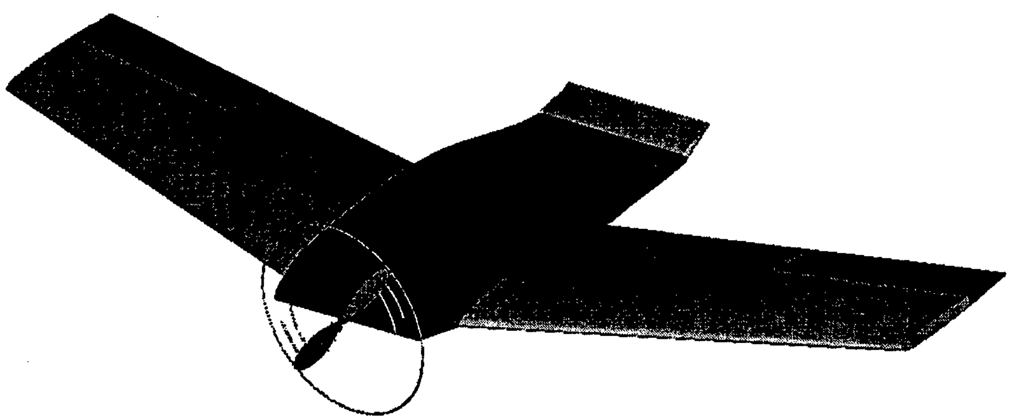
UNIVERSITY OF CALIFORNIA, SAN DIEGO

Proposal Phase Design Report

Submitted March 12, 2002



TLAR 3.5

aka "Brick"

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1 Executive Summary

Flying wings are theoretically extremely efficient aircraft. All an aircraft needs is lift, provided by the wing, and thrust provided by an engine mounted to the wing. All other components that are typically associated with an aircraft, such as a fuselage, tail and nacelles, add weight and drag. Flying wings are lighter, stronger and less expensive airplanes. Less structural interfaces exist, considerably less material and labor is needed to construct them and, with proper analysis, a very strong structure is produced. However, this ideal aircraft precedes itself. Careful design and rigorous analysis must be performed to design a flight worthy flying wing. Stability issues dominate the design of a flying wing, which does not have the luxury of long moment arms to typical or "conventional" pitch and yaw control surfaces. The payload requirements for this competition require that TLAR 3.5, not be a true flying wing, but rather a blended wing-body.

In order to meet these requirements, the team first established a set of design goals that the final aircraft configuration should meet. To maximize the score, it was decided that the design of the aircraft be light and fast, maximizing RAC and flight scores through time optimization. Ideally, the aircraft would complete mission very quickly, while meeting the functional requirements of the design as specified by the rules stated above.

Experience gained from the previous year's entries, "TLAR I" and "TLAR II", were beneficial in designing the new aircraft. This year, the team began the project with a better overall understanding of the design process, materials, design trade-offs and time constraints. This experience and knowledge, coupled with the Figures of Merit (FOMs) and design parameters, enabled the team to work more efficiently and effectively.

1.1 Conceptual Design Phase

The conceptual design phase is intended to generate basic properties of the aircraft based upon mission requirements. The team analyzed various design parameters such as wing shape and fuselage type to eliminate those that did not offer reasonable chances of high flight scores. The basic design parameters were then combined into a total of 12 working configurations. The component interactions of these configurations were then investigated to determine the best possible arrangement for further study in the Preliminary and Detailed Design Phases.

1.1.1 Alternative Designs

The design parameters investigated for the initial set of concepts included all those that could potentially result in a winning flight score. The wing variations included rectangular, swept, and flying wing. The fuselage concepts were torpedo, lifting body, and flying wing. Empennage concepts were limited to t-tail and no tail. The concepts were rated by predicting weight, RAC, and three general FOMs: Manufacturability, Transportation, and Handling. The FOM's were designed to eliminate those concepts that were clearly problematic without having to perform a full aerodynamic analysis on each of the concepts. Handling was predicted using general flight characteristics of similarly built general aviation craft and previous competition aircraft. Manufacturability was determined from previous team experience with TLAR I and TLAR II as was the transportation FOM. When each concept was rated, the final general configuration was chosen. It was determined that a blended wing aircraft would yield the lowest RAC and highest flight scores while still being within the team's ability to construct.

1.1.2 Design Tools

The design tools used were mainly spreadsheets and codes left from previous years in competition. They were modified to account for the new rules and the new types of aircraft configurations being considered. Hand calculations based on general aviation performance equations were also used to estimate parameter interactions.

1.2 Preliminary Design Phase

The goal of the Preliminary Design Phase was general sizing of the best concept generated from the Conceptual Design Phase. Specific aerodynamic properties of various components were introduced as variables in the evolution of the aircraft. More accurate design tools were used to create a better analytical model of the final design concept.

1.2.1 Design Variations

The team examined several variations to each major aircraft component in order to select the best possible component specific configuration. The major components included the wings and the fuselage since it was determined in the Conceptual Design Phase that there would be no empennage. Payload size was also determined in the Preliminary Design Phase.

The payload specifications had to be determined so the rest of the aircraft could be tailored to it. The two choices for payload configuration were light with 12 balls and heavy with 24 balls. The heavy payload depended on softball count for high scores whereas the light payload depended on low flight times and lower RAC for high overall scores. The light payload was chosen as the best possible configuration.

Fuselage variations were influenced by the payload specifications. The lifting body of the fuselage had to be an airfoil shape, and thus the size of the fuselage was dictated by the thickness of the airfoil. Pitch was also considered due to lack of an empennage. It was determined that a reflexed airfoil would provide the necessary positive pitch. The airfoils selected for analysis were the MH60, Roncz/Marske7, S5010, and the E186. The Roncz/Marske7 was selected due to its thickness and low drag. The size of the fuselage was determined to be 16" to accommodate the payload.

The wing variations included span/chord lengths, geometric/aerodynamic twist, and sweep angle. Span was iterated from 80 to 120 inches and chord from 10 to 25 inches for root and tip airfoils. The pitch of the wing was determined to be negative to balance the fuselage moment. Therefore aerodynamic twist was investigated by researching various high lift airfoils with negative moment coefficients. The tip airfoil was selected to be symmetrical or nearly symmetrical to provide good control. The final results indicated a span of 96" (including 16" fuselage), a root chord of 20" (E211), and tip chord of 14" (Ames-A02).

Landing gear options included composite and steel piano wire struts. The steel struts were selected due to their ease of construction and low price. In previous years they have been shown to be effective in absorbing landing loads.

The motor was determined to be the Graupner Ultra 3300/7 from TLAR II. The motor has ample power for TLAR 3.5, which was estimated to weigh less than that of TLAR II. Propeller specifications were varied from 16"x12" to 20"x20" to account for top speed and static thrust. An 18"x12" propeller was estimated to have the best performance.

1.3 Detailed Design Phase

The Detail Design Phase is intended to establish the final sizing of all aircraft components and to calculate the predicted aircraft performance. The final analysis includes aerodynamic calculations as well as structural calculations. All components were balanced to achieve maximum stability for the maximum flight scores.

1.3.1 Design Tools

The Wing Analysis program by Hanley Innovations was used to iterate the final sizings from the Preliminary Design Phase. It generates aerodynamic coefficients for wings and the lifting body fuselage.

Structural calculations were done by hand and using the NASTRAN finite element program.

1.3.2 Final Results

The aircraft components were iterated through the Wing Analysis program and hand calculations until the optimum configuration had been reached. The fuselage consisted of the Roncz airfoil with fairing between the side panels and the wings to increase overall lift/drag efficiency. The wings incorporated twist and dihedral to prevent stall and side-slip effects.

The final MEW was estimated to be 9.1 lbs. The estimated RAC is 7.995. With a top speed of approximately 60mph and a 12 softball payload, the projected final flight score is 3.717. Assuming a paper score of 86, the total final score is 120.

2 Management Summary

The 2002 UCSD Design/Build/Fly Project team consists of eleven 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. Each member would work in a group on one aspect of the plane, when complete move on to the next task. At times it was necessary to go back and change designs. The project manager, Josh Adams, assigned each member into an area of the project of which the member found interesting. The following focuses are listed in Table 1. The amount that each participated is represented by a number from 1 to 5, 5 being a high level of participation. A blank means no involvement.

	Area of the Project that Team Member Participated In									
Team Member	Wings	Fuselage	Landing Gear	Propulsion System	Power Management	Systems Architecture	Drawing Package	Finite Element Analysis	Manufacturing	Fundraising
Josh Adams	5	4	2	4	5	2		5	4	2
Brooke Mosley		2			2	4			5	
Steve Wong		1					5		3	
Aaron Pebley		1		2					2	
Albert Lin		1				4			2	
Guy Watanabe	5	5	5	5		2		3	5	3
Matthew Napoli		2	3				3		5	
Brian Berg		2	3						5	
Jillian Allan		1	1			4			5	5
Ceazar Javallana		1							2	3
Hamarz Argafar		2	2	2	5				5	

Table 1 - Project Participation by each member

Weekly meetings were set where the groups discussed their design ideas, chose the most optimal designs, then reported it to the entire team. The team then reviewed the design and either incorporated it or discussed improvements. Often there were problems with component interactions, where it was necessary for multiple groups to work cooperatively. The end of each meeting was designated as the time to combine each of the group's ideas into one practical plane.

The specific team member profiles are shown in the table below. This table lists some of the important skills that each member possesses; however, this table does not display the full talents and knowledge that the team possesses because aircraft design and manufacturing spans so many disciplines.

	Major	Year	Pro-Engineer	AutoCAD	SolidWorks	FEMAP/Nastran	Technical Writing	Machining
Josh Adams	ME	SR	X	X		X	X	X
Brooke Mosley	AE	FR		X				X
Steve Wong	ME	SR	X	X	X			
Aaron Pebley	AE	SR			X			
Albert Lin	AE	JR		X				X
Guy Watanabe	AE	SR	X	X		X	X	X
Matthew Napoli	AE	FR					X	
Brian Berg	AE	FR		X			X	
Jillian Allan	BE	JR			X			X
Ceazar Javallana	AE	JR	X	X				X
Hamarz Argafar	AE	FR		X			X	X

Table 2 - Highlights of Member Skills

2.1 Task Scheduling

In early October, the group decided upon a schedule of completion dates. Each subgroup was expected to complete tasks by a certain deadline. The chart below (Figure 3) depicts the planned and actual dates of completion (DOC) 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

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. The team eventually solidified with 11 members.

Notice of Intent to Compete: This notice was sent by the project manager Josh Adams, on October 19, 2001.

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) and Jacobs School of Engineering (UCSD). Generous component and material donations were obtained from Hi-Tech RCD, Diversity Model Aircraft, Corland Co. and San Diego Silent Electric Flyers.

Conceptual and Preliminary Design FOMs: Conceptual FOMs were applied in the conceptual design phases and preliminary FOMs designs in order to either eliminate or accept designs.

Conceptual Design: Having found designs that met all of our goals, a final conceptual design could be assembled.

Preliminary Design: The conceptual design having been finalized, the design could be scrutinized and improved, and initial sizing could be made.

Detailed Design: The preliminary design was optimized to ensure the best flight characteristics and mission scores possible given the design parameters.

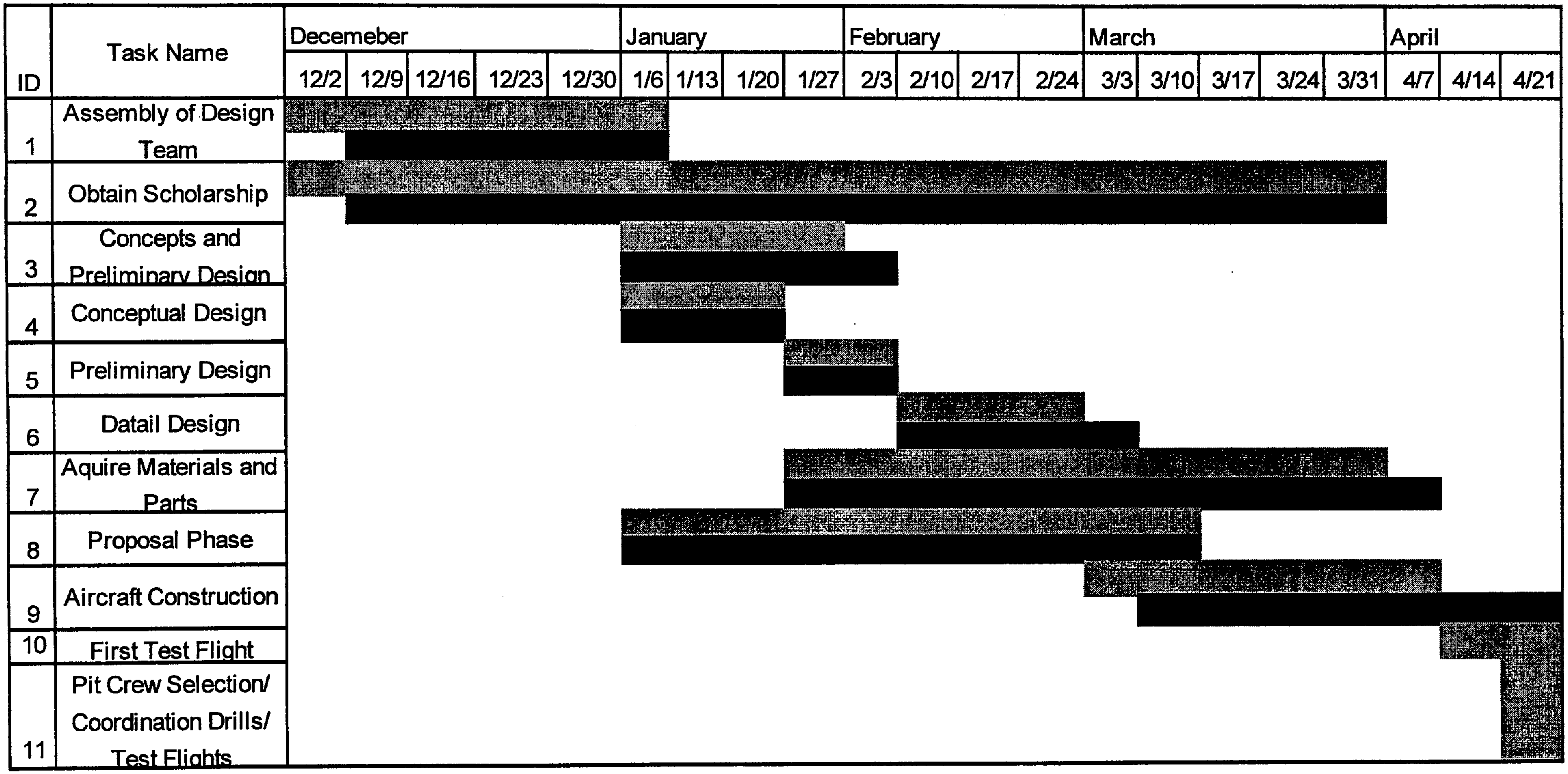
Acquire Materials and Parts: This was an ongoing task. Materials were purchased and replaced as needed. As structural designs and system architecture were finalized, appropriate parts, such as servos, were ordered.

Proposal Phase: Having a large part of the manufacturing complete and all of the performance and mission data calculated, the 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 structural integrity, good component interaction, performance, and most importantly serve 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.



*The gray area represents the desired schedule, while the blue represents the actual.

Table 3 - Project Milestone Chart

3 Conceptual Design Phase

In the Conceptual Design Phase the team brainstormed the most basic aircraft design parameters such as wing planform and fuselage shape. The goal of this phase was to combine the best parameters into several design configurations to be analyzed in more detail in the Preliminary Design Phase. The tools used to evaluate various components were developed in spreadsheets and pencil/paper calculations, as well as from the team's previous experiences with the competition.

3.1 DESIGN PARAMETERS

3.1.1 Wing Planform

The wing planform is a critical design parameter due to the fact that it has a significant effect on the performance of the aircraft in flight. The team desired a planform that performed well at low speeds and gave the optimal control. Towards those goals, it was determined that the primary concerns in the conceptual stage for the wing planform were good low-speed lift/drag characteristics and construction feasibility. The options considered were elliptical, rectangular, swept rectangular, and delta wings.

It was found through research of the various wing types that the delta wing would only reach full potential at speeds greatly exceeding those of the competition. Therefore it was not considered further.

The elliptical wing has better theoretical performance than a rectangular wing due to the fact it creates an elliptical lift distribution. This decreases the end effects of the wing and allows for better lift/drag ratios. However, as in previous years, the problems associated with constructing a precise elliptical shape outweighed the benefits of performance and it was eliminated as a possibility.

Rectangular wings do not perform as well as elliptical wings because of the vortices created at the wing tips. This results in higher drag and reduced efficiency. However, unlike elliptical wings, rectangular wings are relatively easy to construct with precision. Rectangular wings were therefore advanced for further analysis.

3.1.2 Wing Configuration

The choice of configuration has perhaps the largest influence on the development of the aircraft than any other component. The remainder of the aircraft is tailored to the flight characteristics that the wing defines. The goals set in this part were good handling properties, lift/drag efficiency, and structural feasibility. The configurations analyzed in the initial stages were monowing and bi-wing. Winglets were also considered for the monowing.

A bi-wing aircraft can be beneficial to structural integrity and transportation. Shorter wings reduce the stress seen by the spar(s) and are much easier to transport than a longer mono-wing. However, a bi-wing aircraft is less efficient in terms of lift per unit span. Interactions between the top and bottom sections interfere with the lift of the bottom wing, thereby reducing lift across the entire span. A bi-wing would require more wing area to lift the same load as a monowing.

A monowing with winglets has a better lift distribution than a monowing without winglets. This is due to the endplate effect preventing vortices at the wing tips due to pressure differences. The disadvantage to winglets is that they increase drag and require structural reinforcement to the wing tip and the spar. Neither concept had a clear advantage so both were advanced for further study.

3.1.3 Fuselage Configuration

The fuselage is critical part of the aircraft structure as it functions to connect the wings, control surfaces, and landing gear as well as to absorb/transfer the loads created by those components. The fuselage also houses the motor, payload, avionics, and all other important aircraft components. The contest rules dictating that the payload be arranged in the horizontal plane served to reduce the number of practical design possibilities. The concepts selected for analysis were the wide lifting body, flying wing, and narrow "torpedo".

The "torpedo" concept had the payload in two or three rows extending the majority of the fuselage. This would allow a very narrow streamlined body with relatively low drag. However, this year a front/rear loading fuselage would hamper pit stop crews since each softball must be hand loaded. While the torpedo design does not have any overwhelming advantages, it does not have any great disadvantages. It is incorporated into further concepts due to the experience of the team with the design and the success of previous years with it.

The wide lifting body takes advantage of the softball arrangement rules by using the large area required by the payload to create lift. The airfoil shape of the fuselage creates the lift and the payload can be stored in the thickest section. This fuselage allows for a slightly smaller wing area and low drag. Fuselage size is a concern as the airfoil shape must be sufficiently thick to hold the payload without creating an excessively long body. Access to the payload is also an issue but the benefits to performance make the concept worth looking into.

The flying wing body incorporates the fuselage and the wings into one continuous structure. The greatest benefit to this would be the higher efficiency of the entire aircraft. Since the entire body acts as a wing the lift per unit area is increased and the drag normally induced by a fuselage is eliminated. However, such a structure requires very large wings to connect to the fuselage. This is problematic both for construction and transportation reasons.

3.1.4 Empennage

The empennage, with elevators and rudders, allows yaw and pitch control of the aircraft. It is also a stall safeguard either by stalling after the wing to maintain control, or stalling before the wing to prevent the wing from stalling. A number of variations of empennage exist and can provide differing levels of control and efficiency. The options considered were T-Tail, conventional tail, canard, and no empennage (flying wing).

The conventional tail has the horizontal stabilizer under the vertical stabilizer. This design is easy to construct as the stabilizers may be anchored to a boom or on the end of the fuselage without much reinforcement since each only supports its own weight and lift forces. There are no major disadvantages to this design except that the empennage must be sufficiently far way from the fuselage to prevent the fuselage wake from interfering with the elevator. Despite being a viable design, the conventional tail design was discarded in favor of the T-tail.

The T-tail design places the horizontal stabilizer on top of the vertical stabilizer. This not only eliminates possible interference from the fuselage, but also creates an end plate effect for the vertical stabilizer. This increases the overall efficiency of the empennage as tip vortices are eliminated. The disadvantages are that the vertical stabilizer must be reinforced to support the horizontal stabilizer. In past years, this has been accomplished to great success and this concept was chosen as superior to the conventional tail.

A canard places the vertical stabilizers ahead of the main wings and the aircraft center of gravity. Typically the canard has a higher aspect ratio and is designed to stall before the main wings. This makes it much more difficult to stall the main wings as the aircraft will not be able to achieve dangerous angles of attack. The disadvantages include lack of a vertical stabilizer and a short moment arm. Without a vertical stabilizer, there is no yaw control. In order to obtain sufficient pitch control, the canard must either have a large moment arm, or be increased in size over a more conventional tail. The canard still represents a feasible design concept as it could lower the RAC and allow for a smaller structure than other designs.

The flying wing has no empennage. It uses reflexed airfoils and wing twist/sweep for pitch control and either end plate rudders for yaw control or no direct yaw control at all. The benefit to structural weight and RAC is significant. Weight is saved by excluding the boom and control surfaces, allowing for fewer batteries and greater speed. With no control surfaces, the MFHR of the RAC is noticeably reduced. This design provided a clear advantage and was advanced to the next stage.

3.1.5 Propulsion

The propulsion system is the component that allows the aircraft to sustain powered flight. It is required to achieve the 200 ft take off limit and propel the aircraft around the course at maximum speed. The characteristics of the propulsion system of most interest to the project are static thrust, top speed, and battery power management. These aspects must be tuned in such a way as to allow for maximum flight score and lowest RAC. The most practical concepts discussed were dual motors, single motor, and single motor geared along with several battery configurations. The motors used were the Graupner Ultra 3300/7 used last year's competition.

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 last year's competition showed that this was not a desirable arrangement. The team used the previous years 38 cells as a working estimate to be refined in later design stages.

Concerns for power as well as those regarding additional weight of this year's design did necessitate that a dual-motor configuration also be proposed. The dual-motor configuration would place the engines on the wings, supported by the spar. Last year's competition demonstrated that such a configuration provides excellent static thrust and high top speeds. Dual motors also allow for smaller propellers, which in turn aid in shorter landing gear. However, this year the RAC cost is extremely high. It was decided that the high performance was not adequate to justify the increased RAC.

The greatest benefit of a single motor is the minimization of the RAC. In order to generate the required thrust, however, a single non-geared motor requires a larger propeller than does the dual-motor configuration. In the previous year, 14 in. propellers were used to generate a total of 9 lbs of thrust. Using this figure as a baseline, the team estimated that the new propeller would fall into the 17-19 in range to achieve similar results. The larger diameter was still viewed as practical and this concept was advanced.

The use of a gearbox can greatly enhance propeller speeds. It is possible to gear a motor up to achieve higher rpm with a larger propeller to reach higher top speeds at the expense of static thrust. This concept would make it more difficult to make the 200 ft take off distance but would potentially shorten lap times considerably. In previous years the power plants easily managed the take off distance limit by more than 50 ft. Therefore the team considered it possible to advance the geared motor.

3.1.6 Landing Gear

The landing gear determines the ground handling characteristics of the aircraft and adds drag while in flight. A preferable landing gear design has good ground stability and low drag in flight. The concepts included for analysis were tail-dragger, tricycle, and quadracycle.

The tail-dragger design places the main wheels slightly ahead of the CG and the rear wheel farther back near the empennage. The concept was used in previous years and has proven reliable under light to moderate conditions. However, under high wind conditions, ground handling is poor due to the wind moving the empennage, and thus the rear wheel. As relatively high winds are expected at the competition site, it was decided that the tail-dragger would not be practical.

The tricycle landing gear has the two main wheels slightly behind the CG and the third wheel ahead of the CG near the nose. This arrangement has improved handling characteristics over the tail-dragger. The difficulty lies in the fact that if the propeller is in the nose of the aircraft, the nose landing gear must be long enough to allow clearance. With larger propellers, the gear must be longer and stronger. Aerodynamically, the longer the landing gear the more drag is created. This design was advanced due to the very desirable ground handling.

A quadracycle was initially proposed due to the wide rectangular fuselage concepts. There are four wheels placed around the CG. This design does not have any clear advantages over the tricycle landing gear. It does in fact create more drag and requires more structural reinforcement while still facing the same problems as the other designs and was discarded.

3.1.7 Aircraft Configurations

The design concepts remaining to this point in the conceptual design phase were incorporated into 6 configurations with the option of adding winglets, for a total of 12 variations.

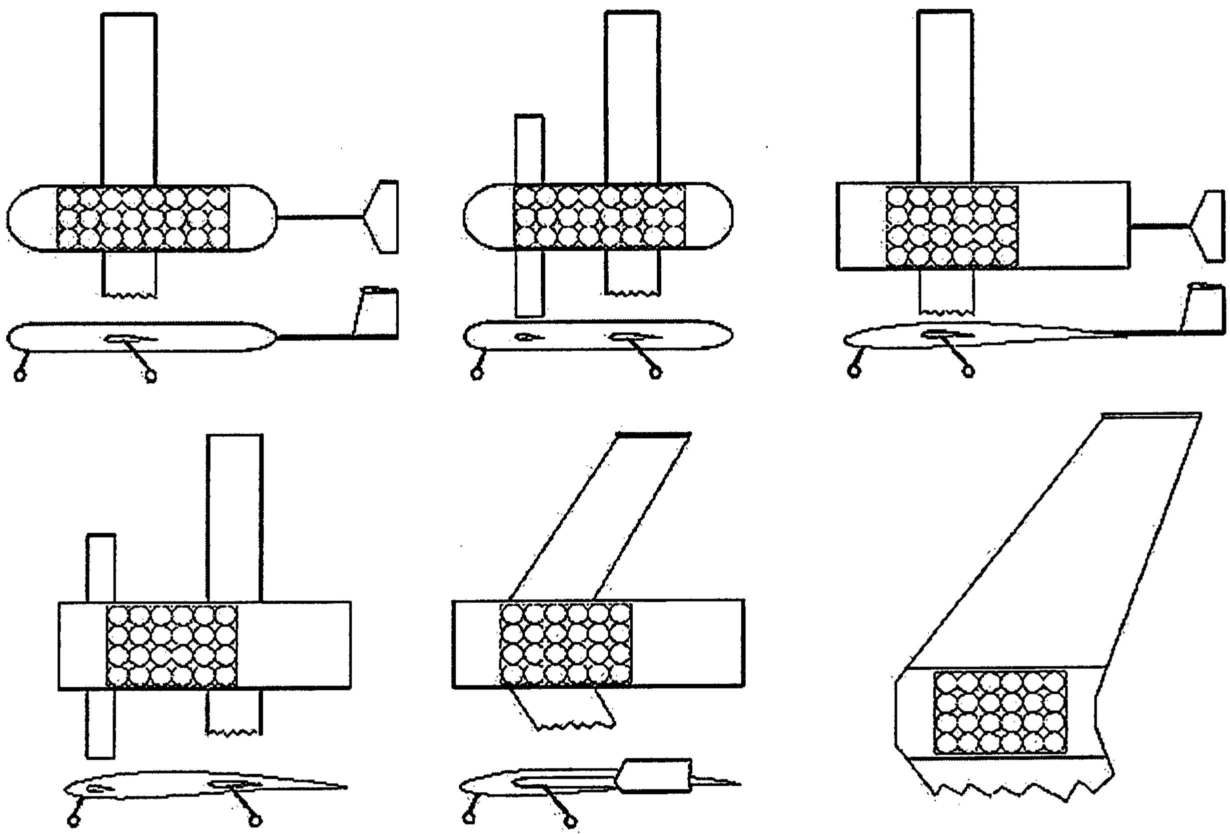


Figure 1 - Design Possibilities (Winglet designs not shown)

Design #	Planform	Winglets	Fuselage	Empennage	Projected Empty Weight (lbs) (X3)	# Control Surfaces (X1)	Handling (X1)	Manufacturability (X2)	Ease of Transportation (X1)	Projected RAC (X3)	Advanced
1	Rectangular	N	Torpedo	T-Tail	15.0	4	3	2	1	9.6	N
2	Rectangular	Y	Torpedo	T-Tail	15.5	4	3	2	1	9.8	N
3	Rectangular	N	Torpedo	Canard	13.0	4	1	1	3	9.4	N
4	Rectangular	Y	Torpedo	Canard	13.5	4	1	1	3	9.6	N
5	Rectangular	N	Lifting Body	T-Tail	15.0	4	3	2	1	9.2	N
6	Rectangular	Y	Lifting Body	T-Tail	15.5	4	3	2	1	9.4	N
7	Rectangular	N	Lifting Body	Canard	13.5	4	1	1	3	9.1	N
8	Rectangular	Y	Lifting Body	Canard	14.0	4	1	1	3	9.3	N
9	**Swept**	**N**	**Lifting Body**	**none**	**12.0**	**2**	**1**	**2**	**3**	**8.6**	**Y**
10	Swept	Y	Lifting Body	none	12.5	2	1	2	3	8.8	N
11	Flying wing	N	Flying wing	none	11.5	2	1	0	1	8.8	N
12	Flying wing	Y	Flying wing	none	12.0	2	1	0	1	9.0	N

Table 4 - CDP Possible Designs and Figures of Merit

3.2 Figures of Merit

The figures of merit quantify the most important design aspects of the aircraft. They are used to optimize the aircraft design and achieve the highest possible flight score. The FOM's used by the team to rate each concept were weight, handling characteristics, ease of transportation, and ease of construction.

3.2.1 Projected Empty Weight

Weight calculations were based on average component densities estimated from previous competitions. As weight directly impacts speed and power consumption, it was considered to be one of the primary FOM's used. Since all concepts generated in the initial stage of the Conceptual Design Phase utilize the same power plant and batteries, it was possible for the team to compare power usage using only weight and drag estimates (i.e. it was not necessary to calculate a flight plan for concept elimination purposes).

3.2.2 Handling Characteristics

This FOM rates basic stability pitch/yaw control, turn radius, and ground handling. The flight performance of the aircraft is determined by the ability of the pilot to control the aircraft. With good pitch/yaw control and tight turn radii, the pilot can lower the flight times by several valuable seconds. With the emphasis on sortie time in the competition, it was necessary to closely examine the general aerodynamics of each configuration.

3.2.3 Ease of Transportation

A well-designed aircraft is useless unless the team can get it to the competition intact. Therefore, transportation was a major issue as the team operated on a limited budget of time and money. In previous years, the aircraft was designed in part with shipment in mind and no less emphasis was placed on it this year.

3.2.4 Ease of Construction

The final FOM rates the ability of the team to construct the aircraft from the design on paper. It is important to incorporate this FOM in the design process so that the final product matches the calculations. Sacrifices must often be made on performance due to constraints on tools and materials.

3.3 Conceptual Summary

In the Conceptual Design Phase the team reviewed the most basic design parameters. Planform, fuselage and wing configuration, empennage, propulsion, and landing gear concepts were combined into a set of theoretically viable aircraft configurations. Each of these configurations was rated according to the RAC and FOM's geared towards maximizing flight scores. After all aspects had been rated, the design estimated to be the most efficient and most practical was chosen.

Concepts 1 & 2: The first two concepts were generated from TLAR II in the 2001 competition. The monocoque fuselage provides good torsional rigidity and relatively low drag when streamlined. The T-tail empennage allows for excellent pitch and yaw control, resulting in good flight handling. This concept has proven to yield top flight scores in the past.

With a weight estimate of 15 lbs (15.5 with winglets), the initial two design concepts ranked among the heaviest of the group. This would significantly increase lap times and therefore lower flight scores. It was predicted that any benefits gained from the good handling characteristics would have been eliminated by the relatively high RAC. The designs were therefore eliminated as possibilities.

Concepts 3 & 4: The torpedo-canard configuration has the benefit of good stall characteristics. Weight reduction on the order of 2 lbs. accounting for the lack of empennage support allows for faster lap times over concepts 1 & 2. The shorter projected dimensions would make transportation easier than other concepts.

The estimated RAC was not as low as originally predicted. This was due to the lengthening of the fuselage to limit the canard size. The team predicted lower handing capabilities than the more conventional designs due to the lack of direct yaw control and sensitivity of the canard to stall.

Concepts 5 & 6: The lifting body concept was conceived to make maximum use of the area housing the payload. The lift produced by the fuselage allows for smaller wings, and therefore a lower RAC. The payload is limited to the thickest parts of the airfoil, making it more accessible to ground crews.

The lifting body-T-tail designs share much in common with the torpedo-T-tail configuration. The RAC and weight savings were not as significant as originally expected. The handling characteristics are virtually identical and there was no obvious advantage in terms of flight scores.

Concepts 7 & 8: The lifting body-canard configurations are similar to the torpedo counterparts on paper. The handling and RAC are based on the same component assumptions.

While the RAC and weight values are similar to the torpedo concepts, the structural concerns are not. The torpedo designs may be lengthened or shortened as the situation dictates. The lifting body, however, is constrained by the airfoil shape. It was discovered that in order to place the canard at the prerequisite distance to allow maximum efficiency, the fuselage must be enlarged significantly. The sheer size of the fuselage renders these concepts unfeasible.

Concept 10: The blended wing design resulted in the lowest RAC and the second lowest predicted weight. The efficiency of this structure allows for quick lap times at a low power usage.

The disadvantage to this structure is that it is not able to maneuver as well as the other configurations. The lack of direct yaw control raises similar problems to the canard designs. However, the considerable weight savings and the low RAC make this design the best overall configuration.

The winglet design improves the lift distribution by reducing tip vortices. This allows the wingspan to be shortened slightly. However the winglets also increase drag and require significant structural support. These factors led the winglet-blended wing to be eliminated.

Concepts 11 & 12: The flying wing design is theoretically the most efficient in terms of structural weight. The team estimated that the flying wing would have the shortest takeoff distance and one of the lowest RAC.

The difficulty in the flying wing lay in construction. The size of the wings made it difficult to make out of foam for a composite lay-up. A rib structure was ruled out due to the precision required in airfoil shape and wing twist/sweep angles. The large root chord and wingspan also increased the RAC and resulted in the design being disqualified.

Final Design Configuration: The blended wing was the final design choice based on RAC calculations and flight score predictions. With a predicted RAC of 8.6, the blended wing design had as much as a 10% advantage over other possibilities. The weight advantage is also significant. The lighter aircraft would require much less power throughout the entire sortie and could potentially fly much faster.

It was also feasible for both manufacturing and transportation. The structural components for the blended wing were very compact. This is attributed to the fact that it is not required to support an empennage. Thus not only is the empennage eliminated, but all the supporting structure is eliminated as well. Initial scale drawings predict that no structure behind the payload tray will be required.

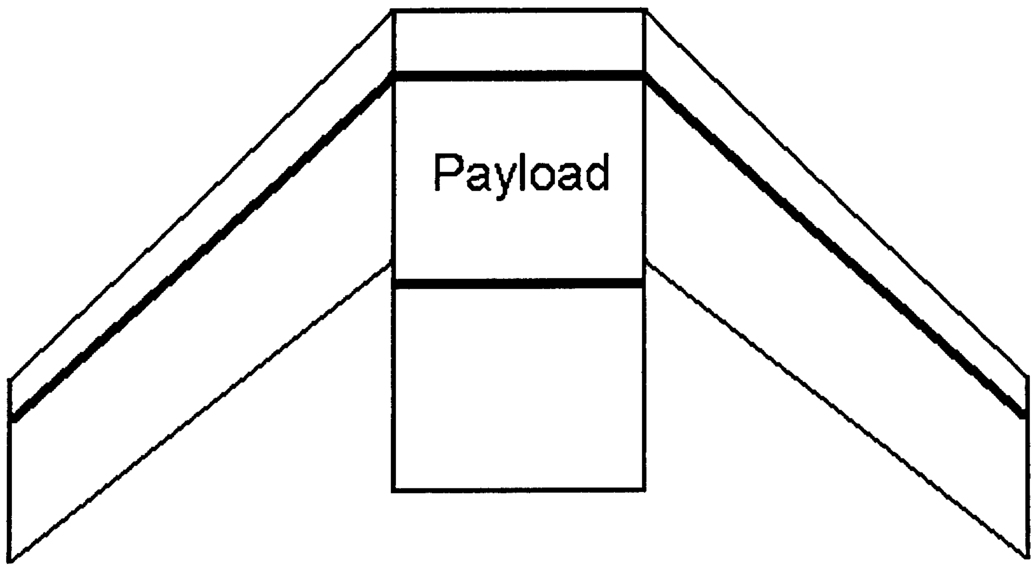


Figure 2 - Final Design Concept: Blended Wing

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 team written computer algorithms as well as the Wing Analysis Program (Hanley Innovations) to analyze the aerodynamic properties of the aircraft. While these techniques are not expected to be exact, they were implemented with confidence as their accuracy was validated by TLAR I (2000) and TLAR II (2001). 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 locally.

4.1 Analytical Tools

The primary tool used in size and score estimations were spreadsheets developed over the last two years of competition. They incorporate the basic aerodynamic equations and RAC/flight score calculations. TLAR I (2000) and TLAR II (2001) were straight wing aircraft with t-tail empennages so the spreadsheets had to be adapted to the blended wing equations. These equations took into account many factors that were not present in the previous aircraft such as sweep, pitching moment, and stability margins.

A program called Wing Analysis (Hanley Innovations) was used in the iteration of various component sizes and airfoil selection once the basics had been established. It is attached to the Hanley Innovations program Visual Foil which contains the entire UIUC airfoil database and NACA specifications. The code runs a numerical analysis on the defined wing to give the theoretical performance. The program inputs included airfoils, planform dimensions, speed, and angle of incidence. The outputs included Reynolds number, drag, lift, moments, bending forces, and power usage. The team found this to be particularly useful since it allowed a greater number of variables to be introduced. It also permitted the calculation of such things as end effects that would otherwise be very time and labor intensive.

4.2 Design Parameters

4.2.1 Payload Size:

The flight score of the 2002 competition depends as much on sortie time as payload capacity. Unlike previous years, carrying less payload does not necessarily equal a lower score. The team evaluated the various possibilities and balancing between capacity and speed.

A large payload achieves a high score by having the numerator of the flight score equation dominate. With the maximum payload of 24 softballs, the numerator equals 30. The minimum payload would have a numerator of 16. Thus a small payload aircraft would have to cut the flight time approximately in half to achieve the same score. This is difficult to achieve, and the large payload aircraft has the advantage in raw flight scores.

The advantage of a small payload is the shorter payload transfer times and a lighter aircraft. The reduced weight of the aircraft impacts several areas of the overall score. A lighter aircraft can achieve higher speeds and can therefore lower flight times. A lower weight also decreases the number of batteries necessary to complete the sortie. Battery weight plays heavily into the RAC. So while the smaller payload may not be able to cut the flight time in half to match the large payload, the difference in flight score is offset by the lower RAC.

It was not possible for the team to calculate which setup had the numerical advantage due to the abundance of variables for which there was very little concrete data. It was decided based qualitative estimation that the light payload was preferable due to the many benefits. As the rules dictated that the softballs must be inline and in the horizontal plane, a 12 ball payload was selected. The 12 ball payload had the largest number of symmetrical configurations.

4.2.2 Fuselage:

Optimization of the fuselage included determining a viable support structure and the necessary dimensions for maximum payload capacity. The fuselage muse also be designed for the motor and all supporting devices. In the case of the blended wing design, aerodynamics also became an important issue with the selection of the airfoil shape. The Reynolds numbers used were approximated from the fuselage of TLAR II to be $2x10^5$.

Airfoil: The airfoil shape of the fuselage for a blended wing must not only provide lift, but must also be factored in pitch control. The team decided that the fuselage would be built as a reflexed airfoil to provide more stability rather than a standard airfoil to provide more lift. This was due to the fact that the fuselage would have a very short span and thus the maximum lift would not be significant compared to the wings. The fuselage could, however, still provide a large amount of pitch with the limited span.

Another primary feature evaluated in the airfoil selection process was the maximum thickness. A thick airfoil was necessary to ensure a short fuselage and a lower RAC. This criterion was applied to the reflexed airfoils in the UIUC and NASG airfoil databases and four possibilities resulted: E186, Roncz/Marske7, S5010, and MH60. The evaluation of these airfoils is provided in the final sizing section.

Payload: The payload configuration affects the size of the fuselage and can indirectly influence pit stop times. Access is also a concern as time is critical to the overall flight score.

The consensus was that the most efficient payload configuration is the most compact arrangement possible. This would reduce the amount of support structure required and make it easier to load/unload. The best configuration to reduce fuselage length and structure was judged to be 3 rows (spanwise) and 4 columns based upon the 12 softball payload.

The options for the payload access were front loading, rear loading, and top loading. The front/rear loading concepts were used in last year's competition and worked well with speed loaders. However this year, with each ball required to be hand loaded, a front/rear loader would restrict access to the payload area and would slow the loading process considerably. A top loading configuration would make the entire payload area accessible and multiple pit crew members would be able to participate in loading. Therefore the top loader was chosen as the best configuration.

Structure: The structure of the fuselage must be stiff enough to resist aeroelasticity effects and survive the loading conditions during high G turns and landing. The top loader configuration established in the payload section complicated matters due to a disruption of shear flow around the fuselage. The possibilities investigated were semi-monocoque, box, and keelson structures.

The first design concept considered was the keelson, which is essentially a panel that runs along the length of the bottom of the fuselage. This panel would have to be quite strong and large in order to transfer and absorb loads effectively, which raised weight concerns. The shape of the fuselage also presented problems with the keelson in that it would have to be curved. Thus the keelson design concept was dismissed.

The semi-monocoque structure uses a cylindrical fuselage reinforced by bulkheads to take both torsion and bending stresses. However, it the semi-monocoque requires the skin of the fuselage to be continuous for shear flow. With the top loading configuration would only work if the loading hatch could be reintegrated with the rest of the structure to transfer loads. Reinforcing the hatch connectors would be difficult to design such that it would not interfere with the pit crews. The semi-monocoque structure was disqualified for this reason.

The box structure consists of side panels connected by several bulkheads to absorb bending stresses. The torsional strength is provided by the payload tray. When the payload tray is elevated several inches from the bottom of the fuselage, it creates a closed loop with the side panels and the skin under the tray. This structure is both compact and efficient in that the payload tray serves multiple purposes. This configuration was deemed to be the best choice overall.

Construction Technique: The most practical possibilities for constructing the payload tray and supporting structure were plywood and foam core carbon composite. It is easier to machine the correct specifications into plywood than it is to form the composite lay-up mold. The composite approach however is lighter and stronger. It is also possible to customize the carbon lay-up to achieve the maximum strength where it is needed. Therefore the composite approach was chosen.

For the skin of the airplane, a similar composite approach was proposed. The skin would be a fiberglass or carbon lay-up over a fuselage shaped mold. The foam would be dissolved away and leave the skin to bond to the bulkheads and side panels.

4.2.3 Wings:

The wings design parameter deals with the general sizing of the wing and associated components as well as construction technique. Wing geometry was chiefly governed by necessary flight characteristics and optimized by RAC concerns while construction methods were based on available tools and skills.

Geometry: The swept planform was selected in the CDP as part of the efficient blended wing configuration. The angle of sweep is important in determining the pitch control of the aircraft as well as the longitudinal stability. Other factors such as taper and twist (aerodynamic/geometric) also contribute to the stability of the aircraft and must be balanced to achieve maximum performance. The final factor to be considered was the lift and pitch characteristics of the fuselage.

The fuselage was determined to be the reflexed Roncz/Marske7 airfoil. The Roncz/Marske7 has a relatively high positive pitch coefficient. Normally the wings of a blended-wing or flying-wing configuration are reflexed for control purposes. The team investigated the possibility of having a more conventional negative pitch wing to balance for the fuselage positive pitch. The advantage to a negative pitch wing is that airfoils with higher lift coefficients may be used, resulting in a smaller wing area. It was not certain if the fuselage would be able to balance out the wing pitch, but the benefits to RAC and construction made this configuration the most promising for the team.

The sweep, taper and twist specifications were iterated using the Wing Analysis program by Hanley Innovations and are covered in the final sizing section.

Lateral Stability: Concerns over side-slipping effects on the aircraft during banked turns were raised due experiences during the previous competition. Dihedral is used to provide stability in these situations. The wings are angled slightly up at the root. When in a banked turn, the dihedral causes the inner wing to be at less of an angle than the outer wing. The inner wing generates more lift, creating a tendency for the aircraft to roll upright. The exact angle required to provide maximum performance is difficult to calculate due to the complexities of the flow during turns. Due to increased stability concerns due to lack of an empennage, dihedral was included in the design.

Another measure taken to ensure stable flight was implementation of both geometric and aerodynamic twist in the wing to prevent stall at the ailerons. The geometric twist serves to reduce the effective angle of attack at the tip, whereas the aerodynamic twist changes the airfoil at the tip to one with better stall characteristics.

Longitudinal Stability: The longitudinal stability is normally controlled by the empennage. In a flying wing or blended wing configuration, the pitch is controlled by the sweep of the wing and the location of the control surfaces on the wing. The team could not accurately determine the dynamic performance characteristics of the design with only 2 aileron control surfaces. It was proposed that a third control surface be included on the fuselage. An elevator on the fuselage could adjust the reflex of the airfoil and thus increase or decrease the pitch without relying on the ailerons. It was decided that this approach would result in more predictable flight characteristics and that the increase in RAC was negligible.

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, initial calculations on the lifting capacity of the wing suggested that the aircraft would have no trouble lifting off in 200 ft. Additionally, the inclusion of flaps would add significantly to the RAC (+6 hrs for 2 flaps +10 hrs for 2 servos).

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.

Construction Technique: The construction techniques determine the internal structure of the wing. The possible methods included a rib structure and a foam core composite structure. The goal was to maximize the strength to weight ratio, while also considering the implications to time and skill management.

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 foam core composite wing holds several advantages over the plywood wing. It was less labor-intensive and was considerably stronger while being comparable in weight. The structure and procedure were established during the development of TLAR II in the 2001 competition. Despite the fact that composite wings are somewhat more expensive than plywood and require specialized tools, the high strength to weight ratio resulted in the decision to use them in the final wing.

4.3 Final Sizing for PDP:

4.3.1 Fuselage:

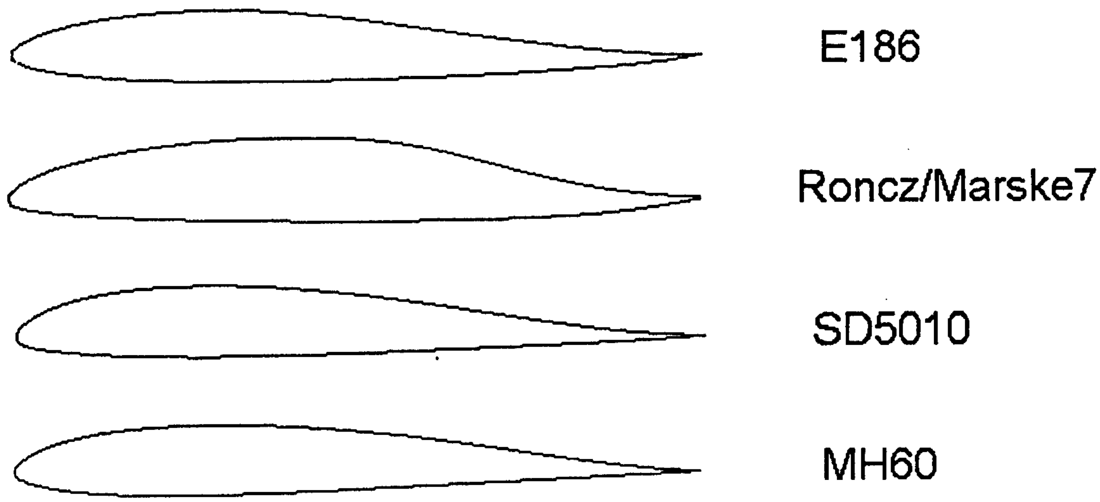


Figure 3 - Best Possible Airfoil Choices

Airfoil	Max Thickness	Max Cl	Max Cd	Cm(c/4)	Stall α	α Cl=0	Length*
E186	0.1027	0.817	0.0127	0.044	10	1.25	50"
Roncz/Marske7	**0.1205**	**0.679**	**0.0087**	**0.005**	**6**	**-0.14**	**40"**
MH60	0.1008	0.996	0.0134	0.026	10	-0.35	48"
S5010	0.098	0.843	0.0069	0.008	9	-0.52	50"

*Length was estimated as the best length required to fit 3 rows of softballs in a horizontal plane

Table 5 - Airfoil Data Calculated at Re=2,000,000

The Roncz/Marske7 was the thickest of the four choices at 12.05%. The fact that the airfoil maintains this approximate thickness along the majority of the chord length allowed for the shortest projected length. The drag was also lower by as much as 54%. The marske7 does not provide nearly as much lift as the other airfoils, however, and it stalls much earlier at 6°, giving the aircraft limited maneuverability (as compared to the 10° stall angles for the E186 and the MH60). In weighing these factors, the team chose to weight thickness and drag over the others. The low lift could easily be compensated for by the wings and the stall angle was judged to be secondary to higher speeds as the flight plan called for low time, not extreme maneuvers.

The final size of the fuselage was determined to be 40" in length, and 16" in width (see table 5). This was based on the 3x4 payload configuration in the thickest part of the Roncz/Marske7 airfoil. The CG of the payload was placed at approximately 14" from the leading edge.

With a chord length of 40" the maximum thickness of the airfoil is 4.82". A softball was measured to be approximately 3.9" in diameter. Based upon these calculations, the payload tray was placed at ¼" above the chord line. With this configuration, the payload tray would have holes cut where the balls would sit. This allowed for more distance from the bottom of the fuselage and thus a larger torsional rigidity.

4.3.2 Wings:

Based upon the estimated dimensions of the fuselage, the moment generated around the quarter chord was calculated using the Wing Analysis program to be 130 in-lb. The wing would have to balance this moment for trim flight. They would also have to provide enough lift to balance the full weight of the plane (minus the lift of the fuselage).

The negative pitch was required to balance the fuselage, which meant that the wings could use conventional high lift airfoils to reduce size. The E214 had worked well in previous years and was analyzed along with the E212 and E211 for the root airfoil. The tip was desired to be a symmetric airfoil for control purposes. The AMES02 was selected as an arbitrary initial airfoil based upon VisualFoil data. Designs were iterated trough the Wing Analysis program varying wing span, taper ratio, root chord, sweep angle, airfoils, and twist. The final design statistics are summarized in Table 6.

	Fuselage	Wing
Speed (mph)	65	65
AOA	3	2
Span (Inches)	**16**	**80**
Sweep (Deg.)/Loc.	0 (c/4)	25 (c/4)
Tip (Inches)	**40**	**14**
Root (Inches)	**40**	**20**
MAC (Inches)	39.9794	17.1778
Tip Airfoil	**RONCZ LOW DRAG**	**NASA/AMES A-02**
Root Airfoil	**RONCZ LOW DRAG**	**E211 (10.96%)**
Planform Area (Sq.Inches)	**640**	**1360.0001**
Taper Ratio	1	0.7
Twist Angle (Degree)	0	0
Tip Reynolds Number	2,021,367	707,478
Root Reynolds Number	2,021,367	1,010,684
MAC Reynolds Number	2,020,328	868,066
Lift Coefficient	0.0176	0.158
Induced Cd	0.0002	0.0033
Profile Cd	0.0044	0.0058
Total Drag Coefficient	0.0047	0.0091
Moment Coefficient	0.069	-0.0712
Lift/Drag	3.7641	17.3445
Total Lift (Pounds)	**0.8439**	**16.1248**
Total Drag (Pounds)	**0.2242**	**0.9297**
Mom. (c/4) (Pounds-Inches)	**132.5**	**-124.9**

Table 6 - Fuselage and Wing Data From Wing Analysis Program

The data provided by the Wing Analysis program allowed preliminary sizing of the fuselage and wings to be balanced through iteration. The areas of focus were the pitching moment, total lift, and lift/drag ratio. In order to balance all the values, an angle of incidence of 1° was created between the wing and the fuselage. Due to the high Cm of the E211 airfoil, it was difficult to lower the pitching moment of the wing to match that of the fuselage. The lift was very favorable at almost exactly what the aircraft was predicted to weigh fully loaded.

In order to place the wing on the fuselage to balance the pitch, a stability margin of .1 was assumed. The exact distance of the neutral point from the C.G. was calculated by multiplying the stability margin by the mean chord of the wing. This gave a distance of 1.7". In order to position the wing so satisfy this criterion, the spar crosses through the fuselage, just ahead of the payload tray. Scale drawings have the back of the spar flush with the front bulkhead supporting the payload tray.

In order to reduce torsion stresses, a pin was designed into the root of the wing approximately 8" behind the spar. This pin would project into the fuselage and transfer the torsion into the side panels of the box structure. This design had been proven in previous competitions.

TLAR II used a 3° dihedral to provide lateral stability. This figure was reached by empirical means. This value was also used for TLAR 3.5.

4.3.3 Control Surfaces:

Typical sizing of a general aviation aileron structure is approximately 25% of the span and 25% of the chord, extending to the outer edge of the wing. This assumes a straight wing configuration with no aerodynamic or geometric twist. The swept wing design would complicate the calculations due to the inclusion of pitch control. However, with the decision to include an elevator on the fuselage, the pitch control problem was eliminated. Therefore the team decided to use the 25% approximations. The resulting ailerons were 24" spanwise and 4.25" long (calculated using mean aerodynamic chord length).

Based upon analysis done on the wings and the fuselage, a third control surface was added to the fuselage to allow for greater pitch control. Unlike the ailerons, the fuselage elevator size was not arrived at by general sizing rules. The VisualFoil component of the Wing Analysis program was used to determine the effect of flap size and deflection on the airfoil aerodynamics. The optimum configuration based upon the effects on stall, pitch and lift was 6"x18". A larger flap would result in a large negative lift, increasing wing loading and structural stresses. A smaller flap would not generate a significant amount of pitch.

4.3.4 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. From efficiency data of Astro and Graupner motors, the Astro motors were eliminated immediately. Upon analysis of the available Graupner motors, the only class that were seen as applicable due to thrust requirements and power available were the Ultra 3300 series. These motors are designed to run off of 20 volts and turn a direct drive propeller.

With the class of motor selected, manufacturer supplied data relating motor current draw to the efficiency, output wattage and RPM was used to determine exactly which 3300 series model would be used. Assuming a maximum current draw of 35 Amps, safely below the 40 Amp limit, the 7 wind series was compared to the 8 wind. At this current level, the efficiency, output wattage and RMP were found to be 81.4%, 565 Watts, and 7000 RPM, respectively, for the 8 wind motor. By contrast, at the same current level, the 7 wind motor gave an efficiency, output wattage and RPM of 83.5%, 650 Watts, and 8300 RPM, respectively. Given the added efficiency and RPM output of the 7 wind model, it was chosen as the motor for the final design.

The propeller choice was made from a decision for a cruise speed of 60 mph, at a current setting below maximum. The Graupner Ultra 3300/7 motor operates most efficiently at a current draw between 23 and 29 Amps. At this setting and RPM, an 18" diameter x 12" pitch propeller gives a speed of approximately 70 mph. This factor of safety will be verified during flight testing to determine if an alternate propeller will be needed. For efficiency during glides and descents, experience gained during last year's competition dictated the use of a thin carbon fiber folding propeller, which is durable, light and has less drag in flight when not powered.

The final step in determining the power system was the choice of batteries. The weight, voltage and current limit was dictated in the rules, so 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 one Graupner 3300/7 motor powered by 20 Sanyo 2400 batteries and turning carbon fiber thin folding props of 18" diameter and 12" pitch.

4.3.5 Landing Gear:

At this stage, more emphasis was placed on general sizing to limit minimize weight and drag. 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: The tricycle landing gear places the two main gear behind the C.G. In previous years, the struts were supported by hard points on the spar. However, this year the spar location was 6.5" ahead of the C.G. at the root of the wing. The landing gear would have to be somewhere near the middle of the wing where the sweep brought the spar back behind the C.G. This would create a large moment arm and unnecessary stresses in the wing structure. The decision was made to locate the main gear at the torsion pin reinforced sections of the fuselage.

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. Due to the difficulty of manufacturing and lack of impact strength, carbon struts were eliminated as a feasible option. Aluminum, despite its reduced weight, would not guarantee the performance requirements needed and was also eliminated. Due to the proven performance of the previous year's struts, a steel piano wire torsional configuration was chosen for the design of the struts. With this design, the majority of the force of the impact of landing would be absorbed by the torsional loading of the piano wire, and would not be directly transferred to the gear block and ultimately the fuselage.

Wheels: For the construction of the wheels, rubber and aluminum were considered. Due to the weight of the rubber and the fact that traction was not a major concern, the front wheels were constructed from aluminum. Due to the fact that the expansion joints in the runway could cause takeoff problems if the front wheels were too small, the wheels were designed to be 4 in. in diameter and ¼ in. in thickness. The front wheel, however, would only absorb approximately 10% of the impact of the landing, so its size could be considerably smaller. For this reason, and to simplify construction, a standard rubber model aircraft wheel of 3" diameter was chosen.

5 Detailed Design Phase

In the detailed design phase (DDP), the aircraft configuration resulting from the Preliminary Design Phase is was analyzed in more detail to optimize the final product. The detailed analysis consisted of final sizing, general performance, and mission performance estimates. Final sizing of the aircraft components was performed to ensure structural integrity and aerodynamic efficiency. General aerodynamic performance was calculated to ensure 200 ft take-off distances and maneuverability. Finally the mission performance was calculated to provide a final score estimate. These calculations were based on estimates of weight and balance, aerodynamics and engine power. The following table outlines the final aircraft dimensions, configuration and properties.

5.1 Final Sizing

The Preliminary Design configuration analysis resulted in general sizes of wings, fuselage, and all other major components. The detailed design phase refined these measurements taking into account the aerodynamic properties of all parts and overall efficiency.

5.1.1 Fuselage

The main goals for the detailed phase fuselage analysis were a reduction of drag and in increase in overall efficiency.

The Preliminary Design fuselage specifications called for a 16" span and a 40" length of the Roncz/Marske7 airfoil. This resulted in a block shape with adverse pressure and vortices at the side panels. The easiest way to eliminate these effects was to create fairing from the fuselage side panel to the wing root. The inner 16" of the fuselage could not be modified due to space restrictions imposed by the payload. Therefore the plane was lengthened spanwise to include room for the fairing. The variables ideally would include fairing size and airfoil interpolation. However the Wing Analysis program would not allow variation of the airfoil at selected positions along the body. The final results are summarized in the table below.

	Fuselage(20in)	Fuselage(16in)
Speed (mph)	65	65
AOA	**2**	**2**
Span (Inches)	20	16
Sweep (Deg.)/Loc.	0 (c/4)	0 (c/4)
Tip (Inches)	40	40
Root (Inches)	40	40
MAC (Inches)	40.0	40.0
Tip Airfoil	RONCZ/Marske7	RONCZ/Marske7
Root Airfoil	RONCZ/Marske7	RONCZ/Marske7
Planform Area (Sq.Inches)	800	640
Taper Ratio	1	1
Twist Angle (Degree)	0	0
Tip Reynolds Number	2,011,714	2,011,714
Root Reynolds Number	2,011,714	2,011,714
MAC Reynolds Number	2,010,680	2,010,680
Lift Coefficient	0.0058	0.0047
Induced Cd	0	0
Profile Cd	0.0044	0.0044
Total Drag Coefficient	0.0044	0.0044
Moment Coefficient	0.069	0.070
Lift/Drag	**1.30**	**1.08**
Total Lift (Pounds)	**0.34**	**0.23**
Total Drag (Pounds)	0.26	0.21
Mom. (c/4) (Pounds-Inches)	**165.6**	**133.1**

Table 7 - Wing Analysis Summary for Fuselage

A 2" fairing on either side of the fuselage was estimated to be optimum. The lift/drag ratio was increased by 20%. A linear interpolation between the Roncz/Marske7 and the E211 was the most feasible option in terms of construction. Despite the fact that the program could not directly analyze this case it was predicted that there would not be a significant change in results.

5.1.2 Wings

The wing calculations were reanalyzed based upon the detailed fuselage parameters. The wings are required to balance the pitch of the fuselage in order to maintain trim flight. The efficiency of the wings was also analyzed and modifications made to allow for the lowest power consumption and the fastest possible speeds. Stall was also introduced as a variable in the calculations.

In the Preliminary Design Phase the wings incorporated sweep and aerodynamic twist to provide sufficient control of the aircraft. The new fuselage specifications dictated that the wing parameters be adjusted to insure stability. Tip stall was also a concern as the chord of the wing was 70% of the root chord, causing a lower Reynolds number and a lower stall angle. The design parameters were input into the Wing Analysis program and the final results are summarized below.

	Prelim Wings	Final Wings
Speed (mph)	65	65
AOA	**2**	**2**
Span (Inches)	80	80
Sweep (Deg.)/Loc.	25 (c/4)	25 (c/4)
Tip (Inches)	14	14
Root (Inches)	20	20
MAC (Inches)	17.1778	17.2
Tip Airfoil	NASA/AMES A-02	NASA/AMES A-02
Root Airfoil	E211 (10.96%)	E211 (10.96%)
Planform Area (Sq.Inches)	1360.0001	1360
Taper Ratio	0.7	0.7
Twist Angle (Degree)	0	-2
Tip Reynolds Number	707,478	704,100
Root Reynolds Number	1,010,684	1,005,857
MAC Reynolds Number	868,066	863,921
Lift Coefficient	0.158	0.1569
Induced Cd	0.0033	0.0033
Profile Cd	0.0058	0.0064
Total Drag Coefficient	0.0091	0.0097
Moment Coefficient	-0.0712	-0.089
Lift/Drag	**17.3445**	**16.22**
Total Lift (Pounds)	**16.1248**	**15.92**
Total Drag (Pounds)	0.9297	0.98
Mom. (c/4) (Pounds-Inches)	**-124.9**	**-155.3**

Table 8 - Wing Analysis data for Wings

In order to delay tip stall, a geometric twist angle of -2° was introduced. The pitching moment was increased to keep pace with the fuselage. These figures were used in the final performance analysis and for the final configuration of the aircraft.

5.1.3 Final Configuration Aerodynamic Data

The wings and fuselage were both iterated in the Wing Analysis program to create static equilibrium. The next stage was an angle of attack analysis for the final configuration. Thus far the majority of the calculations had been restricted to trim flight. Varying the angle of attack allows for more accurate mission performance analysis.

The primary concern of the team throughout the initial design processes has been pitch control. The moment diagrams were plotted by the Wing Analysis program and are summarized in the figures below.

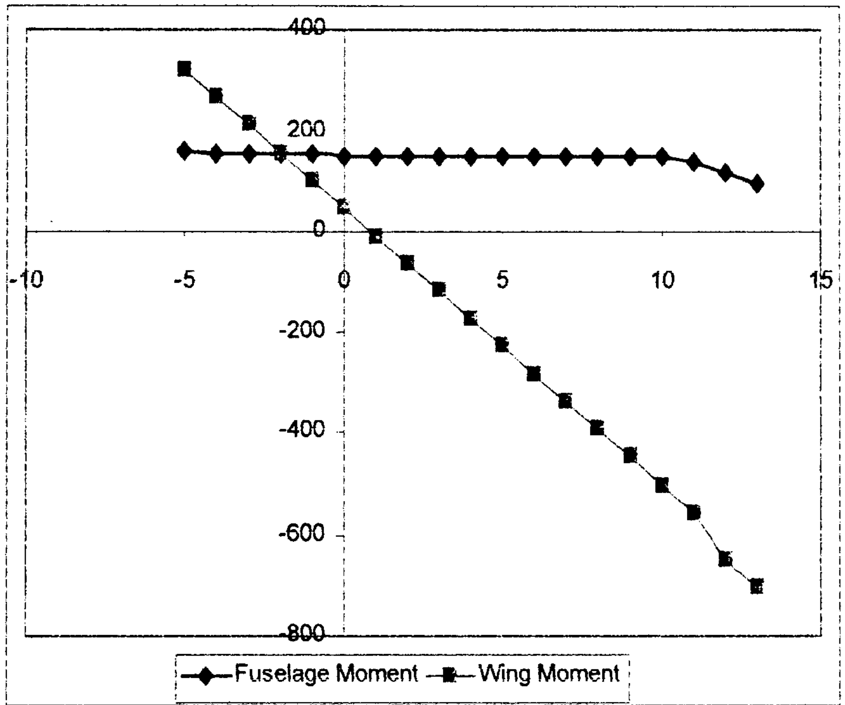


Figure 4 - Wing and Fuselage Moments (in-lb) vs. AOA

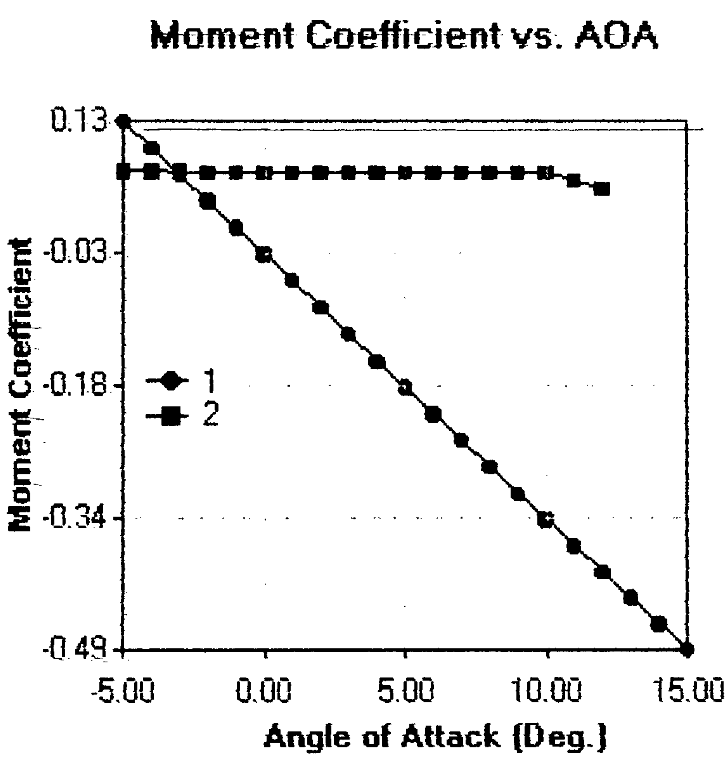


Figure 5 – Fuselage and Wing Moment Coefficients vs. AOA

The plots show clearly that the aircraft has a tendency to remain within a narrow angle of attack range. As the aircraft pitches downward, the wingtips experience a negative lift due to their near symmetrical nature. Therefore the wing structure has an overall positive moment. As the aircraft pitches upward, the wings increase their negative moment, tending to return to trim flight. While this effect was desired in the design process, it potentially limits maneuverability.

Stall characteristic analysis was also performed on the final configuration. The characteristics were derived from lift and induced angle vs. AOA plots.

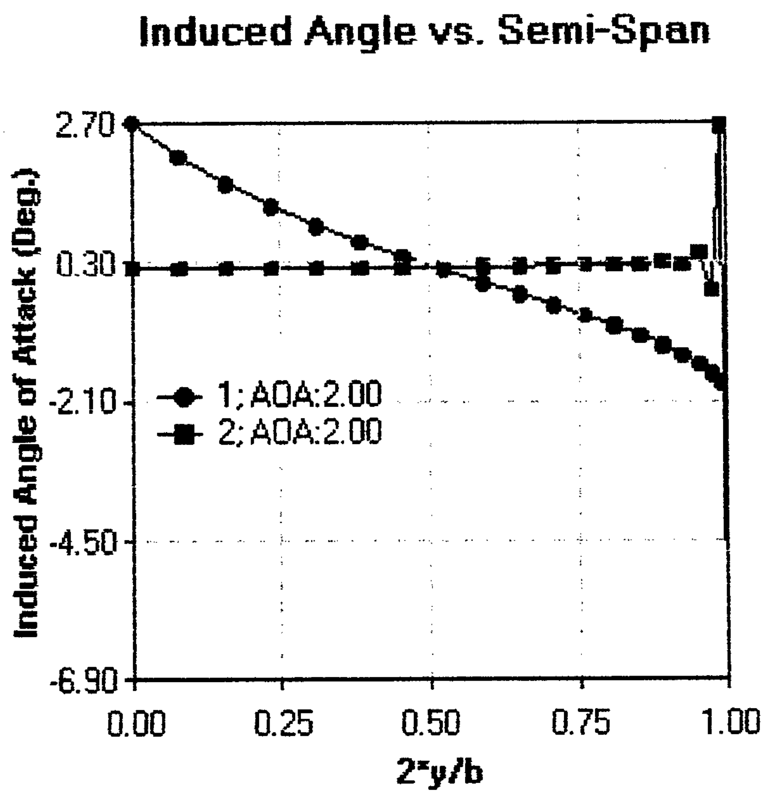


Figure 6 - Induced AOA (Wings-1, Fuselage-2)

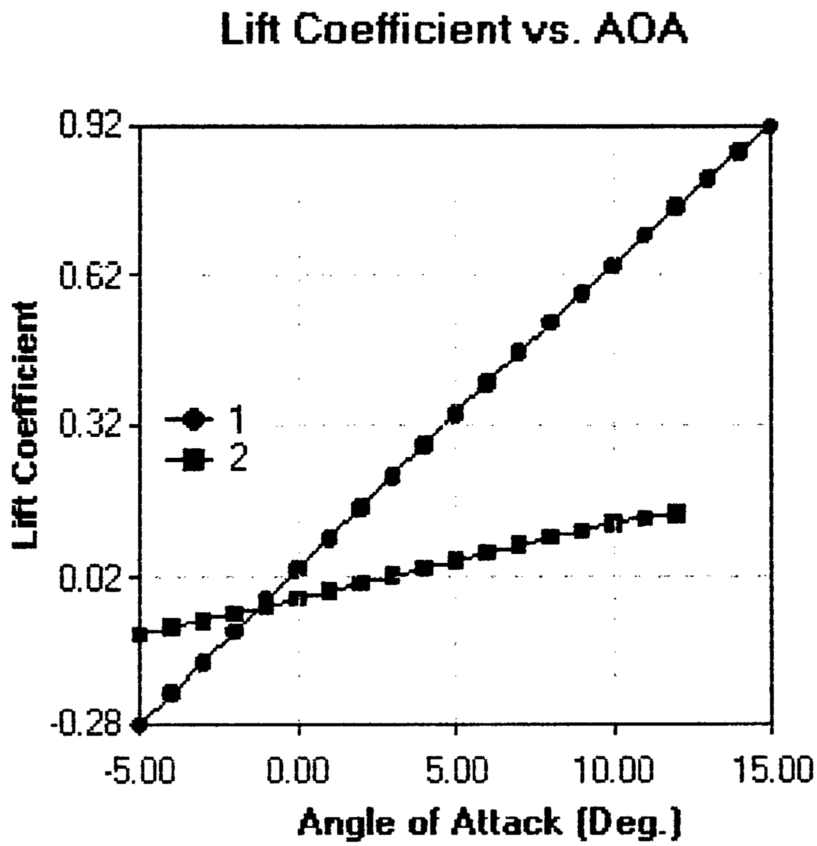


Figure 7 - Cl vs. AOA(Wings-1, Fuselage-2)

C_L versus AOA can be seen in figure 7 and shows that the fuselage clearly stalls before the Wings. From figure 6 the wing tips have a slight downward force in level flight, and the lift can easily be changed to provide roll or pitch control.

The final plots were used to determine the optimum level flight angle of attack. Minimum drag occurs at approximately 3°, which also closely agrees with the trim flight calculations in the final sizing section.

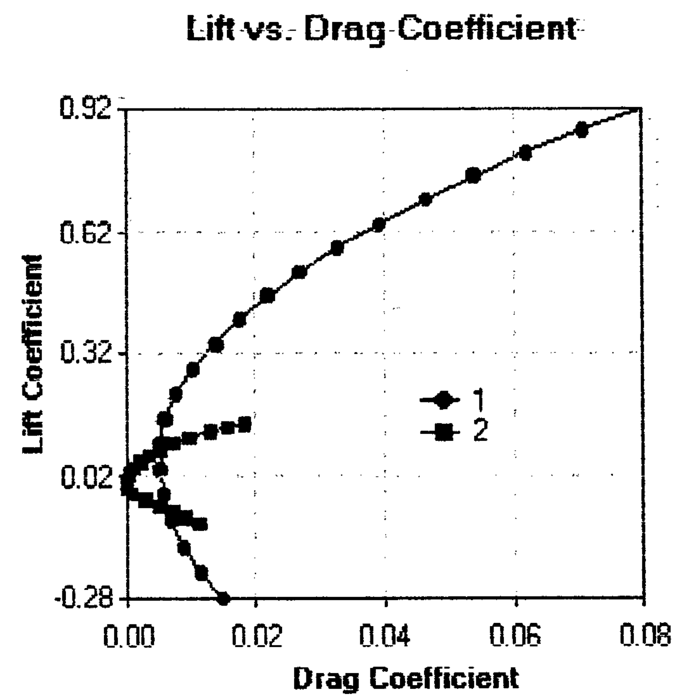


Figure 8 - CL vs CD (Wings-1, Fuselage-2)

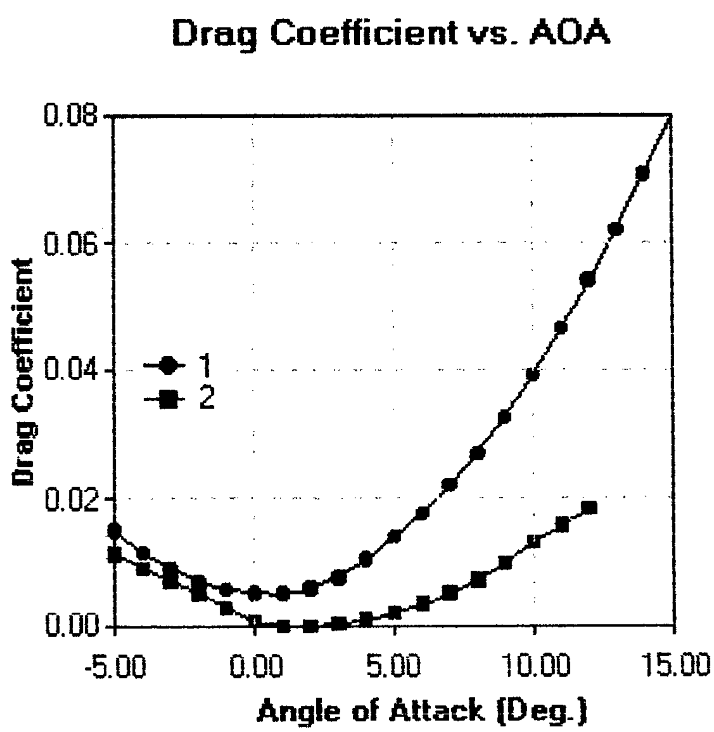


Figure 9 - Cd vs. AOA (Wings-1, Fuselage-2)

5.2 Performance

In the performance calculations it is necessary for the aircraft to remain within its structural and aerodynamic limits. When the aircraft experiences accelerations, the loading of the aircraft changes, this is referred to as the load factor, n. In order for the plane to be gaining altitude, the lift must greater than the weight of the plane, so using the equation, L = n*W, where n is the load factor, gives a lift greater than the weight. As the lift increases the forces and moments experienced in the aircraft also increase, so at certain load factor, the forces are too great and some component of the structure will fail.

The spar, as the backbone of the wings, is subject to load factors more than any other component. Due to the sweep, twist and taper of the spar, it was decided that the finite element (FE) method would be the most accurate analysis method. This was due to the complex coupling effects of bending and torsion under various load conditions. A FE model of the spar was made with the Pre/Post Processor FEMAP and analyzed using MSC/Nastran. It was determined, with a factor of safety of 1.5 and the fact that the wing skins and torsion pin are not included, that the spar could withstand a 3g loading with full payload and fuel. In the performance calculations, the climb rate and turn radius will both be limited by this load factor of 3. A summary of the results in the following sections can be viewed in Table 9 below.

Aircraft Performance	
Cruise Speed	60 mph
Takeoff Distance	112 ft
Climb Rate	764 ft/min
Turn Radius	99.7 ft
Endurance (Average Current)	5.6 minutes
Stall Speed	44 ft/s
Rated Aircraft Cost	**7.995**

Table 9 - Aircraft Performance Summary

5.2.1 Takeoff Distance

The takeoff distance allowed is less than 200ft; however, since time is a large factor in the flight score, the takeoff distance desired is much less than 200ft, since the distance is directly related to aircraft speed. It was determined for takeoff that the rotate/stall speed needed was **43.75 ft/s**, while the actual takeoff speed was **48.1 ft/s**. In order to approximate takeoff distance using an integration of Newton's second law over the ground run of the aircraft, the induced drag was assumed negligible. This integration of the acceleration can be reduced to the following equations from reference 1:

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

Using the takeoff speed and the equation below from reference 1 where S_G is the ground roll and K_T and K_A are thrust terms and aerodynamic terms respectively, the takeoff distance was calculated.

$$S_G = \left(\frac{1}{2gK_A}\right)\ln\left(\frac{K_T + K_A V_f^2}{K_T + K_A V_i^2}\right) \text{ where,}$$

$$K_T = \left(\frac{T}{W}\right) - \mu \quad \text{, and } K_A = \frac{\rho}{2(W/S)}\left(\mu C_L - C_{D_O} - KC_L^2\right)$$

A ground roll of **102 ft** was calculated for a rolling resistance factor (μ) of 0.05 and a total takeoff distance of **112 ft** with a rotate factor. This is well within the takeoff constraint and the likelihood of winds being present during the competition will shorten the actual takeoff distance.

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) 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 **764 ft/min**.

5.2.3 Turning Radius

The turn radius calculations began with the assumption that the turn will be made at the cruise speed of 60-mph.

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

This equation gave a load factor of 3 for the turn. From this, and geometry, a bank angle of 70 degrees and turn radius value of **99.7 ft** was calculated.

5.2.4 Estimated Mission Performance

Endurance characteristics are essential performance indicators for an aircraft designed to participate in timed, limited fuel flight mission. The range figure of TLAR 3.5 was based on the power available and the power that the flight profile will require, so that a determination of the number of sorties possible can be made.

The power available is the number of cells multiplied by the power rating for each cell. This equated to 1 battery pack multiplied by 2300 milliAmp-hours for at total of 2.3 Amp-hours. This allows **3.45 minutes** of flight time at the maximum current setting of 40 Amps, which subsequently gave a cruise range of **3.5 miles**.

While this flight time was less than the flight period, an Excel spreadsheet was used to determine the detailed flight plan and current setting breakdown for the entire mission profile, with gliding and powered back cruises to be ample for the completion the mission. The average current draw during the mission was calculated to be **24.7 amps**, which allows for a mission flight time of **5.6 minutes**.

Using an Excel worksheet, the estimated time to complete one mission was **4.85 minutes**. From this time and a payload of 12 softballs, the final mission score will be **3.7**.

The following table shows the RAC calculations.

Rated Aircraft Cost (RAC) = (A * MEW + B * REP + C * MFHR) / 1000 = 7.9952

Manufacturers Empty Weight Multiplier (MEW)				A = $	100
Total Weight w/o payload =	12	lbs			
				MEW =	11.6
Rated Engine Power (REP)				B = $	1500
# of engines =	1				
Battery Weight =	2.6	lbs			
				REP =	2.6
Manufacturing Man Hours (MFHR = SUM(WBS))				C = $	20/hour
WBS 1.0 Wings					
Wing Span =	8.3	ft	8hr/ft		
Max Chord =	1.7	ft	8hr/ft		
# of Control Surfaces =	3	c.s	3hr/c.s		
				WBS 1.0 =	88.76 hr
WBS 2.0 Fuselage					
Fuselage Length =	3.3	ft	10hr/ft		
				WBS 2.0 =	33 hr
WBS 3.0 Empenage					
# of Vertical Surfaces =	0	v.s	5hr/v.s		
# of Vertical Surfaces w/ =	0	v.s	10hr/v.s		
# of Horizont Surfaces w/ =	0	h.s	10hr/h.s		
				WBS 3.0 =	0 hr
WBS 4.0 Flight System					
# Servo or Motor Contro =	3	ser	5hr/ser		
				WBS 4.0 =	15 hr
WBS 5.0 Propulsion Systems					
# of engines =	1	Eng	5hr/eng		
# of props =	1	Prop	5hr/prop		
				WBS 5.0 =	10 hr
				MFHR =	146.76
				RAC =	7.995

Table 10 - Rated Aircraft Cost

Using the RAC above, equation for the competition score shown below, the paper score from last year's competition and the competition scoring equation shown below, a final competition score of **120** was estimated.

Flight Score Equation: Flight Score = (Total Laps Flown + Total Balls Carried) / Time

3.717 = (6+12)/4.84

Competition Score: SCORE = (Paper Score * Flight Score) / RAC

120 = (86 * 3 * 3.717)/ 7.995

5.3 Static Stability

The calculations focused on determining the exact placement of aircraft CG and attaining a good Stability Margin. 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.

$$x_N = \frac{l_r}{4} + \frac{2b}{3\pi} \cdot \tan\phi_{c/4}, \quad for\ taper\ ratio \geq 0.375$$

The neutral point was determined to be at **2 inches** behind the CG. From this and the following equation, the Stability Margin, σ, was calculated to be 0.1.

$$\sigma = \frac{x_N - x_{CG}}{c_{mac}}$$

Table 11 calculates the center of gravity of the aircraft from the weights of the components and their location in the plane. The aircraft is symmetric across the centerline, so there is no moment. The calculation of the moment around the y-axis (parallel to wingspan) was not important, so it was calculated.

Total Length (in)	40		
Item Name	Item Weight (oz)	Arm (in)	Moment (in-oz)
Main Wing	40	20	800
Fuselage Shell	32.88	15	493.2
Fuselage Spar Support	10	8	80
Main Landing Gear (x2)	16	20	320
Nose Gear Structure	5	3	15
Engine (x1)	21.12	4	84.48
Battery Packs (x1)	45	15	675
Propeller (x1)	8	1	8
Wiring Harness	2	18	36
Speed Controller	6	4	24
Receiver	1.65	22	36.3
Main Wing Servos (x2)	2	22	44
Elevator Servo	1	35	35
S-Ball Payload	80	14.00	1120
S-Ball Payload Tie-Downs	0	14.00	0
Empty	0	14.00	0
Total Weight S-Ball Payload	270.65 Oz		3770.98 in-oz
Total Weight No Payload	190.65 Oz		2650.98 in-oz
	Heavy Payload		No Payload
MEW	9.1Lb		9.1lb
Gross T/O Weight	16.9Lb		11.9lb
CG from Nose	**13.93In**		**13.90in**
Distance of CG ahead of Xn	2.0In		2.0in

Table 11 - Weight and Balance

5.4 Systems Architecture

The Systems Architecture describes the electrical components used to fly the aircraft including the batteries, servos, receivers, and handset. The type of motors, batteries, receiver and handset used in the aircraft are shown in table 12.

Given the values obtained for the torque required by each servo, the HS-545BB servo, capable of 62-73 $^{oz}/_{in}$ of torque manufactured by Hitec RCD Inc. was chosen for the elevons, and elevator.

Systems Architecture	
Motor	Graupner Ultra 3300/7
Servos	HS-225MG
Batteries	Sanyo 2400
Receiver	HPD-07RB (PCM)
Handset	Prism 7X (PCM)

Table 12 - Systems Architecture

6 Drawing Package

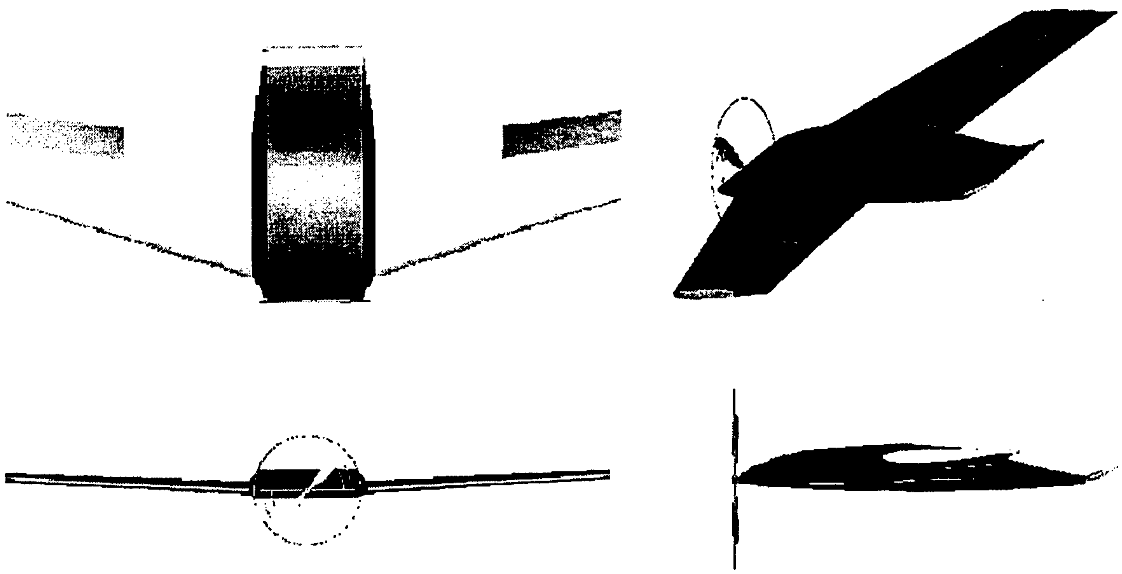


Figure 10 - Three View of Aircraft

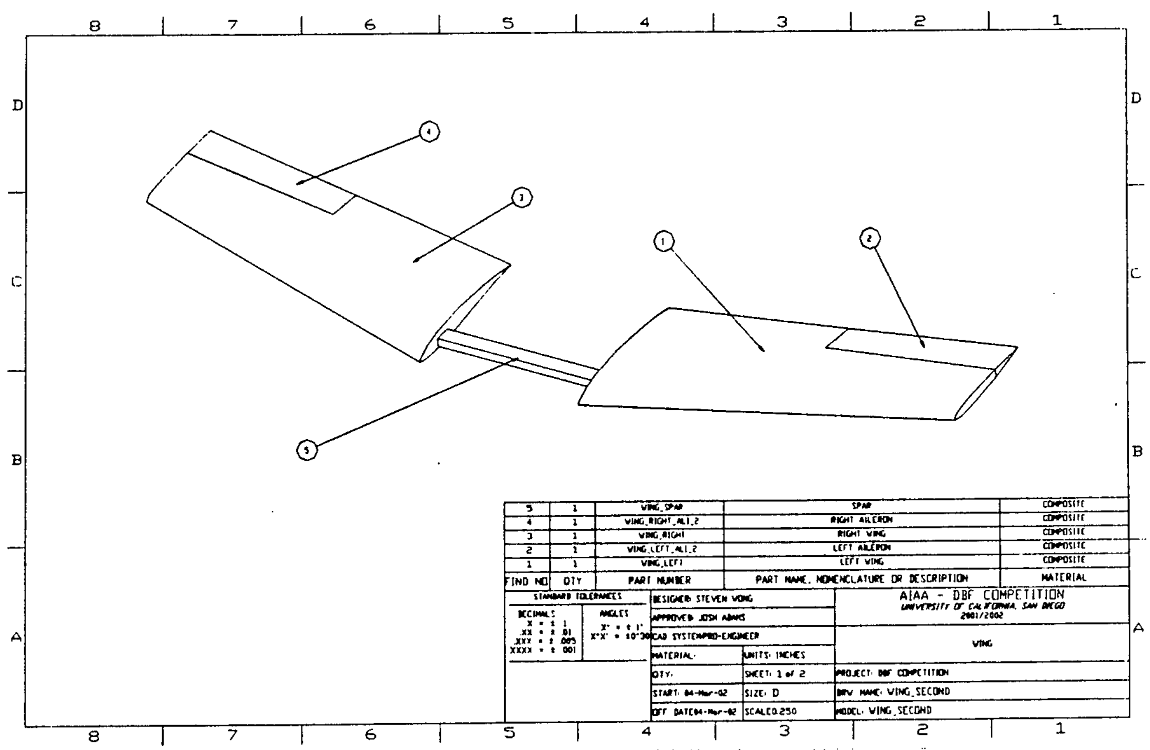


Figure 11 - Wing Assembly Isometric View

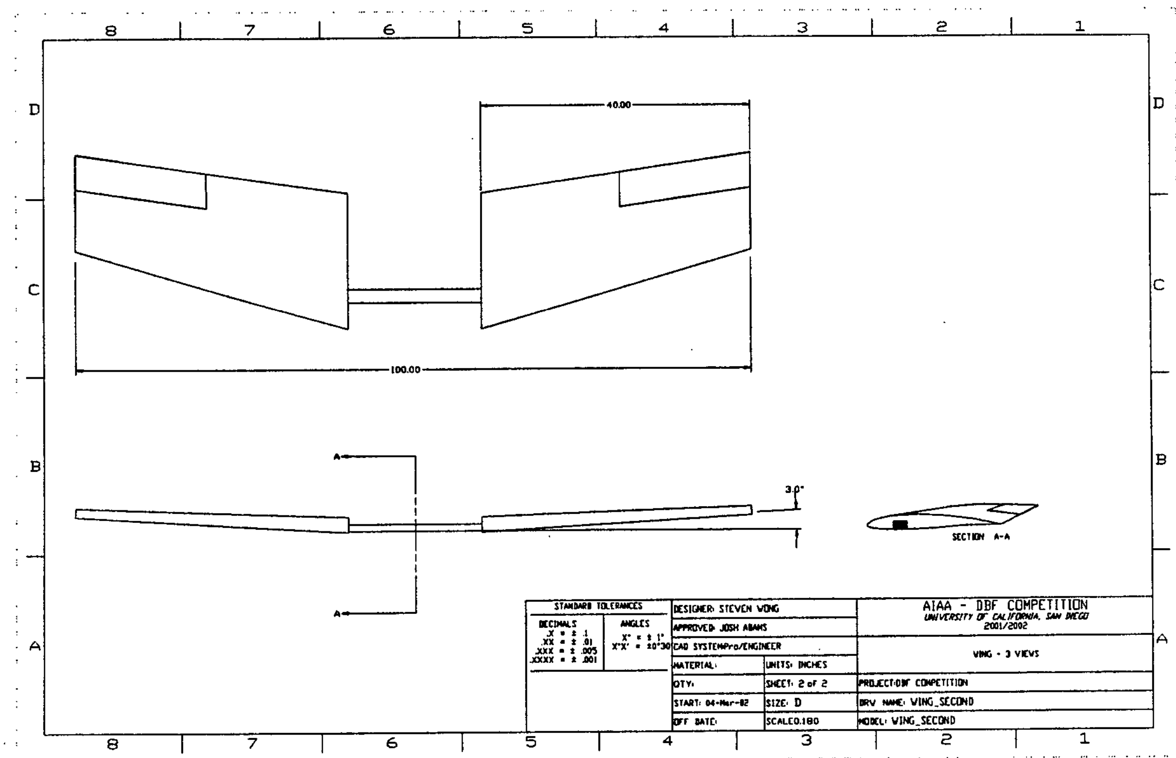


Figure 12 - Wing Assembly

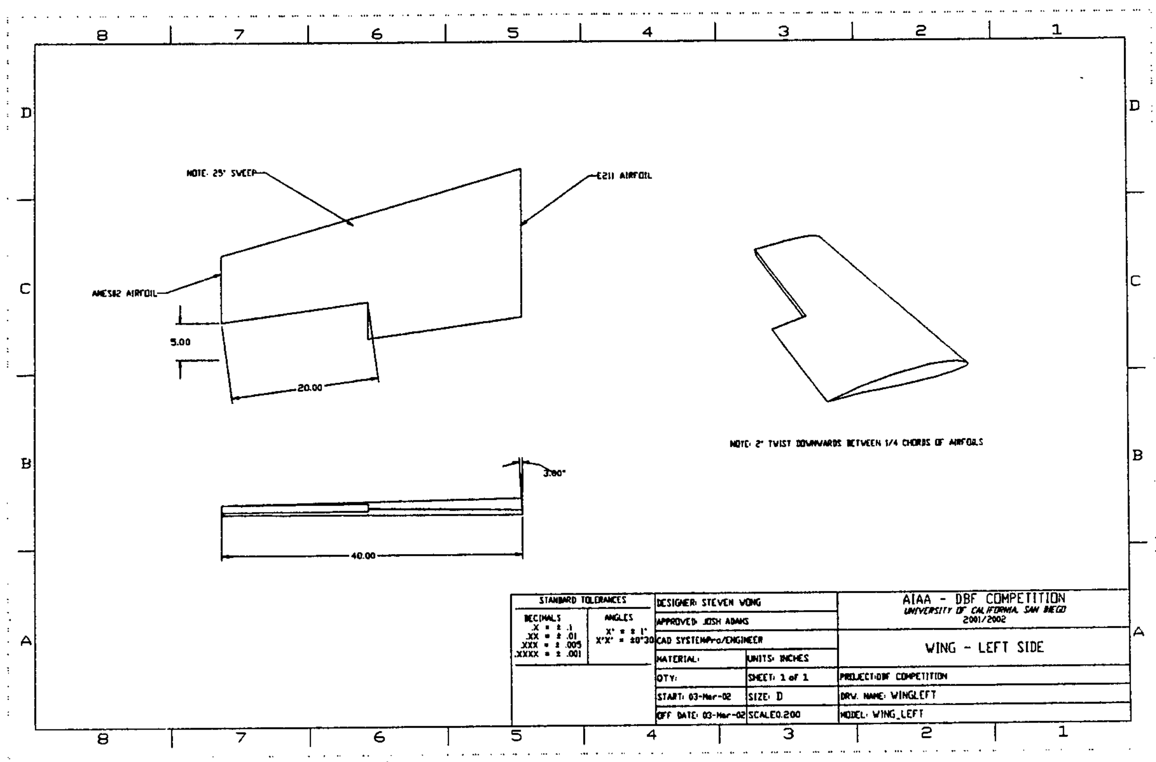


Figure 13 - Wing Detailed View

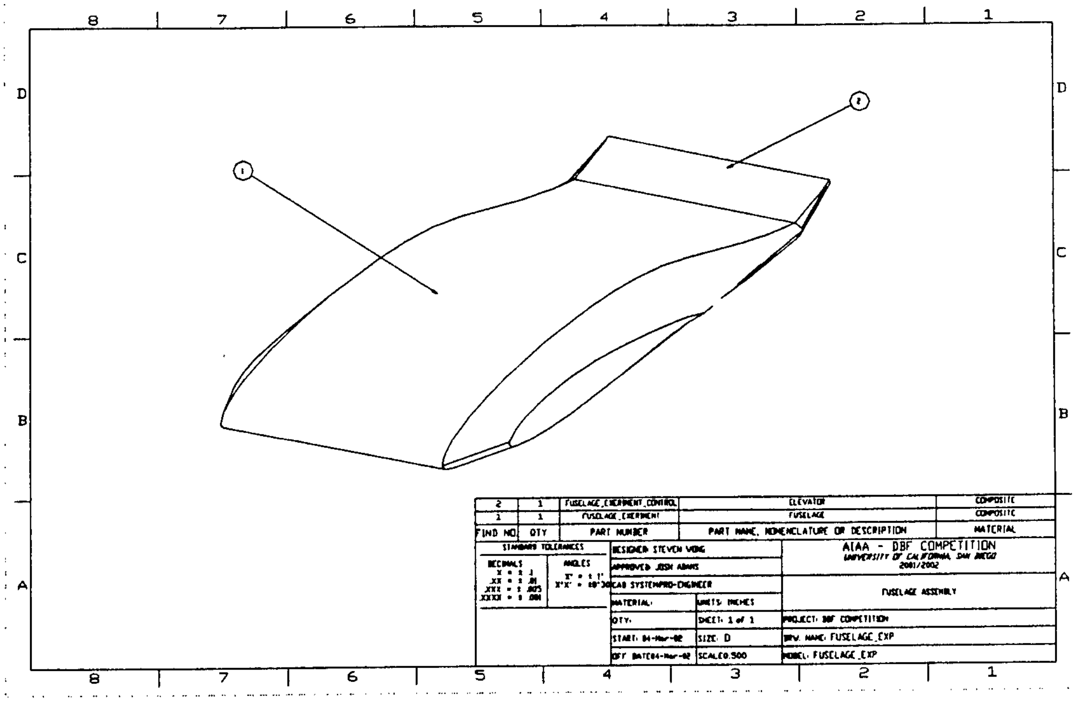


Figure 14 - Fuselage Isometric

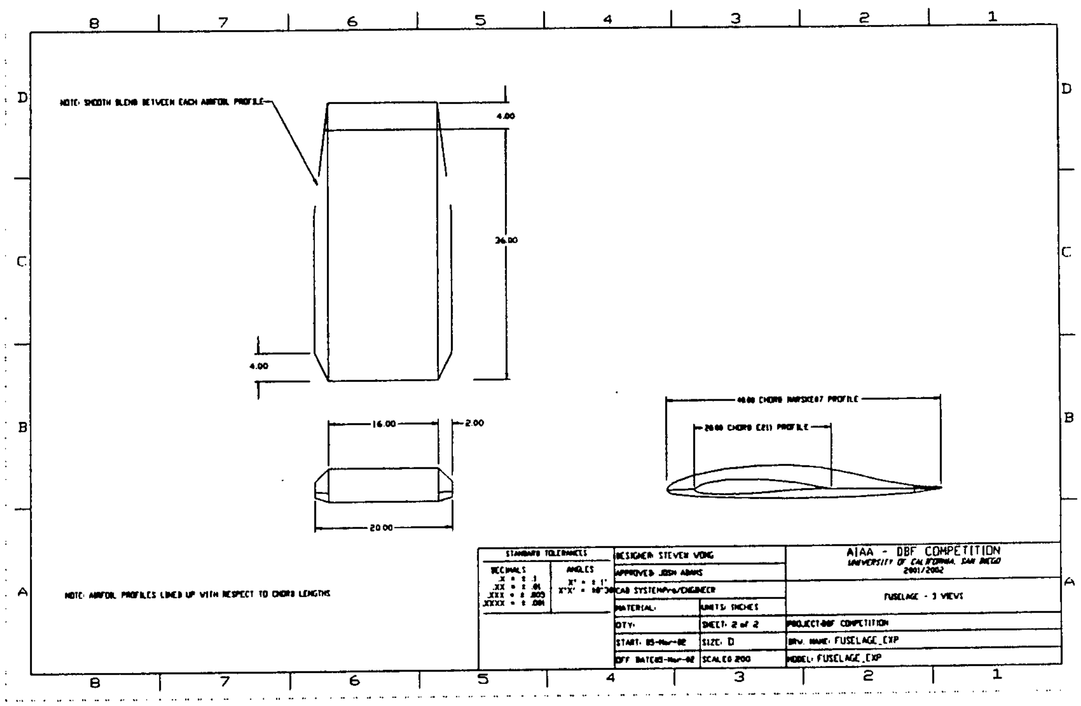


Figure 15 - Fuselage Detailed View

7 Manufacturing

		Strength to Weight Ratio	Cost	Complexity	Time Requirements	Durability	Total
		x3	x2	x2	x1	x1	
Spar	Plywood I-Beam	2	2	1	1	3	16
	Carbon Foam Core	**2**	**1**	**2**	**2**	**3**	**17**
Wings	Plywood Rib	1	2	0	0	2	9
	Foam Core Composite	**2**	**1**	**2**	**2**	**3**	**17**
	Hollow Composite	2	1	2	1	3	16
Fuselage	Plywood	1	2	1	1	2	12
	Foam Core Composite	**2**	**1**	**1**	**1**	**3**	**14**
Landing Gear	**Steel Piano Wire**	**2**	**2**	**2**	**2**	**3**	**19**
	Carbon Composite	2	1	1	1	2	13

Table 13 - Construction Technique Figures of Merit (scale 0-3)

7.1 Figures of Merit

The figures of merit for construction focused mainly on the ability of the team to complete the project rather than performance. As a result, only one of the FOMs affects RAC and flight scores in any way. The others are geared towards the team's supplies of manpower, expertise, and money.

7.1.1 Strength to Weight Ratio

The strength to weight ratio of the aircraft structure is of primary concern as weight affects almost all of the aircraft's flight characteristics. It is also important for the structure to support the loading that occurs during landings and high G turns. This factor was given a weight of x3 to reflect its impact on many aspects of the design process.

7.1.2 Cost

The team had a limited budget to work off of so the price of materials was a large factor to consider. Foam core composites perform exceptionally well but the cost of carbon/fiberglass, epoxy, and foam can be several times that of conventional wood or metal. This FOM was given a weight of x2 to reflect the significance of keeping costs down so that the team would have funds left to get to the competition.

7.1.3 Complexity

The Complexity FOM covers both team skill/experience level and tool availability. The team has limited access to machine shops and scheduling time is problematic. Since the project participation is voluntary, work is restricted to those times in which members can meet. This is often during the evenings when campus facilities are not available. Therefore any construction technique that requires extensive use of machinery or power tools would not receive a favorable rating.

Individual construction experience varies from person to person. Many of the competition veterans have had experience with TLAR I and TLAR II and the methods used in them. Therefore those manufacturing processes that are most similar to previous years would get a higher rating.

This FOM was weighted at x2 due to the impact of team experience on the project. The team consults with, but is not directed by, more experienced and trained engineers. Therefore the limit of the teams experience is general indication of the limit of the project.

7.1.4 Time Requirements

The time requirements are important for a number of reasons, which include part retries, construction flexibility, and flight testing changes.

Part retries involves remaking parts that have been incorrectly constructed or that have been damaged. If a part requires intensive labor over a long period, it is not as feasible as a readily replaced part. Therefore a higher rating goes to the technique which is faster.

Construction flexibility describes the need to make small adjustments during the construction/assembly of the aircraft. The team builds everything by hand and thus has very generous tolerances. Parts which cannot be modified readily to fit are not advantageous.

The flight testing changes are those large scale changes which might need to be made following the first few flights of the aircraft. Higher scores go to the construction technique that allows for easy modification or replacement.

7.1.5 Durability

Durability is a less important FOM that the others to a certain extent. The parts do need to withstand several flights and also assembly and transportation. However, they only need to last for a few months until the competition is over. Higher scores go to the methods that can endure multiple flight test and competition sorties without structural failure or threat of structural failure.

7.2 Manufacturing Overview

7.2.1 Wings and Spar

Since the wings are the most important component of an aircraft, the decision was made to build the wings and spar first. All other parts would be built around the wing structure. A foam core composite was selected as the technique to be used in construction as the team had extensive experience with it. It also judged to be the best method to maintain accuracy in the wing specifications.

Airfoil templates will be made from formica (due to its low thermal conductivity and ease of shaping) for the upper and lower surfaces of the wing. The templates will account for the taper, aerodynamic twist, and geometric twist of the wing. A hot wire cutter will be used to cut the core of the wing from low-density EPS foam. The spar core will be cut from the wing core as a straight beam at the quarter chord. An extra section will be cut and added to the spar to account for the fuselage pass through.

The spar will be laid up with a single layer 14K tow uni-directional carbon caps to stiffen it in bending. Then it will be wrapped in single layer 12K bi-directional carbon at 45° to account for torsion loads. The layers at the root of the wing will be doubled for added strength.

Before the wing is glassed over, the ailerons are cut and shaped, and the servo mounts are installed. The wiring channels are also cut before glassing occurs. When the wing is prepared, the leading edges and trailing edges are epoxied to the spar and a single layer of fiberglass oriented at 45° is laid up over the entire structure.

7.2.2 Fuselage

The fuselage will be constructed around the wings once they have been completed. Again, foam core composite was selected as the preferable construction technique. It allows for accuracy and strength while not sacrificing weight.

The bulkheads, side panels and payload tray will all be cut and shaped from 1/8" low-density foam sheets. They will be covered in bi-directional carbon and reinforced with 14K tow uni-directional carbon. When set, they will be bonded together around the wing assembly. The 2" fairing between the side panel and the wing root will be cut from the same foam and bonded between the two structures. Holes will be drilled for wiring and to reduce unnecessary weight. A hard point will be constructed in each fairing for the landing gear. The skin will be made of fiberglass laid up over a foam mock-up of the fuselage. The foam will be removed when the epoxy has set and the skin will be bonded to the bulkheads and fairing. Hatches will be cut into the top skin to allow access to the motor and the payload. The fuselage elevator will be made in the same manner as the ailerons.

7.2.3 Landing Gear

The landing gear, unlike the other components, will not be made from composites. This is due to the fact that composites are complex and time consuming. In previous years, landing gear needed to be replaced several times. It would not be feasible to replace composite landing gear.

The landing gear struts will be made out of 1/8" steel piano wire. The wire can be bent using pliers and a vice grip making them easy to modify and to replace should they break. The wheels will be store bought inline skate wheels machined to reduce weight and to conform to the piano wire. Simple store bought EM brakes will also be installed. The struts will fit into the hard points in the fuselage fairing and be secured by plastics tabs and nylon bolts.

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
Tape/Paint/Glue/Other consumables	$ 100.00	1		$ 100.00
Graupner 3300/7 Electric Motors	$ 300.00	1	Motor	$ 300.00
HS-545BB	$ 35.00	3	Servos	$ 105.00
Recievers	$ 75.00	1	Reciever	$ 75.00
Sanyo 2400 Batteries	$ 2.00	40	Battery	$ 80.00
Hysteris Brakes	$ 25.00	2	Brake	$ 50.00
Axel/Wheels/Bearings/Nose Strut	$ 45.00	1		$ 45.00
Expendable Tools	$ 125.00	1		$ 125.00
Piano Wire	$ 10.00	3	Landing Gear	$ 30.00
Softball	$ 5.00	12	Payload	$ 60.00
Total				**$ 1,265.00**

Table 14 - Cost Summary

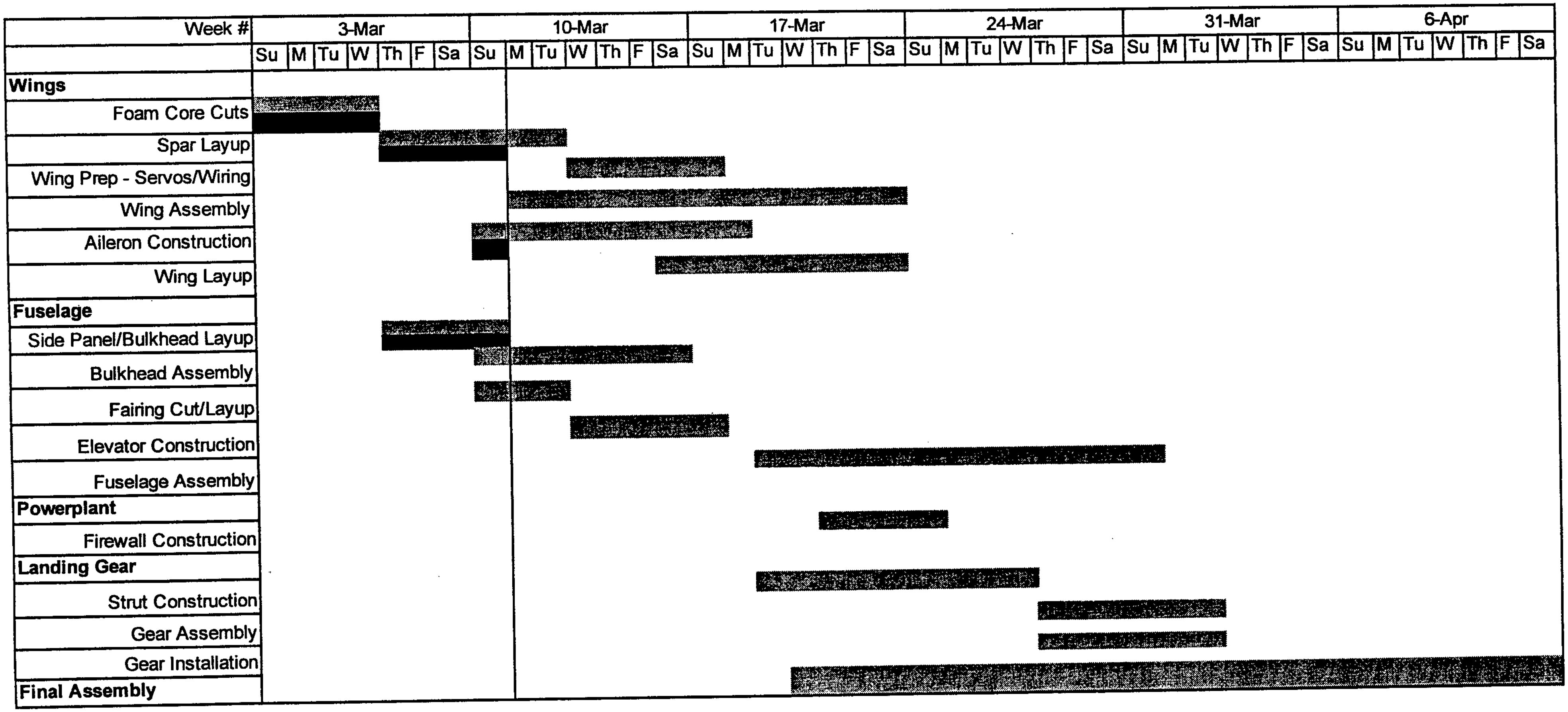


Table 15 - Manufacturing Milestone Chart

8 References:

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