*

The tail boom was the only part of the plane to remain constant throughout the entire design process. The carbon fiber tube was chosen because of its strength characteristics and aerodynamic shape. It also acts as a conduit for the wiring of servos in the tail, eliminating the need for a push-rod assembly. The connection of the tail boom to the fuse was based on a simple plumbing principle. A carbon fiber tube with a inner diameter slightly larger than the outer diameter of the tail boom receives the tail boom. The larger carbon fiber tube, which is permanently attached to the fuselage, has slots cut at two of its quadrants. The clamping power of this system is derived from a simple hose clamp, which effectively locks the tail boom into place by compressing the outer tube around the inner.

*5.3.5 Tail Design*

The design of the tail was based on landing gear considerations, stability, and control. The design concept behind the v-tail versus the t-tail included many factors, the first of which was weight, a v-tail possessing less. Second was a concern that a hard landing on our single gear might cause a t-tail to separate from the tail boom. Third, in keeping with the main focus that the contest is a competition, not a long term usage type of mission, the v-tail's handling aspects would suit this mission perfectly.

# 6. MANUFACTURING PLAN

## 6.1 Introduction to Manufacturing Process

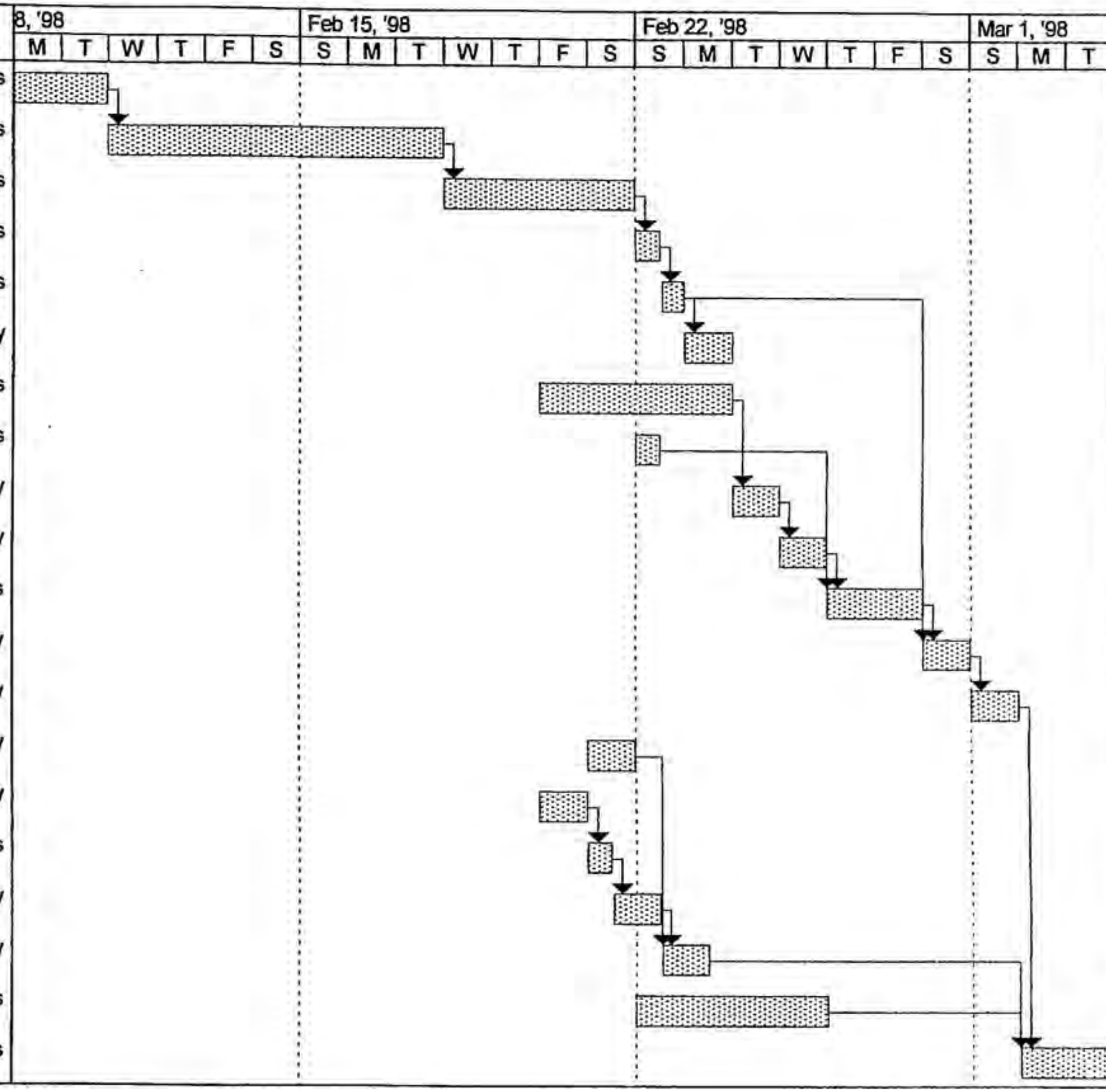
Considerations for material selection and overall process of building the plane were cost, speed, transportation, and quality. Since many of the team members have built and flown airplanes before, their skill level and experience were also considered. Many students in the group also had experience using composites to build airplane parts. Although many of these composites are not cheap, they are very light and strong, can be molded into intricate parts, and be made quickly. They are also more durable to bumps and accidents which come from competition, landing, and being transported half way across the country. The skill required to make many of these parts is minimal compared to the quality and reliability they ensure; nevertheless, building the major components of the plane (fuselage, wing, landing gear, tail) is a skilled process.

## 6.2 Fuselage Construction

The carbon fiber fuselage with aircraft plywood reinforcing hard points was to be molded. This carbon fiber shell can be very strong and lightweight. Hard points made out of aircraft plywood transfer concentrated loads into the strong carbon shell.

# USC AIAA Student Design/Build/Fly Competition
## Manufacturing Schedule

| ID | Task Name | Duration |
|---|---|---|
| 1 | plug shaping | 2 days |
| 2 | mold making | 7 days |
| 3 | fuse completed | 4 days |
| 4 | cut and shape bulkheads for fuse | 0.5 days |
| 5 | install bulkheads in fuse | 0.5 days |
| 6 | install motor, radio,and steel block in fuse | 1 day |
| 7 | cut and glue wing cores | 4 days |
| 8 | cut mylar for wing | 0.5 days |
| 9 | cut and glue in wing supports for fuse junction | 1 day |
| 10 | installing servos in wing cores | 1 day |
| 11 | glue and vacuum bag wing | 2 days |
| 12 | fit wing to fuse | 1 day |
| 13 | cutting ailerons and flaps in wing | 1 day |
| 14 | build tail boom | 1 day |
| 15 | cut tail cores | 1 day |
| 16 | install servos and linkages in tail | 0.5 days |
| 17 | vacuum bag tail | 1 day |
| 18 | glue tail to tail boom | 1 day |
| 19 | landing gear | 4 days |
| 20 | final assembly of plane | 2 days |




Project: Fabrication
Date: 2/1/98

Progress

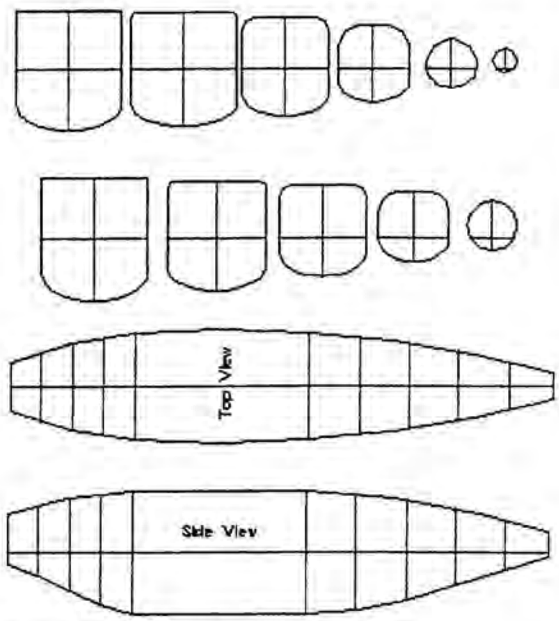



*Figure 6.1 Sections and Views of Wood Plug*

This carbon fiber shape is made by first making a plug out of wood. The plug or shell can be machined to the exact shape desired, but this method was not chosen because the process is expensive; instead the plug was shaped by hand in about 15 hours. A shell is made around the plug out of fiberglass in two pieces so that the plug can be removed. This shell was divided into top and bottom halves. When the halves were joined, an inch strip of carbon fiber cloth was added. Having these two joiners run along the sides of the fuselage added strength needed when the cut out for the mount of the wing was done. A layer of carbon fiber cloth and epoxy is laid up inside each side of the shell, and a one-inch fiber stinger is run down the inside to join the two halves.

Once the carbon has cured, the two shells can be pulled off the finished part. This whole procedure takes about 40 man-hours but each successive part only takes about 5 hours to reproduce. Hard points made out of quarter inch aircraft plywood were shaped to the fuse and glued in with 30-minute epoxy. These were cut out by hand on a scroll saw using a printout as a guide. The aircraft plywood is cheap, easy to work with, and has the strength required for the loads this airplane will encounter.

This process of making the fuselage is inexpensive and creates excellent parts that are very strong and durable. Materials such as carbon fiber and plywood are easily available from hobby stores and specialty shops such as C.S.T. There are several drawbacks of this procedure, including that the construction of the first part is time consuming. Another problem is that creating a plug by sanding and carving may lead to imperfections which were not designed for, possibly creating a fuselage that is not as light as a built up balsa fuse. However, the durability of the finished product over many hard landings and "hangar rash" is well worth the small increase in weight.

## 6.3 Wing Construction

### *6.3.1 Concept for wing construction*

There are many ways to build a small, light wing. Instead of a balsa wing or a molded composite wing, foam as a core and a composite, vacuum-bagged skin for strength was used. Plywood was shaped for hard points and aluminum dowels and a Teflon screw was to be used to attach the wing to the fuselage. A foam core wing and composite skin were considered because they take less time to build and make a very high quality wing. The major disadvantage of this choice was the flight load.

### *6.3.2 Wing skin structural tests*

There was little data on how to produce foam core wings that have a skin able to take 7.56-g flight loads, so it was decided that spending time for tests on sample wing skins was needed to assure the plane's safety. Spyder foam was selected because it possesses the highest compression to weight ratio of many polystyrene foams. Twelve samples were created with varying compression skins under loading. Some of the skins had a 1/64" plywood stiffeners in them. Each sample was crushed in an Instron machine, the time for usage donated by the Mechanical Engineering department at USC. The results were accurate and very helpful in determining the lay-up for the spar to be in the wing skin. It was found that adding a sandwich of carbon, (1/64) plywood, and carbon gave a great increase in load-failure over conventional layers of carbon of the same weight.

### *6.3.3 Wing construction methods*

Taking a block of foam and passing a hotwire over an airfoil shaped block on each side cuts out the shape of the wing by melting out the styrofoam. The process is quick (about 10 minutes) and produces excellent wing shapes that are nearly identical to those described in the design. The servos for the plane are glued into a cavities cut out of the core to hide them and reduce drag. Once the entire wing has been hot-wired out, glued together and hard-points installed, the composite skin can be applied. In this case another small indent was made in the upper surface to lay in a flush wing spar. The composite skin is epoxied to a sheet of Mylar that is shaped to fit and cover the wing. Once the Mylar sheet has been completely covered and the spar has also been glued on, the Mylar is wrapped around the core and placed in a vacuum bag until it is cured. This process is highly skilled and creates excellent parts. Some of the students on the team have experience doing this, and it was not a problem to produce parts and train less experienced students at the same time. Equipment such as a vacuum pump and hotwire are expensive, but the quality of the final product is worth it.

### *6.3.4 Tail and landing gear construction*

The tail was made in a similar to the wing using a foam core and composite skin for strength. It was,however, easier to make because there was no spar, connected to the tail boom with epoxy.

Drawings for the landing gear called for a ¼" plywood sheath with a carbon fiber coating on each side. The shape of the landing gear was cut out of plywood by hand using plans as a guide. Carbon fiber was glued on either side and vacuum-bagged to ensure no delamination. A wheel faring was to be made out of something lightweight and inexpensive, so a sanded and shaped piece of foam was used.

### *6.3.5 Summary of construction process*

The plane had to be built on a limited amount of time and at a reasonable cost. With limited resources and time, the best job thought possible was done. The schedule made for building the plane was reasonably kept, and the high quality end result was well worth the time and efforts.

The quality came from hard work throughout, especially at the inception. Beginning with a 'class' on how to design a model airplane, students began to develop thoughts and ideas for what was a plane built from scratch. Once a thorough academic background was in place, a schedule for design and building was set up.

Design of the aircraft was performed using computers. This was invaluable as several hundred combinations of configurations were analyzed using an extensive Excel spreadsheet, a near impossible and very tedious task if done by hand. However, it was discovered that at least one hand calculation should be done to be sure that there were no mistakes done in developing the software package utilized. Simple mistakes in equations caused serious differences in output results of weight. Once the problem was discovered, better results led to good comparisons of various aircraft based on primary design of the plane.

During the building phase of the schedule, it turned out to be very important to stay on pace. Our team almost got completely off schedule before a long work session caught us up. Academic constraints made the entire team susceptible to delays, but due to previous experience, it was deemed absolutely necessary to complete the plane as scheduled.

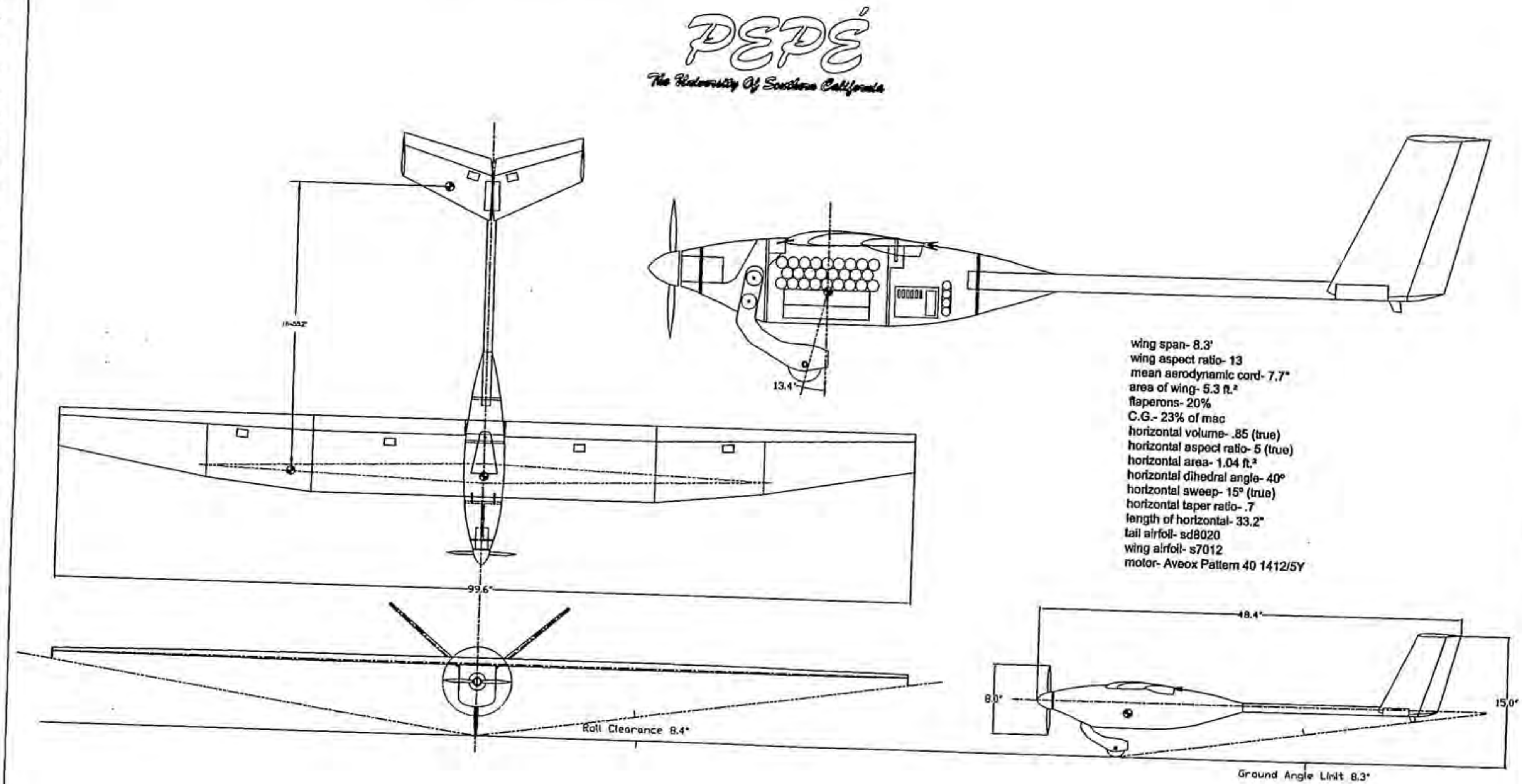
There is room for concern that the airplane will not perform as predicted. Further tests of the live aircraft still need to be completed, and it is possible that the aircraft built is not as clean as the aircraft designed on paper. In addition, there is no guarantee that the propeller selected in design will work as efficiently as other similar propellers, so further studies will be done using different props at future test flights. Also, if a larger propeller selected, a gearbox might be used, leading to questions of capability that cannot be answered at this time.

Another question that must be answered is how well the plane will handle with only one wheel. The pilot may deem the takeoff and landing gear too difficult to manage and require a change. Again, further answers will be discovered on future test flights.

Limited time to develop the plane was also a result of a fewer number of participants compared to years past. With only eight students involved throughout the year, and less than half with experience building anything, more teaching was necessary and mistakes were made. But, the team came together due to its commitment, and the performance as a whole was far beyond what has been seen in several years.

Thanks need to be given to our sponsors, Lockheed Martin Skunkworks and the Northrop Grumman Corporation, whose financial support allowed us the freedom to create the envisioned design. In addition, gratitude is given to Blaine Rawdon and Mark A. Page for the countless hours they spent driving to USC, teaching the fundamentals of model (and real) airplanes, and working out errors made during the course of the design process. Without them, the plane would be far different than the one built at present.

Final praise is given to the University of Southern California's Aerospace Department and to Dr. Blackwelder, whose continual support, efforts and experience proved invaluable.




wing span- 8.3'
wing aspect ratio- 13
mean aerodynamic cord- 7.7"
area of wing- 5.3 ft.²
flaperons- 20%
C.G.- 23% of mac
horizontal volume- .85 (true)
horizontal aspect ratio- 5 (true)
horizontal area- 1.04 ft.²
horizontal dihedral angle- 40°
horizontal sweep- 15° (true)
horizontal taper ratio- .7
length of horizontal- 33.2"
tail airfoil- sd8020
wing airfoil- s7012
motor- Aveox Pattern 40 1412/5Y

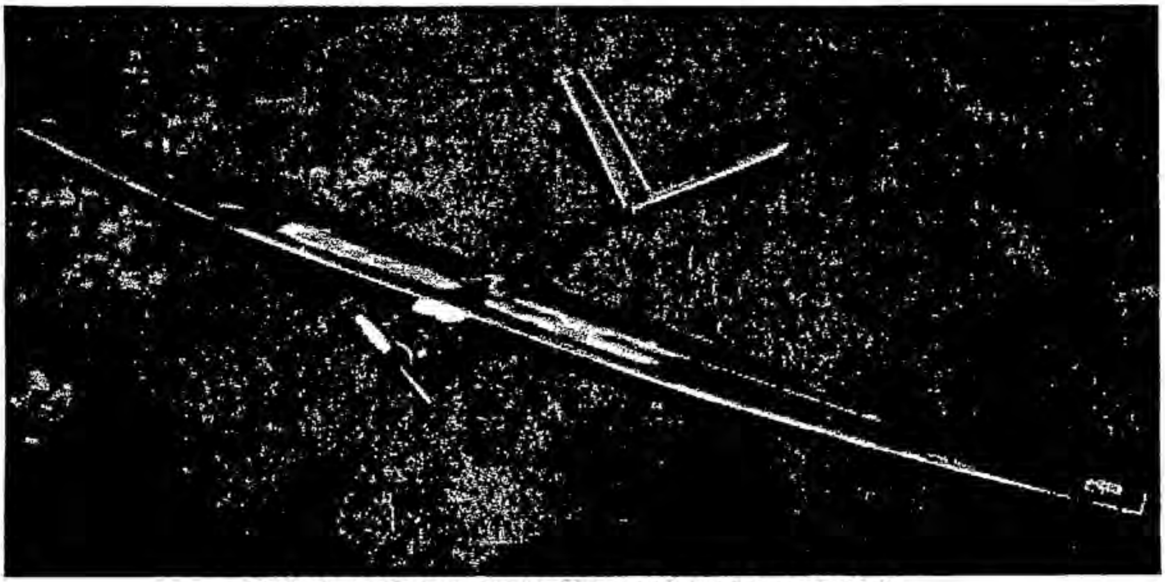
General Arrangement Plan
University Of Southern California Pepé
AIAA Competition
Ryan Romo
March 10, 1998

# Design Report – Addendum Phase

## *University of Southern California*

April 13, 1998

1997/1998 AIAA Student Design/Build/Fly Competition

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# 7. LESSONS LEARNED

## 7.1 Differences between final and proposal design

### *7.1.1 Fillets*

Upon closer inspection of the proposal design, it was discovered that there were sharp corners in the airplane surface. These corners, located at the wing-fuselage junction on each side of the airplane, would create horseshoe vortices that would increase the drag on the airplane.

Fillets were then proposed to alleviate these horseshoe vortices. A brief drag calculation was done and the fillets were shown to reduce the drag by about 3%. These fillets were made of balsa wood, shaped and sanded by hand, and then attached to the fuselage with epoxy at the locations shown in Figure 7.1. The time required to implement this change was six man-hours, and the cost was only for the balsa wood, which was ten dollars.

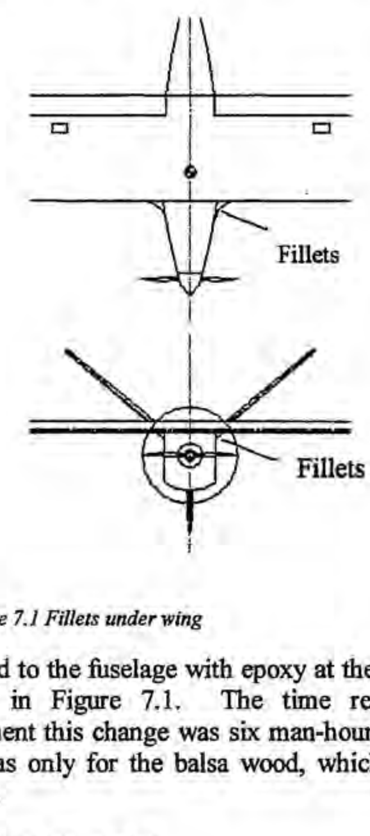


*Figure 7.1 Fillets under wing*

### *7.1.2 SD7003 Airfoil*

In the course of the design phase and early into the manufacturing stage, research continued to ensure that the airfoil and other components selected in the design phase provided the best performance. During this research, another airfoil, the SD7003 with flap, was shown to perform half a lap better than the S7012 airfoil when entered into the Excel design spreadsheet.

Although foam cores had already been cut for the S7012 airfoil, it was decided that the half lap increase was enough to warrant the purchase of new foam and to justify switching the airfoil completely. The cost of changing airfoils was \$46.25, the cost of the new spyder foam, since no other parts had been installed in the wing at that point. This cost was not an issue in the decision to make the change. The main issue debated was the time to get the new airfoils cut out of the foam and the wing construction back on schedule. The time to cut the new airfoils was one week, because new foam needed to be ordered and received before any actual cutting was done. It was decided that the predicted half lap increase in performance was worth the one week delay. In reality, very little time was lost, as the manufacturing focus was redirected towards the fuselage, tail boom and the tail, which were all constructed during that week.

*Figure 7.2 SD7003 airfoil*

### *7.1.3 Wingtip Washout*

During the turns, the airplane is designed to pull up to 85% of $C_{Lmax}$. In the event that the airplane passes the limit of $C_{Lmax}$, good stall characteristics are necessary for the pilot to recover control and continue the flight. To this end, the wing was designed to have a 3° washout at the wingtips. This would help guarantee that the wingtips would stall after the center section of the wing stalls. This decision was made before the wing core sections were cut, so there was no increase in time required or cost to put washout in the wingtips.

## 7.2 Static load tests

When the wing and the wing spar caps were completely constructed, a static wing load test was done on the wing. The wing spar caps are several sandwiched layers of carbon fiber and 1/64" plywood inlaid into the wing. A picture of the layers are shown in Figure 7.3.

The predicted flight of the airplane included turns at 7.6g's. The static load test was designed to determine if the wing and the wing-fuselage junction would withstand a 9g turn. The wing was attached to the fuselage so as to test the strength of the wing and the wing-fuselage attachment. The fuselage and wing were suspended

*Figure 7.3 Carbon fiber and plywood layers laid out separately. The layers were then inlaid in the top of the wing to be used as the wing spar. A similar lay-up was used in the bottom surface of the wing.*

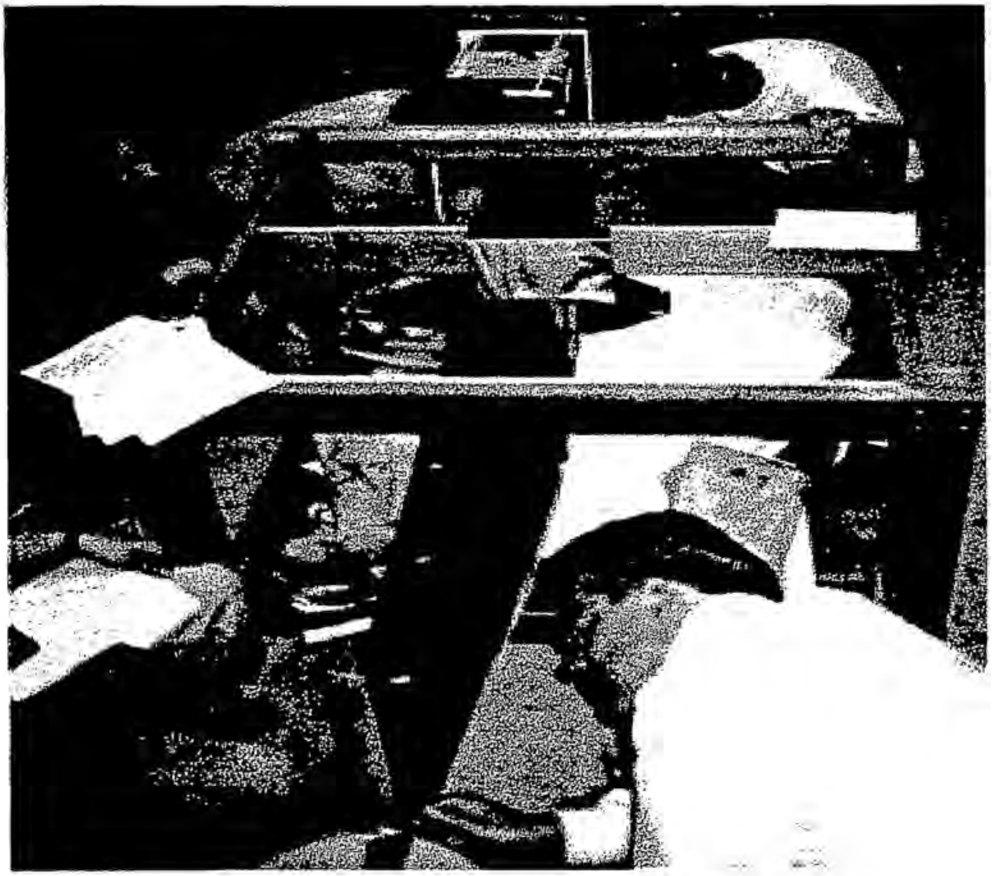

*Figure 7.4 Fuselage and wing suspended from workbench in preparation for static load test*

in an inverted configuration from a wood frame with duct tape. Figure 7.4 shows the experimental setup without applied loads. The position of the wingtips were recorded without any loads. Sandbags were used for weight and were applied to the wing in an approximately elliptical loading pattern. At the weight distribution that simulated a 9g turn, the wingtips deflected 4.25 inches. Figure 7.5 shows the wing with the maximum elliptical load pattern applied. There was some local buckling of the wing skins, and a wave on the secondary structure of the wing, but neither the wing spar caps nor the foam structure of the wing failed.

## 7.3 Landing gear shock test

One of the concerns raised when the decision was made to build a single strut, single wheel landing gear was the ability to absorb the shock of a hard landing. The design landing gear was built and tested for strength in a seven inch vertical drop that simulated a rate of sink of 6 ft/s. When subjected to the seven inch drop, the landing

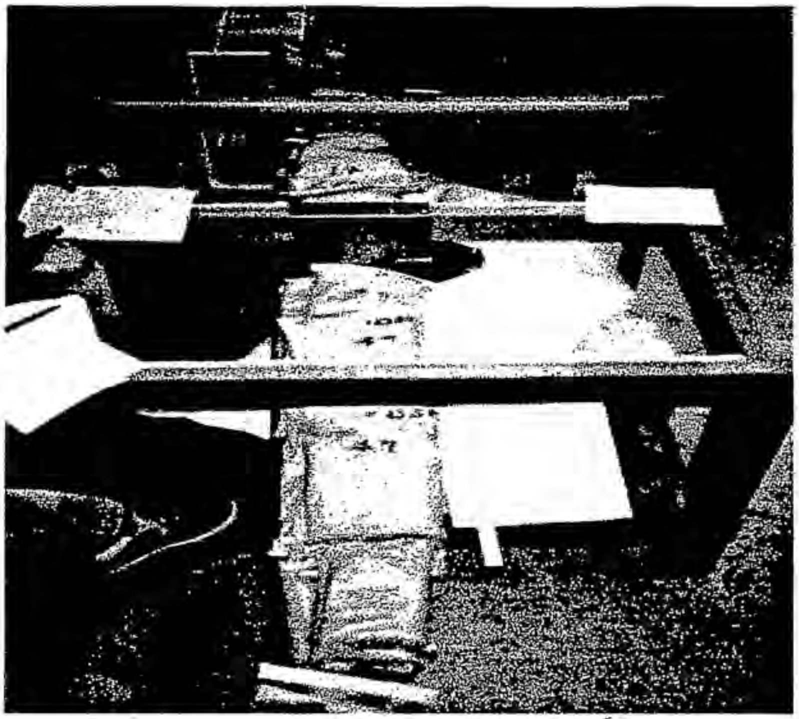

*Figure 7.5 Fuselage and wing with simulated 9g load factor*

gear completely absorbed the load. No parts were damaged, and the gear did not bend back and hit the underside of the fuselage.

## 7.4 Areas for improvement

*7.4.1 Design Process*

Improvements that will be made in the next design process will be mainly adjustments to the Excel design spreadsheet. The first area for improvement is the range of alternatives investigated. For example, only four motors and seven types of batteries were included in the spreadsheet workbook. The addition of more motors and battery types would introduce more flexibility in the final design and could produce better performance results.

Another area for improvement in the design process is in the scope of what the Excel spreadsheet can do. More graphical outputs based on the spreadsheet's calculations would be helpful in the selection of various components of the aircraft.

Optimization of the parameters examined in the spreadsheet was done manually, and as a result, delayed the design process. A third improvement that could be made in the design process is the automation of spreadsheet optimization. If the spreadsheet could be programmed to locate the design that produces the maximum number of laps, the selection time of the components would be greatly reduced. This would have allowed for an earlier start on construction and detailed design.

*7.4.2 Manufacturing Process*

One manufacturing technique that can be improved is the inclusion of wingtip washout. In the current wing, the washout was cut into the foam cores. In the vacuum bagging process, weight was applied to the top of the wing to make sure it cured without any large amount of wing twist. The weight applied at the wingtips, however, prevented all wing twist, including the 3° washout desired in the wingtips. This problem will be solved in the future by laying the vacuum bagged wing into the airfoil-shaped beds before applying any weight to the top of the wing. Uniformly cut beds will ensure that the washout will not be twisted out and also will provide a flat surface upon which to lay weight down on the wing.

In order to correct the washout of the current wing, a slit was cut along the leading edge of the wing, greatly reducing torsional rigidity, and weights were hung off the leading edge to twist it to the desired amount. Fiberglass was reapplied to the leading edge fixing the weak edge caused by the initial cut.

Experience was the most important asset in the construction of the airplane. Over half the team had at least two years fabrication experience. Knowledge of carbon fiber and fiberglass construction techniques resulted in higher product quality. This quality was apparent in weight reduction without loss of strength. Experience also decreased construction time, as parts were constructed correctly the first time. The end result was a very clean aircraft fully constructed in a month.

### 7.5 Cost comparisons

The actual costs of the materials and components of the airplane were about the same as the predicted costs. There was an increase in cost ($56.25) due to the cost of the extra spyder foam purchased after the new airfoil was selected and the cost of the balsa wood for the fillets. There was a reduction in cost due to the decision to build the carbon fiber tail boom as opposed to purchasing a commercially available tube. This resulted in a savings of $50. All the other costs involved in materials, electronics, and hardware were as expected from retail prices.

Manufacturers List Price

| | |
|---|---|
| *Component (quantity)* | *Total Price ($)* |
| | |
| | |
| **Propulsion Systems** | **$981** |
| Aveox 1412/5Y motor (2) | 420 |
| Aveox motor controller (1) | 250 |
| Batteries (26) | 117 |
| Battery charger (1) | 149 |
| propellers (3) | 20 |
| spinner (1) | 5 |
| propeller adapters (2) | 20 |
| | |
| | |
| **Building Materials** | **$691** |
| Wood | 100 |
| Epoxy | 110 |
| Releasing Agents | 40 |
| Spyder Foam | 74 |
| Carbon fiber | 224 |
| Fiberglass | 63 |
| glue | 80 |
| | |
| | |
| | |
| **Other** | **$1146** |
| Radio (1) | 459 |
| Servos (7) | 406 |
| servo links (12) | 20 |
| steel weight (3 pieces) | 20 |
| shrink wrap | 20 |
| paint | 7 |
| digital scale | 100 |
| vacuum bagging material | 83 |
| miscellaneous | 31 |
| | |
| | |
| ***TOTAL*** | ***$2818*** |

# AIAA Student Design/Build/Fly Competition

# The Texas Tall Boy

Proposal Phase


Designed and developed by:

Robert "Rip" Rippey III

M. Shea Parks

Kendrah S. Smith

David Sellmeyer

Texas A&M University, College Station, Texas


March 16, 1998

# Table of Contents

# 1. Executive Summary

## *1.1. Major development areas*

Designated the Texas Tall Boy (TTB), the 1997-1998 entry from Texas A&M University began as a second-generation aircraft with its origins in the 1996-1997 entry, the Aggie Flyer. After the team considered the rule changes for this year's contest, most notably the air race style competition imposed by the new time limit, it was observed that the Aggie Flyer could easily be modified to perform better under the new rules. With that in mind, the team derived the Texas Tall Boy from the Aggie Flyer by making slight changes to sizing, configuration, and structure.

Initially though, many design changes and alternative configurations were investigated in the conceptual design stage in order to be verify that the TTB would perform best if based on the Aggie Flyer. Included in this list of possible configurations was the consideration of a flying wing, a canard configuration, tandem wings, and eventually variable geometry.

In first considering a flying wing aircraft, it was decided that working around the stability and control issues that accompanied a flying wing concept was beyond the scope of the project, and so that concept was abandoned. Similarly, the second alternative of a canard configuration was rejected because the team was not as familiar with the design of such an unconventional layout. For the third option, a tandem wing aircraft was investigated, but was later discarded because the additional induced drag of a second wing would have cost precious speed. Finally, the team considered an airplane with variable geometry since wing sweep could be changed to the optimal position for each flight phase. This idea was later ruled out due to the figures of merit governing the conceptual design phase.

Throughout this conceptual design phase, tools used to guide the design included computer programs and other electronic tools, but most influential was the team's experience with the previous DBF competition. After considering all possible alternatives, the team settled on a conventional aircraft layout similar to that of the Aggie Flyer. Since the team wanted to optimize the propulsion system and airframe size to produce an airplane that would complete as many laps around the race course as possible in the given time limit, it was decided that the TTB could be designed to have a lower profile than its predecessor.

By using the previous design entry, many aspects of the new design were refined and improved while allowing the positive aspects of the original design survive. Subsequently, the considered changes to the design included reducing the frontal area of the fuselage while retaining much of the same layout of internal components. The final airplane configuration resembled a more refined and sleek derivative of the Aggie Flyer.

During the preliminary design phase, the team began to use computational tools. For estimating initial thrust and endurance performance, the different power systems and airplane configurations were related using the ElectriCalc software by SLK Electronics. In order to manipulate different performance and handling qualities, an Excel tool was developed which used the standard methods outlined in *Airplane Design, Part I: Preliminary Sizing of Airplanes* by Roskam. Much of the information obtained during this phase was further refined through decisions based on the figures of merit identified/developed during the competition and the conceptual design.

### *1.2. Design tools overview*

During the preliminary design phase more computational tools were used. For determining initial thrust and endurance estimates relating many different power system configurations, the software ElectriCalc by SLK Electronics was used. In order to manipulate different performance and handling qualities, a personally developed general computing program in Microsoft Excel was set up using the standard methods outlined by *Airplane Design, Part I: Preliminary Sizing of Airplanes* by Roskam. Much of the information obtained during this phase was further refined through decisions based on the figures of merit yielded by the competition and the conceptual design. These calculations are shown in Appendix A: Preliminary and Detailed Performance Development Calculations.

The detailed design allowed more use of computation methods for developing the design of the TTB. For the determination of the airfoil section and the 3-D to 2-D needs of the aircraft, computer programming was needed. An airfoil analysis software, PANZ, was used with information produced from the preliminary design. This allowed more insight on the interaction of many different airfoils with the general needs of the aircraft.

The general design programming used previously in the preliminary design for the performance and handling qualities was further refined for the detail design. This programming allowed easy access to make modifications and manipulate final concepts without starting from scratch. Also, for specific performance areas such as stability and control and handling qualities, further Matlab programming was developed using methods from small perturbation stability and control analysis. The primary source of this information was derived from the methods in *Flight Stability and Automatic Control* by Nelson.

## 2. Management Summary

### *2.1. Architecture and assignment areas of the design team*

The assignment areas of the design team were divided among the four team members, Rip, Shea, Kendrah, and Dave. Robert "Rip" Rippey III, a senior Aerospace Engineering major, was the team leader. He monitored the budget and ordered materials and parts for the airplane. Because of Rip's ten years of R/C experience and position as team leader in the previous AIAA Design/Build/Fly (DBF) competition, the team designated him pilot, airframe constructor, and materials coordinator. Rip also researched and selected a cooling system for the propulsion system. Rip and Shea collaborated during the conceptual, preliminary, and detailed design phases of the TTB.

M. Shea Parks, also a senior Aerospace Engineering major, chose the airfoil and design for the Texas Tall Boy based on graphs, charts, and calculations from his and Rip's research and their previous DBF experience. Because of Shea's two years of wind tunnel experience, he was chosen to conduct tests on various motor/battery/propeller combinations for final component selection. In addition, Shea compiled the bulk of the drawings for the completed aircraft.

Kendrah Smith, a freshman Math major with previous experience in an aerospace engineering related project, assisted Shea with the motor/battery/propeller testing and the drawing package. Also, Kendrah arranged preliminary data for the airfoil selection and motor/battery/propeller combinations. Furthermore, she assisted Dave in obtaining real time performance data during flight testing of the TTB.

Dave Sellmeyer, a junior Aerospace Engineering major, brought knowledge gained from his experience with an unmanned aerial vehicle (UAV) company, construction of composite structures, and radio control (R/C) modeling to the team. For this reason, he constructed the composite main landing gear for the TTB. In addition, Dave tested and modified several composite landing gears previous to selecting the final construction lay-up. Finally, Dave obtained performance measurements during the flight testing of the aircraft.

### *2.2. Management structures and timing*

The overall design and development of the TTB was regulated by a series of management structures. Configuration and design control rarely presented a problem due to the overall methodology and objectives of the design team. Once a major aspect of the design and development was finally decided upon, little deviation from the concept was incorporated.

Design task schedule control, primarily governed by the team leader, was developed as a guide for the design team. This allowed the team to continuously evaluate the state of events and advancements in the competition development. Located in Appendix J: Scheduled and Actual Timing of Major Events, are a milestone chart and table of all major events focused on for the entire development of the TTB. The preliminary scheduled event completion dates and the actual event completion dates are represented. In many of the production phases of the design the team did not meet the projected dates. However, all phases were completed with marginal time to allow intermediate alterations and refinements.

## 3. Conceptual Design

### *3.1. Figures of merit*

The figures of merit considered during the conceptual design phase were an optimized propulsion system, the projected speed of the aircraft, and the final flying weight of the aircraft. The team wanted to have an aircraft that would be considerably faster than the previous airplane. Initially, the airplane was to have a cruising speed of 100 ft/sec. Such increased speeds involved looking at lowering the drag and increasing the wing loading of the previous generation design. The weight of the aircraft needed to be reduced in every way possible for the best performance. More importantly, a propulsion system would be required to provide enough thrust for a climb-and-glide strategy similar to that used in the 1996-1997 competition; however, the run time would have to be balanced to complete the laps within the seven minutes of flying.

The final ranking of the figures of merit were established and evaluated with the aid of the design and development programming methods of *Airplane Design, Part I: Preliminary Sizing of Airplanes* by Roskam, and the power combinations yielded from the ElectriCalc software. They are listed below in order of importance:

- Optimized propulsion system
- Projected speed of the aircraft
- Final flying weight

## *3.2. Alternative concepts investigated*

The basis of the conceptual design started with the Texas A&M University AIAA (DBF) entry from the 1996-1997 competition. Since this airplane was optimized for range by using high speed, it was considered a derivative of the previous generation aircraft. The Aggie Flyer was by far the lightest and fastest airplane at the 1996-1997 competition. Using the method of evolving the previous design based on past experience proved to be the primary method of conceptual design.

Although the team derived a second-generation aircraft, many alternative concepts were investigated in order to try to improve the overall design of the Aggie Flyer. Concepts investigated initiated with the examination of the wing configuration. The previous competition entry was a conventional fixed wing aircraft, which utilized a single carbon fiber and balsa wood spar assembly. An array of ideas such as a flying wing, tandem wing, variable geometry wing, and canard configurations were debated.

The flying wing, tandem wing, and canard configurations were rejected due to the stability and control challenges and all around impracticality that was represented through initial wing concept research. Variable geometry was debated with slightly more detail. It was recognized that, with a variable geometry wing, the design aircraft might be able to deliver an improved performance at different phases of the competition flight course when compared to a conventional wing. However, this concept also proved to be impractical due to the amount of mechanical structure that would be needed in order to be effective. The amount of extra mechanics and weight was simply not worth the performance tradeoffs. The end result of the conceptual stage was to remain with a conventional fixed wing and stabilizer design.

The single wing spar concept was also further investigated. The previous design proved to be effective in many of the design target areas and mission features, however, some of the figures of merit such as easy transportation and disassembly (which will be discussed in later sections), were not maximized to their full potential. Therefore, modular wings and joined carbon tubing spars were investigated.

The empennage concepts of the Aggie Flyer were investigated. The truss (non-airfoil) concept was used previously with performance and handling results that could be improved.

Therefore, when developing the TTB, airfoiled vertical and horizontal tail sections were researched and debated in order to push the previous design to more efficient states of performance. Specifically, the incorporation of an airfoil into the tail surfaces was to help keep airflow attached to the surface, resulting in more effective control surfaces.

### *3.3. Design parameters investigated*

Once initial alternatives in the configuration were investigated and decided upon, the design parameters were established. Early in the design process, the team watched video footage of the flights made by the Aggie Flyer to determine the time of flight and average flight speed. First, the aircraft had a relatively high wing loading (for this size airplane) of 30.0 oz/ft$^2$. Second, flight strategy consisted of using full power only for half of the upwind leg of the course and a power-off glide for the rest of the course. These two features produced flight averaging eight minutes, including takeoff, landing, and the two 360-degree turns, as required by the competition rules. At most, eleven laps at a speed of approximately 80 ft/sec around the course were completed during any of the flights made by the Aggie Flyer during the competition. A list of the design parameters of this aircraft is given in Appendix F.

## 4. Preliminary Design

### *4.1. Figures of merit*

Ranked in the order of importance, the figures of merit that governed this phase of the design process were:

- Transportation of the aircraft
- Structural component accommodation
- Payload and propulsion system access
- Simplicity of design
- Propulsion system cooling
- Final flying weight
- Total drag
- Aesthetics

## *4.2. Design parameter and sizing trades*

### 4.2.1. Flying weight

The basis of the preliminary design started with establishing the major design parameters and sizing trades. The mission requirements focused greatly around the payload fraction and the influence of systems component weight. The mandated 7.5 pound steel payload and an optimized total performance weight of 16 pounds (256 oz.) were the first parameters established. This total weight was derived from estimations of systems components (motor, batteries, radio equipment, etc.), airframe structure, landing gear, and all other components from the previous design. Overall weight and its effects on range and performance became the key issues in deriving the other design parameters and sizes.

Once the preliminary total performance weight was derived, the wing efficiency was examined. By using the weight parameters in addition with the pilot control skills, research results from the previous design, and preliminary calculations a wing loading range of 2 lbs/ft$^2$ (32 oz/ ft$^2$) to 2.30 lbs/ ft$^2$ (36.8 oz/ ft$^2$) was incorporated. After debate and examination it was decided that to better accommodate a more efficient design the wing loading should be established at 2.25 lbs/ft$^2$ (36.0oz/ ft$^2$), thus yielding a wing area of 7.11 ft$^2$.

### 4.2.2. Aspect ratio

The next parameter derived was the aspect ratio. The Aggie Flyer had an extremely efficient aspect ratio of 10.0, which proved to also be a feasible sizing tradeoff for the TTB. Also incorporated into the wing efficiency was the design parameter of the airfoil performance and thickness. An airfoil needed to be selected that could perform with efficient aerodynamic characteristics and be able to accommodate the necessary internal wing control devices and allow for the overall structural rigidity. The aerodynamic qualities demanded a relatively thin airfoil due to the sizing trades of speed verses drag. However, the systems accommodations required slightly thicker families of airfoils.

### 4.2.3. Handling qualities

The all around performance and handling qualities of the TTB were also major design parameters inspected. These parameters primarily focused upon keeping drag coefficients reduced while allowing the lifting and velocity potentials to be maximized efficiently based upon energy and power available from the power combination. This method yielded great scrutiny over the power combination and the trades of performance, which was aided in using the previous design as solid reference.

Stability and ease of pilot control presented some problems in the previous design. Therefore, focus was placed on improving some of the aspects of these problems. One case in the Aggie Flyer design was that the wing was incorporated with an incidence angle in relation to the fuselage centerline that caused the fuselage to cruise at trim with an angle of attack. Although preliminary calculations showed a positive result, the actual model proved to have less than desirable handling in certain maneuvers. As a result, the Texas Tall Boy incorporated an incidence angle of 2 degrees relative to the thrust line.

### 4.2.4. Landing gear

Another design parameter was the focus of the most practical and efficient type of landing gear. The landing gear for the TTB needed to have minimal static deflection while the aircraft was fully loaded in order to keep the wheels somewhat aligned during takeoff and landing roll. If the gear could not keep the axles aligned properly, a ground loop could occur, resulting in damage to the aircraft.

Large dynamic deflection (25%-40% deflection relative to the length of the landing gear) due to landing could be acceptable for the purpose of allowing the landing gear to absorb landing loads without transferring too much force into the fuselage structure.

As mentioned for figures of merit, overall aircraft weight and total drag were important factors in determining the landing gear configuration. The fewest wheels and accompanying structure would result in the lightest and cleanest landing gear configuration. However, at least three wheels were desired to maintain longitudinal stability on the ground (without relying on wing skids) and smooth steering. Ultimately, if all ground contact points were wheels, rather than skids, the takeoff acceleration would be higher, and the ground roll would be shorter. The propulsion system should not waste any of its limited energy in getting the aircraft off the ground.

Tricycle and tailwheel landing gear were left to choose from. From experience, it was known that the tricycle gear was more stable on the ground, while the tailwheel configuration could have more problems with ground loops.

Going back to the low-weight figure of merit, the team decided that appropriately-sized wheels and accompanying structure for a tailwheel landing gear would be about 25% lighter than that for a tricycle gear. The tailwheel landing gear was chosen to for the competition aircraft.

Structurally, the main gear would be required to take lateral loads presented in the case of a ground loop at landing speeds (to be determined in the detailed design phase). Also, the tail wheel and accompanying structure would need to be able to withstand side loads; however, experience showed that vertical loads on the tail wheel would be minimal.

Retractable landing gear was considered, but two of the figures of merit overrode the one in favor. Although retractable gear would reduce the drag of the aircraft in flight, the mechanical complexity and the weight of the additional structure required for such an operation rendered this feature nearly profitless for the aircraft.

### 4.2.5. Propulsion cooling

Cooling for the propulsion system was mandatory. The electronic speed control for the motor was the most critical component to be cooled since overheating could cause damage to the circuitry. The propulsion battery pack and motor needed adequate cooling for maximum power output, as stated by the manufacturers of the items.

Since overall drag on the aircraft was a figure of merit during the preliminary design phase, the cooling system would be required to have the lowest drag possible. The tradeoff for this figure of merit was pressure recovery in the cooling system. Research and development of air intake geometry by NACA produced a low-drag flush inlet with up to 92% pressure recovery for subsonic speeds. Published data detailing the geometry of the NACA flush inlets was found in *Aircraft Design: A Conceptual Approach* by Raymer.

The single inlet was placed on the bottom of the fuselage, immediately behind the plane of the propeller. This area was determined to be a high-pressure area for all desired flight conditions. Motor cooling was provided by such a forward location of the inlet. Intake air would then flow past the heat sink side of the speed control (the side of the speed control with the electronic components was mounted to the bottom of the "ducting" that maintained airflow only where desired through the bottom of the aircraft).

The propulsion battery was offset from the sides of the fuselage (as opposed to a tight, high-contact fit inside the fuselage) in order to provide quicker heat radiation. The rails that would raise the battery pack from the bottom of the fuselage would serve as the last stage of the ducting before the air exited the aircraft.

As explained previously the wing incidence relative to the fuselage centerline was set such that the fuselage centerline has no angle of attack when cruising. The fuselage bottom was shaped relative to the centerline to provide a low-pressure area aft of the propulsion battery for the cooling air to exit. A NACA flush inlet was reversed and installed in this area. The area of the outlet was 56% larger than that of the inlet in order to prevent stagnation in the cooling duct. The entire cooling system is detailed in Appendix I: Drawing Package for the Texas Tall Boy.

#### 4.2.6. Aircraft disassembly

One of the figures of merit governed the disassembly of the aircraft. The team desired to be able to transport the airplane in a small, two-door car. With a wingspan of 101 inches already determined, the airplane could not fit in the car with a single-piece wing. For simplicity, the wing separated into only two pieces. This disassembly resulted in three components, namely the fuselage, which was 55 inches long, and the two wing panels, which were 49.5 inches long, each.

The two wing panels joined by means of a 12-inch-long ½" O.D. pulltruded (referring to the manufacturing process) carbon fiber tube that remained fixed in the fuselage. Two 8-32 bolts attached the wings by threading into the two overlapping secondary hardwood joiners that were fixed in the wing panels.

Not only did the removable wings provide disassembly for easy transportation, but this feature also allowed the steel payload to be installed and removed. The 7.5 pounds of steel were shaped as two rectangular blocks that secured in the fuselage and extended nonstructurally into the wing panels.

### 4.2.7. Component access

For component access, three hatches were built into the aircraft. One hatch was on the upper side of the fuselage, just ahead of the wing leading edge. It extended to the fuselage centerline (rather than a panel just on the top of the fuselage) to provide easy access to the speed control and the battery-motor connection. Although aesthetics were relatively unimportant compared to some of the other figures of merit, this forward hatch doubled as a "canopy" that would be seen on larger, manned aircraft.

Propulsion battery access was provided by means of the second hatch. This large (eight-inch-long), removable panel served as the floor of the fuselage, immediately aft of the main landing gear. The receiver and receiver battery pack could also be accessed when this panel was removed.

Finally, a small panel was located on the bottom of the fuselage for access to the rudder and elevator servos. All of the hatches can be seen in the Drawing Package for the Texas Tall Boy (Appendix I).

## *4.3. Analytic methods*

Several computational methods were utilized during the preliminary design phase. The primary method was to use basic computational programming software such as Microsoft Excel to develop and organize the preliminary configuration, sizing, and performance parameters. The method of developing this parts of this programming were the computational and sizing estimates in, *Airplane Design, Part I: Preliminary Sizing of Airplanes* by Roskam and *Model Aircraft Aerodynamics* by Simons. The performance computational portions of the programming were based upon the methods dictated in *Fundamentals of Aerodynamics*, by Anderson and *Introduction to Flight* by Anderson. Appendix A, Preliminary and Detailed Performance Development Calculations, details theses preliminary results using many different parameter choices.

Another computational analysis method used in the preliminary design phase was the ElectriCalc power system evaluation software by SLK Electronics. This software allowed the design team to evaluate many different combinations for the propulsion and power system before having to make any decisions or purchases on any components. The ElectriCalc software was used in the previous year's competition design development and was proven to be an effective tool for systems selection. Appendix C, ElectriCalc Data, shows output and results of the software for some of the initial combinations examined. As a comparison to a small selection of the combinations researched the Aggie Flyer's results are displayed.

The information most importantly examined was the overall thrust output at full throttle and the propulsion battery total power depletion time. These parameters were maximized for efficiency, and the other yielded information was used as secondary screening factors.

A non-computational analytic method was the development of a low-speed wind tunnel test in order to screen power system combinations. Basis for the development of the testing came from methods described in *Low-Speed Wind Tunnel Testing*, by Rae and Pope. Many different components had been purchased or borrowed from other modelers to see the real time effects of different components. A full detail of the wind tunnel test and its results is located in Appendix E: Wind Tunnel Propulsions Test Data.

To aid in the preliminary airfoil selection for the wing, an airfoil analysis software named PANZ was used. PANZ is software written and developed by Dr. Tom Pollock, Professor, Aerospace Engineering Department, Texas A&M University. This software uses the actual shape and design of a prescribed airfoil and analyzes the 2-dimensional performance characteristics based on the design flight conditions. This 2-D information is returned and matched to the optimized conditions and design parameters desired.

Displayed in Appendix D, Airfoil Analysis Data, are the 2-D coefficients of lift curves of several different airfoil possibilities examined. Also included are coefficient of lift curves for PANZ calculated data and widely published data for selected airfoils. The publications used were the *Comprehensive Reference Guide to Airfoil Sections for Light Aircraft*, by Aviation Publications, and *New Airfoils for R/C Sailplanes*, by Selig and Gopalarathnam. By plotting the curves for the R.A.F. 32 airfoil used in the Aggie Flyer and those of the most efficient possible airfoils (SA7035 and SA7038), the proficiency and accuracy of the PANZ software is shown with positive results.

## *4.4. Minimum configuration and vehicle sizing*

The minimum configuration and vehicle sizing developed during the preliminary design phase is divided into many parameters. Beginning with the weight breakdown, a total weight of 16 pounds was based upon approximate airframe, propulsion system, control system choices. This weight and corresponding wing loading yielded a conventional wing (area:7.11 $ft^2$ and span: 8.63 ft), empennage (vertical tail volume: 0.496 $ft^3$ and horizontal tail volume: 0.66 $ft^3$), and control surface (aileron: 5.0%, rudder 12.0%, and elevator: 20.0%) sizing is located in Appendix A.

The fuselage sizing was established with the initial payload, systems components, wing, and empennage placement. The fuselage was initially designed to be 2.5 in. wide and 3 inches deep at the maximum (center of gravity) cross section. The length from firewall to trailing edge was at a minimum 4 ft.

The payload was placed at the estimated center of gravity, laying into the wings from the fuselage. The propulsion and control systems were laid out down the centerline axis of the fuselage. The overall static margin due to all components was estimated to be 14.0%.

The wing airfoil performance developed to make the preliminary selections required maximum 2-D coefficients of lift during cruise, take off and landing of 0.132 and 0.113. However, the maximum coefficients of drag 0.045 were 0.033, respectively. The vertical and horizontal tail airfoil requirements, which needed to provide a clean and attached flow, were established with a 8% – 12% symmetrical airfoil. This information is also held in Appendix A.

### *4.5. Key features which distinguish the final configuration*

The Texas Tall Boy incorporated several key features which distinguished it from typical model aircraft. First, over ninety percent of the airframe and empennage is built with lightweight balsa wood. This construction practice yielded an extremely light airframe of only three pounds. In order to offset any losses of strength caused by this application, high strength carbon fiber was used as a spar cap (detailed in the section titled "Manufacturing Plan"). A set of wound carbon tubes were embedded between balsa stock to form the spar box in each wing with unidirectional carbon adhered to the outer surfaces of the spars. A pulltruded carbon fiber tube was used to join the two wing halves together. In addition to strengthening the wing, this design allows for easy transportation to the flying site.

Further weight reductions were realized without costing strength through the use of composite materials in the landing gear. Carbon roving was layered around a balsa core to form the main landing gear strut. In combining the carbon strut with low profile molded-resin wheels, a six-ounce weight savings resulted over traditional aluminum strut/rubber wheels. Bending tests indicated that the composite landing gear yielded one third as much as the aluminum gear when subjected to normal landing loads.

Another feature found in the Texas Tall Boy was the incorporation of NACA cooling scoops into the fuselage design. Since the main battery required a large surrounding air mass to prevent overheating, cooling scoops were used to provide a continuous supply of air over the lower surface of the battery. This feature allowed the overall dimensions of battery compartment to remain small, thus reducing the fuselage profile drag and increasing the airplane's speed and efficiency.

As a signature by the builder of the TTB, a long dorsal fin introduced a distinctive sweeping vertical stabilizer ending in a sharply pointed rudder. This added a sleek look to the aircraft, which when combined with the other key features, allowed it to be distinguished from other aircraft on the flight line.

# 5. Detailed Design

### *5.1. Final design*

Final performance information such as the takeoff, landing, thrust, and handling qualities are highlighted in Appendix A. In summary, the TTB has a takeoff coefficient of lift of 0.139, at a velocity of 80.4 ft/s, yielding a rolling distance of 76.2 ft. The landing coefficient of lift is 0.118, at a velocity of 87.1 ft/s, and a rolling distance of 187 ft. The values of maximum velocity and minimum glide sink are 88.0 ft/s and 73.3 ft/s. The overall drag polars are; zero lift drag: 0.043, clean: 0.046, and total takeoff configuration: 0.067. The G-loading capability on a maximum bank angle of 53 degrees is 1.9. And a maximum G-loading in a sudden pull-up at a stall angle of 10 degrees is 1.79.

The endurance requirements of the TTB were fulfilled by identifying important mission objectives, optimizing the flight strategy, and incorporating results reduced from the wind tunnel test into the design of the propulsion system. The resulting performance of the engine/battery combination turned out to be highly efficient, yielding a total battery endurance of approximately 3½ minutes, which included a 20-second takeoff phase. With this endurance, a 4½-minute power-off glide was possible in order to satisfy the mission requirements of a 7-minute maximum on-course flight time.

Using small perturbation theory as described in *Flight Stability and Automatic Control*, some simple stability and control analyses were done in order to check the modal characteristics of the Texas Tall Boy. Matlab was used to perform the calculations as shown in Appendix B. The determination of the modal characteristics was important since the aircraft was required to complete the course without stability augmentation. Of particular interest was the period and damping ratio of the phugoid mode. With a period of 9.30 seconds and a relatively low damping ratio of 0.042, the altitude oscillations caused by the phugoid mode would yield challenging landings. Since the phugoid damping ratio was inversely proportional to the lift to drag ratio of the aircraft, altitude variations during the low landing speeds could be reduced by increasing drag and/or reducing lift during the landing approach. Raising the ailerons, to simulate spoilers, could achieve this goal, but only flight testing would confirm the effectiveness.

The rest of the modes had stable roots, showing that the aircraft would be able to maneuver around the course within the skills of the pilot. Lateral/directional stability was ensured by the damping ratio of 0.071 and period of 1.70 seconds presented with the dutch roll mode.

The team selected the components for the plane according to the figures of merit for the detailed design. Analysis data from ElectriCalc and research of electric propulsion systems led the team to choose the Aveox 1412/2Y coupled with a 3.7:1 inline gearbox. The Aveox M60 speed control (for 14-32 cells) was chosen because of size and weight reduction and ease in programming compared to its predecessor (used in the Aggie Flyer during 1996-97 DBF competition). To keep the propulsion battery pack under the 2.5-pound limit, nineteen 2000 mAh cells were used. ElectriCalc data confirmed these cells as having the highest capacity of any cells commercially available.

To reduce the drag while gliding with the climb-and-glide strategy, a folding propeller was used. The ElectriCalc data showed that a 15-inch propeller with a 9.5-inch pitch would result in high thrust (125 oz.) with moderate run times (2.6 minutes). The data for this combination is shown in Appendix C. Specifically, a Graupner carbon fiber propeller with these specifications was used because of its weight difference compared to a heavier, injection-molded nylon propeller.

All components of the propulsion system are shown in Appendix I: Drawing Package for the Texas Tall Boy.

Control was provided by a Futaba 8-channel PCM radio system. The transmitter provided mixing required for the separate aileron servos, allowing them to work together as flaps. Rather than using a 500 mAh receiver battery pack (common for this size airplane), the team chose to use a 250 mAh pack to reduce the overall weight of the aircraft (by 1.2 oz).

Standard ball-bearing servos were used for the rudder and elevator, but smaller, lighter servos were used for the ailerons due to the limited room inside the wing panels. The aileron servos also had ball bearings, but their metal gears (as opposed to plastic gears) and coreless motors set them apart from the rudder and elevator servos. Ball bearings around the output shaft on a servo reduce the slop. This is important since any slop in control linkages can allow aeroelasticity to become a problem, resulting in flutter. Coreless servos were desired for the ailerons because of their quick response and accurate control response. Metal gears ensured that the gear teeth would not skip under high-load conditions such as a fast roll rate.

Control system component locations are shown in the Drawing package for the Texas Tall Boy (Appendix I).

Weights of the control and propulsion components are given in Appendix K. The total weight of the unloaded aircraft was seven pounds. With the payload weighing seven pounds 8 ounces, this gave a payload fraction of 51.7%.

## *5.2. Innovative techniques*

Though a modular wing design is no longer considered an innovative design in model airplanes, the way in which it was accomplished deserves special attention. In most modular wing model airplanes, the wing is primarily constructed from foam, which easily accommodates a tube/joiner design. In the case of the TTB, nearly 95 percent of the wing was constructed in the traditional wood framework style.

In almost every case, a design such as this would rely on a standard spar-box configuration. However, the TTB built upon this old design by adding new configuration ideas found in modern foam-core wings. A wound carbon fiber tube was located in between the top and bottom spars of the box and was secured to the shear webs by adding triangular balsa stock to each side of the tube. For added strength, the tube and spars were then wrapped with kevlar ribbon.

Once the wings were completed, they were joined at the fuselage by a single pulltruded carbon fiber rod. A secondary joiner was added directly forward of the carbon joiner and consisted of overlapping hardwood members extending from each wing. The two halves of the secondary joiner were then secured by metal bolts driven through the top surface of the fuselage.

Other composite construction found its place in the landing gear design (detailed in the "Manufacturing Plan"). The elliptical shape could more easily be produced by molding unidirectional carbon fiber than by bending aluminum, for example. The fact that this landing gear configuration was fixed, rather than retractable, also let the team stay away from costly retraction components.

In choosing a construction material, weight became the key element essential to reducing the total weight of the new assembly. Carbon fiber roving was chosen as the primary structural element with the secondary material being balsa wood. The carbon provided a superior strength to weight ratio for the purpose of absorbing transverse loads, while the balsa provided enough crush strength to resist the lay-up process.

### 5.3. Cost reductions

Looking into the systems architecture of the aircraft, the analysis tools used greatly reduced the overall cost of the design process. For example, the ElectriCalc data (shown in Appendix C) allowed us to analyze several motor/battery/propeller combinations without having to purchase and test all of the equipment.

Cost reduction for the detailed design rested ultimately on the fuselage. The fuselage was simple enough in design that it could easily be constructed of wood (common for aircraft of this size) rather than expensive composites required for a more complex fuselage design. However, if this aircraft were to be produced in larger quantities, it would be desirable to have a single mold to lay up many composite fuselages, regardless of the shape.

### 5.4. New configuration ideas

New configuration ideas for the Texas Tall Boy allowed the wing to be divided into halves for convenient transportation. Wound carbon tubes in the wing panels served to connect the wing panels and to distribute loads to the wing spar. A pulltruded carbon rod served as the primary structural element in the spar assembly.

In an attempt to improve the ground handling qualities of the TTB over its predecessor, the Aggie Flyer, a new landing gear was designed. Of the issues considered for change, overall stiffness was foremost on the list with total weight coming in a close second. The new design called for a single-piece strut formed to an elliptical shape instead of the previous straight-legged strut. This shape was chosen to reduce the internal moments of the structure near the fuselage.

## 6. Manufacturing Plan

### 6.1. Figures of merit

The manufacturing process and selection of materials used to produce the airframe revolved around several figures of merit. The first and foremost element of the manufacturing process centered on selecting the materials. Since the design of the TTB originated from the concept of a lightweight airframe, the weight of the materials involved was considered premium. Second in the hierarchy was the level of skill and sophistication of machinery required to produce various parts of the airplane. Since direct access to expensive and complex manufacturing machinery as well as the knowledge of how to use such machinery was limited, it was important to select processes that could be carried out using common shop equipment, such as band saws and drill presses.

After considering theses issues, the third figure of merit taken into account was the time required to complete each process. Because the schedule set forth by the team's management structure allowed for only a small production window in December and early January, each process needed to span a short time frame. Such short production times were illustrated in the production of the landing gear, where the total time required to produce and to test a landing gear strut was only three and a half days. Beyond these considerations, availability and cost did not seriously enter the picture when determining the manufacturing process, as funding and supplying of materials was provided almost exclusively by Texas A&M University.

Below the figures of merit governing the manufacturing plan are listed below in order of importance:

- Selection of light-weight materials
- Level of skill required to produce components
- Time required to construct components

## *6.2. Manufacturing processes for final design*

### 6.2.1. Manufacturing plan

All components of the aircraft were built simultaneously for efficiency. Completion of each assembly was followed by integration with the major assembly and alignment with the other components.

Throughout the construction process, epoxy and carpenter's wood glue were used exclusively due to their easy application characteristics and reputations for consistently good joints.

### 6.2.2. Wing construction

The basic structure of the wing panels was formed by 3/32" balsa ribs connected by two ¼" x 3/8" balsa spars located at 25% chord. One-sixteenth-inch balsa was used as shear webbing between the top and bottom spars to complete a box spar for the wing.

To satisfy the structural requirement of having the fully loaded aircraft picked up by its wingtips, 3/8" unidirectional carbon fiber was applied as spar caps. The carbon fiber was applied symmetrically (top and bottom) as follows. Two layers were applied over the full span of each panel. One layer spanned the inboard 50% of each wing panel. A physical test using this identical spar structure showed that the spar alone, without any additional structure (such as leading edge sheeting) satisfied the structural requirement for an aircraft weighing 16 pounds (the estimate for the Aggie Flyer). To reduce the discontinuity effects of having two full-span layers and the 50%-span layer as spar caps for the new aircraft, an additional strip of carbon fiber was applied, symmetrically top and bottom, spanning the inboard 75% of each panel. This also added a higher safety factor for the overall structural integrity of the wing.

Knowing the fragility of balsa, the team realized that it would not be feasible to have sharp balsa trailing edges using just 1/16" balsa sheeting. For this reason, 3/8"-wide strips of 1/64" 3-ply birch plywood were glued between the top and bottom trailing edge pieces. When sanded, this produced a sharp, durable trailing edge.

The 1/16" balsa leading edge sheeting completed the D-tube structure of the wing panels, yielding high torsional rigidity in the wing.

Cap strips made of 3/8"-wide strips of 1/16" balsa were cemented to the ribs in the wing. These provided more surface area for the covering material to adhere to. This was important since the wing panels relied on the high tensile strength of the covering material to provide more structural rigidity.

Ailerons were cut from the trailing edge and hinged to a false spar installed along the cut in each wing panel. The hinge line was at the top surface of the wing. The resulting gaps in the bottom surface of the wing were sealed by plastic strips anchored along the hingeline on the wing.

One servo was used for each aileron to simplify linkage for the two wing panels. Since the wing panels separated at the fuselage, only a wire from each servo had to be plugged into the receiver to make the ailerons operational. Alternatively, a single servo could have been mounted in the fuselage, requiring aileron linkage to be assembled every time the wing panels were installed.

Separate servos also allowed mixing functions for the control surfaces on the wings. For example, the surfaces could move independently as ailerons or together as flaps be means of electronic mixing provided by the transmitter.

A 2-56 threaded pushrod coupled with a control horn mounted on each aileron provided control from the servo.

The carbon fiber joiner tube in the fuselage joined the wing panels by inserting into a 17"-long ½" I.D. graphite tube mounted in each wing panel. These tubes were epoxied to the shear webbing on the aft side of the box spar. Triangle stock completed the joint between the tube and the shear webbing. The entire box spar, wing graphite tube, and triangle stock were wrapped with 1/8"-wide kevlar ribbon to prevent any separation of the wing joining components. The wraps were spaced about ½" apart along the full span of the tube in order to distribute the load evenly to the main wing spar.

### 6.2.3. Tail surface construction

Since the horizontal and vertical stabilizers had airfoil sections (as opposed to flat surfaces), they were built up, similar to the wing. Construction of the tail surfaces started with a 3/32" balsa spar laminated with a single layer of unidirectional carbon fiber on each side. Placed such that the long dimension of the cross section was normal to the chord of the ribs, each spar extended the full length of its respective stabilizer. The 3/32" balsa ribs for each surface slid onto the spar and were aligned via a construction jig. One-quarter-inch square balsa was used for the leading edges of the stabilizers.

The roots of the stabilizers were sheeted with 1/16" balsa to provide solid mounting surfaces for the fuselage. Torsional rigidity was also increased from the root sheeting.

Construction of the rudder and elevators were similar to the ailerons in that the trailing edge had 3/8" strips of 1/64" 3-ply birch plywood between the 1/16" balsa sheeting. The elevator was hinged at the upper surface and sealed on the bottom, similar to the ailerons. Rudder hinges were put along the centerline of the cross section.

In order to take the loads presented by the built-in tailwheel, the rudder was built up with two layers of 1/32" 3-ply birch plywood on the inside of the sheeting and two layers of 2-oz. fiberglass cloth on the outside.

#### 6.2.4. Fuselage construction

The fuselage construction began with 3/32" balsa slab sides doubled with 1/32" 3-ply birch plywood from the firewall to the location of the wing root trailing edge. Additional doubling was used around the wing joiner and payload openings. One-eighth-inch balsa was applied cross-grain to the top and bottom of the fuselage to provide torsional rigidity to the semi-monocoque fuselage structure. This was the lightest way to build the fuselage since it eliminated the need for any internal structure, such as bulkheads and stringers.

One-eighth-inch light ply was used for the propulsion battery access hatch on the bottom of the fuselage. Immediately forward of this hatch was the landing gear block, made from 1/8" 5-ply birch plywood. The same material was used to make the firewall for the single electric motor.

#### 6.2.5. Landing gear construction

Composite construction was used exclusively for the fabrication of the main landing gear. Several layers of unidirectional carbon fiber were surrounded a 1/16" balsa core. The resin-laden lay-up was vacuum bagged over a blue foam template to form its elliptical shape. Appendix B shows the lay-up of the carbon fiber layers. Vinyl sheets placed around the lay-up allowed the landing gear to cure with a smooth finish.

Simple drop tests with the expected weight of the fully loaded aircraft (16 pounds) attached to a board determined the properties of heavier and lighter lay-ups.

Four ¼ x 20 nylon bolts attached the final main landing gear to the fuselage. Nylon bolts were used in order to allow the gear to detach without damaging the fuselage in the event of a rough landing.

Solid 2-56 pushrods ran from the elevator and rudder to the respective servos. Two supports along the length of the pushrods were installed to keep the pushrods from bowing while in compression.

### *6.3. Alternative manufacturing processes investigated*

Alternative manufacturing processes were investigated to optimize the construction efficiency of the aircraft. First of all, an all-balsa and plywood structure was considered. The team members were quite familiar with the construction techniques involving wood. However, this method of fabrication was avoided on the wing in particular. In order to satisfy the structural requirement of having the fully loaded aircraft supported by its wingtips, a relatively massive wooden spar would be required.

Bulkhead fuselage construction involves using a series of bulkhead throughout the fuselage to support the sheeting on the airframe. The team considered this method of fabrication but realized that it was not necessary since a light and simple tube structure could be achieved with two slab sides and top and bottom sheeting.

A molded composite fuselage was also examined. Since only two aircraft were to be built, the team members did not want to take to the time to produce a mold. Also, molded fiberglass fuselages of similar size (compared to some competition radio controlled sailplanes in production) were 10% - 20% heavier than built-up balsa and plywood structures.

Composite wing panels and tail surfaces were considered for their inherent structural integrity. However, the team members lacked experience with forming carbon or fiberglass around such thin foam cores that would form the basis of the wing panels and tail surfaces.

Foam wing panels and tail surfaces could simply be sheeted with thin balsa. Such construction methods could reduce building time by an estimated 60%, but even these components with low-density white foam cores are substantially heavier than their built-up counterparts.

A completely aluminum main landing gear was considered for this aircraft. Comparison to the aluminum landing gear from the Aggie Flyer showed that the composite gear (with comparable stiffness) was 65% lighter.

### *6.4. Analytic methods used*

Having decided on of using a two-piece wing for transportation reasons, the team put a lot of emphasis on the integrity of the joining structure. Knowing that the spar structure within the wing panels was sufficient from data acquired for the Aggie Flyer's main wing spar, a ½" O.D. carbon fiber tube, identical to the wing panel joiner, was tested for strength. A three-point test was conducted such that the two supports were 5.75 inches apart. Fracture of the outer fibers occurred with a load of 650 pounds applied to the middle. Simple calculations showed that the aircraft could weigh up to 43.6 pounds with the current wing panel joiner and still satisfy the structural requirements.

### *6.5. Manufacturing timing*

The manufacturing of the first prototype of the TTB began on November 20, 1997 and was completed on January 1, 1998. Approximately 425 hours was spent on the construction. Displayed in Appendix J, Scheduled and Actual Timing of Major Events, is a manufacturing milestone completion chart.

### *6.6. Key features*

Some innovative techniques were introduced during the manufacturing process to accommodate the elements of the detailed design. For example, the tailwheel was embedded inside the rudder by using an 8-32 bolt as the axle and the control horn attachment. The rudder was built up as described in the manufacturing process to handle the loads presented by control actuation and steering.

In order to yield the cleanest configuration, the control linkages for the elevator were concealed inside the vertical stabilizer. Access to the clevis and elevator control horn was provided by a cutout in the base of the vertical stabilizer that was later sealed by covering material.

Another innovation used to reduce the drag even further involved installing the receiver switch inside the fuselage. The switch was toggled by means of a small hole on each side of the fuselage through which a pin could be inserted.

In producing the landing gear, the layup shown in Appendix H was formed over a male mold made from blue foam. It was then vacuum-bagged under 15 psi for 12 hours. After curing, the landing gear was trimmed of excess material and smoothed to a low-drag profile.

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# Appendix A

*Preliminary and Detailed Performance Development Calculations*

## Nomenclature for Preliminary and Detailed Performance Development Calculations

| Symbol | Description |
|---|---|
| ALPHA, $\alpha$ | Aircraft angle of attack |
| ARht, ARHtail | Horizontal tail aspect ratio |
| ARvt, ARVtail | Vertical tail aspect ratio |
| ARw, ARwing | Wing aspect ratio |
| B | Wing reference span |
| Bh | Horizontal tail reference span |
| bv | Vertical tail reference span |
| CD, CD | Drag force coefficient |
| CDo | Zero lift drag polar |
| CDclean | Clean aircraft drag polar |
| CDto | Clean drag polar at takeoff |
| CDld | Clean drag polar at landing |
| CDlg | Clean drag polar with landing gear attached |
| CL,CL3D | 3-D Lift force coefficient |
| Cl,CL2D | 2-D Lift force coefficient |
| CLmean | 3-D Averaged powered cruise lift coefficient |
| Clmean | 2-D Averaged powered cruise lift coefficient |
| CLmnsnk | 3-D minimum sink/gliding lift coefficient |
| Clmnsnk | 2-D minimum sink/gliding lift coefficient |
| CLto | 3-D Coefficient of lift at takeoff |
| Clto | 2-D Coefficient of lift at takeoff |
| CLld | 3-D Coefficient of lift at landing |
| Clld | 2-D Coefficient of lift at landing |
| Cmean,Cbar | Mean Aerodynamic chord |
| Cr | Wing root chord |
| Ct | Wing tip chord |
| CN, CN | Normal force coefficient |
| CPM, Cm | Pitching moment coefficient |
| CRM, Cl | Rolling moment coefficient |
| CY, CY | Side force coefficient |
| CYM, Cn | Yawing moment coefficient |
| DELTA, $\delta$ | Downwash correction factor |
| DPDL, dp/dl | Test section longitudinal static pressure gradient (psf/ft) |
| DRAG | Drag force (lbs) |
| EOR | End of run wind off balance check point |
| ESBS, $\varepsilon$SBsupport | Solid blockage correction factor due to support system |
| F | Drag polar parasite area |
| HMC | Vertical moment transfer distance (ft) |
| HPC | Vertical pivot point transfer distance (ft) |
| L/D | Lift force to drag force ratio |

| | |
|---|---|
| Lambda, ∇ | Wing taper ratio |
| Lambdav, ∇h | Horizontal tail taper ratio |
| Lambdav, ∇v | Vertical tail taper ratio |
| M | Mach number |
| Mu, Λ | Wing sweep angle |
| Mu, μ | Air viscosity (lbs-sec/ft2) |
| N/A | Normal force to axial force ratio |
| PHI, φ | Model roll angle (deg.) |
| PM | Pitching moment (ft-lbs) |
| PSI, ψ | Model yaw angle (deg.) |
| PT | Data point number |
| Q, q | Dynamic pressure (psf) |
| QCORR | Dynamic pressure correction option flag |
| Re No,Re | Reynolds number |
| Rho, ρ | Air density (slugs/ft3 or lbs-sec2/ft4) |
| RK1, K1 | Wing blockage correction factor |
| RK3, K3 | Body blockage correction factor |
| RL | Reynolds number reference length (ft) |
| RM | Rolling moment |
| S | Wing reference area |
| SIDE | Side force (lbs) |
| SOR | Start of run wind off balance check point |
| ST, Stail | Horizontal tail platform area (ft2) |
| Sw | Drag polar parasite wetted area |
| TAU1B, τ1body | Body blockage correction factor |
| TAU1W, τ1wing | Wing blockage correction factor |
| TAU2T, τ2tail | Horizontal tail streamline curvature correction factor |
| TAU2W, τ2wing | Wing streamline curvature correction factor |
| TEMP | Test section temperature (°F) |
| THETA, θ | Maskell dynamic pressure correction constant |
| TMAX, tmax | Maximum body thickness (ft) |
| UMC | Longitudinal moment transfer distance (ft) |
| UPC | Longitudinal pivot point transfer distance (ft) |
| VCr | Vertical tail root chord |
| VCt | Vertical tail tip chord |
| WL | Wing loading |
| Wto | Total takeoff and performance weight |
| X | Horizontal 2-D geometric wing coordinate |
| Xmean | Mean aerodynamic center horizontal coordinate |
| Y | Vertical 2-D geometric wing coordinate |
| Ymean | Mean aerodynamic center vertical coordinate |
| YM | Yawing moment (ft-lbs) |

## *Preliminary and Detailed Performance Development Calculations*

### Configuration Estimates

*All final values listed in bold face

| Total Weight, Wto | | Wing Loading, WL | | Aspect Ratio, AR | |
|---|---|---|---|---|---|
| 14.00 | Wto | 1.80 | Wto/S | 7.00 | B^2/S |
| 14.50 | lb | 1.90 | lb/ft^2 | 8.00 | |
| 15.00 | | 2.00 | | 8.50 | |
| *15.50* | | 2.10 | | 9.00 | |
| 16.00 | | **2.25** | | 9.25 | |
| 16.50 | | 2.30 | | 9.50 | |
| 17.00 | | 2.35 | | 10.00 | |
| 18.00 | | 2.40 | | 11.00 | |

### Wing Area, S (ft^2)

| | WL | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Wto | 1.80 | 1.90 | 2.00 | 2.10 | **2.25** | 2.30 | 2.35 | 2.40 |
| 14.00 | 7.78 | 7.37 | 7.00 | 6.67 | 6.22 | 6.09 | 5.96 | 5.83 |
| 14.50 | 8.06 | 7.63 | 7.25 | 6.90 | 6.44 | 6.30 | 6.17 | 6.04 |
| 15.00 | 8.33 | 7.89 | 7.50 | 7.14 | 6.67 | 6.52 | 6.38 | 6.25 |
| 15.50 | 8.61 | 8.16 | 7.75 | 7.38 | *6.89* | 6.74 | 6.60 | 6.46 |
| 16.00 | 8.89 | 8.42 | 8.00 | 7.62 | **7.11** | 6.96 | 6.81 | 6.67 |
| 16.50 | 9.17 | 8.68 | 8.25 | 7.86 | 7.33 | 7.17 | 7.02 | 6.88 |
| 17.00 | 9.44 | 8.95 | 8.50 | 8.10 | 7.56 | 7.39 | 7.23 | 7.08 |
| 18.00 | 10.00 | 9.47 | 9.00 | 8.57 | 8.00 | 7.83 | 7.66 | 7.50 |

S1 = 6.89 **S2 =** 7.11

**Wing Span, B (ft)**

| AR | S1 | S2 | | |
|---|---|---|---|---|
| 7.00 | 6.94 | 7.05 | | |
| 8.00 | 7.42 | 7.54 | | |
| 8.50 | 7.65 | 7.77 | | |
| 9.00 | 7.87 | 8.00 | B1 = | 7.87 |
| 9.25 | 7.98 | 8.11 | B2 = | 8.43 |
| 9.50 | 8.09 | 8.22 | | |
| 10.00 | 8.30 | 8.43 | | |
| 11.00 | 8.71 | 8.84 | | |

**Taper Ratio, Lambda**

| | |
|---|---|
| 0.40 | |
| 0.45 | Lambda = 0.45 |
| 0.50 | |
| 0.55 | |
| 0.60 | |
| 0.65 | |

**Sweep Angle, Mu**

Mu = 0.0

**Mean Aerodynamic, Tip and Root Chords, Cmean, Ct, and Cr**

| | | | |
|---|---|---|---|
| Cmean = | 0.84 | ft | Cmean = S/B |
| | 10.12 | in | |
| Ct = | 0.52 | ft | Ct = S / ((B/2) x (1+Lamda / Lambda)) |
| | 6.28 | in | |
| Cr = | 1.16 | ft | Cr = S / ((B/2) x (1+Lambda)) |
| | 13.96 | in | |

**Tail Sizing Vertical Tail, V and Horizontal Tail, H**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| xh= | 2.50 | ft | xv= | 2.29 | ft | Arh= | 4.50 |
| | 30.00 | in | | 27.48 | in | Arv= | 1.20 |

**Horizontal Tail Volume, Area and Span, Vh, sh, and bh**

| | | | | | |
|---|---|---|---|---|---|
| Vh= | 0.66 | sh= | 1.06 | ft^2 | sh=Vh*S*cmean/xh |
| | | | 152.01 | ft^2 | |
| bh= | 2.18 | ft | | | bh=(Arh*sh)^1/2 |
| | 26.15 | in | | | |

**Horizontal Mean Aerodynamic, Tip and Root Chords, Hcmean, HCt, and HCr**

| | | | | | |
|---|---|---|---|---|---|
| Cmean= | 0.48 | ft | Hcmean=sh/bh | Lambdah= | 0.65 |
| | 5.81 | in | | Mu 1/4Chord= | 7 Degrees |
| Ct= | 0.47 | ft | HCt=sh/((bh/2)x(1+Lambdah/Lambdah)) | | |
| | 5.63 | in | | | |
| Cr= | 0.72 | ft | HCr=sh/((bh/2)x(1+Lambdah)) | | |
| | 8.63 | in | | | |

**Vertical Tail Volume, Area and Span, Vv, sv, bv** sv=Vv*s*b/xv

| | | | | | |
|---|---|---|---|---|---|
| Vv= | 0.0496 | sv= | 0.49 | ft^2 | |
| | | | 70.93 | in^2 | |
| bv= | 0.77 | ft | | | bh=(Arv*sv)^1/2 |
| | 9.23 | in | | | |

**Vertical Mean Aerodynamic, Tip and Root Chords, VCmean, VCt, and VCr**

| | | | | | |
|---|---|---|---|---|---|
| Vcmean= | 0.64 | ft | Vcmean=sv/bv | | |
| | 7.69 | in | | Lambdav= | 0.33 |
| VCt= | 0.32 | ft | VCt=sv/((bv/2)x(1+Lambdav/Lambdav)) | | |
| VCr= | 1.50 | ft^3 | VCr=sv/((bv/2)x(1+Lambdav)) | | |
| | 17.96 | in^3 | | | |

| Cart Coord, Y | Y/(B/2), 2Y/B | Chord(Y), cy |
|---|---|---|
| 0.00 | 0.00 | 13.96 |
| 0.25 | 0.06 | 13.50 |
| 0.50 | 0.12 | 13.05 |
| 0.75 | 0.18 | 12.59 |
| 1.00 | 0.24 | 12.14 |
| 1.25 | 0.30 | 11.68 |
| 1.50 | 0.36 | 11.23 |
| 1.75 | 0.42 | 10.77 |
| 2.00 | 0.47 | 10.32 |
| 2.25 | 0.53 | 9.86 |
| 2.50 | 0.59 | 9.40 |
| 2.75 | 0.65 | 8.95 |
| 3.00 | 0.71 | 8.49 |
| 3.25 | 0.77 | 8.04 |
| 3.50 | 0.83 | 7.58 |
| 3.75 | 0.89 | 7.13 |
| 4.00 | 0.95 | 6.67 |
| 4.22 | 1.00 | 6.28 |

**Preliminary Lifting Perfomance**

| Time of Flight, Tf | | Lap Distance, Lap | |
|---|---|---|---|
| 7.00 | min | 700.00 | ft |
| 420.00 | sec | | |

**Total Flight Distance, Dt** Dt = Lap x Laps Completed

**Cruise and Soar Velocities, Vcmax and Vcminsink**

Vcmax = Dt / Tf or timed

| Vcmax | | Vcminsink | |
|---|---|---|---|
| m/h | ft/s | m/h | ft/s |
| 40.00 | 58.67 | 30.00 | 44.00 |
| 45.00 | 66.00 | 35.00 | 51.33 |
| 50.00 | 73.33 | 40.00 | 58.67 |
| 55.00 | 80.67 | 45.00 | 66.00 |
| 60.00 | 88.00 | 50.00 | 73.33 |
| 65.00 | 95.33 | 55.00 | 80.67 |

**Atmospheric Density, rho**

rhosl = 378 slugs/ft^3

rhowk = 227 slug/ft^3

Stall Velocity, Vstall

| m/h | ft/s |
|---|---|
| 67 | 98.27 |

| Take Off Velocity, Vto | Landing Velocity, Vld |
|---|---|
| ft/s | ft/s |
| 80.40 | 87.10 |

| Takeoff Roll | Landing Roll |
|---|---|
| fts | ft |
| 76.20 | 187.00 |

Cr, Soar, Toff, and Ld Velocity Coefficient of Lift, CL

| CLmean | Lmnsnk | CLto | CLld | CL= (2 x Wto)/rho x Vc^2 x S |
|---|---|---|---|---|
| 0.244 | 0.352 | 0.136 | 0.116 | |

C and S Airfoil Coefficient of Lift, Cl

| Clmean | Clmnsnk | Clto | Clld | |
|---|---|---|---|---|
| | | | | Cl=4/pi x CLxS/B x (1-(2Y/B)^2)^1/2 |

Preliminary Drag Polar Coeffiecient Data

Parasite Wetted Area, Sw (ft^2) Parasite Area, F (ft^2)

| | | | | |
|---|---|---|---|---|
| 51.16 | ft^2 | Sw=10^(C + (D x Log10 Wto)) | 0.307 | ft^2 |
| | | F=10^(A + (B x log10 Sw)) | | |

| | | | |
|---|---|---|---|
| A = | -2.2218 | Wto | 16.00 |
| B = | 1.0000 | | |
| C = | 1.0892 | | |
| D = | 0.5147 | | |

Zero Lift Drag Polar, CDo Cdo= F/S

CDo = 0.043

Clean Aircraft Drag Polar, CDclean

CDclean= 0.04546 CDclean = CDo + (CL^2 / Pi * AR *e)

**Drag Poles for Other Configurations**

| | **Delta CDo** | **Efficiency Factor, e** |
|---|---|---|
| Clean | | 0.83 |
| Take Off Flaps | 0.016 | 0.78 |
| Landing Flaps | 0.068 | 0.73 |
| Landing Gear | 0.021 | — |

**Clean with Landing Gear Drag Polar, Cdolg**

CDto = 0.061

CDld = 0.114

CDlg = 0.066

CDclean = (CDo+delta) + (CL^2 / Pi * AR *e)

# Appendix B

*Stability and Control Calculations*

## Nomenclature for Longitudinal Stability Calculations

| Symbol | Description |
|---|---|
| M | Mach number, using a temperature of 75°F |
| V | Velocity (ft/s) |
| Uo | Velocity (ft/s) |
| W | Weight (lbs) |
| g | gravity (ft/s$^2$) |
| m | mass (slugs) |
| S | Surface area of the wing (ft$^2$) |
| b | Wingspan (ft) |
| ARw | Aspect ratio of the wing |
| Cbar | Mean aerodynamic chord (ft) |
| Lt | Distance from aircraft C.G. to horizontal tail quarter chord |
| St | Surface area of the horizontal tail (ft$^2$) |
| ARt | Aspect ratio of the horizontal tail |
| Se | Surface area of the elevator (ft$^2$) |
| Xcg | Location of the aircraft C.G. w.r.t. the mean aerodynamic chord leading edge (ft) |
| Xac | Location of the wing aerodynamic center with respect to the MAC leading edge(ft) |
| Claw2D | 2-D wing lift curve slope |
| Clat2D | 2-D horizontal tail lift curve slope |
| CDu | Drag coefficient due to compressibility effects |
| Cmu | Moment coefficient due to compressibility effects |
| CmaFuse | Moment coefficient contribution from the fuselage |
| Sweepw | Sweep of the wing quarter chord (degrees) |
| Sweept | Sweep of the horizontal tail quarter chord (degrees) |
| Beta | Interpolation variable used to determine CLaw3D and CLat3D |
| kw | Interpolation variable used to determine Claw3D |
| kt | Interpolation variable used to determine Clat3D |
| CLaw3D | 3-D wing lift curve slope |
| CLat3D | 3-D horizontal tail lift curve slope |
| eta | Efficiency factor of the horizontal tail |
| Vh | Horizontal tail volume (ft$^3$) |
| rho | Density of air at 1500 ft (altitude of contest site) (slug/ft$^3$) |
| Q | Dynamic pressure (lb/ft$^2$) |
| CDo | Reference drag coefficient |
| Iy | Moment of inertia about the y-axis of the aircraft (slug-ft$^2$) |
| tau | Flap-effectiveness parameter |
| XdelE | Force in x-direction produced by elevator deflection (lbs) |
| DeDa | Change in downwash due to a change in angle of attack |
| CLalpha | Aircraft lift curve slope |
| Cmalpha | Aircraft moment curve slope |

| | |
|---|---|
| CDalpha | Aircraft drag curve slope |
| CLu | Lift coefficient due to compressibility effects |
| CXu | X-force coefficient due to compressibility effects |
| CLalphadot | Aircraft unsteady lift curve slope |
| Cmalphadot | Aircraft unsteady moment curve slope |
| CLq | Aircraft lift curve slope with respect to pitch rate |
| Cmq | Aircraft moment curve slope with respect to pitch rate |
| CLdelE | Elevator lift coefficient |
| CmdelE | Elevator moment coefficient |
| alphaW | Wing angle of attack (radians) |
| iw | Wing incidence angle relative to fuselage centerline (radians) |
| it | Horizontal tail incidence angle relative to fuselage centerline (radians) |
| Clow | Reference wing lift coefficient |
| epsilonO | Reference downwash angle (radians) |
| Clo | Reference aircraft lift coefficient |
| Lalpha | Aircraft lift as a function of angle of attack (lbs) |
| Malpha | Aircraft moment as a function of angle of attack (ft-lbs) |
| Lu | Aircraft lift due to compressibility effects (lbs) |
| Lalphadot | Unsteady aircraft lift (lbs) |
| Malphadot | Unsteady aircraft moment (ft-lbs) |
| Lq | Aircraft lift as a function of pitch rate (lbs) |
| Mq | Aircraft moment as a function of pitch rate (ft-lbs) |
| LdelE | Elevator lift (lbs) |
| MdelE | Elevator moment (ft-lbs) |
| Xu | Force in x-direction due to compressibility effects (lbs) |
| Zu | Force in z-direction due to compressibility effects (lbs) |
| Mu | Moment due to compressibility effects (ft-lbs) |
| Mwdot | Moment due to vertical acceleration (ft-lbs) |
| Xw | Force in x-direction due to vertical velocity (lbs) |
| Zw | Force in z-direction due to vertical velocity (lbs) |
| Mw | Moment due to vertical velocity (ft-lbs) |
| ZdelE | Force in z-direction due to elevator deflection (lbs) |
| Omega_SP | Natural frequency of the short period oscillations (Hz) |
| DR_SP | Damping ratio for the short period mode oscillations |
| Thalf_SP | Time for the amplitude of the short period mode oscillations to half (sec) |
| T_SP | Period of the short period mode oscillations (sec) |
| Nhalf_SP | Number of oscillations for the amplitude of the short period mode oscillations to half |
| Omega_Phugoid | Natural frequency of the phugoid mode oscillations (Hz) |
| DR_Phugoid | Damping ratio for the phugoid mode oscillations |
| Thalf_Phugoid | Time for the amplitude of the phugoid mode oscillations to half (sec) |
| T_Phugoid | Period of the phugoid mode oscillations (sec) |
| Nhalf_Phugoid | Number of oscillations for the amplitude of the phugoid mode oscillations to half |

### Additional Comments

The orthogonal coordinate system used has the x-axis extending forward through the nose of the aircraft, the y-axis going through the right-hand side, and the z-axis pointing through the bottom of the aircraft.

All stability derivatives and coefficients were derived assuming level flight with small perturbations only.

## *Longitudinal Stability Calculations*

### Code written for Matlab

```
M = 0.0781
V = 88
Uo = V
W = 16.0
g = 32.174
m = W / g
S = 7.11
b = 8.43
ARw = 10.0
Cbar = 0.84
Lt = 2.29
St = 1.06
ARt = 4.50
Se = 0.212
Xcg = 0.35 * Cbar
Xac = 0.25 * Cbar
CLaw2D = 5.80
CLat2D = 6.14
CDu = 0
Cmu = 0.05
CmaFuse = .5
Sweepw = 0.0
Sweept = 7.0
Beta = sqrt (1 - M^2)
kw = CLaw2D / (2 * 3.1416)
kt = CLat2D / (2 * 3.1416)
CLaw3D = 2 * 3.141 * ARw / (2 + sqrt(ARw^2 * Beta^2 / kw^2 * (1 + (tan(Sweepw/57.3))^2 / Beta^2) + 4))
CLat3D = 2 * 3.141 * ARt / (2 + sqrt(ARt^2 * Beta^2 / kt^2 * (1 + (tan(Sweept/57.3))^2 / Beta^2) + 4))
eta = 1
Vh = St / S * Lt / Cbar
rho = 0.00227
Q = .5 * rho * V^2
CDo = 0.025
Iy = .8
tau = 0.4
XdelE = 0

DeDa = 2*CLaw3D / (3.1416*ARw)

% Coefficients
CLalpha = CLaw3D + eta * St / S * CLat3D * (1 - DeDa)
Cmalpha = CLaw3D * (Xcg - Xac) / Cbar + CmaFuse - eta * Vh *CLat3D * (1 - DeDa)
CDalpha = 0.04 * CLalpha
CLalphadot = 2 * eta * CLat3D * Vh * DeDa
Cmalphadot = -2 * eta * CLat3D * Vh * Lt / Cbar * DeDa
CLq = 2 * eta * CLat3D * Vh + CLaw3D * (.5 + 2 * (Xac - Xcg) / Cbar)
Cmq = -2.2 * eta * CLat3D * Vh * Lt / Cbar
CLdelE = St / S * eta * CLat3D * tau
CmdelE = - eta * Vh * CLat3D * tau
alphaW = 2.0*3.1416/180
iw = alphaW
it = 0.0
```

```
Clow = CLaw3D*alphaW
epsilonO = 2*Clow/(3.1416*ARw)
CLo = eta * (S/St) * CLat3D * (iw + it - epsilonO)
CLu = M^2 / (1 - M^2) * CLo
CXu = -CDu

% Dimensional counterparts
Lalpha = (CLalpha + CDo) * Q * S / m
Malpha = Cmalpha * Q * S * Cbar / Iy
Lu = (CLu + 2 * CLo) * Q * S / (m * Uo)
Lalphadot = CLalphadot * Cbar * Q * S / (2 * Uo * m)
Malphadot = Cmalphadot * Q * S * Cbar^2 / (2 * Uo * Iy)
Lq = CLq * Q * S * Cbar / (2 * Uo * m)
Mq = Cmq * Q * S * Cbar^2 / (2 * Uo * Iy)
LdelE = CLdelE * Q * S / m
MdelE = CmdelE * Q * S * Cbar / Iy

% Additional Stuff for the A and B matrices (Longitudinal Equations of Motion)
Xu = - (CDu) * Q * S / (m * Uo)
Zu = - Lu
Mu = Cmu * Q * S * Cbar / (Uo * Iy)
Mwdot = Malphadot / Uo
Xw = - (CDalpha - CLo) * Q * S / (m * Uo)
Zw = - (CLalpha + CDo) * Q * S / (m * Uo)
Mw = Cmalpha * Q * S * Cbar / (Uo * Iy)
ZdelE = - CLdelE * Q * S / m

% A and B matrices
A = [Xu Xw 0 -g ; Zu Zw Uo 0 ; Mu+Mwdot*Zu Mw+Mwdot*Zw Mq+Mwdot*Uo 0 ; 0 0 1 0]

B = [XdelE 0 ; ZdelE 0 ; MdelE+Mwdot*ZdelE 0 ; 0 0]

% eigenvectors and eigenvalues
[evec,eval] = eig(A)
fac = diag(1./[Uo Uo (2*Uo)/Cbar 1]);
evec = fac * evec;
evec = evec * diag(1./evec(4,: ))

% for the short period
Omega_SP = norm (eval(1,1))
DR_SP = abs(real(eval(1,1)))/Omega_SP
Thalf_SP = 0.69 / abs(real(eval(1,1)))
T_SP = 2 * pi / abs(imag(eval(1,1)))
Nhalf_SP = Thalf_SP / T_SP

% for the phugoid
Omega_Phugoid = norm (eval(3,3))
DR_Phugoid = abs(real(eval(3,3)))/Omega_Phugoid
Thalf_Phugoid = 0.69 / abs(real(eval(3,3)))
T_Phugoid = 2 * pi / abs(imag(eval(3,3)))
Nhalf_Phugoid = Thalf_Phugoid / T_Phugoid
```

## Matlab Output

| | | |
|---|---|---|
| M = 0.0781 | Beta = 0.9969 | it = 0 |
| V = 88 | CLaw3D = 4.8384 | Clow = 0.1689 |
| Uo = 88 | CLat3D = 4.0158 | epsilonO = 0.0108 |
| W = 16 | eta = 1 | CLo = 0.6506 |
| g = 32.1740 | Vh = 0.4064 | CLu = 0.0040 |
| m = 0.4973 | rho = 0.0023 | CXu = 0 |
| S = 7.1100 | Q = 8.7894 | Lalpha = 663.2226 |
| b = 8.4300 | CDo = 0.0250 | Malpha = -9.5531 |
| ARw = 10 | Iy = 0.8000 | Lu = 1.8639 |
| Cbar = 0.8400 | tau = 0.4000 | Lalphadot = 0.6031 |
| Lt = 2.2900 | XdelE = 0 | Malphadot = -0.8585 |
| St = 1.0600 | DeDa = 0.3080 | Lq = 2.8284 |
| ARt = 4.5000 | CLalpha = 5.2527 | Mq = -3.0657 |
| Se = 0.2120 | Cmalpha = -0.1456 | LdelE = 30.0943 |
| Xcg = 0.2940 | CDalpha = 0.2101 | MdelE = -42.8396 |
| Xac = 0.2100 | CLalphadot = 1.0055 | Xu = 0 |
| CLaw2D = 5.8000 | Cmalphadot = -2.7411 | Zu = -1.8639 |
| CLat2D = 6.1400 | CLq = 4.7159 | Mu = 0.0373 |
| CDu = 0 | Cmq = -9.7891 | Mwdot = -0.0098 |
| Cmu = 0.0500 | CldelE = 0.2395 | Xw = 0.6291 |
| CmaFuse = 0.5000 | CmdelE = -0.6529 | Zw = -7.5366 |
| Sweepw = 0 | alphaW = 0.0349 | Mw = -0.1086 |
| Sweept = 7 | iw = 0.0349 | ZdelE = -30.0943 |

### Matrix A

$$\begin{bmatrix} 0 & 0.6291 & 0 & -32.1740 \\ -1.8639 & -7.5366 & 88.0000 & 0 \\ 0.0555 & -0.0350 & -3.9242 & 0 \\ 0 & 0 & 1.0000 & 0 \end{bmatrix}$$

### Matrix B

$$\begin{bmatrix} 0 & 0 \\ -30.0943 & 0 \\ -42.5460 & 0 \\ 0 & 0 \end{bmatrix}$$

### Matrix evec

$$\begin{bmatrix} -0.0135 + 0.1217i & -0.0135 - 0.1217i & -0.7083 + 0.7005i & -0.7083 - 0.7005i \\ -0.1446 - 0.9817i & -0.1446 + 0.9817i & 0.0709 - 0.0431i & 0.0709 + 0.0431i \\ 0.0072 - 0.0188i & 0.0072 + 0.0188i & -0.0086 + 0.0117i & -0.0086 - 0.0117i \\ -0.0017 + 0.0030i & -0.0017 - 0.0030i & 0.0167 + 0.0134i & 0.0167 - 0.0134i \end{bmatrix}$$

**Matrix eval**

$$\begin{bmatrix} -5.7590 + 0.9310I & 0 & 0 & 0 \\ 0 & -5.7590 - 0.9310i & 0 & 0 \\ 0 & 0 & 0.0286 + 0.6754i & 0 \\ 0 & 0 & 0 & 0.0286 - 0.6754i \end{bmatrix}$$

**Matrix evec**

$$\begin{bmatrix} 0.3695 - 0.1626i & 0.3695 + 0.1626i & -0.0608 + 0.5248i & -0.0608 - 0.5248i \\ -2.5611 + 2.0356i & -2.5611 - 2.0356i & 0.0151 - 0.0414i & 0.0151 + 0.0414i \\ -0.0275 + 0.0044i & -0.0275 - 0.0044i & 0.0001 + 0.0032i & 0.0001 - 0.0032i \\ 1.0000 + 0.0000i & 1.0000 - 0.0000i & 1.0000 + 0.0000i & 1.0000 - 0.0000i \end{bmatrix}$$

**Modal Characteristics**

Omega_SP = 5.8338
DR_SP = 0.9872
Thalf_SP = 0.1198
T_SP = 6.7489
Nhalf_SP = 0.0178
Omega_Phugoid = 0.6760
DR_Phugoid = 0.0423
Thalf_Phugoid =24.1150
T_Phugoid = 9.3035
Nhalf_Phugoid = 2.5921

## Nomenclature for Lateral/Directional Stability Calculations

| Symbol | Description |
|---|---|
| Uo | Velocity (ft/s) |
| M | Mach number, using a temperature of 75°F |
| rho | Density of air at 1500 ft (altitude of contest site) (slug/ft3) |
| S | Surface area of the wing (ft2) |
| W | Weight (lbs) |
| g | gravity (ft/s2) |
| m | mass (slugs) |
| Ix | Moment of inertia about the x-axis of the aircraft (slug-ft2) |
| Iz | Moment of inertia about the z-axis of the aircraft (slug-ft2) |
| ARw | Aspect ratio of the wing |
| Arvt | Aspect ratio of the vertical tail |
| Claw2D | 2-D wing lift curve slope |
| Clavt2D | 2-D vertical tail lift curve slope |
| EtaV | Efficiency factor of the vertical tail |
| Sv | Surface area of the vertical tail (ft2) |
| dsigmadbeta | Change in sidewash due to change in angle of sideslip |
| Zv | Distance from fuselage centerline to vertical tail aerodynamic center |
| Lv | Distance from aircraft center of gravity to vertical tail quarter chord |
| b | Wingspan (ft) |
| Cbar | Mean aerodynamic chord (ft) |
| Vv | Vertical tail volume (ft3) |
| Q | Dynamic pressure (lb/ft2) |
| volumefuse | Volume of the fuselage (ft3) |
| widthfuse | Average width of the fuselage (ft3) |
| Hatwingroot | Height of the fuselage at the ring root (ft) |
| Cnbetafuse | Weathercock effect due to the fuselage |
| Clo | Reference aircraft lift coefficient |
| Sweepw | Sweep of the wing quarter chord (degrees) |
| Sweepvt | Sweep of the vertical tail quarter chord (degrees) |
| Beta | Interpolation variable used to determine CLaw3D and CLavt3D |
| kw | Interpolation variable used to determine Claw3D |
| kt | Interpolation variable used to determine Clavt3D |
| Cybetatail | Side force coefficient due to sideslip caused by the vertical tail |
| Cybeta | Side force coefficient due to sideslip |
| Cyp | Side force coefficient due to roll rate |
| Cyr | Side force coefficient due to yaw rate |
| Clbeta | Dihedral effect coefficient |
| Clp | Damping coefficient in roll |
| Clr | Rolling moment coefficient due to yaw |

| | |
|---|---|
| Cnbeta | Weathercock effect coefficient |
| Cnp | Yawing moment coefficient due to roll |
| Cnr | Damping coefficient in yaw |
| Ybeta | Side force due to sideslip (lbs) |
| Yp | Side force due to roll rate (lbs) |
| Yr | Side force due to yaw rate (lbs) |
| Lbeta | Dihedral effect (ft-lbs) |
| Lp | Damping in roll (ft-lbs) |
| Lr | Rolling moment due to yaw (ft-lbs) |
| Nbeta | Weathercock effect (ft-lbs) |
| Np | Yawing moment due to roll (ft-lbs) |
| Nr | Damping in yaw (ft-lbs) |
| Omega_roll | Natural frequency of the roll mode oscillations (Hz) |
| Thalf_roll | Time for the amplitude of the roll mode oscillations to half (sec) |
| Omega_spiral | Natural frequency of the spiral mode oscillations (Hz) |
| Thalf_roll | Time for the amplitude of the spiral mode oscillations to half (sec) |
| Omega_DR | Natural frequency of the dutch roll mode oscillations (Hz) |
| DR_DR | Damping ratio for the dutch roll mode oscillations |
| Thalf_DR | Time for the amplitude of the dutch roll mode oscillations to half (sec) |
| T_DR | Period of the dutch roll mode oscillations (sec) |
| Nhalf_DR | Number of oscillations for the amplitude of the dutch roll mode oscillations to half |

## Additional Comments

The orthogonal coordinate system used has the x-axis extending forward through the nose of the aircraft, the y-axis going through the right-hand side, and the z-axis pointing through the bottom of the aircraft.

All stability derivatives and coefficients were derived assuming level flight with small perturbations only.

## *Lateral/Directional Stability Calculations*

### Code written for Matlab

```
Uo = 88
M = 0.0781
rho = 0.00227
S = 7.11
W = 16.0
g = 32.174
m = W / g
Ix = 15
Iz = 16
ARw = 10.0
ARvt = 1.2
Claw2D = 5.80
Clavt2D = 6.14
etaV = 1
Sv = 0.49
dsigmadbeta = 0.3
Zv = 0.375
Lv = 2.5
b = 8.43
Cbar = 0.84
Vv = (Sv/S) * Lv/Cbar
rho = 0.00227
Q = 0.5 * rho * Uo^2

%Fuselage stuff
volumefuse = (2.375*3*36)/12^3
widthfuse = 2.375/12
Hatwingroot = 3/12

Cnbetafuse = -1.3*volumefuse*Hatwingroot/(S*b*widthfuse)
 Clo = W / (Q*S)
Sweepw = 0.0
Sweepvt = 41
Beta = sqrt (1 - M^2)
kw = Claw2D / (2 * 3.1416)
kt = Clavt2D / (2 * 3.1416)
ClalphaW = 2 * 3.141 * ARw / (2 + sqrt(ARw^2 * Beta^2 / kw^2 * (1 + (tan(Sweepw/57.3))^2 / Beta^2) +
4))
ClalphaV = 2 * 3.141 * ARvt / (2 + sqrt(ARvt^2 * Beta^2 / kt^2 * (1 + (tan(Sweepvt/57.3))^2 / Beta^2) + 4))
Cybetatail = ClalphaV
Q = .5 * rho * Uo^2

% Stability Coefficients

Cybeta = - etaV * (Sv/S) * ClalphaV * (1 + dsigmadbeta)
Cyp = - 2 * etaV * (Sv/S) * ClalphaV * (Zv/b)
Cyr = 2 * etaV * Vv * ClalphaV
Clbeta = 0.0
Clp = - ClalphaW / 12 * (1 + 3 * Sweepw) / (1 + Sweepw) - 2 * etaV * (Sv/S) * (Zv/b)^2 * ClalphaV
Clr = Clo / 4 - 2 * (Lv/b) * (Zv/b) * Cybetatail
Cnbeta = Cnbetafuse + etaV * Vv * ClalphaV * (1 + dsigmadbeta)
Cnp = - Clo / 8 + 2 * etaV * Vv * ClalphaV * (Zv/b)
```

```
Cnr = - 2 * etaV * Vv * (Lv/b) * ClalphaV

% Directional Derivatives

Ybeta = Q*S*Cybeta / m
Yp = Q*S*b*Cyp / (2*m*Uo)
Yr = Q*S*b*Cyr / (2*m*Uo)
Lbeta = Q*S*b*Clbeta / Ix
Lp = Q*S*b^2*Clp / (2*Ix*Uo)
Lr = Q*S*b^2*Clr / (2*Ix*Uo)
Nbeta = Q*S*b*Cnbeta / Iz
Np = Q*S*b^2*Cnp / (2*Iz*Uo)
Nr = Q*S*b^2*Cnr / (2*Iz*Uo)

% Set up the matix for the lateral/directional equations of motion

A = [Ybeta/Uo Yp/Uo -(1-Yr/Uo) g/Uo; Lbeta Lp Lr 0; Nbeta Np Nr 0;0 1 0 0]
[evec,eval] = eig(A)

% Roll mode

Omega_roll = norm (eval(3,3))
Thalf_roll = 0.69 / abs(real(eval(3,3)))

% Spiral mode

Omega_spiral = norm (eval(4,4))
Thalf_spiral = 0.69 / abs(real(eval(4,4)))

% Dutch roll mode

Omega_DR = norm (eval(1,1))
DR_DR = abs(real(eval(1,1)))/Omega_DR
Thalf_DR = 0.69 / abs(real(eval(1,1)))
T_DR = 2 * pi / abs(imag(eval(1,1)))
Nhalf_DR = Thalf_DR / T_DR
```

## Matlab Output

| | | |
|---|---|---|
| Uo = 88 | Cbar = 0.8400 | Cybeta = -0.1476 |
| M = 0.0781 | Vv = 0.2051 | Cyp = -0.0101 |
| rho = 0.0023 | rho = 0.0023 | Cyr = 0.6757 |
| S = 7.1100 | Q = 8.7894 | Clbeta = 0 |
| W = 16 | volumefuse = 0.1484 | Clp = -0.4036 |
| g =32.1740 | widthfuse = 0.1979 | Clr = 0.0205 |
| m = 0.4973 | Hatwingroot = 0.2500 | Cnbeta = 0.4352 |
| Ix = 15 | Cnbetafuse = -0.0041 | Cnp = -0.0019 |
| Iz = 16 | Clo = 0.2560 | Cnr = -0.2004 |
| ARw = 10 | Sweepw = 0 | Ybeta = -18.5455 |
| ARvt = 1.2000 | Sweepvt = 41 | Yp = -0.0608 |
| Claw2D = 5.8000 | Beta = 0.9969 | Yr = 4.0672 |
| Clavt2D = 6.1400 | kw = 0.9231 | Lbeta = 0 |
| etaV = 1 | kt = 0.9772 | Lp = -0.6790 |
| Sv = 0.4900 | ClalphaW = 4.8384 | Lr = 0.0346 |
| dsigmadbeta = 0.3000 | ClalphaV = 1.6472 | Nbeta =14.3279 |
| Zv = 0.3750 | Cybetatail = 1.6472 | Np = -0.0031 |
| Lv = 2.5000 | Q = 8.7894 | Nr = -0.3160 |
| b = 8.4300 | | |

### Matrix A

$$\begin{bmatrix} -0.2107 & -0.0007 & -0.9538 & 0.3656 \\ 0 & -0.6790 & 0.0346 & 0 \\ 14.3279 & -0.0031 & -0.3160 & 0 \\ 0 & 1.0000 & 0 & 0 \end{bmatrix}$$

### Matrix evec

$$\begin{bmatrix} -0.2476 + 0.0340i & -0.2476 - 0.0340i & 0.0080 & -0.0083 \\ 0.0090 - 0.0001i & 0.0090 + 0.0001i & 0.5465 & -0.0176 \\ 0.1181 + 0.9610i & 0.1181 - 0.9610i & -0.2965 & -0.3561 \\ -0.0002 - 0.0024i & -0.0002 + 0.0024i & -0.7832 & -0.9342 \end{bmatrix}$$

### Matrix eval

$$\begin{bmatrix} -0.2635 + 3.6981i & 0 & 0 & 0 \\ 0 & -0.2635 - 3.6981i & 0 & 0 \\ 0 & 0 & -0.6978 & 0 \\ 0 & 0 & 0 & 0.0189 \end{bmatrix}$$

## Modal Characteristics

Omega_roll = 0.6978
Thalf_roll = 0.9889
Omega_spiral = 0.0189
Thalf_spiral = 36.5516
Omega_DR = 3.7075
DR_DR = 0.0711
Thalf_DR = 2.6191
T_DR = 1.6990
Nhalf_DR = 1.5415

### *Summary of Stability Calculations*

| Mode | Natural Frequency (rad/s) | Damping Ratio | Time to Half (s) | Period (s) |
|---|---|---|---|---|
| **Short Period** | 5.83 | 0.987 | 0.12 | 6.75 |
| **Phugoid** | 0.68 | 0.042 | 24.12 | 9.30 |
| **Roll** | 0.70 | N/A* | 0.99 | N/A* |
| **Spiral** | 0.02 | N/A* | 36.55 | N/A* |
| **Dutch Roll** | 3.71 | 0.071 | 2.62 | 1.70 |

* N/A since the roll mode and spiral mode are non-oscillatory.

# Appendix C

*ElectriCalc Data*

# ElectriCalc Data

The information displayed below was the actual output produced by ElectriCalc for various aircraft power combinations.

## Setup and Combination

| | Aggie Flyer 1996-97 Design | Texas Tall Boy Combination 1 | Texas Tall Boy Combination 2 | Texas Tall Boy Combination 3 | Texas Tall Boy Combination 4 |
|---|---|---|---|---|---|
| Motor | 1412/2Y | 1412/2Y | 1412/3Y | 1412/3Y | Max15-13Y |
| Motor Manufacturer | Aveox | Aveox | Aveox | Aveox | MaxCim |
| Gearing | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 |
| Motor KRPM | 22.9 | 24.9 | 17.0 | 18.8 | 17.0 |
| Motor Power (Watts) | 990.0 | 880.0 | 834.0 | 680.0 | 1020.0 |
| Motor Current (amps) | 59.5 | 49.5 | 45.0 | 34.4 | 62.8 |
| Motor Voltage (volts) | 16.6 | 17.8 | 18.5 | 19.8 | 16.2 |
| Propeller Type | Carbon folder | Carbon folder | Carbon folder | Carbon folder | Carbon folder |
| Propeller Diameter (inches) | 15.0 | 15.0 | 18.0 | 18.0 | 18.0 |
| Propeller Pitch (inches) | 13.6 | 9.5 | 8.0 | 8.0 | 8.0 |
| Propellor Yoke Pitch (degrees) | 5.0 | 0.0 | 5.0 | 0.0 | 5.0 |
| Pitch Speed (ft/sec) | 80.0 | 60.0 | 56.0 | 38.0 | 56.0 |
| Propeller KRPM | 6.2 | 6.7 | 4.6 | 5.1 | 4.6 |
| Propeller Power (Watts) | 859.0 | 767.0 | 691.0 | 576.0 | 689.0 |
| Battery Current (amps) | 59.5 | 49.0 | 45.0 | 34.4 | 62.2 |
| Battery Milli-amp hours | 1950.0 | 2200.0 | 2200.0 | 2200.0 | 2200.0 |
| Battery Duration Time (minutes) | 1.9 | 2.6 | 2.8 | 3.6 | 2.0 |
| Cell Type | N-1700SCRC | N-2000CR | N-2000CR | N-2000CR | N-2000CR |
| Cell Count | 19.0 | 19.0 | 19.0 | 19.0 | 19.0 |
| Cell Voltage (volts) | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Cell Resistance (milli-ohms) | 5.5 | 5.3 | 5.3 | 5.3 | 5.3 |
| % Throttle | 100.0 | 99.0 | 100.0 | 100.0 | 99.0 |
| % System Efficiency | 61.0 | 66.0 | 65.0 | 70.0 | 47.0 |
| % Motor Efficiency | 89.0 | 90.0 | 85.0 | 87.0 | 70.0 |
| Watts/Pound | 62.0 | 55.0 | 52.0 | 43.0 | 64.0 |
| Thrust (ounces) | 123.0 | 125.0 | 125.0 | 106.0 | 125.0 |

# Appendix D

*Wing Airfoil Analysis Data*

# Wing Airfoil Analysis Data

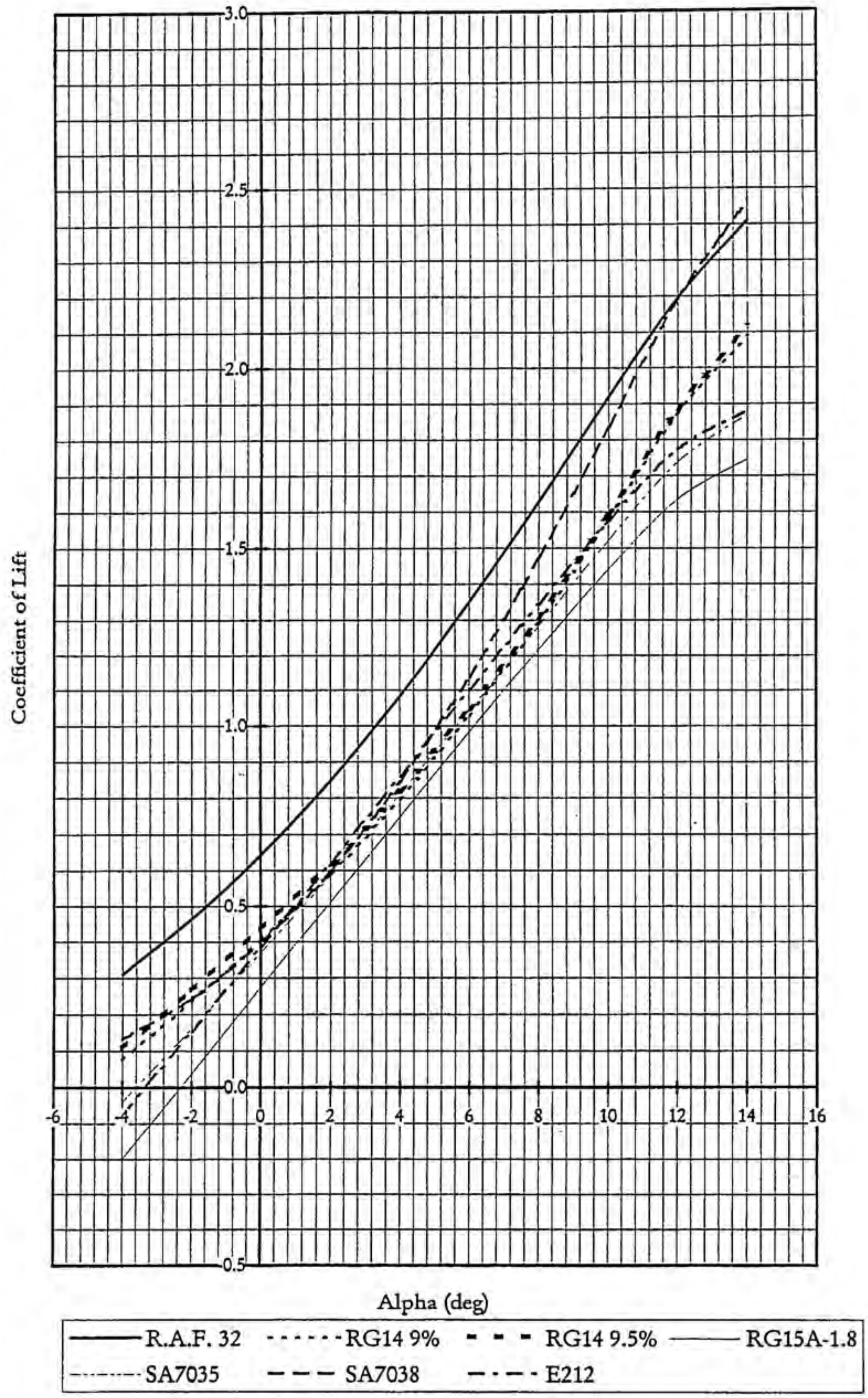
### Calculated Cl vs. Alpha ValuesUsing PANZ

| | | | | Airfoil | | | |
|---|---|---|---|---|---|---|---|
| Alpha | RAF32 | SA7038 | SA7035 | E212 | RG14 9% | RG14 9.5% | 15A-1.8/11 |
| -4 | 0.311 | 0.133 | -0.039 | -0.074 | 0.078 | 0.109 | -0.199 |
| -2 | 0.465 | 0.244 | 0.162 | 0.154 | 0.237 | 0.268 | 0.038 |
| 0 | 0.643 | 0.399 | 0.370 | 0.386 | 0.406 | 0.436 | 0.275 |
| 2 | 0.849 | 0.599 | 0.586 | 0.621 | 0.592 | 0.618 | 0.512 |
| 4 | 1.084 | 0.845 | 0.811 | 0.860 | 0.798 | 0.820 | 0.748 |
| 6 | 1.351 | 1.138 | 1.043 | 1.102 | 1.031 | 1.048 | 0.984 |
| 8 | 1.629 | 1.472 | 1.282 | 1.343 | 1.292 | 1.306 | 1.217 |
| 10 | 1.921 | 1.835 | 1.521 | 1.575 | 1.580 | 1.592 | 1.440 |
| 12 | 2.196 | 2.192 | 1.737 | 1.772 | 1.873 | 1.886 | 1.634 |
| 14 | 2.411 | 2.463 | 1.871 | 1.881 | 2.089 | 2.114 | 1.746 |

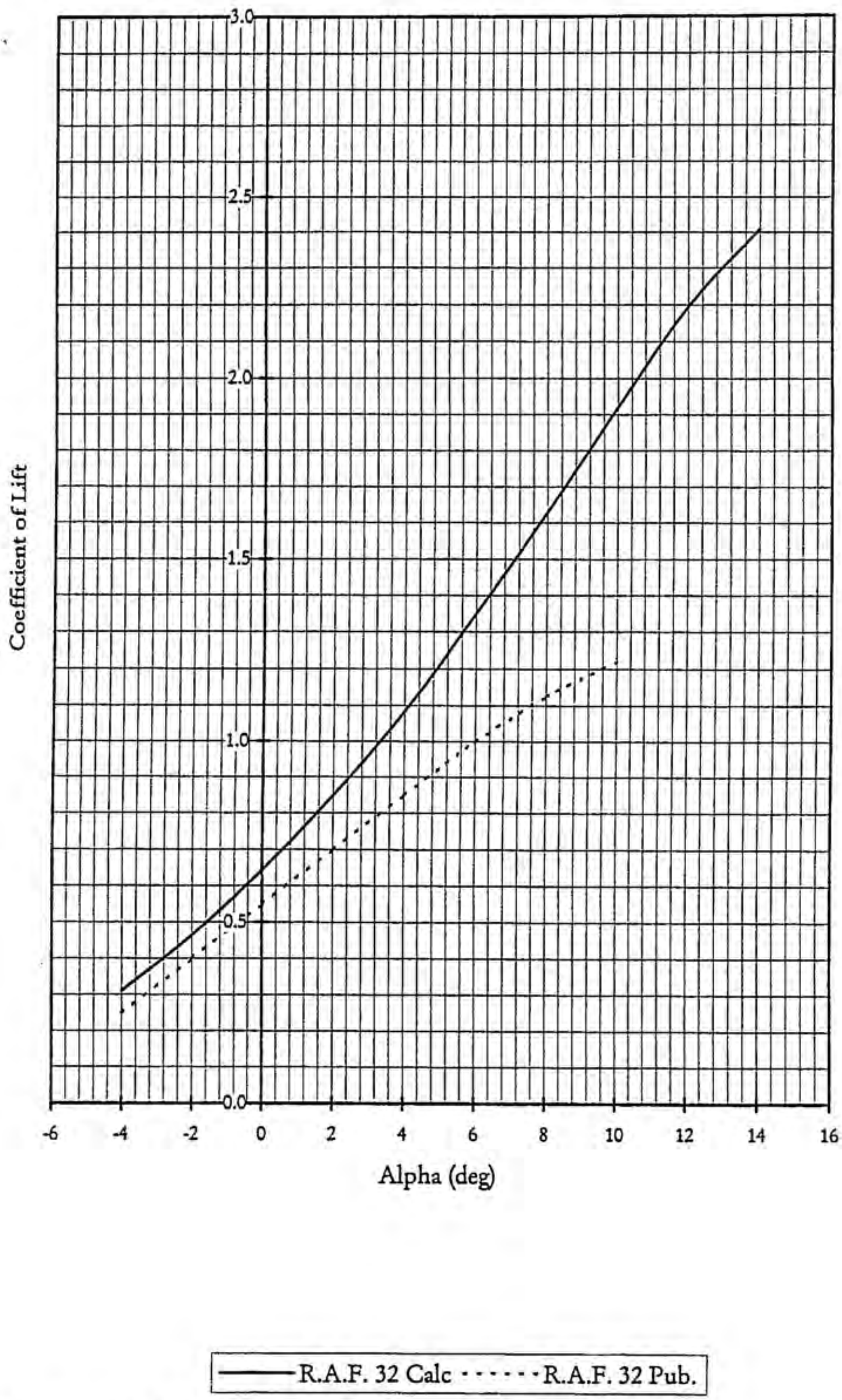
### Published Cl vs. Alpha Values

| | | Airfoil | |
|---|---|---|---|
| Alpha | RAF32 | SA7038 | SA7035 |
| -4 | 0.249 | — | — |
| -2 | 0.400 | 0.200 | 0.120 |
| 0 | 0.550 | 0.400 | 0.300 |
| 2 | 0.700 | 0.625 | 0.560 |
| 4 | 0.850 | 0.800 | 0.750 |
| 6 | 1.000 | 1.030 | 0.900 |
| 8 | 1.125 | 1.210 | 1.120 |
| 10 | 1.220 | 1.300 | 1.250 |

## Calculated Cl vs. Alpha for Various Airfoils

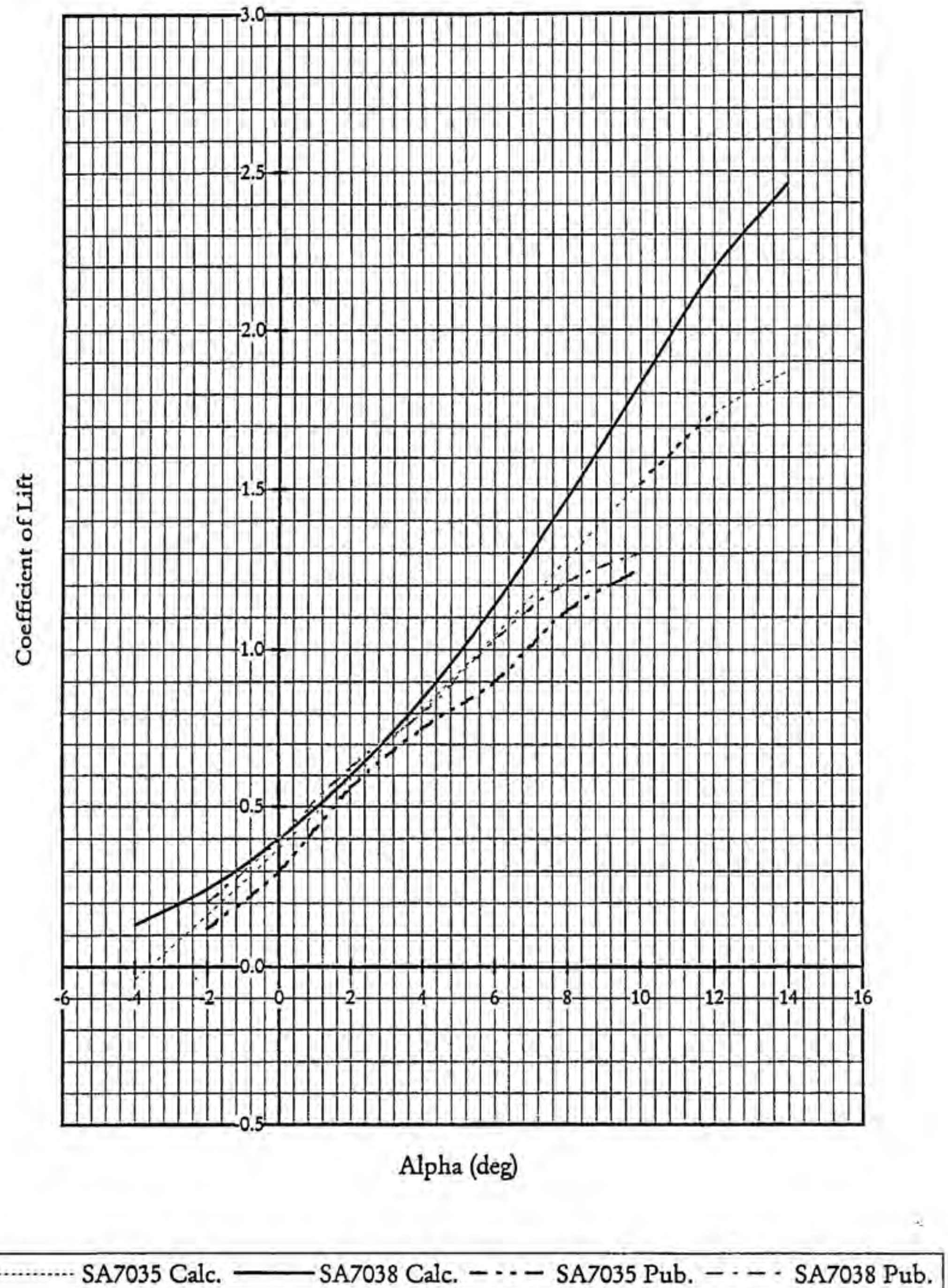


## Published and Calculated Cl vs. Alpha for the R.A.F. 32*




*Airfoil used on the Aggie Flyer

## Published and Calculated Cl vs. Alpha for the SA7035 and the SA7038*




*Airfoil used on the Texas Tall Boy

# Appendix E

*Wind Tunnel Propulsion Test Data*

## *Wind Tunnel Propulsion Test Data*

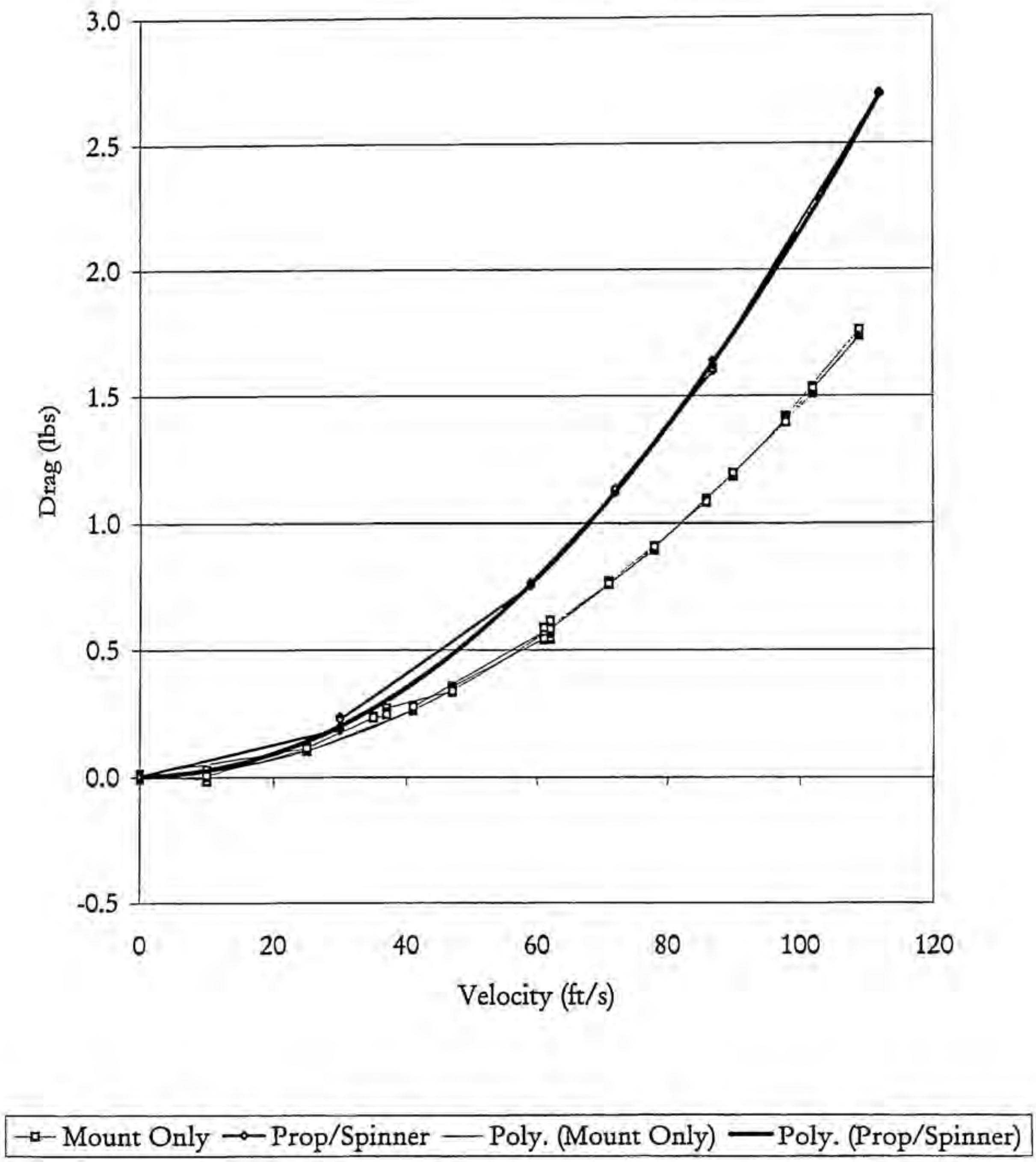
A low speed wind tunnel test was developed in order to help determine the most efficient motor/battery/propeller combination for the Texas Tall Boy. The testing facility was a 3 ft. by 5 ft. closed system wind tunnel located at the Department of Aerospace Engineering, Texas A&M University. The setup and data reduction procedures are methods taken from *Low-Speed Wind Tunnel Testing*, by Rae and Pope.

The primary focus of the test was to aid in answering the efficient drag and thrust design parameters set for by the mission requirements and overall needs of the TTB airframe design. Force and moment data was obtained using an external balance and data acquisition system developed at TAMU. The information collected allowed the values of raw force to be reduced and modified for use in endurance calculations and estimates for both the preliminary and detailed design of the TTB.

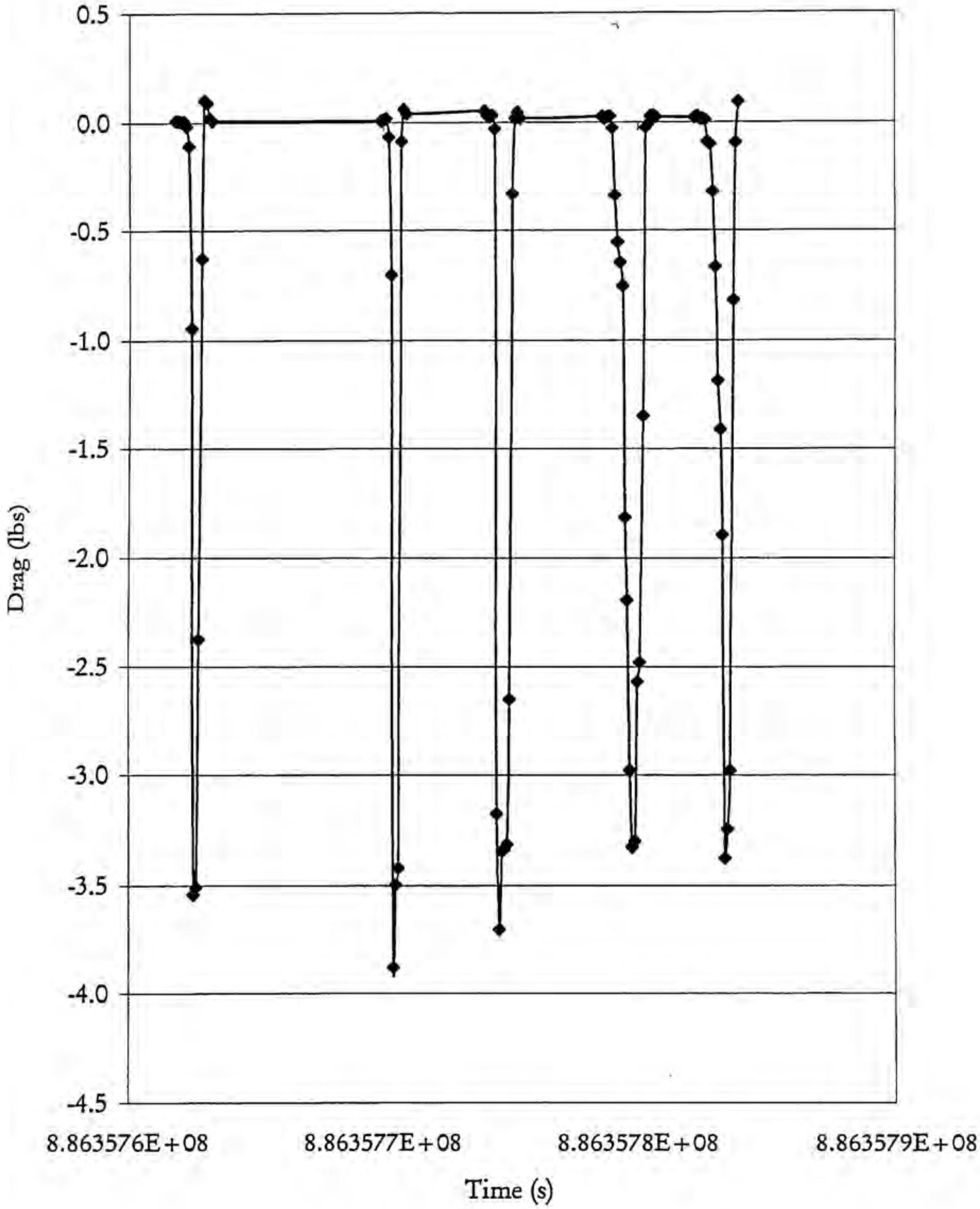
The reduced and refined information displayed below was obtained by testing a variety of types of components primarily broken up into two major combinations. Combination 1 consisted of the power system from the Aggie Flyer, and combination 2 consisted of highly researched purchased or borrowed components.

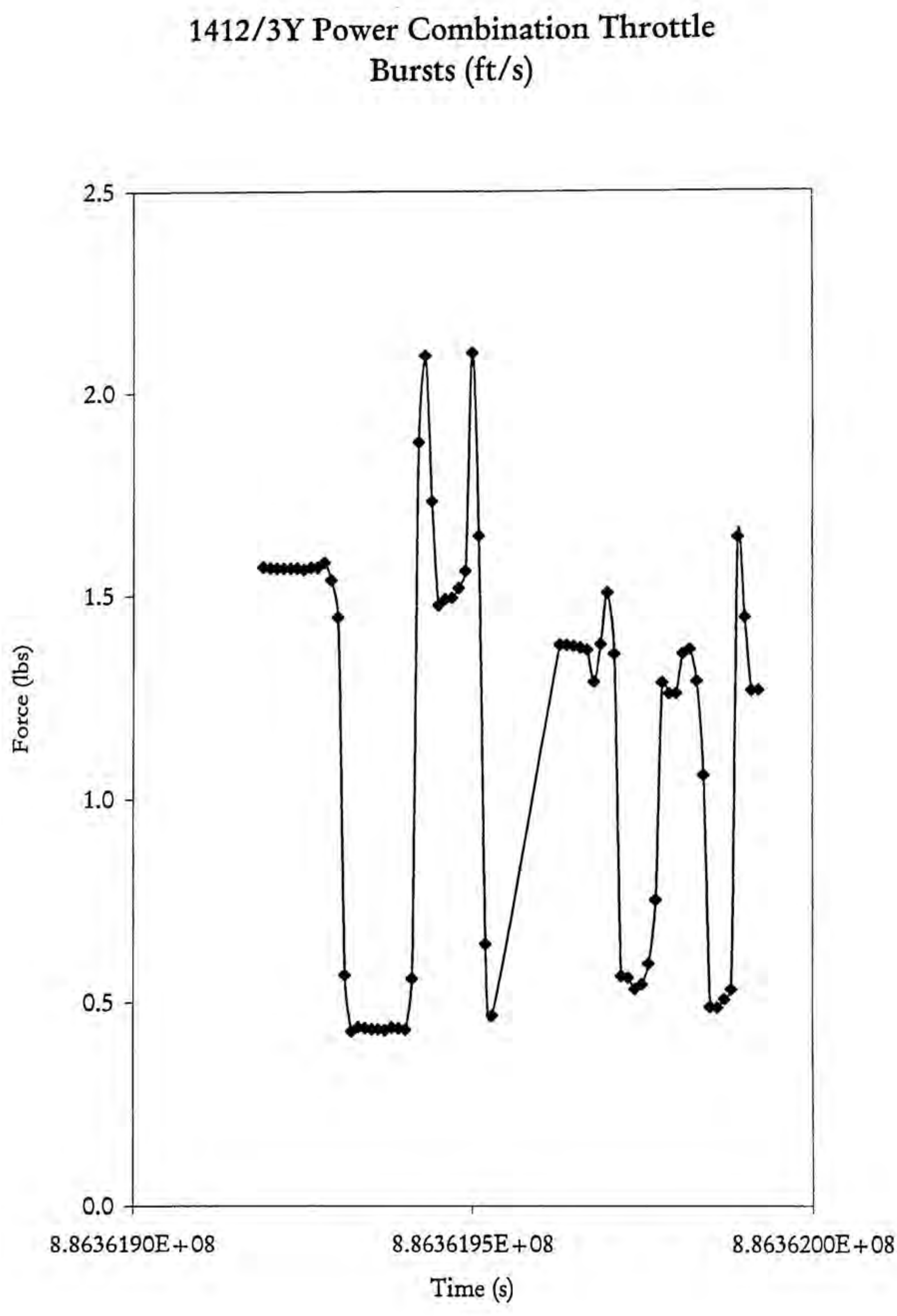
The test data began with a series of wind-on tare velocity sweeps in order to determine the drag effects of the power combination testing mount and motor-off propeller effects. This mount housed any of the combinations of motors, controller, batteries, and propellers. Then, selected motor combinations were tested at set wind tunnel velocities offering a range of estimated flight conditions. Appendix E, Wind Tunnel Propulsion Test Data, contains the examples of major test information used for further analysis of the TTB power system.

# Wind-on Tares for the Testing Mount and Propeller

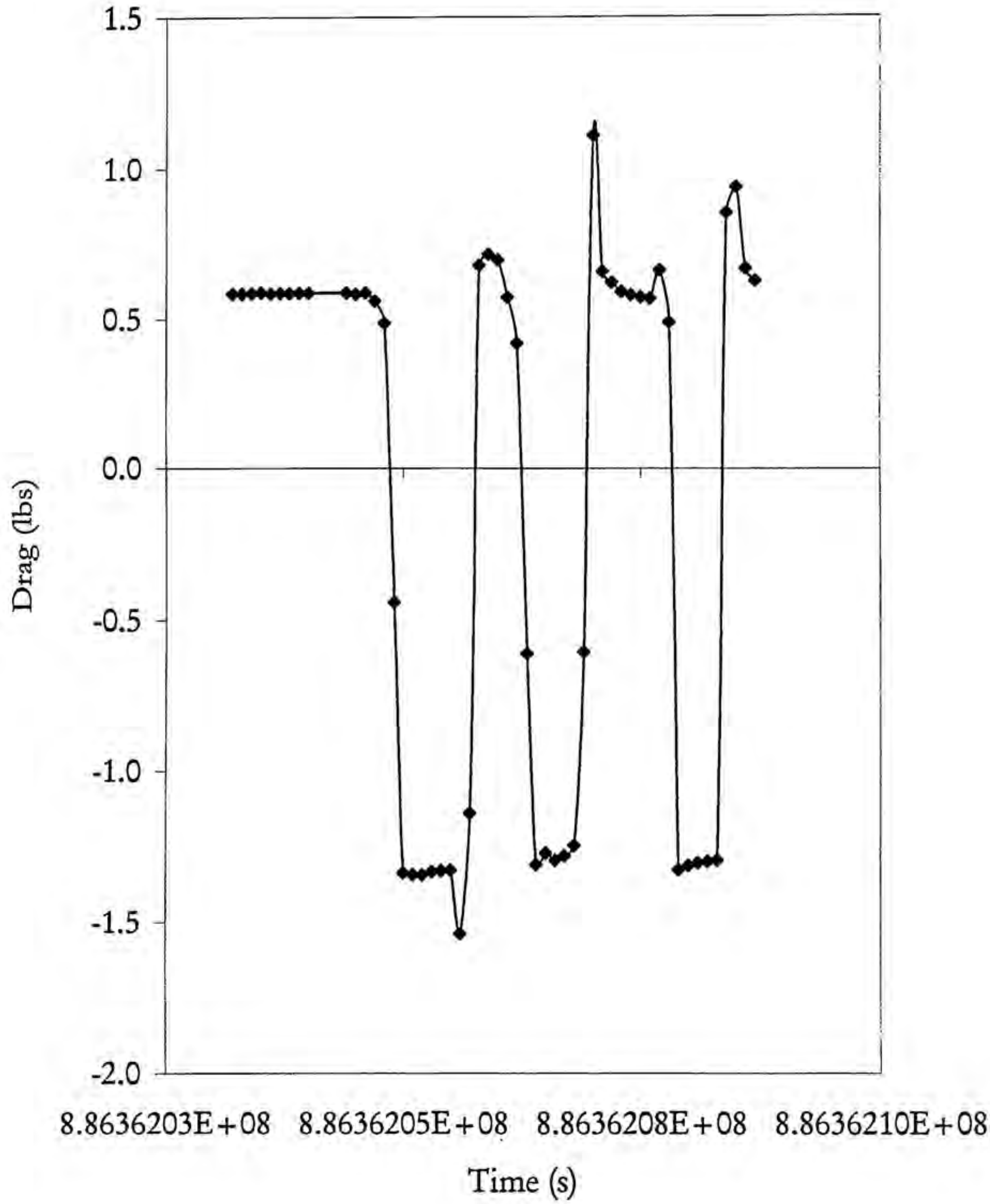


## 1412/3Y Power Combination Throttle Bursts at Wind Tunnel Speed of 0 ft/sec

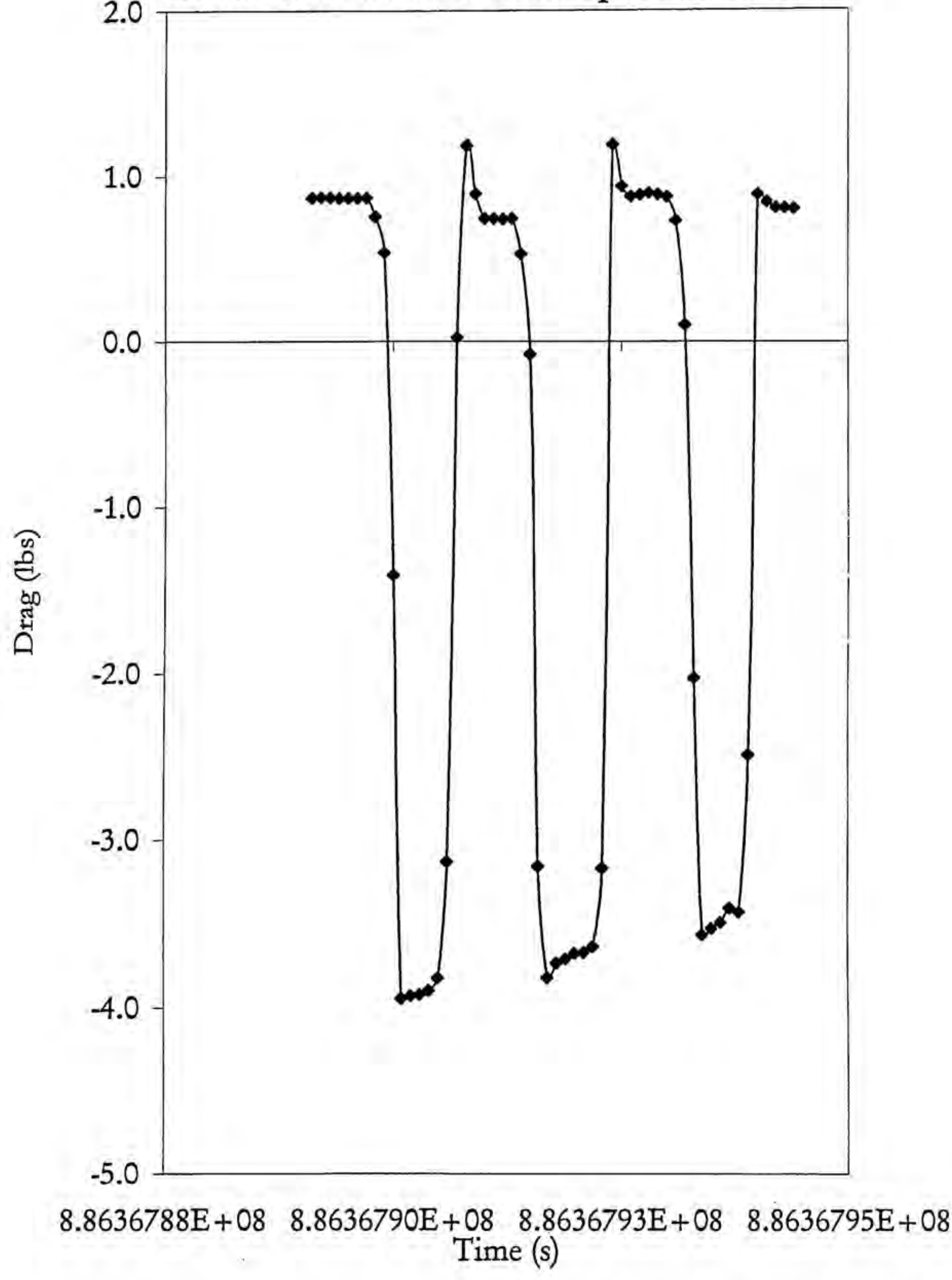


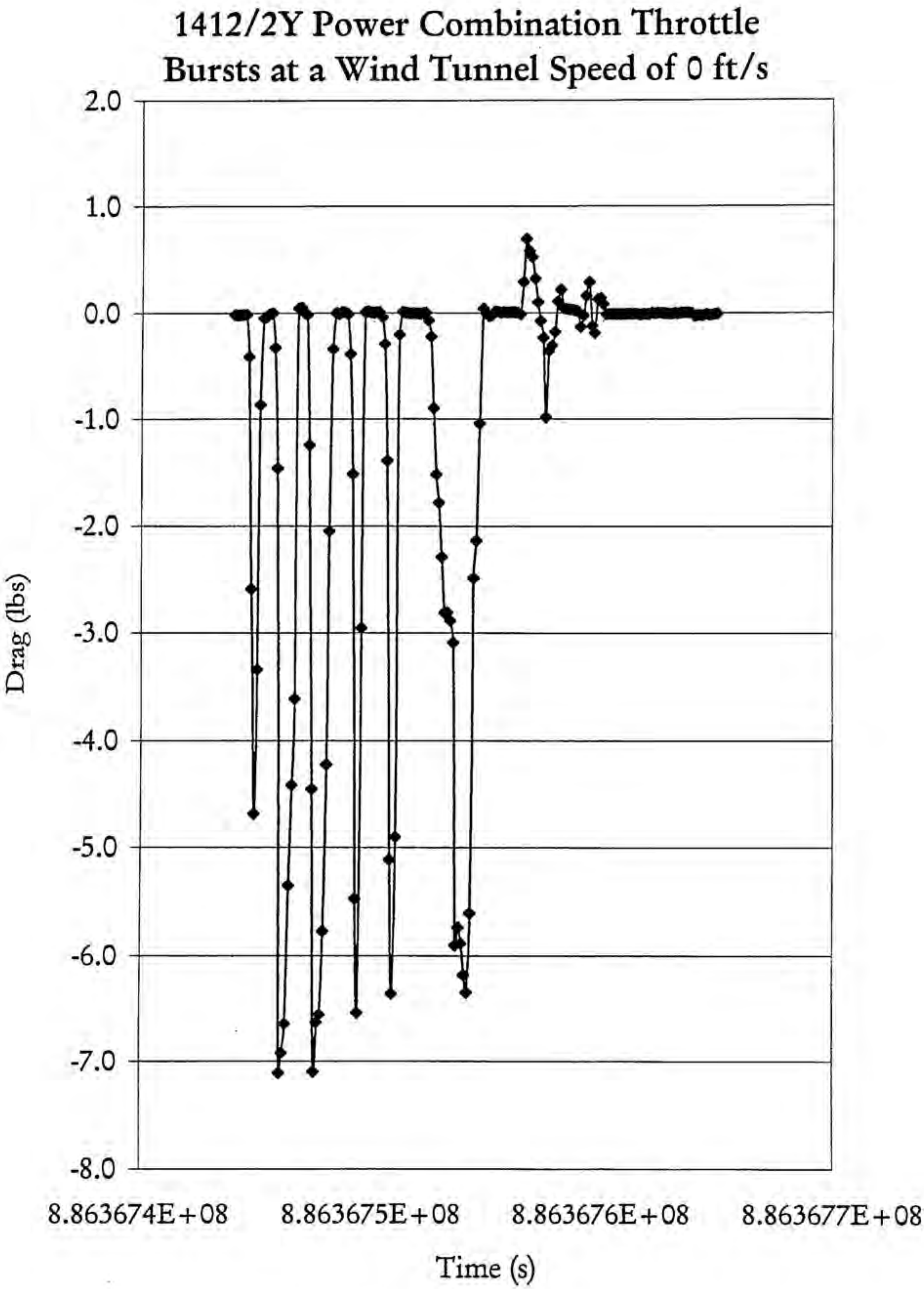

1412/3Y Power Combination Throttle Bursts (ft/s)
2.5
2.0
1.5
1.0
0.5
0.0
Force (lbs)
8.8636190E+08
8.8636195E+08
8.8636200E+08
Time (s)

## 1412/3Y Power Combination Throttle Bursts at Wind Tunnel Speed of 56 ft/s

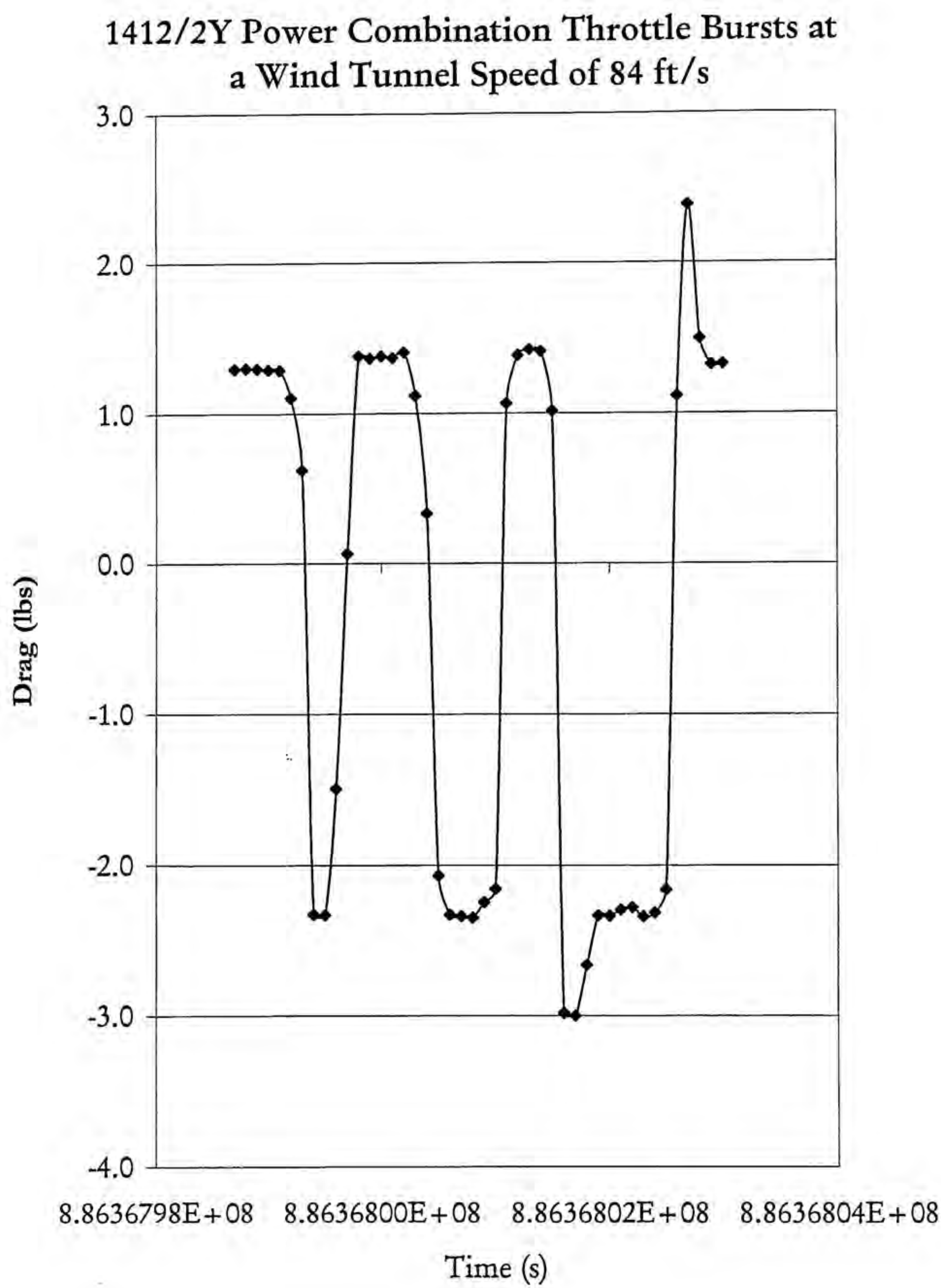


# 1412/2Y Power Combination Throttle Bursts at a Wind Tunnel Speed of 66 ft/s





1412/2Y Power Combination Throttle Bursts at a Wind Tunnel Speed of 0 ft/s
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
Drag (lbs)
8.863674E+08
8.863675E+08
8.863676E+08
8.863677E+08
Time (s)


1412/2Y Power Combination Throttle Bursts at a Wind Tunnel Speed of 84 ft/s
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
Drag (lbs)
8.8636798E+08
8.8636800E+08
8.8636802E+08
8.8636804E+08
Time (s)

# Appendix F

*Design Parameters for the Aggie Flyer*

## *Design Parameters for the Aggie Flyer*

### Geometry

#### Wing

| | |
|---|---|
| Wingspan: | 107.3 inches |
| Wing area: | 1152.0 square inches |
| Aspect ratio: | 10.0 |
| Taper ratio: | 0.45 |
| Airfoil: | R.A.F. 32, 12.9% thickness |
| Sweep: | 0 degrees at 30% chord |
| Dihedral: | None |

#### Horizontal Tail

| | |
|---|---|
| Span: | 28.5 inches |
| Area: | 169.2 square inches |
| Aspect ratio: | 4.80 |
| Taper ratio: | 0.667 |
| Airfoil: | Flat |

#### Vertical Tail

| | |
|---|---|
| Height: | 9.875 inches |
| Area: | 82.1 square inches |
| Aspect ratio: | 1.19 |
| Taper ratio: | 0.415 |
| Airfoil: | Flat |

#### Tail Moment Arms (from mean aerodynamic leading edge)

| | |
|---|---|
| To horizontal tail aerodynamic center: | 30.0 inches |
| To vertical tail aerodynamic center: | 27.0 inches |

#### Wing Incidence (relative to thrust line)

0 degrees

### Propulsion Systems

| | |
|---|---|
| Motor: | Aveox 1412/2Y |
| Motor Speed Controller: | Aveox F5HV |
| Power Battery Cells/Pack: | RC1700 SCR (19 cells) |
| Propeller/Yoke Combination: | Aeronaut 15 inch x 9.5 inch/5° |

### Aircraft Takeoff Weight

15 pounds, 1 ounce

# Appendix G

*Design Parameters for the Texas Tall Boy*

## *Design Parameters for the Texas Tall Boy*

### Geometry

#### Wing

| | |
|---|---|
| Wingspan: | 101.2 inches |
| Wing area: | 1024.0 square inches |
| Aspect ratio: | 10.0 |
| Taper ratio: | 0.45 |
| Airfoil: | Selig SA7038, 9.2% thickness |
| Sweep: | 0 degrees at 25% chord |
| Dihedral: | None |

#### Horizontal Tail

| | |
|---|---|
| Span: | 26.15 inches |
| Area: | 152.0 square inches |
| Aspect ratio: | 4.50 |
| Taper ratio: | 0.65 |
| Airfoil: | NACA 0010 |

#### Vertical Tail

| | |
|---|---|
| Height: | 9.23 inches |
| Area: | 70.9 square inches |
| Aspect ratio: | 1.20 |
| Taper ratio: | 0.33 |
| Airfoil: | NACA 0008 |

#### Tail Moment Arms (from mean aerodynamic leading edge)

| | |
|---|---|
| To horizontal tail aerodynamic center: | 30.0 inches |
| To vertical tail aerodynamic center: | 36.0 inches |

#### Wing Incidence (relative to thrust line)

2 degrees

### Propulsion Systems

| | |
|---|---|
| Motor: | Aveox 1412/2Y |
| Motor Speed Controller: | Aveox M60 |
| Power Battery Cells/Pack: | RC2000 SCR (19 cells) |
| Propeller/Yoke Combination: | Graupner 15 inch x 9.5 inch/0° |

### Aircraft Takeoff Weight

14 pounds, 8 ounces

# Appendix H

*Landing Gear Layup*

## Landing Gear Layup

All layers are unidirectional carbon fiber unless otherwise noted.

Angles are given relative to the forward edge of the landing gear.

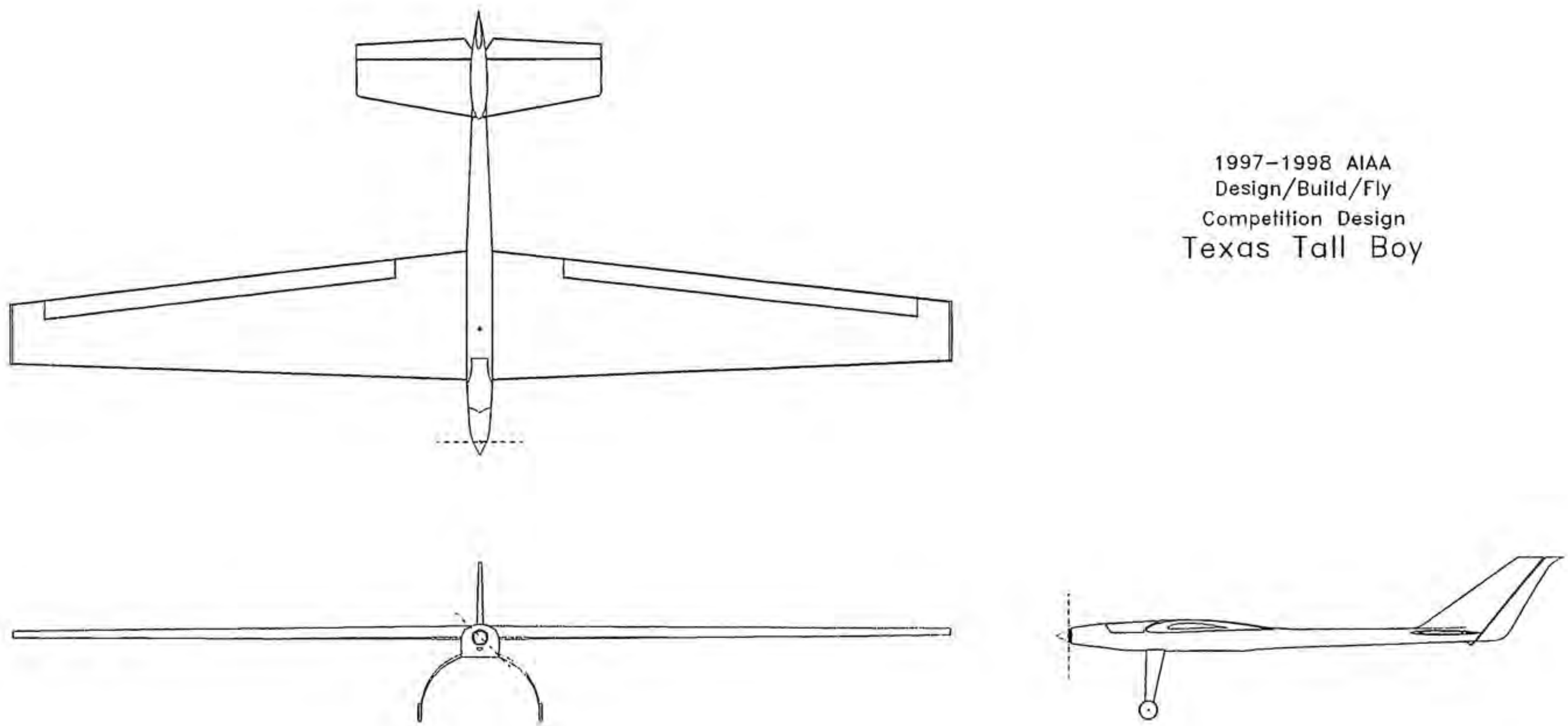
TOP

| | |
|---|---|
| 0 degrees | ---------------------------------------------------- |
| 0 degrees (short) | ---------------------------------------- |
| 0 degrees | ---------------------------------------------------- |
| 45degrees | \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\ |
| -45 degrees | //////////////////////////////////////////////////////////// |
| 0 degrees | ---------------------------------------------------- |
| 0 degrees | ---------------------------------------------------- |
| 1/16" balsa | ==================================== |
| 0 degrees | ---------------------------------------------------- |
| 0 degrees | ---------------------------------------------------- |
| -45 degrees | \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\ |
| 45 degrees | //////////////////////////////////////////////////////////// |
| 0 degrees | ---------------------------------------------------- |
| 0 degrees | ---------------------------------------------------- |

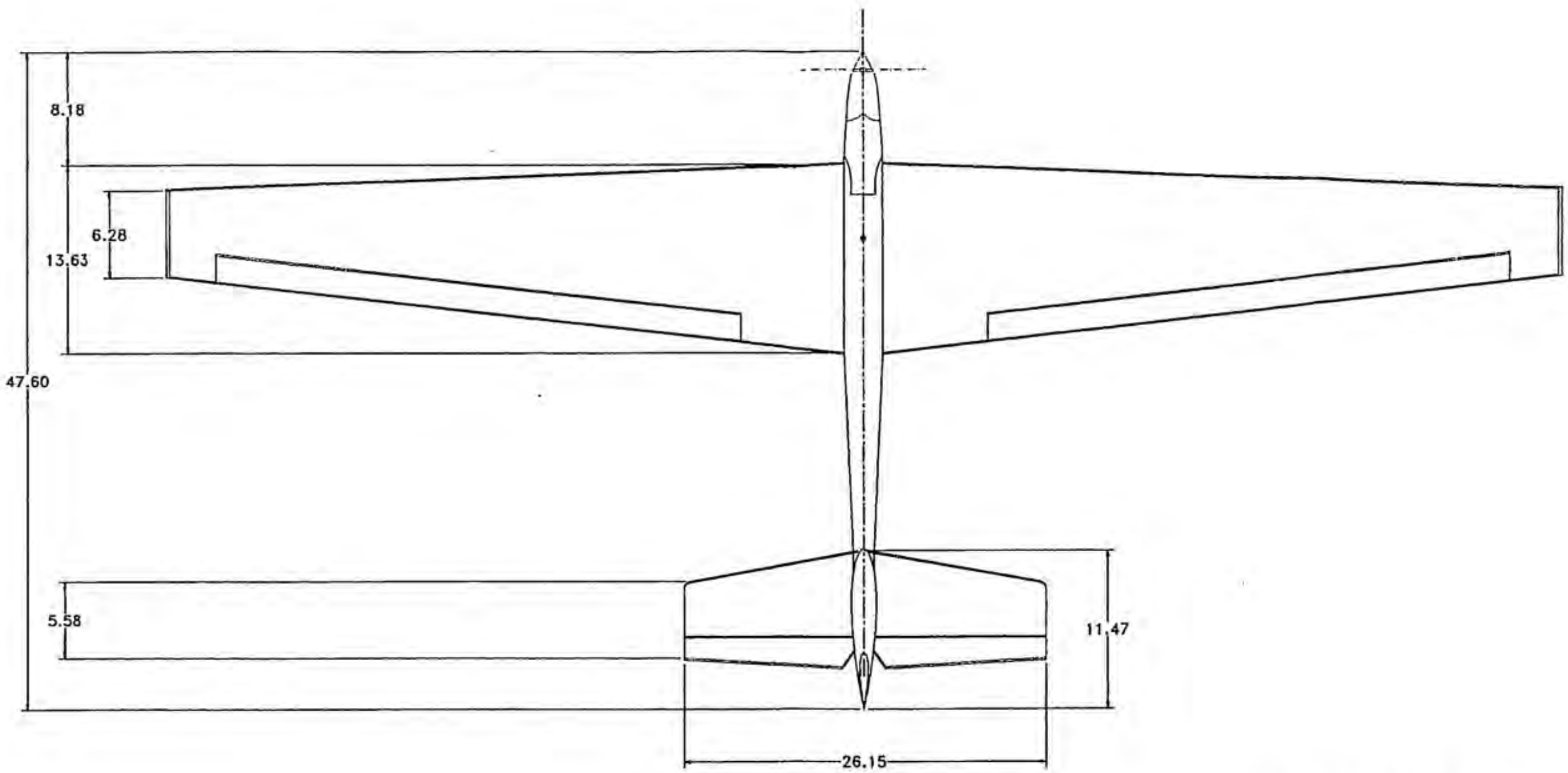
BOTTOM

# Appendix I

*Drawing Package for the Texas Tall Boy*

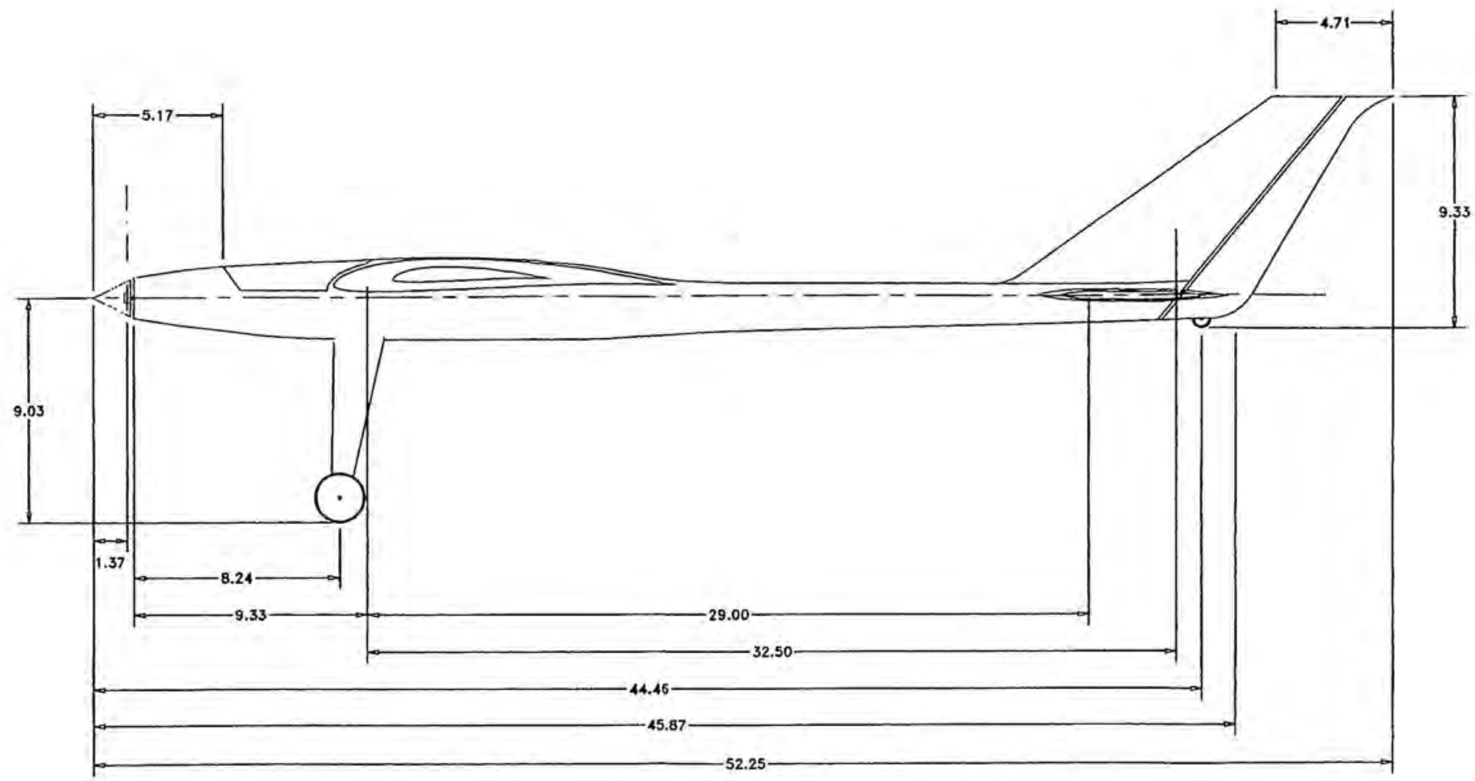


1997–1998 AIAA
Design/Build/Fly
Competition Design
Texas Tall Boy

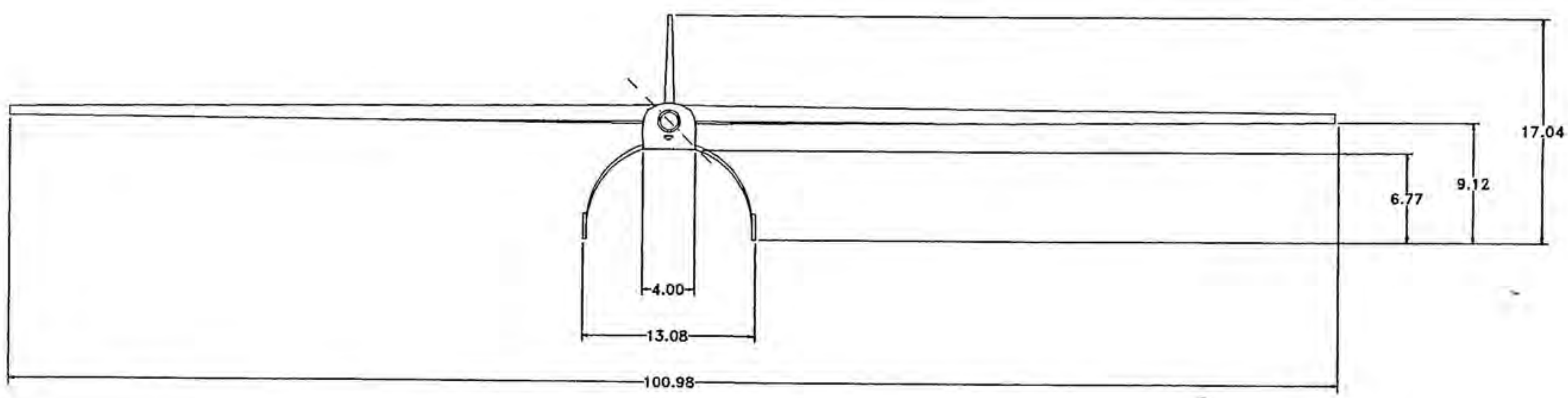



Texas Tall Boy
Dimensioned Top View

All Dimensions are In Inches

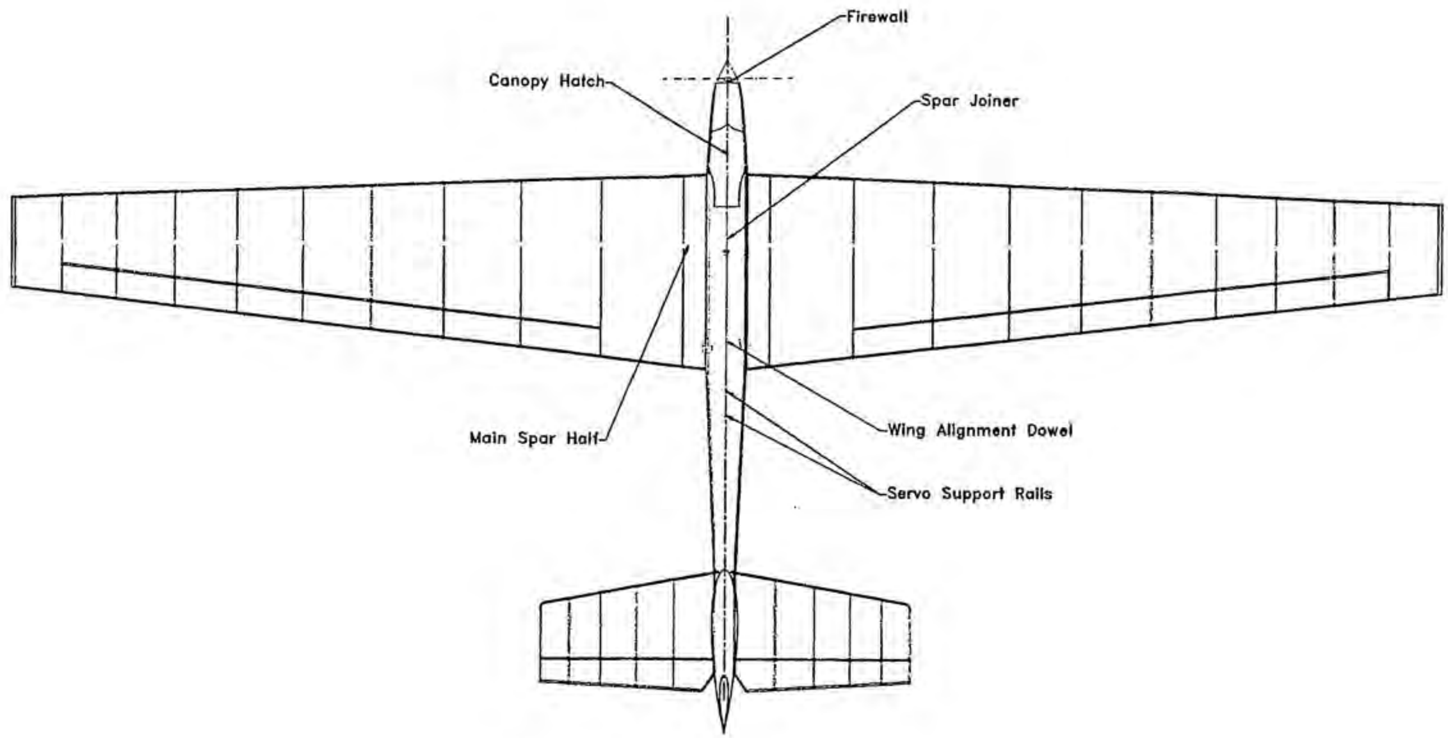



Texas Tall Boy
Dimensioned Side View



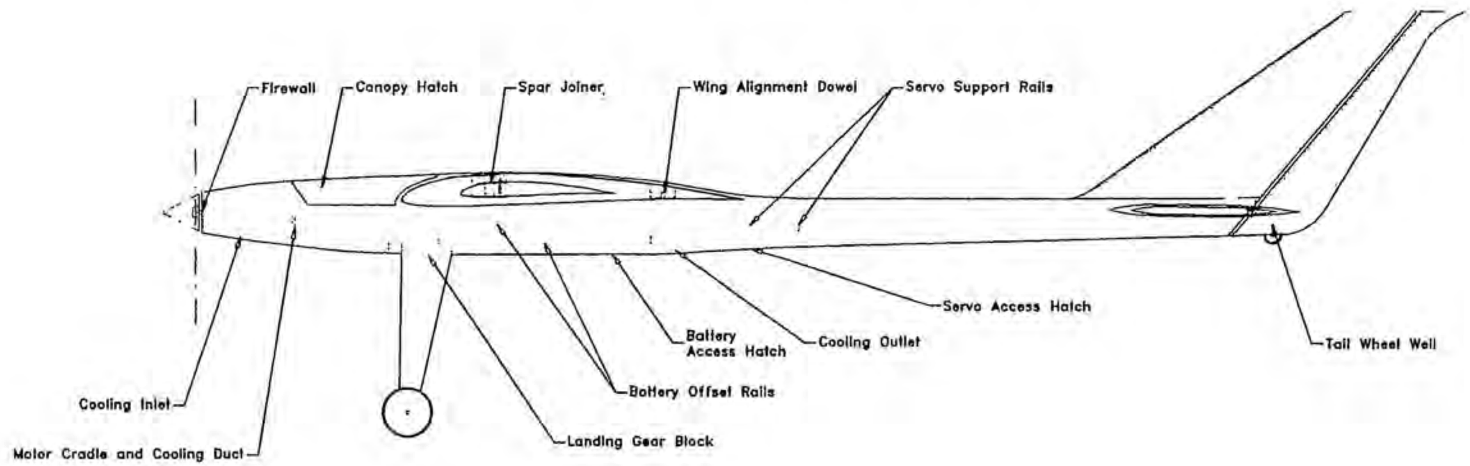

Texas Tall Boy
Dimensioned Front View

All Dimensions are in Inches

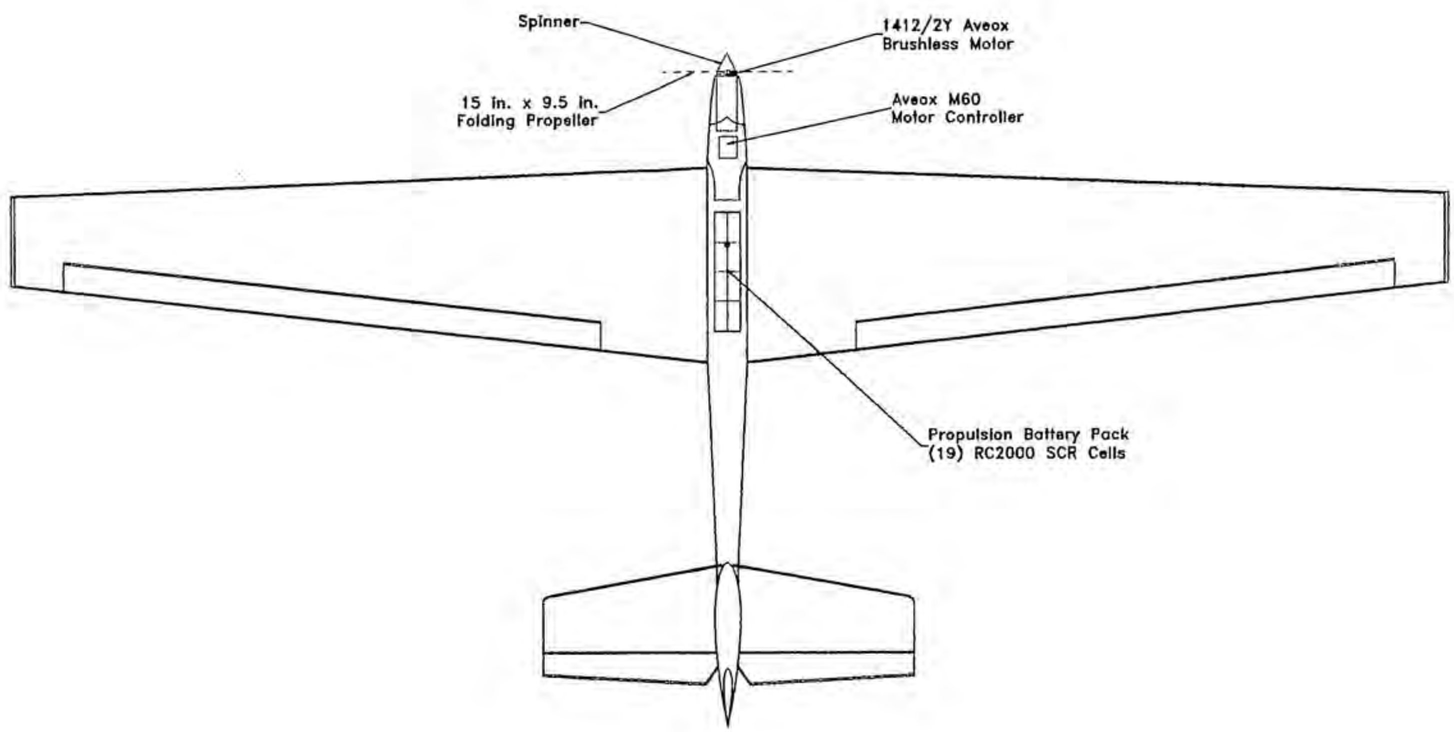



Texas Tall Boy Internal
Structure Top View

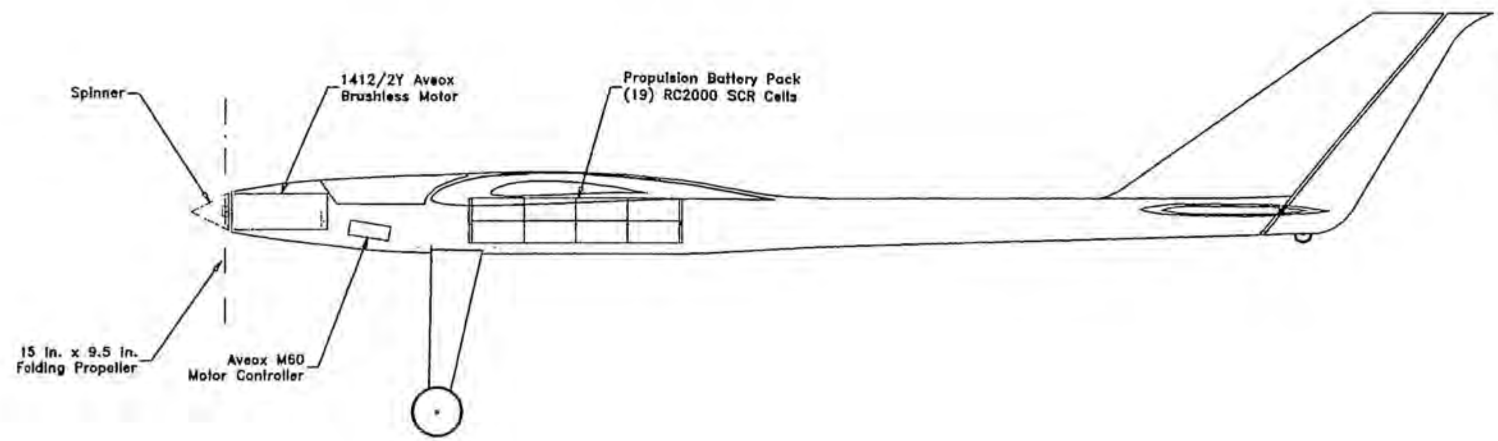
All Dimensions are in Inches



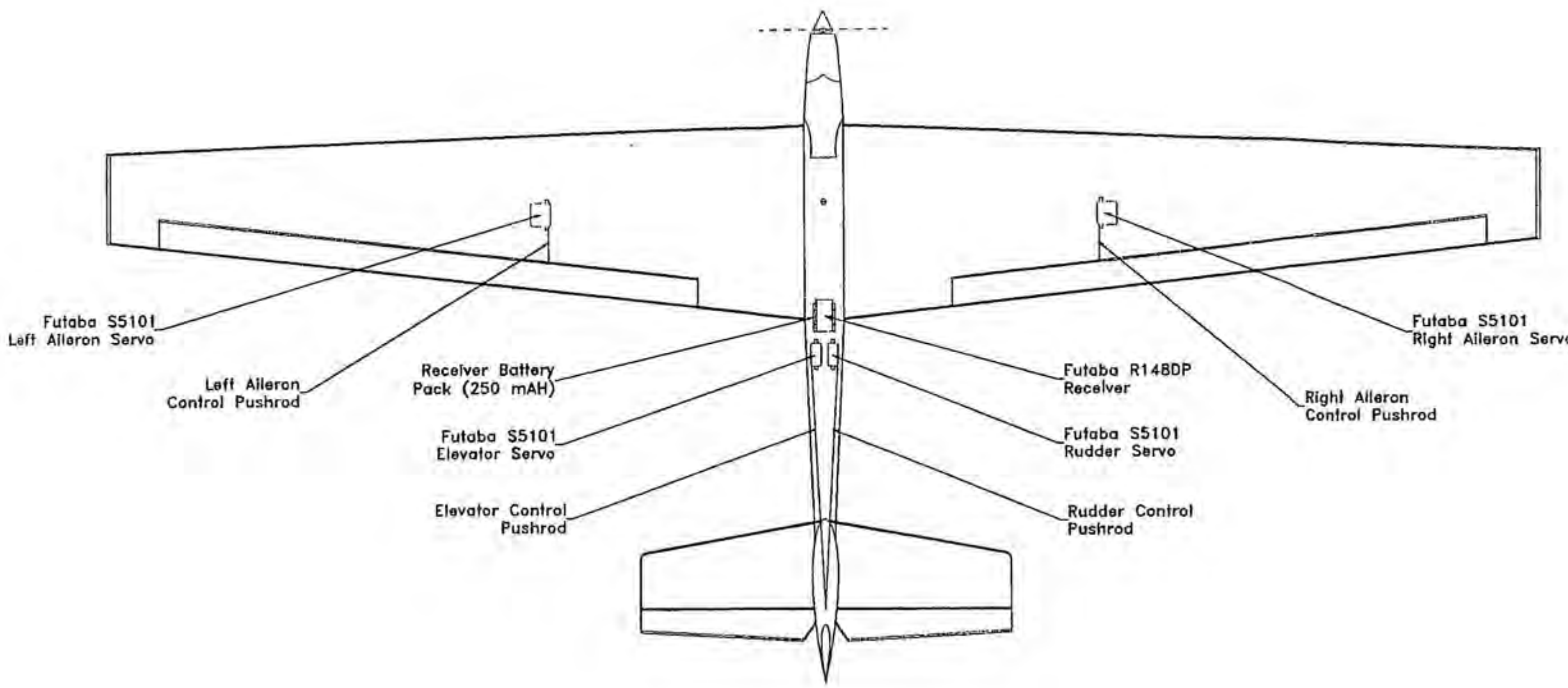

Texas Tall Boy Fuselage
Internal Structure Side View



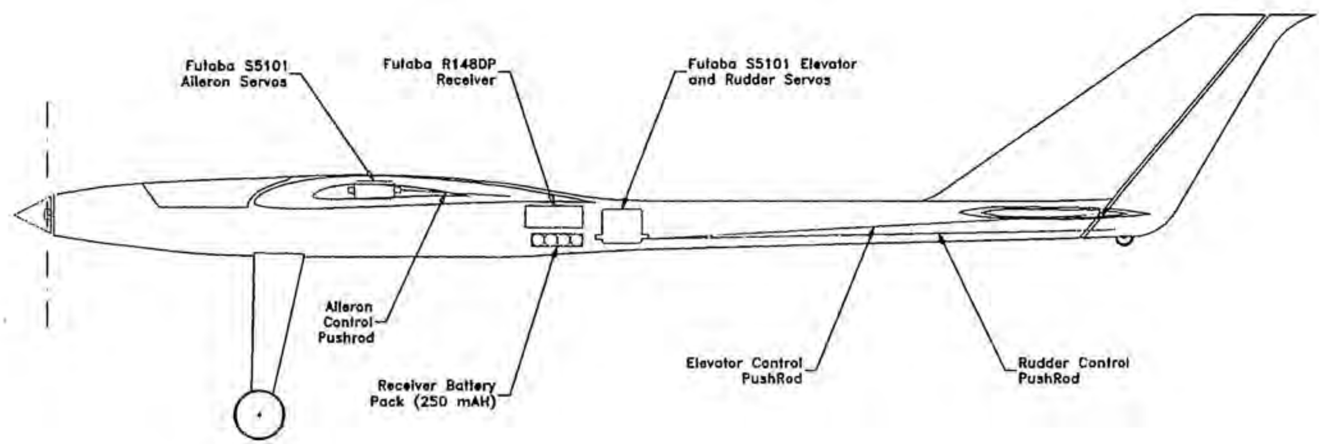

Texas Tall Boy
Propulsion System
Top View



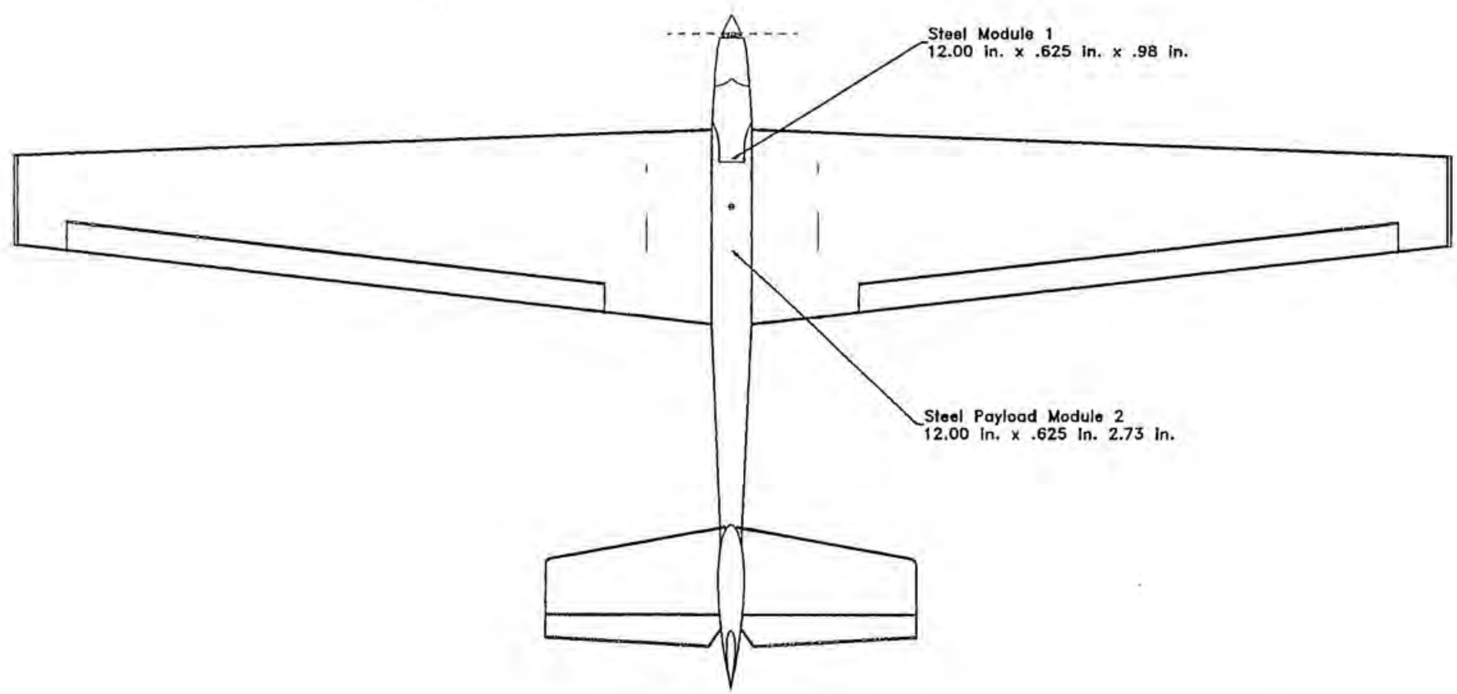

Texas Tall Boy Propulsion
System Side View



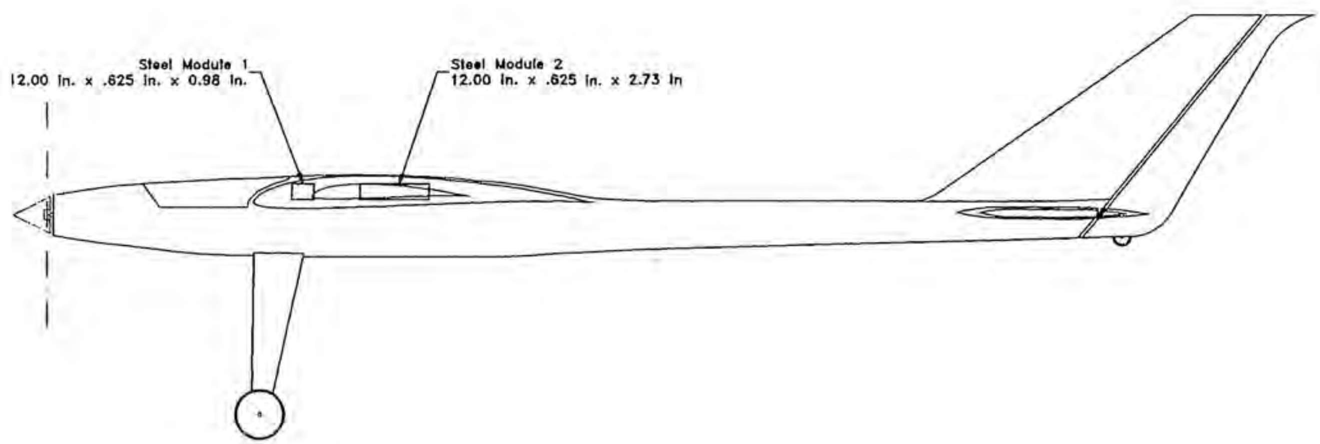

Texas Tall Boy Control
System Top View




Texas Tall Boy Control
System Side View




Texas Tall Boy
Payload Module
Location Top View

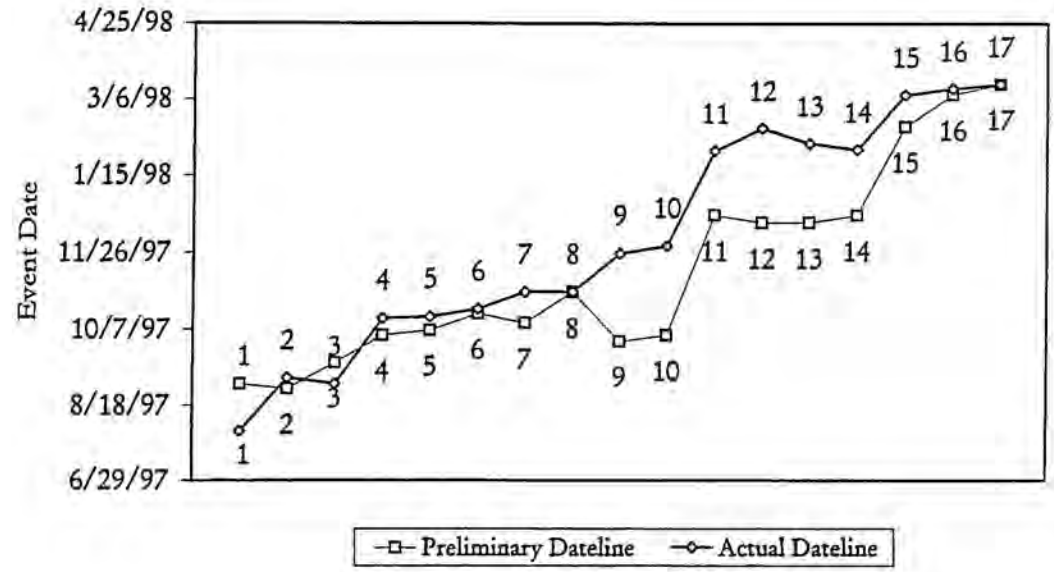



Texas Tall Boy Payload
Module Location Side View

# Appendix J

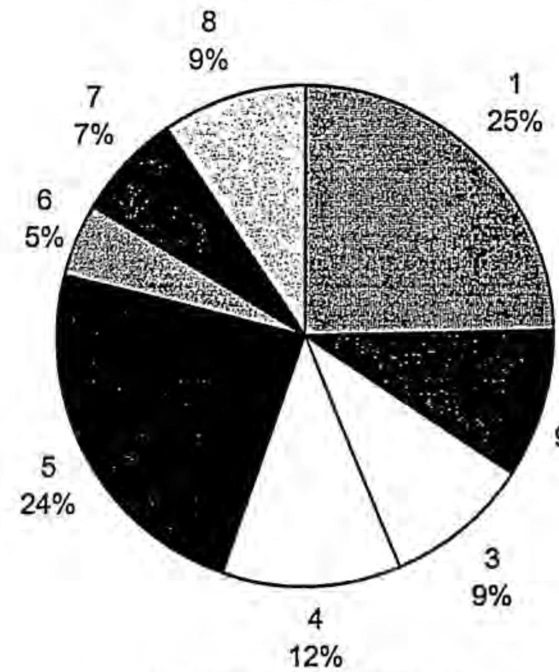
*Scheduled and Actual Timing of Major Events*

## Design and Development Milestone Completion Chart for the Texas Tall Boy




| | Event and Number | Scheduled Dates | Actual Dates |
|---|---|---|---|
| 1 | Conceptual Design Stage | 9/1/97 | 8/1/97 |
| 2 | Determine faculty advisor (Dr. Valasek) | 8/29/97 | 9/5/97 |
| 3 | Preliminary Design Stage | 9/15/97 | 9/1/97 |
| 4 | Submit list of materials for first model to faculty advisor | 10/3/97 | 10/14/97 |
| 5 | Order materials for first model | 10/6/97 | 10/15/97 |
| 6 | Send Notice of Intent to Compete, 1997-98 Contest Year | 10/17/97 | 10/20/97 |
| 7 | Wing Spar Testing | 10/11/97 | 10/31/97 |
| 8 | DUE DATE - Notice of Intent to Compete | 10/31/97 | 10/31/97 |
| 9 | Detailed Design Stage | 9/29/97 | 11/25/97 |
| 10 | General drawings of first model ready | 10/3/97 | 11/30/97 |
| 11 | Aircraft Construction | 12/20/97 | 1/31/98 |
| 12 | Research of Power Systems | 12/15/97 | 2/15/98 |
| 13 | Power System Testing | 12/15/97 | 2/5/98 |
| 14 | First flight of first model | 12/20/97 | 2/1/98 |
| 15 | Proposal Phase of written report preporation | 2/16/98 | 3/9/98 |
| 16 | Send in 5 copies of Proposal Phase of written report | 3/9/98 | 3/13/98 |
| 17 | DUE DATE - Proposal Phase of written report | 3/16/98 | 3/16/98 |
| 18 | First flight of second model | 3/14/98 | – |
| 19 | Determine changes for second model | 1/12/98 | – |
| 20 | Submit list of materials for second model to faculty advisor | 1/16/98 | – |
| 21 | Order materials for second model | 1/19/98 | – |
| 22 | Have general drawings of second model ready | 1/26/98 | – |
| 23 | Start construction of second model | 1/26/98 | – |

Manufacturing Milestone Completion
Chart for the Texas Tall Boy



Divisions by Manufacturing Event

| | Event and Number | Stating Date | Completion Date | Estimated Time Yeilded (hours) |
|---|---|---|---|---|
| 1 | Wing Panels | 11/20/97 | 12/28/97 | 105 |
| 2 | Landing Gear Construction | 12/18/97 | 12/23/97 | 40 |
| 3 | Empennage Surfaces Without Control Surfaces | 12/23/97 | 12/28/97 | 40 |
| 4 | Control Surfaces | 12/29/97 | 1/11/98 | 50 |
| 5 | Fuselage | 1/5/98 | 1/11/98 | 100 |
| 6 | Final Assembly - Component Joining | 1/12/98 | 1/18/98 | 20 |
| 7 | Entire Airframe Covering | 1/19/98 | 1/25/98 | 30 |
| 8 | Installation of propusion, control and radio systems | 1/26/98 | 1/30/98 | 40 |
| | Complete Aircraft Construction | 11/20/97 | 1/30/98 | Total = 425 |

# Appendix K

*Component Weight Breakdown*

## *Systems Architecture*

### Propulsion System

| | |
|---|---|
| Aveox 1412/2Y motor: | 10.6 oz |
| Aveox M60 speed control: | 1.5 oz |
| Propulsion battery pack: | 39.5 oz |

### Control System

| | |
|---|---|
| Futaba R148DP receiver: | 1.1 oz |
| Receiver battery pack: | 2.0 oz |
| Futaba S5101 servo (elevator): | 1.5 oz |
| Futaba S5101 servo (rudder): | 1.5 oz |
| Futaba S9602 servo (aileron): | 1.1 oz |
| Futaba S9602 servo (aileron): | 1.1 oz |

### Airframe

| | |
|---|---|
| Fuselage with tail surfaces: | 8.4 oz |
| Fuselage hatches and access panels: | 2.2 oz |
| Wing joiner: | 1.2 oz |
| Right wing panel: | 8.3 oz |
| Left wing panel: | 8.3 oz |
| Right aileron: | 1.2 oz |
| Left aileron: | 1.2 oz |
| Elevator: | 0.8 oz |
| Rudder: | 0.4 oz |
| Landing gear: | 3.4 oz |
| Main wheels: | 1.2 oz |
| Tail wheel: | 0.2 oz |

**Total*** (without payload)

7 pounds, 0 ounces

*The total weight of the aircraft includes the covering material and miscellaneous hardware.

# AIAA Student Design/Build/Fly Competition

# The Texas Tall Boy

**Addendum Phase**

Designed and developed by:

Robert "Rip" Rippey III

M. Shea Parks

Kendrah S. Smith

David Sellmeyer

Texas A&M University, College Station, Texas

April 13, 1998

# AIAA Student Design/Build/Fly Competition

# The Texas Tall Boy

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April 13, 1998

# Table of Contents

# 7. Lessons Learned

## *7.1. Final Contest Aircraft vs. Proposal Design*

Experience from the 1996-1997 AIAA Design/Build/Fly Competition allowed the team to produce an aircraft that was identical to the Proposal design aircraft. Since the Texas Tall Boy was a derivative of the Aggie Flyer, the aircraft construction proceeded smoothly according to what the team had planned.

## *7.2. Areas of Improvement*

There were some areas of the Texas Tall Boy design and competition aircraft that could be improved in order to develop a next generation aircraft. After a period of flight testing, two primary types of possible alterations were discovered. They were changes in the structural design and sizing as well as improvements in the manufacturing process.

### 7.2.1. Changes in the Aircraft Structure

There were only a few changes that could be made for the TTB in terms of all around sizing and structural design. There was not any need for changes concerning the wing configuration. It was still felt that the most efficient configuration for the AIAA DBF competition was a conventional fixed wing aircraft. However, flight testing showed that directional control decreased substantially with low airspeeds. With the Texas Tall Boy fully loaded, the stall speed was high enough that this was not a problem. At low airspeeds, the unloaded aircraft would occasionally lose directional control and enter a short-lived spin.

The Texas Tall Boy flew well at its design weight, but the sizing of the vertical tail could be altered in order to improve the stability and handling qualities of the aircraft while flying without the payload. Through a great deal of flight time and pilot familiarization, it was decided that a larger vertical tail would be more desirable when flying without the full payload.

Such simple modifications of the airframe would require no additional time to incorporate into a next-generation design of the TTB. The actual size of the vertical tail has not been fully determined, but the amount of time that it would take for the development of the size change would be minimal. The majority of time would be in the research and investigation of the sizing, as opposed to the additional amount of manufacturing time required. The new design process would not be any more time intensive than the process allotted previously for the construction of TTB. Monetary costs of the development would also be minimal. This is due to the idea that the same materials and methods of construction would be used for any changes.

### 7.2.2. Changes in the Landing Gear Design

A derivative of the Texas Tall Boy would also have an improved landing gear. The ten degrees of camber built into the main gear proved to be too much since it put excessive loads on the wheels during landing. It was estimated that with less than five degrees camber, the wheels would be subjected to loads closer to the plane of the wheel. This amount of camber would also be enough to prevent ground loops on landing.

### 7.2.3. Changes in the Manufacturing Process

Changes in the manufacturing process are also minimal. Since the primary constructor of the TTB was highly skilled and had knowledge of the most efficient building methods, little was examined for improvement. The only improvement in the manufacturing process would involve the installation of the carbon joiner tube in the wing. The initial wing construction used a method of placing the joiner tube directly behind the shear webbing connecting the top and bottom spars. It was learned that a simpler structure could be used to accommodate the joiner tube. This alteration would be to add the spar joiner tube between the top and bottom spars before the shear webbing is applied. There would be no additional cost involved in implementing this modification, while the time used for incorporating the joiner would actually be reduced.

## *7.3. Manufacturing and Component Price Lists*

Lists of components and their prices are given in Appendix L. The items are separated according to the airframe, propulsion system, control system, and ground support. Of these, the propulsion system was the most costly area of the Texas Tall Boy. This was due to the fact that the TTB incorporated technology that is relatively new and expensive. The design utilized both a brushless motor and a microprocessor speed controller.

Since this was the second time that Texas A&M University entered the AIAA Design/Build/Fly competition, the Texas Tall Boy was able to incorporate many of the components used in the previous years Aggie Flyer. For example, some of the components used in the 1996-1997 competition for the propulsion system, control system, and ground support were also used for the 1997-1998 competition. These items are marked in the appropriate tables of Appendix L.

The total cost for the Texas Tall Boy came to $ 2030.57. However, excluding the reused components, the additional cost in order to produce the TTB was only $ 913.07.

# Appendix L

*Manufacturing and Component Price Lists*

## Airframe

| Component | Cost (each) |
|---|---|
| **Wood for airframe** | $ 35.00 |
| **Wing spar joiner** | $ 20.00 |
| Kennedy Composites | |
| **Wing spar joiner tubes (2)** | $ 20.00 |
| Kennedy Composites | |
| **Wheels** | $ 6.95 |
| Performance Specialties speed wheels | |
| **Covering material (4 rolls, 6 feet each)** | $ 11.99 |
| TopFlite Monokote | |
| **Adhesives** | $ 20.00 |
| **Miscellaneous hardware** | $ 20.00 |
| (hinges, control horns, clevices, screws, etc.) | |
| **Subtotal** | **$ 189.91** |

## Propulsion System

| Component | Cost (each) |
|---|---|
| **Motor*** | $ 184.76 |
| Aveox 1412/2Y Brushless Motor | |
| **Speed control** | $ 219.96 |
| Aveox M60 | |
| **Gearbox*** | $ 116.95 |
| Robbe 3.7:1 Planeta gearbox | |
| **Battery pack** | $ 181.05 |
| New Creations NC19N2000 | |
| **Propeller/Spinner** | $ 61.51 |
| Graupner 15 x 9.5 carbon folder | |
| **Propeller yoke** | $ 9.72 |
| **Subtotal** | **$ 773.95** |

*reused from the 1996-1997 AIAA DBF competition

| Control System | |
|---|---|
| Component | Cost (each) |
| **Radio*** | $ 439.99 |
| Futaba 8UAP 8 channel PCM | |
| **Aileron servos (2)** | $ 89.99 |
| Futaba S9203 coreless, ball-bearing | |
| **Elevator and rudder Servos (2)*** | $ 54.99 |
| Futaba S5101 ball-bearing | |
| **Receiver battery pack** | $ 16.99 |
| Futaba 250 mAh | |
| **Subtotal** | **$ 746.94** |

*reused from the 1996-1997 AIAA DBF competition

## Ground Support

| Component | Cost (each) |
|---|---|
| **Propulsion battery charger*** | $ 164.95 |
| Astro 112D Digital Charger 1-36 cell | |
| **Source for propulsion battery charger*** | $ 42.93 |
| Heavy Duty Marine Battery | |
| **Source battery charger*** | $ 57.94 |
| **Digital ammeter** | $ 53.95 |
| **Subtotal** | **$ 319.77** |

*reused from the 1996-1997 AIAA DBF competition

| Total Cost | |
|---|---|
| Category | Subtotals |
| Airframe | $ 189.91 |
| Propulsion System | $ 773.95 |
| Control System | $ 746.94 |
| Ground Support | $ 319.77 |
| Total | $ 2030.57 |

# PROPOSAL FOR THE DESIGN OF AN UNMANNED AIR VEHICLE

*Prepared for Gregory Page*

*Submitted 16 March 1998*

*by the Syracuse University Chapter of the American Institute of Aeronautics and Astronautics*


*Design Team Members:*

*Kevin Bendowski*

*Kevin Bishop*

*Nick Borer*

*Marc Brock*

*Jarrod Cafaro*

*Arun Chawan*

*Garvin Forrester*

*Tom Jones*

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# 1. EXECUTIVE SUMMARY

## 1.1 Development

In September of 1997, several members of the Syracuse University chapter of the American Institute of Aeronautics and Astronautics met to discuss the possibility of competing in the 1997-1998 Cessna/ONR Design/Build/Fly competition. Some of the members, who competed in the previous year's contest, came forward to heap praise upon it. After some discussion, many of the members decided to commit themselves to the new project, and many of those members have remained committed in the months since.

The design of any aircraft, whether it be a small radio-controlled model or an enormous cargo jet, involves many first steps. The basic concept must be determined before work is done on specific sections of it. This process, referred to as conceptual design, occupies the intellect of the assembled group until a consensus is reached among them. In the Syracuse University design team, this process took approximately two months.

In this two month span, many alternative ideas were expressed for the overall configuration of the UAV (unmanned air vehicle). These ranged from general propulsion requirements to wing shape. Some ideas were dismissed outright due to knowledge of the situation, but most required further thought and research. Much of this time was spent either meeting as a group or researching various concepts. Once the ideas had been narrowed down, detailed research began, resulting in team-wide debates. As more information became available, the same picture of the UAV began to circulate through the teams' collective head.

Since the motor was arguably what the aircraft needed to be designed around, a specific type needed to be chosen. Doing this would form the basis of the calculations necessary for preliminary design. Thus, before the end of the Fall Semester, the electronic components of the UAV were chosen and ordered, so preliminary design could start at the beginning of the next semester.

The next month was spent calculating the performance and dimensions of the aircraft, based upon the results of the conceptual design phase. At the end of this period, the team had a good idea as to how much the UAV would weigh, as well as its linear dimensions. These figures paved the way for the detailed design phase that followed.

In detailed design, the UAV was drawn up on a CAD program with the dimensions specified from preliminary design. Its performance and handling characteristics were also determined from the aforementioned data. While the data was being scrutinized, other team members discussed the materials that would comprise the aircraft's fuselage, boom, empennage, and wing. Members who advocated different materials again returned to research, and discussions ensued. It was at this point that the materials were priced, selected, and ordered in sufficient quantity to construct the aircraft.

Once the parts arrived, construction began. This was the last major phase started before the design report was submitted. Following the completion of the UAV, flight testing will occur to ensure that the design will perform to standards.

## 1.2 Design Tool Overview

The use of dedicated design tools was essential to the completion of the UAV. As a result, a vast array of resources were tapped to complete the various design phases.

For conceptual design, the tool utilized most often was the Internet. It proved to be an invaluable asset in the research of various propulsion systems, and was helpful in securing information on aircraft configurations. Every aspect of this phase was, in some way, connected to it. Indeed, it was on the Internet that the data for the brushless motor were found and utilized. The AVEOX home page included a "static test stand" to test the thrust and current draw of various motors connected with different propeller sizes and pitches. This was very helpful in providing information as to which motor to buy, as well as the base information of the preliminary design phase.

Research was not limited to the Internet. Configurations of full-size aircraft were sought through books such as Jane's all the World's Aircraft, as well as others. Specialty books on radio-controlled aircraft provided answers when Internet research did not. As powerful a tool as the Internet is, it is sometimes hard to beat what the local library has to offer.

For the preliminary design stage, more advanced design tools were necessary to obtain meaningful results. Many of the desired results required iterative solutions, so the most efficient way to get answers was to write computer code. Most of the coding was done using C++, and checked by a simple mechanical process using MATCHAD software. Spreadsheet work was extensively used in predictions and comparison, and EXCEL was the choice program. Text on aerodynamic design and performance were invaluable as well. The two main books used were Aerodynamics, Aeronautics, and Flight Mechanics by Barnes McCormick, and Introduction to Flight, by John Anderson.

The final detail design relied mostly on the use of EXCEL, since estimations of performance were strictly formula based. A motor prediction program called MOTOCALC was used to predict the behavior of electric powered motors on an aircraft.

# 2. MANAGEMENT SUMMARY

## 2.1 Design Team

The number of people actively involved in the design team has decreased since the letter of intent was sent last October. There are currently eight members of the Syracuse University chapter of the AIAA involved with design and production of this UAV. Garvin Forrester and Marc Brock, both seniors, contributed their considerable knowledge in the field of aeronautics. AIAA chapter president and team leader Kevin Bendowski, a junior, gave both his experience gained with radio-controlled aircraft and of last year's competition to the team. Tom Jones, also a junior, proved to be a valuable asset due to his knowledge of composite materials and of computerized stress analysis tests. Sophomore Arun Chawan applied lessons learned in last year's competition to the current design. Sophomores Nick Borer and Jarrod Cafaro, as well as freshman Kevin Bishop, added their problem-solving skills and basic know-how to the team. Dr. Hiroshi Higuchi, AIAA chapter faculty advisor, lent his talents to the mix of students.

## 2.2 Management Structure

Specific aspects of the UAV design were delegated to specialized design teams. Obviously, those with more experience in a given field were assigned to that corresponding area. For example, the seniors of the team (who have the most experience in aircraft design) provided the dimensions of the aircraft, as well as its performance characteristics. The list of team assignments are given in Table II-I.

| Assignment | Team members |
|---|---|
| Sizing & Performance Characteristics | Forrester, Brock |
| Wing & Empennage Design | Forrester, Brock, Bendowski, Chawan |
| Fuselage Design & Component Placement | Jones, Borer, Cafaro, Bishop |
| Fuselage Material Selection | Jones |
| CAD Drawings: Wing & Empennage | Chawan |
| CAD Drawings: Fuselage | Chawan, Bishop |

**Table II-I.** *Team Member Assignments*

Timing was essential to the team's readiness. At the beginning of the project, team members came up with a schedule or "milestone chart" (Table II-II). This chart was used as a guide to keep the project on track. The detailed design took longer than anticipated; therefore, the project was delayed for more than a month. This, in turn, delayed the design proposal, but that time was almost made up for in the end due to the efforts of the team members.

| Item | Proposed Date | Actual Date |
|---|---|---|
| Letter of intent submitted | 10/22/97 | 10/26/97 |
| Conceptual design complete | 12/1/97 | 12/9/97 |
| Electronic components ordered | 12/16/97 | 12/9/97 |
| Preliminary design complete | 1/20/98 | 2/5/98 |
| Detailed design complete | 1/31/98 | 3/5/98 |
| All materials ordered | 2/6/98 | 3/6/98 |
| Design proposal complete | 3/8/98 | 3/12/98 |
| Design proposal submitted | 3/10/98 | 3/13/98 |
| Construction complete | 3/28/98 | TBA |
| Flight testing | 3/29/98 | TBA |

**Table II-II.** *Milestone Chart*

# 3. CONCEPTUAL DESIGN

## 3.1 Design Parameters

Deciding the basic concept for the UAV was the first major hurdle on the path to its completion. In this initial phase of the project, the design team met once a week to discuss various ideas that would pertain toward a particular facet of the aircraft. Ideas were given, discussed, and either rejected outright or left for later discussion. In this fashion, the basic concepts for propulsion, fuselage shape, and wing configuration were born. These basic concepts trickled down to others, such as the number of motors required. The concepts were discarded or adopted based on the general knowledge of team, and, when necessary, further research was made into the matter.

Propulsion was the first item considered, since it had the most number of limiting factors (according to the rules). These include the type (electric), the weight of the power source (no more than 2.5 pounds, or about 20 cells), and the endurance (seven minutes of flight plus a reserve). From these limiting factors, the team concluded that a powerful and efficient electric motor was necessary to be competitive. Another consideration was how the motor choice would effect the design of the internal structure of the aircraft. Weight and cost completed the figures of merit (FOMs) required in motor selection. Table III-I shows a comparison of motor configurations versus the various FOMs.

First considered was the use of a direct drive standard electric motor connected to an external propeller. As this was used on last year's UAV, some of the team members were able to list the good and bad qualities of this configuration. It was powerful, yet it drew too much current, limiting the endurance of the aircraft. Thus, this configuration failed the efficiency test, yet passed the power test. However, these motors are the cheapest of the lot.

Next a direct drive brushless electric motor connected to an external propeller was considered. It was discovered through research that brushless motors could be as powerful as their brushed counterparts, yet not draw as much current. Power could also be increased by combining the motor with a gearbox, at little cost in current draw. Therefore, the brushless electric motor with a gearbox passed both the power and efficiency tests. The only drawback seemed to be the higher cost.

The next idea was to utilize an electric ducted fan to propel our UAV. Essentially, a ducted fan is a direct drive electric motor connected to an internal propeller. The amount of thrust provided through such a configuration was in question, however, and it would complicate the design of the airframe. The more powerful ducted fans drew quite a bit of current. Ducted fans were also quite expensive.

After direct drive motors, belt-driven electric motors connected to an external propeller were considered. The main concern was that the belt would be susceptible to slipping, which would reduce the power of the aircraft. Also, a belt could break, robbing the UAV of thrust completely. The only redeeming quality of a belt-driven motor was the lower RPM the motor would need to acquire.

The use of multiple motors was the final consideration. This would increase power, but would also increase weight, drag, and current draw. This would result in a more powerful aircraft, but at the expense of endurance. Also, this would be quite an expensive undertaking, doubling the cost of the motor chosen, while not doubling the amount of thrust.

| Type | Power | Efficiency | Cost | Weight | Ease of Design | Total |
|---|---|---|---|---|---|---|
| Standard Electric Motor | 3 | 2 | 4 | 3 | 4 | 16 |
| (With Belt Drive) | 3 | 1 | 3 | 3 | 3 | 13 |
| Brushless Electric Motor | 3 | 4 | 3 | 3 | 4 | **17** |
| (With Belt Drive) | 3 | 3 | 2 | 3 | 3 | 14 |
| Ducted Fan | 3 | 3 | 2 | 3 | 1 | 12 |
| Multiple Motors | 4 | 2 | 1 | 1 | 2 | 10 |

4-Excellent 3-Good 2-Fair 1-Poor

**Table III-I.** ***Propulsion FOMs***

Once the team had decided what would power the aircraft, the fuselage configuration was looked into. Considerations (and thus the FOMs used) were weight, drag, strength, and ease of manufacture. At this stage, the team opted not to take material into consideration.

The design team decided to approach the fuselage from a "minimalist" point of view. In doing so, the fuselage would have as small a cross-sectional area as possible, while still containing all of the necessary components: the motor, batteries, speed controller, servos, weights, and the radio receiver. The empennage would be attached to the main body of the fuselage with a boom or booms. This would reduce both weight and drag.

This decision left few options. The body could be rectangular or cylindrical, and attached to the tail using one or two booms. The rectangular body would be easier to manufacture, but would do so at a cost of extra drag, and perhaps extra weight as well. A cylindrical body would be a bit harder to manufacture, but would reduce drag, weight, and increase the overall strength (see Table III-II).

The number of booms was similarly scrutinized. Two booms would keep the tail from twisting as much, but at a cost of additional weight. A single boom would reduce both weight and drag while maintaining enough strength to prevent significant tail twist (see Table III-II).

| Type | Weight | Drag | Strength | Ease of Manufacture | Total |
|---|---|---|---|---|---|
| Rectangular Body | 2 | 3 | 2 | 3 | 10 |
| Round Body | 3 | 4 | 3 | 2 | **12** |
| Twin Boom | 2 | 2 | 4 | 2 | 10 |
| Single Boom | 3 | 3 | 3 | 3 | **12** |

4-Excellent 3-Good 2-Fair 1-Poor

**Table III-II.** ***Fuselage FOMs***

Wing placement was the next item discussed. This would have an effect on the design of the fuselage as well as the wing, so it was necessary to discuss in detail. There were only three possibilities available: low, middle, or high placement. The FOMs were similar to those used for determining wing position on full-size cargo planes (see Table III-III). However, some adjustments were made (from full-size aircraft) out of necessity. For example, cabin visibility was not considered, for obvious reasons.

| Placement | Drag | Stability | Landing Gear | Crash Worthiness | Wing Structure | Total |
|---|---|---|---|---|---|---|
| High | 2 | 3 | 1 | 3 | 3 | **12** |
| Middle | 3 | 2 | 2 | 2 | 1 | 10 |
| Low | 1 | 1 | 3 | 1 | 2 | 8 |

3-Best 2-Okay 1-Poor

**Table III-III.** ***Wing Placement FOMs***

The final area addressed during the conceptual design phase of the UAV was the wing configuration. Three FOMs from the fuselage selection carried over: weight, drag, and ease of manufacture (see Table III-IV). Lift was also considered as an important figure of merit. Four possibilities were discussed for the wing design.

The first idea presented was to utilize a straight wing to provide lift for the aircraft. This was similar to the wing used in the previous year, allowing previous participants to provide useful insight. This type of wing would provide ample lift and would be easy to manufacture, at a cost of additional weight and drag.

A tapered wing was discussed next. Using this configuration, a decrease in weight would be achieved while maintaining lift comparable to the straight wing. There was minimal difference in drag between the two, but a tapered wing would be harder to manufacture.

Next addressed was the idea of a swept wing. This would give some relief from drag by reducing the amount of wing viewed head-on, and would weigh about the same as the other configurations considered. However, a swept configuration would make the center of gravity calculations much more difficult, and thus the eventual design and manufacture of the wing and fuselage. This, coupled with the fact that the drag relief would be very small at the low speeds attained by UAVs, made this configuration undesirable.

Finally, a hybrid delta wing in a diamond configuration was considered. Again, this would give enough lift, but would complicate the design. Unfortunately, there was no available background information for such a configuration. Also, there was minimal time available to develop research data necessary for such an undertaking.

Because the drag encountered by the aircraft would be relatively small in comparison to the other characteristics, it was given less weight than the other FOMs. While drag and wing sweep are important to full size high speed aircraft, they are of little consequence to a UAV that cannot attain more than seventy miles per hour. Therefore, the design team decided to focus more on keeping weight and other design difficulties low.

| Type | Lift | Weight | Drag | Ease of Manufacture | Total |
|---|---|---|---|---|---|
| Straight | 4 | 2 | 2 | 4 | 12 |
| Tapered | 4 | 4 | 2 | 3 | **13** |
| Swept | 3 | 3 | 3 | 2 | 11 |
| Hybrid Delta | 3 | 3 | 3 | 1 | 10 |

4-Excellent 3-Good 2-Fair 1-Poor

**Table III-IV.** ***Wing Shape FOMs***

### 3.2 Conclusions

At the end of much debate and discussion, the team tallied its results to yield the concept used for the UAV. It would be propelled by a brushless electric motor with a gearbox. Around this choice, the exact dimensions and speeds the aircraft could be determined. The fuselage would be as small as possible to contain all of the necessary components, and would be cylindrical to reduce drag. The wing would be attached to the upper part of the fuselage, for reasons discussed earlier. A single boom would connect the fuselage to the empennage. The wing would be without sweep, but would hold some degree of taper so weight would be reduced.

The brand and type of motor were then selected so that work could begin on the rest of the aircraft. This would provide the basis for the preliminary design of the UAV.

# 4. PRELIMINARY DESIGN

Early aeronautical engineers were only concerned with lifting and propelling aircraft from the ground; what happened after that was viewed with little importance. However, the sweeping movements in aviation during the pre-World War I era caused the airborne performance of the airplane to come under more intense scrutiny.

Questions arose such as: What is the maximum speed or the airplane? How fast can it climb to a given altitude? How far can it fly? How long can it stay in the air? Answers to these questions constitute the study of airplane performance, and contribute to the sizing and powering of a vehicle.

The first consideration of flight is much like our predecessors, getting it airborne:

From the free body diagram of an airplane, as sketched in Figure 4.1, the lift of the airplane must equal the weight for a level flight (**L = W**, Equation 4.1), where L is the lift of the airplane and W is the weight.

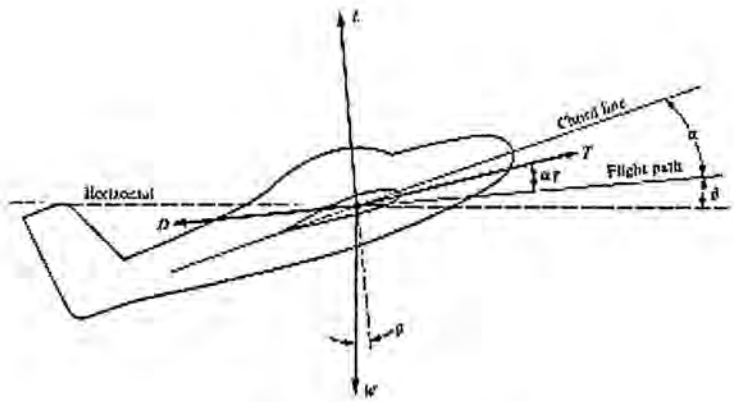



**Figure 4-1.** ***Airplane forces during flight***

Equation (2) arises from basic aerodynamics, and gives the relation between the necessary lift coefficient of an airplane and the weight at a given altitude.

$$c_L = \frac{W}{0.5\rho_\infty V_\infty^2 S} \tag{2}$$

Where, $c_L$ is the lift coefficient, $V_\infty$ the freestream velocity and S the wing area.

Using equation (2), a useful relation for an airplane at sea level conditions at take-off can be achieved (equation 3, using the English System of units). Here, $C_{L\max} = 1$ is assumed, as is discussed later. Since the aircraft is restricted to low altitude for reasons of visibility, the sea level condition of air will be used for the necessary calculations.

$$\left(\frac{W}{S}\right) = \frac{V_\infty^2}{841.4} \tag{3}$$

Here, the Wing Loading is a defined factor that is labeled as:

$$\frac{W}{S} \equiv \text{wing loading}$$

This quantity is quite important, since the design wing loading of an airplane is usually determined by factors such as range, maximum velocity, and payload. Also from equation (3) the velocity at which the aircraft can reasonably lift-off (stall velocity) can be iteratively chosen for a given wing loading at a $C_{LMAX} = 1$. Table IV-I shows a list of required wing loading at a specified speed. Note that for higher wing loading, greater take-off speed is necessary.

| Takeoff Speed (ft/s) | Wing Loading (W/S, lb/ft²) |
|---|---|
| 20 | 0.48 |
| 40 | 1.90 |
| 50 | 2.97 |
| 60 | 4.28 |
| 70 | 5.82 |

**Table IV-I.** ***Wing Loading as a Function of Lift-Off Speed ($C_l$=1)***

In almost all designs of aircraft, it is essential to know the maximum take-off weight (**MTOW**) of the airplane to achieve the functionality/performance and sizing of the airplane. The MTOW is not often a given parameter, however, and design for such becomes an iterative process. For example, a commercial airline design must take into account the transport of *x* amount of passengers and their baggage, the fuel to get to its destination, the effects of altitude and compressibility on the wings' airfoil, etc. These parameters and others contribute to the final weight of the airplane.

For this airplane, there are preset guidelines (Appendix I) that must be met in order to build a successful aircraft. These guidelines, as alluded to before, contribute to the MTOW of the airplane. For example, the aircraft must carry a simulated passenger payload of 7 1/2 pounds, so the next important stage of design is to predict the MTOW.

### 4.1 Weight Estimation

Unavoidable load contributions in the design of an aircraft come from the structural weight of the vehicle and the weight of the propulsion device (powerplant). The structural weight includes the weight of the wing, empennage, fuselage and landing gear. The powerplant in this case includes the weight from the motor, batteries, propeller and gear. Fixed system and miscellaneous weights from items such as servos and connectors also need to be estimated.

Components can be estimated by using relations compiled over the years for real aircraft. These calculations initially require realistic assumptions of the airplane dimensions, and are highly iterative since the equations include the final MTOW as a parameter. Notice that the wing loading is an important parameter in these equations, which means that these evaluations produce useful aircraft dimensions.

A computer program (Appendix II) was necessary to compute the weights for each component, and thus the total take-off weight.

#### 4.1.1 The Wing

The wing weight is estimated from its planform dimensions when $k_{ts} = 0$ as follows:

$$W_{wing} = \frac{(1 + k_{ts})\,(0.00945)\,(MTOW)^{1.195}(A)^{0.8}(1 + \lambda)^{0.25}k_w(n)^{0.5}}{(t/c)^{0.4}\cos(\Lambda_{c/4})(W/S)^{0.695}} \tag{4}$$

$\mathbf{k_{ts}}$ is the coefficient used when there are engines either mounted on the wing or aft of the fuselage, thus $k_{ts}=0$; **A** is the aspect ratio, $\lambda$ is the taper ratio; $\mathbf{k_w}=1$, **n** is the ultimate load factor (1.5 is used for small aircraft), **t/c** is the average thickness to chord ratio; this parameter usually predicts a sensitive choice of airfoil section at high Reynolds numbers at speeds above the critical Mach number. Thus, thin wings with high sweep are used to reduce wave drag. However, this is not a concern since the Mach number and Reynolds number will be quite low throughout the entire mission flight and t/c will strictly be inherited by the choice of airfoil section.

$\Lambda_{c/4}$ is the angle of sweep at the quarter chord (because of low subsonic speed, the sweep is not necessary to delay drag divergence).

### 4.1.2 The Empennage

The empennage is typically about 17% of the total wing weight:

$$W_{empennage} = 0.17\ W_{wing} \tag{5}$$

### 4.1.3 The Fuselage

The fuselage weight depends mostly on its length (L) and the maximum diameter (D):

$$W_{fuselage} = 0.6727\ k_f(n)^{0.3}(MTOW)^{0.235}(L)^{0.6}(D)^{0.72} \tag{6}$$

For aircraft that carry passengers, $k_f$ is a necessary coefficient that depends on the number of passengers, assume $k_f=1$. It is kept in mind while dimensioning the fuselage that the payload needs to sit inside and must be readily accessible. An initial estimate of 9.6 inches was used.

### 4.1.4 The Landing Gear

The landing gear does not contribute much to the total weight of the aircraft, since it is typically assumed to be only 4% of the total airplane weight:

$$W_{LANDING\ GEAR} = 0.04\ (MTOW) \tag{7}$$

### 4.1.5 Fixed Systems And Miscellaneous

These extra components can be assumed to take up only 3.5% of the total plane weight:

$$W_{system} = 0.035\ (MTOW) \tag{8}$$

As a result, the total plane weight is given by:

$$MTOW = \frac{(1 + k_{ts})\ (0.00945)\ (MTOW)^{1.195}(A)^{0.8}(1 + \lambda)^{0.25}k_w(n)^{0.5}}{(t/c)^{0.4}\cos(\Lambda_{c/4})(W/S)^{0.695}} + 0.0627k_f(n)^{0.3}(MTOW)^{0.235}$$

$$+ (L)^{0.6}(D)^{0.72} + 0.04(MTOW) + 0.035(MTOW) + W_{payload} + W_{powerplant} \tag{9}$$

where $W_{payload}$ is the payload weight and $W_{powerplant}$ is the contributing weight of the propulsion components described above.

### 4.2 Airfoil Selection

#### 4.2.1 Airfoil Characteristics at Low Reynolds Number

In many applications, it is not uncommon to have the need arise for airfoil characteristics at Reynolds number (**R**) values much lower than those for which most of the NACA and NASA data were obtained for. These data were obtained at R values of $3 \times 10^6$ or higher.

Experiments have been carried out to predict airfoil behavior at low R ranges. NASA affiliates R. Eppler and D.M. Somers wrote a program for the design of low speed airfoils. It was found that the form of the lift curves change substantially, over the R range from $4.2 \times 10^5$ to $0.42 \times 10^5$. Particularly at the lowest Reynolds number, the $C_l$ versus $\alpha$ plot is no longer linear. The flow separates at all positive angles just downstream of the minimum pressure point, near the maximum thickness location.

A more recent experimental and numerical study was performed by two engineers, (Donovan, J.F., and Selig, M.S., ***Low Reynolds Number Airfoil Design and Wind Tunnel Testing at Princeton***). Using Eppler and Somers Airfoil Code, Donovan and Selig investigated a number of airfoils followed by wind tunnel testing. The study included new airfoils designed to tailor the chordwise pressure distribution at low Reynolds numbers to promote low drag. At R values less than approximately $5.0 \times 10^5$, an extensive laminar separation bubble can form on either surface, which significantly increases the drag. Therefore, the study examined means to shorten the bubble or promote transition to a turbulent boundary layer at a low value of R.

#### 4.2.2 Airfoil Tradeoffs

Keeping in mind the discussion above, an airfoil section can now be chosen. Two choices exist at this stage;

**(i).**. Typically, conventional airfoils without any special lifting devices will deliver $C_{lmax}$ values of approximately 1.3 to 1.7, depending on Reynolds number, camber, and thickness distribution.

An existing airfoil can be chosen and its drag polar (**$C_{d,p}$**) corrected for low Reynolds numbers. $C_{d,p}$ can further be estimated as a flat plate (drag polar data is available in Appendix III for a flat plate) for R values less than 150,000. This should be a good estimation since by adding thickness to a thin, cambered plate and providing a rounded leading edge, the performance of the plate is improved over a range of angles, with the leading edge separation being avoided all together. Thus, in a qualitative sense we have defined a typical airfoil shape. Camber and thickness are not needed to produce lift (a **flat plate** can produce lift), but are instead used to increase the maximum lift that a given wing area can deliver.

It is appreciated that $C_{lmax}$ is dependent on R. Thus , looking at two typical airfoils, the GA(W)-1 and the NACA four-digit airfoils, the variation of $C_{lmax}$ can be compared. Experimental data shows that $C_{lmax}$ as a function of R and thickness ratio (t/c) for NACA four series increases with t/c. At an intermediate thickness ratios of around 0.12, the variation of $C_{lmax}$ with R parallels that of the 17% thick GA(W)-1 airfoil. Note at least for this camber function that a thickness ratio of 12% is about optimum and the increased design maximum lift coefficient is a better tradeoff with a larger chord length. Also the data also shows that around t/c = 0.16 values of $C_{lmax}$ become linear and are maximum.

On further inspection, the NACA five-digit series uses the same thickness distribution as the four-digit series. The mean camber line is defined differently, to increase $C_{lmax}$. In fact, for comparable thickness the five series $C_{lmax}$ is of the order 0.1 to 0.2 higher. The 23012 airfoil would therefore be a good choice, having a design $C_l$=0.3 and $C_{lmax}$=1.8. Further characteristics of the airfoil are presented in Appendix IV.

**(ii).** The previously mentioned study produced an airfoil shape designated E374, which is pictured in Appendix V along with its lift and drag characteristics. It is designed to operate at a lift coefficient of 0.55 and $C_{lmax}$=1.0. However, below an R of 150,00 the drag coefficient rises rapidly.

### 4.2.3 Final Airfoil Choice

The decision was made to go with the NACA 23102 airfoil, whilst accommodating for necessary drag as discussed beforehand, since at the time of the "close" of the design stage the optimum low speed airfoils were not found.

An average thickness ratio of 16% was chosen and hence fixed the average geometric chord at 0.75 ft for the 12% thick airfoil.

Note: Initial estimates used for the program were: b=6.5 ft, $\lambda$=0.5 (for small aircraft the root chord is recommended to be twice the tip chord length), A=8.67, t/c=0.16, c=0.75 ft, $c_t$=0.5 ft, $c_o$=1 ft..

| Wing Loading (W/S, lb/ft$^2$) | 2 | 2.5 | 3 | 4 |
|---|---|---|---|---|
| **Component** | **Weight(lbs.)** | | | |
| WING | 2.796 | 2.303 | 1.975 | 1.563 |
| EMPENNAGE | 0.475 | 0.391 | 0.336 | 0.266 |
| FUSELAGE | 2.681 | 2.660 | 2.647 | 2.629 |
| LANDING GEAR | 0.692 | 0.685 | 0.655 | 0.637 |
| TOTAL STRUCTRAL WEIGHT | 6.644 | 6.025 | 5.613 | 5.094 |
| MOTOR | 0.43 | | | |
| BATTERIES | 2.50 | | | |
| PROP & GEAR | 0.10 | | | |
| TOTAL POWER PLANT WEIGHT | 3.03 | 3.03 | 3.03 | 3.03 |
| TOTAL PAYLOAD WEIGHT | 7.5 | 7.5 | 7.5 | 7.5 |
| FIXED SYSTEMS AND MISC. | .606 | .586 | .573 | .557 |
| **Maximum Take-off Weight** | **17.78** | **17.141** | **16.716** | **16.18** |

**Table IV-II.** ***The Comparison of MTOW to the Wing Loading***

### 4.3 Initial Performance

Table IV-II presents some critical design considerations, but they are nothing without investigating the effect on parameters such as the lift coefficient, $C_L$, and total drag, $C_D$, of the aircraft at the varying wing loading as presented in Table IV-III.

The estimation of the total drag of an airplane is difficult, even for the simplest configurations. The following possible drag modes partly reveal why this is so.

**The induced drag,** $C_{di}$, is the drag that results from the generation of a trailing vortex system downstream of a lifting surface of finite aspect ratio.

$$C_{Di} = \frac{C_L^2}{\pi e A} \quad (10)$$

$$e = 0.95.$$

$$C_{di} = kC_L^2, \; k = 1/\pi eA$$

**The parasite drag,** $C_{D,O}$, is the drag of the airplane not directly associated with the production of lift, and includes many drag components, such as, the skin friction drag, form drag, interference drag, trim drag, profile drag and cooling drag. The parasite drag can be estimated in terms of the total wetted area of the plane and its MTOW.

$$C_{D,O} = \frac{f}{S} \tag{11}$$

where f is calculated as shown below.

$$\log_{10} S_{wet} := 0.0199 + 0.7531 \cdot \log(MTOW)$$

$$\log_f := \log_{10} S_{wet} + -2.5229$$

$$f := \exp(\log_f \cdot 2.3025)$$

Since it is apparent that the 2-D airfoil section will see more skin friction and form drag, it is estimated from the charts in Appendix IV.IV & V and corrected for thickness. The profile drag should be more than the parasite drag as a check for correctness.

$$C_{d,o} = C_{d,p}(Re = 5x10^6)\ t \tag{12}$$

Now, the total drag can be estimated:

$$C_D = C_{d,o} + C_{di} \tag{13}$$

| W/S, lb/ft$^2$ | MTOW, lbs. | S, ft$^2$ | b, ft | $\log_{10}(S_{wet})$ | $\log_f$ | f, ft$^2$ | $C_{D,O}$ |
|---|---|---|---|---|---|---|---|
| 2 | 17.78 | 8.89 | 11.85333 | 0.952 | -1.571 | 0.027 | 0.003037 |
| 2.5 | 17.14 | 6.856 | 9.141333 | 0.942 | -1.581 | 0.026 | 0.003792 |
| 3 | 16.7 | 5.566667 | 7.422222 | 0.934 | -1.588 | 0.026 | 0.004671 |
| 4 | 16.18 | 4.045 | 5.393333 | 0.9245 | -1.588 | 0.025 | 0.006 |

**Table IV-III.** ***Wing Dimensions and Variation of Plane Drag at Different Wing Loadings***

Now, there exists a tradeoff for vehicle sizing. It is seen that the maximum take-off weight of the vehicle increases as the wing span increases. However, from Table I, a small W/S allows the vehicle to be airborne sooner, which makes a take-off speed of 40 ft/s is a tempting choice. This requires a W/S close to two. As Table IV-III clearly shows that at this W/S the vehicle would require a wing span of nearly 12 feet, which would raise questions of deflection failure and overall strength of the wing.

Not shown in the tables, but easily interpolated from equation 2, is the fact that $C_L$ needs to increase with W/S. The only drawback is that $C_{di}$ increases also. Since the profile drag of the airfoil is going to drive the contribution of the parasite drag, the induced drag is the main contributor to the overall drag. An optimum choice from the preceding discussion would be a wing loading between 3 - 4 lb/ft$^2$, representing realistic take-off velocities from 50 to 60 ft/s.

The variation of the drag with lift over these ranges of W/S are looked at in Table IV-IV. The final contributing factor is the thrust required by the plane to lift-off. This parameter contributes to the sizing of the power plant and thus the lift-off distance and in-flight performance:

$$T_R = \frac{W}{L/D} \tag{14}$$

| W/S | Velocity(ft/s) | Re | $C_L$ | $C_{DI}$ | $C_{d,o}$ | $C_D$ | L/D | $T_R$(lbs) |
|---|---|---|---|---|---|---|---|---|
| 3 | 50 | 250,592 | 1.01 | 0.0394177 | 0.108 | 0.1474177 | 6.849 | 2.438 |
| 3 | 55 | 275,651 | 0.83 | 0.0269228 | 0.1104 | 0.1373228 | 6.077 | 2.748 |
| 3 | 60 | 300,710 | 0.70 | 0.0190093 | 0.009 | 0.0280093 | 25.033 | 0.667 |
| 3 | 65 | 325,769 | 0.60 | 0.0138012 | 0.00852 | 0.0223212 | 26.766 | 0.624 |
| 4 | 50 | 250,592 | 1.35 | 0.070076 | 0.108 | 0.178076 | 7.560 | 2.140 |
| 4 | 55 | 275,651 | 1.11 | 0.0478628 | 0.1104 | 0.1582628 | 7.030 | 2.302 |
| 4 | 60 | 300,710 | 0.93 | 0.0337944 | 0.009 | 0.0427944 | 21.846 | 0.741 |
| 4 | 65 | 325,769 | 0.80 | 0.0245356 | 0.00852 | 0.0330556 | 24.098 | 0.671 |

**Table IV-IV.** ***Variations of Coefficients with Wing Loadings***

From here it can be seen that a W/S of 4 yields slightly better results, requiring less thrust at lift-off. On closer inspection, however, increasing the W/S decreases the wing area. Looking at Equation (15) for the lift-off distance, $s_{LO}$, of an aircraft, the $s_{LO}$ is decreased by increasing the wing area, increasing $C_{L,max}$, and increasing the available static thrust, **T**. Lift-off distance is very sensitive to weight, and looking at equation 16, the necessary thrust is increased with higher W/S. Since the weight difference between the two wing loadings are minimal a W/S of 3 would be the ideal choice.

$$s_{LO} = \frac{1.44W^2}{g\rho S C_{L,max} T} \quad \textbf{(15)}$$

In fact, knowing the field distance, a relation for least available thrust for take-off as a function of W/S can be compiled. Assume that $C_{L,max}$ is limited to 1.

$$T_{min} = \frac{18.814W}{300}\left(W/S\right) \quad \textbf{(16)}$$

From here it can be seen that the minimum thrust increases with wing loading, so at a W/S equal 3, $T_{min}$ required is 3.14 lbs (50 ounces).

As of this stage the vehicle sizing looks as follows:

| | |
|---|---|
| Wing Loading, lb/ft$^2$ | 3.00 |
| MTOW, lbs | 16.7 |
| Wingspan b, ft | 7.4 |
| Wing Area S, ft$^2$ | 5.67 |
| Aspect ratio, A | 8.67 |
| Root Chord, ft | 1 |
| Tip Chord, ft | 0.5 |
| Fuselage Diameter, ft | 0.8 |
| Mean Chord(geometric), ft | 0.75 |
| Mean Chord (dynamically), ft | 0.788 |
| $T_{mino}$ (lbs.) | 3.14 (50.24 ounces) |

This closes the section on the preliminary design of the vehicle. Now the question of producing necessary thrust for the vehicle arises. Also, dimensioning will change as the optimum performance of the aircraft is zeroed in on. Components may decrease or increase in number and size as performance optimization is explored. The time of flight will depend on the number of battery cells and other factors which will contribute to affecting the total weight. These and other factors are explored in the next section.

# 5. DETAIL DESIGN

As of the start of this stage of the design, the payload dimensions were modeled reducing the fuselage diameter to 0.33 ft. Re-estimating the weights as in the previous section the weight was reduced and the final configuration and performance calculations are shown in Appendix V.

The aircraft's control surfaces were estimated following the discussion on stability and control in the next section and then the propulsion of the vehicle.

## 5.1 Stability and Control

Stability of an aircraft refers to its movement in returning, or tendency to return, to a given state of equilibrium, frequently referred to as trim. More specifically, an aircraft can experience two types of stability phenomena. Static stability refers to the tendency of an aircraft under steady conditions to return to a trimmed condition when disturbed rather than any actual motion it may undergo following the disturbance. The forces and moments are examined to determine if they are in the direction to force the aircraft back into equilibrium. If so, the aircraft is statically stable.

### 5.1.1 Dynamic stability

There are three basic controls on an airplane: the ailerons, elevator, and rudder -- which are designed to change and control the moments about the x, y, and z axes. These control surfaces are flaplike surfaces that can be deflected back and forth at the command of the pilot.

**Vertical Stabilizer**

A fin area from 7% to 12 % of the wing's area is recommended

**Rudder Area**

A rudder area of 30% to 50% of the total fin area will work well.

**Horizontal Stabilator**

The total area of the horizontal stabilator should be about 20% to 26% of the total wing area. For a fin of 7% make the stabilator 20% of the wing area.

**Elevators**

Normally 25% to 30% of the total stabilizer area.

**Engine location**

An engine located 21% to 27% of the wing span is suitable. A nose moment of 25% of the wingspan is a good average. The actual engine location is usually measured from the C.G. to the propeller. The distance used was measured from the leading edge of the wing to the propeller.

**Neutral Point**

For an aircraft to be statically stable, the cg must be ahead of the neutral point. A static margin of at least 5% is recommended to maintain static longitudinal stability. The calculation for the location of the center of gravity is found in Appendix VI.

## 5.2 Production of Thrust

Now it is obvious that the necessary thrust has to be produced from the motor in Appendix I. This requires gearing and placing the right propeller dimensions and battery cells to produce the required thrust for a certain amount of time. This is important since, as shown before, more thrust equals a shorter takeoff distance and the aircraft has to (1) get off the ground and (2) fly for at least 7 minutes also the number of battery cells influences the planes total weight. Hence it is necessary to determine the optimum propeller size and cell configuration for the best static and in-flight thrust characteristics of the plane.

Importantly, the $s_{LO}$, must accommodate for a safety clearance of 6 feet after takeoff. Assuming that a 6 foot obstacle is placed at the end of the 300 foot runway, then a minimum lift-off distance x and climb angle must be achieved at a minimum climb thrust.

From eq.(16), $$T_{minobject} = \frac{18.814W}{300 - x}\left(W/S\right) \quad \textbf{(16a)}$$

$$V_c = 1.2V_s \quad \textbf{(17)}$$

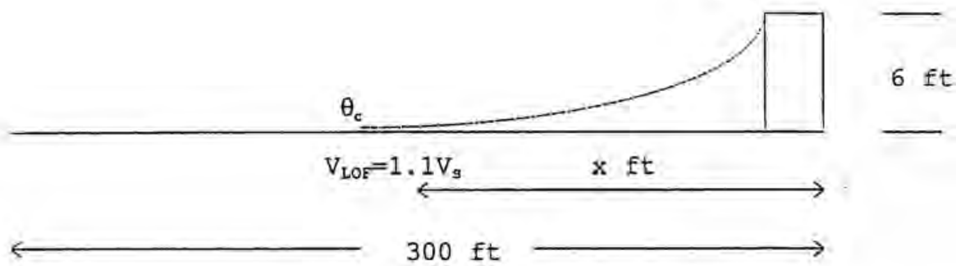



**Figure 5-1.** ***Takeoff Obstacle Diagram***

The necessary climb angle $\theta_c = \tan^{-1}(6/x)$ eq. (17). This correlation is also related to the velocities during the climb of the vehicle as follows:

$$\theta_c = \tan^{-1} V_c/V \quad \textbf{(18)}$$

$V_c$ (R/C) is the climb velocity(fps) at the climb rate and can be estimated as given by FAA rules for climb over a 35 ft obstacle as $1.2V_s$, where

$$V_s = \sqrt{\frac{2W}{\rho S C_{L,max}}} \quad \textbf{(19)}$$

$C_{L,max} = C_{lo} + C_{L\alpha}\alpha$, however, in ground roll estimate $C_{L,max} = 1$, since the angle of attack of the plane is restricted such that the tail doesn't drag the ground. V is the ground speed which could be estimated as the lift-off speed, $V_{LOF}$.

Thus from Eq's (17) & (18), $$x = \frac{6}{\left(\frac{RC}{60} / V_{LOF}\right)}$$

The rate of climb R/C at $T_{min}$ is given by: $$60[V_c(T_{min} - D)]/W \quad \textbf{(20)}$$

where D is the drag at that time and W is the weight of the plane.

From the value of $V_S$ (from Appendix IX) and equation (17), the climb velocity is 59.8 ft/s. D is 0.67 lbs and the R/C = 533.2 fpm at 9.2°. Thus, the minimum takeoff distance for the aircraft is x = 37 feet.

From equation (16a), and a couple of iterations the static thrust of the prop must be equal to at least 3.5 lbs (57.34 ounces) to clear the object leaving the ground at x = 32 feet before the obstacle. Hence, the plane should leave the ground at least 268 feet down the runway.

### 5.3 Propeller Analysis

The airflow seen by a given propeller section is a combination of the airplane's forward motion and the rotation of the propeller itself. The net thrust of a propeller when summed over its entire length of the blades, yields the net thrust available which drives the airplane forward. The propeller is analogous to a finite wing that has been twisted. The propeller efficiency, n, is defined as

$$n = P_A/P \tag{21}$$

where P is the shaft brake power (the power delivered to the propeller by the shaft of the engine) and $P_A$ is the power available from the propeller.

The power input would simply be the total current available x the terminal voltage. The output power would be affected by the heat dissipated by the batteries.

The efficiency for an electric motor can be determined in terms of its power loading. Hence the available power would be in terms of the output power loading (W/lb) and the shaft brake power an input power loading (W/lb or W/kg) .

The power available is an aerodynamic phenomenon which is dependent on the angle of attack and pitch angle of the propeller airfoil. So the pitching of the propeller is important to the thrust it produces.

The propeller may become stalled if the propeller blades are producing far less thrust than predicted (they are basically just beating the air and absorbing a lot of power from the motor). This is typical with high pitch:diameter ratio propellers at low flight speeds.

An effective propeller pitch (in inches or centimeters) also has to be looked at, and indicates the effective pitch of the propeller at the indicated airspeed (as the plane gains speed and begins to move through the air, the propeller works as if it had a reduced pitch). Another contributor to the time of flight is the predicted pitch speed, in miles per hour or meters per second. This is the speed of the air as it leaves the back of the propeller, relative to the plane (i.e. the excess pitch speed, beyond the speed at which the plane is flying).

### 5.4 Thrust Charts

The static thrust for a motor is given by:

$$T = P_{io}^{2/3}(2\rho A)^{1/3} \tag{17}$$

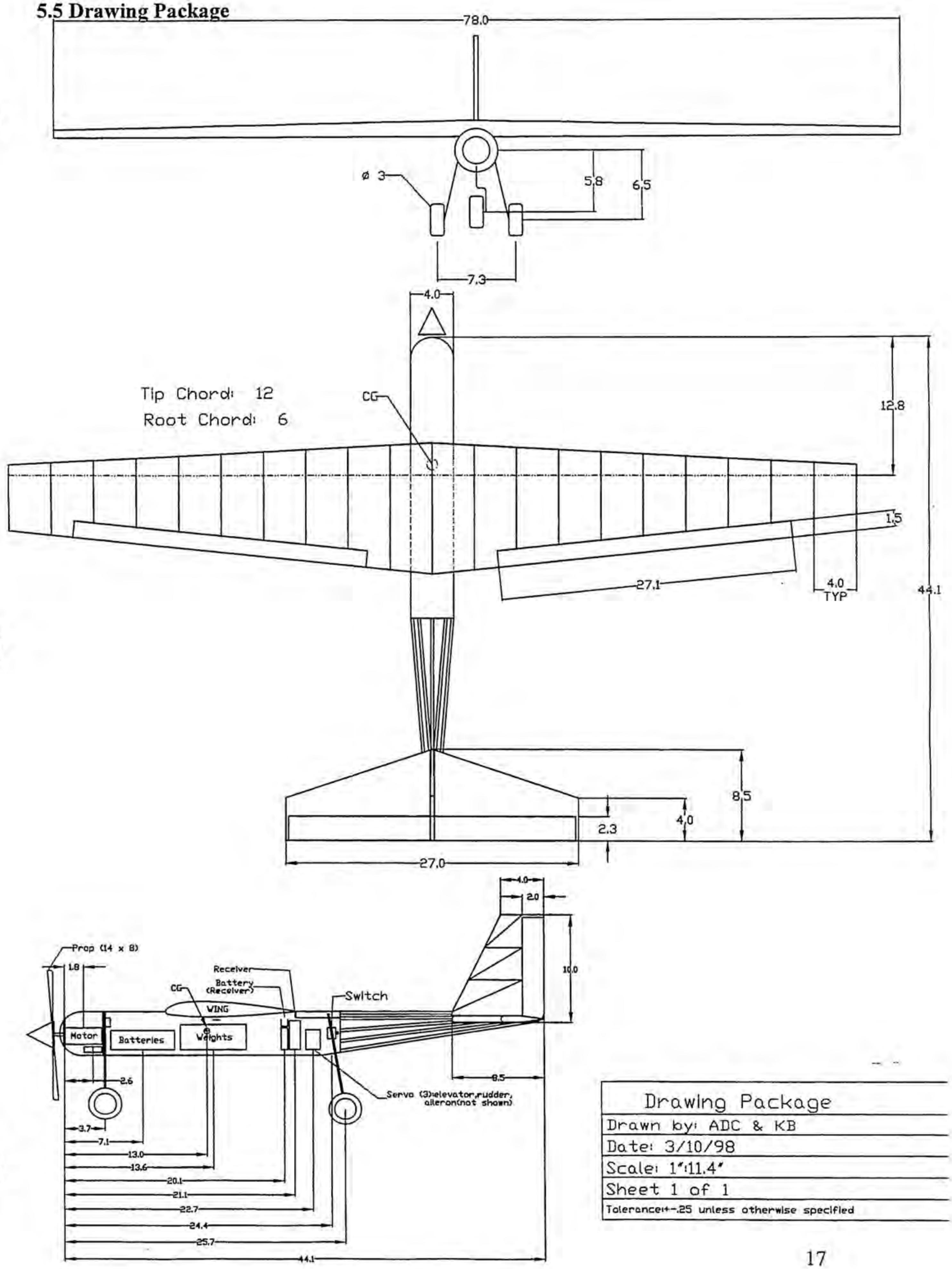
where A is the cross-sectional area of the blade and $P_{io}$ is the motor output power.

Prediction of the motor performance is a little complex, hence, the aid of a computer program was rendered. Appendix VII shows data used to screen possible configurations. The battery cell count was minimized to from 15 - 19 cells, since one cell weighs about 2.05 oz. The motor has already been geared and as such, a range of propeller diameters and pitch lengths have been specified in Appendix I.

Looking at Appendix VII, the table shows that there is not sufficient static thrust available without possible stall of the blades at a diameter of 11 inches over the entire range of available pitch. Therefore, a higher blade diameter has to be used. On continuing iterations of the propeller versus the pitch and diameter of the blades an optimum thrust and time of flight at level flight was found to be for a 14 x 9 propeller on seventeen battery cells at a static thrust of 84.2 ounces. Results in Appendix VIII show that maximum flight time at 87% throttle to be 12 minutes at a maximum speed of 60 MPH. At 100% throttle the flight time is reduced to to 8 minutes at level flight at the maximum speed of 70 MPH.

Appendix IX shows that performance calculations of the plane. They indicate a level speed of 41 MPH and a stall speed of 34 MPH. A take-off distance of 168 feet is estimated.

## 5.5 Drawing Package



# 6. Manufacturing Plan

## 6.1 Wing and Empennage

The final manufacturing process for the wing and empennage was selected after researching three possible procedures. A polystyrene core wing with balsa sheeting, a traditional balsa wood wing with ribbed internal structure, and a graphite composite structure were considered. The factors which determined the selection of a final procedure were cost, availability, reparability, and skill level required to manufacture the material. A traditional balsa wing turned out to be the best overall option according to these parameters.

Characteristics for each material were researched and charted in comparison to each other.

| | Foam | Balsa | Graphite |
|---|---|---|---|
| Availability | Excellent | Excellent | Excellent |
| Reparability | Average | Excellent | Poor |
| Skill Level | Moderate | Low | High |
| Density | 1.0 g/cm$^3$ | 0.15 g/cm3 | 1.8 g/cm$^3$ |
| Tensile Strength | 40 MNm$^{-2}$ | 35 MNm$^{-2}$ | 650 MNm$^{-2}$ |
| Cost | $45.00 | $53.00 | $200.00 |

**Table VI-I.** ***Wing Materials***

Each material was readily available through mail order or local hobby supply shops, and therefore was not a determining factor in selecting one material over another. The reparability factor was more influential in the final selection. The wing must have the capability to be quickly repaired during competition in case of damage sustained during a hard landing or crash. Polystyrene foam is not easily mended because many adhesives deteriorate it. Graphite composite is difficult to repair in the field because the process used to form any graphite composite part is time consuming. Balsa has the best reparability characteristics because it can quickly and easily be mended in the field using cyanoacrylate (CA) glue.

The skill level required to manufacture the material was also an influential factor because time is a constraint. Polystyrene is moderately difficult to work with because a hot wire must be used to shape it. Graphite composite is an advanced material which was not considered for the wing and empennage because the time requirements necessary for design and construction of a mold were not acceptable. Balsa was the easiest material to manufacture because no special tools are needed to shape it.

The cost of graphite composite was a major factor in eliminating it from possible contention even though it has a higher tensile strength than either balsa or foam. Balsa and polystyrene are comparable in cost, and balsa was the better choice due to its favorable reparability characteristics and ease of construction.

The fabrication process for balsa was created by researching radio control model airplane books and manuals. The dimensions of the ribs are critical to the construction of the wing because they hold the shape of the airfoil. ModelCalc, an airfoil program, was used to produce accurate full scale plots of the various size ribs for the tapered wing. The wing was drawn on AutoCad R13 and plotted full scale to be used as direct reference during construction. The wing plans include placements of spars, ribs, sheeting, ailerons, and the leading and trailing edge. This reduced the cost of manufacturing by eliminating the need to buy full scale blueprints at a cost of $9.00 per drawing. The drawings are covered with wax paper and placed on an angled surface due to the wing taper. The wood must be prepared prior to beginning construction. The ribs are cut by placing balsa wood sheets under the full scale rib plots and cutting the pattern for each individual rib. In order to reduce weight, the unnecessary interior area of each rib is removed. The balsa spars are cut to length and strengthened by adding strips of graphite fiber to two opposite sides. This technique gives it added strength with a minimal weight increase of 0.2oz.

The wing is constructed of two symmetric halves. The bottom spar and trailing edge are pinned into place on top of the plans. First, the trailing edge is attached to a jig which ensures that the ribs are aligned in proper orientation. Next, each rib is glued to the trailing edge and spar. Then, the top spar is attached, and webs are glued into place for reinforcement. The leading edge and sheeting are now glued into place. Wingtips are made by carving blocks of balsa, and are small in size due to the tapered wing. The ailerons are the only moving parts on the wing, and attach to the trailing edge by CA hinges. The second half of the wing is built, and the two halves are joined using epoxy and fiberglass.

The construction of the empennage is much more simple than the wing because it is not designed as an airfoil. The plans for the empennage truss design were drawn on AutoCad, and were plotted to be used as reference for construction. In order to minimize weight, the vertical and horizontal stabilizer are built by constructing a frame, and reinforcing it with a simple truss. The elevator and rudder must be attached with control rods and CA hinges by a similar procedure used for the ailerons.

### 6.2 Fuselage

During the preliminary design phase for the fuselage, there were four material choices available to the team. The material choices were: 1) Balsa, 2) Fiberglass, 3) Kevlar, and 4) Graphite. These four materials were compared on the basis of a series of criteria that would be applicable for this project. The qualitative comparison is shown below in Table VI-II.

A preliminary construction plan was necessary at this time to assist in the evaluation of the material selection. However, a wooden fuselage would have to be constructed differently than a composite fuselage. Therefore, both wooden and composite construction plans needed to be developed. In comparison to the design from the previous year, a wooden fuselage would be constructed as a box from four planes. Whereas, typically, high strength, light weight composite materials are cast from molds pulled off precision made plugs. However, due to the construction phase time constraints, a more expedient method of construction would be required if a composite material was to be chosen. This resulted in a study into alternate means of composite construction.

These alternate means consisted of moldless construction and pre-made molds, in addition to the typical mold casting process. Moldless construction is a method typically utilizing a foam core with composite materials draped over top of the foam. Whereas a pre-made mold would have to be already in existence and be exact to the specifications of the fuselage required.

A radical, low cost, fast construction method was suggested for composite molding by one of the members of the team. Instead of building a mold to fit the needs of the fuselage, a section of 4 inch diameter PVC piping could be cut lengthwise to reveal two half cylinders, which then could be surface finished as typical composite molds and used as the final molds. These two molds would produce two composite half cylinders which would then be placed back into the molds and attached together to produce a thin walled composite cylinder for use as the fuselage. It was suggested that the curing time could be shortened by heating the molds during the cure cycle. This would require an oven. An additional radical method was conceived to shorten the manufacturing time by this heating procedure. A steel cabinet with a space heater placed inside was suggested for use as an oven. A thermometer must be placed inside the cabinet for use as the thermostat. The setting of the space heater was altered until a constant temperature of roughly 100°F was reached. This mold making procedure would be effective at a low cost, and would produce a product with minimal construction time.

A comparison as to the overall strength of each material was also necessary. Balsa, being the least strong, would be comparable to fiberglass. Kevlar was shown to be roughly twice as strong. Graphite would then be stronger still, at roughly three times the strength of fiberglass. Each of these materials are however differ in other various properties; kevlar has high impact resilience, while graphite has high flexural strength.

It was believed that cost would weigh greatly into the material selection. However, after a series of detailed studies, it became apparent that the three composite materials would all be comparable, with a balsa configuration being marginally less expensive (see Appendix X).

After taking all things into account (as shown in Table VI-II), Graphite became the material of choice. It was also decided to use the PVC molding method as described above. This was expected to produce a strong lightweight fuselage at a lower cost than typical molding techniques. This would then be used as the structural member of the airframe.

| | Balsa | Fiberglass | Kevlar | Graphite |
|---|---|---|---|---|
| **Cost** | 3 | 3 | 2 | 1 |
| **Strength to Weight** | 2 | 2 | 3 | 4 |
| **Elastic Strength** | 2 | 2 | 3 | 4 |
| **Flexural Strength** | 2 | 3 | 2 | 4 |
| **Availability** | 3 | 3 | 3 | 3 |
| **Workability** | 3 | 2 | 2 | 2 |
| **Prerequisite of Experience** | 3 | 2 | 2 | 2 |
| **Time of Manufacture** | 3 | 2 | 2 | 2 |
| **Knowledge Gained** | 2 | 3 | 4 | 4 |
| **Design Improvement Over Previous Year** | 1 | 2 | 3 | 4 |
| **Total** | 24 | 24 | 26 | 30 |

4-Excellent 3-Good 2-Fair 1- Poor

**Table VI-II.** ***Qualitative Fuselage Materials Comparison***

A finite element model was developed to determine the specific number of layers and orientation of the plies of graphite needed to withstand the loads that the fuselage would see in flight (see Figure 6-1). This model suggested that the fuselage could be constructed with only two layers and still withstand to in-flight loads. However, a decision was made to use three layers, in order to account for any fabrication errors.

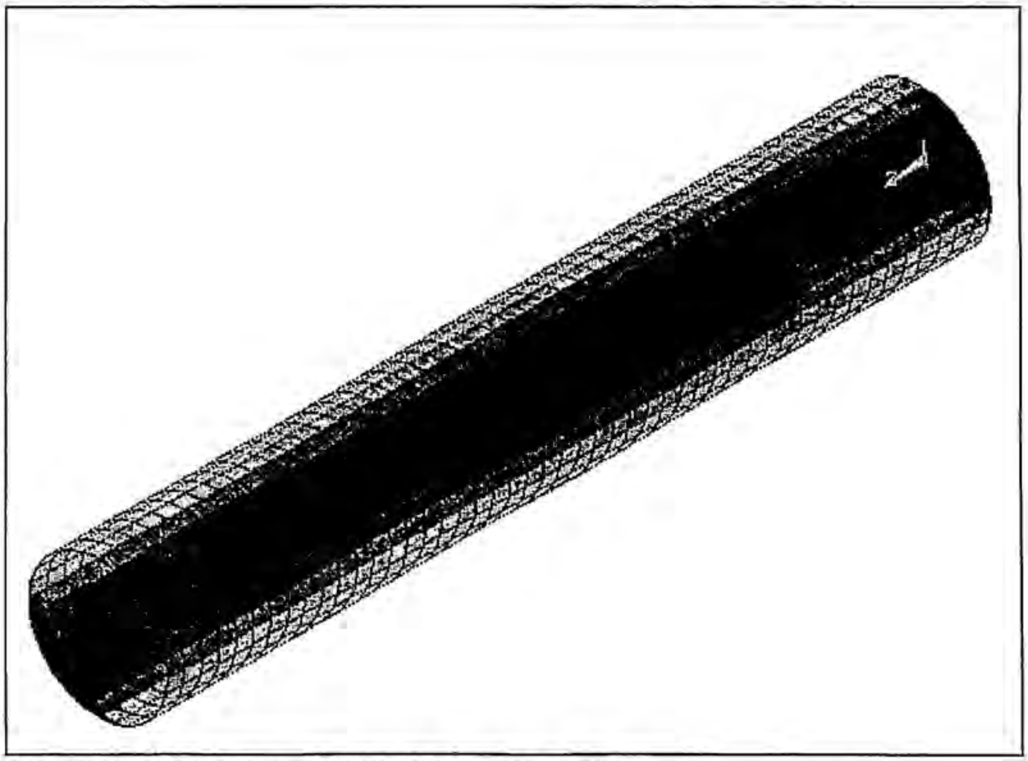


Figure 6-1. *Finite Element Model of Composite Fuselage*

### 6.3 Boom

Connection of the fuselage to the empennage was another major consideration to take into account. A similar PVC molding method was considered for fabrication of a boom which would connect the fuselage to the empannage. However, it was decided that there would be too many places for error in the fabrication phase of a tapered boom which could result in an in-flight failure. Another consideration was a wooden dowel for use as the boom. This idea was ruled out after weight consideration. This lead to the decision of designing a balsa wood boom to connect the fuselage to the empannage. A design for this boom was developed utilizing a finite element model (see Figure 6-2). This boom would be connected to the interior of the finished fuselage and it would run to the empannage. The boom was designed such that the vertical tail and horizontal stabilizer could be inserted into the rear section of the boom through sized cutouts. It was decided to use a frame of eight balsa beams that would connect together at the rear of the aircraft and connect directly to the fuselage.

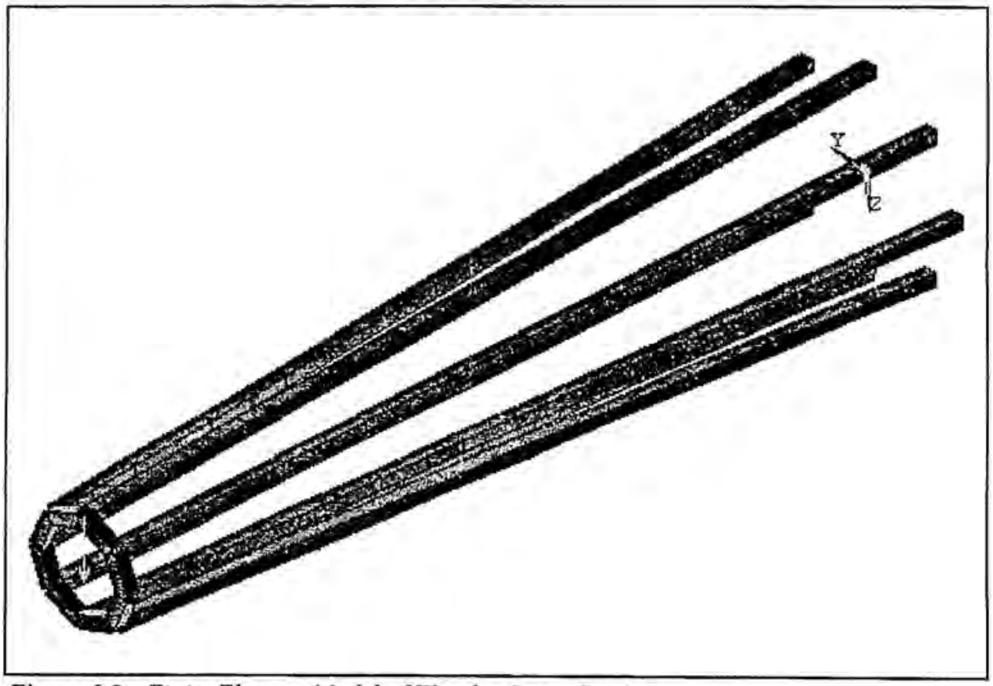



Figure 6-2. *Finite Element Model of Wooden Boom Section*

### 6.4 Assembly

Following construction of all necessary components, the aircraft would have to be assembled. In order to reduce any unforeseen assembly problems an assembly plan was conceived. This determined the steps in manufacturing, and resulted in a manufacturing schedule (see Table VI-III). This schedule was to coincide with the Management milestone schedule.

It was decided that the fuselage should be constructed first, as every part of the aircraft, except the empennage, will be attached to it directly. This would take at least a week to construct, as each molded piece takes 24 hours to cure. Also, if there are any unforeseen problems in utilizing the radical molding procedure, there would be ample time to correct for them. Shortly after beginning construction of the fuselage, there would be sufficient time to begin construction of the wing.

| Task | State | Proposed Date | Actual Date |
|---|---|---|---|
| Ordering of Parts | Begun | 2/6/98 | 3/6/98 |
| Ordering of Parts | Completed | 2/13/98 | 3/10/98 |
| Fuselage Construction | Begun | 2/13/98 | 3/9/98 |
| Wing Construction | Begun | 2/17/98 | 3/10/98 |
| Fuselage Construction | Completed | 2/20/98 | TBA |
| Nose Construction | Begun | 2/20/98 | TBA |
| Nose Construction | Completed | 2/24/98 | TBA |
| Wing Construction | Completed | 3/6/98 | TBA |
| Wing Cutout | Completed | 3/9/98 | TBA |
| Boom Construction | Begun | 3/9/98 | TBA |
| Empennage Construction | Begun | 3/10/98 | TBA |
| Empennage Construction | Completed | 3/17/98 | TBA |
| Boom Construction | Completed | 3/17/98 | TBA |
| Boom/Empennage Integration | Begun | 3/18/98 | TBA |
| Boom/Empennage Integration | Completed | 3/23/98 | TBA |
| Electronics Integration | Begun | 3/24/98 | TBA |
| Landing Gear Integration | Begun | 3/24/98 | TBA |
| Landing Gear Integration | Completed | 3/28/98 | TBA |
| Electronics Integration | Completed | 4/1/98 | TBA |
| Control Rod Integration | Begun | 4/3/98 | TBA |
| Control Rod Integration | Completed | 4/6/98 | TBA |
| Final Manufacturing & Painting | Completed | 4/13/98 | TBA |

**Table VI-III.** ***Manufacturing Schedule***

As soon as the fuselage is completed, extra attention should be given to the wing. As soon as the wing is completed, the cutout of the fuselage for the wing must be done. It must be done as soon as possible so that the boom can be attached to the fuselage section. Also at this time, the nose can be manufactured. This nose piece will assist in the aerodynamic flow from the spinner to the main fuselage. It is to be carved out of four pieces of balsa and sanded down to create a smooth surface. It must be made to fit just inside the fuselage cylinder and still have a flush transition from the one piece to the next.

Soon after completing the fabrication of the nose piece, the wing fabrication should be completed. This will now allow for the removal of the section of the fuselage which will be replaced by the wing in the final construction phase. If the wing is not complete at this time, the dimensions of the cutout section can be found using the dimensions of the wing ribs. This construction alternative assist in keeping the construction phase moving if there are setbacks in wing fabrication. After the wing cutout has been removed from the fuselage, construction can begin on the boom.

After the boom construction has begun, the empennage construction can also begin. These two components should be completed in similar intervals of time. Thus the integration of these two components can begin as soon as they are both completed. At the completion of this manufacturing step, there will be a fuselage with a nose, a boom, an empennage, and a fully fabricated wing.

At this stage the electronics and weights will be mounted inside the fuselage utilizing conformed pieces of balsa to distribute loading on the composite cylinder shell. Also, all control rods must be installed inside the fuselage at this time. Following this installation and the connection of the wing to the fuselage, the aircraft will be ready for aesthetic alterations, such as painting and covering with monocote. After this stage, the aircraft will be ready for ground testing and then flight testing.

## APPENDIX
## I

### DESIGN GUIDLINES AND PERFORMANCE SPECIFICATIONS

| | | |
|---|---|---|
| Payload | = | 7.5 pounds |
| Battery Pack | = | 2.5 pounds* |
| Field Length | = | 300 feet |
| Scheduled flight time | = | 7 minutes |

| | | |
|---|---|---|
| Baseline Motor | | Aveox 1406/4Y |
| Gear Box | | Aveox/Robbe 3.7:1 |
| Recommended pitch | | 7 - 13 inches |
| Recommended diameter | | 11 - 16 inches |
| Turns | = | 4 |
| Speed constant | = | 1500 RPM/V |
| Continuous/Peak current | = | 18A/41A |
| Resistance | = | .06 Ohms |
| Idle Current | = | 1.2 Amps |
| Weight | = | 6.9 ounces(0.43 pounds) |

**Notes:** A six foot obstacle must be cleared within the field length takeoff.

* The maximum battery pack weight allowed.

# APPENDIX II

WEIGHT ESTIMATION PROGRAM

```
#include<iostream.h>
#include<math.h>
#include<stdlib.h>
#include<conio.h>
#include<stdio.h>

double ar,tr, tc;
double mc,s;
double W, WL, lf;
double L, D, payload, motor, battery, prop;


double Max_Weight(double MTOW,double aspect_ratio, double taper_ratio,
double n, double thick_chord, double sweep, double wing_loading, double
Length, double Diameter)


{

      cout <<  "\n\nEnter the total payload weight (pounds): " ;
    cin  >> payload;

      cout <<  "\n\nEnter the motor weight (ounces): " ;
    cin  >> motor;

      cout <<  "\n\nEnter the max. battery pack weight (pounds): " ;
    cin  >> battery;

      cout <<  "\n\nEstimate the gear and prop weight (ounces): " ;
    cin  >> prop;


      double WING = ((0.00945)* pow(MTOW,1.195) * pow(aspect_ratio,0.8)
* pow((1+taper_ratio),0.25) * pow(n,0.5))/ (pow(thick_chord,0.4) *
cos(sweep) * pow(wing_loading,0.695));
      double EMPENNAGE = 0.17 * (WING);
      double FUSELAGE = 0.6727 * pow(n,0.3) * pow(MTOW,0.235) *
pow(Length,0.6) * pow(Diameter,0.72);
      double LANDING = 0.04*(MTOW);
      double SYSTEM  = 0.035*(MTOW);

      double STRUCT =  WING + EMPENNAGE + FUSELAGE + LANDING;

      double PAYLOAD = payload;
      double POWER = motor/16 + battery + prop/16;
```

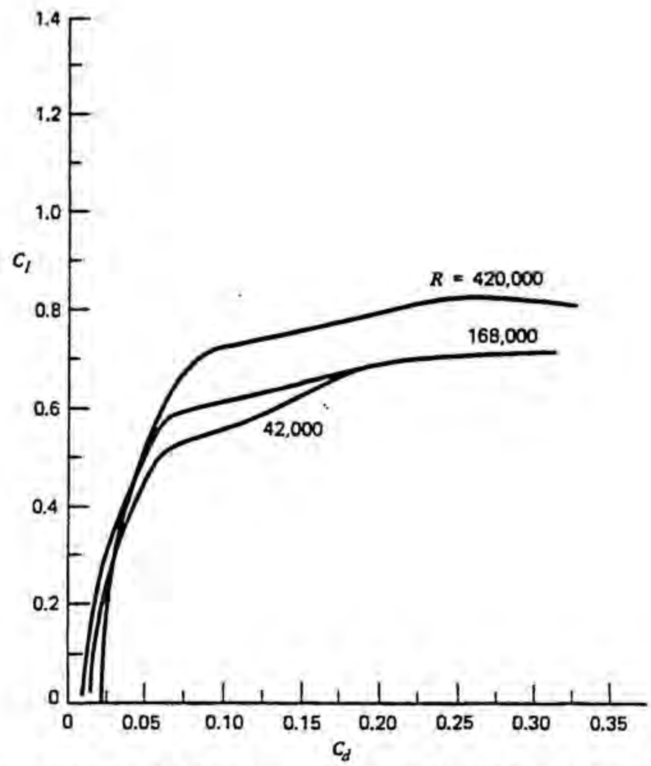
```
	cout <<		"\n\nThe wing weight  = " <<  WING << " pounds " ;
	cout <<  "\n\nThe empennage weight = " << EMPENNAGE << " pounds ";
	cout <<  "\n\nThe fuselage weight = " << FUSELAGE << " pounds ";
	cout <<  "\n\nThe landing gear weight = " << LANDING << " pounds
";
	cout <<  "\n\nThe total structural weight = " << STRUCT <<
"pounds";
	cout <<  "\n\nThe total payload weight = " << PAYLOAD << " pounds
";
	cout <<  "\n\nThe fixed system weight = " << SYSTEM << " pounds ";
	cout <<  "\n\nThe total power plant weight = " << POWER << "
pounds ";

	cout <<  "\n\nThe total plane weight = " << PAYLOAD + SYSTEM +
STRUCT << " pounds ";

	cout << "\n\n\n\nThe required wing area = " << (MTOW/wing_loading)
<< "feet";

	return WING,EMPENNAGE,LANDING,SYSTEM;
}


void main ()
{

	double span;
	double ct, co, t;




cout << "\nEnter the wingspan(feet): ";
cin  >> span;

cout << "\nEnter the root chord (feet): ";

cin  >> co;

cout <<		"\nEnter the tip chord (feet): ";
cin  >> ct;

cout << "\nEnter the thickness of the airfoil section (12% is
recommended): ";
cin  >> t;

cout << "\nEnter the sweep angle at the quarter chord(degrees): ";
cin  >>  s;

cout << "\nEnter the length of the fuselage (feet): ";
cin  >> L;
```

```
tr = ct/co;
mc  = co*(1-(1-(tr)) * (span/2)/span);
tc = (t*.01)/mc;
ar =(2 * span)/ (co * (1 + tr));

cout << "\n\nThe taper ratio of the wing = " << tr;
cout << "\n\nThe mean geometric chord     = " << mc;
cout << "\n\nThe thickness to chord ratio = " << tc;
cout << "\n\nThe aspect ratio = " << ar;

cout << "\nEnter a guess for the total weight (lbs): ";
cin  >> W;

cout << "\nEnter the wing loading(lb/sq.feet): ";
cin  >> lf;


lf=1.5;


Max_Weight(W,ar,tr,lf,tc,s,WL,L,D);

}
```

APPENDIX

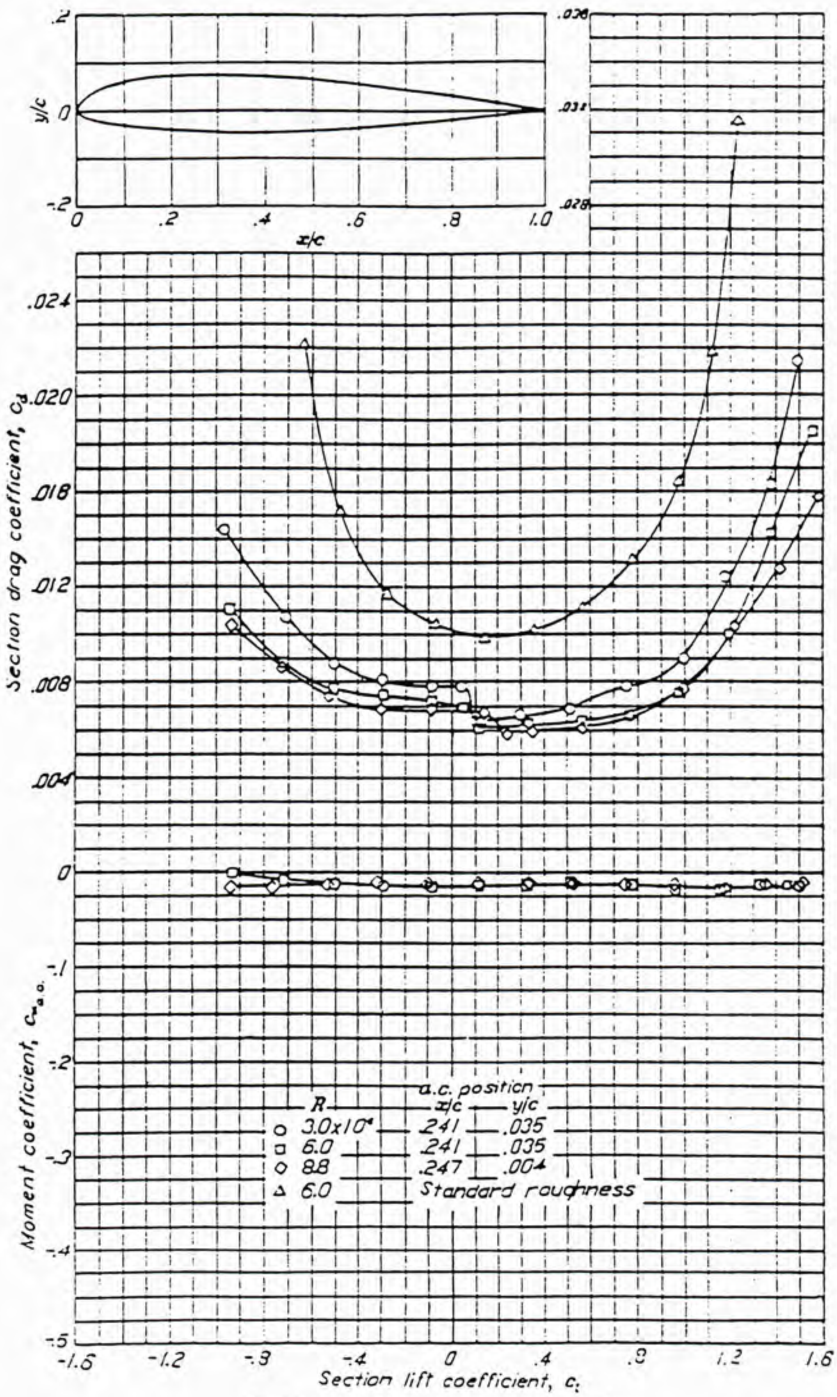
III

DRAG POLAR CHARACTERISTICS OF A FLAT PLATE

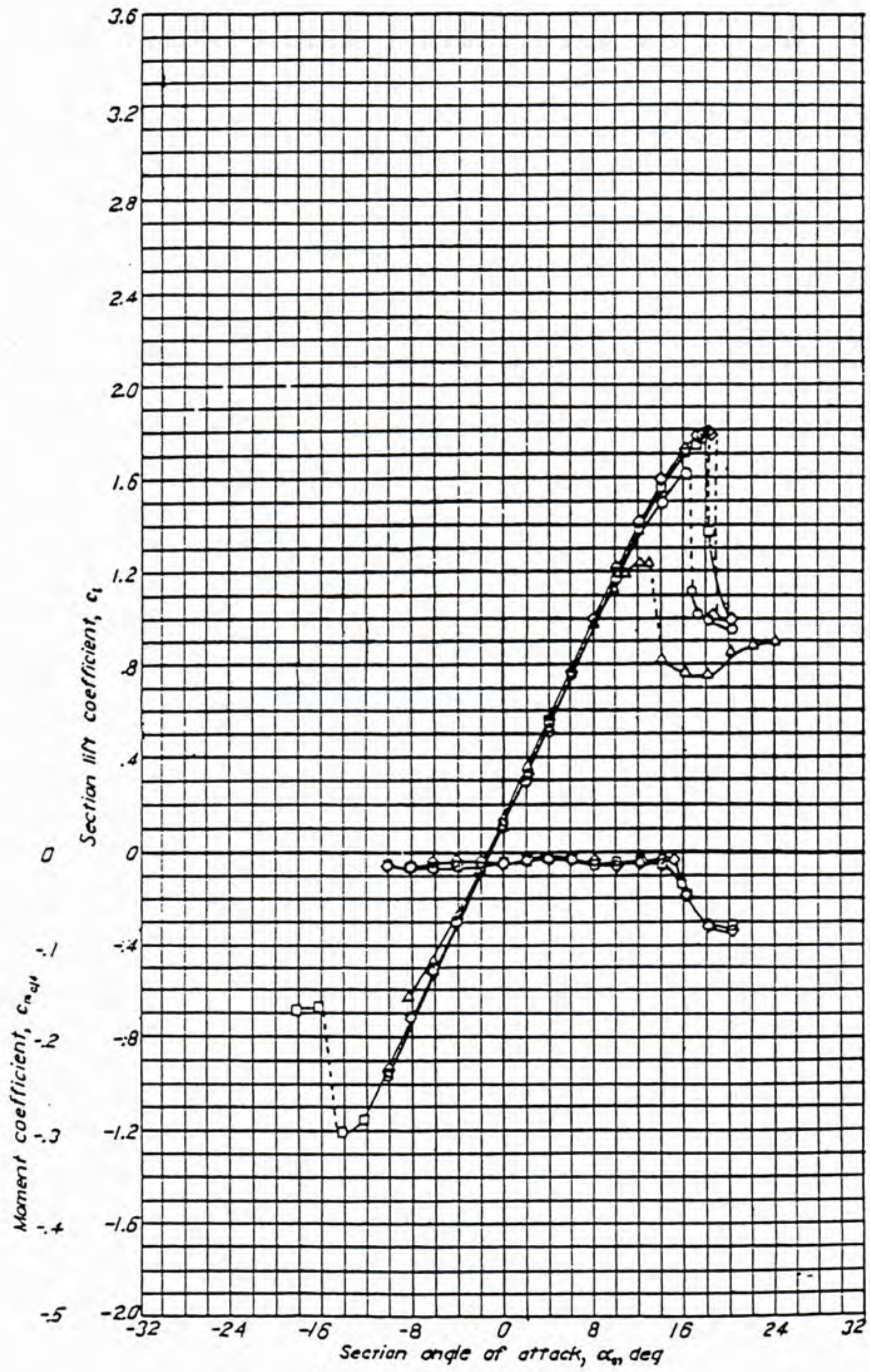



Drag polar for the flat-plate airfoil at low Reynolds numbers.

NACA 23012 WING SECTION



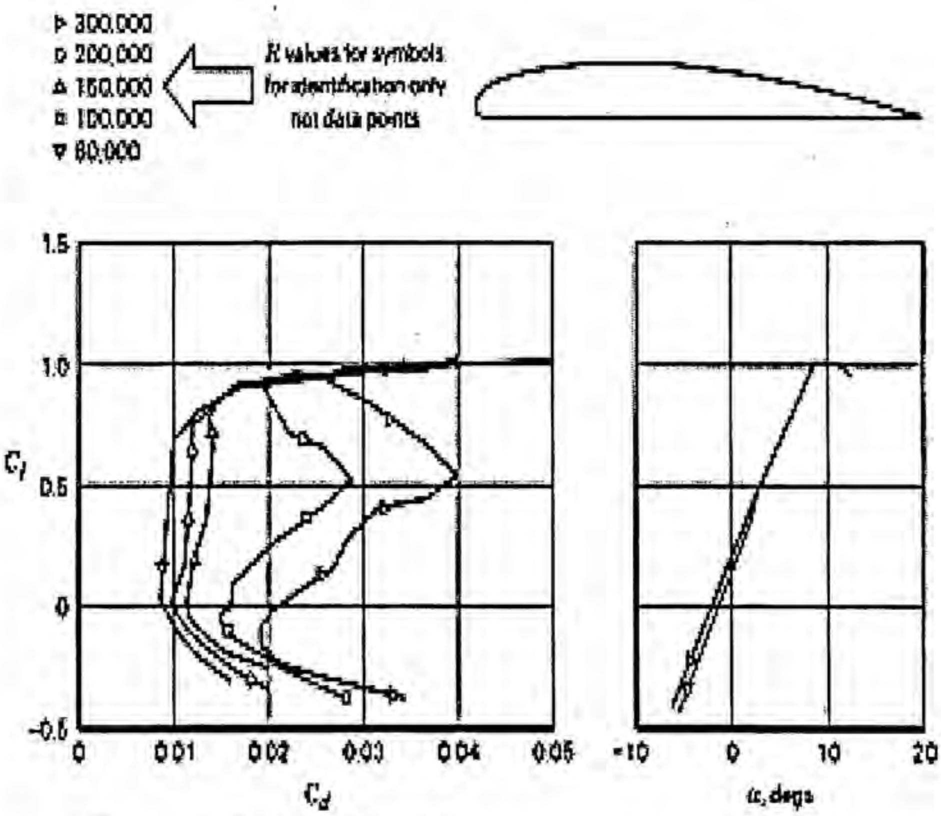

NACA 23012 Wing Section (Continued)




NACA 23012 Wing Section

APPENDIX
V

LOW SPEED AIRFOIL (E374) CHARACTERISTICS




Test results for the E374 airfoil.

# APPENDIX VI

CALCULATION OF CENTER OF GRAVITY LOCATION

## Constants

| Components | Weights (lb) | Lengths to CG from Engine Mount (in) | Moment of each Component (lb in) |
|---|---|---|---|
| Cone&prop | 0.10 | -1.000 | -0.1 |
| Motor | 0.68 | 1.750 | 1.19 |
| Controller | 0.16 | 4.000 | 0.64 |
| Battery Pack | 2.50 | 7.147 | 17.8675 |
| Weights | 7.50 | 13.600 | 102 |
| Battery (control) | 0.20 | 20.625 | 4.125 |
| Receiver | 0.11 | 21.250 | 2.3375 |
| Servo1 | 0.08 | 22.875 | 1.83 |
| Servo 2 | 0.08 | 22.875 | 1.83 |
| Switch | 0.02 | 24.125 | 0.4825 |
| Fuselage | 0.70 | 12.000 | 8.4 |
| Wing | 2.00 | 12.900 | 25.8 |
| Boom&rods | 0.36 | 30.200 | 10.872 |
| Empannage | 0.40 | 40.000 | 16 |
| **Totals** | 14.89 | | 193.2745 |

## Equations

Find total moment about Engine Mount

$$M_{AboutEngineMount} = \sum FL$$

$M_{AboutEngineMount} =$ 193.2745 lb in

Location of the Centroid from Engine Mount

$$\bar{x} = \frac{\sum FL}{W_T}$$

$W_T =$ 14.89 lb

$\bar{x} =$ 12.98 in

# Static Analysis - Eddy Bee

**Motor:** Aveox 1406/4Y; 1500 RPM/V; 0.06 Ohms; 1.2A idle.
**Battery:** Sanyo 2000SCR; 15 to 19 cells; 2000mAh; 0.004 Ohms/cell.
**Speed Control:** Astro 211; 0.002 Ohms.
**Drive System:** Aveox/Robbe 3.7:1 Gearbox; 11x7 to 11x13 geared 3.7:1.
**Airframe:** Eddy Bee; 702sq.in; 241.5 to 249.7oz; 49.5 to 51.2oz/sq.ft; Cd=0.063; Cl=0.7; Clmax=1.24.
**Filter:** 50A max, 75A max (ESC).

| NC | Gear Ratio | Diam (in) | Pitch (in) | Weight (oz) | Amps | Volts | Input (W) | Output (W) | Loss (W) | Effic (%) | InPLd (W/lb) | OutPLd (W/lb) | Prop RPM | Thrust (oz) | PSpd (MPH) | Time (m:s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 3.70 | 11.0 | 7.0 | 241.5 | 11.3 | 17.3 | 194.8 | 167.3 | 27.6 | 85.9 | 12.9 | 11.1 | 6740 | 33.9 | 44.7 | 10:39 |
| 15 | 3.70 | 11.0 | 8.0 | 241.5 | 12.5 | 17.2 | 215.2 | 186.0 | 29.1 | 86.5 | 14.3 | 12.3 | 6679 | 38.0 | 50.6 | 9:36 |
| 15 | 3.70 | 11.0 | 9.0 | 241.5 | 13.7 | 17.2 | 234.6 | 203.8 | 30.8 | 86.9 | 15.5 | 13.5 | 6621 | 42.0 | 56.4 | 8:46 |
| 15 | 3.70 | 11.0 | 10.0 | 241.5 | 14.8 | 17.1 | 253.3 | 220.7 | 32.6 | 87.1 | 16.8 | 14.6 | 6564 | 45.9 | 62.2 | 8:05 |
| 15 | 3.70 | 11.0 | 11.0 | 241.5 | 15.9 | 17.0 | 271.2 | 236.7 | 34.5 | 87.3 | 18.0 | 15.7 | 6509 | 49.6 | 67.8 | 7:32 |
| 15 | 3.70 | 11.0 | 12.0 | 241.5 | 17.0 | 16.9 | 288.4 | 251.9 | 36.5 | 87.3 | 19.1 | 16.7 | 6455 | 53.2 | 73.4 | 7:03 |
| 15 | 3.70 | 11.0 | 13.0 | 241.5 | 18.1 | 16.9 | 304.9 | 266.4 | 38.5 | 87.4 | 20.2 | 17.6 | 6404 | 56.8 | 78.8 | 6:39 |
| 16 | 3.70 | 11.0 | 7.0 | 243.6 | 12.5 | 18.4 | 229.8 | 199.3 | 30.5 | 86.7 | 15.1 | 13.1 | 7145 | 38.1 | 47.4 | 9:36 |
| 16 | 3.70 | 11.0 | 8.0 | 243.6 | 13.9 | 18.3 | 253.6 | 221.1 | 32.5 | 87.2 | 16.7 | 14.5 | 7075 | 42.6 | 53.6 | 8:39 |
| 16 | 3.70 | 11.0 | 9.0 | 243.6 | 15.2 | 18.2 | 276.3 | 241.7 | 34.6 | 87.5 | 18.1 | 15.9 | 7008 | 47.1 | 59.7 | 7:54 |
| 16 | 3.70 | 11.0 | 10.0 | 243.6 | 16.5 | 18.1 | 298.0 | 261.2 | 36.8 | 87.7 | 19.6 | 17.2 | 6943 | 51.3 | 65.8 | 7:18 |
| 16 | 3.70 | 11.0 | 11.0 | 243.6 | 17.7 | 18.0 | 318.8 | 279.7 | 39.1 | 87.7 | 20.9 | 18.4 | 6881 | 55.5 | 71.7 | 6:47 |
| 16 | 3.70 | 11.0 | 12.0 | 243.6 | 18.9 | 18.0 | 338.6 | 297.1 | 41.5 | 87.7 | 22.2 | 19.5 | 6820 | 59.4 | 77.5 | 6:22 |
| 16 | 3.70 | 11.0 | 13.0 | 243.6 | 20.0 | 17.9 | 357.7 | 313.7 | 44.0 | 87.7 | 23.5 | 20.6 | 6762 | 63.3 | 83.2 | 6:00 |
| 17 | 3.70 | 11.0 | 7.0 | 245.6 | 13.8 | 19.4 | 268.2 | 234.4 | 33.8 | 87.4 | 17.5 | 15.3 | 7543 | 42.4 | 50.0 | 8:42 |
| 17 | 3.70 | 11.0 | 8.0 | 245.6 | 15.3 | 19.3 | 295.7 | 259.6 | 36.1 | 87.8 | 19.3 | 16.9 | 7464 | 47.5 | 56.5 | 7:51 |
| 17 | 3.70 | 11.0 | 9.0 | 245.6 | 16.7 | 19.2 | 321.9 | 283.2 | 38.7 | 88.0 | 21.0 | 18.4 | 7388 | 52.3 | 63.0 | 7:10 |
| 17 | 3.70 | 11.0 | 10.0 | 245.6 | 18.1 | 19.1 | 346.8 | 305.4 | 41.4 | 88.1 | 22.6 | 19.9 | 7315 | 57.0 | 69.3 | 6:37 |
| 17 | 3.70 | 11.0 | 11.0 | 245.6 | 19.5 | 19.0 | 370.5 | 326.4 | 44.2 | 88.1 | 24.1 | 21.3 | 7244 | 61.5 | 75.5 | 6:10 |
| 17 | 3.70 | 11.0 | 12.0 | 245.6 | 20.8 | 18.9 | 393.2 | 346.1 | 47.1 | 88.0 | 25.6 | 22.5 | 7177 | 65.8 | 81.6 | 5:47 |
| 17 | 3.70 | 11.0 | 13.0 | 245.6 | 22.0 | 18.9 | 414.9 | 364.8 | 50.1 | 87.9 | 27.0 | 23.8 | 7111 | 70.0 | 87.5 | 5:27 |
| 18 | 3.70 | 11.0 | 7.0 | 247.7 | 15.1 | 20.5 | 310.1 | 272.8 | 37.2 | 88.0 | 20.0 | 17.6 | 7934 | 46.9 | 52.6 | 7:56 |
| 18 | 3.70 | 11.0 | 8.0 | 247.7 | 16.8 | 20.4 | 341.6 | 301.5 | 40.1 | 88.3 | 22.1 | 19.5 | 7845 | 52.4 | 59.4 | 7:09 |
| 18 | 3.70 | 11.0 | 9.0 | 247.7 | 18.3 | 20.2 | 371.4 | 328.2 | 43.2 | 88.4 | 24.0 | 21.2 | 7760 | 57.7 | 66.1 | 6:32 |
| 18 | 3.70 | 11.0 | 10.0 | 247.7 | 19.9 | 20.1 | 399.6 | 353.3 | 46.4 | 88.4 | 25.8 | 22.8 | 7678 | 62.8 | 72.7 | 6:03 |
| 18 | 3.70 | 11.0 | 11.0 | 247.7 | 21.3 | 20.0 | 426.5 | 376.8 | 49.7 | 88.3 | 27.5 | 24.3 | 7600 | 67.6 | 79.2 | 5:38 |
| 18 | 3.70 | 11.0 | 12.0 | 247.7 | 22.7 | 19.9 | 452.0 | 398.9 | 53.2 | 88.2 | 29.2 | 25.8 | 7524 | 72.3 | 85.5 | 5:17 |
| 18 | 3.70 | 11.0 | 13.0 | 247.7 | 24.0 | 19.8 | 476.4 | 419.7 | 56.7 | 88.1 | 30.8 | 27.1 | 7451 | 76.9 | 91.7 | 5:00 |
| 19 | 3.70 | 11.0 | 7.0 | 249.7 | 16.5 | 21.5 | 355.5 | 314.5 | 41.0 | 88.5 | 22.8 | 20.1 | 8319 | 51.6 | 55.1 | 7:16 |
| 19 | 3.70 | 11.0 | 8.0 | 249.7 | 18.3 | 21.4 | 391.1 | 346.7 | 44.4 | 88.6 | 25.1 | 22.2 | 8219 | 57.6 | 62.3 | 6:33 |
| 19 | 3.70 | 11.0 | 9.0 | 249.7 | 20.0 | 21.2 | 424.7 | 376.7 | 48.0 | 88.7 | 27.2 | 24.1 | 8125 | 63.3 | 69.2 | 6:00 |
| 19 | 3.70 | 11.0 | 10.0 | 249.7 | 21.6 | 21.1 | 456.4 | 404.6 | 51.8 | 88.6 | 29.2 | 25.9 | 8034 | 68.7 | 76.1 | 5:33 |
| 19 | 3.70 | 11.0 | 11.0 | 249.7 | 23.2 | 21.0 | 486.5 | 430.8 | 55.7 | 88.5 | 31.2 | 27.6 | 7947 | 74.0 | 82.8 | 5:11 |
| 19 | 3.70 | 11.0 | 12.0 | 249.7 | 24.7 | 20.9 | 515.0 | 455.2 | 59.8 | 88.4 | 33.0 | 29.2 | 7863 | 79.0 | 89.4 | 4:52 |
| 19 | 3.70 | 11.0 | 13.0 | 249.7 | 26.1 | 20.8 | 542.1 | 478.2 | 63.9 | 88.2 | 34.7 | 30.6 | 7783 | 83.8 | 95.8 | 4:36 |

# In-Flight Analysis - Eddy Bee at 87% Throttle

**Motor:** Aveox 1406/4Y; 1500 RPM/V; 0.06 Ohms; 1.2A idle.
**Battery:** Sanyo 2000SCR; 17 cells; 2000mAh; 0.004 Ohms/cell.
**Speed Control:** Astro 211; 0.002 Ohms.
**Drive System:** Aveox/Robbe 3.7:1 Gearbox; 14x9 geared 3.7:1.
**Airframe:** Eddy Bee; 702sq.in; 245.6oz; 50.4oz/sq.ft; Cd=0.063; Cl=0.7; Clmax=1.24.
**Filter:** 50A max, 75A max (ESC).
**Stats:** 27 W/lb in; 23 W/lb out; 32 MPH stall; 42 MPH level @ 87% (12:06); 127ft/min @ 2.6°; -266ft/min @ -5.5°.

| AirSpd (MPH) | EPitch (in) | Drag (oz) | Lift (oz) | Amps | Volts | Input (W) | Output (W) | Loss (W) | Effic (%) | Prop RPM | Thrust (oz) | PSpd (MPH) | Time (m:s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 9.00 | 0.0 | 0.0 | 26.4 | 15.9 | 419.4 | 360.5 | 58.9 | 86.0 | 5805 | 66.6 | 49.5 | 4:33 |
| 1.0 | 8.82 | 0.0 | 0.1 | 26.0 | 15.9 | 414.5 | 356.6 | 57.9 | 86.0 | 5824 | 65.7 | 48.6 | 4:37 |
| 2.0 | 8.64 | 0.1 | 0.6 | 25.7 | 16.0 | 409.5 | 352.7 | 56.8 | 86.1 | 5842 | 64.7 | 47.8 | 4:40 |
| 3.0 | 8.46 | 0.1 | 1.3 | 25.3 | 16.0 | 404.5 | 348.7 | 55.8 | 86.2 | 5861 | 63.8 | 47.0 | 4:44 |
| 4.0 | 8.28 | 0.2 | 2.2 | 25.0 | 16.0 | 399.4 | 344.6 | 54.8 | 86.3 | 5879 | 62.8 | 46.1 | 4:48 |
| 5.0 | 8.10 | 0.3 | 3.5 | 24.6 | 16.0 | 394.3 | 340.5 | 53.8 | 86.4 | 5898 | 61.9 | 45.3 | 4:53 |
| 6.0 | 7.93 | 0.5 | 5.0 | 24.2 | 16.1 | 389.2 | 336.4 | 52.8 | 86.4 | 5917 | 60.9 | 44.4 | 4:57 |
| 7.0 | 7.75 | 0.6 | 6.8 | 23.9 | 16.1 | 384.0 | 332.2 | 51.8 | 86.5 | 5936 | 60.0 | 43.6 | 5:01 |
| 8.0 | 7.58 | 0.8 | 8.9 | 23.5 | 16.1 | 378.7 | 327.9 | 50.8 | 86.6 | 5955 | 59.0 | 42.8 | 5:06 |
| 9.0 | 7.41 | 1.0 | 11.3 | 23.2 | 16.1 | 373.4 | 323.6 | 49.9 | 86.6 | 5975 | 58.1 | 41.9 | 5:11 |
| 10.0 | 7.24 | 1.3 | 14.0 | 22.8 | 16.2 | 368.1 | 319.2 | 48.9 | 86.7 | 5994 | 57.1 | 41.1 | 5:16 |
| 11.0 | 7.07 | 1.5 | 16.9 | 22.4 | 16.2 | 362.7 | 314.8 | 48.0 | 86.8 | 6014 | 56.1 | 40.3 | 5:21 |
| 12.0 | 6.90 | 1.8 | 20.1 | 22.0 | 16.2 | 357.3 | 310.2 | 47.0 | 86.8 | 6033 | 55.1 | 39.4 | 5:27 |
| 13.0 | 6.73 | 2.1 | 23.6 | 21.7 | 16.2 | 351.8 | 305.7 | 46.1 | 86.9 | 6053 | 54.1 | 38.6 | 5:32 |
| 14.0 | 6.57 | 2.5 | 27.4 | 21.3 | 16.3 | 346.2 | 301.1 | 45.2 | 86.9 | 6073 | 53.2 | 37.8 | 5:38 |
| 15.0 | 6.40 | 2.8 | 31.4 | 20.9 | 16.3 | 340.7 | 296.4 | 44.3 | 87.0 | 6093 | 52.2 | 36.9 | 5:44 |
| 16.0 | 6.24 | 3.2 | 35.7 | 20.5 | 16.3 | 335.0 | 291.6 | 43.4 | 87.0 | 6113 | 51.1 | 36.1 | 5:51 |
| 17.0 | 6.07 | 3.6 | 40.3 | 20.2 | 16.3 | 329.3 | 286.8 | 42.5 | 87.1 | 6133 | 50.1 | 35.3 | 5:57 |
| 18.0 | 5.91 | 4.1 | 45.2 | 19.8 | 16.4 | 323.6 | 281.9 | 41.7 | 87.1 | 6153 | 49.1 | 34.4 | 6:04 |
| 19.0 | 5.75 | 4.5 | 50.4 | 19.4 | 16.4 | 317.8 | 277.0 | 40.8 | 87.2 | 6173 | 48.1 | 33.6 | 6:11 |
| 20.0 | 5.59 | 5.0 | 55.8 | 19.0 | 16.4 | 312.0 | 272.0 | 40.0 | 87.2 | 6194 | 47.1 | 32.8 | 6:19 |
| 21.0 | 5.43 | 5.5 | 61.5 | 18.6 | 16.4 | 306.1 | 266.9 | 39.2 | 87.2 | 6214 | 46.0 | 32.0 | 6:27 |
| 22.0 | 5.27 | 6.1 | 67.5 | 18.2 | 16.5 | 300.1 | 261.7 | 38.4 | 87.2 | 6235 | 45.0 | 31.1 | 6:35 |
| 23.0 | 5.12 | 6.6 | 73.8 | 17.8 | 16.5 | 294.1 | 256.5 | 37.6 | 87.2 | 6256 | 44.0 | 30.3 | 6:44 |
| 24.0 | 4.96 | 7.2 | 80.4 | 17.4 | 16.5 | 288.1 | 251.2 | 36.8 | 87.2 | 6277 | 42.9 | 29.5 | 6:53 |
| 25.0 | 4.81 | 7.9 | 87.2 | 17.0 | 16.6 | 281.9 | 245.9 | 36.0 | 87.2 | 6298 | 41.9 | 28.7 | 7:03 |
| 26.0 | 4.65 | 8.5 | 94.3 | 16.6 | 16.6 | 275.8 | 240.5 | 35.3 | 87.2 | 6319 | 40.8 | 27.9 | 7:13 |
| 27.0 | 4.50 | 9.2 | 101.7 | 16.2 | 16.6 | 269.5 | 235.0 | 34.6 | 87.2 | 6340 | 39.7 | 27.0 | 7:24 |
| 28.0 | 4.35 | 9.8 | 109.4 | 15.8 | 16.6 | 263.2 | 229.4 | 33.8 | 87.1 | 6361 | 38.7 | 26.2 | 7:35 |
| 29.0 | 4.20 | 10.6 | 117.4 | 15.4 | 16.7 | 256.9 | 223.8 | 33.1 | 87.1 | 6383 | 37.6 | 25.4 | 7:47 |
| 30.0 | 4.05 | 11.3 | 125.6 | 15.0 | 16.7 | 250.5 | 218.0 | 32.5 | 87.0 | 6404 | 36.5 | 24.6 | 8:00 |
| 31.0 | 3.91 | 12.1 | 134.1 | 14.6 | 16.7 | 244.0 | 212.2 | 31.8 | 87.0 | 6426 | 35.4 | 23.8 | 8:13 |
| 32.0 | 3.76 | 12.9 | 142.9 | 14.2 | 16.8 | 237.5 | 206.4 | 31.1 | 86.9 | 6448 | 34.3 | 23.0 | 8:28 |
| 33.0 | 3.61 | 13.7 | 152.0 | 13.8 | 16.8 | 230.9 | 200.4 | 30.5 | 86.8 | 6470 | 33.2 | 22.1 | 8:43 |
| 34.0 | 3.47 | 14.5 | 161.3 | 13.3 | 16.8 | 224.3 | 194.4 | 29.9 | 86.7 | 6492 | 32.1 | 21.3 | 9:00 |
| 35.0 | 3.33 | 15.4 | 171.0 | 12.9 | 16.8 | 217.6 | 188.3 | 29.3 | 86.5 | 6514 | 31.0 | 20.5 | 9:17 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36.0 | 3.18 | 16.3 | 180.9 | 12.5 | 16.9 | 210.8 | 182.1 | 28.7 | 86.4 | 6537 | 29.9 | 19.7 | 9:36 |
| 37.0 | 3.04 | 17.2 | 191.1 | 12.1 | 16.9 | 204.0 | 175.8 | 28.2 | 86.2 | 6559 | 28.7 | 18.9 | 9:57 |
| 38.0 | 2.90 | 18.1 | 201.5 | 11.6 | 16.9 | 197.1 | 169.5 | 27.6 | 86.0 | 6582 | 27.6 | 18.1 | 10:19 |
| 39.0 | 2.76 | 19.1 | 212.3 | 11.2 | 17.0 | 190.1 | 163.1 | 27.1 | 85.8 | 6604 | 26.5 | 17.3 | 10:42 |
| 40.0 | 2.63 | 20.1 | 223.3 | 10.8 | 17.0 | 183.1 | 156.5 | 26.6 | 85.5 | 6627 | 25.3 | 16.5 | 11:08 |
| 41.0 | 2.49 | 21.1 | 234.6 | 10.3 | 17.0 | 176.0 | 149.9 | 26.1 | 85.2 | 6650 | 24.2 | 15.7 | 11:36 |
| 42.0 | 2.35 | 22.2 | 246.2 | 9.9 | 17.1 | 168.9 | 143.2 | 25.6 | 84.8 | 6673 | 23.0 | 14.9 | 12:07 |
| 43.0 | 2.22 | 23.2 | 258.0 | 9.5 | 17.1 | 161.7 | 136.5 | 25.2 | 84.4 | 6696 | 21.8 | 14.1 | 12:41 |
| 44.0 | 2.09 | 24.3 | 270.2 | 9.0 | 17.1 | 154.4 | 129.6 | 24.8 | 84.0 | 6720 | 20.7 | 13.3 | 13:18 |
| 45.0 | 1.95 | 25.4 | 282.6 | 8.6 | 17.1 | 147.0 | 122.6 | 24.4 | 83.4 | 6743 | 19.5 | 12.5 | 14:00 |
| 46.0 | 1.82 | 26.6 | 295.3 | 8.1 | 17.2 | 139.6 | 115.6 | 24.0 | 82.8 | 6767 | 18.3 | 11.7 | 14:46 |
| 47.0 | 1.69 | 27.7 | 308.3 | 7.7 | 17.2 | 132.1 | 108.4 | 23.6 | 82.1 | 6791 | 17.1 | 10.9 | 15:38 |
| 48.0 | 1.56 | 28.9 | 321.5 | 7.2 | 17.2 | 124.5 | 101.2 | 23.3 | 81.3 | 6815 | 15.9 | 10.1 | 16:37 |
| 49.0 | 1.43 | 30.2 | 335.1 | 6.8 | 17.3 | 116.9 | 93.9 | 23.0 | 80.3 | 6839 | 14.7 | 9.3 | 17:44 |
| 50.0 | 1.31 | 31.4 | 348.9 | 6.3 | 17.3 | 109.2 | 86.5 | 22.7 | 79.2 | 6863 | 13.5 | 8.5 | 19:01 |
| 51.0 | 1.18 | 32.7 | 363.0 | 5.8 | 17.3 | 101.4 | 78.9 | 22.4 | 77.9 | 6887 | 12.3 | 7.7 | 20:31 |
| 52.0 | 1.06 | 34.0 | 377.4 | 5.4 | 17.4 | 93.5 | 71.3 | 22.2 | 76.3 | 6911 | 11.1 | 6.9 | 22:17 |
| 53.0 | 0.93 | 35.3 | 392.0 | 4.9 | 17.4 | 85.6 | 63.6 | 22.0 | 74.3 | 6936 | 9.8 | 6.1 | 24:24 |
| 54.0 | 1.66 | 36.6 | 406.9 | 9.5 | 19.7 | 187.8 | 159.4 | 28.4 | 84.9 | 7769 | 22.0 | 12.2 | 12:37 |
| 55.0 | 1.55 | 38.0 | 422.2 | 9.0 | 19.8 | 178.2 | 150.3 | 28.0 | 84.3 | 7795 | 20.7 | 11.4 | 13:19 |
| 56.0 | 1.44 | 39.4 | 437.7 | 8.5 | 19.8 | 168.6 | 141.1 | 27.5 | 83.7 | 7822 | 19.3 | 10.7 | 14:06 |
| 57.0 | 1.33 | 40.8 | 453.4 | 8.0 | 19.8 | 158.8 | 131.7 | 27.1 | 83.0 | 7848 | 18.0 | 9.9 | 14:59 |
| 58.0 | 1.22 | 42.3 | 469.5 | 7.5 | 19.9 | 149.0 | 122.3 | 26.7 | 82.1 | 7875 | 16.6 | 9.1 | 16:01 |
| 59.0 | 1.12 | 43.7 | 485.8 | 7.0 | 19.9 | 139.1 | 112.7 | 26.3 | 81.1 | 7902 | 15.3 | 8.4 | 17:11 |
| 60.0 | 1.01 | 45.2 | 502.4 | 6.5 | 19.9 | 129.0 | 103.1 | 26.0 | 79.9 | 7929 | 13.9 | 7.6 | 18:33 |
| 61.0 | 0.90 | 46.7 | 519.3 | 6.0 | 20.0 | 118.9 | 93.3 | 25.7 | 78.4 | 7957 | 12.6 | 6.8 | 20:10 |
| 62.0 | 0.80 | 48.3 | 536.5 | 5.4 | 20.0 | 108.8 | 83.3 | 25.4 | 76.6 | 7984 | 11.2 | 6.0 | 22:05 |
| 63.0 | 0.70 | 49.9 | 553.9 | 4.9 | 20.1 | 98.5 | 73.3 | 25.2 | 74.4 | 8012 | 9.8 | 5.3 | 24:27 |
| 64.0 | 0.59 | 51.4 | 571.6 | 4.4 | 20.1 | 88.1 | 63.1 | 24.9 | 71.7 | 8039 | 8.4 | 4.5 | 27:22 |
| 65.0 | 0.49 | 53.1 | 589.6 | 3.9 | 20.1 | 77.6 | 52.8 | 24.8 | 68.1 | 8067 | 7.0 | 3.8 | 31:07 |
| 66.0 | 0.39 | 54.7 | 607.9 | 3.3 | 20.2 | 67.0 | 42.4 | 24.6 | 63.3 | 8095 | 5.6 | 3.0 | 36:06 |
| 67.0 | 0.29 | 56.4 | 626.5 | 2.8 | 20.2 | 56.4 | 31.9 | 24.5 | 56.5 | 8123 | 4.2 | 2.2 | 43:00 |
| 68.0 | 0.19 | 58.1 | 645.3 | 2.3 | 20.2 | 45.6 | 21.2 | 24.4 | 46.4 | 8151 | 2.8 | 1.5 | 53:14 |
| 69.0 | 0.09 | 59.8 | 664.4 | 1.7 | 20.3 | 34.9 | 10.4 | 24.4 | 29.9 | 8180 | 1.4 | 0.7 | 70:00 |

# In-Flight Analysis - Eddy Bee

**Motor:** Aveox 1406/4Y; 1500 RPM/V; 0.06 Ohms; 1.2A idle.
**Battery:** Sanyo 2000SCR; 17 cells; 2000mAh; 0.004 Ohms/cell.
**Speed Control:** Astro 211; 0.002 Ohms.
**Drive System:** Aveox/Robbe 3.7:1 Gearbox; 14x9 geared 3.7:1.
**Airframe:** Eddy Bee; 702sq.in; 245.6oz; 50.4oz/sq.ft; Cd=0.063; Cl=0.7; Clmax=1.24.
**Filter:** 50A max, 75A max (ESC).
**Stats:** 39 W/lb in; 33 W/lb out; 32 MPH stall; 42 MPH level @ 87% (12:06); 300ft/min @ 6.2°; -266ft/min @ -5.5°.

| AirSpd (MPH) | EPitch (in) | Drag (oz) | Lift (oz) | Amps | Volts | Input (W) | Output (W) | Loss (W) | Effic (%) | Prop RPM | Thrust (oz) | PSpd (MPH) | Time (m:s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 9.00 | 0.0 | 0.0 | 33.0 | 18.1 | 597.7 | 512.8 | 84.8 | 85.8 | 6529 | 84.2 | 55.6 | 3:38 |
| 1.0 | 8.84 | 0.0 | 0.1 | 32.7 | 18.1 | 591.7 | 508.3 | 83.4 | 85.9 | 6549 | 83.2 | 54.8 | 3:40 |
| 2.0 | 8.68 | 0.1 | 0.6 | 32.3 | 18.1 | 585.6 | 503.7 | 82.0 | 86.0 | 6569 | 82.2 | 54.0 | 3:43 |
| 3.0 | 8.52 | 0.1 | 1.3 | 31.9 | 18.2 | 579.6 | 499.0 | 80.6 | 86.1 | 6589 | 81.2 | 53.2 | 3:46 |
| 4.0 | 8.36 | 0.2 | 2.2 | 31.5 | 18.2 | 573.4 | 494.3 | 79.2 | 86.2 | 6609 | 80.2 | 52.3 | 3:48 |
| 5.0 | 8.20 | 0.3 | 3.5 | 31.1 | 18.2 | 567.2 | 489.5 | 77.8 | 86.3 | 6630 | 79.2 | 51.5 | 3:51 |
| 6.0 | 8.05 | 0.5 | 5.0 | 30.7 | 18.2 | 561.0 | 484.6 | 76.4 | 86.4 | 6650 | 78.1 | 50.7 | 3:54 |
| 7.0 | 7.89 | 0.6 | 6.8 | 30.4 | 18.3 | 554.7 | 479.7 | 75.0 | 86.5 | 6671 | 77.1 | 49.9 | 3:57 |
| 8.0 | 7.74 | 0.8 | 8.9 | 30.0 | 18.3 | 548.3 | 474.7 | 73.7 | 86.6 | 6691 | 76.1 | 49.0 | 4:00 |
| 9.0 | 7.58 | 1.0 | 11.3 | 29.6 | 18.3 | 541.9 | 469.6 | 72.3 | 86.7 | 6712 | 75.0 | 48.2 | 4:04 |
| 10.0 | 7.43 | 1.3 | 14.0 | 29.2 | 18.4 | 535.5 | 464.5 | 71.0 | 86.7 | 6733 | 74.0 | 47.4 | 4:07 |
| 11.0 | 7.28 | 1.5 | 16.9 | 28.8 | 18.4 | 528.9 | 459.3 | 69.6 | 86.8 | 6754 | 72.9 | 46.6 | 4:10 |
| 12.0 | 7.13 | 1.8 | 20.1 | 28.4 | 18.4 | 522.4 | 454.0 | 68.3 | 86.9 | 6775 | 71.8 | 45.7 | 4:14 |
| 13.0 | 6.98 | 2.1 | 23.6 | 28.0 | 18.4 | 515.7 | 448.7 | 67.0 | 87.0 | 6796 | 70.8 | 44.9 | 4:17 |
| 14.0 | 6.83 | 2.5 | 27.4 | 27.6 | 18.5 | 509.1 | 443.3 | 65.8 | 87.1 | 6818 | 69.7 | 44.1 | 4:21 |
| 15.0 | 6.68 | 2.8 | 31.4 | 27.2 | 18.5 | 502.3 | 437.8 | 64.5 | 87.2 | 6839 | 68.6 | 43.3 | 4:25 |
| 16.0 | 6.54 | 3.2 | 35.7 | 26.7 | 18.5 | 495.5 | 432.3 | 63.2 | 87.2 | 6861 | 67.6 | 42.5 | 4:29 |
| 17.0 | 6.39 | 3.6 | 40.3 | 26.3 | 18.6 | 488.6 | 426.7 | 62.0 | 87.3 | 6882 | 66.5 | 41.7 | 4:33 |
| 18.0 | 6.25 | 4.1 | 45.2 | 25.9 | 18.6 | 481.7 | 421.0 | 60.7 | 87.4 | 6904 | 65.4 | 40.8 | 4:38 |
| 19.0 | 6.10 | 4.5 | 50.4 | 25.5 | 18.6 | 474.7 | 415.2 | 59.5 | 87.5 | 6926 | 64.3 | 40.0 | 4:42 |
| 20.0 | 5.96 | 5.0 | 55.8 | 25.1 | 18.6 | 467.7 | 409.4 | 58.3 | 87.5 | 6948 | 63.2 | 39.2 | 4:47 |
| 21.0 | 5.82 | 5.5 | 61.5 | 24.7 | 18.7 | 460.6 | 403.5 | 57.1 | 87.6 | 6970 | 62.1 | 38.4 | 4:52 |
| 22.0 | 5.68 | 6.1 | 67.5 | 24.2 | 18.7 | 453.4 | 397.5 | 56.0 | 87.7 | 6993 | 60.9 | 37.6 | 4:57 |
| 23.0 | 5.54 | 6.6 | 73.8 | 23.8 | 18.7 | 446.2 | 391.4 | 54.8 | 87.7 | 7015 | 59.8 | 36.8 | 5:02 |
| 24.0 | 5.40 | 7.2 | 80.4 | 23.4 | 18.8 | 438.9 | 385.3 | 53.7 | 87.8 | 7037 | 58.7 | 36.0 | 5:08 |
| 25.0 | 5.26 | 7.9 | 87.2 | 23.0 | 18.8 | 431.6 | 379.0 | 52.5 | 87.8 | 7060 | 57.6 | 35.2 | 5:14 |
| 26.0 | 5.12 | 8.5 | 94.3 | 22.5 | 18.8 | 424.2 | 372.7 | 51.4 | 87.9 | 7083 | 56.4 | 34.4 | 5:20 |
| 27.0 | 4.99 | 9.2 | 101.7 | 22.1 | 18.9 | 416.7 | 366.3 | 50.3 | 87.9 | 7105 | 55.3 | 33.6 | 5:26 |
| 28.0 | 4.85 | 9.8 | 109.4 | 21.7 | 18.9 | 409.1 | 359.9 | 49.3 | 88.0 | 7128 | 54.1 | 32.8 | 5:32 |
| 29.0 | 4.72 | 10.6 | 117.4 | 21.2 | 18.9 | 401.5 | 353.3 | 48.2 | 88.0 | 7151 | 53.0 | 32.0 | 5:39 |
| 30.0 | 4.58 | 11.3 | 125.6 | 20.8 | 18.9 | 393.9 | 346.7 | 47.2 | 88.0 | 7175 | 51.8 | 31.1 | 5:46 |
| 31.0 | 4.45 | 12.1 | 134.1 | 20.3 | 19.0 | 386.1 | 340.0 | 46.1 | 88.0 | 7198 | 50.6 | 30.3 | 5:54 |
| 32.0 | 4.32 | 12.9 | 142.9 | 19.9 | 19.0 | 378.3 | 333.2 | 45.1 | 88.1 | 7221 | 49.5 | 29.5 | 6:02 |
| 33.0 | 4.19 | 13.7 | 152.0 | 19.5 | 19.0 | 370.4 | 326.3 | 44.2 | 88.1 | 7245 | 48.3 | 28.7 | 6:10 |
| 34.0 | 4.06 | 14.5 | 161.3 | 19.0 | 19.1 | 362.5 | 319.3 | 43.2 | 88.1 | 7269 | 47.1 | 27.9 | 6:19 |
| 35.0 | 3.93 | 15.4 | 171.0 | 18.6 | 19.1 | 354.4 | 312.2 | 42.2 | 88.1 | 7292 | 45.9 | 27.2 | 6:28 |
| 36.0 | 3.80 | 16.3 | 180.9 | 18.1 | 19.1 | 346.4 | 305.0 | 41.3 | 88.1 | 7316 | 44.7 | 26.4 | 6:38 |
| 37.0 | 3.68 | 17.2 | 191.1 | 17.6 | 19.2 | 338.2 | 297.8 | 40.4 | 88.1 | 7340 | 43.5 | 25.6 | 6:48 |
| 38.0 | 3.55 | 18.1 | 201.5 | 17.2 | 19.2 | 330.0 | 290.4 | 39.5 | 88.0 | 7364 | 42.3 | 24.8 | 6:59 |
| 39.0 | 3.43 | 19.1 | 212.3 | 16.7 | 19.2 | 321.6 | 283.0 | 38.7 | 88.0 | 7389 | 41.1 | 24.0 | 7:10 |
| 40.0 | 3.30 | 20.1 | 223.3 | 16.3 | 19.3 | 313.3 | 275.5 | 37.8 | 87.9 | 7413 | 39.8 | 23.2 | 7:23 |
| 41.0 | 3.18 | 21.1 | 234.6 | 15.8 | 19.3 | 304.8 | 267.8 | 37.0 | 87.9 | 7438 | 38.6 | 22.4 | 7:36 |
| 42.0 | 3.06 | 22.2 | 246.2 | 15.3 | 19.3 | 296.3 | 260.1 | 36.2 | 87.8 | 7462 | 37.4 | 21.6 | 7:50 |
| 43.0 | 2.94 | 23.2 | 258.0 | 14.9 | 19.4 | 287.7 | 252.3 | 35.4 | 87.7 | 7487 | 36.1 | 20.8 | 8:05 |
| 44.0 | 2.81 | 24.3 | 270.2 | 14.4 | 19.4 | 279.0 | 244.3 | 34.7 | 87.6 | 7512 | 34.9 | 20.0 | 8:20 |
| 45.0 | 2.70 | 25.4 | 282.6 | 13.9 | 19.4 | 270.2 | 236.3 | 33.9 | 87.4 | 7537 | 33.6 | 19.2 | 8:38 |
| 46.0 | 2.58 | 26.6 | 295.3 | 13.4 | 19.5 | 261.4 | 228.2 | 33.2 | 87.3 | 7562 | 32.3 | 18.5 | 8:56 |
| 47.0 | 2.46 | 27.7 | 308.3 | 13.0 | 19.5 | 252.5 | 220.0 | 32.5 | 87.1 | 7588 | 31.1 | 17.7 | 9:16 |
| 48.0 | 2.34 | 28.9 | 321.5 | 12.5 | 19.5 | 243.5 | 211.6 | 31.9 | 86.9 | 7613 | 29.8 | 16.9 | 9:37 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49.0 | 2.23 | 30.2 | 335.1 | 12.0 | 19.6 | 234.4 | 203.2 | 31.2 | 86.7 | 7639 | 28.5 | 16.1 | 10:01 |
| 50.0 | 2.11 | 31.4 | 348.9 | 11.5 | 19.6 | 225.3 | 194.6 | 30.6 | 86.4 | 7664 | 27.2 | 15.3 | 10:26 |
| 51.0 | 2.00 | 32.7 | 363.0 | 11.0 | 19.6 | 216.0 | 186.0 | 30.0 | 86.1 | 7690 | 25.9 | 14.5 | 10:54 |
| 52.0 | 1.88 | 34.0 | 377.4 | 10.5 | 19.7 | 206.7 | 177.2 | 29.5 | 85.7 | 7716 | 24.6 | 13.8 | 11:25 |
| 53.0 | 1.77 | 35.3 | 392.0 | 10.0 | 19.7 | 197.3 | 168.4 | 28.9 | 85.3 | 7742 | 23.3 | 13.0 | 11:59 |
| 54.0 | 0.81 | 36.6 | 406.9 | 4.4 | 17.4 | 77.6 | 55.8 | 21.8 | 71.9 | 6961 | 8.6 | 5.3 | 26:58 |
| 55.0 | 0.69 | 38.0 | 422.2 | 4.0 | 17.5 | 69.5 | 47.9 | 21.6 | 68.9 | 6985 | 7.3 | 4.5 | 30:10 |
| 56.0 | 0.56 | 39.4 | 437.7 | 3.5 | 17.5 | 61.3 | 39.8 | 21.5 | 65.0 | 7010 | 6.1 | 3.8 | 34:15 |
| 57.0 | 0.44 | 40.8 | 453.4 | 3.0 | 17.5 | 53.1 | 31.7 | 21.4 | 59.7 | 7036 | 4.8 | 3.0 | 39:38 |
| 58.0 | 0.33 | 42.3 | 469.5 | 2.5 | 17.6 | 44.8 | 23.5 | 21.3 | 52.5 | 7061 | 3.6 | 2.2 | 47:05 |
| 59.0 | 0.21 | 43.7 | 485.8 | 2.1 | 17.6 | 36.4 | 15.2 | 21.2 | 41.6 | 7086 | 2.3 | 1.4 | 58:03 |
| 60.0 | 0.09 | 45.2 | 502.4 | 1.6 | 17.6 | 27.9 | 6.7 | 21.2 | 24.0 | 7112 | 1.0 | 0.6 | 75:50 |

## APPENDIX IX

### PERFORMANCE CALCULATIONS

Type: Motor & Battery [redacted]

| Dimensions: | | Weights: | | |
|---|---|---|---|---|
| Span: | [redacted] ft | Wing: | [redacted] lb | |
| Root Chord: | [redacted] ft | Fuselage | [redacted] lb | |
| Tip Chord | [redacted] ft | Stabilator: | [redacted] lb | |
| Taper Ratio | 0.5 | Battery Pack | [redacted] lb | (Maximum) 2.5 |
| Mean Chord (geometrical): | 0.75 ft | Undercarriage: | [redacted] lb | |
| Mean Chord (dynamical): | 0.788 ft | Motor (with Gear and Prop.): | [redacted] lb | |
| Wing Area: | 4.875 ft² | Payload: | [redacted] lb | (Maximum) 7.5 |
| Wing Aspect Ratio: | 8.67 | RC-Equipment: | [redacted] lb | |
| Wing Loading: | 3.03 lb/ft² | | | |
| Total Area Loading (incl. stab.): | 2.52 lb/ft² | Total Weight: | 14.748 lb | |
| Length of Fuselage: | [redacted] ft | | | |
| Height of Fuselage: | [redacted] ft | | | |
| Width of Fuselage: | [redacted] ft | | | |
| Stab. Lever Distance: | [redacted] ft | | | |
| Parasitic Drag Area | 0.1056 ft² | | | |
| Stab. Span: | [redacted] ft | | | |
| Stab mean Chord | [redacted] ft | | | |
| Stab. Area | 0.975 ft² | | | |
| Stab. Aspect Ratio. | 2.31 | | | |
| Vert. Stab Area(Vertical Tail Area) | 0.4875 ft² | | | |
| Fin Height | 1.16 ft | | | |
| Fin Mean chord | 0.42 ft | | | |
| Rudder Area | 0.195 ft² | | | |
| Elevators area if used | 0.2535 ft2 | | | |
| ENGINE lOCATION | 1.625 ft | | | |
| Nose length | 1 ft | | | |
| Fin offset from wing L.E | 0.6 ft | | | |
| Aerdynamic Center | 1.1875 ft | from prop driver | | |
| Wing TE to stab LE | 1 ft | | | |

How to use this spreadsheet:
Before changing any variables in the purple cells, make a safety copy from this file.
SI dimensions must be used, otherwise the values will not calculate correctly.
For different profiles than indicated, you may change the factor 1.2 under Cd. For a 12% thick airfoil (like Clark Y) it should be 1.5.
The power values listed are the ones required by the plane. To get the values for your drive you must divide these values by the efficiency of your drive, usually around 0.6 - 0.7
1 ft/sec = 0.7 mph

Wing profile NACA 23012

| Velocity ft/sec | Dynamic Pressure q(lb/ft²) | Wing $C_L$ | RE-No. | RE-No. corrected $C_{d,o}$ | $C_{D,O}$ | $C_{Di}$ | $C_D$ | Glideangle $C_L/C_D$ | Resistance Thrust T(lb) | Resistance Thrust T(ounces) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 0 | 0.00000 | 0.00500 | 0.00000 | 0 | 0.00 | 0.00 | 0.00 |
| 15 | 0.27 | 11.31 | 75,178 | 2.40000 | 0.00500 | 4.94798 | 7.353 | 1.54 | 9.59 | 153 37 |
| 20 | 0.48 | 6.36 | 100,237 | 0.18000 | 0.00500 | 1.56557 | 1.751 | 3.64 | 4.06 | 64 91 |
| 30 | 1.07 | 2.83 | 150,355 | 0.12000 | 0.00500 | 0.30925 | 0.434 | 6.51 | 2.26 | 36.23 |
| 35 | 1 46 | 2.08 | 175,414 | 0.06000 | 0.00500 | 0.16692 | 0.232 | 8.96 | 1 65 | 26.34 |
| 40 | 1.90 | 1.59 | 200,474 | 0.02400 | 0.00500 | 0.09785 | 0.127 | 12.54 | 1.18 | 18.81 |
| 45 | 2.41 | 1.26 | 225,533 | 0.02520 | 0.00500 | 0.06109 | 0.091 | 13.77 | 1.07 | 17.14 |
| 60 | 4.28 | 0.71 | 300,710 | 0.00900 | 0.00500 | 0.01933 | 0.033 | 21.22 | 0.70 | 11.12 |
| 75 | 6.69 | 0 45 | 375,888 | 0.00816 | 0.00500 | 0.00792 | 0.021 | 21 47 | 0.69 | 10.99 |
| 90 | 9.63 | 0 31 | 451,065 | 0.00804 | 0.00500 | 0.00382 | 0.017 | 18.64 | 0.79 | 12.66 |
| 105 | 13 10 | 0.23 | 526,243 | 0.00744 | 0.00500 | 0.00206 | 0 015 | 15.92 | 0.93 | 14.82 |

| Loadfactor | CL | ft/sec | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3.1 g | 0.5 | 125.62 | 5.99E+05 | 0.007 | 0.005 | 0.0092 | 0.0212 | 23.6049 | 2.32 |
| 4 g | 0.6 | 130.27 | 6.21E+05 | 0.0072 | 0.005 | 0.0132 | 0.0254 | 23.6015 | 3.00 |
| 5 9 g | 0.7 | 146.47 | 6.99E+05 | 0.0077 | 0.005 | 0.0180 | 0.0307 | 22.8037 | 4.58 |

| Wing Dimensions | | |
|---|---|---|
| Chord c | [redacted] | ft |
| Wing Span b | [redacted] | ft |
| e(for elliptic wing) | [redacted] | |
| Wing Area S | 4.875 | $ft^2$ |
| Aspect Ratio | 8.666667 | |

**Airfoil Data**

[redacted]

| | |
|---|---|
| Thickness | [redacted] |
| Max. Camber located at feet from L.E | [redacted] |

[redacted]

**Maximum Weight of Aircraft** [redacted] lb

**Since dealing with a finite wing, need to obtain slope. The wing slope, $a_0$ can be obtained from any two points the linear curve.**
**Also we can assume that the Reynolds Number will not be higher than 5 x $10^6$**

| | Angle of Attack | Coeficient of cl | cd(at zero lift) |
|---|---|---|---|
| Alpha1 | [redacted] | | |
| Alpha2 | | | |
| Alpha at zero | [redacted] | | [redacted] |

| | |
|---|---|
| $a_0$(per degree) | 0.106 |
| **a** | 0.085834 |

$C_{Lmax}$ 1.24

| Angle of Attack of Wing | CL | CD |
|---|---|---|
| 0 | 0.1287513 | 0.00685451 |
| 1 | 0.2145855 | 0.00837363 |
| 2 | 0.30041969 | 0.01065232 |
| 3 | 0.38625389 | 0.01369058 |
| 4 | 0.47208809 | 0.01748839 |
| 5 | 0.55792229 | 0.02204577 |
| 6 | 0.64375649 | 0.02736271 |
| 7 | 0.72959068 | 0.03343922 |
| 8 | 0.81542488 | 0.04027529 |
| 9 | 0.90125908 | 0.04787092 |
| 10 | 0.98709328 | 0.05622611 |
| 11 | 1.07292748 | 0.06534087 |
| 12 | 1.15876168 | 0.07521519 |
| 13 | 1.24459587 | 0.08584907 |
| 14 | 1.33043007 | 0.09724252 |
| 15 | 1.41626427 | 0.10939553 |
| 16 | 1.50209847 | 0.1223081 |
| 17 | 1.58793267 | 0.13598024 |
| 18 | 1.67376686 | 0.15041194 |

**Performance:**

| | |
|---|---|
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] Turn Radius | [illegible] |
| [illegible] | |
| [illegible] | |
| [illegible] | |
| **Lift-off Distance** | 167.88 [illegible] |
| [illegible] Fraction | [illegible] |

SPECIFIC FUSELAGE MATERIAL COST ESTIMATIONS

## Fiberglass only

| Catlg # | Part name | Material | Amount/Qnty | Qnty | Cost / item | Cost |
|---|---|---|---|---|---|---|
| **FibreGlast Developments Corp** | | | | | | |
| 1094-B | Bi-directional E-Glass | 9 oz Fiberglass | 3 yards | 1 | 19.95 | 19.95 |
| 543-A | Style 7781 E-Glass | 9 oz Fiberglass | 1 yard | 1 | 12.95 | 12.95 |
| 2000-A | System 2000 Epoxy Resin | Epoxy resin | 1 quart | 1 | 24.95 | 24.95 |
| 2120-A | 2120 Epoxy Hardener | Epoxy Hardener | 1/2 pint | 1 | 9.95 | 9.95 |
| 1016-A | Parting Wax | Mold Wax | 24 oz. | 1 | 8.95 | 8.95 |
| 13-A | PVA Release Film | Mold Release Mat. | 1 quart | 1 | 8.95 | 8.95 |
| 577-B | Polyethelene Bagging Film | Vacume Bagging | 3 yards | 1 | 6.95 | 6.95 |
| 579-B | Breather/Bleeder | Molding Mat. | 3 yards | 1 | 16.95 | 16.95 |
| 582-B | Nylon Release Peel Ply | Molding Mat. | 3 yards | 1 | 29.95 | 29.95 |
| 891-A | Vacume Connector | Vacume Connector | 1 connector | 1 | 4.95 | 4.95 |
| 893-A | Vacume Tubing | 1/2" Plastic Tubing | 1 foot | 8 | 0.95 | 7.60 |
| 581-A | Sealant Tape | Vacume Bag Sealer | 25 feet | 1 | 6.95 | 6.95 |
| 591-A | Quart Starter Kit | Gloves,brushes,etc | various | 1 | 9.95 | 9.95 |
| 588-A | Quart Mixing Kit | Cups,sticks,etc | various | 1 | 4.95 | 4.95 |
| | | | | | Sub Total | $173.95 |
| **Hechingers Hardware** | | | | | | |
| 5041611 | 9x11 Ultra Fine Abrasive 660 | Sandpaper | 4 sheets | 1 | 3.41 | 3.41 |
| 5093513 | Alum Oxide Abrasive Pack | Sandpaper | 20 sheets | 1 | 5.79 | 5.79 |
| 4046207 | Flannel Cloths | Buffing Cloths | 6 sheets | 1 | 4.99 | 4.99 |
| 5993225 | Paint Pail | Mixing Cup | 1 cup | 2 | 0.33 | 0.66 |
| 5429915 | PVC Pipe | 4" Dia Pipe | 5 feet | 1 | 6.79 | 6.79 |
| | | | | | Sub Total | $21.64 |
| | | | | | Total Cost | $195.59 |

# Kevlar & Fiberglass

| Catlg # | Part name | Material | Amount/Qnty | Qnty | Cost / item | Cost |
|---|---|---|---|---|---|---|
| **FibreGlast Developments Corp** | | | | | | |
| 545-B | 5HS Kevlar Second Quality | 5 oz Kevlar | 1 yards | 1 | 16.95 | 16.95 |
| 543-A | Style 7781 E-Glass | 9 oz Fiberglass | 1 yard | 1 | 12.95 | 12.95 |
| 2000-A | System 2000 Epoxy Resin | Epoxy resin | 1 quart | 1 | 24.95 | 24.95 |
| 2120-A | 2120 Epoxy Hardener | Epoxy Hardener | 1/2 pint | 1 | 9.95 | 9.95 |
| 1016-A | Parting Wax | Mold Wax | 24 oz. | 1 | 8.95 | 8.95 |
| 13-A | PVA Release Film | Mold Release Mat. | 1 quart | 1 | 8.95 | 8.95 |
| 577-B | Polyethelene Bagging Film | Vacume Bagging | 3 yards | 1 | 6.95 | 6.95 |
| 579-B | Breather/Bleeder | Molding Mat. | 3 yards | 1 | 16.95 | 16.95 |
| 582-B | Nylon Release Peel Ply | Molding Mat. | 3 yards | 1 | 29.95 | 29.95 |
| 891-A | Vacume Connector | Vacume Connector | 1 connector | 1 | 4.95 | 4.95 |
| 893-A | Vacume Tubing | 1/2" Plastic Tubing | 1 foot | 8 | 0.95 | 7.60 |
| 581-A | Sealant Tape | Vacume Bag Sealer | 25 feet | 1 | 6.95 | 6.95 |
| 591-A | Quart Starter Kit | Gloves,brushes,etc | various | 1 | 9.95 | 9.95 |
| 588-A | Quart Mixing Kit | Cups,sticks,etc | various | 1 | 4.95 | 4.95 |
| | | | | | Sub Total | $170.95 |
| **Hechingers Hardware** | | | | | | |
| 5041611 | 9x11 Ultra Fine Abrasive 660 | Sandpaper | 4 sheets | 1 | 3.41 | 3.41 |
| 5093513 | Alum Oxide Abrasive Pack | Sandpaper | 20 sheets | 1 | 5.79 | 5.79 |
| 4046207 | Flannel Cloths | Buffing Cloths | 6 sheets | 1 | 4.99 | 4.99 |
| 5993225 | Paint Pail | Mixing Cup | 1 cup | 2 | 0.33 | 0.66 |
| 5429915 | PVC Pipe | 4" Dia Pipe | 5 feet | 1 | 6.79 | 6.79 |
| | | | | | Sub Total | $21.64 |
| | | | | | Total Cost | $192.59 |

## Graphite & Fiberglass

| Catlg # | Part name | Material | Amount/Qnty | Qnty | Cost / item | Cost |
|---|---|---|---|---|---|---|
| **FibreGlast Developments Corp** | | | | | | |
| 1069-A | 3K 2x2 Twill Weave | 5.7 ox Graphite | 1 yard | 1 | 59.95 | 59.95 |
| 1094-A | Bidirectional E-Glass | 9 oz Fiberglass | 1 yard | 1 | 9.95 | 9.95 |
| 2000-A | System 2000 Epoxy Resin | Epoxy resin | 1 quart | 1 | 24.95 | 24.95 |
| 2120-A | 2120 Epoxy Hardener | Epoxy Hardener | 1/2 pint | 1 | 9.95 | 9.95 |
| 1016-A | Parting Wax | Mold Wax | 24 oz. | 1 | 8.95 | 8.95 |
| 13-A | PVA Release Film | Mold Release Mat. | 1 quart | 1 | 8.95 | 8.95 |
| 577-B | Polyethelene Bagging Film | Vacume Bagging | 3 yards | 1 | 6.95 | 6.95 |
| 579-B | Breather/Bleeder | Molding Mat. | 3 yards | 1 | 16.95 | 16.95 |
| 582-B | Nylon Release Peel Ply | Molding Mat. | 3 yards | 1 | 29.95 | 29.95 |
| 891-A | Vacume Connector | Vacume Connector | 1 connector | 1 | 4.95 | 4.95 |
| 893-A | Vacume Tubing | 1/2" Plastic Tubing | 1 foot | 8 | 0.95 | 7.60 |
| 581-A | Sealant Tape | Vacume Bag Sealer | 25 feet | 1 | 6.95 | 6.95 |
| 591-A | Quart Starter Kit | Gloves,brushes,etc | various | 1 | 9.95 | 9.95 |
| | | | | | Sub Total | $206.00 |
| **Hechingers Hardware** | | | | | | |
| 5041611 | 9x11 Ultra Fine Abrasive 660 | Sandpaper | 4 sheets | 1 | 3.41 | 3.41 |
| 5093513 | Alum Oxide Abrasive Pack | Sandpaper | 20 sheets | 1 | 5.79 | 5.79 |
| 4046207 | Flannel Cloths | Buffing Cloths | 6 sheets | 1 | 4.99 | 4.99 |
| 5993225 | Paint Pail | Mixing Cup | 1 cup | 2 | 0.33 | 0.66 |
| 5429915 | PVC Pipe | 4" Dia Pipe | 5 feet | 1 | 6.79 | 6.79 |
| | | | | | Sub Total | $21.64 |
| | | | | | Total Cost | $227.64 |

## Balsa only

| Catlg # | Part name | Material | Amount/Qnty | Qnty | Cost / item | Cost |
|---|---|---|---|---|---|---|
| **Tower Hobbies** | | | | | | |
| TOWR1360 | 1/8 x 4 x 36 balsa sheet | outer fuselage | 8 sheets | 2 | 7.49 | 14.98 |
| TOWR1905 | 1/6 x 6 x 12 plywood | inner fuselage | 1 sheet | 4 | 1.49 | 5.96 |
| TOWR1855 | 1 x 3 x 30 balsa block | bottom front | 1 block | 1 | 2.59 | 2.59 |
| TOWR1910 | 1/8 x 6 x 12 plywood | bulkheads | 1 sheet | 2 | 1.79 | 3.58 |
| TOWR1655 | 3/8 x 3/8 x 36 triangle | reinforcements | 8 sticks | 2 | 2.99 | 5.98 |
| HCAR3600 | Bullet CA glue | adhesive | 2oz. | 3 | 7.99 | 23.97 |
| HCAR3650 | Bullet CA+ glue | slow adhesive | 2oz. | 2 | 7.99 | 15.98 |
| HCAR3750 | Activator Spray | accelerator | 2oz. | 2 | 4.79 | 9.58 |
| XACR2180 | X-Acto knife set | cutting tools | 1 set | 1 | 15.59 | 15.59 |
| HCAR5100 | Steel T-pins 1" | temp.fasteners | 100/box | 1 | 2.09 | 2.09 |
| | | | | | Sub Total | $100.30 |
| **Hechingers Hardware** | | | | | | |
| 5041611 | 9x11 Ultra Fine Abrasive 660 | Sandpaper | 4 sheets | 1 | 3.41 | 3.41 |
| | | | | | Sub Total | $3.41 |
| | | | | | Total Cost | $103.71 |

# PROPOSAL FOR THE DESIGN OF AN UNMANNED AIR VEHICLE

## ADDENDUM PHASE: PART SEVEN

*Prepared for Gregory Page*

*Submitted 13 April 1998*

*by the Syracuse University Chapter of the American Institute of Aeronautics and Astronautics*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# 7. LESSONS LEARNED

## 7.1 Aircraft Design Changes

Since its completion, some changes have been implemented into the original design proposed. These are believed to be necessary or desirable based on technical and budget considerations. These alterations are not trade-offs, but instead decisions made after careful analysis.

### 7.1.1 Tail Boom

The first change takes place at the rear of the fuselage, to the boom that connects the main body (where the avionics and payload are housed) to the empennage. Originally, this was going to be made from eight pieces of balsa wood, which were to run from the rear of the composite main body to the empennage.

This configuration will be replaced with a lightweight yet durable section of 1.5 inch PVC pipe. This section of PVC pipe will be connected to the main body of the fuselage through two plywood bulkheads at the rear of the graphite main body. The empennage will pass through slots cut into the pipe, and everything will be fastened with epoxy. This will save on some weight, while easing the manufacturing process. Also, no covering will be needed for the PVC pipe, saving a little on overall cost.

### 7.1.2 Landing Gear Configuration

The original design called for a tricycle type landing gear configuration, with the nose gear attached to the front "firewall" bulkhead (at the rear of the motor) and controlled via an extension of the rudder servo. The main gear would pass through the fuselage and into a bulkhead aft of the wing saddle. While this would make the aircraft easier to land, it would be a bit difficult to design and link, and would cause more drag.

This has been waived in favor of a taildragger configuration, with a smaller tail wheel attached directly to the rudder. The main gear will be moved forward to a bulkhead forward of the wing saddle. This saves on weight and drag, and is easier to manufacture. Also, the special accessories required to affix a nose gear to an aircraft will not be needed.

### 7.1.3 Front Motor Cowling

Finally, the front cowling design was changed. Initially, the design report proposed to cut and sand down four rectangular pieces of balsa to a more aerodynamic shape. This would involve quite of bit of time and patience, and there would be difficulty involved in getting an exact fit between the pieces.

The remedy was found in a bottle – a two-liter plastic soda bottle, to be exact. The bottle will be trimmed and fastened to the front of the main body with balsa scraps and small wood screws (so it can be removed later for access). The soda bottle proved to be about four inches in diameter, so the fit will be very close. The save in design time and hassle is great, at very little in cost.

### 7.1.4 Projections for Next Year

This year's entry so far has met all expectations that were entered at the beginning of the year. While there still is more testing and manufacturing to be completed, the design team is nonetheless happy about this revelation. However, this does not mean that there is not room for improvement next year. More experimental techniques will probably be integrated into next year's entry.

Some of these techniques could include a radical change in wing design. So far, the team's two entries (last year's and this year') have been straight, high wing monoplanes. Winglets could be added to the wingtips to decrease the vortices encountered there, thus increasing the available lift. A more efficient low speed airfoil could be found, or even designed by team members. Other control surfaces, such as flaps, may be integrated as well. Finally, the wing could be composed of advanced materials, as opposed to the wood that gives its shape now.

The fuselage may need to be radically altered to make way for a mid- or low-wing monoplane, if deemed necessary. A pusher prop or ducted fan may be used for propulsion, further increasing the need for a change in the design of the body. Retractable landing gear, while requiring heavier equipment to operate, may be desirable to reduce drag, and the fuselage would have to change for that as well.

Some of these changes have already been proposed. Next year's entry from Syracuse will probably have winglets, a custom airfoil, and more control surfaces. This aircraft will most likely have more accessories and will be better suited for its mission since more funds can be used for the aircraft and not its components (radio, receiver, charger, etc.). Only time will tell for sure.

### 7.2 Cost Estimate

| Component | Estimated Cost |
|---|---|
| Motor & Speed Controller | 350 |
| Radio & Receiver | 250 |
| Battery Pack | 300 |
| Battery Charger | 150 |
| Materials | - |
| - balsa/glue | 100 |
| - composite | 200 |
| Accessories | 100 |
| - covering materials | - |
| - propellers | - |
| - landing gear | - |
| - control rods/horns | - |
| Other | 50 |
| **Estimated Total** | **1500** |

**Table VII-I.** *Estimated Cost*

| Component | Manufacturer | List Price |
|---|---|---|
| Motor & Speed Controller | Aveox | 339.44 |
| Radio & Receiver | Futaba | 231.05 |
| Battery Pack | Trinity | 319.96 |
| Battery Charger | AstroFlight | 154.99 |
| Materials | | - |
| - balsa/glue | Tower Hobbies | 52.21 |
| - composite | Fibre Glast | 227.64 |
| Accessories | Tower Hobbies | 107.82 |
| - covering materials | | - |
| - propellers | | - |
| - landing gear | | - |
| - control rods/horns | | - |
| Other | | - |
| - printing | Kinko's | 60 |
| - shipping | USPS | 20 |
| - battery pack assembly | S.U. Chemistry Dept. | 20 |
| | **Actual Total** | **1533.11** |

**Table VII-II.** *Actual Cost*

The actual cost of the project closely matched the estimated value. The prices for the most costly components could easily be guessed due to readily available manufacturers' catalogs, and the valuable experience gained from team members who also participated in the previous year's competition. The budget overflow was due to unexpected expenses such as printing and shipping. The unanticipated costs will be useful for future cost estimations.

### 7.3 Cost Reduction Techniques

The manufacturing of the aircraft on a limited budget required some cost saving techniques. The area where the most attention to cost cutting was on the design and manufacture of the fuselage. For one, the mold was not custom made. Instead, a four-inch diameter piece of PVC (polyvinyl chloride) pipe provided the basic shape needed. The pipe was cut in half, and the two halves used as the molds for the fuselage. The PVC pipe was an inexpensive alternative to other methods of creating molds such as the use of RTV (Room Temperature Vulcanizing) rubber.

This molding process involved creating a vacuum to remove the excess epoxy from the matrix while the epoxy cured. For this process, plastic vacuum bags were needed to enclose the mold and graphite. While some vacuum bags were purchased, not enough were on hand for the entire process. Instead of purchasing more bags, it was decided that some could be made. This was achieved by utilizing excess window insulation sheets, which were of the same grade as the vacuum bags. This proved to be well suited for sealing the molds. These sheets of plastic were cut to size and sealed with duct tape, at virtually no cost to the group.

An oven was needed to place the vacuum-sealed molds in while they cured. Instead of purchasing a curing oven, one was improvised by placing a space heater inside a steel cabinet. The space heater was able to bring the temperature inside the cabinet up above one hundred degrees Fahrenheit. This method was very effective, and the entire curing oven came at no cost to the team.

The materials for the fuselage we were carefully calculated, so none would be wasted. A precise amount of graphite was ordered, with a little excess to account for rounding and cutting errors. In addition, the amounts of epoxy and resin that were used during the molding process was carefully monitored, so little would be wasted.

The last aspect of the fuselage included an inexpensive way of constructing a cowling for the aircraft. Molding the graphite into a conical shape in the PVC pipe would prove to be quite difficult, so improvisation prevailed again. It was decided that using the top half of a two-liter soft drink bottle would be the easiest and cheapest thing to do, and would provide the right shape. Since the bottle would be a non-load-bearing member, the strength of the material was not a great consideration, and its very low cost was augmented by the fact that the team members could also relieve their thirst in its manufacture.

The most important cost saving technique for the wing was in the use of materials. The wing used was made from balsa wood, a very inexpensive and readily available material. It is cheap to manufacture and easy to repair, which fit all the necessary criteria.

Some investments for future competitions were made with the electronic equipment purchased. The radio transmitter, batteries, and battery charger are all things that can be reused in the future. Since these items needed to be purchased this year, it was the general consensus not to go "cheap" on them. Between these three items, about seven hundred dollars was spent, almost half of our budget. This amount may seem like quite a bit, however, by carrying over this equipment for use on future planes, this team is saving each group to come seven hundred dollars. Hence, we resisted the urge to buy the cheapest electronics needed, and instead invested in quality equipment.