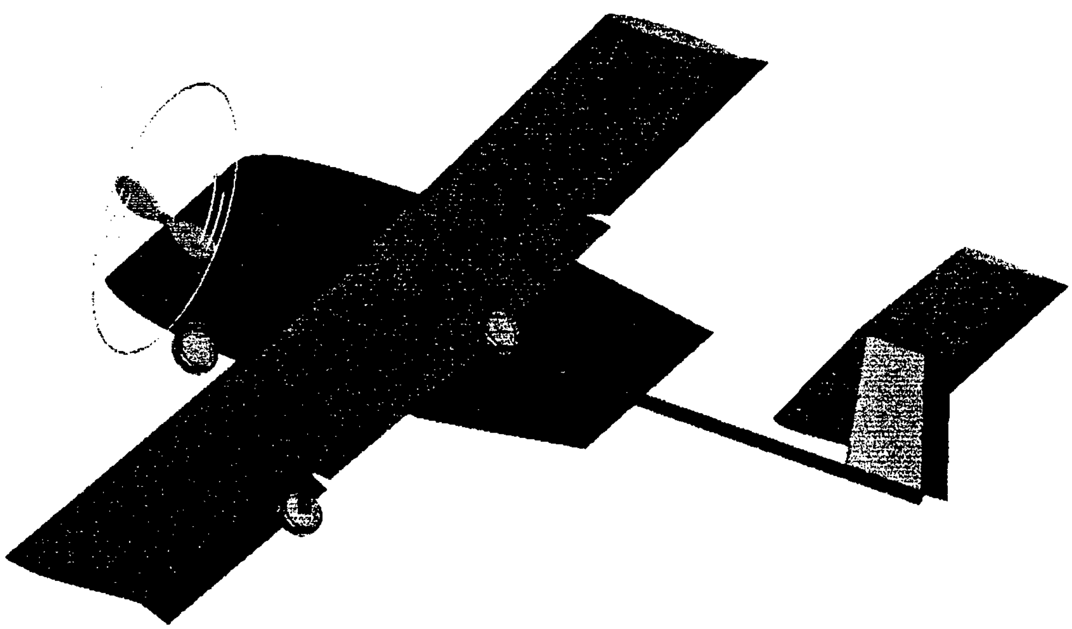
UNIVERSITY OF CALIFORNIA, SAN DIEGO

Proposal Phase Design Report

Submitted March 12, 2002



TLAR III

TLAR III

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1 Executive Summary

Student members of the American Institute of Aeronautics and Astronautics (AIAA) at the University of California, San Diego designed and built a remote-controlled aircraft for the 2002 AIAA Design/Build/Fly Competition to apply and broaden their knowledge of aircraft design and manufacturing.

The AIAA Design/Build/Fly Competition emphasizes the importance of design, construction, and the actual flight performance of the final plane. Based on one of the Mission Tasks requiring the aircraft to carry between 10 to 24 softballs, the team designed the aircraft to carry a high volume payload of 24 softballs each weighing approximately 180 grams with a take-off distance less than 200 ft. The wingspan is approximately 84 in. in length, and the empty weight is 14.9 lbs.

1.1 Objectives

The main objective of the team is to earn the highest score possible. The Rated Aircraft Cost (RAC) must be as low as possible; the Written Report must be as high as possible; and during the actual flight competition, the flight speed must be high while the pit stops must be quick. The lowest RAC was achieved through trial calculations for all of the design phases. To achieve the highest Written Report score, the team edited the Written Report based on the reviews of the faculty and mentor advisors during all paper preparation phase. To achieve the highest flight speed, the team selected the airfoil and propulsion system for TLAR III, and to achieve the quickest pit stop, the team ran pit stop coordination practices.

The second objective is to allow experienced members of the UCSD team to pass knowledge onto novice members. This year, most of the team members are new, being involved in the project for the first time and/or as first year students entering college. The competition is meant to convey the importance of responsible leadership and teamwork.

1.2 Analytical Tools

Several analytical tools were used throughout the entire design process. The most important was Microsoft Excel, which was used for everything from calculations of weight-and-balance, the quickest time to complete task, climb rate, take-off distance, and turn radius, to financial analysis and Rated Aircraft Cost (RAC). General aviation design principles and equations were used in determining exact dimensions and specifications. The mathematical toolbox, Matlab 6.0, was used to perform numerical analysis of flight performance of the chosen wing configuration. Finally, the programs AutoCAD 2000 and PRO/E 2000i were crucial tools used to visualize and present aircraft design ideas.

FOMs and Design Parameters were chosen to provide requirements to ensure that the design would meet the functional requirements dictated by the contest administrators, as well as the design goals as defined by the UCSD AIAA team. They were applied to each stage within the entire design process to analyze the strengths and weaknesses of each component as well as those of the overall aircraft configurations. The design process used to determine the final configuration began with the Conceptual Design Phase (CDP). Next was the Preliminary Design Phase (PDP) followed by the Detail Design Phase (DDP), from which emerged the final configuration of the aircraft.

1.3 Conceptual Design Phase Outline

The CDP consists of two stages, Stage I and Stage II. Stage I incorporates a range of ideas for each component that was considered. The FOMs of Stage I were geared towards eliminating ideas that were intuitively and/or obviously impractical. These FOMs centered on material availability, handling characteristics, RAC, ease of transportation and complexity of manufacture in relation to time and skill level required. Stage I analysis resulted in component concepts that were determined to be viable. These components were assembled into three different configurations that initially met the design parameters and FOMs. The three configurations were then progressed into Stage II.

The goals of applying Stage II FOMs were to maximize the overall flight score, minimize the RAC, and develop a preliminary aircraft design. Stage II FOMs focus on an in depth analysis of the components, with specific attention to payload access, construction feasibility, propulsion and maximizing strength to weight ratios, operator and component safety, difficulty of repairs, component and interfacing strength, and payload capacity. The analysis of Stage II resulted in a single overall design configuration, at which point, the question was raised of whether it met the functional and design goal requirements. If it was determined that the configuration met these requirements, it continued into the PDP. Otherwise, it was reiterated through Stage II of the CDP in an attempt to optimize the configuration with alternate component designs.

1.4 Preliminary Design Phase Outline

Once an overall design configuration was decided upon, the next step was to conduct a more thorough and detailed analysis of the configuration using the PDP FOMs. The main purpose of the PDP was to optimize sortie performance, RAC, and structural integrity of each component individually, and as part of the entire configuration. Specific design parameters, such as sizing, materials, connection interfaces, and exact location of each part within the assembly were also determined. These, combined with optimization of power requirements, led to a complete detailed aircraft configuration.

1.5 Detail Design Phase Outline

The DDP was less focused on actual aircraft configuration design as compared to the previous two phases. The focus in this section was on determining the flight performance of the detail configuration to discern whether or not the design met the functional requirements. To complete these calculations the team made use of performance analysis techniques suited to propeller driven general aviation and radio controlled aircraft. These techniques were validated by the previous year's design, "TLAR II" and used to determine characteristics such as takeoff distance, turn radius, stall speed and sortie times.

Though manufacturing related FOMs had been applied to eliminate ideas throughout the both the Conceptual and Preliminary Design Phases, in the Manufacturing Phase, each component underwent a rigorous investigation as to the best method of construction possible. Specific FOMs were developed to take into consideration the restrictions of skill level, availability of materials and machinery as well as time constraints and cost.

The final product of the design process was a configuration in which each component satisfied the contest functional requirements, design goals as well as the FOMs of each category. The resulting design was conventional, single engine, single fuselage, low mono-wing aircraft with a 84 in. wingspan and a 54 in. nose-to-tail length. The specific details of the aircraft are given in Table 1.1.

Table 1-1 Final Design Specifications

Design Parameter	Specification
Manufacturer's Empty Weight	14.9 lbs
Payload Capacity/Weight	24 Softballs/9.6 lbs.
Main Wing Configuration	Low Mono-Wing
Main Wing Airfoil	Eppler-212
Wing Span	84 in.
Length	54 in.
Motor	Graupner Ultra 3300/7
Rated Aircraft Cost	**9.29**
Final Flight Score	6.2

2 Management Summary

2.1 Architecture of the Design Team

The 2002 UCSD Design/Build/Fly Project team consists of seventeen undergraduate students from various engineering disciplines. At the first project meeting it was decided that the most efficient way to design and build the plane would be to group members together with assigned areas to work on. The project manager, Maziar Sefidan, assigned each group with one of the following focuses: wing, fuselage, propulsion, landing gear or the tail. All members were responsible for fundraising. The specific team member profiles and assignment areas are shown in the table below.

Table 20-1 Archtecture of Team Members

Name	Major	Year	CAD Programs			Matlab	Technical Writing	Machining	Assignment Area
			Pro-Engineer	AutoCAD	SolidWorks				
Maziar Sefidan	ME	SR	X	X		X	X	X	Wings
Josh Adams	ME	SR	X	X		X	X	X	Fuselage
Chad Valenzuela	AE	JR		X			X	X	Propulsion System
Mark Shtayerman	AE	JR	X	X		X	X	X	Landing Gear
Brooke Mosley	AE	FR		X				X	Manufacturing
Steve Wong	ME	SR	X	X	X				Drawing Package
Aaron Pebley	AE	SR			X				Systems Architecture
Hamarz Argafar	AE	SO		X				X	Manufacturing
Justin Smith	AE	SR	X	X					Power Management
Guy Watanabe	AE	SR	X	X		X	X	X	Finite Element Analysis
Matthew Napoli	AE	FR					X		Tail
Brian Berg	AE	FR		X			X		Manufacturing
Carrie Nishimura	AE	FR							Systems Architecture
Lynn Chouw	AE	FR					X		Manufacturing
Jillian Allan	BE	JR			X			X	Graphic Design
Mann Chau	ME	SR	X		X		X	X	Fundraising
Ceazar Javallana	AE	JR	X	X				X	Fundraising

Weekly meetings were set where each sub-group discussed their design ideas, chose designs that were useable, then reported it to the entire team. The end of each meeting was designated as a time to assign topics for which ideas would be needed for the next week's meeting. The product of these brainstorming meetings commenced in the conceptual design of our plane. This management structure allowed the plane to have a safe, stable, and fast design while considering the contributions and ideas of all members of the team. In addition, this format was conductive to a timely completion of the airplane's configuration.

2.1.1 Task Scheduling

In early September, the group decided upon a schedule of completion dates. Each subgroup was expected to complete tasks by a certain deadline. The chart below (Figure 2.1.2) depicts the planned and actual dates of completion (D.O.C.) of each major event. Problems that were encountered completing these tasks were quickly resolved through teamwork and subgroup collaboration. The subgroup dependencies were as follows, each task's completion vital to starting the next:

Assembly of Design Team: The returning DBF members from 2001 met two weeks before the start of school to decide how many new members the project would need to compete in this years competition. A meeting was held the first week of classes, and the team began to form. Only a month from competition, the team has solidified with 17 members.

Notice of Intent to Compete: This notice was sent by the project manager, Maziar Sefidan, on October 19, 2001, binding our participation in the work ahead of us.

Obtain Funding: While our search for project funding has been continuous over the past 11 months, our saving grace has come in the form of grants from General Atomics (Aeronautical Systems), Jacobs School of Engineering (UCSD), Hitec RCD, Corland Co., San Diego Silent Fliers, and Diversity Model Aircraft .

Concepts and Preliminary Design FOMs: The figures of merit were applied to all conceptual and preliminary designs in order to either eliminate or accept designs based on the structural, weight, safety, or financial needs of the plane.

Conceptual Design: Having found designs that met all of our necessities, a final conceptual design could be assembled and taken to be critiqued by our mentors.

Preliminary Design: The conceptual design having been finalized, a preliminary design could be made and analyzed.

Data Design: Taking our preliminary design to the computers, we digitally took apart our design analyzing each piece to ensure the best flight characteristics possible under design parameters.

Acquire Materials and Parts: The ongoing task of replacing materials that have been used in the manufacture of the plane, and acquiring needed manufactured parts as the project calls for them.

Proposal Phase: Having a large part of the manufacturing complete and all of the data collected, the design proposal phase report was able to be written for submission to competition judges.

Aircraft Construction: The longest and most important process of the entire project, having started in December, will commence with the test flights of our plane in late March.

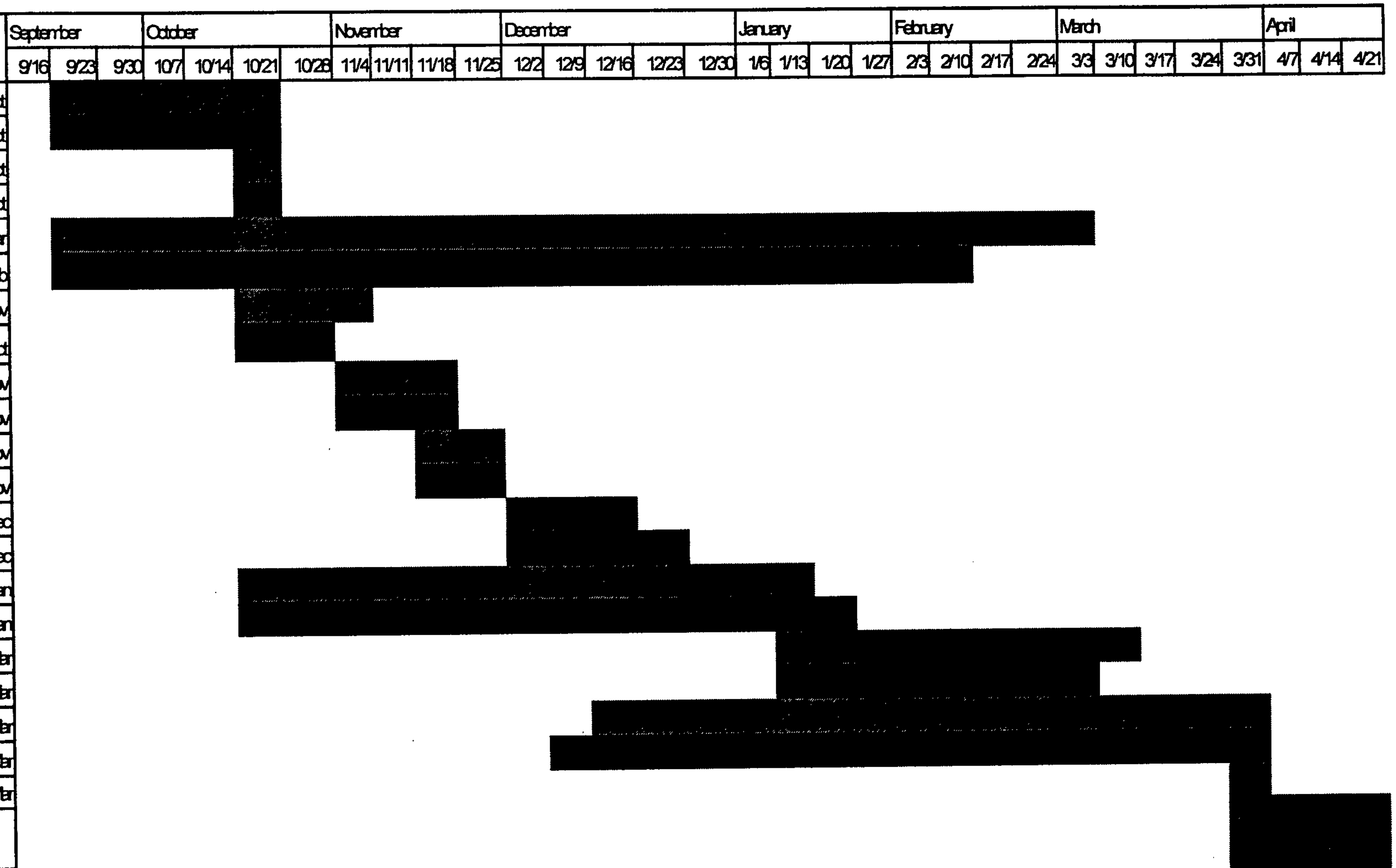
Test Flight(s): Having completed construction, test flights are vital to ensure flyability, structural integrity under true loads, and good component interaction, as well as serving as practice for the pilot.

Pit Crew Selection and Coordination Drills: Since the competition will be timed, having a good "Pit Crew" that is coordinated in thoughts and procedures in different scenarios to unload our cargo will be imperative to scoring well and winning the contest.

2.1.2 Milestone Chart

Figure 2.1.2 Milestone Chart

ID	Task Name	Start	Finish
1	Assembly of Design Team	21-Sep	17-Oct
		21-Sep	17-Oct
2	Notice of Intent to Complete	19-Oct	19-Oct
		19-Oct	19-Oct
3	Obtain Funding	22-Oct	4-Mar
		22-Oct	10-Feb
4	Concepts and Preliminary Design FCMS	20-Oct	2-Nov
		20-Oct	28-Oct
5	Conceptual Design	2-Nov	14-Nov
		2-Nov	14-Nov
6	Preliminary Design	15-Nov	29-Nov
		15-Nov	29-Nov
7	Data Design	30-Nov	19-Dec
		30-Nov	23-Dec
8	Aquire Materials and Parts	22-Oct	14-Jan
		22-Oct	20-Jan
9	Proposal Phase	19-Jan	9-Mar
		19-Jan	3-Mar
10	Aircraft Construction	16-Dec	30-Mar
		3-Dec	30-Mar
11	First Test Flight	31-Mar	31-Mar
12	Pit Crew Selection/ Coordination Drills/ Test Flights	31-Mar	21-Apr



Key: Grey = **Proposed duration of task,** Blue = **Actual duration of task**

3 Conceptual Phase

3.1 Stage I – Feasibility Analysis

Table 3-1 Design Parameter FOM analysis – Stage I

(-) - Not Applicable

(r) - Rejected

(K) - Kept

Design Parameters – Stage I		Figures of Merit – Stage I (x weighting)										
		Ease of Manufacture (x2)	Material Availability (x1)	Strength to Weight Ratio (x2)	Handling Characteristics (x1)	Rated Aircraft Cost (x1)	Cost (x1)	Motor Power Limitations (x1)	Thrust Ratings (x2)	Motor Installation Flexibility (x1)	Sum of Ratings	Decision
Wing Configuration	Low	1	-	-	0	0	0	-	-	-	2	K
	Mid	-1	-	-	0	0	0	-	-	-	-2	r
	High	1	-	-	0	0	0	-	-	-	2	K
	Bi-plane	0	-	-	0	-1	0	-	-	-	-1	r
Wing Planform	Delta	-1	0	-1	-1	-1	0	-	-	-	-6	r
	Elliptical	-1	0	1	1	1	0	-	-	-	2	r
	Tapered	1	0	1	1	0	0	-	-	-	5	K
	Rectangular	1	0	1	1	0	0	-	-	-	5	K
Airfoil	E214	0	0	-	-1	0	0	-	-	-	-1	r
	E211	0	0	-	-1	0	0	-	-	-	-1	r
	E212	0	0	-	1	0	0	-	-	-	1	K
Structural System	One Piece	-1	-	0	-	-	-	-	-	-	-2	r
	Two Piece	0	-	0	-	-	-	-	-	-	0	K
	Three Piece	0	-	0	-	-	-	-	-	-	0	K
	Strut Braced	-1	-	0	-	-	-	-	-	-	-2	r
	Bending Beam	0	-	1	-	-	-	-	-	-	2	K
	Ring Frame	-1	-	1	-	-	-	-	-	-	0	K
Tail Structure	Conventional	1	-	-	1	0	-1	-	-	-	2	r
	Canard	-1	-	-	0	-1	-1	-	-	-	-4	r
	T-tail	1	-	-	1	0	0	-	-	-	3	K
	Cruciform	0	-	-	0	0	0	-	-	-	0	r
	V-tail	1	-	-	-1	0	0	-	-	-	1	r
	Inverted V-tail	1	-	-	1	0	0	-	-	-	3	K
	H-tail	-1	-	-	1	-1	-1	-	-	-	-3	K
Fuselage Structure	Trusses	-1	-	0	1	-	1	-	-	-	0	r
	Monocoque	1	-	-1	-1	-	0	-	-	-	0	r
	Semi-monocoque	0	-	1	1	-	0	-	-	-	3	K
Landing Gear	Tail-Dragger	1	-	-	1	-	-	-	-	-	3	K
	Tricycle	0	-	-	1	-	-	-	-	-	1	K
	Bicycle	-1	-	-	0	-	-	-	-	-	-2	r
	Quadracycle	0	-	-	-1	-	-	-	-	-	-1	K
Power Plant	1 motor 19 cells	-	-	-	-	-	-	1	-1	1	0	r
	1 motor 22 cells	-	-	-	-	-	-	0	1	1	3	K
	2 motors/20 cells	-	-	-	-	-	-	1	0	0	1	K
	2 motors/22 cells	-	-	-	-	-	-	0	0	0	0	r

The purpose of Stage I was to apply FOMs to eliminate and analyze concepts for aircraft components that were proposed during brainstorming sessions at the beginning of the design process. The goal was to produce a set of desirable components to incorporate into three conceptual aircraft designs. The Stage I FOMs consisted of five primary areas. First, material availability required that any material not commercially available or unreasonably expensive be ruled out. Second, handling characteristics were used to eliminate concepts that were initially thought to have poor ground or flight performance. Third, designs that did not promote ease of transportation and/or manufacture were dismissed from consideration. The fourth consideration for Stage I was simplicity and tooling. Simple structures are easier to analyze and build without necessarily losing functionality or performance characteristics. These guidelines established a solid set of conceptual components to consider for the aircraft.

3.1.1 Airfoil

When choosing an airfoil, the lift to drag ratio was the most important feature to be considered. For the final design, an aircraft constrained by take-off distance, an airfoil that maximized lift while minimizing drag was necessary. Three airfoils (Eppler 211, 212, and 214) were analyzed in order to obtain their respective coefficients of lift and drag. We chose the airfoil Eppler 212 over the two others due to its desirable lift and drag coefficients. When calculating the C_L and C_D coefficients, a Reynolds number of 200,000-300,000 was considered, which was determined by an average cruise velocity of 65 MPH.

The maximum lift and drag coefficients calculated for airfoil Eppler 212 were 0.79 and 0.0142, respectively. The maximum lift and drag coefficients calculated were 0.78 and 0.012, respectively, for airfoil Eppler 214. For the E212, the maximum lift and drag coefficients were found to be 1.544 and 0.023104, respectively. While the other Eppler airfoils are low drag sections that would be better than the E212 for cruise performance, they are predicted to generate insufficient lift to achieve takeoff in 200 ft given power limitations imposed by contest rules. The lift generated by E212 section was determined to be sufficient for takeoff within 200 feet distance limit and was chosen as the plane's airfoil.

3.1.2 Wings

The wings are a primary defining characteristic of an aircraft. In this year's design, they were optimized to the role of the aircraft's flight objectives. Other primary, secondary and tertiary structures were designed around the general wing structure. In this design process, there were limitations imposed by contest rules, flight conditions, and structural feasibility. The initial design parameters being investigated were wing configuration and wing planform. The available wing configurations included a high and low placement mono-wing and a bi-plane configuration. The considered wing types were delta, elliptical, tapered, and rectangular. The intent of the Stage I wing analysis was to eliminate design parameters based on FOMs to determine their applicability to the design goals. FOMs that were used consisted of handling characteristics, RAC, ease of transportation, and complexity of manufacture.

3.1.2.1 Wing Configuration

The wing configurations presented as options (low and high mono-wing and bi-plane) represented the traditional configurations that were well documented for planes of our size. One of the basic limitations was that the payload was to be carried within the fuselage. Bi-plane configuration would have caused an array of problems with payload access and would have increased the planes RAC thus was ruled out of consideration. The high and low wing configurations would not pose a payload problem and were therefore left for further analysis.

3.1.2.2 Wing Planform

Delta: A delta wing was eliminated immediately as a design possibility due to the fact that it is optimized for transonic and supersonic flight.

Elliptical: Elliptical wings, which feature a constantly varying chord length, were eliminated due to their difficulty of manufacture and increase of the RAC.

Rectangular: The rectangular wing satisfied the initial set of FOMs and was selected for further analysis in Stage II.

Tapered: The tapered wing also satisfied Stage 1 FOMs and will be further analyzed in Stage II.

3.1.3 Empennage

The tail surfaces of TLAR III will be referred to as empennage, and are an essential part of an aircraft's control and stability.

Existing empennage configurations were selected from documented styles (stage 1 – feasibility analysis). Each was analyzed based on the experience of the team members gained in past year's competitions and through application of basic FOMs. The goal of the first stage of the CDP was to complete the analysis of proven empennage configurations so as to select three designs to investigate further in the second stage.

The purpose of empennage is to provide stability and pitch/yaw control. The three main FOMs were handling characteristics, RAC, and ease of manufacture. Other FOMs, such as material availability, ease of transportation, and reparability were not considered explicitly in this section, as the materials of all designs were understood to be the same, and the types of tails were assumed to be equally transportable and repairable.

3.1.3.1 Tail Configuration

Canard: A canard configuration would reduce the required control surfaces at the rear of the aircraft to a single vertical stabilizer. The benefit of a reduction in control surfaces at the rear, however, would be negated by the complexity of both pitch and roll capabilities integrated into the aileron control. While this configuration had benefits that included main wing stall prevention and less control surface actuators, the design, analysis and fabrication was complex and was eliminated for these reasons.

Conventional: Major benefits of a conventional design were ease of construction and lightweight design. However, the low placement of the horizontal stabilizer usually puts it in the wake of the main wing "washing out" the airflow over the horizontal stabilizer and rendering elevator control ineffective. This configuration was eliminated due to its poor efficiency, susceptibility to damage and loss of control.

"T": The most important benefit of the "T"-Tail design is that the horizontal stabilizer is above the turbulence from the body and main wing, thus allowing the horizontal control area to be reduced. It also acts as an endplate for any control deflections caused by the vertical fin, which increases the vertical fin's efficiency and allows a reduction in the fin's area. This allowed a large reduction in weight and the "T" style tail was deemed the first design to be considered in Stage II.

Cruciform: The fourth concept examined was the cruciform design, a hybrid of the Conventional and the "T"-Tail. It was determined that this style shared several benefits of both, but was difficult to construct and the end plate effect from the "T" was lost. For those reasons, this design was eliminated.

"V": The next configuration investigated was the "V"-Tail design, which was efficient because it eliminates one wing tip vortex, decreasing induced drag. The design was discarded due to its many disadvantages, including high control surface complexity, and an induced opposite roll when given rudder input.

Inverted "V": The inverted "V", by contrast, produces favorable yaw-roll coupling. Elevator control was less affected by turbulent wake from the fuselage and main wing, and the use of only two control surfaces reduced the number of servos needed for both rudder and elevator control. This design had bad ground clearance and complex control surface design. However, it was kept for further analysis because of the good turning characteristics and the reduced drag of one less wing tip vortex.

"H": This was deemed a good design, as turbulence from the fuselage does not flow around the vertical fins. The vertical fins also prevent spillover of the elevator with an end plate effect, therefore eliminating drag from tip vortices induced by elevator input. Although this design is complex, it was kept for further analysis as it worked well with a twin-body design.

3.1.4 Fuselage

The fuselage serves as a primary structure of the aircraft and acts as a critical load path for the aircraft to transmit forces between the tail and wings, in addition to housing flight equipment and payload. Design of the fuselage is somewhat dependent on the design of the wing and tail because it links the components. The FOMs that were used to optimize the design parameter of structural reinforcement were ease of manufacture, strength to weight ratio, handling characteristics, and cost. The four types of fuselage structural reinforcement investigated were trusses, monocoque, semi-monocoque, and box-beam.

3.1.4.1 Structural Reinforcement

Truss: While a truss structure in the fuselage would have a relatively good strength to weight ratio, it may interfere with the payload volume. Trusses are very difficult to manufacture, so it was quickly dismissed as a means of reinforcement in the fuselage.

Monocoque: A monocoque design has good torsional strength, but it is weak in bending, which is the type of load transferred by the tail to the fuselage. The required skin thickness needed to support these bending loads would increase the weight significantly and therefore it was eliminated as a design parameter.

Semi-Monocoque: A semi-monocoque structure combines the torsional strength of the skin with bending strength that can be customized for the aircraft by means of stringers and ribs. This type of configuration allows the strength to be customized for specific loads. However, due to the positioning of the cargo, a semi-monocoque structure would be too large and not feasible.

Box Beam: A box-beam structure utilizes the fuselage's skeletal frame for structural strength. This frame would be made of a carbon/foam/carbon sandwiched material. This material would act much like steel "I" beams of buildings act. This box structure could sufficiently accommodate the torsional forces induced during flight thus was chosen for further analysis.

3.1.5 Landing Gear

The functional requirement of the main landing gear is to absorb and dissipate landing loads effectively. The design parameters considered included: tail dragger, quadracycle, bicycle and tricycle. During Stage I of the CDP various landing gear configurations were screened according to the established FOMs, such as ease of manufacture and ground handling characteristics.

3.1.5.1 Landing Gear Configurations

Bicycle: The bicycle landing gear configuration consisted of two in-line wheels straddling the CG of the fuselage and another wheel on each wing for balance. Due to complexity of manufacture and poor ground handling characteristics, the bicycle design was immediately eliminated.

Tricycle: The tricycle landing gear has two main wheels aft of the CG and an auxiliary wheel forward of the CG. The advantage of this arrangement is that it is stable and the aircraft can be landed at a large "crab" angle. Also, the tricycle landing gear allows for a level fuselage which is helpful when loading the softballs. The tricycle will be kept for further analysis.

Tail dragger: This design would place two main wheels forward of the CG, and a small auxiliary wheel attached to the boom directly below the empennage. This configuration would be sufficiently stable on the ground while giving the propeller extra ground clearance. The tail dragger will be kept for further analysis.

Quadracycle: This configuration would be used in the event that we choose the dual fuselage body structure. It would be very stable on the ground due to it's two wheels forward the CG along with one wheel placed under each of vertical stabilizers on the "H" style empennage. The quadracycle will also be kept for further analysis.

3.1.6 Propulsion and Power System

The propulsion design began with little knowledge about the overall configuration of the aircraft, so the initial decisions related to propulsion choices were based on experience gained from last year's project.

The amount of power available to propel the aircraft is dependent upon the total power of the system and the efficiency of the entire propulsion system. To maximize this number, given that the battery power was limited by weight restrictions, a maximally efficient engine/propeller combination was chosen. Optimizing the efficiency of the motor as well as motor configurations while lowering the REP was the goal of the propulsion design portion of the conceptual phase.

The battery weight restriction of 5 lbs. limited the number of battery cells to 38, which amounted to approximately 40 volts. For standard radio controlled propulsion systems, 40 volts exceeded the rated power of many motor possibilities. While a motor's power is related to the input voltage, they can normally withstand higher voltages. Problems experienced in the competition two years ago showed that this was not a desirable arrangement, yet it was determined that a single motor design was still a valid concept.

Single-Motor: Initially, due to concerns with overpowering the single motor, the single motor configuration was developed with a maximum of 19 cells connected to the motor. However, due to the lower thrust of this configuration, the single motor connected to 22 cells was considered instead. This design was left for analysis in Stage II.

3.1.7 Structural System

The structural system was required to provide efficient "load paths" which resolve forces experienced during landing and flight sequences. The spar structure, which reinforces the wings, transmits the bending loads through the fuselage, is the major component of the structural system. When considering viable structural configurations it was noted that several options placed constraints on other component design solutions. These affected components included the wing platform (swept and tapered), wing configuration (biplane, delta and monoplane) and fuselage parameters. Several of these concepts were analyzed during Stage I of the CDP to effectively meet the various requirements of the structural system. Various spar cross-sectional geometric shapes were also considered for each of the competing component designs. These included the box beam, hollow cylindrical, solid rectangular and I-beam cross-sections.

The primary objective of the Stage I screening process was to eliminate design concepts that were complex, raised the RAC, and/or were difficult to repair or replace. The one structural system design idea that remained following the application of the Stage I FOMs follows:

Spar Structure: Initial concepts that were considered were the one and two piece spars. The one-piece spar was chosen.

3.1.8 Conceptual Design Phase – Stage I Summary

The CDP Stage I was focused on the development of initial aircraft designs that feature various component concepts that were determined to have merits applicable to the mission goal. By the end of the first stage, concepts that were immediately discernable as inadequate had been eliminated. Any remaining concepts were combined into several comparable configurations. These configurations would be evaluated further in the second stage of the CDP as to their individual component interactions and total system performance.

The decisions made when combining the components into complete configurations were somewhat arbitrary. However, each component that survived the first stage was examined to determine its ability to interact with other components. For each component, this process was done to piece compatible components together and develop three aircraft configurations.

First configuration, featured a single fuselage mounted over a low mono-wing. The tail dragger concept was considered for this model with an advantage of propeller clearance. However, the unstable nature of the tail dragger design made the team skeptical of this configuration.

Second configuration employed a single fuselage with a high mono-wing concept. The high wing necessitated the use of the tricycle landing gear concept and allowed, due to the height of the fuselage, an inverted "V" tail mounted to a tail boom. The single motor mounted to the front of the fuselage also required that the payload access be from the rear of the fuselage.

Other designs consisting of "hybrids" of the above mentioned configurations will most likely yield more and better designs that will incorporate the best aspects of each into the most efficient, lowest cost, best performing design desired. These concepts will be taken as the configurations examined in the second stage of the CDP. There, they are to be analyzed with regards to component interaction and initial flight characteristics while further determination of RAC and ease of manufacture will be made.

3.2 Stage II – Generalized Analysis

Table 3-2 Design Parameter FOM Analysis – Stage II

(-) - Not Applicable

(r) - Rejected

(K) - Kept

Design Parameters – Stage II		Ease of Construction (x2)	Component Safety (x1)	Component Safety (x1)	Component Interactions (x2)	Sortie Performance (x2)	Difficulty of Repairs (x1)	Rated Aircraft Cost (x1)	Cost (x1)	Motor Aerodynamic Flow (X2)	Motor Access/Mounting Ease (x1)	Sum of Ratings	Decision
		Figures of Merit – Stage II (x weighting)											
Wing Types	Low Mono-wing	1	-	-	1	0	0	0	0	-	-	4	K
	Bi-plane	-1	-	-	-1	0	0	0	0	-	-	-4	R
	High Mono-wing	1	-	-	0	0	0	0	0	-	-	2	R
Wing Structure and Materials	Rib Structure	-1	0	-1	-1	0	-1	-	1	-	-	-5	R
	Foam Core	1	0	0	0	0	-1	-	0	-	-	1	K
Structural System	One Piece	1	-	1	1	-	0	0	-	-	-	5	K
	Three Piece	0	-	0	-1	-	0	0	-	-	-	-2	R
	Bending Beam	1	-	-	1	-	0	0	-	-	-	4	K
	Ring Frame	-1	-	-	-1	-	0	0	-	-	-	-4	R
Tail Structure	Twin Body H	-1	0	0	-1	0	-1	0	0	-	-	-5	R
	Inverted V-tail	0	0	-1	0	0	0	0	-1	-	-	-2	R
	T-tail	1	0	0	1	1	0	0	0	-	-	6	K
Fuselage Configuration	Flying Wing	-1	-	-	-1	0	-1	1	0	-	-	-4	R
	Lifting-Body	0	-	-	1	1	1	-1	0	-	-	4	K
Fuselage Materials	Fiberglass	0	-	-1	0	1	1	0	0	-	-	2	R
	Aircraft Grade Plywood	-1	-	-1	0	1	0	0	1	-	-	0	R
	Kevlar	0	-	1	0	-1	1	0	-1	-	-	-1	R
	Carbon Fiber Reinforced Kevlar	-1	-	1	1	1	1	0	-1	-	-	3	K
Landing Gear	Tail-Dragger	0	-	1	0	0	0	0	0	-	-	1	R
	Tricycle	0	-	1	1	0	0	0	0	-	-	3	K
	Quadracycle	-1	-	-1	1	0	-1	-1	-1	-	-	-4	R
Power Plant	1 motor 22 cells	-	-	-	1	-	-	1	1	0	1	6	K
	2 motors 11 cells each	-	-	-	0	-	-	-1	-1	0	-1	-2	R

Stage II of the CDP was necessary to obtain our final aircraft characteristics. This stage rendered the designs that promoted a finished product, which in turn satisfied all of the design parameters. FOMs for Stage II included ease of construction, payload access and capacity, strength to weight ratio, difficulty of repair, component and interfacing strength, and component/flight safety. The application of these FOMs to specific design parameters resulted in a final set of components that, when assembled, produced an aircraft design with all of the desired characteristics.

3.2.1 Wings

Wing FOMs in Stage II focused mainly on structural complexity and construction. The FOMs were applied to the determination of the best wing type.

3.2.1.1 Wing Type

Bi-wing: The bi-wing implemented failed to satisfy the ease of manufacture FOM as it required the fuselage to be reinforced in multiple places and had the possible necessity of external bracers. The increased difficulty of manufacturing, increased cost, and additional induced drag thus eliminated it as a design concept.

High Mono-wing: High mono-wing design carried the benefit of large ground clearances for propellers (for wing mounted motors). It was however a major challenge in terms of designing fuselage mounted landing gear, which would not interfere with the payload. This was therefore eliminated due to the structural stipulations.

Low Mono-Wing: Low mono-wing configuration demonstrated to be effective in both TLAR I and TLAR II. Landing gear length is minimized, allowing for lighter and/or stronger struts. Torsion load transfer can be accomplished with limited interference with fuselage layout. The possibility of low propeller clearance was shown to be inconsequential due to the nose mounted motor which yielded several extra inches of clearance. This configuration was chosen for further analysis and development.

3.2.2 Empennage

The goal for the second stage of the CDP of empennage was to analyze the interaction of the surviving Stage I conceptual designs as combined with the rest of the aircraft. The primary focus areas were the structural and aerodynamic dependencies and interactions with other components in the design under the application of further FOMs. The sorties that TLAR III will fly consist of steep climbs, tight turns and short take-off and landings.

"Twin Body H": In the conceptual design "Twin Body H" configuration was implemented. While the construction was viewed as reasonably simple and sturdy, several disadvantages were immediately apparent. This design required having two fuselages and an additional servo, both of which significantly increase the RAC and add to the aircraft weight. While the structural and aerodynamic properties of this design were favorable, the added cost to the overall weight and RAC of the aircraft was too much to consider it further for the final design.

Inverted "V": A tricycle landing gear and high tail boom, provided the opportunity to apply the "Inverted V" configuration due to the fact that it would have enough ground clearance. Aerodynamically, the concept was free of major concerns related to interaction with the fuselage and main wing. While the aerodynamic and structural constraints were satisfied by this configuration, there were distinct drawbacks related to the complexity of the control design and the ease of manufacture. This increased complexity eliminated the possibility of an Inverted "V" configuration.

"T" Tail: T-tail configuration prevents tail surface washout and related loss of stability, the high placement of the horizontal stabilizer was essential. The fact that this configuration has been proven effective in the flight competition in past years while still being simple and efficient, led to the decision that it would again be the tail configuration of choice for TLAR III.

3.2.3 Fuselage

Stage II fuselage design involved the evaluation of the fuselage design possibilities within the various configurations. The FOMs used to ensure that the design goals were met included ease of construction, payload access, RAC and component and interfacing strength. The two aircraft configurations considered Blended Wing and Lifting Body. An analysis of the characteristics of these three styles was necessary to decide which will best satisfy the FOMs.

Blended Wing: first design featured a fuselage blended into a wing thus providing a good drag characteristics. Also there is no empenage thus provides a better RAC because of time saved in not making those components. One major concern arose in this design that lack of tail empenage provides a poor stability thus can lead to increased risk of crashing the plane.

Lifting Body: second design style featured a single fuselage that would house the payload and flight equipment. This configuration was considered because it provides good airflow around the fuselage, maintains interfacing strength and would not affect the RAC drastically. In addition, efficient access to the payload is granted via a hatch located at the end of the fuselage. This design meets all the FOMs and was thus considered a viable design option.

3.2.4 Landing Gear

In Stage II of the CDP, advantages and disadvantages of each remaining landing gear configuration were explored as they related to specific design choices made for other components of the aircraft. The three major considerations focused on were; ground handling, plausibility of adding brakes, and minimization of weight and drag during flight.

3.2.4.1 Landing Gear Configuration

Tricycle: Tricycle arrangement was implemented because of the additional stability due to the center of gravity is ahead of the main (rear) wheels, the aircraft would be inherently more stable on the ground and can be landed at a fairly large "crab" angle. While this configuration required one extra gear block and steering servo for the nose landing gear, which added more weight to the design and increased the RAC, the increased ground stability and ability to add brakes to the rear wheels was a desirable perk. Having brakes would enable shorter landing roll time thus bettering the flight scores. This concept therefore satisfied the Stage II FOMs and was chosen as the landing gear configuration for TLAR III.

Quadra-cycle: This configuration has good ground handling stability and an improved strength to weight ratio due to the lack of struts. However, two wheels require two servos for steering ability, thereby increasing the RAC greatly. Due to these unnecessary RAC increases, the Quadracycle was eliminated as a viable configuration.

Tail Dragger: The tail dragger landing gear configuration provided ample propeller clearance by angling the nose off the ground. In addition, its simple configuration of connecting the tail wheel to the same servo that controls the rudder would make the aircraft more easily controlled on the ground. While this dual use for a servo provided an excellent reduction in RAC, the design had structural strength concerns due to the thin rear wheel strut being under increased plane and payload weight. Therefore the tail dragger design was eliminated as being a configuration for further analysis.

3.2.5 Propulsion and Power System

The three configurations developed in Stage I of the CDP provide a basis for the propulsion requirements that needed to be met. At this stage however, thrust or specific efficiency requirements were not determined. Instead, FOMs such as power limitations of the motor and a low REP were applied to the design parameters such as number of motors and number of batteries per motor. This was similar to the FOM/design parameter process applied during Stage I of the conceptual phase, except that here it was applied in parallel, with analysis of the interaction with the other components in the design. This was accomplished by applying FOMs relating to aerodynamic flow of the thrusting air, ease of construction and motor/controller cooling to determining the final rating of each design.

Single Motor: The single engine configuration was the only configuration seriously considered for the design of the aircraft. Even though multiple motors result in better trust and power, the penalty incurred for this option is extremely high. This penalty would also factor into the total number of batteries being used to power the aircraft motors. For this reason the total weight of the battery pack must be kept to the bare minimum.

Summary: In order to minimize the RAC of the aircraft the only acceptable form of power system would have to be a single motor configuration. This configuration would also have to be powered via a single battery pack with minimum weight. The propellors, will have to be optimized for cruise speed, as this will be crucial in reducing the mission completion time. Further analysis of all these configurations will be required to conclude if a gearbox will be necessary.

3.2.6 Structural System

The purpose of Stage II for the structural system was to evaluate the individual strength as well as the interface strength within the various configurations. The Stage II FOMs that were pertinent to the structural system were RAC, component interaction and ease of construction. Through the application of these FOMs the individual structural components remaining from Stage I are evaluated. The structural system components were evaluated as follows:

3.2.6.1 Spar Structure

The shear and bending stress increases approaching the fuselage interface, therefore in the interest of weight conservation, the size of the spar structure could be made to vary. In all CDP aircraft configurations, it was also determined that torsional loads were a major concern, needing to be addressed by the design of the spar structure.

Two piece: The two piece spar model consisted of two separate spar lengths, one from the wing tip to half of the wing span, and the other continuing to the wing's root. The exact size would be determined by the existing stresses due to the shear and moment. However, the required torsional strength was not sufficient enough to consider this design further.

One piece: The one piece model is a solid, single-piece spar running the length of the wing. The size, and therefore weight, of the spar could be further reduced in respect to multiple piece spars. An additional benefit of the One Piece was its ability to accurately maintain the wing angle of attack. This model satisfied the Stage II FOMs and thus was considered a feasible spar design.

3.2.7 Conceptual Design Phase – Stage II Summary

The combined Conceptual Stage I and Stage II had the goal of determining a final configuration for the aircraft design. For each possible component of the configuration: airfoil; wing; tail; fuselage; landing gear and power supply, design parameters were defined and then eliminated through the application of FOM to determine the best final choices for the preliminary aircraft design.

The result of this process was the aircraft designated as "TLAR 2.9", a design very close to the final design, "TLAR III", though lacking final sizing and optimization of the components. "TLAR 2.9" features a single aerodynamically faired cylindrical fuselage riding over a low mono-wing. The payload access, through the nose of the fuselage, was facilitated by the symmetric mounting of two motors to the leading edges of the wings. Similar to last year's design was the implementation of a "T" tail configuration on a tail boom extending from the center of rear of the fuselage. This lengthened design allowed the use of the tail dragger landing gear to increase the lateral stability of the aircraft on the ground. Overall the preliminary design was simple and efficient and reflects the great effort put forth in the conceptual design to determine the best choice for each concept.

4 Preliminary Design Phase

As the design of the aircraft progresses, estimates for actual design specifications need to be made. The PDP of the design focuses on completing the initial calculation and estimation of general sizing, performance, and configuration with regards to the final aircraft design created in the second stage CDP.

During this process, techniques developed for the design of propeller driven general aviation aircraft were used to a large extent. Standard aerodynamic theories, such as Prandtl's lifting line method, were also implemented in computer algorithms to analyze the aerodynamic properties of the wing. While these techniques are not expected to be exact, they were implemented with confidence as TLAR II validated their accuracy in last year's competition. Overall, these proven methods provided excellent analysis results while directly exposing the design team to the fundamental principles of aircraft design.

As the CDP was highly focused on determining design parameters and FOMs to apply to the design process, so was the PDP. Here, however, the considerations that need to be made are more related to the optimization of flight performance and aircraft component interaction, than with the broader concerns examined in the previous sections. For each area of the preliminary phase, design parameters and FOMs will be applied as suit that particular area, and will be described specifically. Overall, we are still concerned with component and personnel safety, structurally and aerodynamically favorable component interaction, ease of manufacture and construction, and a low RAC.

4.1 Wings

The wings PDP deals with the general sizing of the wing and associated components as well as materials selection. Wing geometry was chiefly governed by necessary flight characteristics and optimized by RAC concerns.

Materials: Strength to weight ratio was a primary FOM in this stage, as was cost. The goal was to maximize the strength to weight ratio, while also considering the implications to construction. Aircraft grade plywood is relatively cheap and lightweight. Manufacturing a wing with this material, however, is a complicated task. The wing would have to be made out of a series of ribs, each of which had to be individually assembled and shaped. The difficulty of this fails to satisfy the ease of construction FOM. A composite wing holds several advantages over the plywood wing. It was easier to construct and was considerably stronger while being comparable in weight. The structure and procedure were established by TLAR II in the 2001 competition. Composite wings are somewhat more expensive than plywood, but the increased ease of construction resulted in their selection for the final wing structure.

Wing Geometry: The rectangular wing planform selected out of the CDP required optimization to reduce unnecessary drag and maximize lift and stability. Many geometric characteristics either had an adverse impact on performance or simply were not applicable to a model aircraft. Adaptations such as sweep and wing twist were not considered due to complexity of design and manufacture.

The wing sizing was begun with a desired aspect ratio of at least 8. Since there is no wingspan limitations, it was necessary to design the wing to not just perform well, but also reduce RAC as much as possible. In short, it is easy to over-design a wing that will produce lots of lift, but it might not be fully optimized. After analysis of the power system and an estimate of the fully loaded aircraft, and 84" wingspan with a 13.5" chord length was decided upon. It was also decided that no taper would be introduced in the design of the wing. Although a taper tends to reduce the wing tip angle of attack during high G maneuvers, thus unloading the wing, it also reduces the wing's area, therefore reducing the lift attained from the wing. Because of the way the RAC of the aircraft is calculated, it would be more advantages to have a wing without any taper. Finally, the wings are connected to each other. This significantly makes construction easier by eliminating the need for a wing joiner.

Stability: Documented performance characteristics of the chosen platform and low wing configuration led to some concern over roll axis stability. The low wing configuration creates a pressure buildup during a banked turn due to side-slipping (the fuselage interferes with airflow over the upwind wing). This causes a tendency for the aircraft to roll into a turn as the leading wing loses lift. To compensate for this, a dihedral angle was introduced to roll the aircraft back to its stable flight position. Due to the lack of a simple method to calculate the appropriate dihedral angle, empirical data was used to determine that, for radio controlled aircraft design, a 3° dihedral is most effective.

Control Surfaces: The type and location of control surfaces were dependent, in part, upon the rest of the primary aircraft structures. The available options included flaps, ailerons, or a hybrid control surface. Achieving the necessary level of control was the principal concern, followed by the impact to the RAC and building complexity.

Flaps were considered to increase lift during takeoff in order to minimize the takeoff distance. However, the inclusion of flaps would add significantly to the RAC. Spoilerons were chosen in place of ailerons to ensure control of the rolling/turning of the aircraft at low airspeeds. They are hybrid structures combining spoiler effects with aileron control surfaces. They help the flow stay attached to the wing during slow, high AOA flight, ensuring that the ailerons do not stall before the main part of the wing. They can also be used after touch down to reduce the lift of the main wing and ensure that the aircraft stays on the ground. In using spoilerons, the RAC penalty of the flaperons is avoided. Typical sizing of an aileron structure is approximately 25% of the span, extending to the outer edge of the wing. Thus our initial control surfaces were each 21 inches long.

4.2 Empennage

The preliminary phase of the Tail design focused on the initial determination of the sizes of the vertical and horizontal members, the size of the control surfaces, and the placement of the tail surfaces away from the aircraft's CG. Other design parameters considered at that point in the design were material choices, and manufacturing techniques. The main FOMs that were applied to these design parameters were ease of construction and stability.

General Sizing: The Tail sizing calculations used were a combination of general aviation and R/C aviation empirical data relations. Specifically to design the volume coefficient of both the horizontal and vertical members as well as the size of the elevator and rudder control surfaces.

The sizes of the tail components are functions of their distance from the CG of the aircraft and main wing size. Empirical data gives a function for tail volume coefficient, which is the standard method of approximating initial tail size, dependant on these parameters (equations shown below). Modifications to this empirical relationship for a T-tail allowed the vertical coefficient to be reduced by approximately 5%

due to end plate effect of the horizontal member. Also, with the engines mounted on the leading edge of the fuselage, the tail arm was given to be roughly 50% of the fuselage length as measured from the mean aerodynamic chord of the main wing.

Typical values used for the volume coefficients depend on the type of aircraft and, from experience for homebuilt aircraft, are approximated as 0.5 and 0.03 for the horizontal and vertical respectively. With these available parameters, and the size of the aircraft configuration at this stage giving an arm of 31 in, the initial areas of the tail sections were determined to be 237 in^2 for the horizontal and 96 in^2 for the vertical.

$$Area_{HorizontalStabilizer} = \left(Coefficient_{HorizontalVolume}\right)\left(MAC_{MainWing}\right)\left(Area_{MainWing}\right)/\left(Arm_{HorizontalStabilizer}\right)$$

$$Area_{VerticalStabilizer} = \left(Coefficient_{VerticalVolume}\right)\left(Span_{MainWing}\right)\left(Area_{MainWing}\right)/\left(Arm_{VerticalStabilizer}\right)$$

An empirical approach was utilized in the preliminary sizing of the tail control surfaces. Guidelines derived from empirical data suggest that the rudders and elevators be approximately 25% of the tail chord, while extending from the tail boom to about 80-90% of the tail span. Given these areas and control surface relationships, as well as an Aspect Ratio and Taper Ratio of 3.4 and 0.92 proven successful for TLAR II, the horizontal stabilizer was determined to need a span, root chord, tip chord and elevator chord of 26.0, 9.5, 8.75, and 2.0 inches respectively. With the Aspect Ratio and Taper Ratio of 1.59 and 0.76, again from TLAR II, the vertical stabilizer was determined to need a span, root chord, tip chord and elevator chord of 12.0 in, 8.50 in, 7.0 in, 2.5 in. respectively.

Manufacturability: Similar to the main wings, FOMs such as ease of construction and strength to weight ratio must be applied to all material choices. One technique considered was a rib/spar structure of aircraft ply, which is lightweight and strong, but again very complex and time consuming to manufacture. The materials that were finally chosen fitted well with the most simple of available manufacturing techniques which was foam core, carbon spar, and fiberglass skin structure. These materials provide excellent strength to weight ratios and the ability to manufacture the components quickly with tools already available from the construction of TLAR II.

4.3 Fuselage

Optimization of the fuselage included determining a viable support structure and the necessary dimensions for maximum payload capacity. In order to determine the necessary dimensions for the fuselage a packing structure for the softballs was needed. The FOMs that were considered pertinent during this design phase were interfacing and component strength, weight and payload access.

A satisfactory packing arrangement was found following several attempts to find an arrangement that was not too long or too wide. This arrangement consisted of a rectangular organization of 4 softballs wide and 6 softballs long giving a total of 24 softballs (See Drawing Package). With the softballs packed as tightly as possible this resulted in a cargo loading area of 16x24 inches. However this rectangular box sitting on top of the wing would create much undesirable drag. In order to mitigate this problem, a symmetric airfoil (NACA 0013) would be designed to overlay the cargo ball array.

In order to avoid payload access problems and to accommodate the batteries and flight equipment, the fuselage dimensions would have to be slightly larger. This was not a problem, as the thickest part of the symmetric airfoil allowed for ample room for these accessories. The room created also accommodates a support structure for the wing and boom interfaces. Working closely with the structural system group allowed for mutually beneficial solutions.

Box Beam Structure: This arrangement describes a box type structure designed to be able to withstand shear and torsional stresses. Since the top skin of the fuselage would be breached to access the payload, the fuselage needs to have an internal structure designed to withstand the transfer of forces and moments from the tail and wing. Similar to a drawer from a cabinet, in essence the structure of the fuselage is an open-topped box that is able to resist shear and torsional forces. This torque box consists of ball-floor, airfoil-shaped sides, lower skin, and wing. The walls of this box would have to be very strong, yet very light. This introduced the idea of "Sandwich Material" for this design. "Sandwich Material" consists of two very stiff but thin layers of carbon, which surround a slightly thicker layer of anisotropic (stronger in one dimension than the other) foam or balsa. This creates an I-beam effect, resulting in great strength-to-weight ratio.

Final Sizing: The final size of the fuselage was determined to be 39.5" in length, 16.25" in width and 5.5" in height at its thickest point. The box structure itself (entirely made of "Sandwich Material") consists of two side walls in the shape of a symmetrical airfoil. These two side walls are then connected together with a 39.5"x16.25" bottom with circular cutouts for where softballs can be placed. This structure is then reinforced with three bulkheads placed 4.25, 27.5, and 31.5 inches from the leading edge of the side walls. The wing sits directly beneath the latter 2/3 of the softballs, as there is an airfoil cutout for which the wing fits into. Hard-points on both wing and fuselage allow for the attachment of these two components to each other.

4.4 Landing Gear

Due to the previous year's bad experience with failed landing gears this portion of the aircraft was given much attention. It was necessary to optimize the landing gear configuration as well as specific components associated with the landing gear including gear struts, wheels, and gear blocks.

Landing Configuration: At this point, the preliminary calculations and design of a tricycle landing configuration could be completed. To prevent the aircraft from overturning, the main wheels should be laterally separated beyond 25 degrees angle off the center of gravity as measured from the rear in a nose-down attitude. This was evaluated to be a distance of approximately 15 in. from the aircraft centerline at the spar location. The nose landing gear should be placed as close to the front of the aircraft as possible to prevent the propellers from hitting the ground on a hard landing.

Gear Struts: A number of materials were considered for the gear strut, which was designed to interface with the wing spar, including steel, aluminum, and carbon. Carbon and steel would provide the most strength, while aluminum and carbon would be the lightest. Although light, aluminum would not provide the strength required for harsh landings. Due to the previous year's experience with a steel gear strut, the team was confronted with two options; Design a thicker strut from steel, or design a strut from Carbon. It was calculated that steel would be far heavier than a carbon strut with similar strength. The only downside would be the difficulty of manufacturing associated with the composite strut. Despite this, the team decided that composite strut would much greatly improve performance and reliability.

Wheels: Although construction of a lightweight aluminum wheel was a possibility, previous year's experience allowed the team to eliminate this option. It was difficult to attain transverse skid resistance from aluminum wheels, and gluing of rubber o-rings to the aluminum proved a poor tactic as the thin rubber quickly disintegrated upon landing impact. The alternative would be rubber wheels, which are heavier than the custom-made aluminum wheels. To remedy this problem, in-line skating wheels will be purchased and machined to reduce their weight.

4.5 Propulsion and Power System

The propulsion choices that were made in the conceptual phase of the paper were based on general power management, motor life, and RAC concerns. In the PDP, there was a lot more known about the aircraft configuration and more precise propulsion system design could be conducted.

In limiting the motor type and manufacturer, the contest organizers made the determination of motor type a fairly narrow search. Due to recommendations from a number of people with previous experience with such motors, the Astro line of motors was eliminated. We also had our Graupner Ultra 3300 7-wind series motor from the 2001 competition, which was still in great condition and will satisfy this plane's needs and the competition requirements. This motor is designed to run off of 20 volts and turn a direct drive propeller. Assuming a maximum current draw of 35 Amps, safely below the 40 Amp limit, the 7 wind series motor gave an efficiency, output wattage and RPM of 83.5%, 650 Watts, and 8300 RPM, respectively

At this point, using a setup built by the team mentor Steve Neu, a preliminary experiment was performed to qualitatively test how the motor performs under a load. The testing platform was setup precisely for this purpose, as the RPM, Output Voltage, and Input Current were measured. This test also applied a load onto the motor (using hysteresis brakes) and measured the torque applied (using a strain gage) by the motor. From this information, the motor efficiency was calculated. A plot of this experiment can be seen in the following figure. As can be seen from the following figure, the efficiency of the motor is maximized between 12,500 and 13,500 RPM. Because of this and the choice of propeller diameter and pitch, a 2:1 gear ratio will be used to ensure that the motor RPM's are kept at the optimum range.

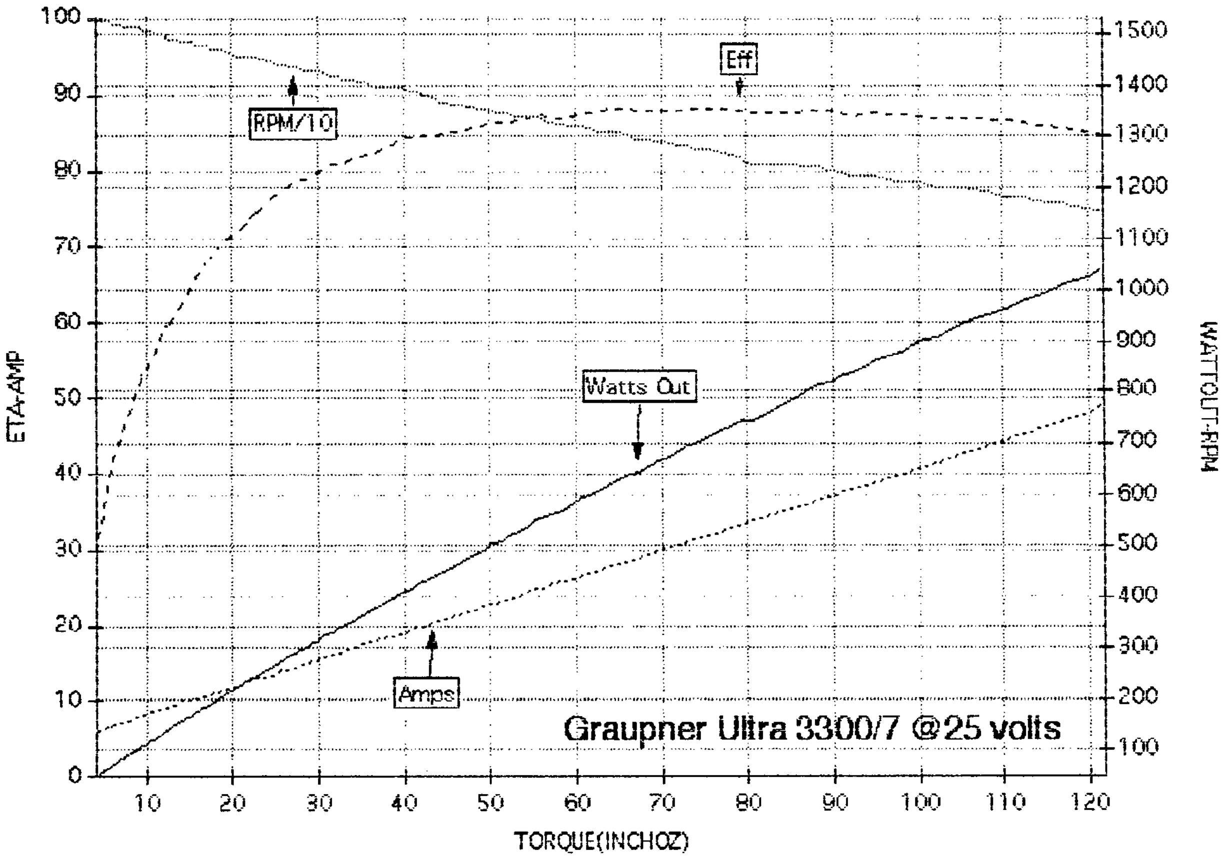


Figure 4.1

Initial testing on the Graupner Ultra 3300/7 motors showing vital statistics.

Courtesy of Steve Neu

The propeller choice was made from a decision for a cruise speed of 65 mph, at a current-draw setting below maximum. The Graupner Ultra 3300/7 motor operates most efficiently at an input voltage of between 23 and 29 volts. At this setting and RPM, a 20" diameter x 20" pitch propeller gives a speed of approximately 65 mph. This factor of safety will be verified during flight testing to determine if an alternate propeller will be needed.

The final step in determining the power system was the choice of batteries. The weight, voltage and current limit was dictated in the rules. The batteries were chosen based on durability, availability and cost. The Sanyo 2400 batteries that were used in last year's competition performed very well under raised current levels and fast discharging, so their reliability had been proven. This fact, combined with their increased availability and reduced cost this year, led to them being selected.

The final configuration for the power plant of TLAR III featured a single Graupner 3300/7 motor, powered by 22 Sanyo 2400 batteries through a 2:1 gear ratio and a commercially purchased propeller of 20" diameter and 20" pitch.

4.6 Structural System

The principal objectives of the PDP for the structural system were to maximize the strength to weight ratio without adversely affecting the payload capacity and access. Focus was placed on structural integrity, to avoid failure under flight and landing loads and component interfacing, as most systems fail at joints and interfaces.

Application of theory from solid mechanics and statics provided the basis upon which necessary design adjustments were made. These adjustments were the variation of the cross-section of the spar structure and the fuselage/wing interface method. In order to determine the best cross-section for the spar structure, stress and static analyses were conducted via the use of Microsoft Excel. Optimization of the fuselage/wing interface involved the determining the maximum stresses, for which it was necessary to determine the maximum load experienced (during banked turns). The following equations were utilized to determine the necessary values of maximum moment and bending loads:

Newton's Law: $\sum F = ma$

Moment Equation: $M = Fd$

Maximum Bending Stress: $\sigma = \dfrac{Mc}{I}$

Moments of Inertia: $I_x = \int_A y^2 dA$ & $I_y = \int_A x^2 dA$

4.6.1 Spar Structure Optimization:

The wing's thickest point was chosen as the location for the spar structure so as to allow the furthest distance, 'c', from the neutral axis for bending. At the wing root and tip the width of the carbon were 2.25" and 1.5", respectively. At specific points along the span, the values of 'c' and 'M' were fixed thus allowing for variation of the moment of inertia by varying the cross-sectional area. The above equations were used, along with values for a 27 lb. aircraft travelling at 65 mph, to calculate the following load values:

Maximum G Force (with safety factor): 9.7

Maximum Load (per wing panel): 2118.5 oz.

Maximum Moment: 18345.6 in.-oz.

Moments of Inertia: 0.3869 in^4 (box beam)

Maximum Bending Stress: 1,002,000 psi (box beam)

Although the maximum bending stress can be taken by both the box-beam and I-beam sections, the box-beam cross-section was chosen due to the additional strength that would result.

4.7 Preliminary Design Phase Summary

The PDP analyzed the preliminary configuration as developed in the CDP with regard to the determination of exact sizing and component interaction. Design parameters that were related to the purpose of sizing the components were defined locally. FOMs such as component safety, structurally and aerodynamically favorable component interaction, ease of construction, and a low RAC were the primary factors determining much of the component design. Most general sizing calculations that were done were based upon those used in designing a propeller-driven general aviation and radio controlled aircraft. Precise calculations on flight performance will be completed during the DDP now that the detail configuration of TLAR II has been established.

5 Detail Design

The goal of the DDP is to optimize the sizing and design parameters that were developed in the PDP with regard to flight and takeoff performance. Similar to the PDP, the primary performance analysis techniques used were those applied to propeller driven general aviation aircraft. The calculation of basic characteristics, such as lift and thrust, allowed for the computation of more specific flight characteristics such as takeoff distance, rate of climb and endurance. In each section of the PDP, individual component weights were estimated.

5.1 General Sizing

5.1.1 Weight Estimate

Estimates based on experience gained from last year's design were assembled into a preliminary weight estimate of 20 lbs. Upon completion of the DDP and construction of the aircraft, the final value for aircraft weight was estimated at 24.5 lbs. While heavier than first estimated, it was still well within the competition rules and design limitations of the aircraft.

5.1.2 Wing Performance

The detailed performance calculations of the main wing were based upon Prandtl's classic lifting line theory. Prandtl's theory was implemented numerically in Matlab code and run with the sizing parameters developed in the PDP given inputs for wing dimensions of span, root chord length, aspect ratio, $\alpha_{CL=0}$. These values were reduced from the theoretical infinite wing data by approximately 26%, which was relatively efficient despite the low aspect ratio. However, by altering the values of the taper ratio, it was possible to achieve a 20% reduction. To minimize RAC, we had to use rectangular wing because the advantages of the tapered wing were negated by the cost factor. The final values for $C_{L\alpha=0}$ and C_{Lmax} 0.562 and 1.544 respectively and for $Cd_{\alpha=0}$ and $Cd_{\alpha max}$ .007055 and .023104 respectively, were realized with a root chord of 13.5 in. This gave the final wing an aspect ratio of 6.22, taper ratio of 1.00, platform area of 1134 in^2. An important quantity resulting from these refined sizing and performance characteristics was a wing loading, W/S, of 2.74lbf/ft^2.

5.1.3 Fuselage Layout

The final configuration of 4x6 softballs in the fuselage brought a peculiar problem of increased drag over the very wide (16.25 in) fuselage. To reduce the drag a more streamlined fuselage was suggested and implemented. NACA 0013 airfoil shape was used for this purpose. Additionally, there will be a benefit of the lift produced at angle of attack, which will decrease the take-off distance and increase the rate of climb. Consideration of the lift generated by the fuselage shall be limited to replacing the wing area displaced by the fuselage. Since a hatch will be cut into the fuselage skin for loading the payload, torsional strength of fuselage will be lost. Torsional stiffness comes from the torque box made up of the fuse sides, bulkheads, ball floor, wing and bottom skin.

5.1.4 Motor Thrust Available

While the static thrust of an engine was a necessary calculation related to the determination of performance characteristics such as takeoff distance and rate of climb. Analysis of power supplied being reduced by the inefficiency of the motor and propeller was used to indicate the amount of power available to actually propel the aircraft. Having determined the number of cells to power each motor in the preliminary phase, the total power available to the motor was calculated using the equation $P = VI$, giving an available power of 1017 Watts. With a combined efficiency of .78, the thrust developed per engine was 6.18 lbs. This gave a final thrust-to-weight ratio of 0.286.

5.2 Flight Performance Calculations

In optimizing sortie performance, it was necessary to evaluate takeoff, rate of climb and range/endurance characteristics as well as static stability. While dynamic stability was also a concern, for a fairly conventional design as TLAR III, dynamic instability has proven to be highly transient in modes that are easily controlled by a skilled pilot.

5.2.1 Takeoff Performance

The takeoff profile for TLAR III was essential, as it was a competition constraint. It was determined for takeoff that the rotate/stall speed needed was 42.1 ft/s, while the actual takeoff speed was 46.3 ft/s.

For the Reynolds's number (~200,000 to 300,000 based on M.A.C.) at which the takeoff was performed, the induced drag of the aircraft was small enough to be approximated to zero. This enables the approximation of integrating Newton's second law over the ground run of the aircraft. This integration of the acceleration can be reduced to the following equations from reference 1:

$$\left(\frac{1}{2gK_A}\right)\ln\left(\frac{K_T + K_A V_f^2}{K_T + K_A V_i^2}\right) \quad \text{with} \quad K_T = \left(\frac{T}{W}\right) - \mu\,, \quad \text{and} \quad \frac{\rho}{2(W/S)}\left(\mu\, C_L - C_{D_o} - KC_L^2\right)$$

A ground roll of 166 ft was calculated for a rolling resistance factor (μ) of 0.05 and a total takeoff distance of 183.5 ft. While this seems close to the distance limit, the likelihood of winds being present during the competition will shorten the actual takeoff distance. If this is not the case, and taking off within the limit proves difficult, reducing the payload may be considered.

5.2.2 Rate of Climb

The rate of climb (R/C) is the vertical component of the aircraft velocity. It can be expressed in terms of weight (W), perpendicular component of drag (W_D) and velocity (V). W_D is a function of thrust (T) and drag (D), therefore yielding:

$$\frac{R}{C} = \frac{(T - D)\times V}{W}$$

The best climb rate will occur at the velocity for maximum lift to drag ratio, L/D_{max}. Although the thrust produced by the propeller and corresponding power available changes with the airspeed, an approximation was made to show that the maximum lift to drag depends only on the values for the parasite drag coefficient, C_D and the wing's aspect ratio, AR.

$$\frac{L}{D_{\max}} = 0.886\sqrt{\frac{AR}{C_D}}$$

Using these formulas, the rate of climb for the aircraft was calculated to be 597 ft/min.

5.2.3 Turning Radius

The turning radius gives an indication of how much distance, time and power are needed to perform a turn and is necessary because it affects sortie flight time and power management.

The turn radius calculations began with the assumption that the turn will be made at the cruise speed of 65-MPH. The equation

$$n = \frac{\left(V_{cruise}\right)^2 \left(C_{L_{\max}}\right)}{2\left(W_{aircraft}\right)}\left(Area_{wing}\right)$$

gave a load factor of 4.87 for the turn. From this, and geometry, a bank angle of 78.1 degrees and turn radius value of 59.3 ft was calculated.

5.2.4 Range and Endurance

Range and endurance characteristics are essential performance indicators for an aircraft designed to participate in timed, limited fuel flight profiles. The range figure of TLAR III was based on the power available and the power that the missions will require, so that the time can be estimated.

Initially, this was accomplished by examining TLAR III in steady flight. The power available is the number of cells multiplied by the power rating for each cell. This equated to 1 battery pack multiplied by 2400 milliAmp-hours for at total of 2.4 Amp-hours. This allows 6.3 minutes of flight time at the current setting of 22.8 Amps, which subsequently gave a cruise range of 6.8 miles and 3.6 minutes and maximum thrust.

While this flight time was less than the maximum flight period, an Excel spreadsheet was used to determine a flight plan. It calculated using average speed and current setting breakdown for the entire mission profiles, with gliding and powered back cruises; the flight time was under five minutes which is far less then the maximum time given.

5.2.5 Static Stability

The ability of the aircraft to return to trimmed flight, if it was somehow deflected, was an important consideration. Due to the symmetry of the aircraft about the centerline of the fuselage, it was possible to achieve some roll stability of the design, with the selection of 3° dihedral in the preliminary phase. The focus was placed on the pitch stability (the directional stability was already addressed in the sizing of the vertical tail stabilizer). A well-designed aircraft that has good static stability, historically will also behave well dynamically.

The pitch stability is related to how the main-wing and horizontal stabilizer work together to correct pitch deflection. For TLAR III, this was especially critical due to the choice of a symmetrical airfoil for the tail. To prevent excessive corrective elevator deflection during steady flight, the pitching moment of the airfoil needs to be balanced by the placement of the center of gravity relative to the center of pressure of the wing. Assuming that any pitch deflections would be small, the pitch static stability is directly dependent on the horizontal stabilizer. The calculations focused on determining the exact placement of aircraft CG for a desired Stability Margin of 0.3. This margin is the geometrical distance between the location of the CG and the location of the neutral point. The neutral point was determined with the following equation along with design parameters defined earlier in the paper.

$$x_{np} = x_{AerodynamicCenter} + V_t\left[1-\left(\frac{4}{AR_{MainWing}}\right)\right]$$

This allowed the placement of the wing at the optimum position for stability. The main wing leading edge was located at 11.375 in from the nose of the aircraft, which places the CG almost directly on the spar location. Additional pitch stability was achieved through decalage (angle between the horizontal stabilizer and the main wing), which was initially set at 1° and will be finalized during flight-testing.

5.2.6 Systems Architecture

The Systems Architecture describes the electrical components used to fly the aircraft including the batteries, servos, receivers, and transmitter. The number, location, and type of motors and batteries were determined in the propulsion section of the PDP. Determining the types of servos remained.

Given the values obtained for the torque required by each servo, two different servos (HS-225MG and HS-545BB) manufactured by Hitec RCD Inc. were chosen for the rudder, elevator, and aileron controls. The HS-225MG, capable of 55-67 $^{oz}/_{in}$ of torque was used to control the elevator. The HS-225MG was also used for the rudder, despite the rudder having less control surface area than the elevator, because the same servo controls both the rudder and the nose wheel. The spoilerons however require more torque to control due to higher surface area, therefore a more powerful servo, HS-545BB, capable of 62-73 $^{oz}/_{in}$ of torque was used.

(Tables on Next Page)

5.2.7 Detail Design Summary

Table 5-1 General Sizing

Design Parameter	Size
Aircraft Dry Weight	12 lbs.
Manufacturers Empty Weight	14.9 lbs.
Full Capacity Weight	24.5lbs. (with 24 Softballs 9.5 lbs.)
Battery Pack Weight	2.9 lbs. (22-2.4 Amp Cells)
Main Wing Configuration	Low Mono-Wing
Main Wing Airfoil	E212
Main Wing Area	1134 in^2
Taper Ratio	1
Aspect Ratio	6.22
Number of Motors	1
Propeller Size	20" x 20"
Total Thrust	5.31 lbs.
Horizontal Stabilizer Area	226 in^2
Vertical Stabilizer Area	125 in^2
Tail Airfoil	NACA 0009
Fuselage Height	5.25 in
Fuselage Length	39.5 in
Fuselage Width	16.25 in
Fuselage Foil	Modified NACA 0013

Table 5-2 Systems Architecture

Component	Description (Amount)
Motors	Graupner Ultra 3300/7
Servos	HS-225MG (2), HS-545BB (2)
Batteries	Sanyo 2400 (22 cells)
Receiver	HPD-07RB (PCM)
Handset (Radio Transmitter)	Prism 7X (PCM)

Table 5-3 Flight Performance Data

Design Parameter	Performance
Cruise Speed	65 mph (95.3 $^{ft}/_{s}$)
Takeoff Distance	183.5 ft
Climb Rate	597 ft/min
Turning Radius	59.3 ft
Payload/Gross Weight Ratio	0.44
Cruise Endurance	6.3 minutes
Mission Completion Goal	All 3 missions in 5 minutes
Rated Aircraft Cost	9.29
Final Flight Score	6.2

Rated Aircraft Cost (RAC) = (A * MEW + B * REP + C * MFHR) / 1000 = 9.28

Manufacturers Empty Weight Multiplier (MEW)					A=	$	100
Total Weight w/o payload =	14.9	lbs					
					MEW =		14.9
Rated Engine Power (REP)					B=	$	1500
# of engines =	1						
Battery Weight =	2.9	lbs					
					REP =		2.9
Manufacturing Man Hours (MFHR = SUM(WBS))					C=	$	20 /hour
WBS 1.0 Wings							
Wing Span =	7	ft	*	8 hr/ft			
Max Chord =	1.13	ft	*	8 hr/ft			
# of Control Surfaces =	4	c.s.	*	3 hr/c.s.			
					WBS 1.0 =		77 hr
WBS 2.0 Fuselage							
Fuselage Length =	4.5	ft	*	10 hr/ft			
					WBS 2.0 =		45 hr
WBS 3.0 Empenage							
# of Vertical Surfaces =	0	v.s.	*	5 hr/v.s.			
# of Vertical Surfaces w/ =	1	v.s.	*	10 hr/v.s.			
# of Horizon Surfaces w/ =	1	h.s.	*	10 hr/h.s.			
					WBS 3.0 =		20 hr
WBS 4.0 Flight System							
# Servo or Motor Contro. =	4	ser	*	5 hr/ser			
					WBS 4.0 =		20 hr
WBS 5.0 Propulsion Systems							
# of engines =	1	eng	*	5 hr/eng			
# of props =	1	prop	*	5 hr/prop			
					WBS 5.0 =		10 hr
					MFHR =		172
					RAC =		**9.28**

5.2.8 Weights and Balances Worksheet

Total Length (in)	54			
Length of the shell	36	11.375	Distance from the nose cone to the leading edge at the root	
Boom Length (in)	18			
Item Name	Item Weight (oz)	Arm (in)	Moment (in-oz)	
Main Wing	40	15.875	635	
Rear Stabilizer	6	49.75	298.5	
Tail	3.5	47.75	167.125	
Boom	5.4	45	243	
Fuselage Shell	29.592	18	532.656	
Fuselage Spar Support	50	15.251	762.54925	
Main Landing Gear (x2)	10	15.875	158.75	
Nose Gear Structure	5	2	10	
Engine (x1)	21.12	4	84.48	
Battery Packs (x1)	48	10	480	
Propellor (x1)	6	3	18	
Wiring Harness	2	30	60	
Speed Controller	6	4	24	
Receiver	1.65	25	41.25	
Main Wing Servos (x2)	2	21.5	43	
Elevator Servo	1	49.75	49.75	
Rudder Servo	1	47.75	47.75	
S-Ball Payload	154.2857143	16.00	2468.571429	Number of Soft Balls: 24
Heavy (S-Ball) Payload	392.5477143	24.5942	6124.981679	Total Soft Balls: 24
No Payload	238.262	14.8914	3655.81025	

w/ Payload		No Payload	
MEW	11.9 lb	MEW	11.9 lb
Gross T/O Weight	24.5 lb	Gross T/O Weight	14.9 lb
CG (F.S. in)	15.60 in	CG (F.S. in)	15.34 in
Dist. To Leading edge at root	11.38 in	Dist. To Cent. Press. (1/2 c) at MAC	11.38 in
CG (%MAC)	31.3 %	CG (%MAC)	29.4 %
Distance In Front of the spar	0.35 in	Distance in front of Cp	0.09 in

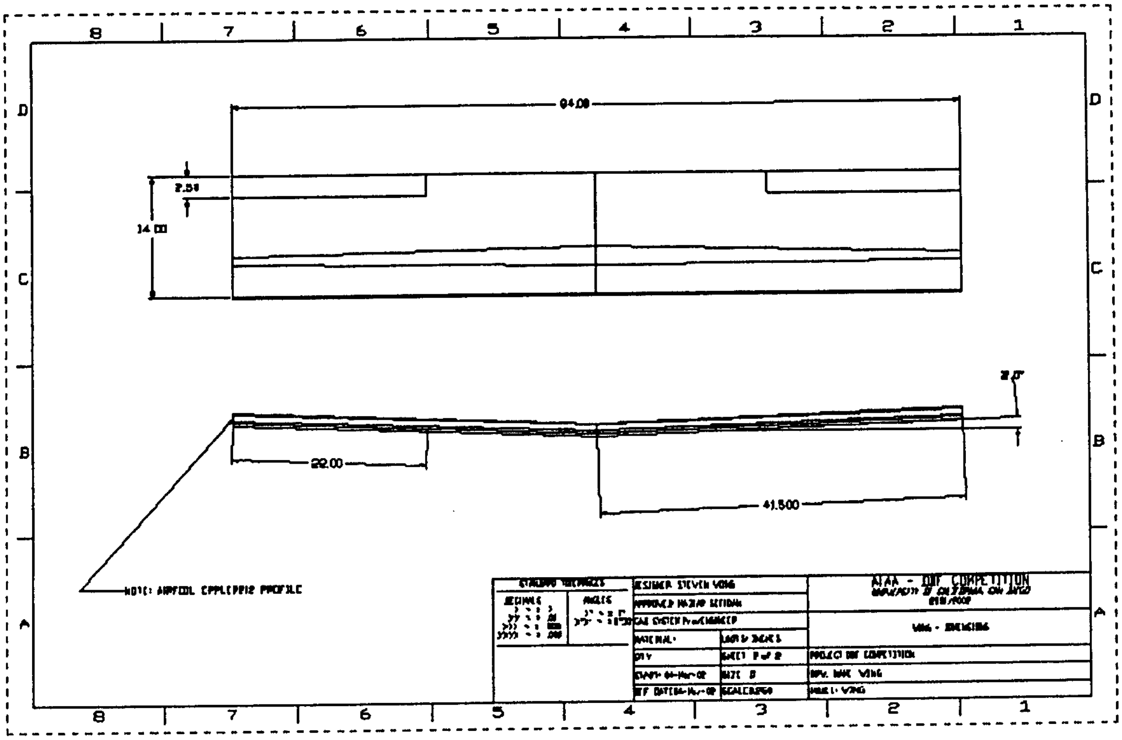
Notes:

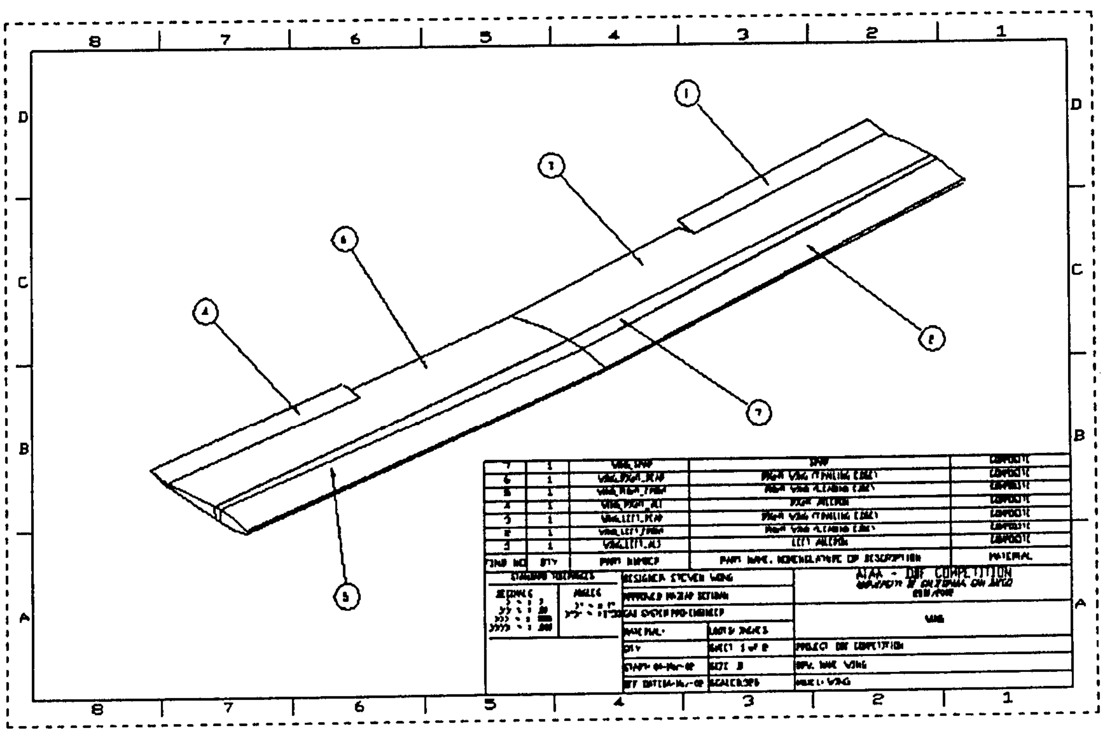
1) All distances are from the CG of the individual item to the nose of the A/C.

2) All weights include attachment hardware.

5.3.2 Flight Component Dimensions

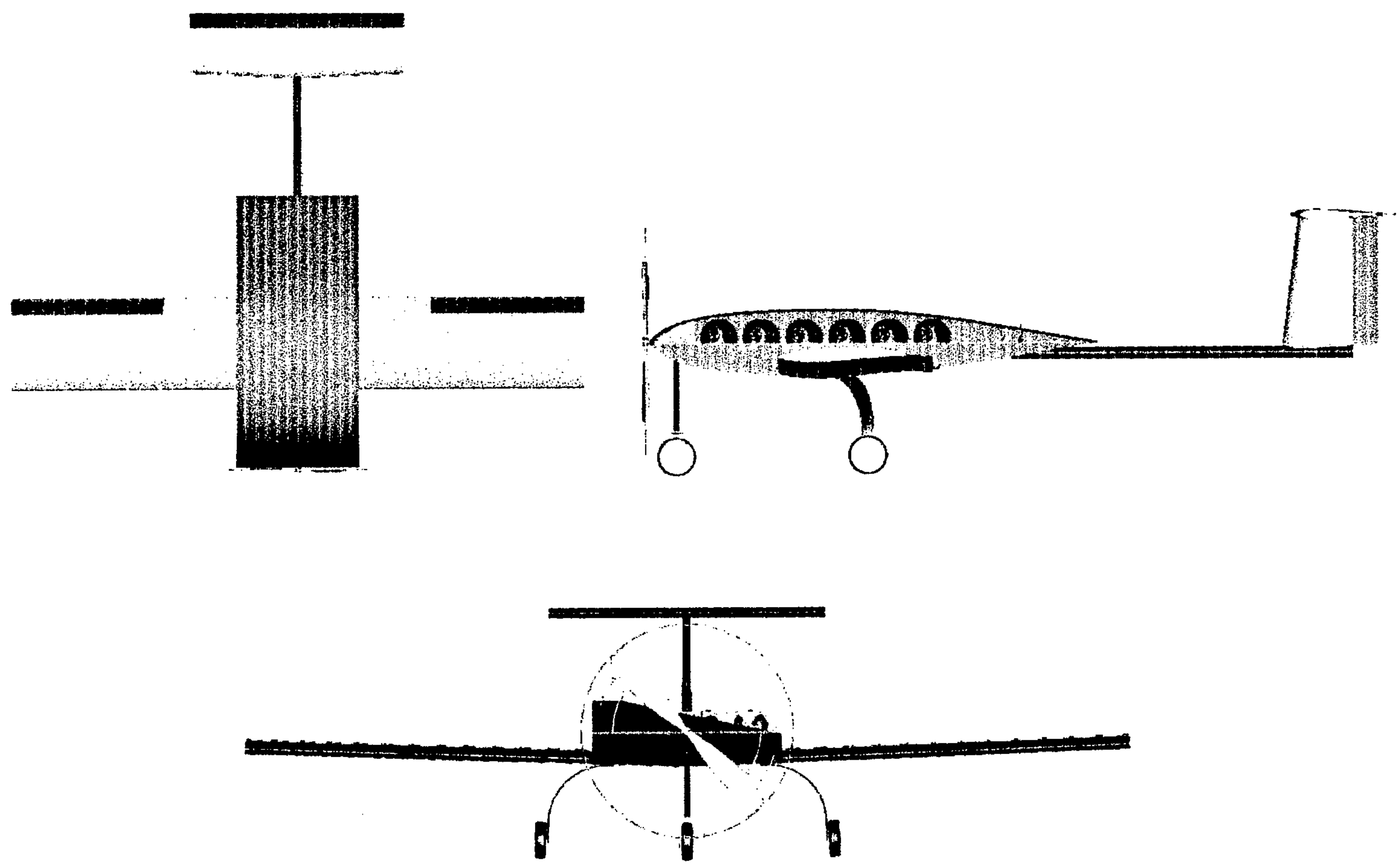
5.3.2.1 WING:





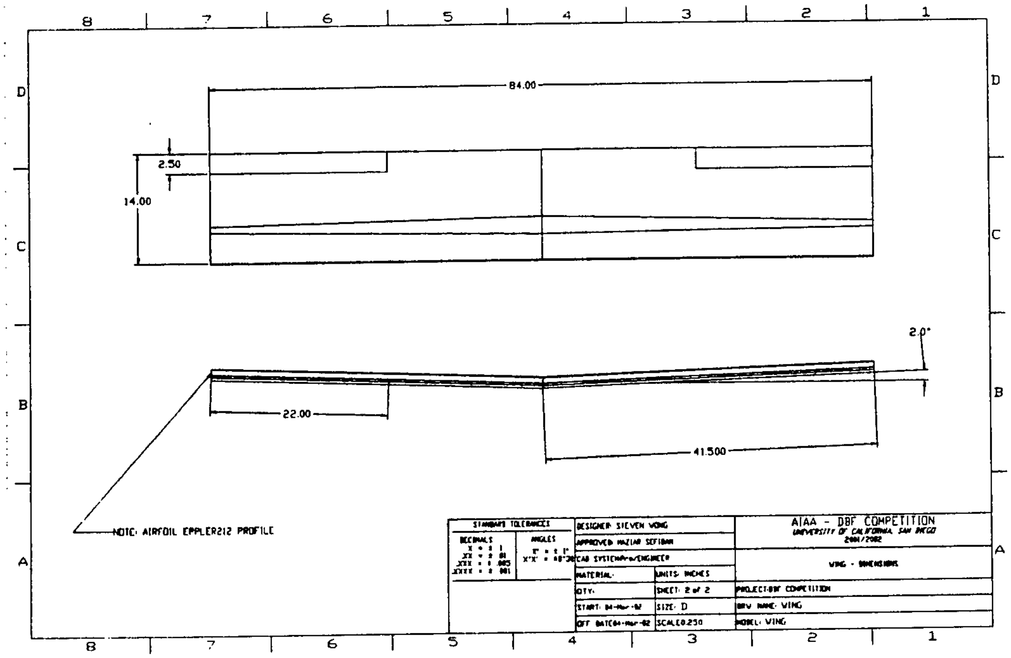
5.3 Drawing Package

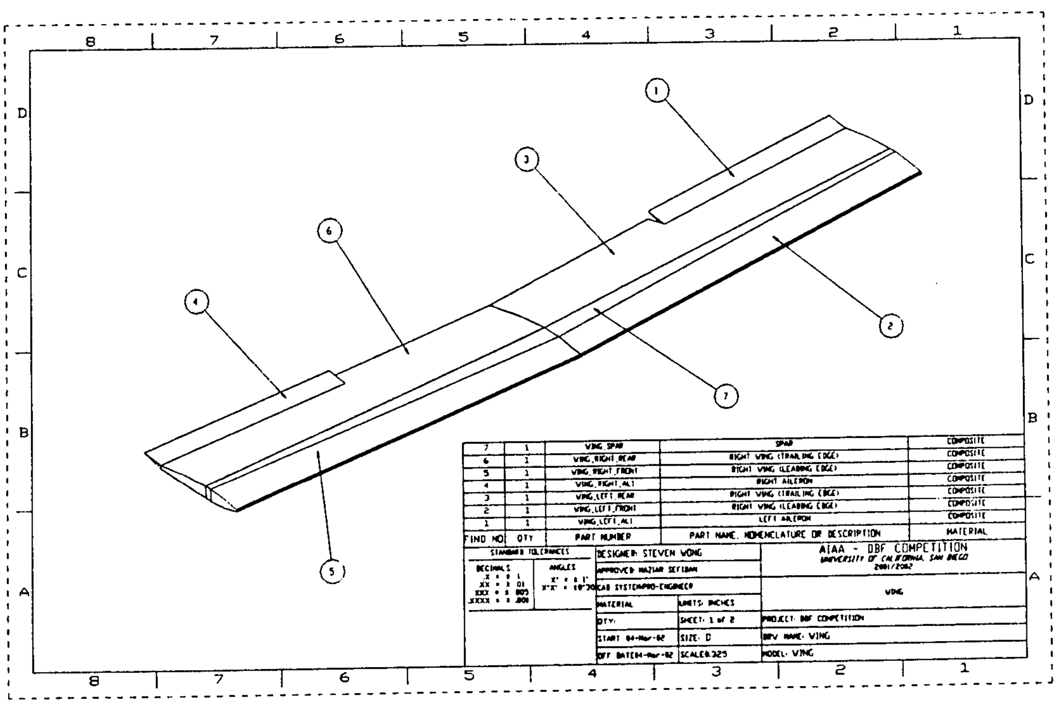
5.3.1 Three View Drawing



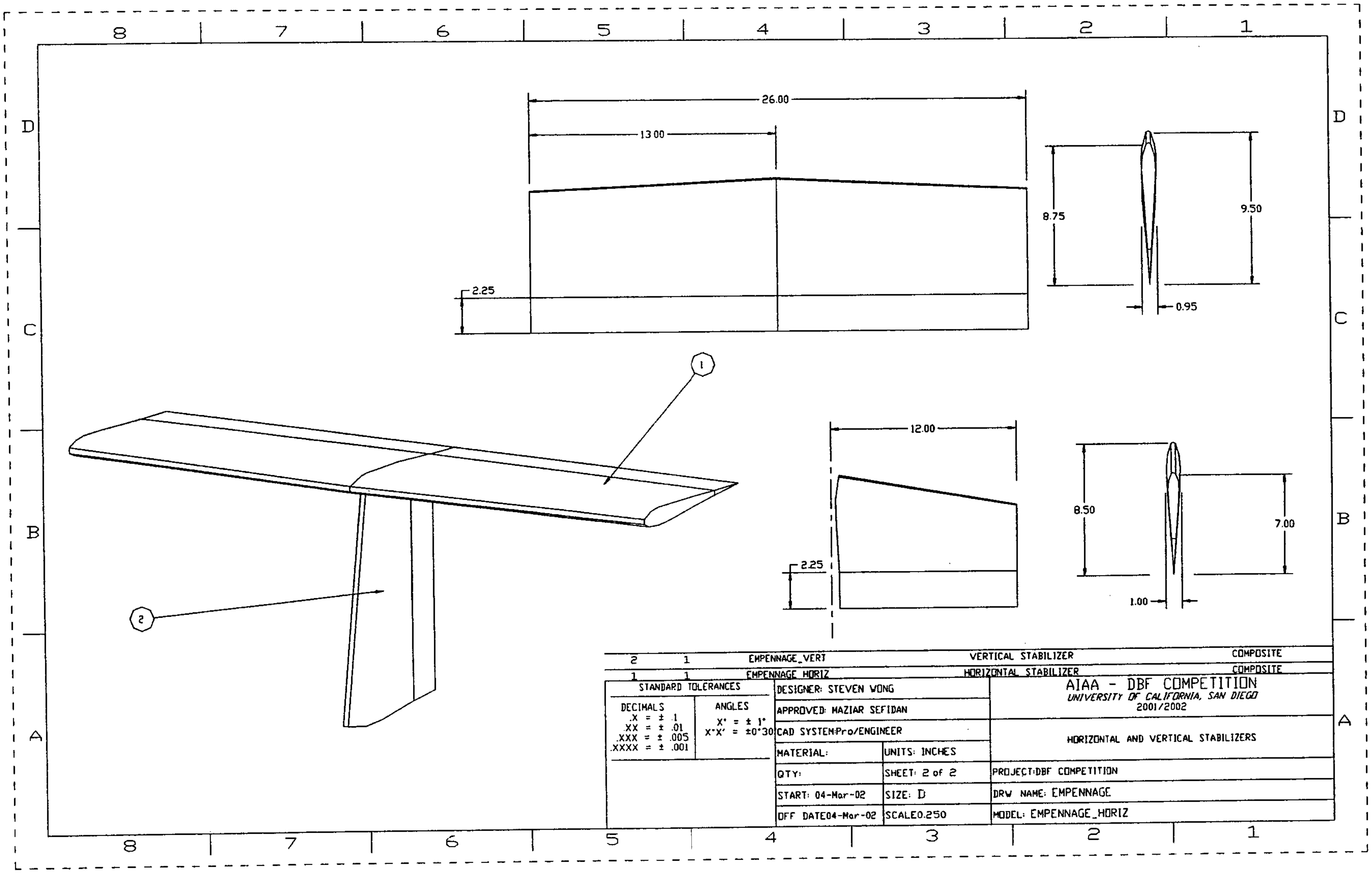
5.3.2 Flight Component Dimensions

5.3.2.1 WING:

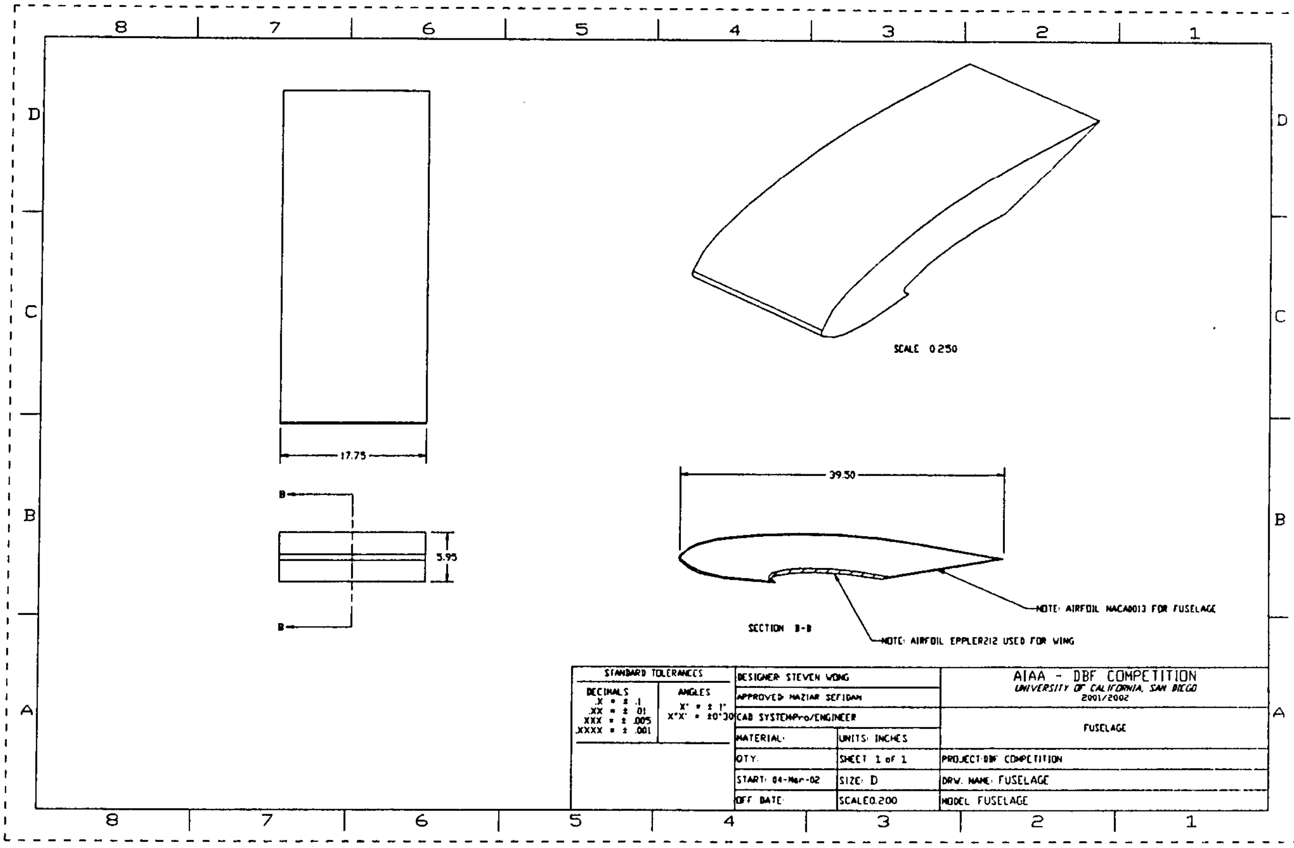


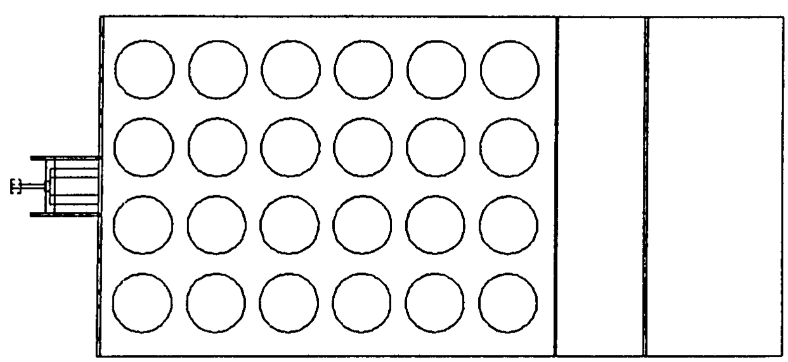


5.3.2.2 HORIZONTAL AND VERTICAL STABILIZER:



5.3.2.3 FUSELAGE:





6 Manufacturing Plan

Logistics and required skill level to manufacturing component design ideas imposed constraints on design options. The manufacturing constraints were continually considered in order to avoid conflicts between a chosen design idea and the ability to construct it. The manufacturing FOMs were used to screen construction techniques and materials based on skill level, physical properties, component and interfacing strength, and logistics. The material FOMs were sometimes used to eliminate construction methods, while construction FOMs were sometimes used to eliminate materials. The order in which the various components and assemblies were completed are shown in the manufacturing timeline presented in section 6.4.

6.1 FOM Reasoning/Discussion

Materials: Materials were screened due to their strength-to-weight ratios, availability, cost and required skill level.

Construction Techniques: "Home-built" construction with limited techniques were the only methods available to the team due to limited experience with an autoclave, time restrictions, and the unavailability of a large CNC machine. Construction FOMs are composed of required skill level, machinery, tools, tooling time, robustness and ease of repair.

6.2 Component Manufacturing Description

6.2.1 Spar Structure

The spar structure assembly consists of the shear web and spar cap. Although the wing itself is constructed of low density white foam, high density blue foam is used in the section where the spar would be placed.

Spar Cap Materials: The spar cap absorbs the majority of the bending stress and is of variable thickness (it is reinforced at the center of the spar). A carbon material was best suited for this component because of its high axial load capacity.

Spar Cap Construction Techniques: Two layers of unidirectional carbon were wetted out with epoxy The strands of 12 K carbon tow were wetted-out with epoxy and laid on top of the spar foam. This was then placed inside a polyurethane bag and vacuum-sealed to roughly 12 PSI.

Shear Web Materials: The shear web is only required to give spacing between the spar caps and to absorb a nominal amount of shear stress. Material FOMs were applied to various lightweight materials in order extract the best material. The materials investigated for the shear web were carbon plate, fiberglass, balsa, and Aircraft plywood. Aircraft plywood was eliminated due to its high relative weight and balsa was eliminated due to its low strength. Fiberglass was eventually chosen over carbon due to its weight and ease of construction.

Shear Web Construction Techniques: The fiberglass was cut out at 45° bias, as this angle provides maximum shear strength. Two layers of this cut fiberglass were then wetted out with epoxy and placed on high-density spar foam between the two spar caps. This technique was applied to both sides of the foam, after which the entire spar structure was placed inside a polyurethane bag and vacuum-sealed to roughly 12 PSI.

6.2.2 Wing Airfoil

Airfoil Templates: The first step in the process of fabricating the wings was to make Eppler 212 airfoil templates.

Materials: The materials considered for the airfoil templates were 6061 aluminum, aircraft plywood and Formica. Since the hot wire method was the desired cutting process for the wing cores, it was necessary for the chosen material to be smooth for the wire path, and not melt under hot wire temperatures. Formica was the clear choice due to smooth surface finish and low thermal conductivity.

Construction Techniques: The two techniques for construction of airfoil templates considered were the "cut-and-paste" and a CNC machine cutting method. The "cut-and-paste" process was used because it was easier. Using data points obtained from the UIUC Database, printouts of the airfoil for chord length of 13.5 inches was created. Since the wing would be rectangular, the root, midpoint, and tip of the wing would have the same chord length, making construction that much less complicated. Printouts were bonded to the Formica, which were then cut into the shape of the airfoil and pegged into both edges of a rectangular piece of low-density EPS foam.

6.2.3 Wing Cores

The purposes of the wing core are to maintain the airfoil cross-sectional shape and to contribute to the composite strength.

Materials: The materials considered were aircraft ply, and blue and EPS foam. Using aircraft ply, would result in a design using a rib structure overlaid with MonoKote, while the foam design could form a solid core for composite lay up. The foam was chosen because a solid core was more structurally sound and required less construction. The stiffness and compressive strength of the blue foam and low weight of the EPS foam made both of them viable choices for the core. A combination of blue and white EPS foam was used. The dense blue foam provides stiffness so it was used in the spar structure while the less dense white EPS foam conserves weight and it used for the rest of the wing core.

Construction Techniques: The two construction techniques investigated for cutting the foam core were utilization of a large CNC machine and a hot-wire cutting process. The CNC machine was immediately eliminated due to the unavailability. The hot-wire technique satisfied the logistical issues and the skill level requirements.

The two wings were 42" in length, which was slightly shorter than the length of the hot-wire cutter. This made construction only a one-cut process. A 45"x15"x3" (slightly larger dimensions than the wing) white EPS foam rectangular block was used to cut the airfoil profile of the wing. The Formica templates were pegged onto the edges of the foam using reference pins. After the reference pins were inserted into the foam blocks, the hot wire was drawn through the foam, following the template, creating the desired E212 airfoil cross-section. The spar area was then hot-wire cut from the wing core. After the instersion of the spar, the two wings are then epoxied together.

6.2.4 Spar Assembly

Even thought the two wings are made separately, the spar is made as one piece. This is essential for load transfers involved with the spar. The strength of the spar also makes it the idea candidate for the insertion of landing gear hard-points. These hard-points are made of airplane grade plywood and are placed on top of the blue foam beneath the spar caps. The spar assembly is then epoxied to the rest of the wing.

6.2.5 Wing Skins

The functional requirement of the wing skin is to provide a smooth surface for airflow over the wings, which reduces parasitic drag. The skin is also required to provide torsional strength to dissipate stresses generated during flight.

Materials: Carbon and fiberglass cloths were the materials considered for the wing skins. Carbon cloth was eliminated due to high cost and difficulty of working with the dimensions that were required. Fiberglass cloth was chosen because it was cheap and easy to work with.

Construction Techniques: The use of foam as the core excluded the possibility of using an autoclave, therefore a wet lay up process was needed. Fiberglass was laid at a 45° bias over Mylar. Each wing core was then sandwiched between the sheets of fiberglass/Mylar. The whole assembly was then placed in a vacuum bag to compress the fiberglass/Mylar. After the epoxy had finished curing, the wings were removed from the vacuum bag, the Mylar was peeled off and the excess fiberglass was trimmed or sanded off.

6.2.6 Final Wing Assembly

The fiberglass covering the hard points was trimmed off, allowing access to the plywood below. The spoilerons were cut out and trimmed to allow enough clearance for full range of motion. The recesses to hold the servos were cut into the wings and the wing tips were cut at a 45-degree angle. Fiberglass was then adhered to the exposed core surfaces to provide strength.

6.2.7 Stabilizers

The airfoil decided on for the horizontal and vertical stabilizers was the NACA 0009. The same materials and construction techniques were chosen for the two stabilizers.

Materials: The horizontal and vertical stabilizers were made from foam and fiberglass for the cores and skins, respectively. The only difference from the wings was that only blue foam was used. To provide stiffness and strength unidirectional carbon cloth was laid along the span at half the chord length. The final material used in the tail was aircraft ply that acted as hard points at the interface with the boom.

Construction Techniques: The final lay-up of the stabilizers was exactly the same as the wings.

6.2.8 Main Landing Gear Strut

The gear struts need to withstand fatigue and to absorb the majority of the loads applied at landing.

Materials: The materials considered for the main landing gear struts were carbon, 6061 aluminum and 1095 cold rolled steel piano wire. Aluminum was eliminated due to its lack of strength, and the steel eliminated due to its weight. This left carbon as the only option. The best type of carbon for this job would be multiple layers of pre-impregnated carbon which would have to baked within an autoclave.

Construction Techniques: Carbon landing gears are not easy to manufacture. First a mold was made from a sheet of aluminum by bending it to semi-circle shape. Next, pre-impregnated carbon was cut at 60°, -60°, 90°, and 0° biases and 22 layers were placed on top of the mold. This created a layout that has high torsional and tensile strength. This whole assembly was then vacuum bagged and placed inside the autoclave. Once the epoxy cured under the intense heat and pressure, it was cut into the desired shape using the band saw.

6.2.9 Gear Blocks

Materials: The two possible materials investigated were aluminum and aircraft ply. Tooling time required caused the aluminum to be eliminated. Aircraft ply was chosen since tooling time, cost and skill level were nominal.

Construction Techniques: Prior experience with the materials and component design eliminated the need to investigate construction techniques. The aircraft ply was cut into the required dimensions and then stacked together and bonded with epoxy. A second layer of plywood consisted of two pieces, thinner than the first layer, for the landing gear strut. Epoxy was applied to T-nuts that were pressed into the wood to hold the bolts that would keep the piano wire in place.

6.2.10 Wheels

Materials: Two possible materials for the wheels were aluminum and high-density rubber. Although the aluminum wheels would be lighter, their manufacturing would be difficult and their lack of traction makes them a poor choice. Because of this, 3" diameter commercially available rubber wheels were used for the aircraft.

6.2.11 Nose Landing Gear

Materials: Due to ease of manufacturing, a 3/16" strut commercially available landing gear was used for the construction of this aircraft.

6.2.12 Fuselage

Materials: The three materials investigated for the construction of the skeleton of the fuselage was bi-directional carbon, spider-foam, and balsa wood. Since the skin would be also constructed from carbon, it was crucial that a light variety of carbon cloth be chosen. After some investigation, a 4.8 oz/yd^2 bi-directional carbon fiber cloth was chosen for this purpose. Although lighter cloth could have been purchased, the cost of this very specialized cloth would have been unaffordable. The spider-foam and balsa wood were considered for the inner layer of the sandwich material. They are both light, yet strong.

Construction Techniques: The construction of the fuselage was a very time consuming and laborious task. First, the skeleton of the fuselage was constructed from sandwich material as described in the PDP section. The spider foam was cut into a 1/8" thick piece and into an airfoil shape using a razor blade. Similarly, the bottom piece spiderfoam, was cut into a 1/8" thick piece and circular holes where softballs sit were cut out of the foam. Lastly, the same technique and material was used to make bulkheads that would fit between the two airfoil-shaped pieces. This foam was then sandwiched by two layers of bi-directional carbon essentially creating an I-Beam structure. Each piece was then vacuum-sealed overnight and trimmed to the exact necessary shape. These pieces were then bonded together using an epoxy/cavasil mixture. The fuselage skin was constructed of bi-directional carbon that was shaped using a male mold of the fuselage. The

6.2.13 Boom

The functional requirements for the boom were stiffness and bending strength to support loads from the tail and landing gear.

Materials: Two materials that were considered for the boom were carbon and aluminum. The carbon was chosen over the aluminum due to issues with weight and stiffness.

Construction Techniques: Due to prior experience with carbon tubes, no addition construction techniques were investigated. A 60" long (1" ID x .032" WT) carbon tube was cut to the necessary 22" length. Aircraft ply was bonded to the inner diameter to provide strength for the connection to the vertical stabilizer and tail gear.

6.3 Manufacturing Timeline

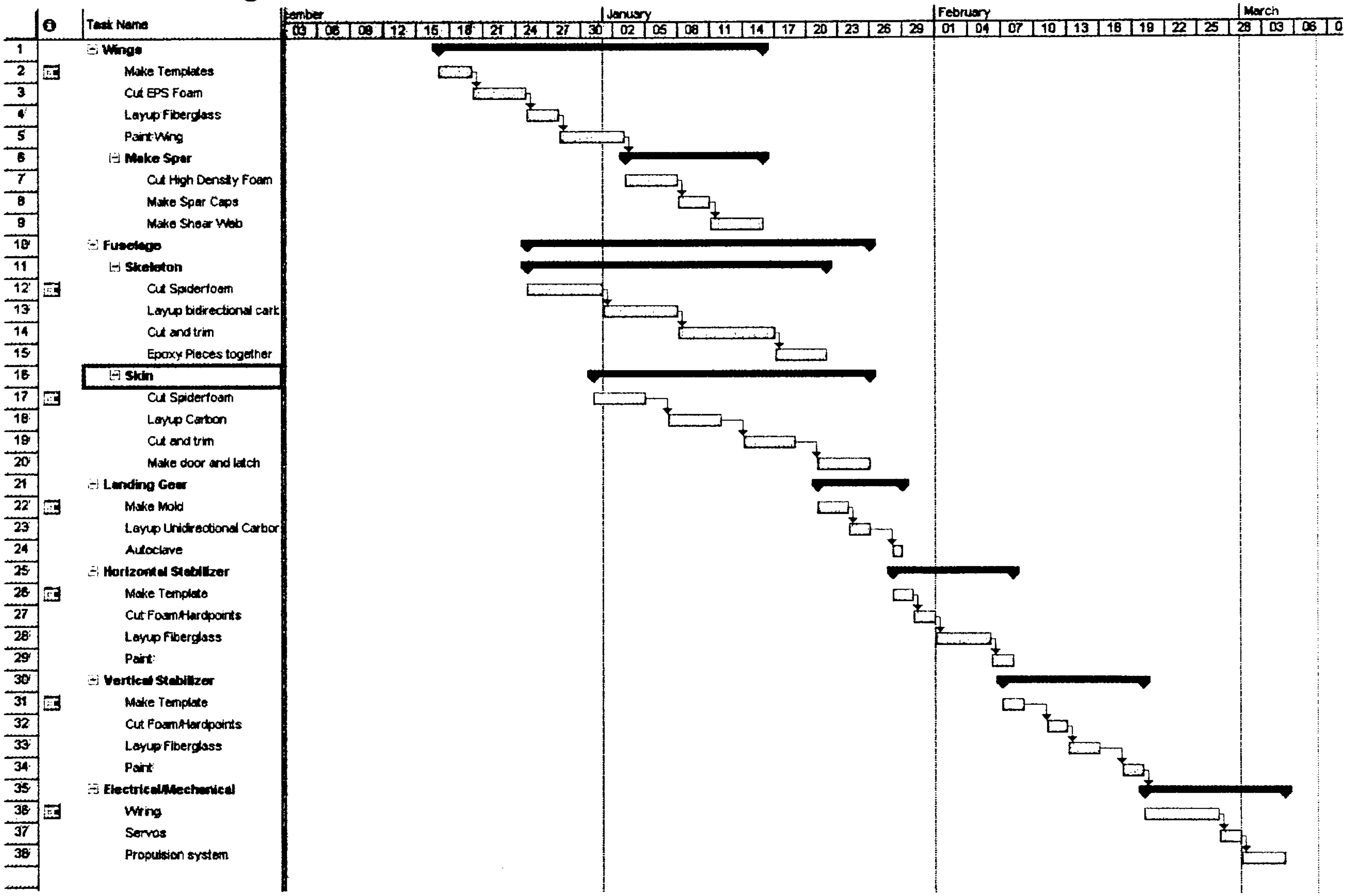


Figure 6-1 Manufacturing Timeline

6.3.1 Cost Matrix

Description	Cost/Unit	Unit	Unit Description	Total Cost
Bi-Directional Carbon Cloth (4.8oz/yard^2)	$ 15.00	5	Linear Yards	$ 75.00
Uni-Directional Carbon Strands	$ 10.00	2	Square Yards	$ 20.00
Bi-Directional Fiberglass Cloth (1.0 oz/yard^2)	$ 10.00	7	Linear Yards	$ 70.00
Epoxy Resin and Hardener	$ 30.00	1	Quart	$ 30.00
EPS Foam (1 lb/ft^3)	$ 25.00	2	3"x36"x60"	$ 50.00
High Density Blue Foam (2 lb/ft^3)	$ 50.00	1	3"x36"x60"	$ 50.00
Spider Foam (4 lb/ft^3)	$ 20.00	1	2"x12"x24"	$ 20.00
Tape/Paint/Glue/Other consumables	$ 100.00	1		$ 100.00
Graupner 3300/7 Electric Motors	$ 300.00	1	Motor	$ 300.00
HS-225MG	$ 25.00	1	Servos	$ 25.00
HS-545BB	$ 35.00	3	Servos	$ 105.00
Recievers	$ 75.00	1	Reciever	$ 75.00
Transimitter	$ 350.00	1	Transmitter	$ 350.00
Speed Controllers	$ 50.00	1	Controller	$ 50.00
Propellors (20" Diameter 20" Pitch)	$ 80.00	1	Prop	$ 80.00
Graupner Spinner	$ 32.00	1	Spinner	$ 32.00
Sanyo 2400 Batteries	$ 5.00	44	Battery	$ 220.00
Hysteris Brakes	$ 25.00	2	Brake	$ 50.00
2:1 ratio Gearbox	$ 150.00	1	Gearbox	$ 150.00
Axel/Wheels/Bearings/Nose Strut	$ 45.00	1		$ 45.00
Expendable Tools	$ 125.00	1		$ 125.00
Softballs	$ 3.00	24	ball	$ 72.00
Total				**$ 2,094.00**

7 Proposal Phase References

1. Raymer, D.P., Aircraft Design: A Conceptual Approach, AIAA Education Series, 1989.
2. Simons, M., Model Aircraft Aerodynamics, Argus Books, 3rd edition, 1994.
3. Lennon, A., The Basics of R/C Model Aircraft Design, Air Age Inc., 1996.
4. McCormick, B.W., Aerodynamics Aeronautics and Flight Mechanics, John Wiley and Sons, 2nd edition, 1995.
5. Nelson, R., Flight Stability and Automatic Control, McGraw Hill, 1989.
6. Stinton, D., The Design of the Airplane, Van Nostrand Reinhold, 1983.

8 Lessons Learned

8.1 Introduction

Throughout the design process, many important lessons were learned and valuable experience was gained. The success of this project relied on the diverse backgrounds and skills contributed by each team member. This included experience with composite materials, structural and aerodynamic analysis, machining techniques, electronics, power systems, computer programs, team/time management, and fundraising.

8.2 Time Management

Establishing a management structure and starting the design process as early as possible allowed room to deal with unforeseen obstacles. An early start enabled the conceptual phase of the design to be completed so that the basic aircraft layout was defined. With this layout, estimations for manufacturing timelines and expenses set a baseline for planning the rest of the project. As the manufacturing process continued, preliminary and detail design could be completed with more information of the actual aircraft characteristics, resulting in the optimum design.

It was important to set a timeline with realistic goals at the start of the project and then adhere to it throughout the design process. One example was planning the Proposal Phase paper well in advance. An outline was created and sections were divided among team members to distribute the workload.

8.3 Teamwork

Creating an organized team was essential in order to allocate responsibilities among the team members. One of the major lessons learned working as a team, was that productivity can decrease with too many people assigned to one element of the project. Delegating separate individual responsibilities allowed specialization. Incorporating each team member's concepts and ideas about their specialized areas into the final design was a process that a great deal was learned from. Dealing with trade off issues between the various component configurations was important to realize the optimum design.

8.4 Design Process

While many of the senior team members had taken advanced design courses, a lesson that was learned early was that the classroom is an ideal. With a short term project, it was found that less complex designs which enabled more simple analysis and took less time to manufacture were desirable. Experience gained from the design classes, combined with practical experience gained by last year's team members provided knowledge that was shared by the newer team members to learn from and apply to their efforts for this year. By providing this knowledge openly, the full talent of every team member could be used most effectively.

8.5 Theoretical vs. Actual

A lesson that was learned last year and re-affirmed with this year's design was that the actual characteristics of TLAR III differed from the designed theoretical characteristics. With even the most careful manufacturing techniques, the components will inevitably change. For example, as the propeller diameter changes, so will the required landing gear length, as the weight increases or decreases so will the required engine thrust. These types of trade-offs were needed throughout the construction even with the extensive factors of safety used during the proposal phase of the design. This is a very important point to realize for any design process.

8.6 Finance

Working within a set budget emulated a real-world design setting. Due to the limited budget, the team was required to rely heavily on analysis to ensure that fabrication went smoothly and to avoid errors that could potentially increase the amount of materials needed. One of the main fundraising techniques learned last year was how to create a well-written proposal package. In addition, establishing and maintaining good relationships with sponsors and keeping them up-to-date on the project was important.