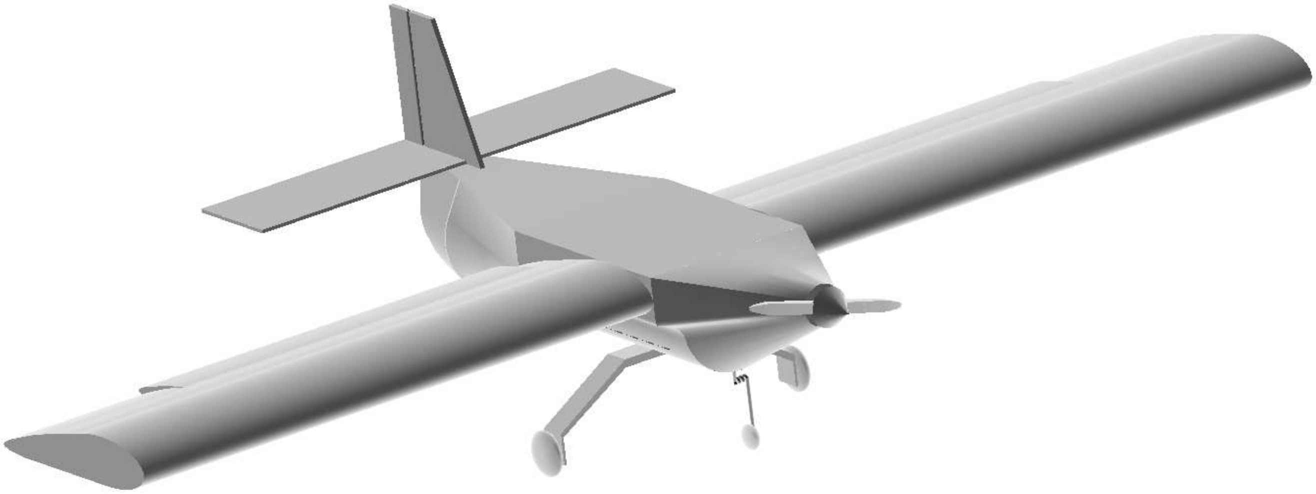
Lion in the Sky

Final Design Report



2005/2006 Cessna and ONR

AIAA Design/Build/Fly Competition

Cessna Aircraft Company Facilities

Wichita, Kansas

Submitted by

Columbia University

01 March 2006

Table of Contents

1.0 Executive Summary

Throughout this academic year Columbia University's Lion in the Sky team has applied our engineering knowledge and intuition in an attempt to satisfy the mission requirements of the 2005/2006 Cessna/ONR Student Design/Build/Fly Competition with our original aircraft design. The development of this design from irresolute elementary sketches to detailed CAD drawings and its subsequent implementation in construction will be detailed throughout the remainder of this report.

1.1Design Teams

The design of the entire aircraft is governed by the missions that it must accomplish in a regulated competition environment. Of five flight attempts and three tasks from which to choose, the two best flight scores, each from a different mission, will comprise the final score. The exercises differ greatly and each is designed to emphasize a specific aspect of the aircraft. In the first, the versatility of the cargo that can be carried within the fuselage is put to the test. Forty-eight loose tennis balls, two 2-liter soda bottles, and a rectangular wooden block are loaded into the aircraft during multiple flight runs. In the second mission, while 96 tennis balls must be flown in laps, the score is dependent upon the RAC. In this year's competition the RAC is entirely determined by weight. An incremental payload is the challenge of the third mission. Beginning with two, 2-liter bottles of water and finishing with a maximum of five bottles, this mission tests the structural stability of the entire aircraft as additional units of weight must be carried.

The plane should be constructed to ensure that each mission can be completed successfully. In the best interest of the final score, the aircraft is optimized for two missions and capable of flying the third. After extensive evaluation of the possible RAC and total score combinations that would result from each pair of missions, it was concluded that the first and second missions, that of cargo flexibility and minimum RAC respectively, had the highest probability of bringing our team a successful series of flights.

1.2Design Teams

The initial design process brought forth a plane that was structurally sound to allow heavy cargo carrying capabilities while remaining light in overall weight to ensure a low RAC, and ultimately a higher total score. In construction, balsa was the material of choice for it low density, but pine spars remained a necessary component for overall support. Throughout the entire construction process, small changes were made in an effort to provide either more stability or to shave off a few more unnecessary ounces.

2.0 Management Summary

2.1Team Architecture

For the 2005/2006 contest season, the membership of the Columbia University Design / Build / Fly team consisted of a group of 10 undergraduate engineering students. The division into task groups was liquid throughout the project. Mission analysis and preliminary design progressed under the support of our entire group. During the conceptual design phase, the membership was divided into complimentary design teams, capable of assisting one another with the technical aspects of design. For the construction and testing phases, membership was again merged into one unified team. Our skeleton layout consisted of three divisions – management, wing, and fuselage – with 2, 4, and 4 members respectively.

2.2Design Teams

Whereas management's primary roles were the organization, coordination, and oversight of the efforts of the design teams, as well as the securing of continued funding necessary to the success of our team – in practice, to compensate for our small membership, management spent the majority of their time assisting wherever possible in the technical aspects of the design phase.

Phase I, mission optimization, proceeded under management's direction, but remained the responsibility of the entire team. The team in its entirety calculated the optimal mission profiles. Given the constraints and capabilities of our organization, the team then divided into the specialized design teams which characterize Phase II.

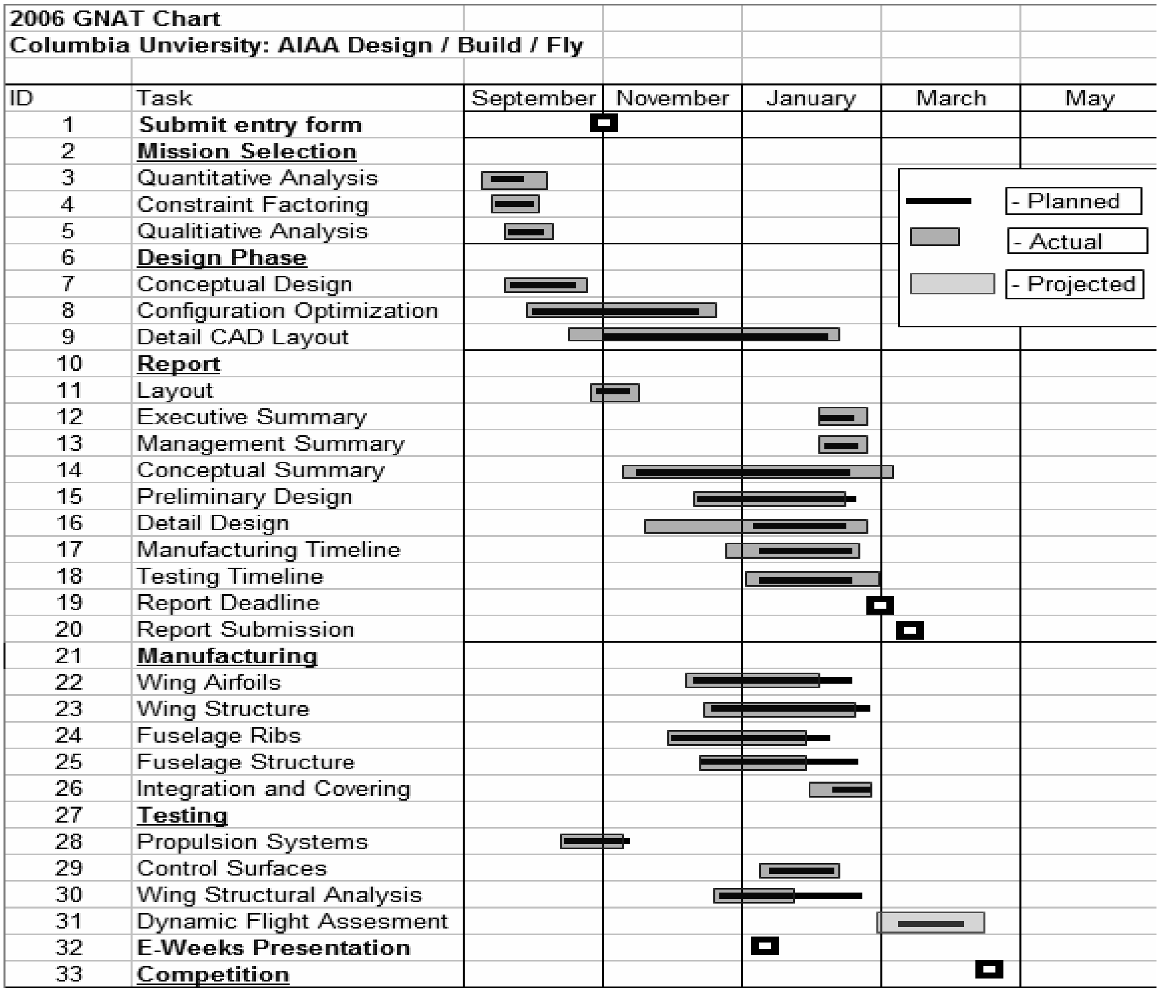
The wing division became responsible for the overall aerodynamic profile of the aircraft, the selection and optimization of an appropriate airfoil, and the placement and position of control surfaces throughout the aircraft. In the end, a blended body design with elliptical wings was jointly selected as the design with optimal performance within our construction capabilities.

The fuselage division's primary responsibilities were 1] to engineer and optimize a light and reliable structure which met the aerodynamic profile selected by the wing team, 2] to select and test an optimal propulsion system, and 3] to arrange the cargo-space of our aircraft as necessary to optimally accommodate the various payloads. The fuselage team was further charged with ensuring the overall weight and balance of the aircraft, the placement of servos and electronics, and the design of an appropriate landing system.

Phase III, construction, was the joint responsibility of the entire team. Working from our CAD designs, more experienced members cut balsa and pine templates for the basic components of our aircraft – airfoils, ribs, and struts – and demonstrated assembly methods to the remainder of the team.

2.3Milestone Chart

Scheduling proceeded according to three general constraints: 1] membership and financial, 2] technical capabilities – namely our lack of CNC capability and limited access to machine shops, and 3] previous Columbia University competition performance. It was decided that due to the club's inability to compete in the 2005 Design Build and Fly Exhibition, our primary aim would be the completion of a reliable, well engineered aircraft – if not one that aimed for the stars – such that we might attend the competition, place well, ensuring the future of our team.



2006 GNAT Chart

Columbia Unviersity: AIAA Design / Build / Fly

ID	Task
1	**Submit entry form**
2	**Mission Selection**
3	Quantitative Analysis
4	Constraint Factoring
5	Qualitiative Analysis
6	**Design Phase**
7	Conceptual Design
8	Configuration Optimization
9	Detail CAD Layout
10	**Report**
11	Layout
12	Executive Summary
13	Management Summary
14	Conceptual Summary
15	Preliminary Design
16	Detail Design
17	Manufacturing Timeline
18	Testing Timeline
19	Report Deadline
20	Report Submission
21	**Manufacturing**
22	Wing Airfoils
23	Wing Structure
24	Fuselage Ribs
25	Fuselage Structure
26	Integration and Covering
27	**Testing**
28	Propulsion Systems
29	Control Surfaces
30	Wing Structural Analysis
31	Dynamic Flight Assesment
32	**E-Weeks Presentation**
33	**Competition**

3.0 Conceptual Design

This section discusses the initial considerations in the team's design as well as the selection (though not form) of its critical design variables used to establish a baseline configuration. In doing so, alternative configurations are generated, analyzed, and evaluated. The first crucial step in any design is to understand the requirements and restraints of that design.

3.1 Mission Requirements

The purpose of this contest is to design and construct an aircraft that has the ability to complete all the flight missions in an effective manner such that it can score the highest possible amount of points according to the contest rules. Keep in mind that the aircraft design is restricted to additional and undocumented requirements used to convey safety, continuity, and rationality to the contest. This being the case, a focus on flight missions and their respective design requirements was an excellent place to begin. The contest consists of three missions: the Cargo Flexibility mission, Minimum RAC mission, and Incremental Payload mission. The total flight score depended only on the highest scores in *two of these three missions*. The overall score on each mission depends on a combination of various factors, including carrying different payloads, loading times of those payloads, number of laps, rated aircraft cost (RAC) as well as a difficulty factor (DF) associated with it. The craft will have up to five flight attempts and the best single flight score (SFS) from each of up to two different missions will count towards the total flight score (TFS).

3.1.1 Payload Requirement

Although it is only required of the aircraft to actually perform two of the three mission types, it nonetheless must be physically capable of supporting *all* specified missions and payloads. The aircraft should effectively house:

1. 48 loose tennis balls (Payload #1)
2. minimum of two 2-Liter bottles filled with water (Payload #2)
3. A single large rectangular wood block no larger than 4"x4"x24" weighing not more than 8 lbs. (Payload #3)

3.1.2 Mission Sections

- Cargo Flexibility Mission (CFM): (DF= 10)

  In this mission, it will be necessary to take each of three payloads (48 tennis balls, two 2-Liter bottles, wood block) one by one into the air for one full lap around the course and effectively land. This mission tests not only the structure and reliability of the plane, but also the design of effective methods to load and unload each of the three payloads. Our team will design inserts and loading mechanisms to speed the loading process. The single flight score on this mission is: (DF x Laps Completed) / Loading Time

- Minimum RAC (MRAC): (DF = 150)

  This mission requires our aircraft to successfully carry 96 tennis balls for a minimum of two minutes in total flight time. However, it is important to note that it is not essential to carry all of the balls simultaneously. Our team will split the 96 tennis balls into two flights of 48 balls. The single flight score on this mission is: DF / RAC. Note that the RAC (which depends on the weight of the aircraft without any payload) is one of the most important factors in this mission. This motivates us to make our plane as light as possible, and the materials we use will reflect this mission score requirement.

- Incremental Payload (IP): (DF = 1.25)

  The mission begins with our team loading two 2-Liter bottles into the payload section of the plane and flying one lap of the course. After landing, an additional 2-Liter bottle will be loaded and the plane will take off and fly an additional lap of the course. In a similar fashion, the payload will increase by a single 2-Liter bottle until there is a maximum of five 2-Liter bottles inside the body of the aircraft. The single score of this mission is = DF*(number of laps)*(number of laps).

3.1.2.1 Preliminary Mission Analysis

Analyzing the missions and point scoring system associated with each was one of the first steps in developing a conceptual design. In order to optimize our chances of winning the contest, we first needed to study the requirements of each mission described in the previous section, and then from those requirements realize which two of the three missions would yield the highest number of points. The following sections describe key requirements which lead us to formulating a number of qualitative and quantitative figures of merit (FOM) used to select the best configuration.

3.1.3 Structural Requirements

Before the competition, all aircraft must undergo an inspection that verifies that it can fly safety. These tests include visual and physical inspections of the plane. All aircraft will be lifted upright and inverted at each wing tip to verify the wing’s strength.

In order to meet the structural requirements of flying the aircraft successfully with the payloads, we will be using, for the most part, a traditional or classic aircraft design. This will make the plane reliable, provide superior stability, and allow for a relatively easy build compared to if we were to try an experimental design.

Our main concerns while building this airplane were maintaining stability while keeping the weight and drag down as low as possible. One of the main ways we are keeping the weight of the plane low is with our use of balsa wood for the major sections of the aircraft. Balsa wood is ideal because it is extremely light, inexpensive and easy to work with. To maintain structural stability, the fuselage is lined with balsa ribs 3.2 inches apart and held together with 6 to 8 spars along the outside of the plane (every 3 inches or so).

One way we are working to reduce drag structurally while at the same time maintaining a relatively large fuselage volume is by implementing the blended wing body design. This will maintain the same handling qualities as a conventional configuration but will have far less drag due to the aircraft's blended intersection and streamlined shape. In addition, we have also chosen an elliptical wing platform because it has the lowest induced drag and stall occurs uniformly. Although this may seem to add difficulty to the manufacturing of the wings, since we are dealing with a wooden model, it is still within our reach.

3.1.4 Design Constraints

The aircraft, dissembled must fit into a box with internal dimensions of 4' x 2' x 1.25'. In addition, the take-off gross weight including payload (TOGW) must be less than 55 pounds.

3.1.5 Takeoff Requirement

The aircraft must be able to take-off within 100 feet of runway (which means the wheels must lift off in up to or less than 100 feet). In addition, all energy for take-off must come from the batter packs that are within the plane. No additional or external energy will be allowed to assist the plane in take-off.

3.1.6 Propulsion System Requirements

For safety, each team is required to use commercially produced propellers/ blades or commercially ducted fan units. The maximum battery weight for propulsion systems is capped at three pounds and must be separate from the Radio Rx and servos battery packs. Each team is, however, allowed to use multiple motors and/or propellers. The batteries must be over the counter NiMH or NiCad.

3.2 Design Constraints

3.2.1. Empennage

Flight is an extremely broad concept that requires individual companies or engineers to set parameters which become indispensable. The goal is to achieve *controlled flight*, which requires the aircraft to be responsive to the inputs of the controller. Thus, this places many constraints on fantastical designs that can lead to flight, but un-controlled flight. The placement of the horizontal stabilizer and vertical stabilizer are dependant upon the weight of the aircraft and the desired flight characteristics. Dual vertical stabilizers can be used (even when they are angled slightly) and can give much maneuverability to the controller. Vertical stabilizers can also be placed below the fuselage, in a seemingly un-orthodox manner. Such a technique is frequently found on un- manned reconnaissance aircraft which are lightweight. The aircraft can take advantage of air density and can float for many miles with remarkable fuel economy. Positioning of the horizontal stabilizer can be varied (see 3.2), placed atop the vertical stabilizer or at a level equal to the fuselage.

3.2.2. Wings

The positioning of the wings can be varied as well. The wings can be positioned towards the top of the fuselage, seen often in cargo aircraft with desired levels of stability and lower levels of maneuverability, towards the middle, much like a passenger aircraft, and can be placed towards the bottom of the fuselage, for maximum stability and minimal stability in long term controlled flight. The wings can be elliptical, with varying chord lengths, and can even be swept back at an angle. Such an action, though minimizing the cross-section of air exposed, can greatly help turbulent air-flow problems. Winglets can often be utilized in such situations, to keep air below the wing from trying to flip upwards, a phenomena which causes turbulent air flow most often in the form of wing-tip vortices.

3.2.3 Landing Gear

Location of the landing gear is also much varied, based primarily on weight requirements and desired lift values. In many antiquated aircraft such as the DC-3, the back of the aircraft is lower than the front. Such aircraft are called tail-draggers. Two bogies are positioned under the wings and one smaller bogie is located below the vertical stabilizer. The added advantage of such an orientation is cross section of wing exposed to the air upon takeoff. Many conventional aircraft position their landing gear systems in a 1-2 bogie system with one nose gear and two bogies located at the center of gravity for the empty aircraft.

3.1.4 Manufacturability

The design, no matter how beautiful, strong, or competitive, must be practical to assemble. The team felt this especially to be true given the lack of experience of the new members (which make up well over 50% of the team this year) as well as a lack of resources. To this end, a stabile, confident design, while not quite a mission requirement, was important for the team to stick close to.

3.2.4 General Considerations and Phase Overview

Multiple designs were considered which positioned the wings, the stabilizers and the landing gear in different functional orientations. These were the three aspects which were considered variable inputs for the final design. Changing the positioning of each of these three variables occurred over the course of 3 phases of design. These phases are detailed quantitatively and qualitatively and are indicative of changes and trade-offs between speed, aerodynamics, maneuverability and pitch-trim controls of the finalized aircraft. As detailed by the competition instructions, each team must choose what control is dominant. An aircraft with a high degree of maneuverability may lack stability and will be extremely responsive to slight changes in aileron pitch and rudder positioning.

3.2.4.1 Phase I

In Phase 1, a basic layout was detailed. This included a wing with root chord length and standard chord length of 12 inches. All airfoils would have uniform chord length and thickness, spaced 3.5 inches apart. The wing is positioned at a height equal to the midpoint of the fuselage and possessed a dihedral angle of 0.9 degrees. The wing was to be positioned over the center of gravity. Below the wing section, a dual bogie landing gear system with shock absorbing abilities spread 24 inches at its widest would be positioned. In Phase 1, a tail-dragger was considered for its ultimate stability and for its resistance of shear wind forces. A standard layout for the horizontal and vertical stabilizers was chosen initially to compensate for the necessity of access to the fuselage through the back of the aircraft. For the loading of the cargo, a twist-off tail section was considered the most beneficial for easy access and fast loading of the cargo. In this initial phase, loading-time was set to a minimal value, a parameter that also set aircraft stability to a minimum and which ultimately compromised the correct orientation of the horizontal and vertical stabilizers. Servos were to be placed on the exterior of the aircraft.

3.2.4.2 Phase II

Of principle concern in phase 2 was the reworking of the tail twist-off section. Through proper physical analysis, such an idea was overthrown. It was determined that while a twist-off tail would ultimately provide the most access to the cargo-hold, which would maximize point allocation in such a respect, it was uncertain as to the ability to replace the tail section (after loading the aircraft) at the correct angle, perpendicular to the tarmac. Though a small aileron trim correction vector is programmable with the all field Airtronics RC Controllers, such was a risk that was un-necessary. Thus, a hinged system was considered. Many cargo aircraft of the modern era (A300-Super Transporter, Lockheed Galaxy, 747-400 Combi, 747-400 Freighter) have sections—towards the front—which flip upwards and allow for easy unloading and loading. Such a design was intended to be used at the back of the aircraft. The entire vertical stabilizer and the section of the fuselage attached to it would flip upwards. To rectify the fact that the servos would impede such a motion, all servos were re-assigned to the interior of the aircraft. Since the maximum size requirements had not changed from phase 1 to phase 2, it was necessary to find a suitable position for all of the servos (wing, and stabilizer) which would not constrain the cargo space needed to hold and transport the tennis balls and the 2-liter bottles.

Thus, a new design was proposed. The wings were re-located to the very top of the fuselage (as seen in Antonov Transport Aircraft and the Avro Regional Jet). A new structure called the *Wingeron* was designed and created in CAD, combining storage (with two under-wing pockets) and additional stability by creating four points of contact between the wings and the fuselage (in lieu of only two). A tail dragger was ultimately abandoned due to the inordinate amount of stress its conformation provided to the ribs of the fuselage. Since a tail-dragger has a characteristic downward pitch (higher at the front, lower at the back), the tarmac would have been at an angle to the landing gear, and to the landing gear attachment. The ribs thus would be receiving a longitudinal stress along the grain of the balsa wood.

To avoid this, a three bogie, triangular landing gear system was implemented. The front landing gear is spring loaded and attached directly to the firewall/engine mounting plate. In phase 2, a more intensive study of aerodynamic characteristics was performed. Ultimately a single decision needed to be made; should the aircraft be very maneuverable and less powerful, or more powerful and more lingering, but more stable. Since the design was geared towards cargo/freighter missions, the team decided to concentrate on a more powerful and stable but less maneuverable aircraft. One major consideration which was engendered through this decision was the placement of the horizontal stabilizer. Most cargo aircraft and aircraft which place turbojet engines at the back of the aircraft (MD-80, 727, 717) have raised a horizontal stabilizer which increases stability for the aircraft and moves its point of rotation towards the back of the fuselage. This was the ideal concept for a projected cargo aircraft.

3.2.4.3 Phase III

Phase 3 involved careful calculations of weight requirements as well as investigations into the final concept design. It was finally decided that the best option for cargo loading is a gated door that rests at a 45 degree angle to the fuselage. Such a flare angle works to the advantage of lying along the line that is extended for the rear landing gear bogie. This is a design feature followed closely by Boeing Aircraft Corporation as well as EADS-Airbus. In the interests of maximum design stability and for positioning of the stabilizer servos, the wings remained at the top of the fuselage and the concept of the raised horizontal stabilizer was abandoned in lieu of a more standard conformation.

3.3 Competition Score and Rated Aircraft Cost Analyses

By simply looking at the equation for the total competition score (TCS) it was obvious that the vital elements needed to obtain the highest possible score were the mission scores (which sum to the TFS), the written report score and the RAC.

$$\mathrm{TCS} = \frac{\text{Written Report Score} * \mathrm{TFS}}{\mathrm{RAC}}$$

(3.1)

3.3.1 Total Flight Score Analysis

Recall that the Total Flight Score (TFS) is the summation of two of the best Single Flight Scores (SFS)from each of the two different mission types. In other words, even if the team attempted all three flight missions, only two missions (the best score from each) would count. With this in mind, the team decided to focus the design on the two missions the team would do best in. This simplified the requirements and allowed the team to move forward on analyzing score optimization.

Each SFS from the missions described in section 3.1.2 are calculated using the number of laps, loading time of the payloads, the RAC, as well as a difficulty factor associated with each. The loading time is defined as the time the team is cleared to go get the payload to begin loading and ends when the prior payload is returned to the staging area and the airplane is secured and begins take-off roll. The RAC for this year's competition is MEW or the Manufactures Empty Weight. The equations below show the calculated SFS for each mission type.

(m1) CFM_SFS = DF * #Laps/Loading_Time

(3.2)

(m2) MRAC_SFS = DF/RAC

(3.3)

(m3) IP_SFS = DF * #Laps * #Laps

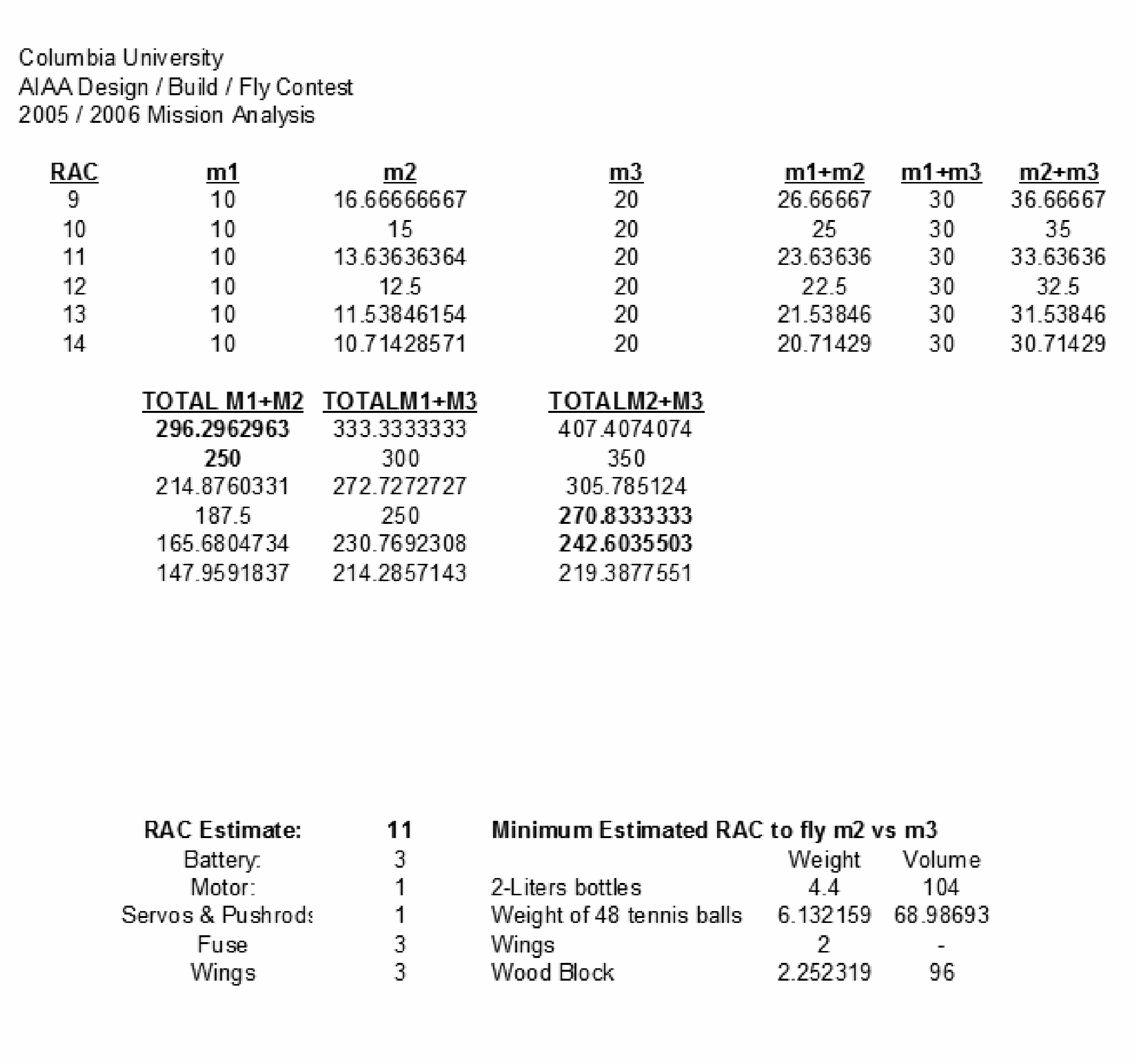
(3.4)

Upon initial assessment it was determined that the SFS from missions two and three (m2 & m3) would yield the highest amount of points. A linear programming technique in was utilized in Excel (see Figure 3.3) to give the team a rough estimate of how many points it would obtain, given a range of the variables described above. This range conveys a reasonable estimate of nominal parameters with deltas and increased difficulty when approaching those +/-deltas, depending on the variable. We then went ahead and calculated which missions and combination of missions that would prove to be the most fruitful. In the end, the team chose missions one and two. While point-wise, missions two and three were the best choice, we concluded that mission 3 was too difficult to be profitable, required unique specifications as compared with one and two and opened up a large uncertainty with one of the most important parameters—the RAC.

3.3.2 RAC Analysis

One of the main goals of the conceptual design is reducing the RAC. This is extremely important because it is inversely proportional to Total Flight Score. The RAC is the empty manufactures weight of the craft; this includes the airframe, all components, batteries, etc. needed to fly the less any payloads. Keeping the weight as low as possible was the primary consideration in the structural design, material selection, configuration, and manufacturing processes. In Figure 3.3 below you can see that RAC was the most defined parameter in the selection of our missions. As stated earlier mission three was opted out because it required a large payload handling which the team felt would raise the RAC to the point where hurt the overall competition score.

Figure 3.3 Excel Linear Programming for Mission Selection



Columbia University
AIAA Design / Build / Fly Contest
2005 / 2006 Mission Analysis

RAC	m1	m2	m3	m1+m2	m1+m3	m2+m3
9	10	16.66666667	20	26.66667	30	36.66667
10	10	15	20	25	30	35
11	10	13.63636364	20	23.63636	30	33.63636
12	10	12.5	20	22.5	30	32.5
13	10	11.53846154	20	21.53846	30	31.53846
14	10	10.71428571	20	20.71429	30	30.71429

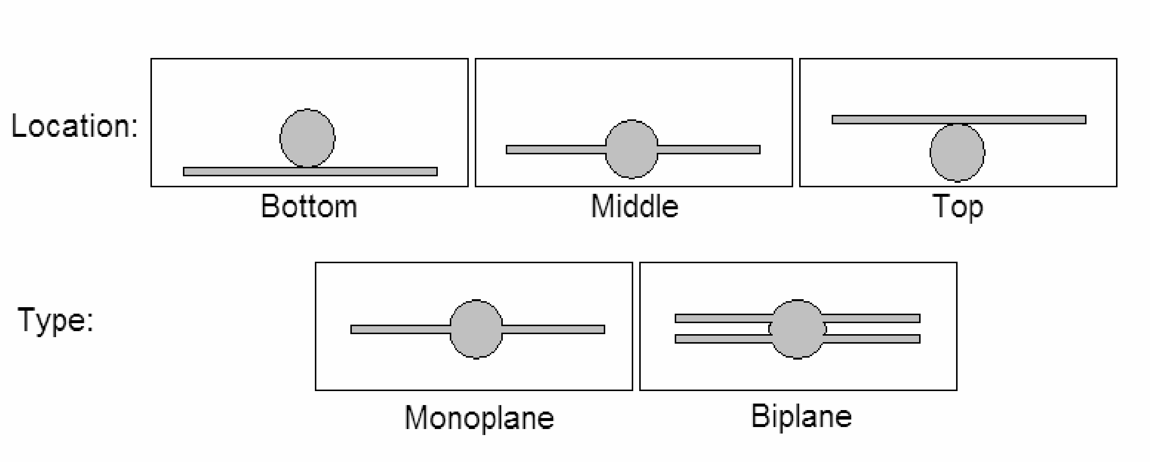
TOTAL M1+M2	TOTALM1+M3	TOTALM2+M3
296.2962963	333.3333333	407.4074074
250	300	350
214.8760331	272.7272727	305.785124
187.5	250	**270.8333333**
165.6804734	230.7692308	**242.6035503**
147.9591837	214.2857143	219.3877551

RAC Estimate:	**11**	**Minimum Estimated RAC to fly m2 vs m3**		
Battery:	3		Weight	Volume
Motor:	1	2-Liters bottles	4.4	104
Servos & Pushrods	1	Weight of 48 tennis balls	6.132159	68.98693
Fuse	3	Wings	2	-
Wings	3	Wood Block	2.252319	96

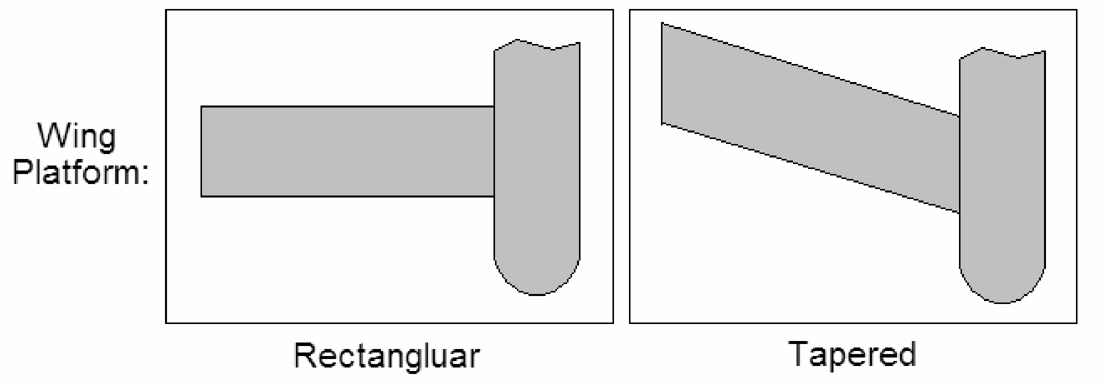
3.4 Alternative Configurations

Understanding the requirements of the missions and associated scoring systems, the team now turned to alternative configurations to begin to develop a top-level conceptual design. These configurations were then screened based on the figures of merit (FOM) derived from the requirements just described.

3.4.1 Wing Types & Location



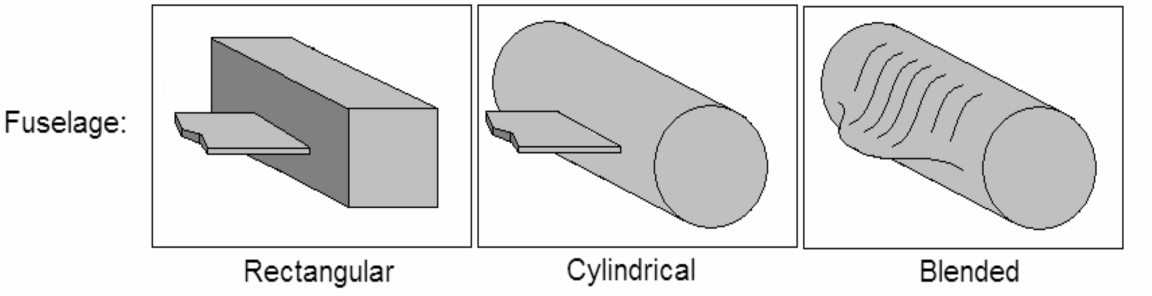
We focused on two wing-type configurations: monoplane and biplane. Monoplane was clearly the simpler manufacturing choice but it also was the lighter of the two which ties into a lower RAC. There are three possibilities of where to mount the wings: On top of the fuselage, in the middle, or at the bottom. Wings mounted on top provide the most stability because they are above the center of gravity and the airplane behaves sort of like a pendulum. However, in front view they are not aligned with the moment of area, where the drag acts, and exhibit a slight moment. Wings mounted in the middle of the fuselage provide no moment arm but have a lower stability. Wings mounted on the bottom provide the least stability but increase the maneuverability of the airplane and are widely used in acrobatic planes. For our mission requirements, the maneuverability is not so important because of the simple course we will be flying. Also the wings are the biggest area in front view and will shift the first moment of area considerably closer to their location. Stability is the most important characteristic because we want to ensure a safe completion of the missions.



3.4.2 Wing Platform

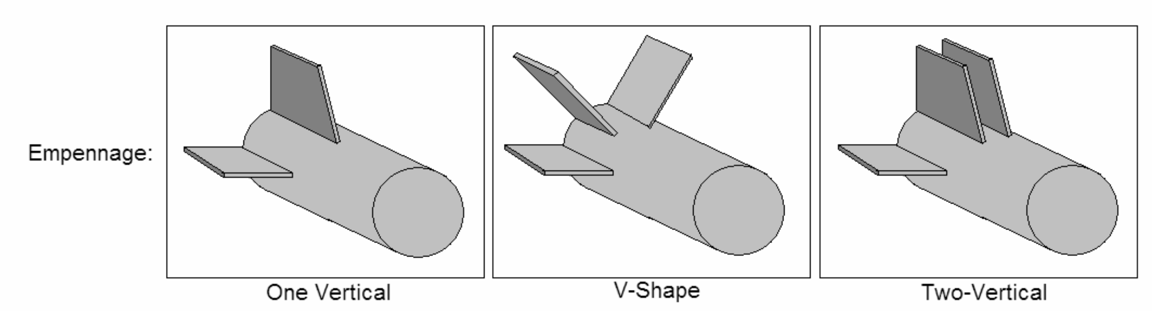
The platform is the top view of the wings and affects the lift and stall characteristics and the stability of the airplane. There are many possible configurations: rectangular, tapered, swept back and forward or elliptical. We decided against a swept forward platform because it is inherently unstable. Rectangular wings are very easy to manufacture but have a high induced drag and bad stall characteristics. Tapered wings improve the drag and stall characteristics but are more complicated to build because of a non-uniform cross-section. Swept back wings have due to the longer chord a better lift but also a higher drag, but are generally more stable. Elliptical wings have the optimal stall behavior and lowest induced drag possible. Their disadvantage is that the construction is really complicated. Again, our most important design criterion is stability and therefore stall behavior. Because we are constructing only one model airplane the manufacturability is least important. Below are the figures of merit which highlight the platform we chose.

3.4.3 Fuselage Types



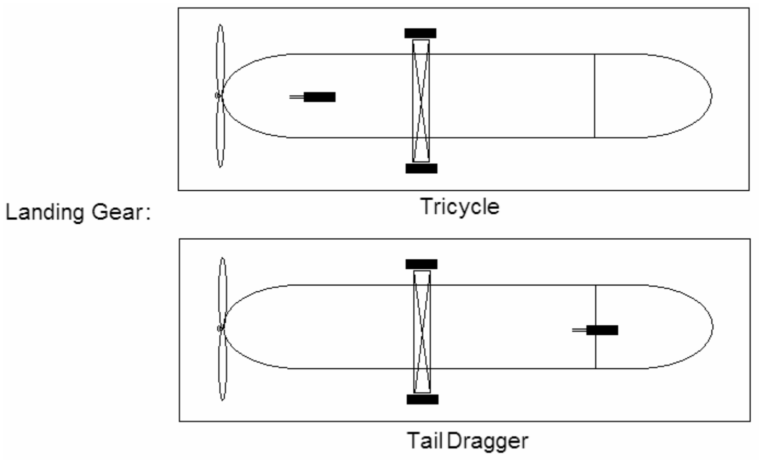
Fuselage is the structure that acts as the body of the airplane and generally contains the motor, batteries, electronics and payload. The wings, tail surfaces and landing gear are mounted to the fuselage. We considered three types of fuselage. A plain rectangular fuselage, or one made out of flat surfaces is very easily built but because of its sharp edges it has a very high drag. A cylindrical fuselage, or one with rounded edges, is harder to build but has better drag characteristics. A blended wing-body configuration provides a smooth transition between the wings and the fuselage, cutting down on drag even further but increasing the difficulty of manufacture. Similar to the argument on wings, manufacturability is less important because this is a prototype plane and any difficulties can be offset with a little extra care.

3.4.4 Empennage Types



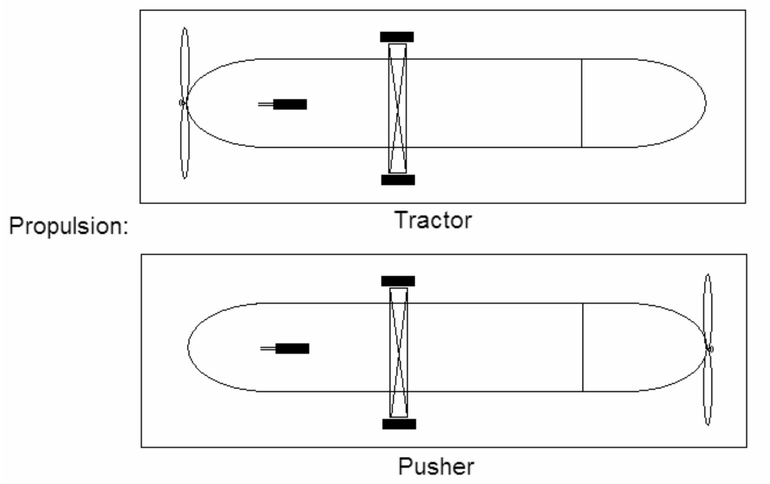
The empennage is the tail assembly of an aircraft, including the horizontal and vertical stabilizers, elevators, and rudder. Possible configurations are one rudder and one tail, two vertical stabilizers possibly angled or a top mounted horizontal stabilizer. Our team does not have the necessary knowledge to analyze the pros and cons of these configurations. We decided on a classical setup with the horizontal tail mounted on top of the fuselage and one vertical tail in the middle. The reason is that this gives us an easily controllable and predictable airplane. Since we are most worried about a successful completion of the missions, we will not be experimental with the tail. We understand that this might be a less than optimal solution, but it still increases our scoring potential because we are sure that it will work.

3.4.5 Landing Gear Types



The major duties of the landing gear are to provide support for the airplane, protect the propeller from shattering on the ground and absorb shocks and impacts from a rough landing. Two types of landing gear were scrutinized: Tricycle and Tail Dagger. Both seem to suite the crafts need to take a hard landing but in consideration of the payload loading, a tail dragger would be an inconvenient placement of the third wheel because a drop door was planned in the bottom of the empennage.

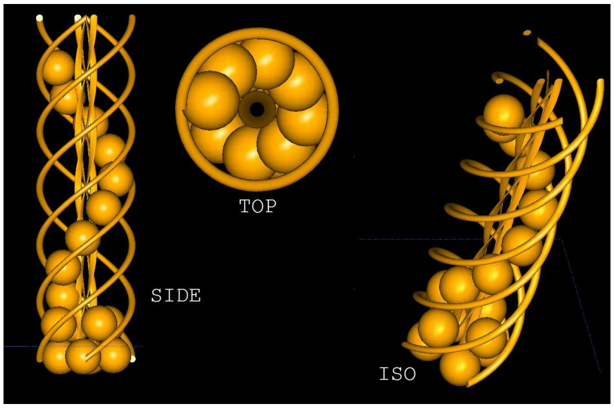
3.4.6 Propulsion Systems



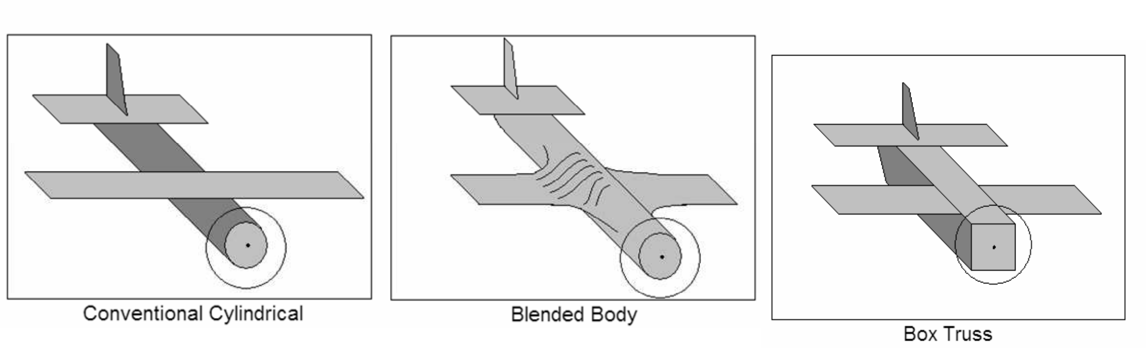
Essentially two types of propulsion were considered: Pusher and Tractor. It was pretty clear to the team that based on a lack for historical data and unknown performance of the pusher configuration; the tractor was the way to go. Again, the team wanted a solid, confident design—choosing a tractor propulsion system reinforces this theme.

3.4.7 Payload Configurations

Configurations for the payloads were pretty straightforward after it was decided that missions one and two were the focus of the design. Both used tennis balls and could be arranged in the same manner. The two-liter bottles could be configured behind one another to retain a slim, longer fuselage design which also accommodated the tennis balls and finally the block wood of similar dimensions would fit nicely into this in-line configuration.

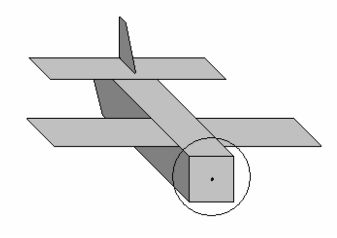


3.5 Figures of Merit



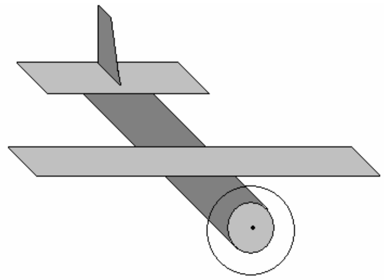
From the various component types described above, three configurations were analyzed using figures of merit, FOM's in both qualitative and quantitative schemes. Normalized factors of -1, 0, and 1 were assigned based on how well a configuration exhibited certain conditions of that FOM. Each FOM was also given a weight factor, all of which summed to 1. Based on the mission requirements, the FOM's were: RAC, strength-to-weight ratio, manufacturability, confidence of flight performance and payload configuration.

3.5.1 Box Truss

			
Figures of Merit (FOM)	Weight Factor	Normalizing Factor	Rating
RAC	.35	-1	-.35
Strength to Weight Ratio	.20	0	.00
Manufacturability	.20	1	.20
CFP	.15	1	.15
Payload Configuration	.10	1	.10
Total:	**1.00**	**-**	**0.10**

The box truss configuration was a considered by the team a confident design. There was historical data and experience in manufacturability. Assurance in performance was also prominent and payload configuration could have been implemented easily in this configuration. However, the major flaw we saw in this design was the weight and strength to weight ratio. The truss format has proven to be a strong design but much to heavy, skewing the ratio between 1.25 and 1.57.

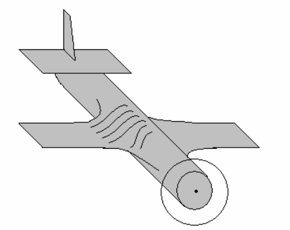
3.5.2 Conventional Cylindrical

			
Figures of Merit (FOM)	Weight	Normalizing Factor	Rating

	Factor		
RAC	.35	1	.35
Strength to Weight Ratio	.20	0	.00
Manufacturability	.20	0	.00
CFP	.15	1	.15
Payload Configuration	.10	1	.10
Total:	**1.00**	**-**	**0.60**

The conventional cylindrical design was considered an alternate design to safer box truss but the shape naturally required less ribs and spars while keeping a high strength to weight ratio. The cylindrical design also accommodated the in-line payload configuration. Manufacturability was more of a concern however and many options presented themselves. Overall this design was much more favorable as those building concerns were addressed.

3.5.3 Blended Body

			
Figures of Merit (FOM)	Weight Factor	Normalizing Factor	Rating
RAC	.35	1	.35
Strength to Weight Ratio	.20	1	.20
Manufacturability	.20	-1	-.20
CFP	.15	1	.15

Payload Configuration	.10	1	.10
Total:	**1.00**	**-**	**0.60**

The blended body design was very similar to conventional cylindrical design with the exception of a blended design to allow minimum drag over the craft profile. While this design retained many of the characteristics of the previous, a blended design raised even more manufacturing concerns because the team did not want to compromise adding materials and complexity to the building processes which would ultimately raise the empty weight of the craft.

3.6 Final Ranking and Configuration Selection

Based on the FOM ranking above the team decided to go with the conventional cylindrical design. This design, while tied with the blended body, proved to be an optimal configuration in terms of payload configuration and installation, strength-to-weight ratio, and flight performance characteristics. Manufacturing what would be essentially a tube proved to be a practical endeavor based on initial analysis and ideas that documented through the FOM process. Major concerns fell on wing-fuselage interfaces, nose and empennage interfaces as well as payload entry and exit.

3.6.1 Final Configuration Selection

To address the interface concerns the team considered including some blended body elements to the conventional cylindrical design. These elements were drawn up and incorporated into the original conceptual design with the expressed knowledge that they may be withdrawn upon parametric design analysis and/or if manufacturing concerns prove them to be unfavorable. The overall selection did demonstrate itself solid enough to allow the team to move into preliminary design.

4 Preliminary Design

The goal of the preliminary design phase was to derive and optimize the general parameters which would impact our overall competition score. Building on our work from the conceptual design phase, our team decided after some consideration that in addition to RAC, probability of mission success, aircraft reliability, and confidence of construction would be heavily weighted FOMs throughout our analysis. After assessing the mission profiles via linear programming in Microsoft Excel, our team assessed numerous potential optimizations in wing and fuselage design and construction. Finally, our team made use of the available computational resources to calculate detailed analysis's of propulsion and aerodynamic systems.

4.1 Design Variable Selection

Design variable selection is the first vital step in the preliminary design. The drivers for selecting these variables were pretty straightforward. The team wanted to minimize weight without sacrificing flight performance. Thoughtful of the contest parameters, configuration drawn from the concept design phase and the RAC, the team decided that geometrical considerations should be focused on optimizing component and payload placement—variation sweeps and tapering was not a major concern given cruise speed. Toward this end, fuselage length was chosen as one of the design variables. It was understood from the beginning that the payload requirements for missions one and two were similar and tended to a slim, in-line orientation—a clear driver for this variable. Wing geometry corresponded to the design variables of wing size and pitch. Historical data and power/flight performance analysis was used to minimize the ranges. Lastly, throttling was to be studied during mission simulation. Conserving power in our propulsion batteries was a major concern for the team given the power requirements for the motor. Using minimal throttle in takeoff but especially during cruise was integral to the mission model. Approximately 60% power would be needed for takeoff, but it would not be required during cruise. Table 4.1 below lists the chosen design variables and the ranges over which they were investigated.

Table 4.1 Design Variable Summary

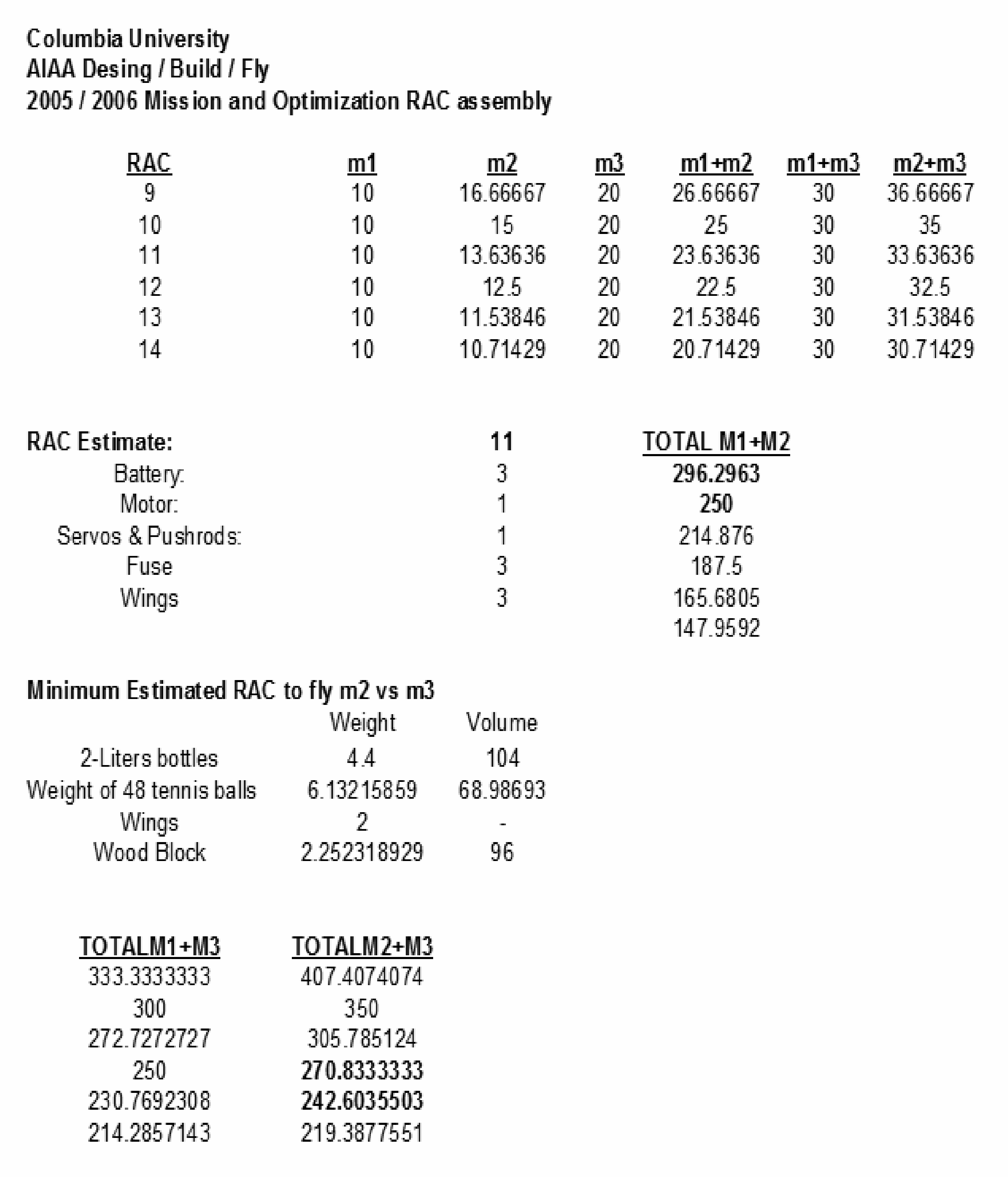
Design Variable	Min Range	Max Range
Fuselage Length	30 inches	30 to 50 inches
Wing Area	1000 sq. inches	1500 sq. inches
Wing Pitch	0 degrees	2 degrees
Throttle	20%	100%

4.2 Mission Model

Missions one and two were modeled using historical data of five different flight modes; takeoff, cruise, descent, landing and taxi. Table 4.2 shows the number of times each mode was used for these two missions.

Flight Modes	# of Modes for Mission 1	# of Modes for Mission 2
Takeoff (<100ft)	3	2
Cruise	6	4
Decent	3	2
Landing	3	2
Taxi	3	2

Assumptions were made based on the mission profiles. We assumed that we could carry 48 tennis balls maximum and therefore require two laps for completion. The time to taxi and to change the payloads was estimated at 15-20 sec for each landing. The estimated time to disassemble and pack the airplane was 20 sec. During takeoff, the throttle was assumed to be at approximately 60%. Analyzed data suggested a takeoff distance of 88ft. with gross weight.



Columbia University
AIAA Desing / Build / Fly
2005 / 2006 Mission and Optimization RAC assembly

RAC	m1	m2	m3	m1+m2	m1+m3	m2+m3
9	10	16.66667	20	26.66667	30	36.66667
10	10	15	20	25	30	35
11	10	13.63636	20	23.63636	30	33.63636
12	10	12.5	20	22.5	30	32.5
13	10	11.53846	20	21.53846	30	31.53846
14	10	10.71429	20	20.71429	30	30.71429

RAC Estimate:	**11**	TOTAL M1+M2
Battery:	3	**296.2963**
Motor:	1	**250**
Servos & Pushrods:	1	214.876
Fuse	3	187.5
Wings	3	165.6805
		147.9592

Minimum Estimated RAC to fly m2 vs m3

	Weight	Volume
2-Liters bottles	4.4	104
Weight of 48 tennis balls	6.13215859	68.98693
Wings	2	-
Wood Block	2.252318929	96

TOTALM1+M3	TOTALM2+M3
333.3333333	407.4074074
300	350
272.7272727	305.785124
250	**270.8333333**
230.7692308	**242.6035503**
214.2857143	219.3877551

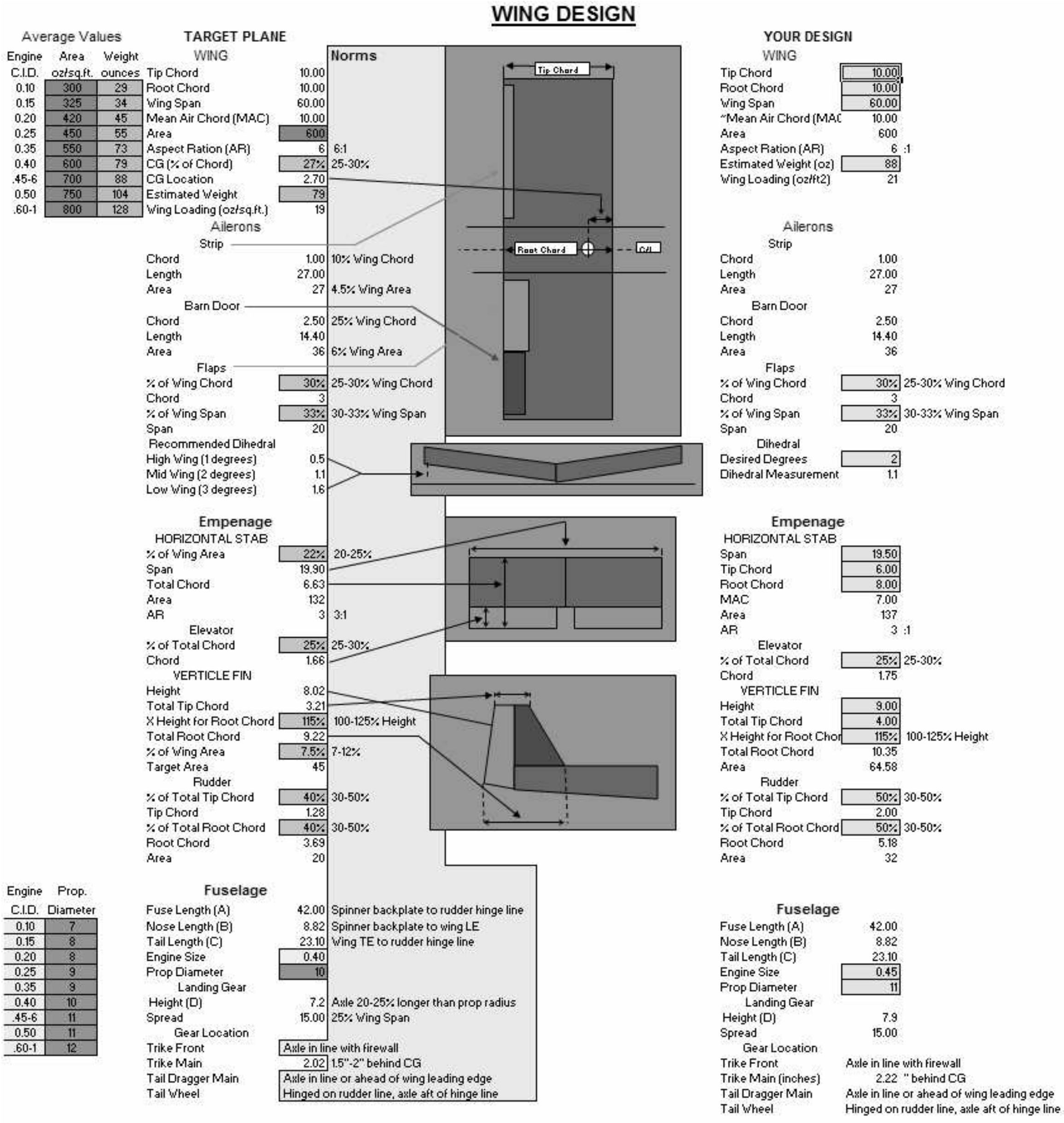
4.3 Analysis Methods

Motocalc was used throughout the entire design process to model the performance of our configuration. It served as an initial starting point to approximately size the motor, battery and propeller. This model was constantly updated as we were making changes to it.

The main tool for wing selection and analysis was Profili2. After general wing parameters were identified in Motocalc, suitable airfoils were compared in Profili2 and the best alternative was selected. The program also interpolated and plotted the individual airfoil sections.

To model the general set-up of the fuselage an excel program named Design Calc was used. The program gave us recommendations of control surface sizing and landing gear configurations, and predicted some behavior characteristics of the airplane.

Figure 4.3.1 Design Calc Parameter Optimization



WING DESIGN

Average Values

Engine C.I.D.	Area oz/sq.ft.	Weight ounces
0.10	300	29
0.15	325	34
0.20	420	45
0.25	450	55
0.35	550	73
0.40	600	79
.45-6	700	88
0.50	750	104
.60-1	800	128

TARGET PLANE

WING		Norms
Tip Chord	10.00	
Root Chord	10.00	
Wing Span	60.00	
Mean Air Chord (MAC)	10.00	
Area	600	
Aspect Ration (AR)	6	6:1
CG (% of Chord)	27%	25-30%
CG Location	2.70	
Estimated Weight	79	
Wing Loading (oz/sq.ft.)	19	
Ailerons		
Strip		
Chord	1.00	10% Wing Chord
Length	27.00	
Area	27	4.5% Wing Area
Barn Door		
Chord	2.50	25% Wing Chord
Length	14.40	
Area	36	6% Wing Area
Flaps		
% of Wing Chord	30%	25-30% Wing Chord
Chord	3	
% of Wing Span	33%	30-33% Wing Span
Span	20	
Recommended Dihedral		
High Wing (1 degrees)	0.5	
Mid Wing (2 degrees)	1.1	
Low Wing (3 degrees)	1.6	
Empenage		
HORIZONTAL STAB		
% of Wing Area	22%	20-25%
Span	19.90	
Total Chord	6.63	
Area	132	
AR	3	3:1
Elevator		
% of Total Chord	25%	25-30%
Chord	1.66	
VERTICLE FIN		
Height	8.02	
Total Tip Chord	3.21	
X Height for Root Chord	115%	100-125% Height
Total Root Chord	9.22	
% of Wing Area	7.5%	7-12%
Target Area	45	
Rudder		
% of Total Tip Chord	40%	30-50%
Tip Chord	1.28	
% of Total Root Chord	40%	30-50%
Root Chord	3.69	
Area	20	
Fuselage		
Fuse Length (A)	42.00	Spinner backplate to rudder hinge line
Nose Length (B)	8.82	Spinner backplate to wing LE
Tail Length (C)	23.10	Wing TE to rudder hinge line
Engine Size	0.40	
Prop Diameter	10	
Landing Gear		
Height (D)	7.2	Axle 20-25% longer than prop radius
Spread	15.00	25% Wing Span
Gear Location		
Trike Front	Axle in line with firewall	
Trike Main	2.02	1.5"-2" behind CG
Tail Dragger Main	Axle in line or ahead of wing leading edge	
Tail Wheel	Hinged on rudder line, axle aft of hinge line	

Engine C.I.D.	Prop. Diameter
0.10	7
0.15	8
0.20	8
0.25	9
0.35	9
0.40	10
.45-6	11
0.50	11
.60-1	12

YOUR DESIGN

WING		
Tip Chord	10.00	
Root Chord	10.00	
Wing Span	60.00	
~Mean Air Chord (MAC	10.00	
Area	600	
Aspect Ration (AR)	6	:1
Estimated Weight (oz)	88	
Wing Loading (oz/ft2)	21	
Ailerons		
Strip		
Chord	1.00	
Length	27.00	
Area	27	
Barn Door		
Chord	2.50	
Length	14.40	
Area	36	
Flaps		
% of Wing Chord	30%	25-30% Wing Chord
Chord	3	
% of Wing Span	33%	30-33% Wing Span
Span	20	
Dihedral		
Desired Degrees	2	
Dihedral Measurement	1.1	
Empenage		
HORIZONTAL STAB		
Span	19.50	
Tip Chord	6.00	
Root Chord	8.00	
MAC	7.00	
Area	137	
AR	3	:1
Elevator		
% of Total Chord	25%	25-30%
Chord	1.75	
VERTICLE FIN		
Height	9.00	
Total Tip Chord	4.00	
X Height for Root Chor	115%	100-125% Height
Total Root Chord	10.35	
Area	64.58	
Rudder		
% of Total Tip Chord	50%	30-50%
Tip Chord	2.00	
% of Total Root Chord	50%	30-50%
Root Chord	5.18	
Area	32	
Fuselage		
Fuse Length (A)	42.00	
Nose Length (B)	8.82	
Tail Length (C)	23.10	
Engine Size	0.45	
Prop Diameter	11	
Landing Gear		
Height (D)	7.9	
Spread	15.00	
Gear Location		
Trike Front	Axle in line with firewall	
Trike Main (inches)	2.22	" behind CG
Tail Dragger Main	Axle in line or ahead of wing leading edge	
Tail Wheel	Hinged on rudder line, axle aft of hinge line	

4.4 Stability and Control Analysis

Stability and control characteristics of the preliminary design were determined from a software package called MotoCalc™. MotoCalc is a program for predicting the performance of an electric model aircraft power system, based on the characteristics of the motor, battery, gearbox, propeller, and speed control and was selected for its comprehensiveness, easy-of-use, and overall top-level interface that allowed us to obtain good to marginal performance predictions and flight characteristics from critical specifications that the team had been confident in obtaining during the preliminary design.

4.4.1 Stability Analysis

Stability analysis of the overall design was a practical summation of the stability of the control surfaces and determination employed by Nelson (1998). The aircraft configuration that came out of the preliminary design is a conventional arrangement with a top-mounted wing, blended-body design for low drag and stability control.

As emphasized throughout our design process, it was of paramount importance to our team to construct a reliable aircraft which would competently complete the missions. We recognized that given our design capabilities, such a condition would impose a performance and RAC penalty on the aircraft. We were comfortable with this tradeoff.

Motocalc was beneficial in so far as it provided us with rough estimates of the performance, stability, and handing characteristics of multiple configurations. The following chart is a sample result of our computational analysis.

MotOpinion - AIAA1

Sea Level, 29.92inHg, 59°F

Motor: Model Motors AXI AC4130/16; 385rpm/V; 1.3A no-load; 0.063 Ohms.
Battery: Sanyo 3400CR; 14 cells; 3400mAh @ 1.2V; 0.0032 Ohms/cell.
Speed Control: Castle Creations Phoenix 45; 0.0026 Ohms; High rate.
Drive System: AIAA001; 16x12 (Pconst=1.31; Tconst=0.95) direct drive.
Airframe: AIAA 001; 1130sq.in; 296.9oz RTF; 37.8oz/sq.ft; Cd=0.058; Cl=0.55; Clopt=0.73; Clmax=1.33.
Stats: 29 W/lb in; 22 W/lb out; 27mph stall; 37mph opt @ 77% (13:40, 102°F); 43mph level @ 86% (10:54, 112°F); 294ft/min @ 5.2°; -316ft/min @ -5.6°.

Possible Power System Problems:

- The estimated steady-state still-air battery temperature at the hands-off cruise airspeed and throttle setting (approximately 196°F) is higher than the suggested maximum temperature for this cell type (140°F). This could result in battery pack damage unless adequate cooling airflow is provided and/or run times are kept short. A lower current would also decrease the battery temperature.
- Current can be decreased by using fewer cells, a smaller diameter or lower pitched propeller, a higher gear ratio, or some combination of these methods.

Power System Notes:

- The full-throttle motor current at the best lift-to-drag ratio airspeed (32.9A) falls approximately between the motor's maximum efficiency current (17.7A) and its current at theoretical maximum output (121.6A), thus making effective use of the motor.
- The voltage (15.1V) exceeds 12V. Be sure the speed control is rated for at least the number of cells specified above.

Possible Aerodynamic Problems:

- The static pitch speed (53mph) is much less than 2.5 times the stall speed (27mph), which may result in reduced performance at typical flying speeds and a low maximum speed. This situation is usually acceptable for an electric sailplane.
- Pitch speed can be increased by using a higher pitched and/or smaller diameter propeller, a higher cell count, or some combination of these methods.
- The diameter (16.0in) to pitch (12.0in) ratio is less than 1.5:1, which will result in reduced propeller efficiency at low speeds (the propeller is stalled). Although this is not likely to affect flying characteristics, it may make take-off or hand launching difficult.

Aerodynamic Notes:

- With a wing loading of 37.8oz/sq.ft, a model of this size will have flying characteristics suited to an experienced pilot. The plane will fly fast, and be readily able to handle fairly strong winds.
- The static thrust (89.7oz) to weight (296.9oz) ratio is 0.3:1, which will result in long take-off runs, especially on grass surfaces. Hand launching is recommended if the surface is not smooth.
- At the best lift-to-drag ratio airspeed, the excess-thrust (31.8oz) to weight (296.9oz) ratio is 0.11:1, which will give slow climbs and low acceleration. Some piloting experience would be beneficial.

General Notes:

- This analysis is based on calculations that take motor heating effects into account.
- These calculations are based on mathematical models that may not account for all limitations of the components used. Always consult the power system component manufacturers to ensure that no limits (current, rpm, etc.) are being exceeded.

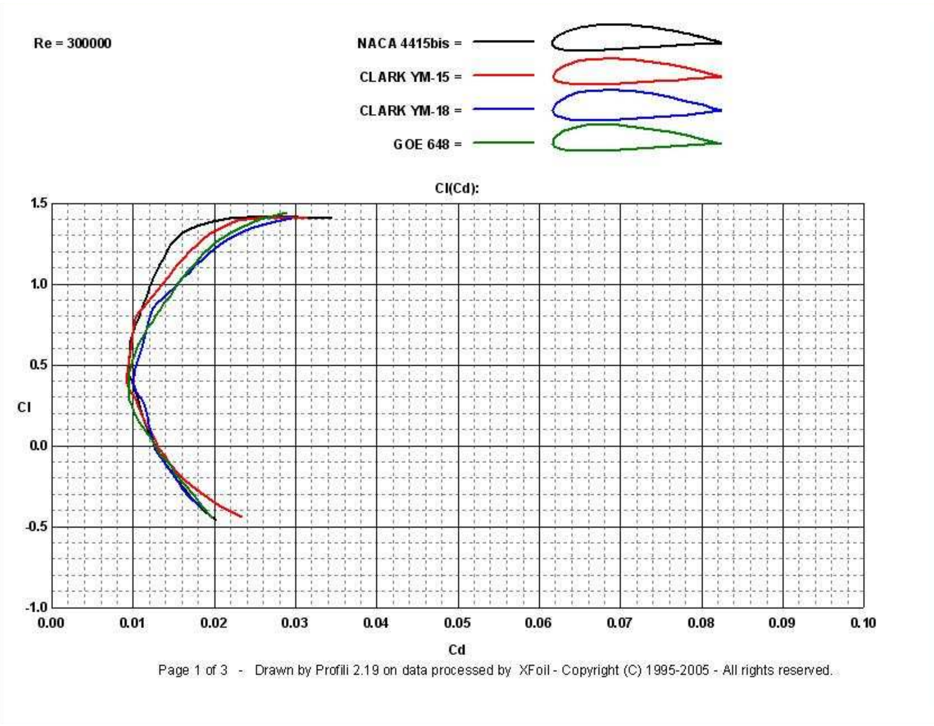
4.5 Aircraft Characteristics

The team selected a blended body for its seamless integration with the spherical wing system implemented. The maximum chord length of the spherical wing is 16 inches. To accommodate for this blended body system, 6 under-wing ribs involving four points of contact were created in AutoCAD and machined. The blended body was created by flaring the fuselage from front to back using a series of gradually increasing diameter ribs. The aircraft will have a maximum level of stability as it is pitched at a slightly inclined angle. These designs incorporated a desire to maximize aerodynamic conformational stability. It was not a concern to substitute stability for velocity and overall power. The spherical wing design is most suited for lift capacities as is the concept of a blended body.

4.6 Airfoil selection

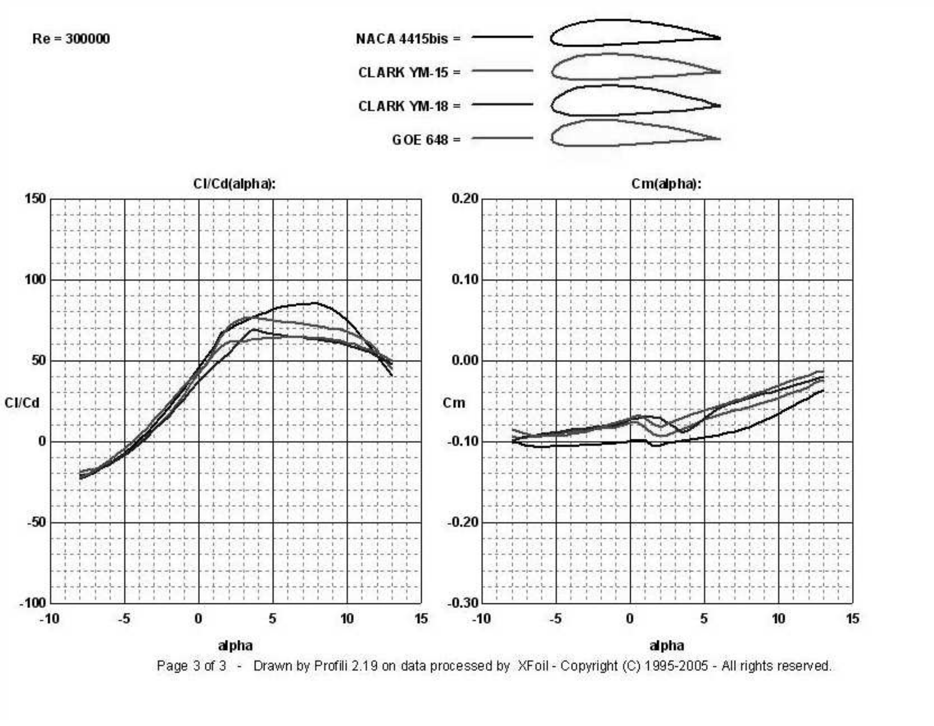
The wing was designed to allow landing speeds less than 30mph and cruising speeds of about 50mph. The landing speed was chosen to be comparable to conventional landing speeds of this airplane size, and to ensure a soft impact on the ground.

The size is dictated by the size of the box. We want to be able to fit the wing lengthwise in one piece. We do not use multiple wing segments to keep the construction and assembly simple. The span is chosen to be 90 inches. This gives us 3 inches per wing for mounting and buffer zone. The maximum chord at the root was chosen to be 16 inches so the total area is 1130in^2. This means a 20 pound airplane will need a lift coefficient of 1.1 for takeoff and landing and a lift coefficient of 0.4 at cruise speeds. Based on these numbers we found rough dimensions (thickness and chamber) of the necessary airfoil with Motocalc. Then we used Profili2 to investigate the lift and drag characteristics of each airfoil with these dimensions, and compared the top candidates to all airfoils in the same family. Figures 1 through 3 show graphs of the lift and drag characteristics along a range of impact angles for the top candidates. We chose the NACA 4415 because of its wide range, stable behavior, overall highest lift and lowest drag characteristic, and lowest coefficient of moment. The airfoil has slightly higher lift characteristics than stated above due to a slight safety factor to account for imperfect manufacturing of the wings.



Page 1 of 3 - Drawn by Profili 2.19 on data processed by XFoil - Copyright (C) 1995-2005 - All rights reserved.

Figure 1. Polar Graph: This diagram was the most important tool in selecting the proper airfoil. In order to minimize drag and maximize lift, the airfoil furthest to the left was chosen.



Page 3 of 3 - Drawn by Profili 2.19 on data processed by XFoil - Copyright (C) 1995-2005 - All rights reserved.

Figure 2. Coefficient Graphs: The airfoil we selected, NACA 4415, has the highest Lift/Drag ratio as well as the lowest coefficient of moment across all angles of incidence.

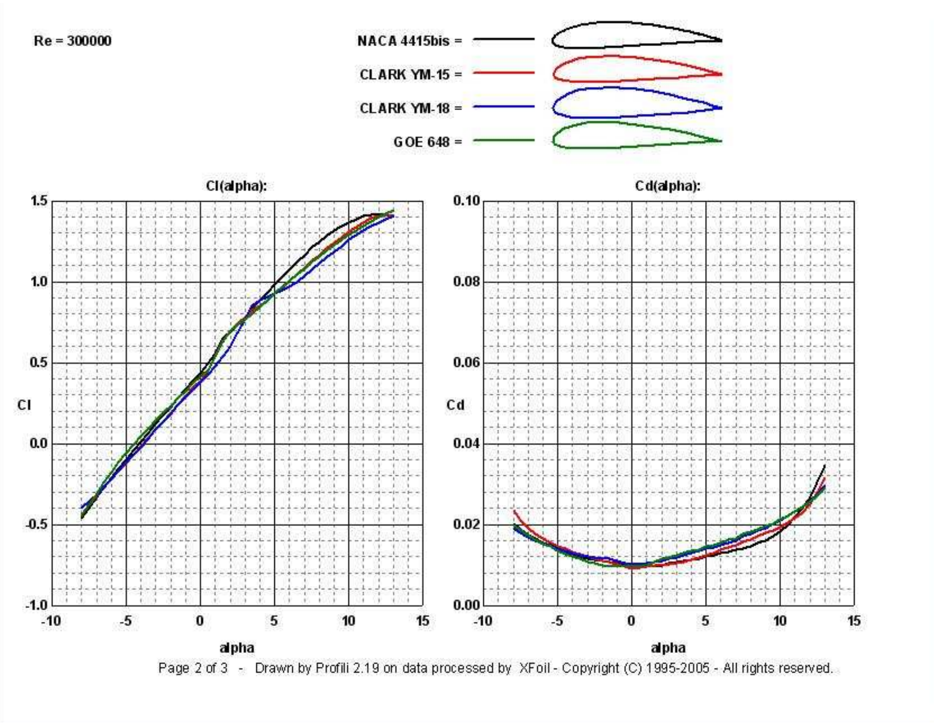


Figure 3. Coefficient Graphs: The selected airfoil has the highest lift coefficient and lowest drag coefficient over all angles of incidence, as compared to the best alternatives.

4.7 Empennage Sizing

The Fuselage has to be able to hold all three payloads and be as light as possible in order to reduce the RAC. In addition, its shape and size has to be such that the induced drag is minimized. The soda bottles and the tennis balls will be loaded lengthwise. The dominant diameter is the diameter of 4 tennis balls, which is a little more than 6 inches. To give ample tolerances an inside diameter of 7 inches was selected, and from structural testing of balsa wood 0.75 inches wall thickness seems appropriate. To reduce drag, the area of the front view of the fuselage is kept at a minimum. Therefore the wings do not extend above the cargo area. As a trade-off, this requires the width of the fuselage at their attachment points to be larger to accommodate the wing spars without interfering with the cargo room.

Lengthwise, the fuselage consists of three sections. In the front is a cone section of 4 inches length which gives room for the motor and flight electronics. After that the cargo area of uniform circular cross-section extends for 31 inches. The rear 10 inches is tapered at the bottom to give a smooth transition and reduce vortex drag.

4.8 Control Surfaces

Control surfaces were limited to percentages of critical design specifications drawn from the preliminary design. The aileron chord was determined to be 15 percent of the wing chord or approximately 3.0 inches; the span approximately 30 percent of the wing span corresponding 43.2 inches. The horizontal stabilizer is within one-quarter of the wing span with rudders approximately 30 percent of the tail.

4.9 Predicted Performance

By inputting into MotoCalc motor, battery, prop, and speed control, a static and in-flight analysis was performed to obtain a marginal understanding on how the design will perform during the competition. Figures 4.7.3-1 and 4.7.3-2 below display the static and in-flight analysis respectively. Figure 4.7.3-3 displays a representative calculation for a given motor/prop/battery configuration in modeled dynamic flight. Figure 4.7.3-4 displays our estimates for the preliminary designs takeoff performance and CG shift on payload carry.

All considered motors were type DC brushless – selected for their low wear, high efficiency, and reliability. Due to the quanity battery / motor combinations available, our team turned to experience model builders to narrow the field of consideration. In the end, an AXI 4130 motor was linked to 2x7 Sanyo 3400c NiMH battery cells.

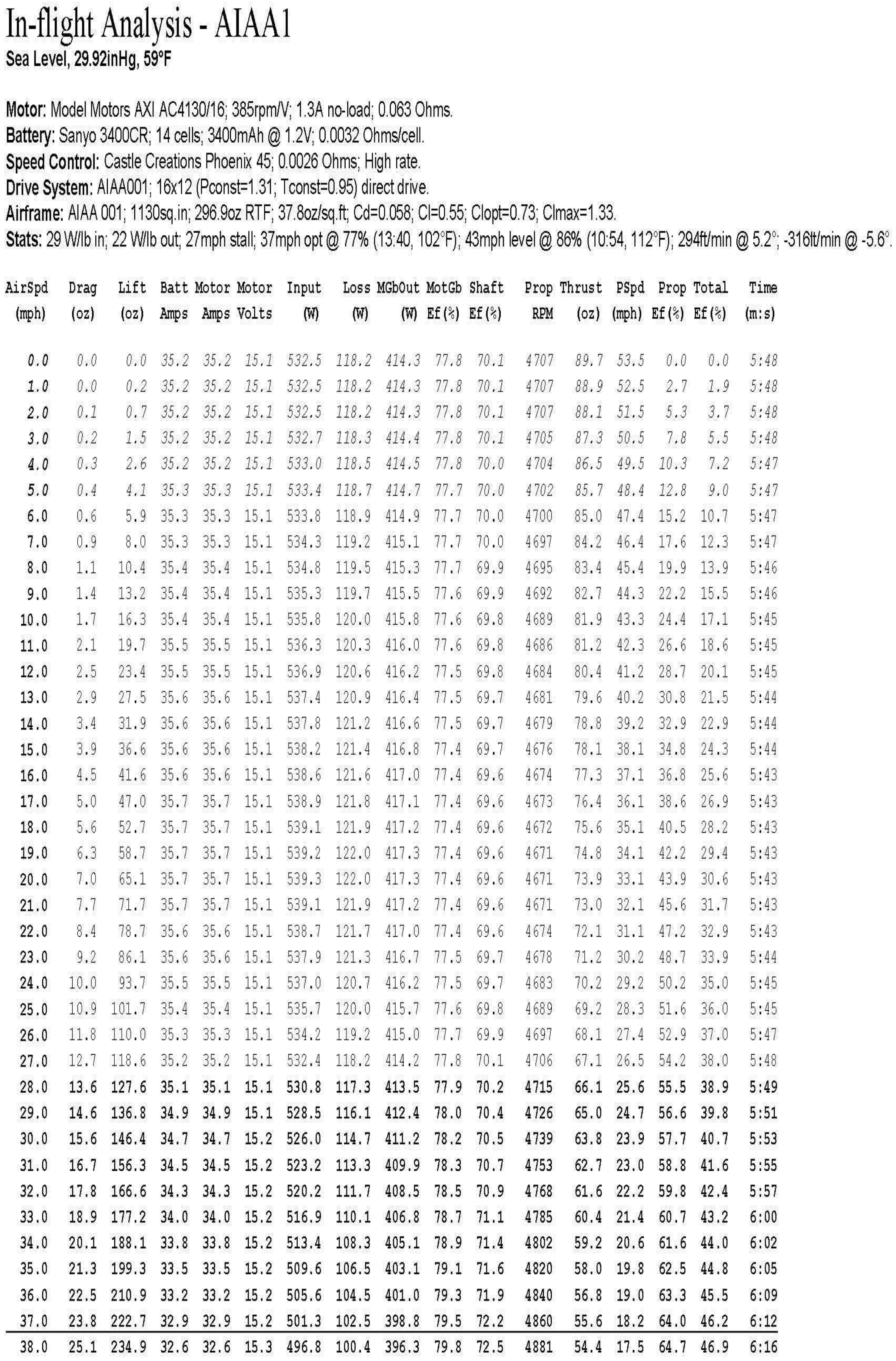
Figure. 4.9.1 Static Analysis

Cells	Dia.(in)	Weight (oz)	Input	Loss	RPM	Trust	PSpd	RofC	Time
14	12	176	600	23	7800	66.9	51.1	413	3:56

Figure. 4.9.2 In-Flight Analysis

AirSpd	Drag	Batt Amps	MtrVt	Loss	RPM	Trust	PSpd	PropEff.	Time
23	12	25.2	343.1	23	23149	45.0	35.5	4.5	3:34

Figure. 4.9.3 Detailed Propulsion Analysis

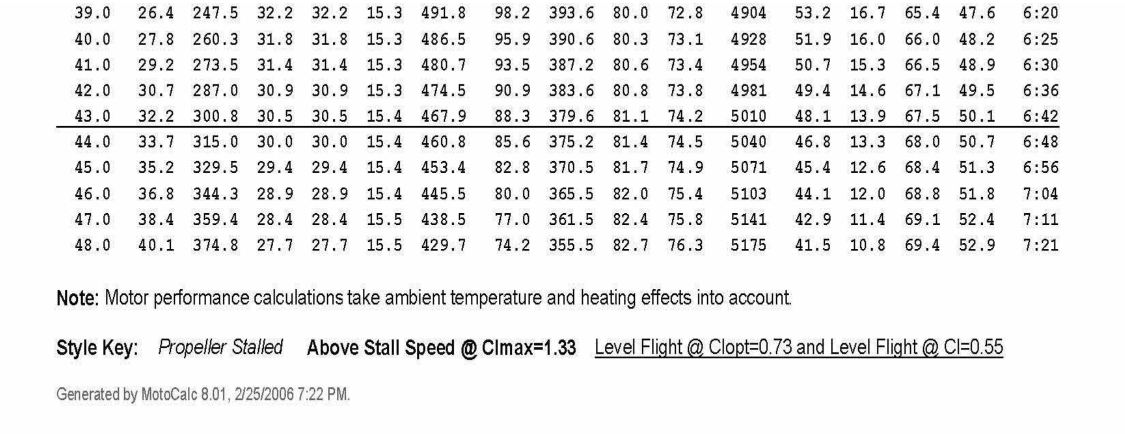


In-flight Analysis - AIAA1

Sea Level, 29.92inHg, 59°F

Motor: Model Motors AXI AC4130/16; 385rpm/V; 1.3A no-load; 0.063 Ohms.
Battery: Sanyo 3400CR; 14 cells; 3400mAh @ 1.2V; 0.0032 Ohms/cell.
Speed Control: Castle Creations Phoenix 45; 0.0026 Ohms; High rate.
Drive System: AIAA001; 16x12 (Pconst=1.31; Tconst=0.95) direct drive.
Airframe: AIAA 001; 1130sq.in; 296.9oz RTF; 37.8oz/sq.ft; Cd=0.058; Cl=0.55; Clopt=0.73; Clmax=1.33.
Stats: 29 W/lb in; 22 W/lb out; 27mph stall; 37mph opt @ 77% (13:40, 102°F); 43mph level @ 86% (10:54, 112°F); 294ft/min @ 5.2°; -316ft/min @ -5.6°.

AirSpd (mph)	Drag (oz)	Lift (oz)	Batt Amps	Motor Amps	Motor Volts	Input (W)	Loss (W)	MGbOut (W)	MotGb Ef(%)	Shaft Ef(%)	Prop RPM	Thrust (oz)	PSpd (mph)	Prop Ef(%)	Total Ef(%)	Time (m:s)
0.0	*0.0*	*0.0*	*35.2*	*35.2*	*15.1*	*532.5*	*118.2*	*414.3*	*77.8*	*70.1*	*4707*	*89.7*	*53.5*	*0.0*	*0.0*	*5:48*
1.0	*0.0*	*0.2*	*35.2*	*35.2*	*15.1*	*532.5*	*118.2*	*414.3*	*77.8*	*70.1*	*4707*	*88.9*	*52.5*	*2.7*	*1.9*	*5:48*
2.0	*0.1*	*0.7*	*35.2*	*35.2*	*15.1*	*532.5*	*118.2*	*414.3*	*77.8*	*70.1*	*4707*	*88.1*	*51.5*	*5.3*	*3.7*	*5:48*
3.0	*0.2*	*1.5*	*35.2*	*35.2*	*15.1*	*532.7*	*118.3*	*414.4*	*77.8*	*70.1*	*4705*	*87.3*	*50.5*	*7.8*	*5.5*	*5:48*
4.0	*0.3*	*2.6*	*35.2*	*35.2*	*15.1*	*533.0*	*118.5*	*414.5*	*77.8*	*70.0*	*4704*	*86.5*	*49.5*	*10.3*	*7.2*	*5:47*
5.0	*0.4*	*4.1*	*35.3*	*35.3*	*15.1*	*533.4*	*118.7*	*414.7*	*77.7*	*70.0*	*4702*	*85.7*	*48.4*	*12.8*	*9.0*	*5:47*
6.0	0.6	5.9	35.3	35.3	15.1	533.8	118.9	414.9	77.7	70.0	4700	85.0	47.4	15.2	10.7	5:47
7.0	0.9	8.0	35.3	35.3	15.1	534.3	119.2	415.1	77.7	70.0	4697	84.2	46.4	17.6	12.3	5:47
8.0	1.1	10.4	35.4	35.4	15.1	534.8	119.5	415.3	77.7	69.9	4695	83.4	45.4	19.9	13.9	5:46
9.0	1.4	13.2	35.4	35.4	15.1	535.3	119.7	415.5	77.6	69.9	4692	82.7	44.3	22.2	15.5	5:46
10.0	1.7	16.3	35.4	35.4	15.1	535.8	120.0	415.8	77.6	69.8	4689	81.9	43.3	24.4	17.1	5:45
11.0	2.1	19.7	35.5	35.5	15.1	536.3	120.3	416.0	77.6	69.8	4686	81.2	42.3	26.6	18.6	5:45
12.0	2.5	23.4	35.5	35.5	15.1	536.9	120.6	416.2	77.5	69.8	4684	80.4	41.2	28.7	20.1	5:45
13.0	2.9	27.5	35.6	35.6	15.1	537.4	120.9	416.4	77.5	69.7	4681	79.6	40.2	30.8	21.5	5:44
14.0	3.4	31.9	35.6	35.6	15.1	537.8	121.2	416.6	77.5	69.7	4679	78.8	39.2	32.9	22.9	5:44
15.0	3.9	36.6	35.6	35.6	15.1	538.2	121.4	416.8	77.4	69.7	4676	78.1	38.1	34.8	24.3	5:44
16.0	4.5	41.6	35.6	35.6	15.1	538.6	121.6	417.0	77.4	69.6	4674	77.3	37.1	36.8	25.6	5:43
17.0	5.0	47.0	35.7	35.7	15.1	538.9	121.8	417.1	77.4	69.6	4673	76.4	36.1	38.6	26.9	5:43
18.0	5.6	52.7	35.7	35.7	15.1	539.1	121.9	417.2	77.4	69.6	4672	75.6	35.1	40.5	28.2	5:43
19.0	6.3	58.7	35.7	35.7	15.1	539.2	122.0	417.3	77.4	69.6	4671	74.8	34.1	42.2	29.4	5:43
20.0	7.0	65.1	35.7	35.7	15.1	539.3	122.0	417.3	77.4	69.6	4671	73.9	33.1	43.9	30.6	5:43
21.0	7.7	71.7	35.7	35.7	15.1	539.1	121.9	417.2	77.4	69.6	4671	73.0	32.1	45.6	31.7	5:43
22.0	8.4	78.7	35.6	35.6	15.1	538.7	121.7	417.0	77.4	69.6	4674	72.1	31.1	47.2	32.9	5:43
23.0	9.2	86.1	35.6	35.6	15.1	537.9	121.3	416.7	77.5	69.7	4678	71.2	30.2	48.7	33.9	5:44
24.0	10.0	93.7	35.5	35.5	15.1	537.0	120.7	416.2	77.5	69.7	4683	70.2	29.2	50.2	35.0	5:45
25.0	10.9	101.7	35.4	35.4	15.1	535.7	120.0	415.7	77.6	69.8	4689	69.2	28.3	51.6	36.0	5:45
26.0	11.8	110.0	35.3	35.3	15.1	534.2	119.2	415.0	77.7	69.9	4697	68.1	27.4	52.9	37.0	5:47
27.0	12.7	118.6	35.2	35.2	15.1	532.4	118.2	414.2	77.8	70.1	4706	67.1	26.5	54.2	38.0	5:48
28.0	**13.6**	**127.6**	**35.1**	**35.1**	**15.1**	**530.8**	**117.3**	**413.5**	**77.9**	**70.2**	**4715**	**66.1**	**25.6**	**55.5**	**38.9**	**5:49**
29.0	**14.6**	**136.8**	**34.9**	**34.9**	**15.1**	**528.5**	**116.1**	**412.4**	**78.0**	**70.4**	**4726**	**65.0**	**24.7**	**56.6**	**39.8**	**5:51**
30.0	**15.6**	**146.4**	**34.7**	**34.7**	**15.2**	**526.0**	**114.7**	**411.2**	**78.2**	**70.5**	**4739**	**63.8**	**23.9**	**57.7**	**40.7**	**5:53**
31.0	**16.7**	**156.3**	**34.5**	**34.5**	**15.2**	**523.2**	**113.3**	**409.9**	**78.3**	**70.7**	**4753**	**62.7**	**23.0**	**58.8**	**41.6**	**5:55**
32.0	**17.8**	**166.6**	**34.3**	**34.3**	**15.2**	**520.2**	**111.7**	**408.5**	**78.5**	**70.9**	**4768**	**61.6**	**22.2**	**59.8**	**42.4**	**5:57**
33.0	**18.9**	**177.2**	**34.0**	**34.0**	**15.2**	**516.9**	**110.1**	**406.8**	**78.7**	**71.1**	**4785**	**60.4**	**21.4**	**60.7**	**43.2**	**6:00**
34.0	**20.1**	**188.1**	**33.8**	**33.8**	**15.2**	**513.4**	**108.3**	**405.1**	**78.9**	**71.4**	**4802**	**59.2**	**20.6**	**61.6**	**44.0**	**6:02**
35.0	**21.3**	**199.3**	**33.5**	**33.5**	**15.2**	**509.6**	**106.5**	**403.1**	**79.1**	**71.6**	**4820**	**58.0**	**19.8**	**62.5**	**44.8**	**6:05**
36.0	**22.5**	**210.9**	**33.2**	**33.2**	**15.2**	**505.6**	**104.5**	**401.0**	**79.3**	**71.9**	**4840**	**56.8**	**19.0**	**63.3**	**45.5**	**6:09**
37.0	**23.8**	**222.7**	**32.9**	**32.9**	**15.2**	**501.3**	**102.5**	**398.8**	**79.5**	**72.2**	**4860**	**55.6**	**18.2**	**64.0**	**46.2**	**6:12**
38.0	**25.1**	**234.9**	**32.6**	**32.6**	**15.3**	**496.8**	**100.4**	**396.3**	**79.8**	**72.5**	**4881**	**54.4**	**17.5**	**64.7**	**46.9**	**6:16**



39.0	26.4	247.5	32.2	32.2	15.3	491.8	98.2	393.6	80.0	72.8	4904	53.2	16.7	65.4	47.6	6:20
40.0	27.8	260.3	31.8	31.8	15.3	486.5	95.9	390.6	80.3	73.1	4928	51.9	16.0	66.0	48.2	6:25
41.0	29.2	273.5	31.4	31.4	15.3	480.7	93.5	387.2	80.6	73.4	4954	50.7	15.3	66.5	48.9	6:30
42.0	30.7	287.0	30.9	30.9	15.3	474.5	90.9	383.6	80.8	73.8	4981	49.4	14.6	67.1	49.5	6:36
43.0	32.2	300.8	30.5	30.5	15.4	467.9	88.3	379.6	81.1	74.2	5010	48.1	13.9	67.5	50.1	6:42
44.0	33.7	315.0	30.0	30.0	15.4	460.8	85.6	375.2	81.4	74.5	5040	46.8	13.3	68.0	50.7	6:48
45.0	35.2	329.5	29.4	29.4	15.4	453.4	82.8	370.5	81.7	74.9	5071	45.4	12.6	68.4	51.3	6:56
46.0	36.8	344.3	28.9	28.9	15.4	445.5	80.0	365.5	82.0	75.4	5103	44.1	12.0	68.8	51.8	7:04
47.0	38.4	359.4	28.4	28.4	15.5	438.5	77.0	361.5	82.4	75.8	5141	42.9	11.4	69.1	52.4	7:11
48.0	40.1	374.8	27.7	27.7	15.5	429.7	74.2	355.5	82.7	76.3	5175	41.5	10.8	69.4	52.9	7:21

Note: Motor performance calculations take ambient temperature and heating effects into account.

Style Key: *Propeller Stalled* **Above Stall Speed @ Clmax=1.33** Level Flight @ Clopt=0.73 and Level Flight @ Cl=0.55

Generated by MotoCalc 8.01, 2/25/2006 7:22 PM.

Figure. 4.9.4 Preliminary Take-off Performance

It was necessary to complete rotation within 100 feet due to the maximum allowable length on the competition runway.

Performance:

Take-off field length empty	33ft
Take-off field length gross weight	88ft

Balance:

Center of Gravity

With wooden block	15 inches from front
With 48 tennis balls	16 inches from front
With two 2-liter bottles	17 inches from front

5 Detail Design

Once preliminary and conceptual design phases were complete, the remaining detailed design challenges – namely structural optimization, component selection, and system integrations – became the responsibility of the Wing and Fuselage design teams under the Detail Design phase.

5.1 Component and Systems Architecture Selection

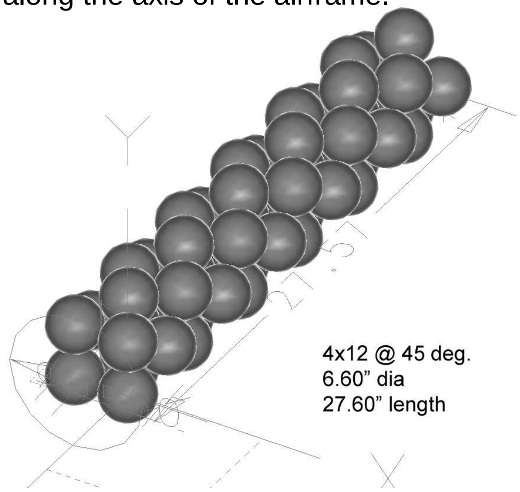
5.1.1 Payload Design

In order to properly secure and carry the mission payloads – (48 loose tennis balls, two 2-Liter soda bottles full of water, one large rectangular wood block no larger than 4”x4”x24” weighing not more than 8 lbs) – several variables were taken into consideration. The main concern of the fuselage design team was to arrange the carrying structure such that the overall center of gravity (CG) of the airframe would remain centered under the wings. Maintaining a consistent overall CG was necessary to minimize the changes the aircraft handling characteristics would experience as payloads of different weights were added and removed.

Maintaining CG requirements entailed designing a variable positioning of the payloads and their respective cargo nets within the fuselage such that the payload CG would rest as closely as possible to the midline beneath the wings. The system was accomplished by means of simple detachable cargo nets positioned internal to the fuselage and accessible through the main cargo door.

The second challenge was efficiently securing the cargo so as to prevent vibration displacement in flight, and such that in the event of a severe landing, the heavier cargo would not ride forward, damaging the airframe. Accordingly, the interior of the fuselage was equipped with both cargo nets and guide rails such that the payloads either fit natively into the airframe, or that if, as in the case of the tennis balls, they were bagged into a simple carrying sack the fuselage would securely accommodate them.

The following configuration was chosen for the tennis ball arrangement within the carrying net. The wood block and the 2-liter soda bottles were carried natively along the rail system with the aid of cargo nets positioned at the extreme ends. The 2-liter bottles were arranged laterally along the axis of the airframe.



5.1.2 Cargo Doors / Access Hatches

The design of Lion in the Sky minimizes additional weight by letting the cross-sectional area be a minimum and the available cargo space a maximum. Thus, making the engine available for emergency servicing is not accomplished via a door or access hatch. The aircraft possesses a blended body with open fuselage ribs. Thus, without applying the Monocot, all internals are accessible. Access to the engine is granted by a slightly varied structure in the ribs surrounding the engine. In the top section, a 4 inch long part of the rib is missing. Structurally, this was accommodated for with a stronger rib section and a larger cross sectional area for this rib (4 of 14). Since the engine is affixed to a firewall and engine mounting plates which are affixed to a frontal rib, the design of our fuselage gives the best access to the engine. The location of the access region also allows for quick servo servicing and re-alignment in the case of a hard landing or accidental triggering of the servo. A MonoCot covering offers the most accessibility, which is a necessary facet of all cargo aircraft.

The rear access hatch is built into the flare angle needed during the take-off roll for proper rotate pitch and stable climb-out. The door is angled at 45 degrees, and thus is root two of the length of the back section of the aircraft. It is hinged at the bottom of the aircraft and fastened via weight-negligible hinges nylon hinges). These same hinges will be used for the flight control surfaces (ailerons, stabilizers, rudder). The door is constructed from ¼ inch balsa wood reinforced by a mixture of cyanoacrylate (CA cement) and epoxy bonding glue. Cargo space is maximized when the rear gate door is perfectly vertical. This conformation would cause much turbulent flow, as evidenced from airfoil wind-tunnel examination. It was discovered that as the orientation of the structure approaches vertical, separation of flow was discovered. This is unacceptable in controlled flight and thus a gate angle of 45-60 degrees was agreed upon as the maximized cargo-minimized turbulent flow condition.

5.1.3 Landing Gear

The frontal and rear landing gear were purchased commercially. The frontal unit, a generic dual strut / single wheel / single spring unit, provides 3 inches of clearance below the propeller as the fuselage rests – which accommodates a negative landing angle of approximately 10 degrees in the worst case before a propeller strike occurs. The additional height of the frontal gear presents the airframe with a positive resting angle which shortens the required runway length on take off.

The rear unit was assembled from generic commercial components, including 1 inch diameter rubber wheels and an aluminum spreader of 12 and 5 inches horizontally and vertically. To obtain an additional 2 inches of horizontal spread, the wheels were positioned at the extremes of the spread. Our calculations showed that in addition to accommodating rapid taxing, a spread of 14 inches was adequate to accommodate landings which occurred slightly off center.

Rubber wheels were selected for both frontal and rear gear as a tradeoff between weight, rolling resistance, and shock absorbance.

5.1.4 Structural systems

The integrity of Lion in the Sky's airframe was insured by a network of pine spars which ran the length of the airframe and were interconnected by a series of pine and balsa circular ribs, alternated to achieve a reasonable balance between strength and weight. The spars were arranged in such a way as to provide maximum strength along the axis and areas predicted to experience the most stress: the fuselage wing connection, the forward motor mount, and the front and rear landing gear.

Landing gear was affixed to the base of the fuselage via pine plates secured to the rib network which ran the length of the fuselage. The wing / fuselage connection was achieved by the use of pinned pine slots fitted to the fuselage rib network. The slots were sized to receive the pine spars of each wing segment, which were then securely affixed by the use of simple aluminum pins which pieced each spar.

The motor was permanently fixed to the airframe via a quarter inch plywood firewall - a selection made after a removable pine firewall fractured during propulsion testing due to minor but continuous vibration produced by a slight rotational misbalance of the copper motor windings.

The skin of the both fuselage and wings was Monocot type plastic, a plastic composite selected for its aerodynamic properties, bright coloration and according visibility to the ground pilot, strength, light weight and ease of application.

In lieu of detailed computational or theoretical analysis, it was determined that it was possible to assess the variables which dictated the strength of our structural systems (material, thickness, number, arrangement, and interconnectedness) through basic structural analysis. The following table was obtained by rough calculations made through stress analysis of five basic configurations.

ID	Spar Material / Thickness	Rib Material / Thickness	Interconnectedness	Strength	Weight
1	Balsa	Balsa	Low	Low	Very low
2	Balsa	Balsa	High	Medium	Low
3	Balsa	Pine	Low	Medium	Medium
4	Pine	Pine	Low	Very high	High
5	Pine	Balsa	Medium	High	Low

In the end, it was determined that both in the cases of wing and fuselage structure, a rib / spar arrangement with high spar count, high interconnectedness, and minimal rib and spar thickness provided the best compromise between reliability, strength, and weight.

5.1.5 Avionics systems

The avionics systems onboard our aircraft consisted of a network of three standard ball bearing servos and one electronic speed control unit linked to a receiver powered by a NiMH battery, controlled by a Airtronics programmable 6 channel radio transmitter. Servo one, positioned between the wings, was linked to the aileron control cables. Servo two, positioned in the tail, was linked to the elevator. Servo three, positioned toward the front of the aircraft, was linked to both the rudder and the frontal landing gear such that it was capable of steering the aircraft on the runway and operating the rudder in flight. It was determined that the weight savings achieved by controlling the wheel and rudder simultaneously outweighed the slight aerodynamic disadvantage consequent to a misaligned front gear during banking. a

An electronic speed control (ESC) in conjunction with a standard type 40watt fuse (as per the competition guidelines) were linked between the receiver box and the motor.

5.1.6 Radio Control Information

Programming of the RC Controller was performed using the advanced controls of the field radio. Fail Safe is not part of the programming of the radio, but rather due to servo connectors (downstream of the receiver) however it does have the capability to cut throttle when radio contact is lost with the aircraft. This was programmed using the advanced throttle functions. When throttle cut was brought to the programming screen, throttle was set to idle and 20% less than V1 (throttle maximum) for the controller. In addition, it was decided that an exponential throttle increase was preferable to a linear increase. This was achieved using the Flight Mode 2 for the Airtronics Controller. Also, the elevator directionality was set to “reversible”. This allows for maximum displacement of ailerons and elevators from the neutral positioning.

5.1.7 Disassembly method

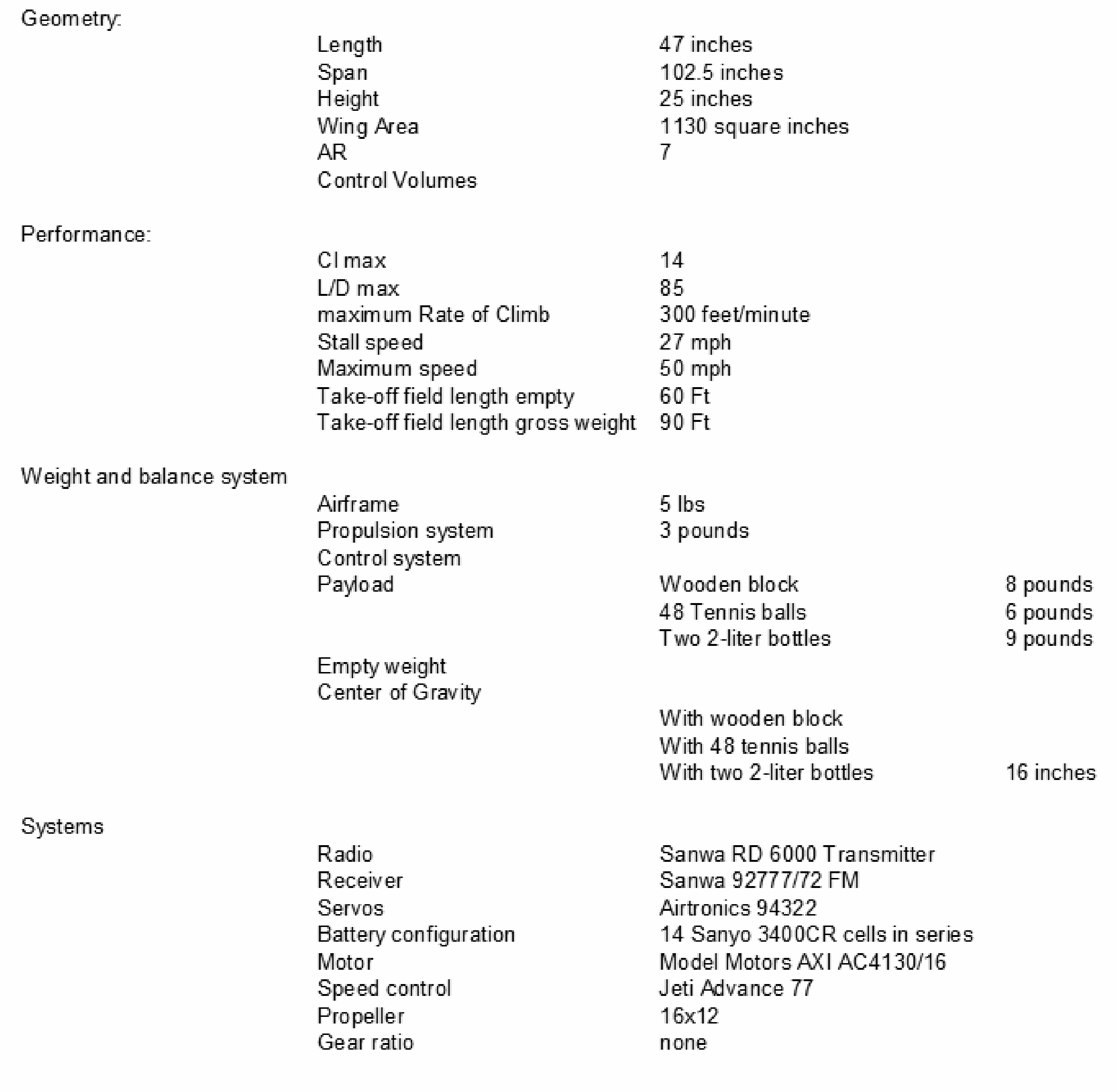
From the start it was clear that the elliptical wing area needed to generate sufficient lift to carry the projected aircraft weight at a reasonable take off speed would mandate a length which would exceed the dimensions of the competition box. As such, anticipating the necessity of disassembling the aircraft, we mitigated our design process with two additional goals: 1) the minimization of the pieces necessary to detach for disassembly, and 2) insuring the structural strength along those segments of the airframe.

As our calculations showed it was possible to adequately accommodate the payloads, engine, propeller, and tail lengthwise within the competition box, we agreed upon a detachable wing system. In the end, a pinned receiver / slot design was engineered such that the wing segments were easily affixed and detached from the fuselage. Due to the positioning of the aileron control servo within the fuselage itself, a constraint existed such that the aileron control wire must be carefully attached and detached to each wing segment at each iteration.

5.2 Final Aircraft’s RAC Table

Component	**Weight (lb)**	**Percent of Total**
Battery	3.0	27
Motor	1.2	11
Servos and Pushrods	0.9	8
Fuselage	3.4	30
Wings	2.7	24
TOTAL	11.2	

5.3 Final airplane specifications:



Geometry:			
	Length	47 inches	
	Span	102.5 inches	
	Height	25 inches	
	Wing Area	1130 square inches	
	AR	7	
	Control Volumes		
Performance:			
	Cl max	14	
	L/D max	85	
	maximum Rate of Climb	300 feet/minute	
	Stall speed	27 mph	
	Maximum speed	50 mph	
	Take-off field length empty	60 Ft	
	Take-off field length gross weight	90 Ft	
Weight and balance system			
	Airframe	5 lbs	
	Propulsion system	3 pounds	
	Control system		
	Payload	Wooden block	8 pounds
		48 Tennis balls	6 pounds
		Two 2-liter bottles	9 pounds
	Empty weight		
	Center of Gravity		
		With wooden block	
		With 48 tennis balls	
		With two 2-liter bottles	16 inches
Systems			
	Radio	Sanwa RD 6000 Transmitter	
	Receiver	Sanwa 92777/72 FM	
	Servos	Airtronics 94322	
	Battery configuration	14 Sanyo 3400CR cells in series	
	Motor	Model Motors AXI AC4130/16	
	Speed control	Jeti Advance 77	
	Propeller	16x12	
	Gear ratio	none	

5.4 *The Drawing Package on the next few pages*

Drawing package page two

Drawing package page three

6.0 Manufacturing Plan and Process

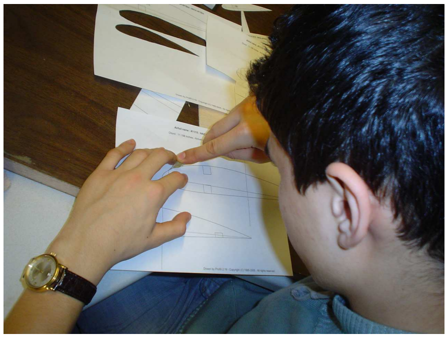
6.1 Process Selected for the Manufacture of Major Components

One of the things clear to the team from the beginning was our lack of expertise and funding that we would encounter throughout the building process. While some of us did have some experience, we decided that our best option was to keep the building phase as simple and inexpensive as possible. With that in mind, in this section we will cover how the plane was actually built, different ideas we had for manufacturing the plane, what methods we used, and how we solved the problems we encountered.

6.1.1 Wing and Empennage Materials and Manufacture

For the wings, the first and most obvious material that came to mind was balsa wood. Its light weight and easy maneuverability would allow space for any imperfections we might encounter. During the building process, we also found that a major advantage of balsa wood was its simple way of adjusting flaws and fixing damaged sections.

To manufacture the wings we manually cut out 15 airfoil profiles out of 3/32" thick balsawood. While we considered cutting out the profiles using computer-aided machines, the idea seemed too complicated, and we assumed we could do an equally good job cutting the profiles manually. We selected 15 because we want a spacing of no more than 3" between them on a 4 foot wing, in order to ensure a good support for the monocot cover and high form stability even at high winds.



The wings will contain two half inch square pine spars at 25% of the cord, one on top and one on bottom. These will be curved to fit the elliptical shape. Additionally, one rectangular ½ by ¼ inch pine spar will be in the rear portion of the wing, which will be straight to hold the shape and give additional support. The front and back will be supported by a balsa spar sanded to shape. This spar has no structural support and is only for shape. The front 25% of the chord will be plated with 1/16 inch thick balsa to help support the shape.

The individual airfoils will be lined up and stuck into groves cut into a Styrofoam plate to be kept in the right configuration until the spars have been glued in. Additionally, each airfoil will be lined along its profile with 1.2 inch wide 1/8 inch thick balsa strips to increase the area for the monocot.

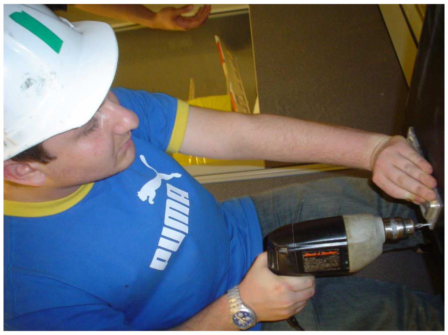
6.1.2 Fuselage Manufacturing Process

Individual cross sections will be cut out of 1/8 thick balsa sheets. Large enough sheets are not available so we will glue some together. Again, the sheets will be lined up in groves cut in a Styrofoam plate and the inner pine spars will be glued in. Then 3/16 inch deep and ¼ inch wide groves will be cut on the outside and lined in the entire length with three 1/16 inch thick balsa strips. The strips will be glued together in their entire length to give structural support, as well as enough area for a monocot covering. Once this rib structure has been constructed all the electronics, landing gear, steering platforms and latches will be installed. Finally the whole fuselage will be covered with monocot.

6.1.3 Landing Gear

The team understood that the materials chosen for the plane were not too strong, and danger was present that the material may fracture when it encountered high stress, prominent in landings. We therefore decided that the landing gear should be strong and flexible, at the expense of some weight gain for our plane. We first looked at the landing gear used by the team in previous years, but decided that it would not dissipate as much energy in a hard landing as we would like it to.

We eventually settled on a landing gear system we found on-line, which consisted of some relatively softer wheels than the one we had. We would have two wheels in the back of the plane and one in the front, which would provide best stability for the plane. The wheels would be connected by a metal frame to the fuselage of the plane, providing a reliable system on which to land.



6.2 Fuselage Materials and Manufacture

Because of the complexity involved in the building of the fuselage, we have divided this title in further sections.

6.2.1 Spar Materials

The team explored a number of possible materials for the construction of the spars in fuselage. Recognizing that the primary source of structural integrity and, possibly, weight came from the rib and spars, themselves, the selection of a material that balanced strength and weight was crucial. The strength aspect of the material had to be further broken down into rigidity versus flexibility. The material needed to be rigid enough to bare the weight of the cargo, yet flexible enough to dissipate energy during stressful landings. Moreover, this material would have to be malleable to conform to the blended body design of the fuselage.

6.2.2 Aluminum

One of the later materials explored was aluminum, more specifically, grade 6061 aluminum tubing. This material exhibits many of the properties that the team desired. It provides lightweight with exceptional strength. Using tubing, over a solid rod, preserves aluminum's high area moment of inertia while drastically cutting down weight. It also provides excellent rigidity with minimal fatigue. Lastly, it can be easily shaped with simple pipe benders. However, the team decided that, although, aluminum was fairly lightweight, it provided more strength than was necessary at the cost of too much weight.

6.2.3 Plastics—High Density Polyethylene (HDPE)

The primary plastic explored was HDPE. This readily available commercial plastic is both cheap and easily attainable. Its material properties include heavy weight, very high strength, low rigidity, and easy malleability. Its plastic properties would have offered superb strength and resiliency. Upon a poor landing, HDPE would not dent, bend, or break; the cargo and fuselage structural integrity would be maintained at all times. However, HDPE, although cost effective and easy to work with, would have been far too strong (again at the cost of weight) and overly flexible.

6.2.4 Balsa Wood Epoxy Composite

This spar material is composed of multiple thin strips of balsa wood bonded to one another by a basic epoxy, then bent into the desired shape and set to cure. The cured epoxy holds the wood in the desired shape and enhances its strength. The natural lightweight of balsa wood aligned with the multiple thin strips of cured epoxy yields a phenomenally light, yet strong, material. This composite is far lighter than any other material explored while providing similar strength properties. It is rigid, yet still capable of dissipating small vibrations and small impulses. It is, however, highly susceptible complete material failure in the event of a large impulse commonly found in a poor landing. This weakness can be compensated for by the use of multiple small spars rather than a few large spars.

6.2.5 Materials Conclusion

After exploring metals, plastics, and woods, the team concluded that the best material was the wood-epoxy composite. This material provided the best strength to weight ratio while also satisfying the need for rigidity and malleability. The team opted to use 6 such spars separated by 60 degrees to symmetrically distribute the load within the ribs.

6.3 Detail of Manufacturing Processes

6.3.1 Strength-to-Weight Ratio

Because of the importance weight has in determining the final score of our airplane, we decided weight should be a greater concern than strength, while making sure strength is also kept at a reliable level. While we had originally decided that the wings should be made out of balsa wood, the fuselage caused greater trouble, as the cargo would require the fuselage to be stronger than we had originally planned. Among the material we looked at were aluminum, plastics, and a balsa wood-epoxy composite, all of which are describe in detail in section 6.1.2.

6.3.2 Skill Level Required

Another important factor was the amount of skill or prior experience required to use certain materials correctly. This also influenced our final decision, as some of the ream members had previously worked with balsa wood and found it both effective and easy to use. On the other hand, we also considered some more advanced materials, but ruled them out after understanding the skill level and cost involved in using them.

6.3.3 Cost and Availability

Yet another issue that influenced our final decision was the accessibility to materials that we could theoretically use in building the airplane. Working on a significantly low budget limited our options to materials that we could easily obtain for reasonable prices. For this category, balsa wood and aluminum stood out as the most reasonable materials.

6.3.4 Time to Build

Working on this project proved to the group how fast time can pass, and how quickly we should start working. This helped us understand that the time it would take to build the airplane should also take a part in choosing a material. This also meant that we had to find a material where flaws or ‘last minute corrections’ would not set us back significantly.

6.3.5 Internal Component Placement

While not necessarily a major factor in deciding what material to use, it did influence the shape we chose for the plane. One of our major objectives was to have the servos, motor, batteries, and receivers to be accessible after the airplane is completed. At the same time, we would have to create a system that would allow the soda bottles and tennis balls to be accessed easily and quickly by the team members.

6.3.6 Durability of Part

As a team, we realized that whatever material we chose for our plane had to be reliable enough that we wouldn't have to build any part twice. The durability of a part does not only rely on strength but also includes its ability to maintain its shape and how easy it is to fix.

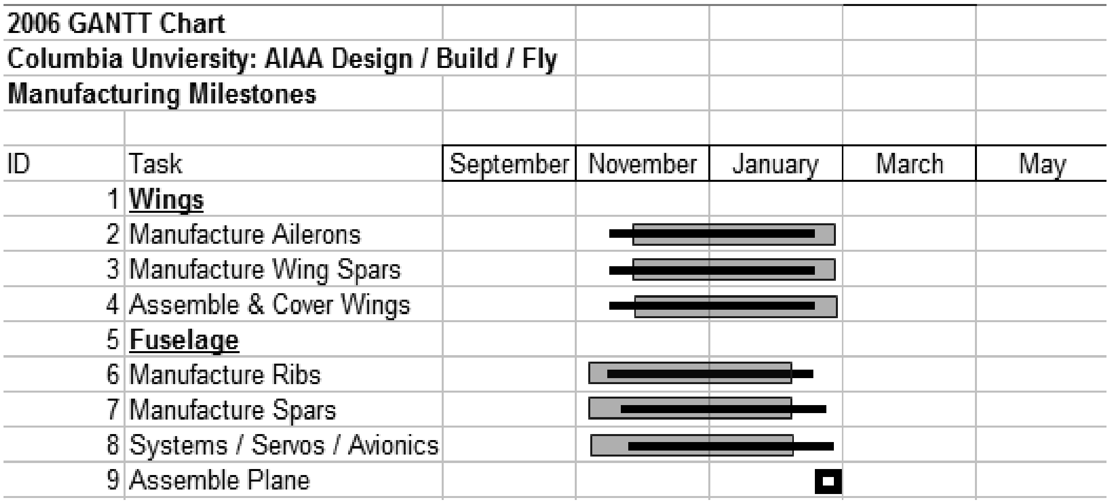
6.3.7 Shape Fidelity

This refers to the capability of a material to preserve its shape when it encounters strong winds and high stresses. This factor's importance made us doubt the use of balsa wood as we did not believe that balsa would be able to hold its shape when encountering excessive forces. It was because of this that the idea of the balsa-epoxy composite arose, allowing us to maintain a fairly good shape, comparable even to those of stronger materials.

6.3.8 Materials Conclusion

We created the following table with a few chosen materials and some of the factors involver in choosing them. It is worth noting that these were not the only three materials

6.4 Manufacturing milestones



7.0 Testing Plan

7.1 Testing Objectives

For the 2005 / 2006 contest season, the testing schedule of “Lion in the Sky” was divided into six sections which included static and dynamic (in flight) testing of structural, electrical, and propulsion systems. A scarcity of specialized equipment meant that the majority of our testing (with the exception of the propulsion systems) was largely qualitative. The aim of testing cycle, rather than to heavily optimize the aircraft, was to insure a safe and reliable flight which met the objectives of the competition while falling well within the performance envelope of our aircraft.

7.1.1 Propulsion Testing

Static testing of the propulsion system (an AXI 4930 DC Brushless motor and two 9-cell Sanyo NiMH battery packs) was performed in response to an overheating event which occurred on the same system as deployed on the partially constructed Flyin Lion of last year’s team. Previously, during static testing, one of the cells in the second battery pack had rapidly overheated – melting the pack casing and damaging its neighbors.

In response, this year’s team cycled the batteries and motor at various rotation speeds and currents to assess the heating cycle of the battery packs. Structurally, we positioned the packs toward the periphery of the airframe. They thus receive cooling from the wind while the plane was in flight.

Different firewall thicknesses were assessed to determine the necessary strength and size to properly secure the motor to the airframe. Further assessments were run at sample motor currents to insure that our objective data loosely met the predictive MotoCalc calculation performed prior to engine selection.

7.1.2 Electrical Testing

Electrical systems – including the receiver pack, receiver battery pack, and servos (two ailerons, one rudder / gear, one elevator) – were tested to insure reliable reception, performance, and calibration. Fail Safe parameters were also met in accordance with competition regulations. The electrical connections were tested for their response to loss of contact with RC controller on frequency 14.

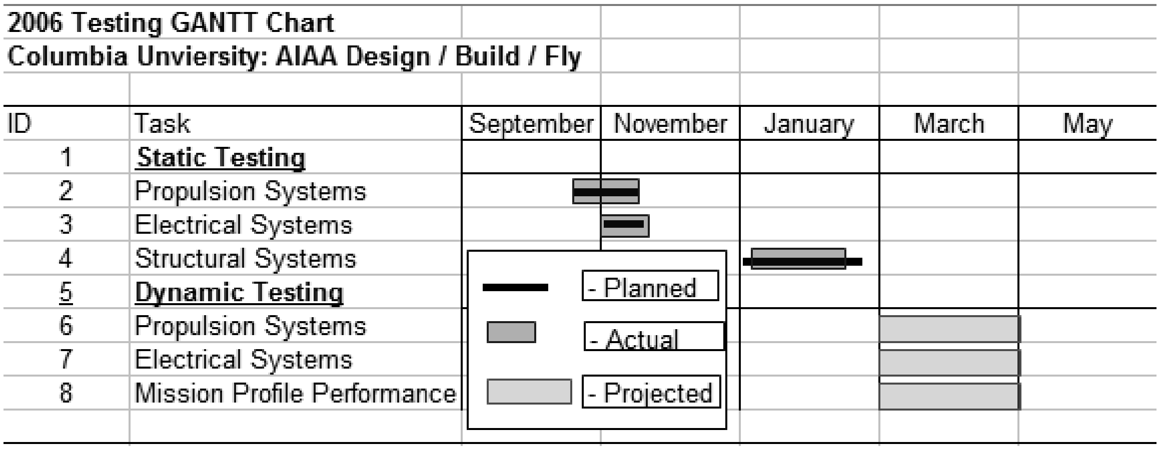
7.1.3 Structural Testing

As RAC would play a key role in scoring, it was preferable to design the lightest airframe possible. In keeping with our goal of achieving a reliable performance, we felt it was important throughout the design and construction process not to compromise the integrity of the airframe in an overzealous effort to lower the RAC.

Both the wings and fuselage of the competition were stressed to determine flexion and likely fracture points (which were correspondingly reinforced) in accordance with the maximum forces we calculated the airframe would experience in flight.

Further, a previously constructed wing set was stressed to breaking by the use of clamps and weights. An analysis of the break pattern heavily influenced both the design of the attachment mechanism which affixed the wings to the fuselage, as well as our material choice for the wing spars.

7.2 Testing Schedule



7.3 Expectations

To reiterate – our expectation throughout the testing phase was to develop a reliable aircraft capable of competently completing the mission parameters. To improve on the performance of previous year’s teams, CU AIAA focused on efforts on optimizing parameters in so far as they did not jeopardize the ability of the aircraft to perform efficiently and safely after the stress of multiple load cycles.

7.4 Mission Design Parameters

With regard to competition performance, our testing cycle including insuring the reliability of the loading door, the ease of inserting and removing the various payloads to and from the airframe, and projecting the response of the aircrafts handing, takeoff, center of gravity, and landing performance with the heaviest, lightest, and mean payload weights.

7.5 What Was Learned

While it was discovered that our battery systems were more than adequate to accomplish the mission profiles we selected, we opted to maintain the addition capacity to give a margin of error which might compensate for any complications which occurred over the course of the competition.

Potential optimizations which were discovered and implemented during testing included:

1) A redesign of the structural wing layout, which included the replacement of balsa spars with pine and the addition of a reinforcement spar to the trailing edge of the aircraft.
2) A reduction in spar count throughout the fuselage – due to more than adequate resistance to the torsion and impact forces anticipated during flight and in landing.
3) The relocation of the battery packs to the exterior of the fuselage such that they would receive addition cooling from wind in flight.
4) It was discovered during static propulsion testing that the motor--despite being type DC brushless--generated significant vibration due to a slight misbalancing of the copper windings. According, a thicker plywood firewall was chosen to replace the pine predecessor which sustained moderate fractures in trial runs.

8.0 References

AIAA 2006 Design / Build / Fly Rules. <http://www.ae.uiuc.edu/aiaadbf/2006_rules.html>