DESIGN BUILD FLY

By

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Aerospace Engineering

STATEMENT BY AUTHOR

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1.0 EXECUTIVE SUMMARY

This report details the entire design process of the University of Arizona's Design/Build/Fly team in preparation for the 2008-2009 AIAA/Cessna/Raytheon Design/Build/Fly Competition. In order to prepare for the competition, the team designed, manufactured, and tested an unmanned surveillance/attack aircraft capable of satisfying all requirements set by the competition rules. The main objective of this project was to maximize the total score received at the competition and produce a stable and controllable aircraft. This involved designing an aircraft and a box to house the aircraft's parts to the lightest weight possible. In addition, the time of payload loading and assembly of the plane factors into the score. Because of this, the payload systems and sections of the aircraft were designed to be easily and quickly assembled. The most important competition constraints were a 100 foot runway, the full 4 liter water bottle and 4 Estes Rocket payloads, and the two 4x2x2 foot boxes for the plane and its support materials. These constraints defined the power required from a motor, a large wing loading, and set the maximum dimensions of the assembled aircraft.

Payload integration and overall design of the aircraft was the first consideration during the design phase. Various aircraft designs were considered including a biplane, flying wing, duel fuselage, and standard configuration. Next, the form of propulsion system was considered and the benefits of a puller, pusher, and duel propellers were weighed. Finally, tail configurations such as a conventional tail, T-tail, twin tail, and V-tail were also considered.

The final preliminary design of the aircraft has a single fuselage, single puller propeller aircraft with a twin boom, T-tail configuration. The single fuselage and twin booms decreased the overall aircraft weight and the T-tail allowed for elevator controllability when the water bottle payload was creating a wake. Also, the overall aircraft configuration allowed for ease of control, manufacturing, and payload integration. The aircraft's fuselage, wing, and empennage were constructed out of balsa wood and hardwoods such as ply wood and bass wood. Carbon fiber tubing was used as wing spars and as the twin booms for the tails. The airfoil shape of the fuselage was built to decrease drag and allow for better wing integration.

A more detailed design resulted from weight optimization, sizing parameters, wing optimization, stability and control calculations, and structural analysis. Computer programs such as SolidWorks, Matlab, Datcom+, XFLR5, and Motocalc helped optimize all parameters of design. Airfoil optimization resulted in a NACA 4415 airfoil due to its soft stall characteristics and flat bottom optimal for construction and payload integration. With an overall empty weight of 12 lbs and a fully loaded weight of 25 lbs, the aircraft's thrust to weight ratio to take off in 100 feet was 0.281. A proper motor and speed controller were fitted to the aircraft to allow for optimum battery life and to provide sufficient power. With a maximum battery life between 15 and 20 minutes, the aircraft should successfully complete every mission of the competition without losing battery power. The Rated Aircraft Cost (RAC) of this aircraft was estimated to be 42.753 lbs.

2.0 MANAGEMENT SUMMARY

2.1 *Team Member Organization*

The team is composed of six aerospace engineering seniors. Each student was the lead on a specific aspect of the design as outline below. All students worked on all aspects of the design, collaborating to determine the final parameters due to the small size of the team. Figure 2.1a shows the breakdown of responsibilities of the team members.

- **Tyler Ebbitt** is the chief aerodynamicist. His responsibilities included airfoil selection, wing optimization, and simulation utilizing XLFR 5. He calculates the stability parameters and determines aircraft stability.

- **Laura Lund** is the team leader. She is in charge of the procurement and manufacturing phase of the project. She quantifies material requirements, orders parts, and coordinates the manufacturing process.

- **Krystine Nelson** is the chief drafter, modeling the aircraft in *SolidWorks*. *SolidWorks* is a computer aided design program with the ability to specify construction materials to predict the strength and durability of the structure. Additionally, the *SolidWorks* model depicts a dimensionally-correct visual model of the aircraft with accurate mass moment distributions.

- **Justin Novacek** is the propulsion engineer, leading the research and design of the electric propulsion system. His responsibilities include the batteries, motors, and propellers of the aircraft. He utilizes *MotoCalc,* a computer software program which analyzes remote control aircraft electric propulsion systems.

- **Regina Reed** is the team organizer. Her duties include coordinating group meetings, organizing the drafting of the report, design configuration matrices, and reporting on the specific mission profiles and rule changes.

- **Jessica Wittner** leads the store and payload configuration design. She is responsible for the deployment of the Patriot missile and Nalgene bottle stores, while insuring the project rules are upheld.

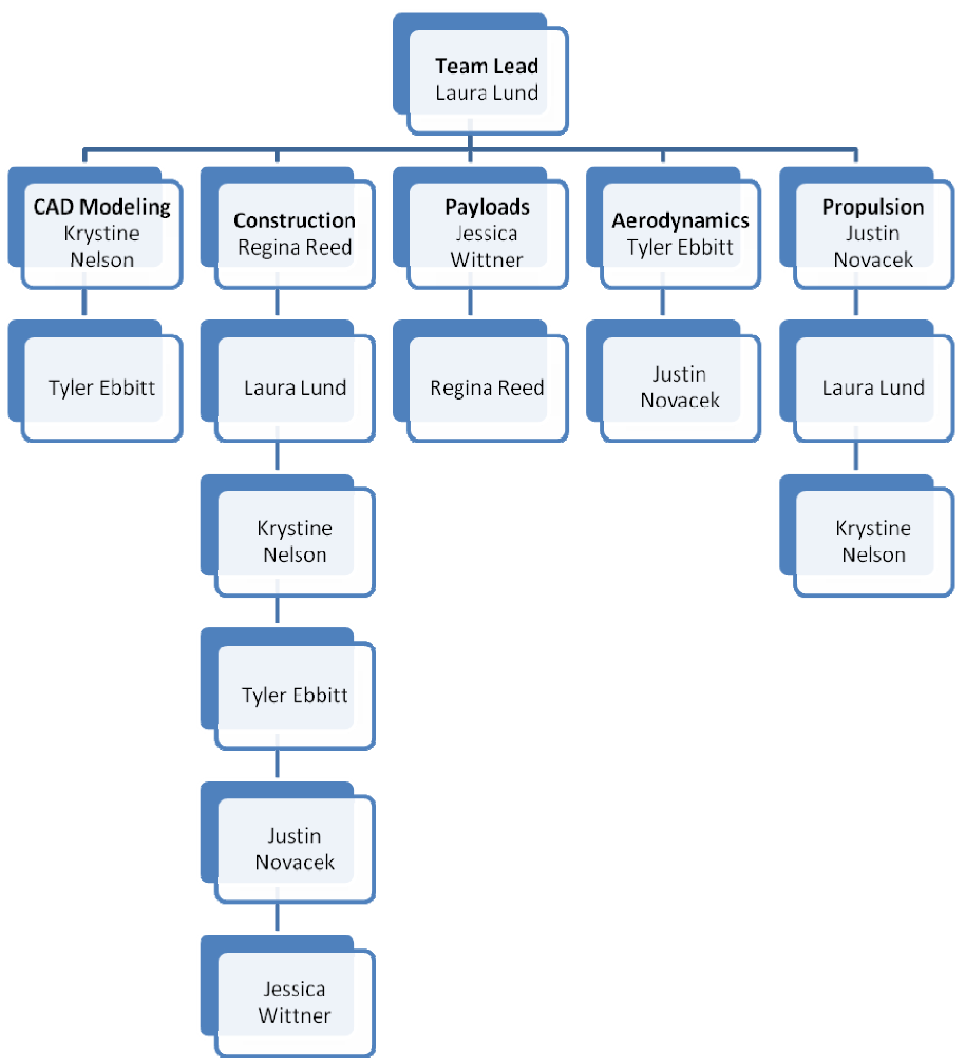


Fig 2.1a Organizational Chart for U of A DBF Team

2.2 *Schedule*

Below, Figure 2.2a shows the anticipated schedule for the design project.

ID	Task Name	Duration	Start	Finish	% Complete
0	**AIAA DBF 2008-2009**	**143 days**	**Mon 10/6/08**	**Fri 4/17/09**	**69%**
1	**Administrative Tasks**	**19 days**	**Mon 10/6/08**	**Thu 10/30/08**	**100%**
2	Determine Team Name	18 days	Mon 10/6/08	Wed 10/29/08	100%
3	Fill out registration form	1 day	Thu 10/30/08	Thu 10/30/08	100%
4	Submit registration form	0 days	Thu 10/30/08	Thu 10/30/08	100%
5	Submit preliminary financial aid request	0 days	Mon 10/6/08	Mon 10/6/08	100%
6	**Design Phase**	**61 days**	**Mon 10/6/08**	**Sun 12/28/08**	**100%**
7	**Conceptual Design**	**30 days**	**Mon 10/6/08**	**Fri 11/14/08**	**100%**
8	Rules finalized	0 days	Fri 10/31/08	Fri 10/31/08	100%
9	Refine rules through questions to judges	30 days	Mon 10/6/08	Fri 11/14/08	100%
10	Define requirements	8 days	Mon 10/6/08	Wed 10/15/08	100%
11	Research different airplane configurations	6 days	Thu 10/16/08	Thu 10/23/08	100%
12	Complete design configuration matrices	1 day	Thu 10/23/08	Thu 10/23/08	100%
13	First design configuration	0 days	Thu 10/23/08	Thu 10/23/08	100%
14	Investigate validity of phase 1 design	7 days	Fri 10/24/08	Mon 11/3/08	100%
15	Meet with Tucson AIAA Members	0 days	Mon 11/3/08	Mon 11/3/08	100%
16	Second design configuration	0 days	Mon 11/3/08	Mon 11/3/08	100%
17	**Preliminary Design**	**20 days**	**Tue 11/4/08**	**Mon 12/1/08**	**100%**
18	Weight Estimation	3 wks	Tue 11/4/08	Mon 11/24/08	100%
19	Wing Sizing	3 wks	Tue 11/4/08	Mon 11/24/08	100%
20	Thrust requirement calculations	2 wks	Tue 11/4/08	Mon 11/17/08	100%
21	Power and propulsion system design	2 wks	Tue 11/18/08	Mon 12/1/08	100%
22	Landing gear design	2 wks	Tue 11/4/08	Mon 11/17/08	100%
23	Airfoil selection	3 wks	Tue 11/4/08	Mon 11/24/08	100%
24	Initial store and release mechanism design	3 wks	Tue 11/4/08	Mon 11/24/08	100%
25	**Detailed Design**	**20 days**	**Tue 12/2/08**	**Sun 12/28/08**	**100%**
26	**Propulsion optimization**	**15 days**	**Tue 12/2/08**	**Mon 12/22/08**	**100%**
27	Motor optimization	1 wk	Tue 12/2/08	Mon 12/8/08	100%
28	Propeller optimization	1 wk	Tue 12/9/08	Mon 12/15/08	100%
29	Battery optimization	1 wk	Tue 12/16/08	Mon 12/22/08	100%
30	Stability and control calculations	4 wks	Tue 12/2/08	Sun 12/28/08	100%
31	Empennage sizing	4 wks	Tue 12/2/08	Sun 12/28/08	100%
32	Control surface sizing	4 wks	Tue 12/2/08	Sun 12/28/08	100%
33	Design finalized	0 days	Sun 12/28/08	Sun 12/28/08	100%
34	**Design Report**	**110 days**	**Mon 10/6/08**	**Tue 3/3/09**	**100%**
35	Compile design information	48 days	Mon 10/6/08	Wed 12/10/08	100%
36	Write class design report	33 days	Mon 10/27/08	Wed 12/10/08	100%
37	Preliminary design report due	0 days	Wed 12/10/08	Wed 12/10/08	100%
38	Write competition design report	36 days	Tue 1/13/09	Tue 3/3/09	100%
39	Report due	0 days	Tue 3/3/09	Tue 3/3/09	100%
40	**Manufacturing**	**79 days**	**Thu 1/1/09**	**Fri 4/17/09**	**26%**
41	Material procurement	37 days	Thu 1/1/09	Wed 2/18/09	60%
42	Wing construction	46 days	Thu 1/1/09	Tue 3/3/09	20%
43	Fuselage construction	41 days	Tue 1/6/09	Fri 2/27/09	20%
44	Propulsion and servo wiring	34 days	Tue 1/13/09	Fri 2/27/09	30%
45	Re-work	33 days	Wed 3/4/09	Fri 4/17/09	0%
46	**Testing**	**60 days**	**Mon 1/26/09**	**Fri 4/17/09**	**23%**
47	Component testing	27 days	Mon 1/26/09	Tue 3/3/09	50%
48	Flight testing	33 days	Wed 3/4/09	Fri 4/17/09	0%
49	Competition Date	0 days	Fri 4/17/09	Fri 4/17/09	0%

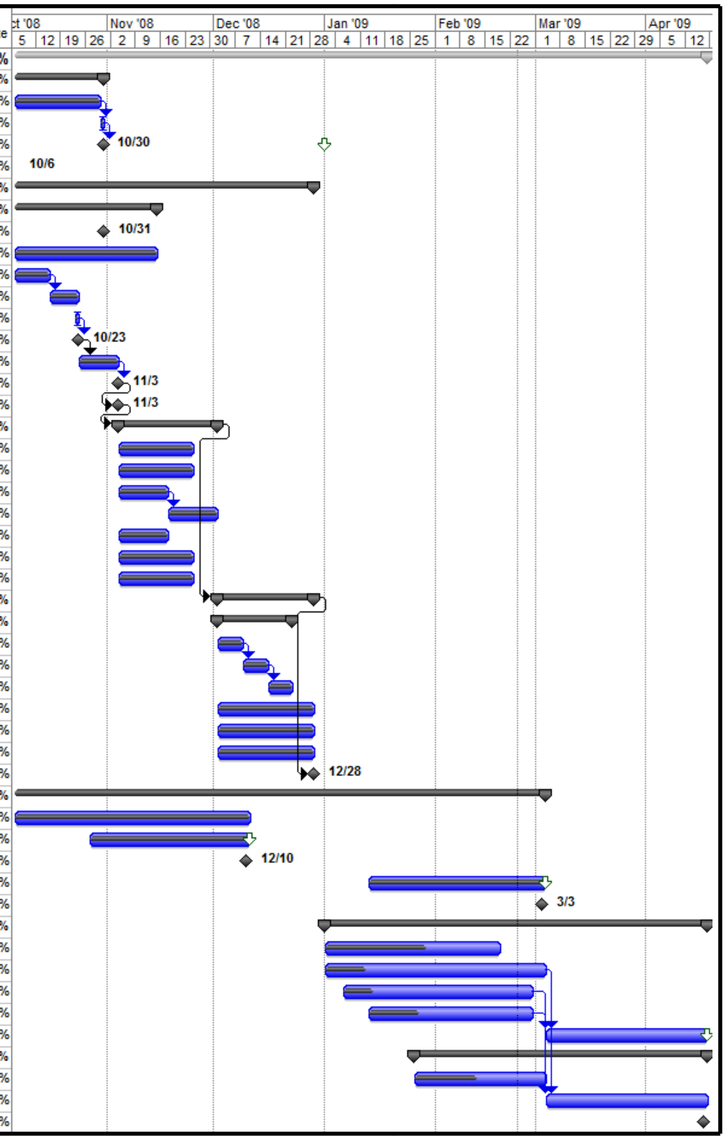


Figure 2.2a Schedule

Figure 2.2b Schedule Legend

2.3 *Budget*

Table 2.3a below outlines the budget for airplane construction. The team is currently working with its sponsors to raise the necessary funds. Also, the team will be reusing supplies from last year so not all necessary items need to be purchased.

Table 2.3a Projected Budget for Design Project

Aircraft Items	Cost	Quantity	Total Price
Motor	$500	1	$500
Motor Mount	$20	1	$20
Motor Heat Sink	$20	1	$20
Fuselage	$60	1	$60
Wing	$80	1	$80
Tail	$30	1	$30
Landing Gear	$250	1	$250
Propeller	$12	4	$48
Propeller Shaft Adapter	$7	2	$14
Aircraft Skin	$25	1	$25
Carbon Fiber Spars	$25	2	$50
Misc.	$100	1	$100

Electronics	Cost	Quantity	Total Price
Remote Control	$250	1	$250
Receiver	$100	1	$100
Speed Controller	$175	1	$175
Servos	$30	2	$60
Batteries for Motor	$20	7	$140
Batteries for Servo	$10	2	$20

Payloads and Safety	Cost	Quantity	Total Price
Fuses	$3	10	$30
Fuse Box	$10	1	$10

Misc	Cost	Quantity	Total Price
Competition Box	$50	1	$50
Estes Missiles	$14	4	$54

Total: $1,586

3.0 CONCEPTUAL DESIGN

3.1 Summary of Mission Requirements

Before any progress could be made in the conceptual, preliminary, and design phases, it was necessary to clearly understand the complete set of rules for the Design-Build-Fly Competition.

3.1.1 Pre-Mission: Assembly

For the pre-mission, the boxes used to store the plane will be turned end over end and dropped from a height of six inches. The contents inside the boxes must not be damaged or shifted in any way. Team members are then timed in the assembly of the plane and scored accordingly.

Scores for the remainder of the mission will be based upon the following:

System Complexity Factor = $$SCF = \frac{1}{AssemblyTime * RAC}$$

where *RAC = Rated Aircraft Cost = Total system weight = weight of the fully packaged boxes* (including tools, batteries included, ground station, payloads loaded to full capacity, and pylons).

It must be noted that SCF is carried throughout each of the remaining missions' scores, and so it is important to maximize this factor as much as possible.

3.1.2 Mission 1: Ferry Flight

During Ferry Flight, the plane must be carrying the four liter water-bottle payload and fly for a total of two complete laps. The water bottle will be empty for this mission. Figure 3.1.2a is a picture of this centerline store. The mission ends when the airplane has completed 2 laps and crosses the finish line in the air. In order for the mission to be scored, the airplane must land on the runway when the mission is complete. This mission is timed.

Figure 3.1.2a Four Liter Nalgene Centerline Store

Scores will be based upon the following equation for this mission:

Score = SCF/Flight Time

3.1.3 Mission 2: Surveillance Flight

The surveillance flight requires the plane to carry the four liter water-bottle payload and fly for a total of four complete laps. The water bottle must be filled completely with water, adding a payload weight of 8.8 lbs to the airplane during the mission. This mission is not timed, but in order for mission to be scored, the airplane must, again, land on the runway.

Scores will be based upon the following equation for this mission:

Score = SCF

3.1.4 Mission 3: Store Release/ Asymmetric Loads

For this final mission, four Estes Patriot Rockets must be attached to the wings via pylons, two on each side. The water bottle store is removed for this flight. See Figure 3.1.4a for an example of the Patriot Rocket payload. Before this mission begins, the team is scored based on how fast the four stores can be attached to the plane and all equipment returned to its box. After this timed pre-mission, the aircraft undergoes a “shake” test to make sure all stores are secure. The flight attempt is fortified if any stores fall off during this test. During the flight mission, the plane will complete a total of four laps, landing in between each lap to drop a rocket in a designated drop zone, and then taking off again. The order of release will be determined at the competition immediately before the mission. The airplane does not need to come to a complete stop when dropping the stores, but it must come to a complete stop before taking off again. After the final lap, the aircraft must have a successful landing on the runway in order for the mission to be scored.

Figure 3.1.4a Estes Patriot Rocket Payload

Scores will be based upon the following equation for this mission:

Score = SCF/Loading Time

3.1.5 Overall Scoring

The overall score for the entire competition is based upon the following formula:

Final Score = Report Score x Total Flight Score

where *Total Flight Score* is the sum of all scores from each mission. Each mission score will be normalized across all aircraft that successfully complete each mission. Partial missions will not be scored. Maximum scores for each mission are broken down as follows:

	Maximum Score
Mission 1	**50**
Mission 2	**75**
Mission 3	**100**

3.1.6 Flight Course

The flight course will adjusted based upon the wind conditions the day of the competition. The flight course is shown Figure 3.1.6a below.

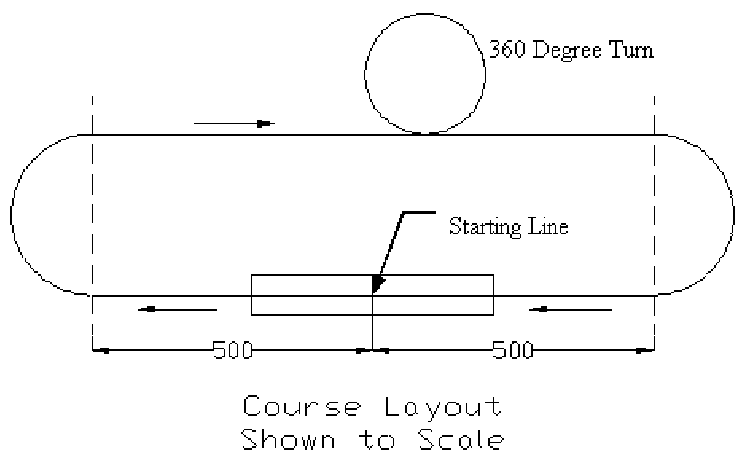


Figure 3.1.6a Scale Diagram of the Competition Flight Course

3.1.7 General Requirements

Beyond the requirements set forth for each mission, additional criteria were considered for the aircraft. These are listed below.

- Aircraft and all support equipment must fit in no more than two *2 ft x 2 ft x 4 ft* boxes
- The boxes will be dropped from a height of 6 inches and turned end over end to be sure that all equipment and pieces of the aircraft are secure
- Aircraft must take off in 100 feet

- Aircraft must support multiple store combinations.
- All stores must be able to be released remotely/individually.
- Wing stores must have at least 6 inch spanwise separation between store centerlines. Innermost wing store location must be at least 24" outboard from aircraft centerline
- The batteries meant for the propulsion system must not weigh more than 4 pounds
- The aircraft must be electrically powered
- The motor is limited to a 40 amp continuous current draw through use of an external fuse

3.2 Conceptual Design Analysis

To begin our conceptual design analysis, we decided to implement a simple ranking system for which we could determine the best overall configuration for a specific aircraft system. We first decided upon the parameters for which each configuration would be ranked. Some parameters were weighed more heavily than others based upon its importance to our mission. These parameters were as follows:

- *Aircraft Empty Weight* – The aircraft empty weight is extremely important because our final competition score is based heavily upon total aircraft weight. Since the payload weight is fixed, a lighter aircraft design is preferable.

- *Take-Off Distance* – Our take-off distance is fixed to 100 feet so the faster that we can generate enough lift for the aircraft to take-off, the better.

- *Stability* – A simple design is preferable since it will simplify our stability calculations. We also need a design that will be stable enough to counteract any environmental factors that we may face, such as wind gusts.

- *Controllability* – The aircraft design must be such that control surfaces can adequately cancel out any moments created from asymmetric wing loading during the last mission.

- *Payload Integration* – The aircraft design must allow for the payload loading configuration defined in the DBF rules. We must also be able to release all stores remotely.

- *CG Control* – we must be able to control and stabilize the aircraft during any CG shift due to payload release during the mission. A configuration that minimizes this shift is preferable.

- *Ease of Loading* – Mission three's final score depends heavily on the loading time of the payload stores. A configuration which allows for uncomplicated and fast loading is preferable.

- *Ease of Implementation* – We must consider that an uncomplicated design allows for simpler construction later in the process.
- *Drag* – a configuration that minimizes the total drag on the airplane will allow for faster flight speeds. The total score in the first mission is weighed heavily upon the total flight time so the faster and more aerodynamic the aircraft is, the better.

- *RAC* – This is the total weight of the entire system packaged inside our two boxes. The less gear and other things we need to support the aircraft, the higher our total score will be. This is closely tied to the complexity of the final aircraft design.

- *Thrust* – We must choose a configuration that allows for maximum thrust.

- *Weight Distribution* –ensure CG location for stability when the aircraft is both loaded and empty. It is also necessary to ensure that the CG shift is minimized as stores are released Care must be taken to minimize the change in the moments of intertia.

- *Endurance* – the propulsion/battery configuration must be one such that we can sustain flight long enough (within some safety margin) to complete our longest mission.

After choosing a neutral configuration as a baseline, we ranked the other configuration's parameters a one if it exceeded the requirements for our mission, a zero if it just satisfied them, and a negative one if it did not met the requirements. We then added them up and the configuration with the highest score was chosen for our preliminary design. This process was used for determining not only our overall aircraft configuration, but also our empennage design and propulsion/battery configurations.

3.2.1 Overall Aircraft Configuration

Based on the mission requirements, we used an Airplane Design Configuration Matrix to determine the optimum configuration. It was necessary to rate each Figure of Merit based on importance. Because our final competition score is dependent on the weight and take-off distance of the airplane, they were chosen as the most important factors in our design. A lower empty weight is necessary in order to decrease our overall weight and allow for more battery time. Also, it was important to create a design that would allow for a maximum take-off distance of 100 feet when fully loaded. Payload integration was also an important factor due to the different types of payloads necessary for the competition, and so it was rated second important. Stability was also rated with a second highest importance due to the changing load distributions presented by the missions. Following that, the Center of Gravity Control was considered to be of reasonable importance due to the uneven payload distributions between missions. The Ease of Loading factors was also rated equally to the Center of Gravity Control due to considerations of our assembly time, which is important to the score. We deemed Drag and Ease of Implementation as lowest importance, as they should be comparable across the configurations and are almost an afterthought compared to the importance of the other parameters. Figure 3.2.1a show the Airplane configuration design matrix used to chose the optimal aircraft configuration.

Based on these weighted parameters, the boom configuration scored the highest and thus became our design of choice. This design scored positively or neutrally in all categories except for CG control, which can be adjusted by quality design, the placement of components, and use of the control surfaces to trim the plane in flight.

						
	Importance	Conventional	Dual Fuselage	Flying Wing	Bi-Plane	Boom
Stability	0.15	0	1	-1	0	0
Payload Integration	0.15	0	1	1	-1	0
Drag	0.05	0	-1	1	-1	1
Empty Weight	0.2	0	-1	1	-1	1
T.O. Distance	0.2	0	0	0	1	0
CG Control	0.1	0	-1	-1	1	-1
Ease of Loading	0.1	0	1	-1	-1	1
Ease of Implementation	0.05	0	-1	-1	-1	0
Total	**1.00**	**0**	**0**	**0**	**-0.25**	**0.25**

Figure 3.2.1a Airplane Configuration Design Matrix

3.2.2 Propulsion Configuration

In analyzing the propulsion configurations, we first looked at the motor and battery configuration and then compared propeller configurations. We compared the layouts using a weighted method as in 3.2.1 for the plane design.

Motor and Battery Configuration

For the motor and battery configuration, we compared different combinations of motors and batteries in singles and in sets of two. We used the properties of Rated Aircraft Cost, Thrust, Ease of Implementation, Weight Distribution, and Endurance to make our comparisons. Figure 3.2.2a shows the matrix used to optimize the motor and battery.

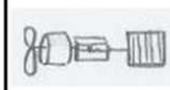
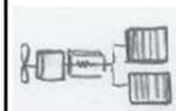
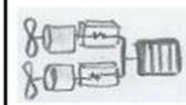
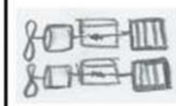
	Importance	 Single Motor, Single Battery	 Single Motor, Double Battery	 Double Motor, Single Battery	 Double Motor, Double Battery
RAC	0.35	0	0	-1	-1
Thrust	0.2	0	0	1	1
Ease of Implementation	0.15	0	-1	-1	-1
Weight Distribution	0.15	0	1	1	1
Endurance	0.15	0	0	-1	0
Total	**1.00**	**0**	**0**	**-0.3**	**-0.15**

Figure 3.2.2a Motor and Battery Configuration Matrix

We rated the importance of the properties by considering weight to be the most important design factor. Second most important was the thrust, as we knew we needed a considerable amount to carry our payload. The ease of implementation, weight distribution, and endurance we rated equally as they were all of similar and fairly high importance. From the matrix, we determined the single motor, single battery configuration would be the best, due to its comparatively high score and its simplicity over the other options. When rating the configurations, we determined that two batteries together would equal the weight of a single battery.

Propeller Configuration

The propeller configuration was analyzed in a similar fashion to the motor and battery configuration. We chose four of the most common propeller designs to compare and rated them on properties including Takeoff Rotation, Weight Distribution, Ease of Implementation, and Drag. Figure 3.2.2b shows the matrix used to optimize the propeller configuration.

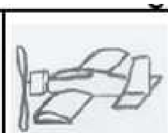
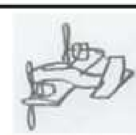
	Importance	 Push	 Tractor	 Multi-Tractor	 Pod
Takeoff Rotation	0.25	-1	0	0	-1
Weight Distribution	0.3	-1	0	1	1
Ease of Implementation	0.2	0	0	-1	-1
Drag	0.25	1	0	-1	0
Total	**1.00**	**-0.3**	**0**	**-0.15**	**-0.15**

Figure 3.2.2b Propeller Configuration Matrix

The importance of each property was rated in order from highest to least importance: weight, drag and takeoff rotation, and ease of implementation. From this scoring set up, the traditional tractor configuration was the optimal choice for our design due its good weight distribution, takeoff rotation, and simple implementation.

3.2.3 Empennage

With the changing payload distribution of Mission 3, the empennage configuration plays a key role. Stability was the most important factor and efficient controllability was rated secondary. It was assumed that the drag for similar planform areas would be relatively similar, causing it to be the least important. Figure 3.2.3a shows the tail configuration matrix.

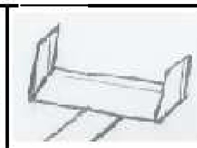
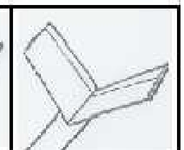
					
	Importance	Conventional	Conventional x2	T-tail x2	V-tail
bility	0.4	0	1	1	-1
Controllability	0.3	0	-1	1	-1
Ease of Implementation	0.2	0	-1	-1	-1
Drag	0.1	0	-1	-1	1
Total	**1**	**0**	**-0.2**	**0.4**	**-0.8**

Figure 3.2.3a Tail Configuration Matrix

The double T-tail design scored highest out of the configurations compared due to its excellent stability and controllability. While it may take more skill to build and might add some drag, we determined that these factors were not much better for the other options and would be a reasonable compromise.

3.2.4 Landing Gear Configuration

When determining the landing gear configuration, we discussed several ideas and consulted our pilot. We mainly considered the trail dragger and tricycle gear setups and ultimately chose the latter. Considering the large size of the Nalgene bottle payload, we realized it would be very difficult to implement the tail dragger configuration. Our decision was supported through discussion with the pilot; he informed us that tail draggers do not take off easily, especially with a large payload. In addition, the tricycle gear configuration would ease the travel of the airplane when taxiing over a grassy terrain. Thus, the tricycle gear proved the better choice.

3.2.5 Conceptual Design Summary

Utilizing design matrices and research of the different configurations considered, our team determined the overall design of the airplane. The boom design was decided as the overall plane configuration based on its lighter weight, ease of loading the payloads, decent stability, and payload integration potential. For the battery and motor configuration, the single motor, single battery design was chosen based on its ease of implementation, its simplicity, and the weight it saves by only having one motor. The tractor configuration for the propulsion placement of the aircraft was chosen due to its ease of implementation and good take-off rotation. The double T-tail empennage configuration was ideal for its added stability and controllability. This tail configuration was also chosen to avoid complications from the empennage being in the wake from the external payloads. Finally, a tricycle gear configuration was chosen for the landing gear. This was based on the clearance needed for the Nalgene bottle payload and the tricycle gear's ability to travel over rough terrain versus the tail-dragger configuration. Thus, with the help of design matrices, research, and some background knowledge of aircraft, we were able to establish our current plane design.

4.0 PRELIMINARY DESIGN

4.1 Site Analysis

Since the competition is being held at the ModelPlex Park here in Tucson, Arizona, we decided to research the weather patterns to better understand the environment in which our aircraft will need to fly. We know from experience that there is a slim chance of rain or any other inclement weather during the early summer months, so our main concern was wind. Using the historical data recorded on www.weatherunderground.com, we found that there was a good chance we would not have a perfectly calm day for the competition. In both 2007 and 2008 average wind speeds did not differ greatly between months. There was, however, a very steady trend of about 7.5 mph all throughout the year. We should expect to have similar wind speeds the day of the competition. Also, in the process of researching average wind speeds, we looked at the average gust speeds for the area. There was also an obvious trend of gusts up to about 22 mph. This would be a worse-case scenario and the chances are very slim that our aircraft would be flying in these conditions for an extended period of time. Still, we should expect wind gusts of some magnitude during the competition. Overall, this information can be very helpful. Understanding the local environment will help us determine the amount of stability needed as we move into a more detailed design phase. Figures 4.1a and 4.1b show both the wind speed and wing gusts for Tucson, AZ.

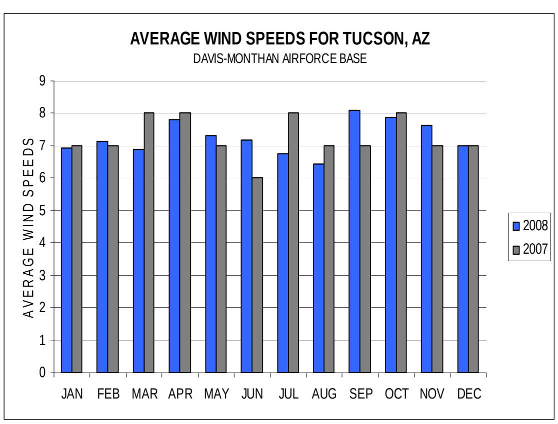


Figure 4.1a: Average Wind Speed for Tucson, AZ

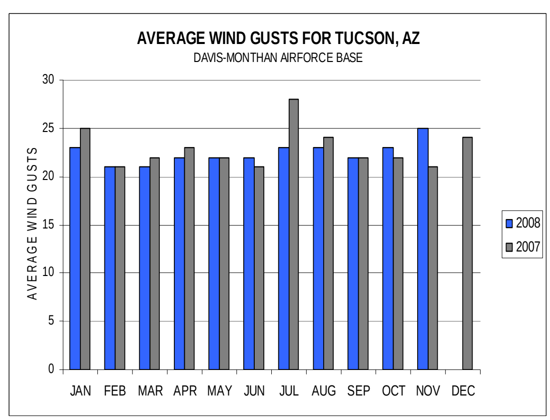


Figure 4.1b: Average Wind Gusts for Tucson, AZ

4.2 Weight Estimates

The first task in the preliminary design was to obtain a realistic weight estimate for the aircraft. After researching data from previous DBF aircrafts similar in size, the team made weight estimates of the structural materials based on density and size of material. The other system components such as electronics, landing gear, batteries, and motor were weighed separately.

An empty weight of around 12 lbs was estimated based on similar DBF aircraft. The rules of the competition limit the battery packs to 4 lbs. The centerline store, filled with water, was weighed and determined to be approximately 9 lbs. Also, the four missile stores mounted on the aircraft's wings each weigh approximately 1.5 lbs. Because the max payload weight of the aircraft corresponds to the mission with the filled centerline tank only (no missiles attached), 9 lbs was used as the payload weight in all of the calculations. Using the following equation given in Roskam,

$$W_{TO} = W_{OE} + W_F + W_{PAYLOAD}$$

W_{TO} = Take-off weight
W_{OE} = Operating empty weight
W_F = Fuel weight (Batteries)

an initial maximum take-off weight was determined to be approximately 25 lbs. Table 4.1.2a shows the initial estimated weights of the plane for various missions.

Table 4.2a Weight Estimates for Competition Flights

Estimated Empty Weight	**12 lbs**
Surveillance Flight	**25 lbs**
Store Release Flight	**22 lbs**

Table 4.1.2b below outlines a weight breakdown of the entire plane and determines that our initial estimated empty weight of 12 lbs was accurate.

Table 4.2b Weight Estimates for Entire Plane

System	Component	Weight (oz)	Number	Total Weight (oz)	Overall System Weight (oz)
PROPULSION	Motor	16	1	16	79.25
	Batteries	54*	1	54	
	Motor Mount	4.5	1	4.5	
	Propeller	1.5	1	1.5	
	Fuse	0.25	1	0.25	
	Fuse Box	1.5	1	1.5	
	Cut-off Switch	1.5	1	1.5	
CONTROL	Batteries	10*	1	10	31.72
	Speed Controller	3.7	1	3.7	
	Servo	1.52	11	16.72	
	Receiver	0.65	2	1.3	
LANDING GEAR	Main Gear Strut	11	1	11	33.5
	Nose Gear	12	1	12	
	Wheels	3	3	9	
	Axles	0.5	3	1.5	
STRUCTURAL	Wing	9.5	2	19	52.328
	Carbon Fiber Spar	5.952**	1	5.952	
	Fuselage	15	1	15	
	Vertical Tail	1.5	2	3	
	Horizontal Tail	4	1	4	
	Boom	2.688***	2	5.376	
TOTAL AIRCRAFT WEIGHT =					**196.798 oz (12.3 lbs)**
AIRCRAFT BOXES	Aircraft Box	160	2	320	487.25
	Rockets	24	4	96	
	Water Bottle	11.25	1	11.25	
	Support Materials	60	-	60	
RATED AIRCRAFT COST (RAC) =					**684.048 (in oz) 42.753 (in lbs)**

* Battery weight is considered as a single battery *pack*.

** One rod at 6 ft (later divided into two spars for the wing sections)

*** Two rods, at 4 ft each

4.3 Wing Sizing and Optimization

Before beginning the initial wing sizing of the aircraft, wing loading was determined to be the most important parameter. The desired wing loading value used in the initial calculation was 30 oz/ft^2. The total weight of the aircraft was estimated through the use of empty weights of similar aircraft, and the addition of this year's max payload requirement. These calculations would yield the aircraft's desired wing area. Since the aircraft would be operating at low speeds, it was determined that a forward swept wing would be used to implement the desired taper ratio (mentioned in section 4.4). The span of the wing was determined based on the distances specified between the rocket payloads. For the rest of the analysis the aircraft was sized and optimized using the computational fluids program XFLR5.

In XFLR5, the 3-D panel model was selected to calculate the aircraft's performance characteristics. Figure 4.3a shows this modeling of both wing and empennage after initial sizing. Table 4.3a displays the wing characteristics after preliminary design.

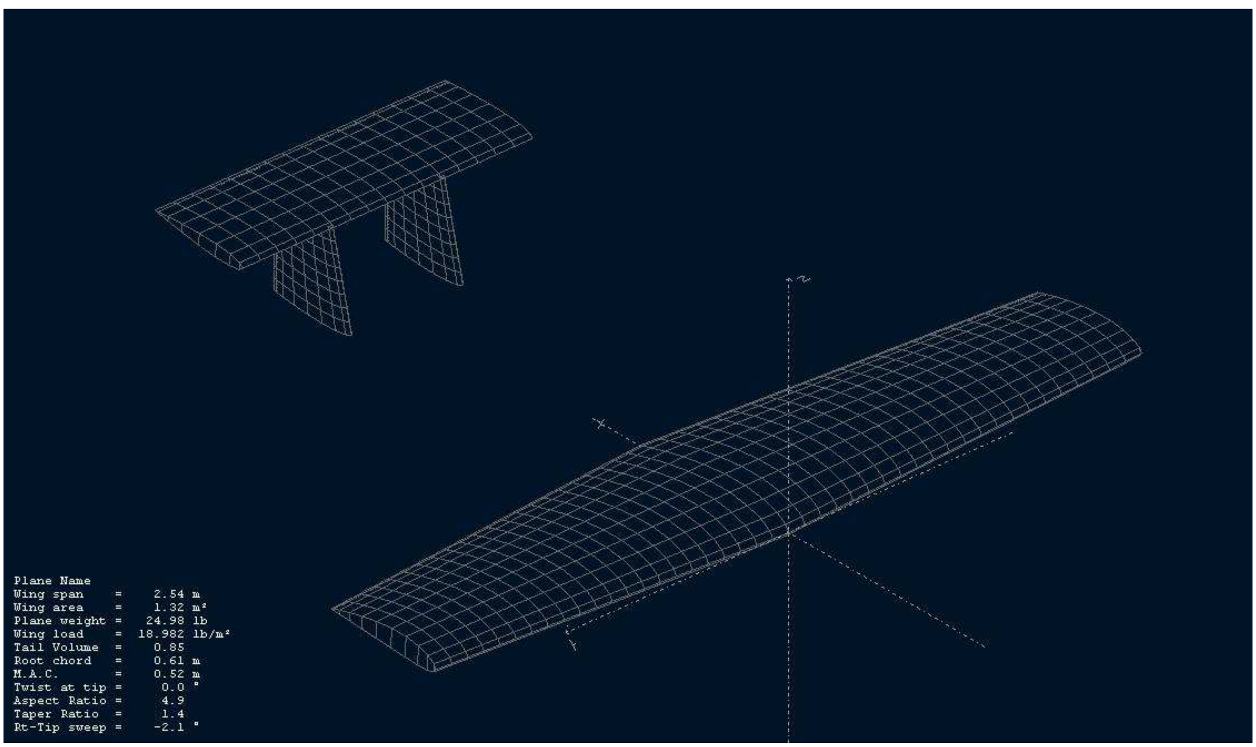


Figure 4.3a XFLR5 Lattice Model of Wing and Empannage

Table 4.3a Wing Characteristics

Wing Characteristics	
Aspect Ratio	4.9
Span	8.33 ft
Mean Aerodynamic Chord	1.70 ft
S_w	14.20 ft^2

4.4 Wing Taper

Tapering of the wing was investigated to improve the performance of the wing. A tapered wing more closely resembles an elliptical wing, which has optimum lift distribution. To choose an initial taper ratio, Figure 4.21 of McCormick's *Aerodynamics Aeronautics and Flight Mechanics* was referenced to compare taper ratio, aspect ratio and induced drag factor (McCormick 172). For the design aspect ratio of approximately 5, a taper ratio of 0.5 produced the smallest induced drag factor. However with such a large taper ratio, the problem of tip stall becomes a serious consideration. To counter act this effect on the wing tips, a taper of 0.7 was selected.

4.5 Airfoil Sizing

Airfoil selection was also accomplished through the use of XFLR5. A series of low speed, low Reynolds number airfoils were analyzed at a range of angles of attack. Due to the fact that the Reynolds number at the root of the wing is different from the Reynolds number at the wingtip, all analysis was performed at a calculated mean value of 550,000. After preliminary analysis, the top airfoils were: the SD-7062, the S-7055, the Clark Z, the NACA 4415, and the LS-413. Figure 4.5a shows the lift coefficient curves for the five different airfoils. For the top airfoils, plots of Cl vs. Cd were compiled and compared to help find the optimum airfoil.

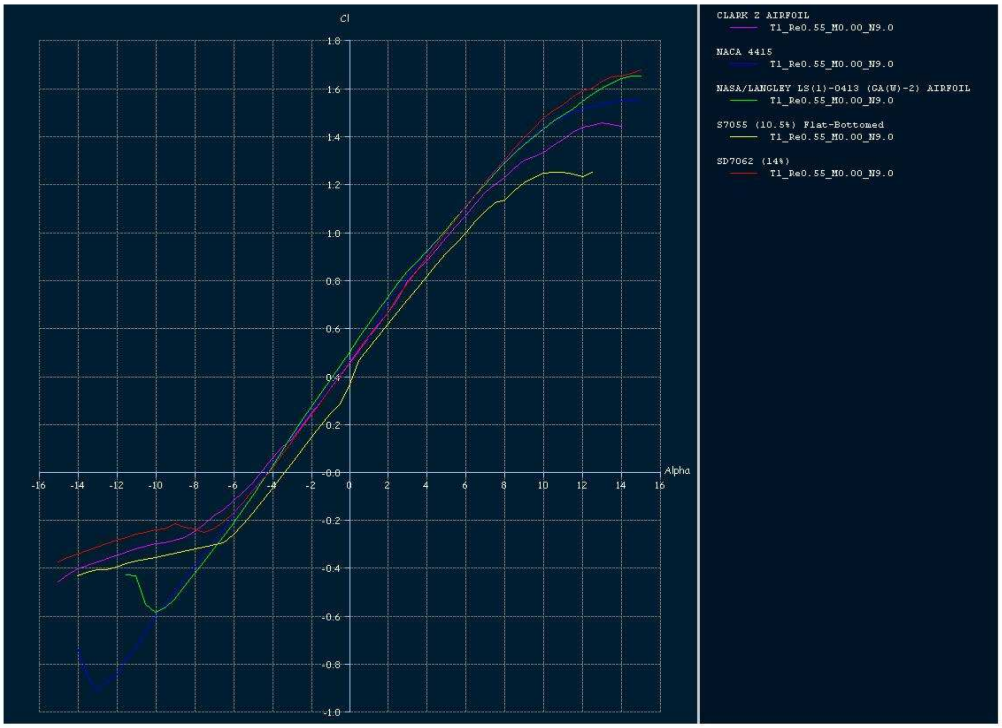


Figure 4.5a Lift Coefficient Curves of Airfoils Considered

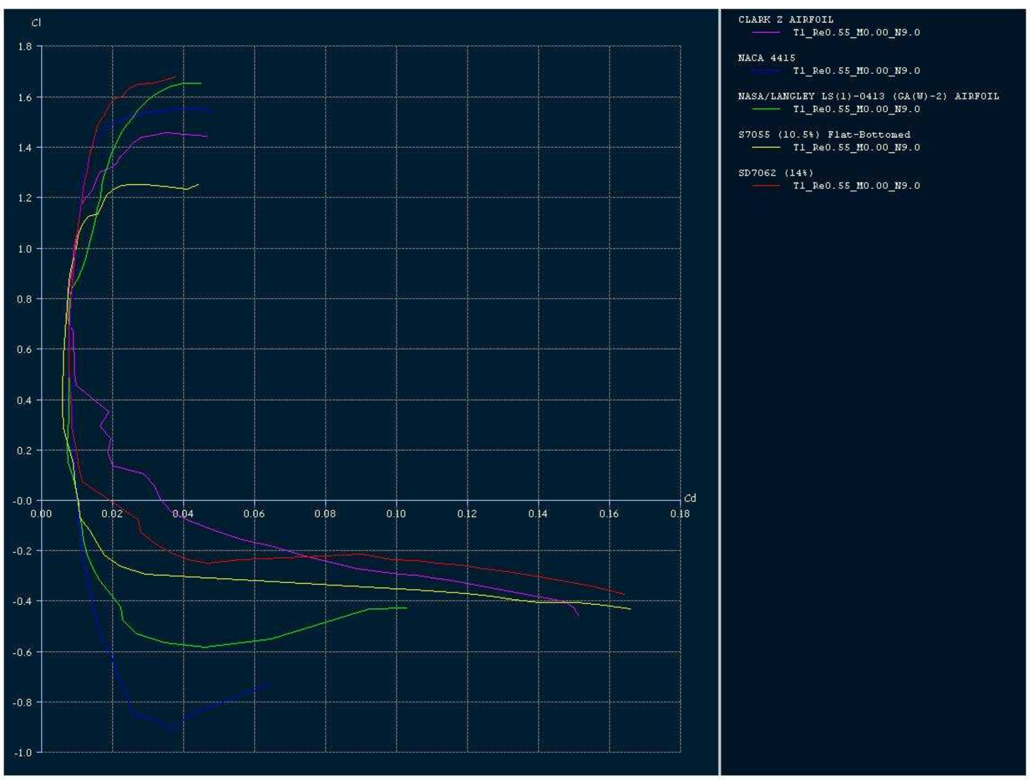


Figure 4.5b Drag Polars

Figures 4.5a and 4.5b show that the two best performing airfoils were the SD-7062 and the LS-0413. However, due to the negative camber possessed by both airfoils, they would both encounter a hard stall when a stall takes place. A flat bottom airfoil on the other hand has the tendency to have a soft stall. This type of flight characteristic is beneficial to an RC aircraft flying low to the ground. A flat bottom airfoil also allows for ease of wing construction and ease of payload integration. For these reasons the NACA 4415 was chosen over the other airfoils. Figure 4.5c shows a plot of the chosen NACA 4415 airfoil.

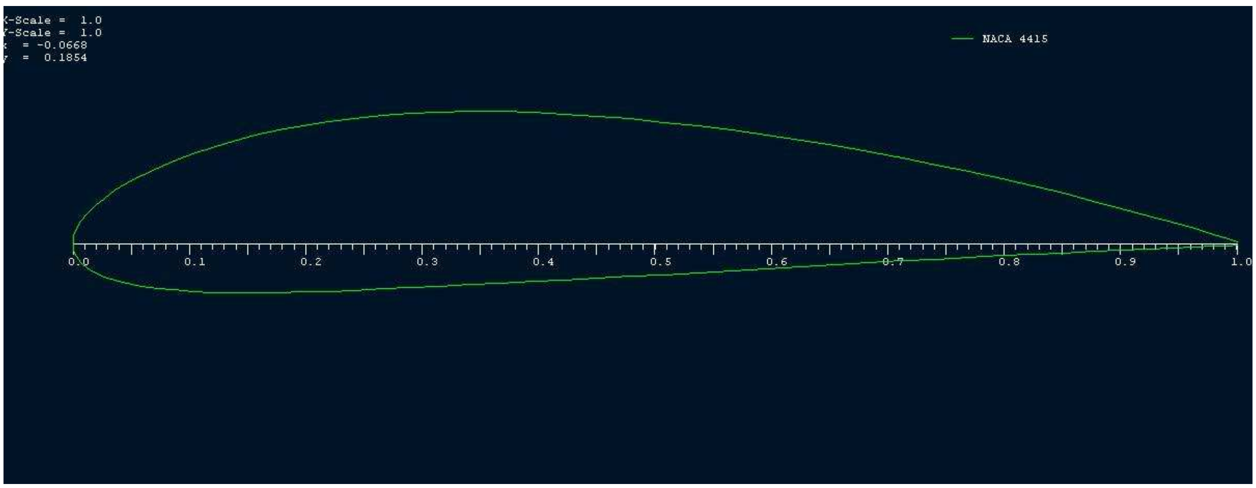


Figure 4.5c NACA 4415 Airfoil

4.6 Empennage Optimization

The horizontal tail sizing was approached in a different manner to that of the sizing of the wing. The group researched comparable horizontal tail volume coefficient values and decided to use a value of $V_h = 0.73$ as a starting point. The span of the tail was estimated to be around one third the size of the wing, and this estimated value was then used in the calculation of the planform area of the horizontal tail, S_h. Once the surface area of the tail was known, Equation 4.1 was used to find l_h, the distance between the aerodynamic center of the wing to the aerodynamic center of the tail

$$V_h = \frac{S_h l_h}{S_w c_{bar}} \qquad \text{Eq. 4.1}$$

Equation 4.1 was then solved for l_h to find a preliminary location of the aerodynamic center of the horizontal tail in relation to the plane's center of gravity. The horizontal tail location was later finalized through the group's stability calculations, which resulted in a horizontal tail volume of 0.78. Table 4.5a shows the horizontal tail characteristics.

Table 4.6a Horizontal Tail Characteristics

Horizontal Tail Characteristics	
Aspect Ratio	2.9
Span	3.67 ft
Chord	1.18 ft
S_w	4.03 ft^2

The vertical tail was designed in a similar fashion. After researching values for the vertical tail volume coefficient, a value of $V_v = 0.055$ was used as a starting point.

$$V_v = \frac{S_v l_v}{S_w b} \qquad \text{Eq. 4.2}$$

Based on equation 4.2, the location of the aerodynamic center of the vertical tail was set slightly in front of the location of the aerodynamic center of the horizontal tail. The vertical tail volume equation was then solved for S_w. This value was increased slightly to help ensure greater stability when the Nalgene bottle is attached to the aircraft. These modifications to the design resulted in a vertical tail volume coefficient of 0.078. Figure 4.3a pictorially depicts the sizing and design of the empennage in XFLR5.

4.7 Control Surface Sizing

Control surfaces are vital for airplane stability, control, and improved performance. Because Mission Three requires releasing wing stores, which creates asymmetrical mass distribution and rolling moments, lateral stability is a major design consideration. Ailerons will be the most effective at balancing this rolling moment, however rudder is also a critical factor. If the center of mass moves longitudinally when stores are dropped, elevator deflection will also be needed.

Roll control is primarily provided by the ailerons. Preliminary design calls for the ailerons to extend the majority of the span of the wing since longer ailerons provide more control in the case of tip stall compared to ailerons only at the end of the wings. Longer ailerons also mean that a smaller deflection angle is required to produce a change in lift. Because the wing has to carry the rocket stores, a smaller deflection angle is ideal to avoid aileron/store interference. When the wing loads are released the ailerons will be trimmed to balance the moments. The ailerons can also be used as flaperons to increase the lift coefficient for take-off and landing, which is particularly useful for the mission with the centerline tank, which requires more lift. The sizes of the ailerons were decided to be 25 percent of the chord of the wing. This would allow for maximum available lift on takeoff while providing adequate control during flight.

An elevator will be used on the horizontal stabilizer to provide pitch control. Since the horizontal stabilizer will be placed above the vertical stabilizer to avoid the wake from the centerline tank, precautions need to be taken so that elevator deflection does not interfere with the rudder. To achieve this design requirement the elevator is positioned at 75 percent of the horizontal chord. Since two vertical stabilizers are being used in the design, two rudders are also being employed. Each rudder is positioned at 75 percent of the root chord and do not taper with the vertical stabilizers.

4.8 Stability and Control

Stability and control are very important aspects of RC plane design. Stability is required for the plane to remain in flight during maneuvers and after a disturbance such as a wind gust. Since maneuverability is not a significant performance requirement, other than to follow the flight course, a very stable configuration is desirable. There will not be any automated control programs, so the plane must also be easy to control by the pilot with suitable control surfaces.

4.8.1 Longitudinal Static Stability

Longitudinal static stability is satisfied when:

1. $C_{m_o} > 0$
2. $\partial C_m / \partial \propto < 0$

where C_{m0} is pitching moment coefficient at zero angle of attack and $\partial C_m/\partial\alpha$ is the change in pitching moment with respect to angle of attack. In order to check the stability of the aircraft, the team utilized a Matlab program created specifically for this purpose and Datcom+, a program created by the United States Air Force to determine the aerodynamic coefficients of an aircraft. The results from these programs were utilized in an iterative process to determine the horizontal tail size and location, vertical tail size, and aircraft control surface areas. The team decided to place the cg of the external stores at the cg of the aircraft so that the longitudinal location of the center of gravity would be constant throughout the various store configurations. Table 4.8.1a shows the longitudinal stability derivatives $\partial C_m/\partial\alpha$ and $\partial C_m/\partial q$, the pitching moment with respect to longitudinal angular acceleration. Figure 4.8.1a shows the graph of $C_m\ vs. \propto$. at zero ∂_e (elevator deflection angle), demonstrating the longitudinal static stability of the plane.

Table 4.8.1a – Longitudinal Stability Derivatives

Derivative	Value (Loaded 25 lbs)	Value (Unloaded 16lbs)
$\boldsymbol{\partial C_m / \partial \propto}$	-.01323529	-.0501
$\boldsymbol{\partial C_m / \partial q}$	-8.087E-03	-8.086E-03

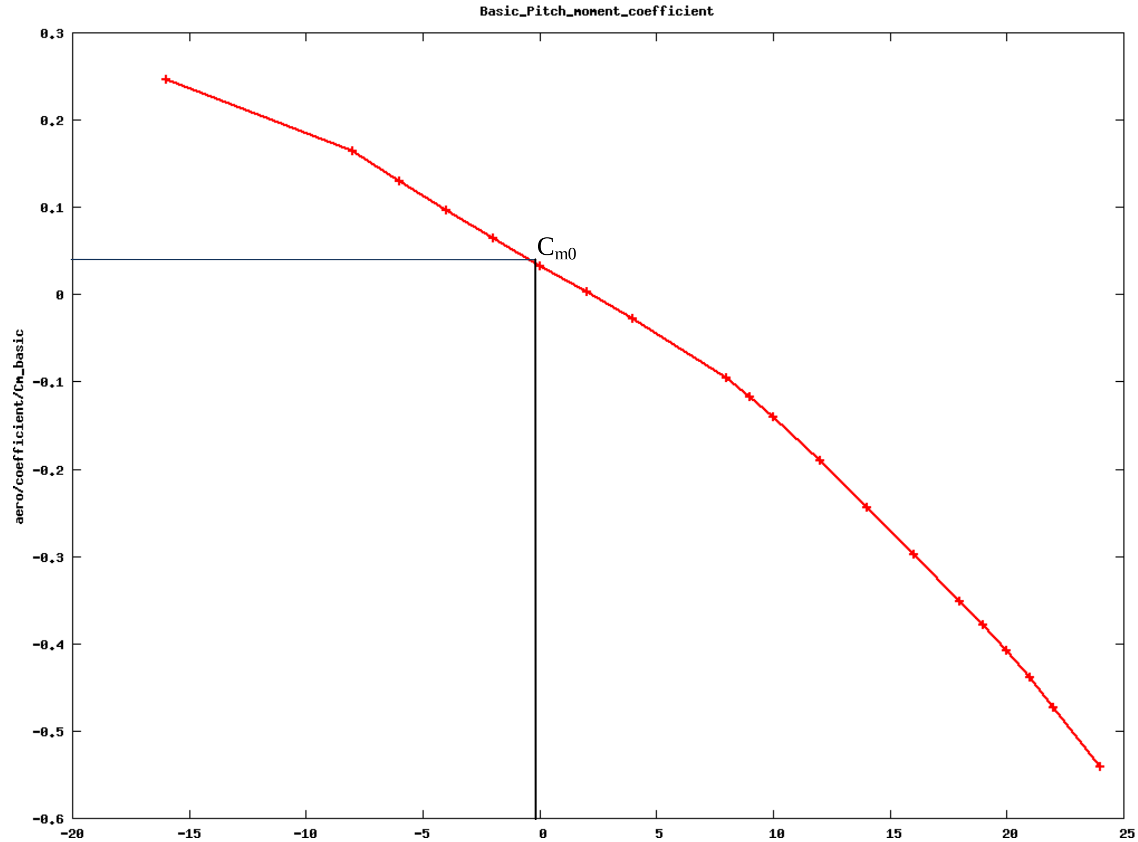
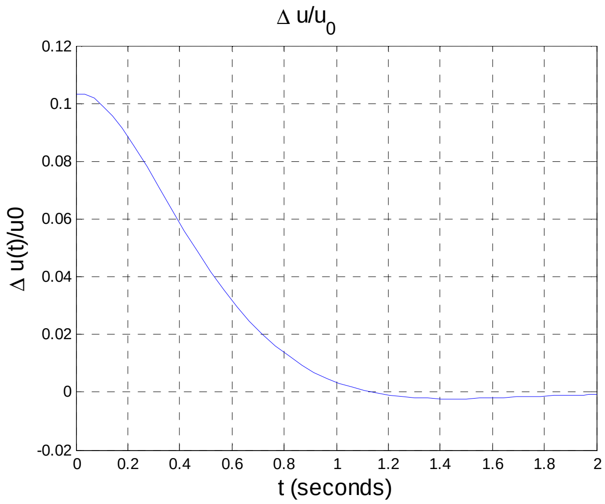


Figure 4.8.1a - $C_m\ vs. \propto$

4.8.2 Dynamic Longitudinal Stability

Dynamic longitudinal stability is determined from the equilibrium state and the longitudinal modes of the aircraft. A Matlab code was created in order to test the dynamic stability of the aircraft by calculating the longitudinal modes. An iterative process was utilized to optimize the longitudinal stability of the aircraft. Figures 4.8.2a-c show the short period referenced to a body-fixed stability axis.



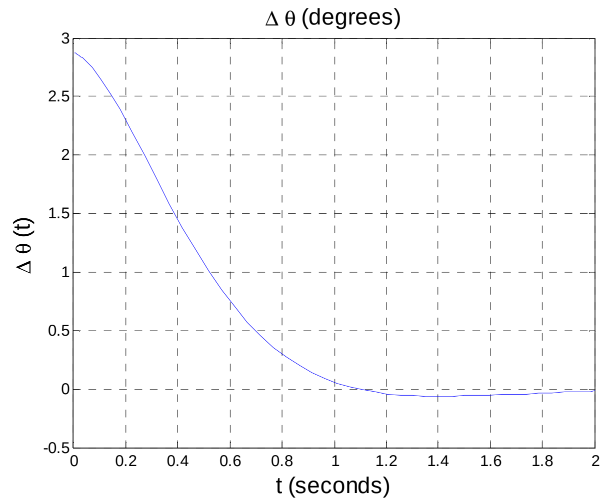


Figure 4.8.2a - Short Period** $\Delta u / u_o$ **vs. Time (s)

***Figure 4.8.2b – Short Period** $\Delta\theta \; vs. Time \; (s)$*

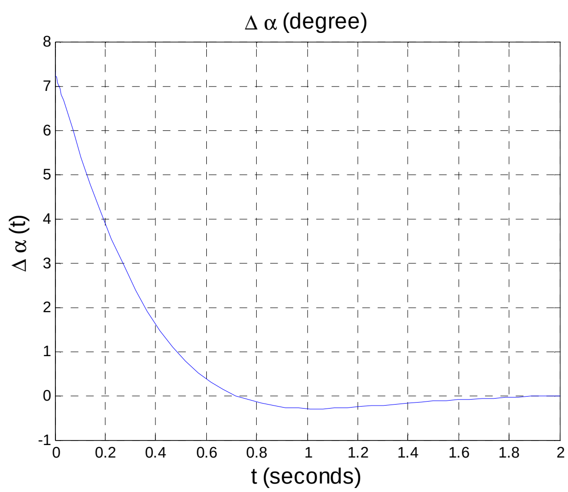


***Figure 4.8.2c – Short Period** $\Delta\propto \; vs. Time \; (s)$*

The phugoid of the aircraft was also analyzed. For our application, we desired a heavily-damped phugoid with a timescale of around 10s, reducing the likelihood of pilot-induced oscillations. Figures 4.8.2 d-f show the phugoid aircraft response over time, and table 4.8.2a shows the Eigenvalues for the short period and phugoid responses. The aircraft dynamic stability is affirmed by the damping of the short period and phugoid as well as the negative eigenvalues.

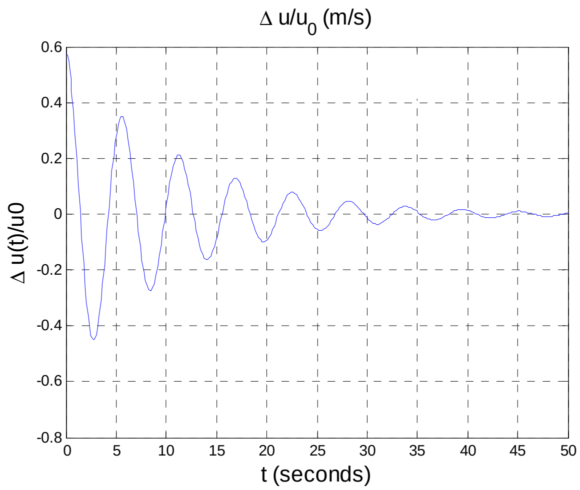


Figure 4.8.2d – Phugoid $\Delta u / u_o$ vs. Time (s)

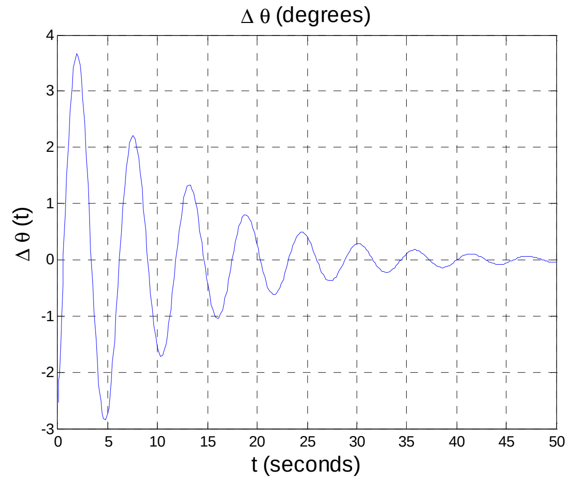


Figure 4.8.2e – Phugoid $\Delta\theta\ vs.Time\ (s)$

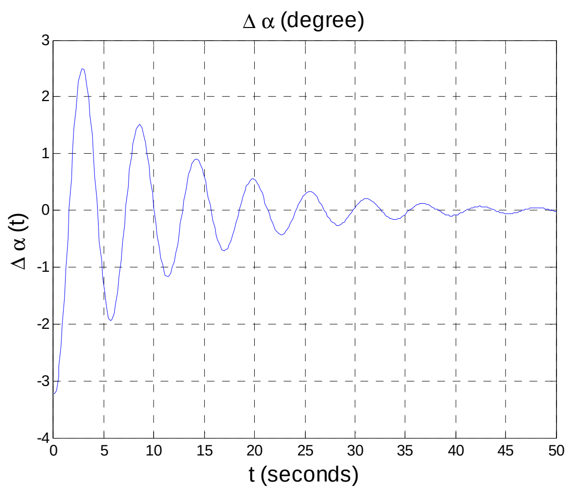


Figure 4.8.2f – Phugoid $\Delta\propto\ vs.Time\ (s)$

Table 4.8.2a – Summary of Eigenvalues for Longitudinal Modes

Mode	Eigenvalue (Loaded)	Eigenvalue (Unloaded)
Short Period	-2.6817 ± 2.1909i	-3.2650 ± 2.2345i
Phugoid	-0.0893 ± 1.1125i	-0.1928 ± 1.2036i

4.8.3 Lateral Stability

To ensure lateral stability:

1. $\partial C_n / \partial \beta > 0$
2. $\partial C_l / \partial \beta < 0$

The values of these derivatives were calculated utilizing Datcom+. These values are demonstrated in Table 4.8.3a, indicating lateral stability

Table 4.8.3a – Lateral Stability Derivatives

Lateral Stability Derivative	Value (25 lbs Loaded)	Value (16 lbs Unloaded)
$\partial C_n / \partial \beta$	1.101E-03	1.135E-03
$\partial C_l / \partial \beta$	-5.744E-04	-5.022E-04

4.9 Propulsion Optimization

A brushless motor configuration was chosen over a brushed motor. The conventional brushed motor has carbon brushes wrapped around the rotor. Current is applied to the wire, which brushes the magnets located on the stator, or stationary portion, of the motor. Brushed motors are abundant and inexpensive, however they require a significant amount of maintenance and wear out relatively quickly. On the other hand, in a brushless motor the magnets are located on the rotor of the motor, and the wire is wrapped around the stator and remains stationary. Since the wire and the magnets do not touch, a microprocessor circuit that includes an integrated electronic speed control is required in order to commute the charge. As a result, brushless motors are significantly more expensive than their brushed counterparts. However, a brushless motor has better heat dissipation, is more efficient, and is more durable than a brushed motor. This would allow future DBF teams to utilize the motor we purchase, and increase its longevity.

The motor was initially sized to be able to accomplish the most demanding mission: take-off with the full centerline tank payload. Sizing the motor to take-off in the required length of 100 ft was accomplished using the following equation:

$$s_g = \frac{1.21(\frac{W}{S})}{g\rho_\infty (C_L)_{TO}(\frac{T}{W})} \qquad \text{Eq. 4.3}$$

where s_g is the ground roll distance, W/S is the wing loading, g is acceleration due to gravity, ρ_∞ is the free-stream density, C_{LTO} is the take-off lift coefficient, and T/W is thrust per weight. As a safety factor the ground roll distance was taken to be 90 ft instead of the maximum of 100 ft. C_{LTO} was determined using XFLR analysis of the lifting surfaces with the flaperons deployed 20°. With a C_{LTO} of 1.26 and a design wing loading of 30 oz/in^2, T/W was calculated to be 0.281. At our estimated take-off weight of 25 lbs, the required thrust for take-off is 31.2 N. The corresponding take-off velocity is 10.8 m/s, making the power required for take-off (P=TV) 337.5 W With an estimated propeller and total system efficiency of 32.2%, the electrical power needed is 1048.1 W.

With this power requirement, along with the plane dimensions and specifications, the team consulted Hacker Brushless Motor Company for a motor recommendation. Based on their recommendation, the team selected the Hacker A50-14L and a 16 in. diameter propeller with 8 in. of pitch. The team then utilized the analysis program *MotoCalc* to analyze the in-flight performance of the propulsion configuration. Optimum performance was determined at 78% thrust (25 N) with an airspeed of 31 mph and flight time of 7 minutes. Various propeller and battery configurations will be investigated during flight testing to optimize the propulsion set-up.

The team chose to utilize Nickel-metal hydride (NiMH) batteries over Nickel-cadmium batteries because of their higher charge densities and better charge performance. The battery choice was limited by maximum battery weight, which is 4 pounds, and a maximum of 40 amp current draw. Previous teams have demonstrated that the slow-blow fuse we are required to use is capable of carrying a 55 amp load for approximately ten seconds. This surge current will be important for take-off since a lower power loading will be possible, whereas in flight higher power loading is sufficient.

The team chose the Gold Peak GP3300 cells as the lightest cells capable of providing the required power for the needed current.

4.10 Payload Design and Integration

A number of different conceptual ideas were considered while developing a preliminary design for our payload integration system. The first idea involved a simple strap system which would be attached to the underside of our aircraft, allowing the missile or centerline tank to hang beneath the wing/fuselage. On command, a device would release one side of the strap allowing the payload to fall to the ground. When discussing the design of the payload, the team decided that there were too many issues that would need to be worked out in order to make it work. For instance, the tension on the payload would have to be such that it wouldn't shift during flight. This would be difficult to accomplish with simple straps.

The second design for consideration was a bit more rigid than the first. It utilized a rail system where two matching payload rails would connect the missile/centerline tank to the aircraft. Figure 4.10a depicts this rail design. One side of the rail system could be attached to the rocket while the other is attached to the underside of the aircraft. The two would slide and lock together, making for simple and quick loading. On command, a single servo could push the two rails apart, releasing the payload from the aircraft. This design would require some machining and proper materials would need to be selected to ensure rigidity.

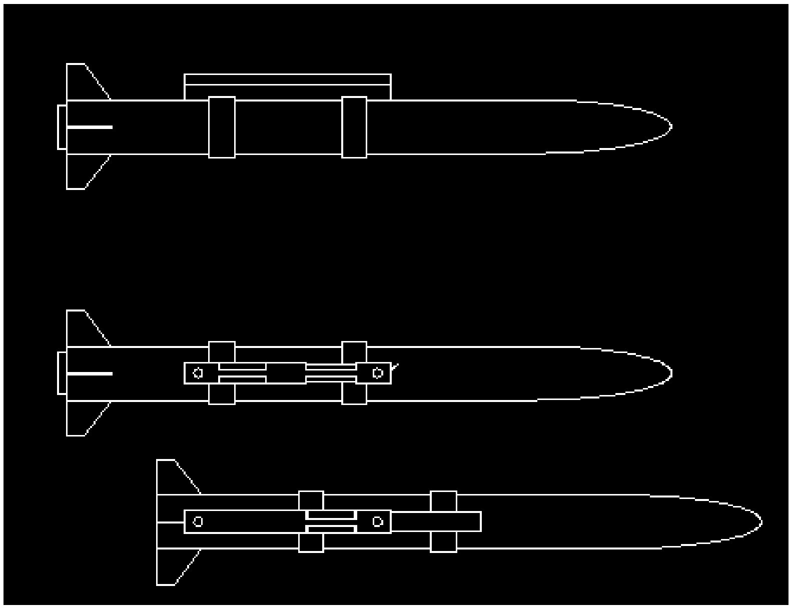


Figure 4.10a Missile Rail Design

The final preliminary design the team considered was a combination of two systems – block support and pin release. A support block would be integrated into the aircraft wing for the purpose of payload support. The block could be molded into a shape such that, when the rail is locked in place, the payload body would be butted against the aircraft. Figure 4.10b shows this block support design and is further discussed in detail in section 5.5. This design was chosen based on its sound design and ease of integration into the aircraft.

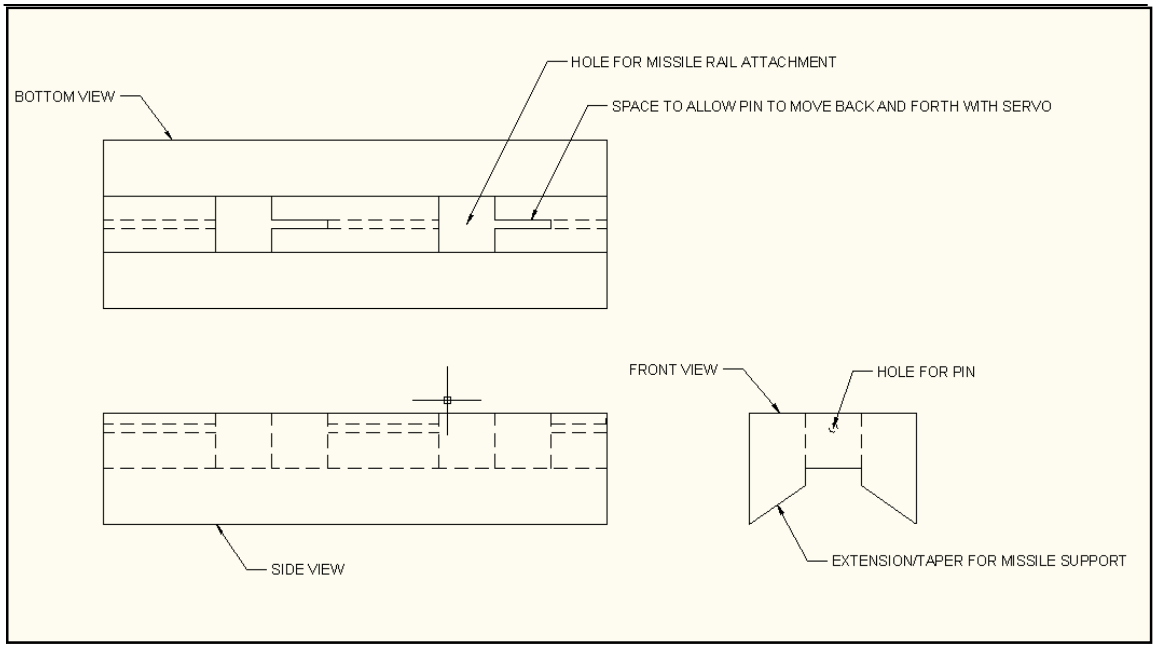


Figure 4.10b Block Support

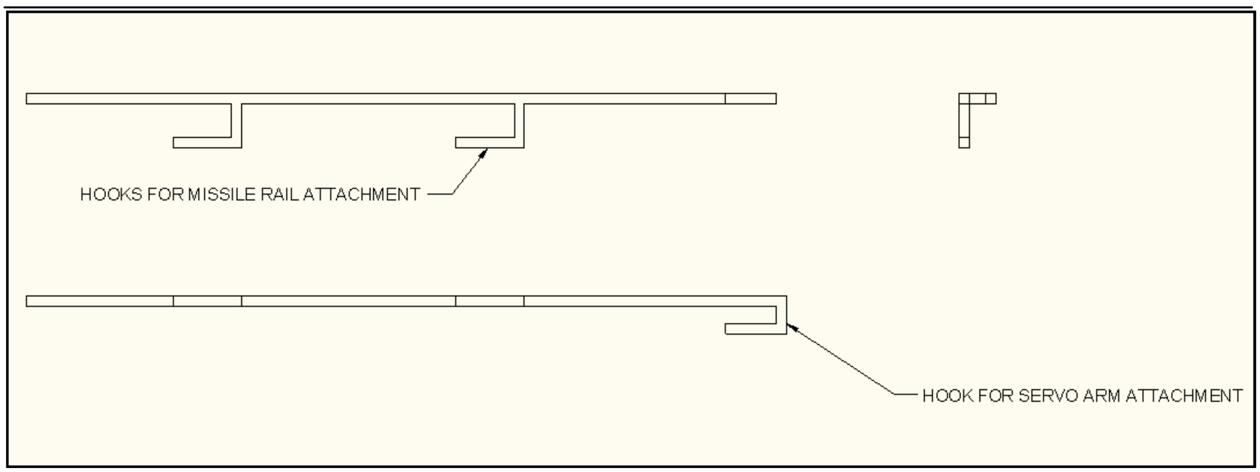


Figure 4.10c Pin Design

5.0 DETAILED DESIGN

5.1 Detailed Sizing and Flight Performance Parameters

Table 5.1 shows important aircraft sizing and flight performance parameters. Figures 5.1 and 5.2 also show lift versus drag performance of the wing with and without flaps.

Table 5.1 Aircraft Sizing and Flight Performance Parameters

Mass		Horizontal Stabilizer	
Airframe Weight	3.21 lbs	**Airfoil**	flat plate
Propulsion System	4.95 lbs	**Chord**	14 in
Control System	1.98 lbs	**Span**	44 in
Landing Gear	2.09 lbs	**Horizontal Tail Area**	616 in^2
Centerline Payload	9 lbs	**Elevator Chord**	3.5 in
Wing Stores Payload	6 lbs	**Angle of Incidence**	-4°
Surveillance Flight	25 lbs	**Vertical Stabilizer**	
Store Release	22 lbs	**Airfoil**	flat plate
Wing		**Height**	12 in
Airfoil	NACA 4415	**Root Chord**	13 in
Span	8.33 ft	**Tip Chord**	10 in
Planform Area	14.17 ft^2	**Vertical Tail Area**	138 in^2
Mean Aerodynamic Chord	1.7 ft	**Rudder Length**	3 in
Aspect Ratio	4.9	**Fuselage**	
Dihedral Angle	3°	**Maximum Width**	10 in
Flaperon Span	7.6 ft	**Maximum Height**	5 in
Flaperon Chord	.425 ft	**Length**	32 in
Aircraft Performance		**Stability Considerations**	
C_{Lmax}, no flaps	1.1	**CG Location***	11.12 in
C_{Lmax}, flaps	1.7	**Horizontal Tail LE***	5.3 ft
C_{D0}	0.0379	**Inner Wing Stores****	24 in
L/D max	20.75	**Outer Wing Stores****	30 in
Empty Weight Performance		**Systems**	
Stall speed, no flaps	20.8 mph	**Motor**	Hacker A50-14L
Stall speed, flaps	17.6 mph	**Battery Configuration**	GP 3300 mAh NiMH (20 cells)
Optimum Cruise speed	31 mph	**Speed Controller**	Master Spin 77
Take-off speed	19.4 mph	**Propeller**	APC 16x8 E-Prop
Take-off Power	173.55 W	**Main Transmitter**	Spectrum JR DX-7 (2.4 GHz)
Gross Weight Performance		**Main Receiver**	Spectrum AR7000
Stall speed, no flaps	26 mph	**Secondary Transmitter**	Sutuba 7-Channel (72 MHz)
Stall speed, flaps	22.0 mph	**Secondary Receiver**	Sutuba 8-Channel
Optimum Cruise speed	35 mph	**Servos**	Hitec HS-475HB
Take-off speed	24.22 mph	*from nose	
Take-off Power	337.5 W	**from centerline	

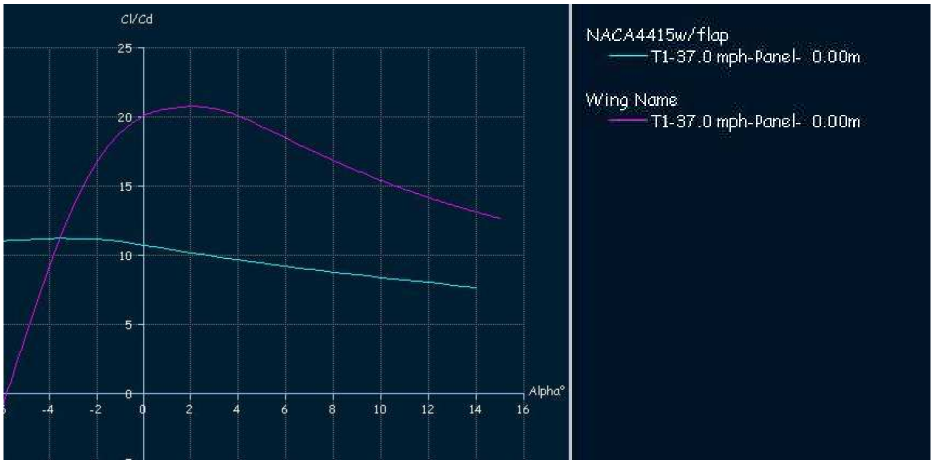


Figure 5.1a: Plot of Cl/Cd vs. alpha for wing

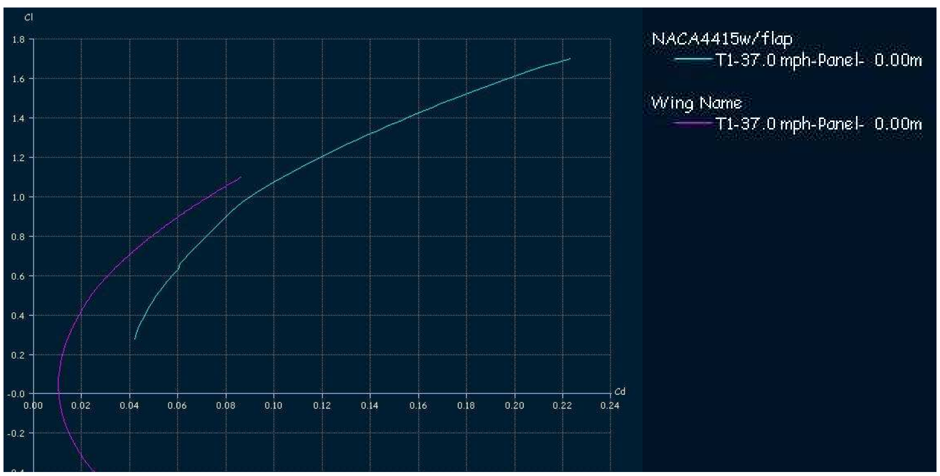


Figure 5.1b: Plot of Cl vs. Cd for wing

5.2 Structural Analysis

Structural analysis was completed using SolidWorks2008's CosmosXpress to find the von Mises stress distribution and deflections of important structural components. The spar running through the center of the fuselage was analyzed under a 12.5 pound load on either end simulating the load transferred from the wings. The maximum deflection of the fuselage spar was 0.8 mm. The results of the stress analysis are shown in Figure 5.2a.

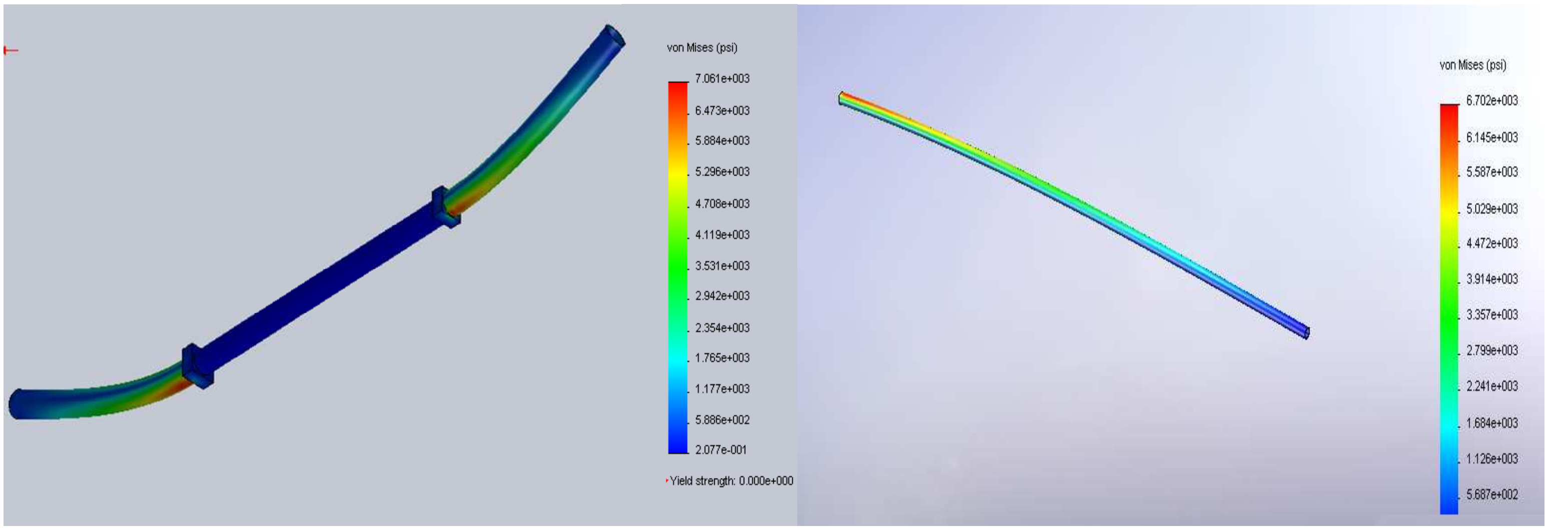


Figure 5.2a Structural Analysis of the Fuselage Spar and Tail Boom

The stress analysis of the tail boom was performed, and the results are shown in Figure 5.2a. The maximum deflection for the tail boom was determined to be 6mm.

Figure 5.2b shows the analysis of the main landing gear of the aircraft under a total 30 pound load. The maximum deflection was found to be 0.5 mm and so the water bottle will still have clearance from the ground.

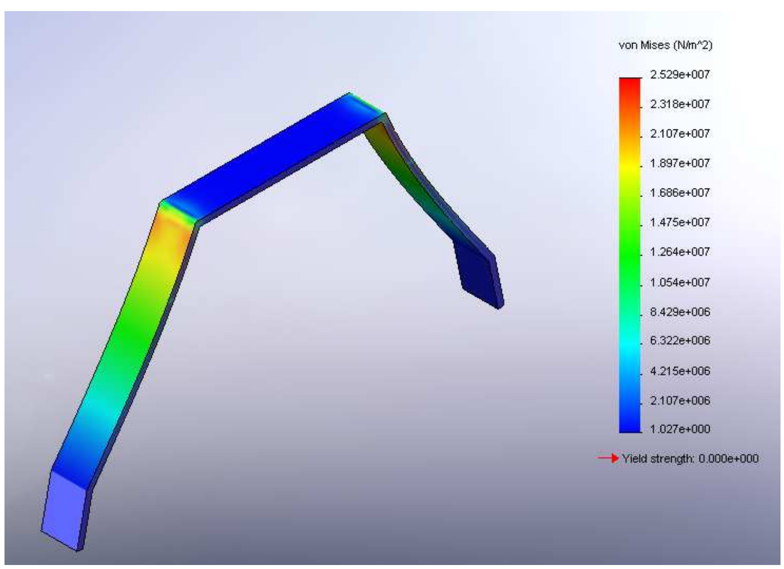


Figure 5.2b Structural Analysis of Main Landing Gear

5.3 Propulsion/Control System Architecture

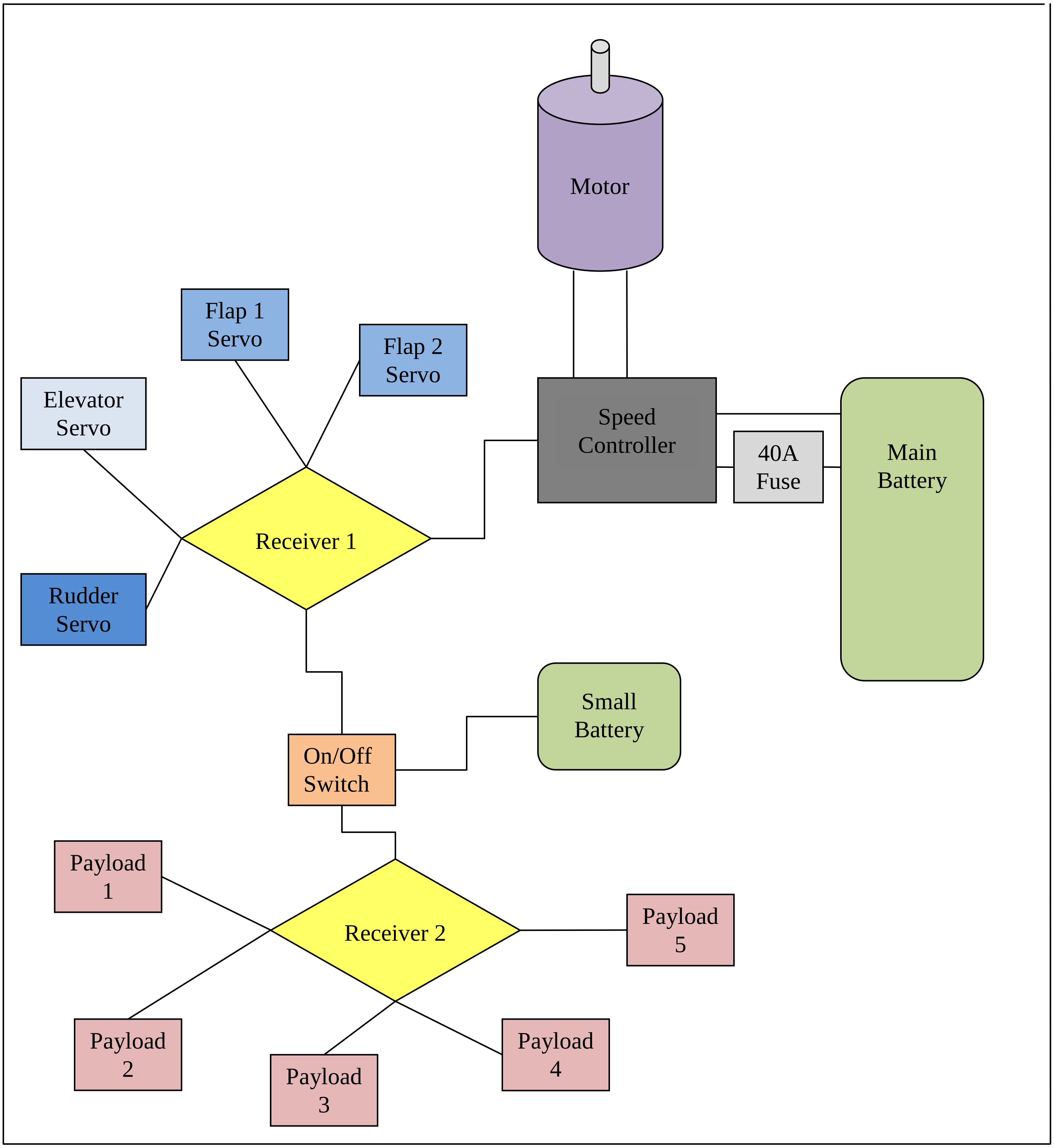


Figure 5.3a: University of Arizona DBF Team's Wiring Diagram

5.4 Landing Gear Selection

The team chose a composite main landing gear because of strength and weight considerations. Composite gears weigh less than aluminum and because of the size of the plane, cutting weight wherever possible is beneficial. Composite gears also flex less than aluminum during landing. Minimizing deflection is important because the centerline tank significantly reduces the ground clearance of the plane. There is only room for a few inches between the bottle and the ground without making the plane too tall to fit in the box. For these reasons the team chose the #1104 AeroWorks 75cc Yak QB Main Landing Gear, suitable for planes up to 28 lbs. The gear base is 8.5 inches wide to fit our 10 inches wide fuselage. It is also 10.75 inches tall, providing approximately 4 inches of ground clearance with the centerline tank.

5.5 Payload Design and Integration

After researching and experimenting with the different payload integration options, we chose to use a hybrid design created from smaller pre-made RC release mechanisms. The design incorporates a servo activated pin and a hard-mounted block. As the pin moves through the block, two L-shaped hooks open and close the “hook gaps” where the payload will attach. Both the rockets and centerline tank only need to be modified slightly for this design. Two small hooks mounted to the surface of each payload will allow for easy and fast connection to the aircraft. In order to install the rockets/centerline tank, the hooks must be placed up into the two hook gaps and the servo arm must be pushed forward, whether by hand or by controller. Once the payload is attached, it is essentially armed for release. A simple and quick activation of the servo pulls the pin and releases the payload.

During initial testing of this system, a few small discrepancies with the design came to our attention. Although the payloads released just as they should, it was noted that there was no control over the swaying of the payload. If this occurred while on the aircraft, it could have been disastrous. Because of this, the initial hook design was modified later to a rectangular shape. This shape when mated with the female end on the aircraft provided the rigidity needed to prevent the swaying problem. After this was changed, no other issues with the design were found. All other tests were successful.

The final payload integration design will be machined on the local CNC machine to ensure good clearances between the two mating surfaces. It will be made from a nylon polymer because of its lightweight properties and strength. This material is also very good for sliding surfaces, as it does not bind up on itself. The "block-like" design will allow for ease of integration when placing them within the wing and fuselage. Balsawood support structures in the wing sections will need to be built up to re-enforce the payload support system. Lightweight epoxy will be used to bond everything together.

After extensive testing, this system is expected to work 100% of the time barring any unrelated problems (such as batteries and servos). It is a very simple hook and rod design that is not only light, it is robust as well. For the missions we are tasked with completing, this is without a doubt the best design for our aircraft.

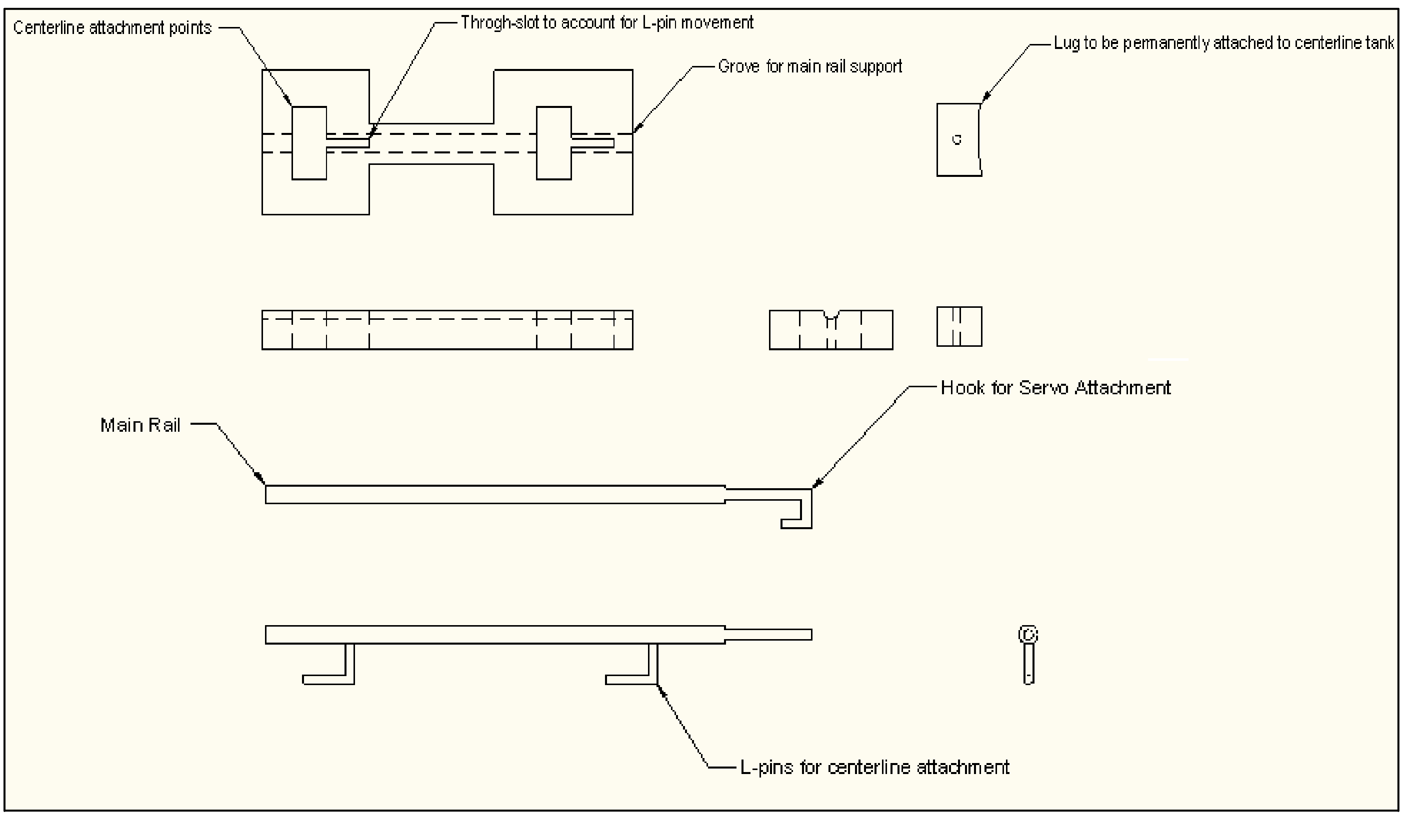


Figure 5.5a: Payload mounting system

5.6 Rated Aircraft Cost

Based on preliminary weight breakdowns, an estimated Rated Aircraft Cost (RAC) was determined to be 684. This value for RAC needs to be as low as possible in order to maximize our System Complexity Factor (SCF), which is carried throughout the scores of each mission of the competition. Since SCF is defined as

$$SCF = \frac{1}{AssemblyTime * RAC}$$

assembly time and RAC must be minimized. Only the RAC value can be controlled before the mission, so it is important the team builds with precision and uses as little materials as possible for all systems. With an estimated RAC of 648.048 from Table 4.2b, Figure 5.6a was created in order to demonstrate how quickly the SCF decreases with increasing assembly time.

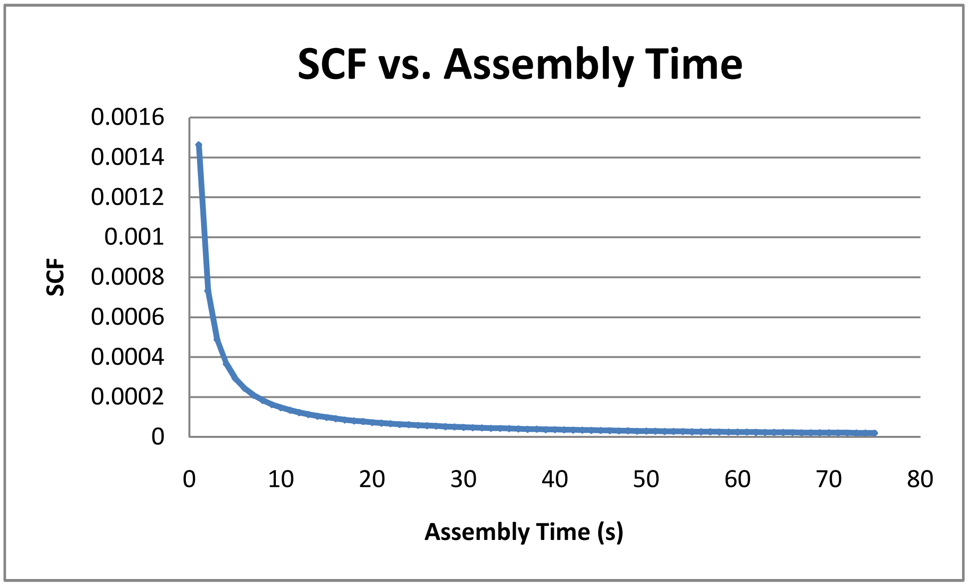


Figure 5.6a System Complexity Factor vs. Assembly Time

And so, in order for the team to be competitive in the competition and obtain a decent SCF score, assembly time must be as quick as possible. Before the mission, the team must practice a routine to assemble the plane as carefully and as efficiently as possible.

5.7 Mission Performance

The mission performance of the plane was estimated based off of details from the Summary of Mission Requirements section. The flight course was estimated to be around 0.7 miles. Flying at a cruise speed of about 51 ft/s (34 mph), the calculated time to complete one lap was 1 minute and 15 seconds.

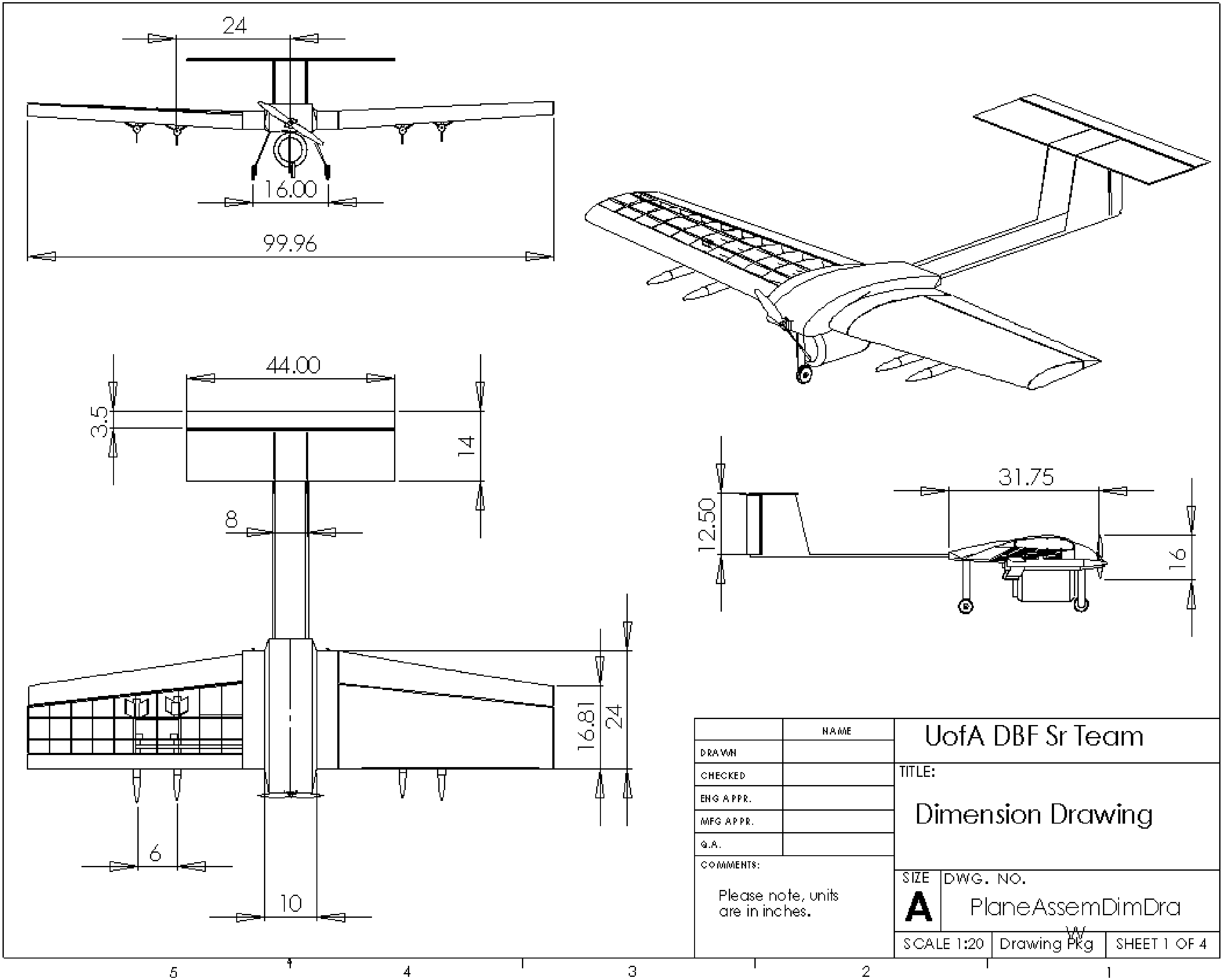
For the Ferry Flight mission, the flight time is considered part of the score, and so it is important for the plane to fly as accurately and as quickly as possible. In this mission, the plane is to complete four laps, taking an estimated 6 minutes considering take-off and landing.

In the Asymmetric Loads mission, flight time is not a factor in the score. However, the life of the batteries is the most important consideration for this mission. Since the plane will be completing four laps, touching down in between each lap to release a rocket, the batteries will have to last up to a maximum estimation of 10 minutes. For this mission, loading time of the rockets is part of the score, and therefore it is essential that the team creates an efficient way of loading the rockets onto the aircraft. And so, the payload systems were designed to be as simple as possible.

5.8 Drawing Package

The drawing package, created using SolidWorks2008, includes the following drawings:

- 3-View Drawing of Aircraft
- Structural Arrangement Drawing
- Systems Layout Drawing
- Payload Accommodation Drawing



	NAME
DRAWN	
CHECKED	
ENG APPR.	
MFG APPR.	
Q.A.	

COMMENTS:

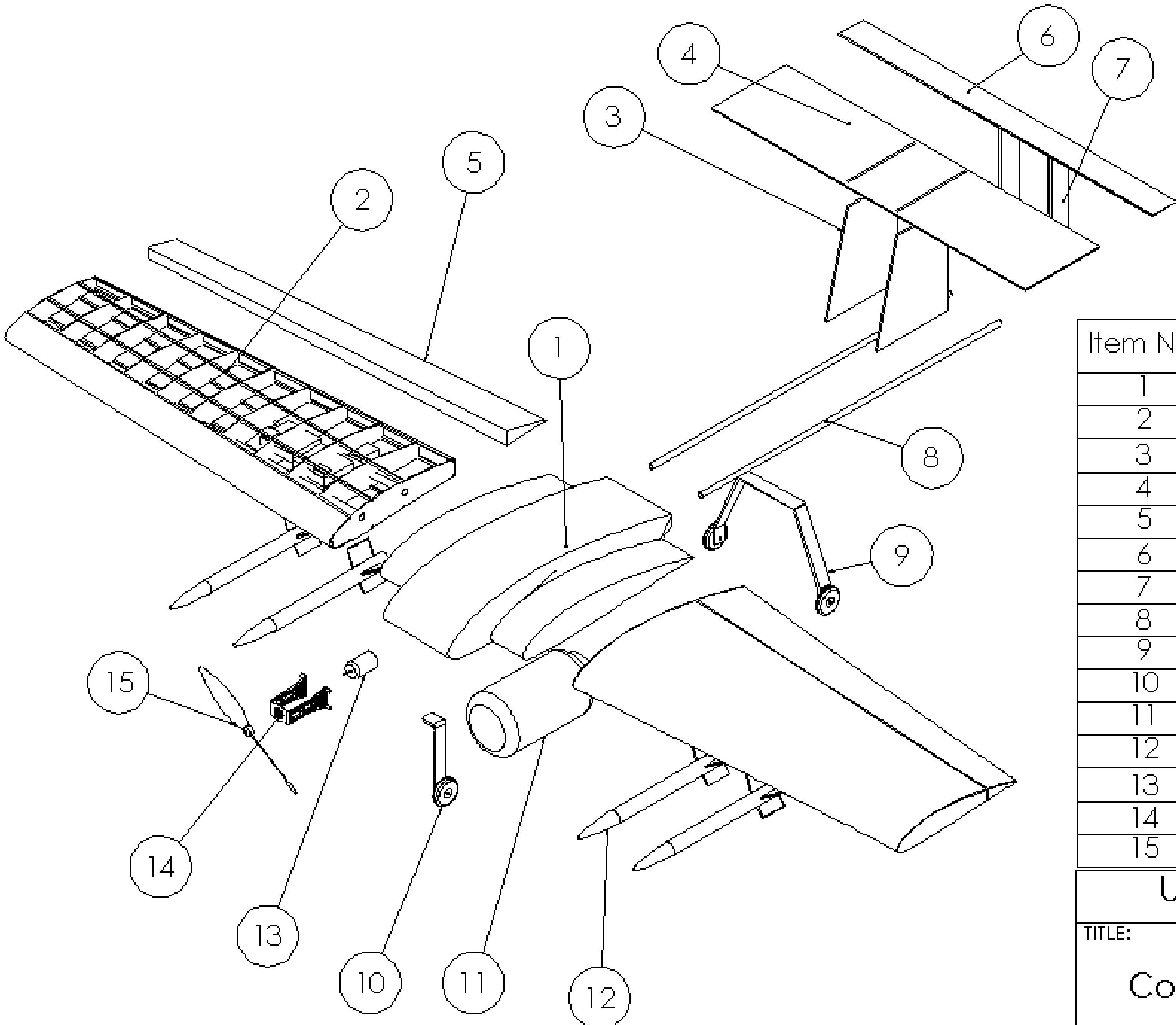
Please note, units are in inches.

UofA DBF Sr Team

TITLE:

Dimension Drawing

SIZE	DWG. NO.	
A	PlaneAssemDimDraw	
SCALE 1:20	Drawing Pkg	SHEET 1 OF 4



Item No.	Component
1	Fuselage Section
2	Wing Section
3	Vertical Stabilizer x2
4	Horizontal Stabilizer
5	Flaperon
6	Elevator
7	Rudder x2
8	Tail Boom Rods x2
9	Main Landing Gear
10	Nose Landing Gear
11	Water Bottle Payload
12	Rocket Payload x4
13	Motor
14	Motor Mount
15	Propeller

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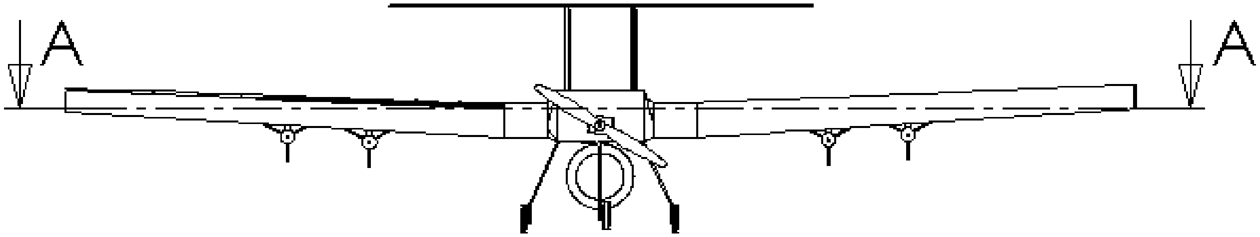
TITLE:

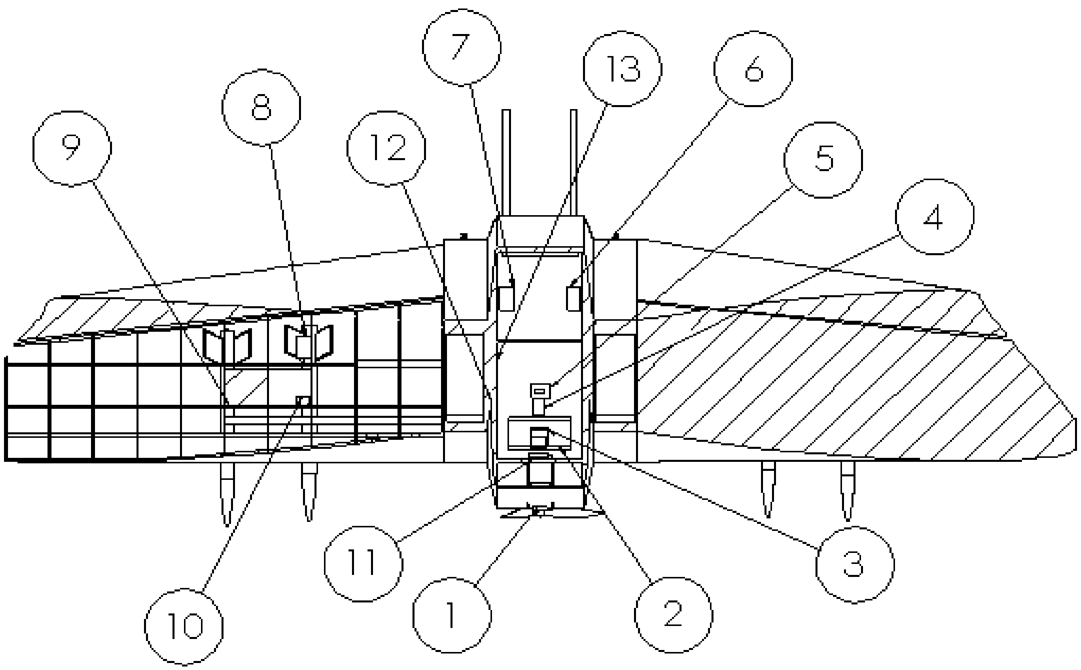
Component Diagram

SIZE	DWG. NO.
A	PlaneAssemExpDraw

SCALE 1:15	Drawing Pkg	SHEET 2 OF 4

5 4 3 2 1





SECTION A-A
SCALE 1 : 20

Item Number	Component
1	Motor
2	Main Battery
3	Receiver Battery
4	Receiver x2
5	Bottle Servo
6	Elevator Servo
7	Rudder Servo
8	Flaperon Servo
9	Outter Rocket Servo
10	Inner Rocket Servo
11	Speed Controller
12	Fuse Box
13	On/Off Switch

UofA DBF Sr Team	
TITLE: Systems Layout	
SIZE A	DWG. NO. PlaneAssemSystems
Drawing Pkg	SHEET 3 OF 4

5 4 3 2 1

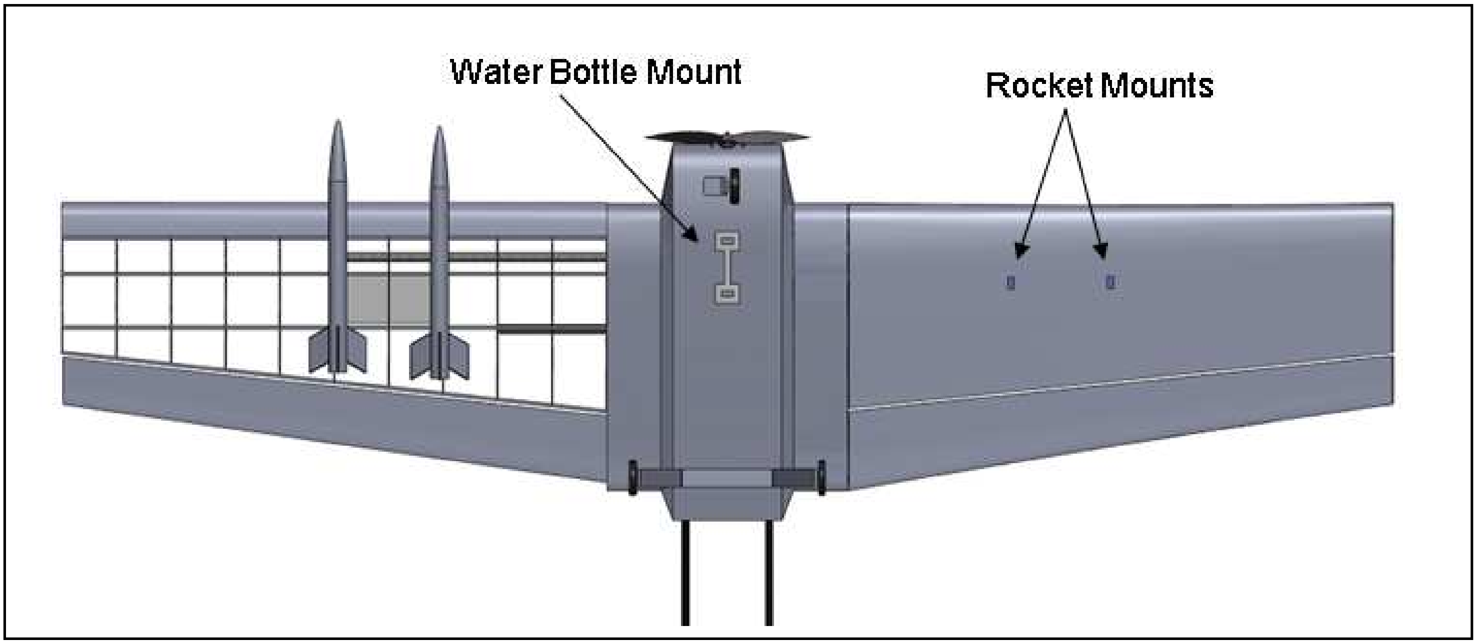


Figure 5.8a Layout of the Payloads and Mounts

5.9 Human Factors Analysis

Human factors analysis considers human ability and how to decrease errors when at competition. The ability of the team's execution during AIAA DBF competitions is crucial to being competitive and scoring well. Since much of the competition is based around timed events, the team must be organized and efficient when assembling the plane and attaching payloads. The team must also be careful not to damage any part of the plane prior or during competition. Human error is inevitable during such a competition, and so it is important to minimize this error as much as possible through practice and becoming familiar with the plane and competition layout. Table 5.7a outlines the timed events during the competition, what possible human errors could occur, and how the team plans to avoid such error.

Table 5.9a Human Errors Analysis

Timed Event	Potential Human Error	Avoidance Methods
Assembly of Aircraft	Slow due to lack of familiarity with the attachment methods Damaging electrical components or plane if rushing	Before competition, become familiar with attachment methods and set up a routine to follow that allows plane to be assembled quickly and carefully
Attachment of Payloads	Slow due to being unfamiliar with payload configurations and loading plan	Before competition, practice loading the payloads quickly onto the aircraft and become familiar with configurations
Ferry Flight	Slow and/or inaccurate at following the course	Perform frequent flight tests so that the pilot becomes familiar with the plane and course

6.0 MANUFACTURING PLAN

6.1 Manufacturing Methods

The team investigated three different construction and material types for the wings and aircraft body: composites, foam, and balsa wood. A composite wing would be light and very strong, especially if it has a foam core. However it is a very complex process. Due to the nature of the competition, multiple test flights are required and crash landing the plane is expected. Because of the complexity and time consuming nature of building a composite wing, repairing the wing after a crash would be very difficult. Integrating the servos for the load release and ailerons would also make the composite process more complex. A foam wing would be the lightest construction material. It would be coated with Monokote, a heat shrink plastic wrap to create a smooth surface. The foam wing would be very simple and fast to build with a foam cutter compared to the composite wing. However, the foam is the weakest method investigated and is most likely to break in a crash. If the plane crashes during the competition, the entire wing would need to be replaced since repairs to the foam would be nearly impossible. Incorporating the servos and wing load supports would also be difficult in the foam wing since sections would need to be cut out of the foam airfoil.

The final construction consideration was a balsa wing with carbon fiber spars for support. A balsa wood wing would be lighter than a composite wing and nearly as strong. It would also be coated with Monokote to create a smooth surface. Initially building the wing would be very time consuming. However, a balsa wing could be repaired in sections fairly easily with replacement pieces available at competition. It would also be simple to incorporate the servos and load infrastructure the balsa wood design. The team ultimately chose the balsa wood design because of the light weight, strength, and ease of repair of balsa. The empennage and fuselage will also be constructed of balsa for similar reasons.

6.2 Actual Construction Methods

6.2.1 Wing and Empennage Construction

The frame of the wing was cut from 3/32-inch thick balsa wood. The NACA 4415 airfoil ribs were accurately cut using a X-660 Laser Cutter. Two 0.700" carbon fiber rods were inserted into the wing to ensure structural integrity, and to eliminate twist. The carbon fiber rods were also used to help create the desired dihedral. In addition to carbon fiber rods, balsa stringers were used to add structural support and maintain the airfoil's desired shape. Figures 6.2.1a and c show the wing architecture in detail.

The horizontal and vertical tails were constructed out of ¼" x ½" and ¼" x ¼" balsa wood. The internal structure of both stabilizers featured a truss construction. Each of the control surfaces for the wing and the tail were made from solid balsa. The wing, the horizontal tail, and the vertical tail were covered with the heat shrink-wrap, MonoKote, to create a smooth surface. Figure 6.2.1b shows the construction of the empennage.

Figure 6.2.1a Wing Construction

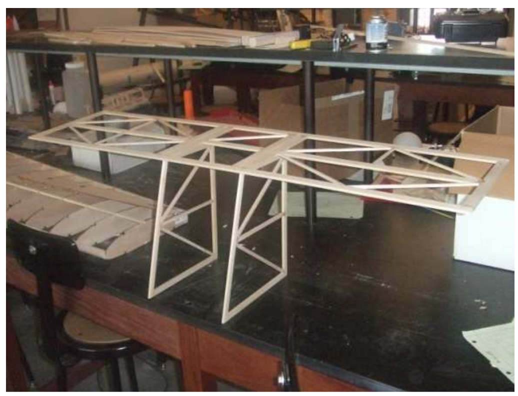


Figure 6.2.1b Empennage Construction

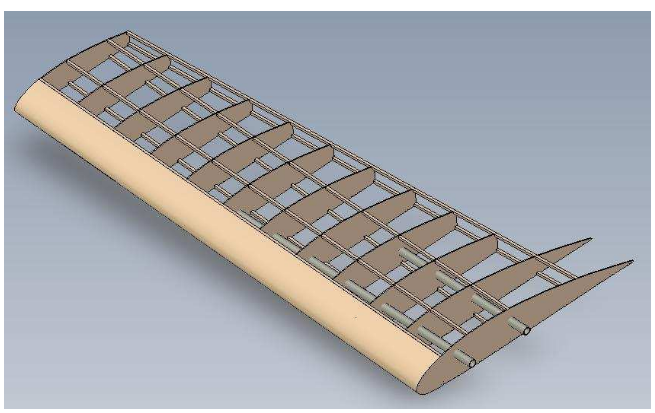


Figure 6.2.1c Solidworks Wing Detail

6.2.2 Fuselage Construction

The fuselage was constructed using the airfoil-shaped rib design similar to the method used for wing construction. Two ribs were cut out of 1/8" birch aircraft ply, scaled larger than the root chord of the wing, to make the main outline of the fuselage. These ribs were then joined with the ¼" birch aircraft ply firewall and several 1/8" ply formers, positioned for structural integrity and to integrate the tail spars. For the underside of the fuselage, 1/8" ply was used to provide the integrity needed to support the water bottle payload and for mounting all the components together. Two carbon fiber rods were inserted through the middle of the fuselage to attach the wings, while two short rods were inserted to the back of the fuselage in order to mount the tail. The airfoil shape of the fuselage allowed for the motor to be mounted semi-internally into the craft, eliminating the need for a traditional nose cone. Two wing sections were built onto either side of the main fuselage section in order to maximize the wing span and to make use of the room in the box on either side of the narrow main section. Hatches were constructed in the top of each of the three sections in order to reach the internal components. Aside from the bottom and sides of the fuselage section, the rest was sheeted in 1/16" balsa wood and then covered in MonoKote. Figure 6.2a shows the construction of the fuselage.

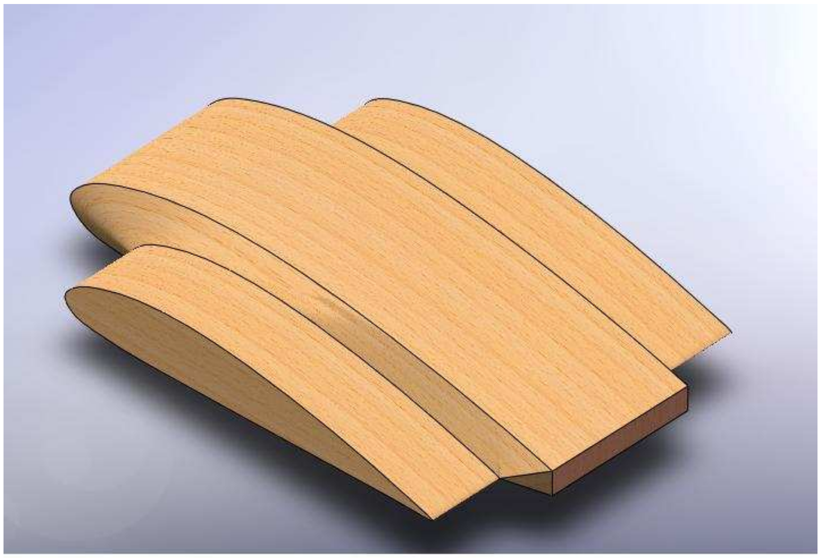


Figure 6.2.2a: Fuselage section

6.3 Overall Construction

The wings will be broken into three sections so that the span fits in the required box dimensions of 2 x 2 x 4 ft. The middle section that is attached to the fuselage is 20 in wide. A carbon fiber rod will extend the width of the fuselage with 1.75 in of rod sticking out on either side for attachment to the wings. The remaining wing sections will each be 3 ft 8 in long with a max cord of 1.98 ft. The wings will have 4 in of carbon fiber rod extending from the ends to slide into the rods sticking out of the fuselage section. A hitch pin will then be used to secure the rods and wings.

In order to maintain longitudinal stability, the horizontal tail will be located 4.9 feet behind the leading edge of the wing. Because of the size limitations of the box, the entire length of the plane will not fit in the box without disassembly. To accommodate this, the boom rods will detach from the fuselage as well as the empennage and placed separately in the box. During assembly the rods will be attached to the fuselage and the bottom of the vertical stabilizers in the same pin and sleeve method as the wings. Since the horizontal tail has a span of 2.5 feet, it must be placed spanwise down the length of the box. The center section containing the fuselage, propulsion configuration, landing gear and boom rods will fit the box lengthwise.

6.3.1 Milestone Manufacturing Chart

ID		Task Name	Duration	Start	Finish	% Complete
40		**Manufacturing**	**79 days**	**Thu 1/1/09**	**Fri 4/17/09**	**26%**
41		Material procurement	37 days	Thu 1/1/09	Wed 2/18/09	60%
42		Wing construction	46 days	Thu 1/1/09	Tue 3/3/09	20%
43		Fuselage construction	41 days	Tue 1/6/09	Fri 2/27/09	20%
44		Propulsion and servo wiring	34 days	Tue 1/13/09	Fri 2/27/09	30%
45		Re-work	33 days	Wed 3/4/09	Fri 4/17/09	0%

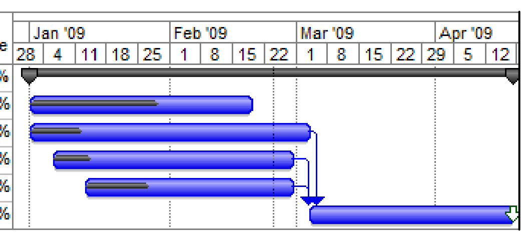


Figure 6.3.1 below shows the plane after all manufacturing was completed.

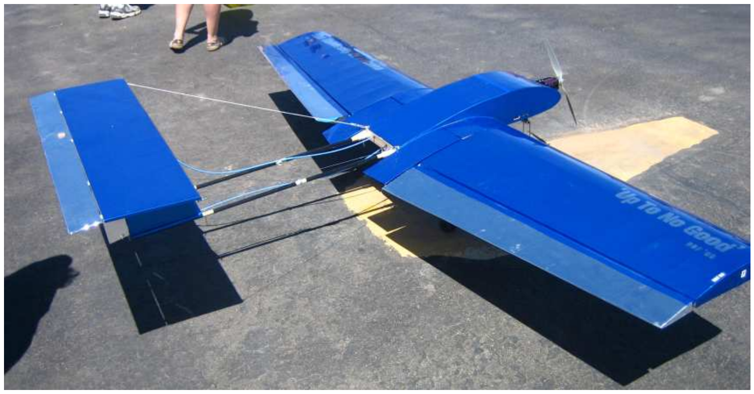


Figure 6.3.1 Finished product

7.0 TESTING PLAN

7.1 Propulsion Testing

The propulsion system will be tested to determine the endurance time and amperage draw from the batteries. The receiver, speed controller, and motor with propeller will be set up and wired as indicated in the wiring diagram in Section 5.3. An ammeter will be placed inline between the batteries and the speed controller to measure the amps while the thrust is varied between throttle settings. The motor will be set at flight thrust of 25 N, approximately 80% throttle, while the amperage is observed. The time until the amperage begins to decrease will be recorded to determine the endurance of the batteries. The batteries will then be recharged and the mAh required for complete recharge noted for comparison to battery drain during flight testing. Based on the results of these tests, the battery configuration will be optimized so that the flight endurance is achieved with minimum battery weight.

7.2 Structural Testing

Testing the structural integrity of the aircraft will be based on the wingtip test as outlined in the competition rules. During the construction phase, a wingtip test will be performed on the airplane at empty weight. If no strain is detected, the test will then be performed at minimum flight weight – total weight minus payload. The test will be repeated with increasing payload weight until the total Surveillance Flight weight is reached without strain. If strain is detected at any point, the aircraft will be inspected for any damage as well as reinforced at the necessary locations.

The wingtip test ensures structural integrity of the plane to handle aerodynamic loads in flight. The spanwise center of pressure on the wing is located a third the distance from the fuselage to the wingtip, or b/6, where b is the wingspan. Half of the total lift force is located at this center of pressure, making the bending moment at the root of the wing:

$$M_b = \frac{L}{2}\frac{b}{6} \quad \text{Eq. 7.2a}$$

But during the wingtip test, half the weight of the airplane is concentrated at b/2, making the bending moment:

$$M_b = \frac{W}{2}\frac{b}{2} \quad \text{Eq. 7.2b}$$

Equating the two moments and rearranging results in L/W=3. This means that the bending moment is three times larger during the wingtip test than during flight. Thus being able to withstand the wingtip test gives our plane a structural safety factor of 3.

7.3 Flight Testing

Flight testing is the most valuable form of verifying conceptual design and performance models. Flight testing is important to work out any problems before competition and to optimize performance.

7.3.1 Flight Test Schedule

The flight test schedule of the test objectives and deadlines can be seen in Table 7.3.1a.

Table 7.3.1a Testing Schedule

Test	Objective	Date
Static Testing	Check electrical connections, mechanical structures, and functionality of control surfaces.	7-Mar
Payload release test	Test setup capabilities of securing and releasing centerline and wing payloads.	7-Mar
Maiden Flight	Test aircraft performance and modify design as needed. Become familiar with flight handling characteristics.	8-Mar
Centerline Tank Test	Test aircraft performance with empty centerline tank to determine drag effects on handling.	14-Mar
Wing Load Testing	Test aircraft performance with wing loads and handling and stability after releasing a load.	21-Mar

Full Centerline Tank	Test aircraft performance with full centerline tank to determine flight capabilities and take-off distance.	28-Mar
Additional Flight testing	Fly aircraft of all simulated missions and optimize performance for competition.	4/4 - 4/16
Pit Crew Practice	Team members practice aircraft assembly and loading	3/14-4/16

Figure 7.3.1 shows the plane during its second test flight.

Figure 7.3.1: Flight test on April 16

7.3.2 Flight Test Check List

Pre-flight and in-flight checklists were created to ensure smooth test sessions and to avoid unnecessary errors and accidents. The preflight checklist is designed to ensure that the plane has been configured properly at the flying location. The in-flight checklists will be used to evaluate each test flight along with pilot feedback. The checklist will be reviewed to identify any adjustments required to improve performance.

Table 7.3.2a Pre-Flight Checklist

Item	Completed
Wings secured	
Tail secured	
Landing gear condition	
Propeller mounting	
Electrical connections	
Payload loaded properly	
Receiver power	
Control surfaces operational	
Emergency procedures	

Table 7.3.2b In-Flight Checklist

Taxi/Ground Operation	Real-time Comments
Low/High speed taxi	
Straight tracks	
Control surfaces operational	
Flight 1 (No Payload)	
Takeoff and landing control	
Control while turning	
Control while climbing and diving	
Check airplane condition	
Flight 2 (Centerline tank)	
Max power takeoff	
Takeoff distance	
Repeat Flight 1 test	
Full deflection of control surfaces	
Full stop landing	
Check airplane condition	
Flight 3 (Wing Loads)	
Max power takeoff	
Takeoff distance	
Repeat Flight 1 test	
Full deflection of control surfaces	
Control after dropping rocket	
Takeoff after dropping rocket	
Full stop landing	
Check airplane condition	
Additional Testing	
Simulate competition mission, study performance	
Ground crew speed and reliability	

8.0 PERFORMANCE RESULTS

The first test flight was conducted on April 12, 2009. The aircraft was determined to be stable and controllable, but problems with the motor mount and batteries prevented further testing. On April 16, 2009, the aircraft successfully flew with all payload configurations. However, problems with the Speed Controller prevented the aircraft from performing to its full capacity, and the plane exceeded the 100 foot runway restriction without the aid of a headwind. On April 19, 2009, the plane successfully took off in less than 100 feet without the aid of a headwind with a full load.

Based on the flight testing conducted by the team, the aircraft is capable of successfully completing all missions. The aircraft is able to take-off in less than 100 feet with a full payload, and the variable weight in the rocket drop mission does not significantly affect aircraft performance. The aircraft is able to fly with an asymmetric loading with minimal to no trim. Additionally, due to the light lift to weight ratio, the airplane is able to safely land without the use of power. This is important for increasing the life of the aircraft in the event of an unplanned loss of power.

Figure 8.0 Mission 1 Ferry Flight at competition

9.0 ACKNOWLEDGEMENTS

The University of Arizona DBF team would like to thank Raytheon Missile Systems for their sponsorship. Special acknowledgement goes to Dr. Thomas Balsa and the Tucson Section of AIAA for all of their support and help throughout the course of this project.

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