ME 628: Aerodynamics
Glider Design Report

December 17, 2014

Team: We Had Another Cool Name But Thomas Didn’t Like That One Either

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Introduction

As a comprehensive final project for our Aerodynamics course, Dr. Beck assigned us the task of designing and building a glider. This glider should be capable of flying 200 ft when launched from a height of 20 ft. Additionally, the glider will be carrying a weight between 2 oz and 18 oz. This report details our initial design process, calculations, material selection, budget, construction, testing, modifications, final Weber Arena flight test, and our evaluation of this final test. We will begin by discussing our design process.

Design Process and Calculations

From our study of gliders in class, we knew that a major factor in the performance of our glider would be the ratio of lift coefficient over drag coefficient. Because of this fact, we researched wing airfoil shapes with an exceptionally high lift coefficient over drag coefficient ratio. Our research led us to the HQ3015 airfoil [1], which is commonly used in sailplanes. The HQ3015 airfoil has several beneficial characteristics, including a high glide ratio at lower Reynold's numbers and a wide range of angles of attack with a positive coefficient of lift. For simplicity we chose a non-cambered airfoil for our horizontal and vertical tails, the NACA 0012 [2].

Now that we had chosen our airfoils, we needed to specify initial values to start the iterative design process. We left ourselves 8 inches to allow for any needed modifications or errors in manufacturing. Next we needed to calculate the center of gravity position. We assumed a rectangular profile for all our components and used the dimensions and the densities we looked up online to define those weights. We also assumed that the center of gravity of each component was halfway through it. This allowed us to calculate the center of gravity at ~9.2 inches from the nose.

Next we wanted to calculate the longitudinal stability of our plane. We defined a starting distance between the A.C of the wing and tail and then iterated until our margin of stability was

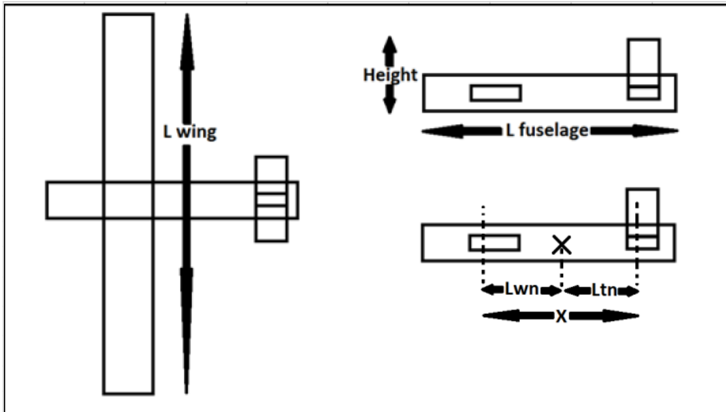
~80% since that made us stable over the full range of the payload weights. Next we sized our vertical tail according to convention since that was the only way we covered it in class. We ended up with a size of about 56 square inches, which was under our specified size of 72 square inches so we believed we had sufficiently accounted for downwash.

Now we needed to calculate the glider characteristics. We started with attitude angle. We used the data given on the airfoil tools website to approximate the angle of the Cl curve for both airfoils and calculated the horizontal tail volume. Using that data we calculated an effective angle of 3.5 degrees.

Next we calculated the glide velocity. We assumed a glide angle to start with that we would change when we calculated it in the next step. We weren't sure how to iterate the Cm of the wing given the curve shape, so we assumed it was symmetric like we did in class for the Starfire glider even though we know our wing has camber. This allowed us to use the moment equation to solve for our q, which we then used to solve for the glide velocity, which we calculated as 34 ft/sec. This seemed really high, but we decided to move forward since we were sure it would be much less than that and we knew there would be some error since we assumed a symmetric airfoil.

Finally we calculated the glide angle. We used the data for our airfoils from online to calculate a Cd for the wing and tail of 0.02. Then we looked back at our drag test lab results and took the value for our fuselage from the 20 mph test of 0.02 since we believed that would be the closest to our actual glide speed. So our total drag coefficient was 0.06. With that and our specified planform areas and weight we calculated the glide angle as 14 degrees, which was higher than what we hoped it would be.

A spreadsheet summary of all these calculations can be seen in Figure 1, on the next page.



Longitudinal Stability		
Lwn =	11.62174	in
Ltn =	37.87826	in
Lw-Lwn =	-6.45458	< 0 Goal
Stability Margin =		80.68%

$$l_{wn} = \overline{X}\left(\frac{S_t}{S_t + S_w}\right)$$

$$Margin\ of\ Stability = \frac{l_{wn} - l_w}{C_w}$$

Lateral Stability		
Vvt =	55.89716	in2

$$V_{vt} = \frac{l_{vt} * S_{vt}}{b * S_w}$$

Attitude Angle Calculation:		
awing =	0.092791	1/deg
atail =	0.082247	1/deg
VHT =	1.700265	unitless
α_{eff} =	3.500061	deg

$$V_H = \frac{l_t * S_t}{C_w * S_w}$$

$$\alpha_{eff} = \frac{V_H * i_t * a_t}{\frac{l_w}{C_w} * a_w - V_H * a_t}$$

Glide Velocity Calculation:		
αg = *	14	deg
q =	1.357648	
Vg =	34.16612	ft/sec

$$V_g = \sqrt{\frac{2 * q}{\rho}}$$

$$q = \frac{W * \cos(\alpha_g)}{S_w * a_w * \alpha + S_t * a_t * (\alpha - i_t)}$$

Center of Gravity		
Distances		
X_{wing} =	6	in
$X_{fuselage}$ =	5	in
X_{tail} =	55	in
X_{boom} =	28.75	in
$X_{payload}$ =	5	in
Weights		
W_{wing} =	0.896296	lb
$W_{fuselage}$ =	0.052083	lb
W_{tail} =	0.12	lb
W_{boom} =	0.114583	lb
$W_{payload}$ =	1.125	lb
ΣW =	2.307963	lb
Calculations		
Xcg =	9.16716	in
Lw =	5.16716	in
Lt =	44.33284	in

$$X_{cg} = \sum_{i=1}^{n} \frac{X_i * W_i}{\sum W}$$

General Dimensions		
L_{wing} =	88	in
$L_{fuselage}$ =	58	in
Height =	16	in
Sum =	162	in
Must be <= 170 in.		

Wing Dimensions		
span =	88	in
chord =	8	in
AR =	11	unitless
S =	704	in^2
X =	49.5	in

Fuselage Dimensions		
$L_{fuselage}$ =	10	in
$H_{fuselage}$ =	3	in
$W_{fuselage}$ =	3	in

Boom Dimensions		
Lboom =	49.5	in
Acs =	0.5	in2

Glide Angle Calculation:		
C_{Dtotal} =	0.06	unitless
α_g =	14.07202	deg

$$\alpha_g = \sin^{-1}\left(\frac{q * C_{Dtotal} * S_{total}}{Weight}\right)$$

Tail Dimensions		
Horizontal Tail		
span =	36	in
chord =	6	in
AR =	6	unitless
S =	216	in^2
Vertical Tail		
Height =	12	in
chord =	6	in
AR =	2	unitless
S =	72	in^2

Foam Density		
1 lb/ft3 =	0.000579	lb/in3
Balsa Density		
8 lb/ft3 =	0.00463	lb/in3

We looked up densities for the foam and balsa so we could calculate weights for our components. We assumed a rectangular cross section for each component.

Wing Airfoil Data		
HQ 3015		
α_{design} =	3.43	deg
h =	3	%chord
thick. =	15	%chord
α_{ZL} * =	-3.43775	deg

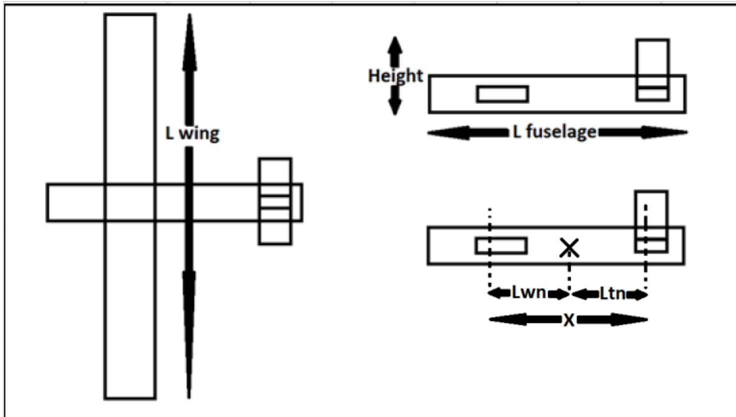
Tail Airfoil Data		
NACA 0012		
α_{design} =	-2	deg
h =	0	%chord
thick. =	12	%chord
α_{ZL} * =	0	deg

Lift Estimate		
V_g guess	26	ft/s
rho air =	0.0749	lbm/ft3
q =	0.786217	lb/ft2
C_{LW} =	0.637266	unitless
Lift =	2.449479	lb

$$L = C_L * q * S_w$$

Figure 1. Initial Excel Calculations Continued

We decided that our calculations looked good enough to go ahead and start construction. After we actually had the parts we were able to correct a lot of our calculations. We were able to measure the actual density of the foam and the actual weight of each component, and we decided to assume a center of gravity at one-third of the chord length for our wing and tail rather than the one-half we started with. With these changes our calculations (and initial testing) showed the plane to be longitudinally unstable. So we added an additional weight inside the nose of our fuselage to correct for that as well as increasing the size of our tail. We have included those corrected calculations in the spreadsheet given below in Figure 2.



Longitudinal Stability		
Lwn =	11.85652	in
Ltn =	38.64348	in
Lw-Lwn =	-3.72925	< 0 Goal
Stability Margin =	46.62%	

$$l_{wn} = \overline{X}\left(\frac{S_t}{S_t + S_w}\right)$$

$$Margin\ of\ Stability = \frac{l_{wn} - l_w}{C_w}$$

Lateral Stability		
Vvt =	58.4829	in2

$$V_{vt} = \frac{l_{vt} * S_{vt}}{b * S_w}$$

Attitude Angle Calculation:		
awing =	0.092791	1/deg
atail =	0.082247	1/deg
VHT =	1.62509	unitless
α_{eff} =	6.786245	deg

$$V_H = \frac{l_t * S_t}{C_w * S_w}$$

$$\alpha_{eff} = \frac{V_H * i_t * a_t}{\frac{l_w}{C_w} * a_w - V_H * a_t}$$

Glide Velocity Calculation:		
αg = *	7.2	deg
q =	0.832978	
Vg =	26.76201	ft/sec

$$V_g = \sqrt{\frac{2 * q}{\rho}}$$

$$q = \frac{W * \cos(\alpha_g)}{S_w * a_w * \alpha + S_t * a_t * (\alpha - i_t)}$$

Center of Gravity		
Distances		
X_{wing} =	5	in
$X_{fuselage}$ =	7	in
X_{tail} =	55	in
X_{boom} =	35	in
$X_{payload}$ =	5	in
X_{weight} =	1	in
Weights		
W_{wing} =	0.52	lb
$W_{fuselage}$ =	0.15	lb
W_{tail} =	0.27	lb
W_{boom} =	0.185	lb
$W_{payload}$ =	1.125	lb
W_{weight} =	0.5	lb
ΣW =	2.75	lb
Calculations		
Xcg =	11.12727	in
Lw =	8.127273	in
Lt =	42.37273	in

$$X_{cg} = \sum_{i=1}^{n} \frac{X_i * W_i}{\sum W}$$

General Dimensions		
L_{wing} =	88	in
$L_{fuselage}$ =	65	in
Height =	17	in
Sum =	170	in
Must be <= 170 in.		

Wing Dimensions		
span =	88	in
chord =	8	in
AR =	11	unitless
S =	704	in^2
X =	50.5	in

Fuselage Dimensions		
$L_{fuselage}$ =	14	in
$H_{fuselage}$ =	3	in
$W_{fuselage}$ =	3	in

Boom Dimensions		
Lboom =	48	in
Acs =	0.5	in2

Glide Angle Calculation:		
C_{Dtotal} =	0.06	unitless
α_g =	7.192251	deg

$$\alpha_g = \sin^{-1}\left(\frac{q * C_{Dtotal} * S_{total}}{Weight}\right)$$

Tail Dimensions		
Horizontal Tail		
span =	36	in
chord =	6	in
AR =	6	unitless
S =	216	in^2
Vertical Tail		
Height =	12	in
chord =	6	in
AR =	2	unitless
S =	72	in^2

Foam Density		
1 lb/ft3 =	0.000579	lb/in3
Balsa Density		
8 lb/ft3 =	0.00463	lb/in3

We looked up densities for the foam and balsa so we could calculate weights for our components. We assumed a rectangular cross section for each component.

Wing Airfoil Data		
HQ 3015		
α_{design} =	3.43	deg
h =	3	%chord
thick. =	15	%chord
α_{ZL} * =	-3.43775	deg

Tail Airfoil Data		
NACA 0012		
α_{design} =	-2	deg
h =	0	%chord
thick. =	12	%chord
α_{ZL} * =	0	deg

Lift Estimate		
V_g guess	27.6	ft/s
rho air =	0.0749	lbm/ft3
q =	0.88596	lb/ft2
C_{LW} =	0.637266	unitless
Lift =	2.760229	lb

$$L = C_L * q * S_w$$

Figure 2. Final Excel Calculations

After we completed these initial calculations, we modeled our design in Solidworks. This Solidworks model provided us with very detailed dimensions of our design. Additionally, this model aided in the construction process by giving us a 3D model to reference. Below are detailed drawings and isometric views of each part of our glider.

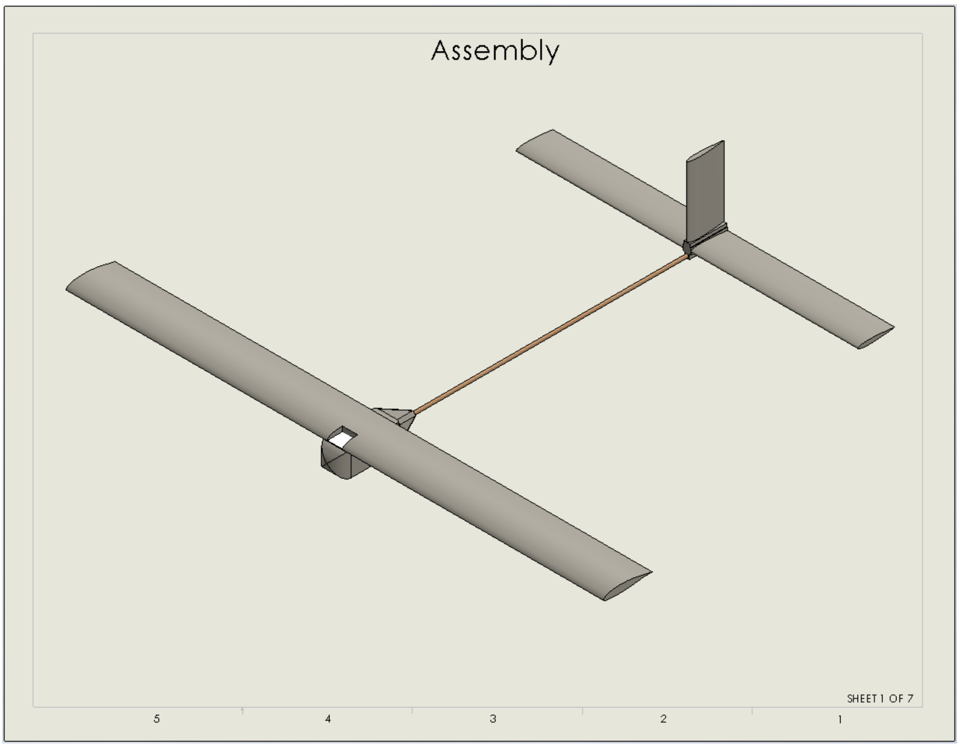


Figure 3: Isometric View of Glider Model

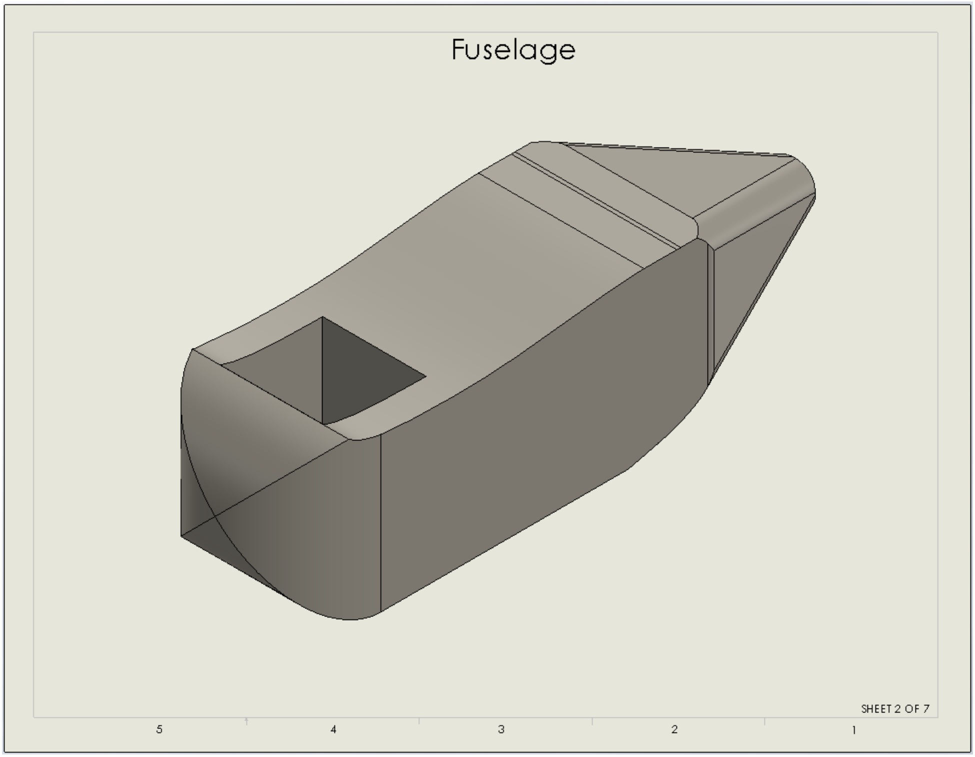


Figure 4: Isometric View of Fuselage Model

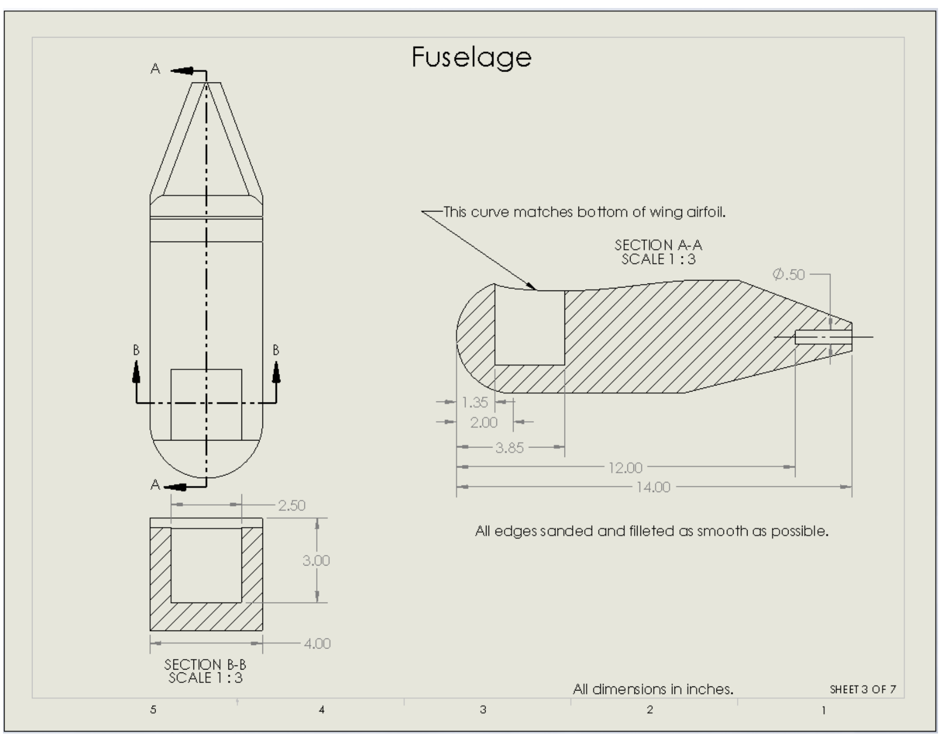


Figure 5: Dimension Drawings of Fuselage

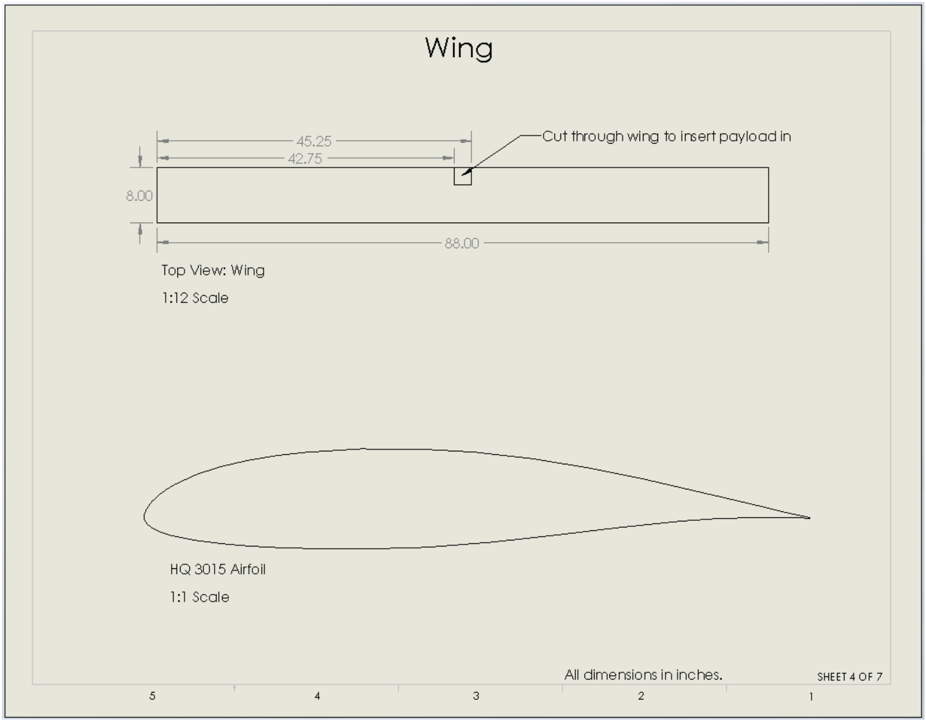


Figure 6: Dimensioned Drawings of Wing

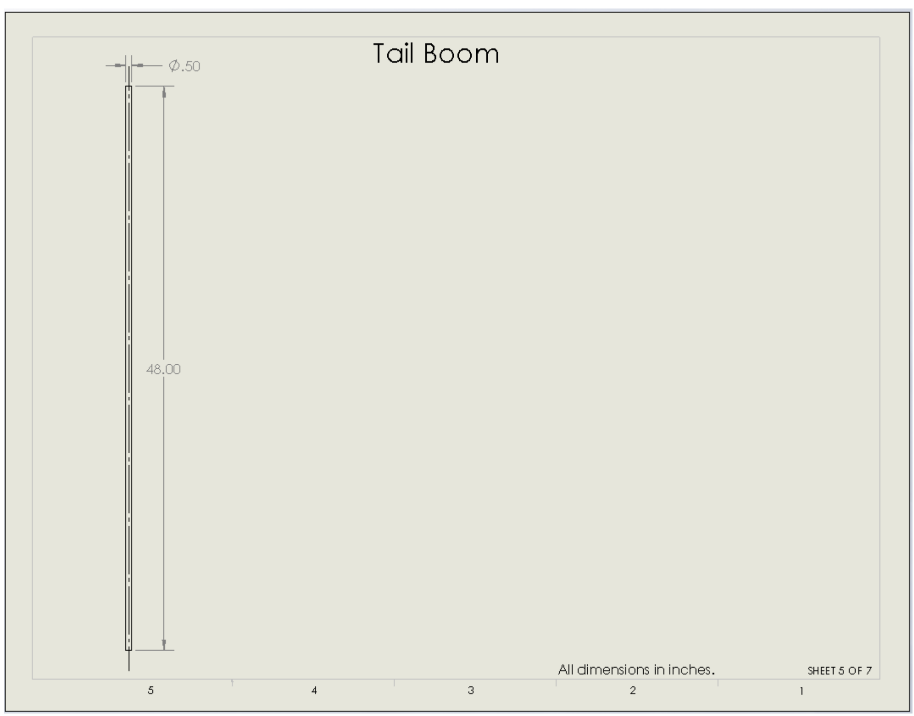


Figure 7: Dimensioned Drawings of Tail Boom

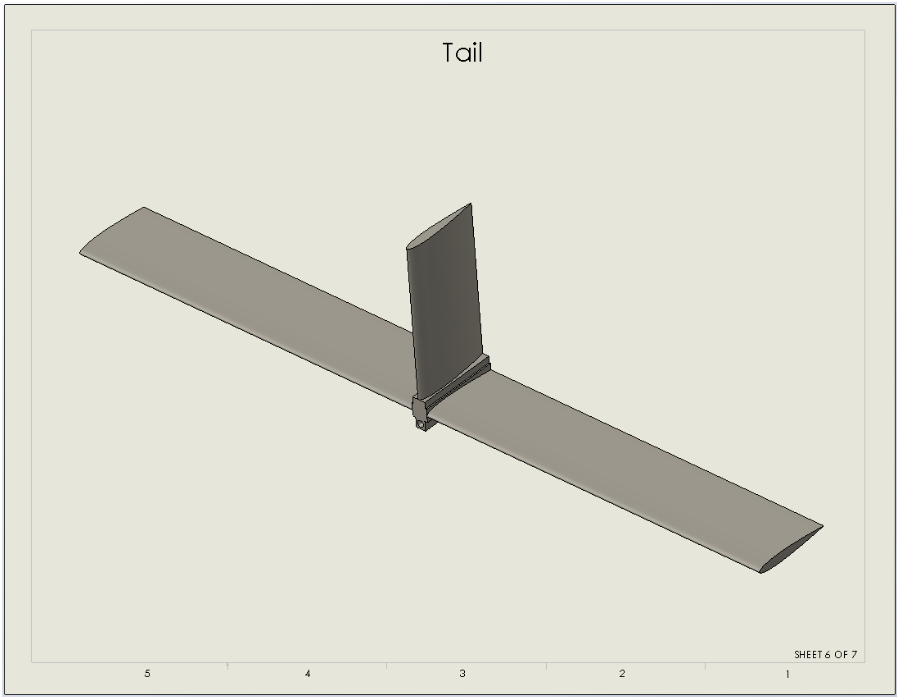


Figure 8: Isometric View of Tail Model

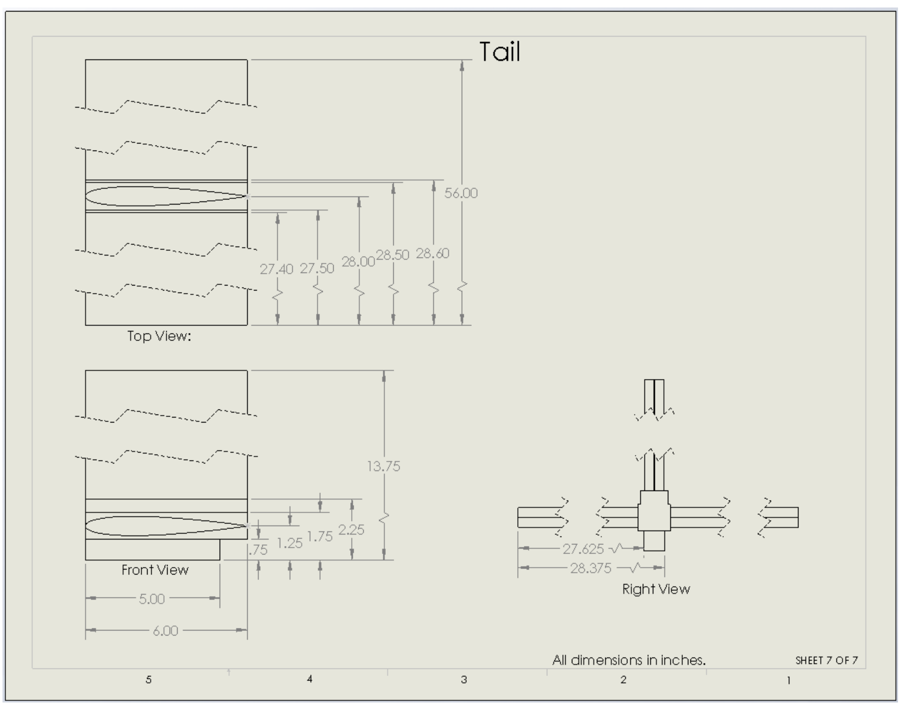


Figure 9: Dimensioned Drawings of Tail

Next, we compiled these drawings with the above calculations to estimate the locations of our center of gravity and neutral point. A final drawing detailing all our overall dimensions is below.

This drawing includes wingspan, glider length, tail span, total glider height, aerodynamic center locations, center of gravity location, and the neutral point location.

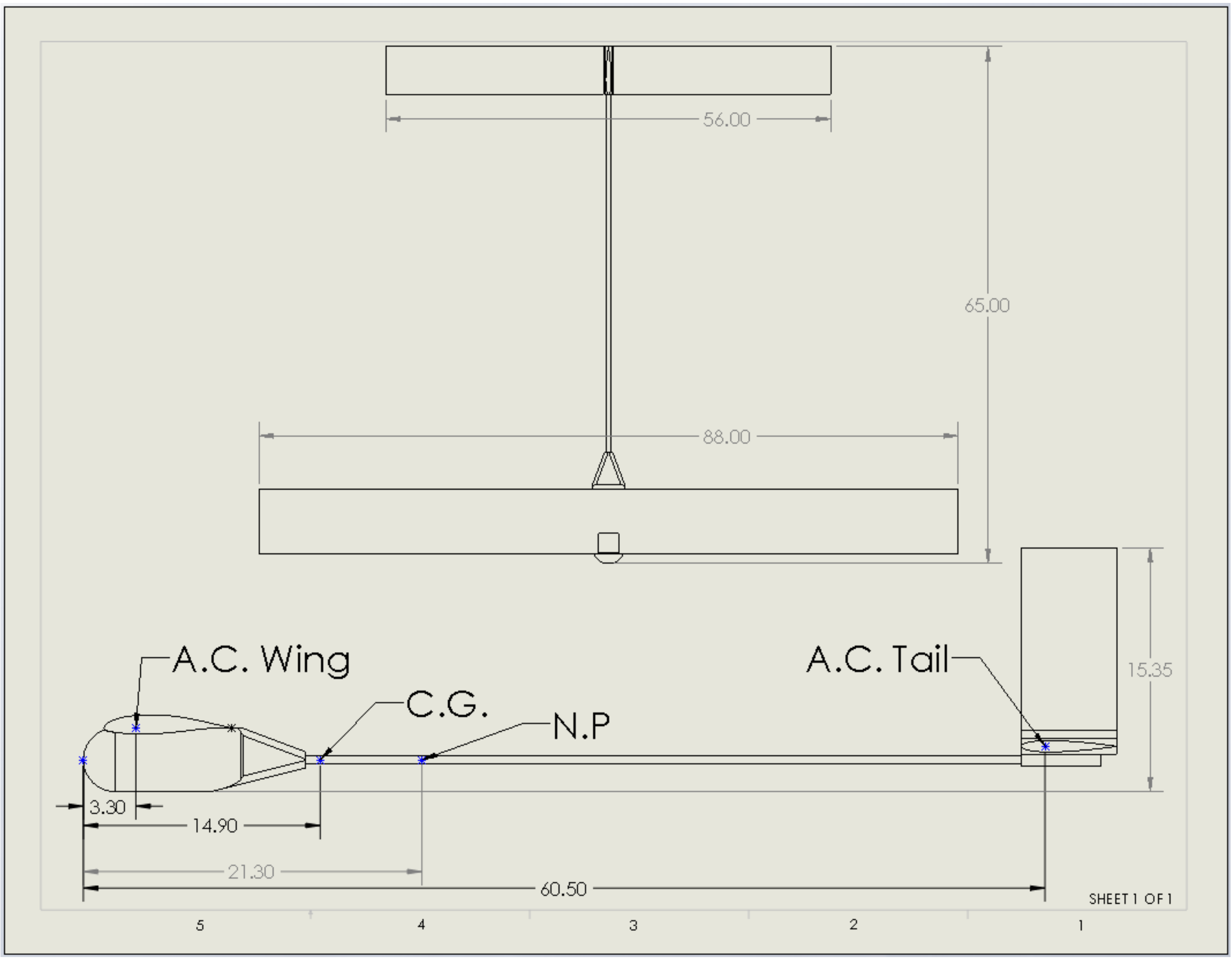


Figure 10. Drawing of Overall Design

Next, we began the construction process by selecting and purchasing materials.

<u>Material Selection and Budget</u>

Unfortunately, we were not able to complete our design process early enough to buy our materials online. This delay increased our overall cost, because ordering items online is often less expensive. It also meant our selection of materials was limited to items that are available in and around Manhattan.

We decided to construct our wing, fuselage, and tails out of foam. We made this selection because of foam's light weight. The only available foam was rigid insulation, which we purchased from Home Depot. To cut our airfoils we planned to use a hot bow borrowed from either the Aero Team or the UAV Team. To utilize a hot bow we would need to cut patterns. Our initial plan was to cut these patterns out of acrylic plastic, which we bought from Home Depot. Unfortunately, we were unable to successfully cut this acrylic and decided to make our patterns out of cardboard, which we bought at Hobby Lobby.

We chose to attach our tails to the fuselage with a balsa rod. However, we could not find a long enough piece of balsa. Instead of balsa, we used a poplar dowel rod purchased from Menards. Finally, we planned to secure all of the components together with epoxy. We initially purchased some J-B Kwik Weld epoxy at Menards, but this brand did not bond to our foam. We were forced to buy a different brand of epoxy from Hobby Lobby.

An itemized list of all our materials can be found below. This list included some items we did not initially plan to include, but bought after testing our glider. Additionally, this list includes the location where the material was acquired and the material's cost.

- 4 ft x 8 ft sheet of rigid insulation - Home Depot - $29.98
- 11 in x 14 in acrylic sheet - Home Depot - $4.24
- Roll of 1.41 in scotch tape - Home Depot - $2.97
- Utility knife - Home Depot - $1.98
- J-B Kwik Weld - Menards - $4.49
- ½ in x 48 in poplar dowel rod - Menards - $1.29
- 5 Minute Epoxy - R/C Hobbies - $11.99
- 3 ft x 3 ft sheet of cardboard - Hobby Lobby - $12.99
- Pack of needles - Walmart - $1.77
- Pack of washers - Walmart - $0.97
- Hand saw - borrowed from Shane - free
- Exacto knife - borrowed from Thomas - free
- Scissors - borrowed from Thomas - free
- Sandpaper - donated by Shane and Travis - free
- Mass of solder - donated by Travis - free
- Fishing line - borrowed from the Measurements Lab - free
- Ketchup cups - McDonald's - free
- Hot bow - borrowed from UAV Design Team - free

- Total Costs: $72.67

Our final costs were considerably over our budget of $50. This excess was largely caused by purchasing materials that did not work properly. These materials include the acrylic and J-B Weld epoxy. If these materials were removed from our budget, we would less than $15 dollars over budget. In hindsight, we should have partnered with another design team to share one sheet of foam. We only used about half of the foam we purchased. Splitting the foam costs with another team would have brought our total costs down near our desired budget. With all our materials purchased, we were able to move on to actual construction.

<u>Construction</u>

Once we had some initial numbers for sizing of various components, we began construction. As the wing and tail were the most crucial components, we started with these first. To ensure proper sizing and geometry we attempted to make guides for use in conjunction with a hot bow. Our first idea for material to make the guides out of was a hard acrylic sheet. Unfortunately, this was extremely difficult to cut into shape. After some thought, we decided to try a hard cardboard material that would be easier to manufacture forms in. We were a little worried at first that it may not work well with the hot wire riding along it, which was why we had originally wanted to use the plastic sheet. We then printed out paper copies that were the slightly larger than our desired chord length. We then cut these into top and bottom sections that would create our airfoils. The paper sheets were then epoxied to the cardboard. After curing, they were then cut out and can be seen in figure 11.

Figure 11. Hot Bow Patterns

Our next step was to procure a hot bow. After some time, we managed to contact the UAV team and receive permission to borrow their hot bow long enough to create our wing and tail sections. We then took foam sections that had been pre-cut and screwed the guides on. With the guides in place, the hot bow was slowly dragged along to carefully cut the airfoil shapes out of the foam pieces.This resulted in a foam sandwich: foam top, airfoil in center, foam bottom, as seen in figure 12.

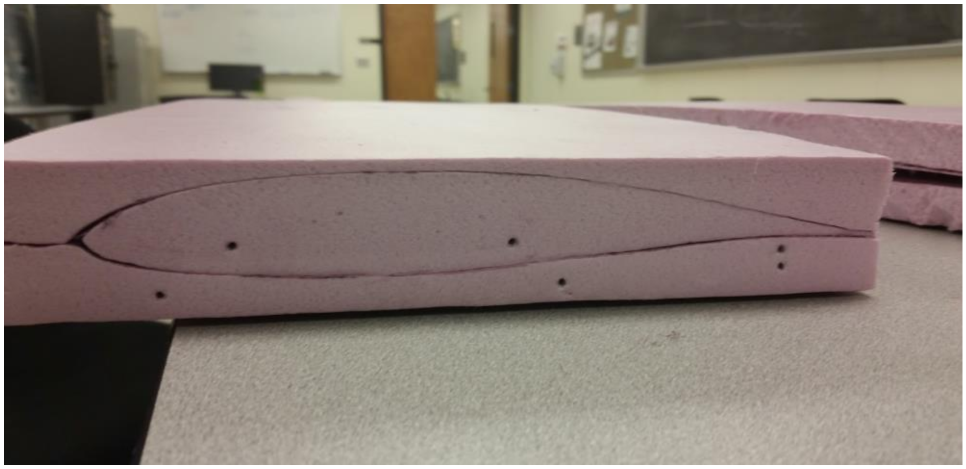
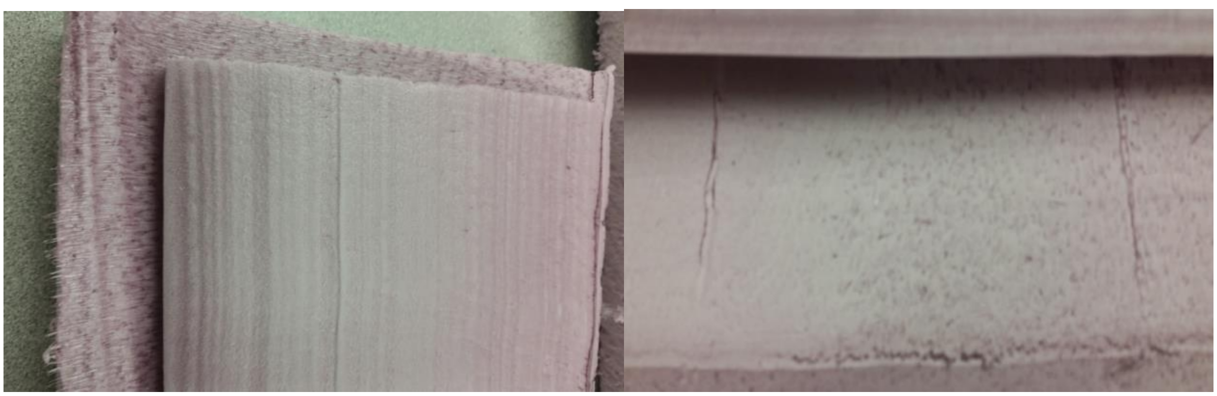


Figure 12. Completed Airfoil

While this resulted in nearly perfect airfoil geometry, the hot bow left surface imperfections and strings that were then sanded down as much as possible without changing the geometry. These imperfections are easy to see in figures 13 and 14.



Figures 13 & 14. Airfoil Errors

With the wing and tail sections cut and sanded, we moved on to creating the fuselage and attaching the wing sections together. The wing sections were epoxied at the ends and left to rest in the foam forms while curing, see figures 15 and 16.

Figures 15 & 16. Wing Construction

While the wing sections cured, we constructed the fuselage. Our first step in creating the fuselage was to use the dimensions from our design process to approximate the size of the fuselage. Our design required a fuselage approximately 14” long, 4” tall, and 4” wide. We then measured and cut two pieces of foam to create this size as shown in figures 17 and 18.

Figures 17 & 18. Fuselage Construction

Before attaching the two pieces of foam together, we decided that we should carve out the 3 in by 2.5 in space for the payload, see figure 19. We then epoxied the two pieces to each other to form our basic fuselage shape.

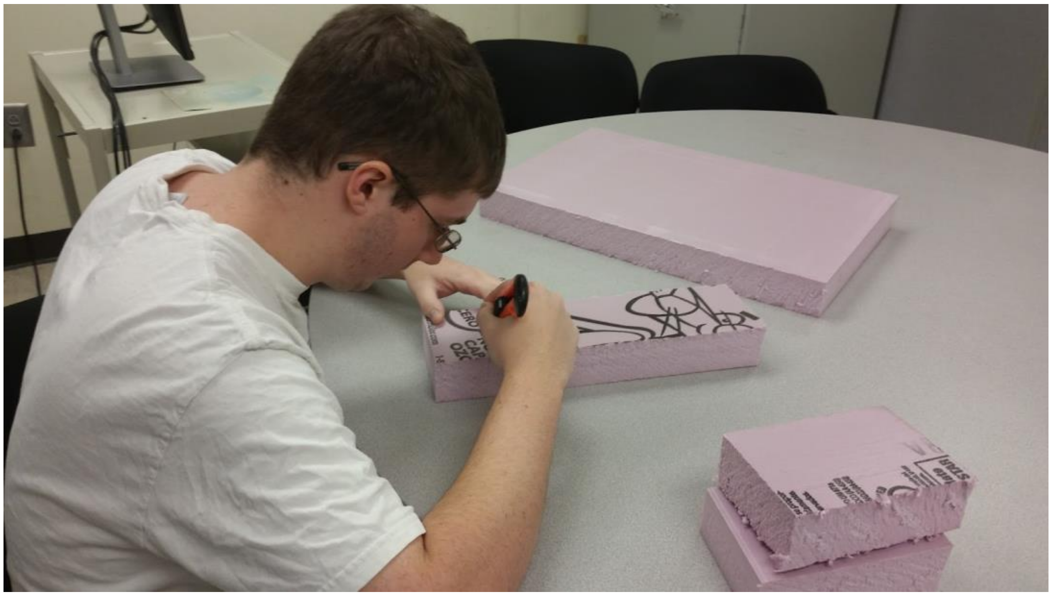


Figure 19. Payload Bay Construction

After the two pieces had set, we decided that it would be best to use a portion of the underside foam left by the airfoil for the wing on the top side of the fuselage. This would make mounting the wing to the fuselage much easier, as the contours were the same. After all the epoxy cured, we proceeded to sand down the nose of the fuselage into a bullet like shape to reduce drag. Several hours later, we had a fuselage shown in figure 20.

Figure 20. Completed Fuselage

During the sanding process on the fuselage, the vertical tail was assembled. We took the vertical tail and epoxied it to two small strips from its form to give a flat mounting surface. This was then epoxied to an upper section of the horizontal tail form and finally to the horizontal tail. A bottom form piece with a small block were epoxied to together and then to the underside of the horizontal tail, see figure 21.

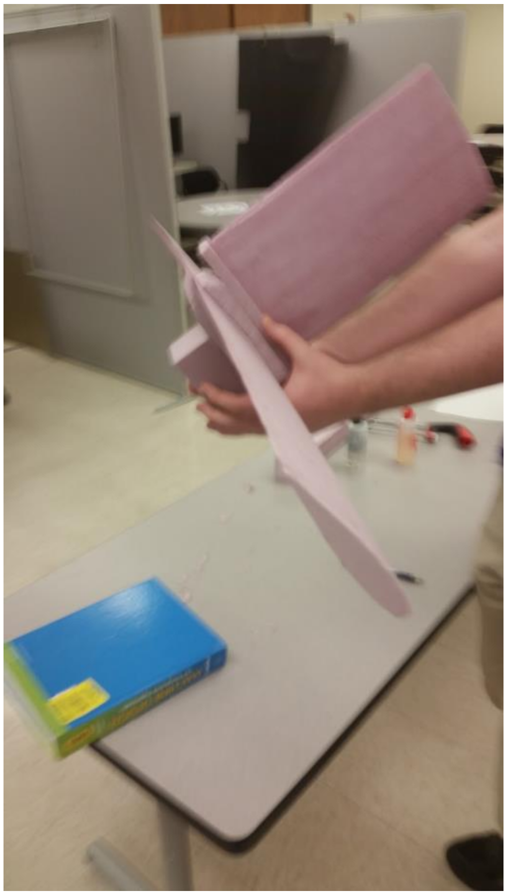


Figure 21. Tail Construction

The block was for mounting the dowel rod from the fuselage to the tail. We then drilled holes into both the fuselage and the block on the tail assembly for mounting. The rear of the fuselage and the block were then sanded to remove as much drag as possible. With all the components complete we proceeded to attach each piece in its proper place with more epoxy. After the curing process was complete, we were finished and very happy to be done!

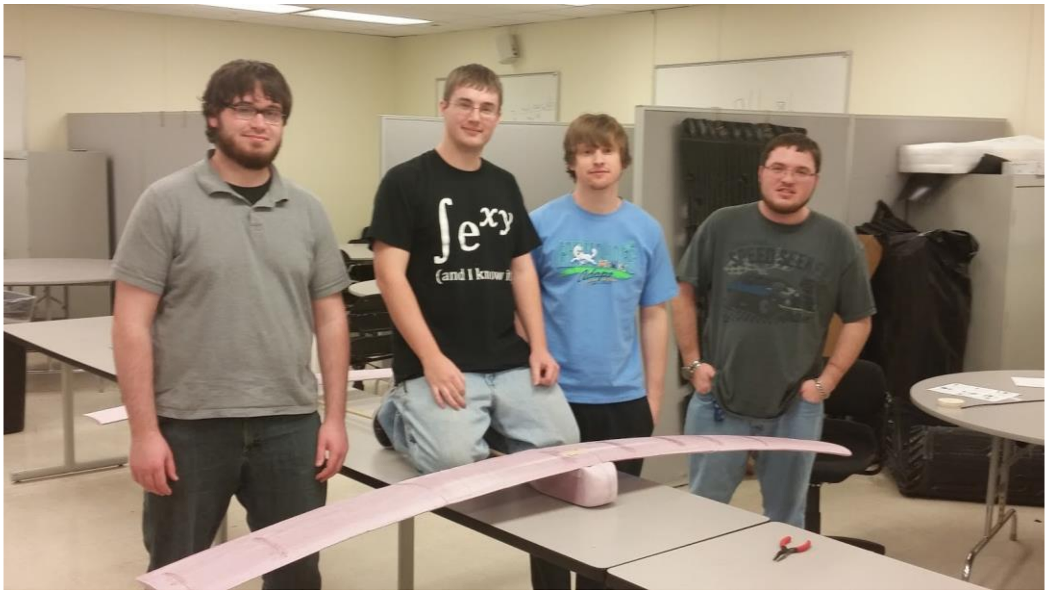


Figure 22. Glider After Initial Construction

<u>Initial Testing</u>

Building completed, we turned to some preliminary testing. We were unsure how well our design would work, if at all, and we knew that our built glider was not exactly the same as our original calculations. Unsure of the strength of the design, our first test was extremely timid. For our first test, we tossed the glider down the length of the table in the senior design room with no obstacles anywhere near it and another person at the far end of the table.

After this first test, we grew more confident and realized that a larger area was needed to adequately test. We proceeded downstairs to the atrium which was almost empty at that late hour. We launched the glider near the second light pole towards north end of the building. The glider pitched up and stalled almost immediately. These initial results from this testing revealed that the glider was longitudinally unstable and needed correction.

Figure 23. First Flight Test

Modifications

The results from the initial testing indicated that some modifications must be done to achieve the desired glide parameters. These adjustments were needed to combat the glider's propensity to stall shortly after its launch. To decrease the upward pitch of the glider during flight, our team decided to adjust the tail size as well as the weight of the fuselage. Along with the stalling issue, our glider's wing curved downward at the outer sections. Our final modification was aimed at correcting this negative dihedral.

Tail size

One way that we attempted to increase longitudinal stability was by increasing the size of the gliders horizontal tail. The size of the tail during initial testing was 36 inches. Using the spreadsheet Shane Smith created, our team determined a new tail size that would provide a greater margin of stability.

After the calculations, the new horizontal tail size turned out to be 56 inches. With the old horizontal tail pattern in hand, we were able to cut two 10 inch sections of foam using a hot bow.

The two airfoils were then attached to both ends of the old horizontal tail as seen in the following photo.

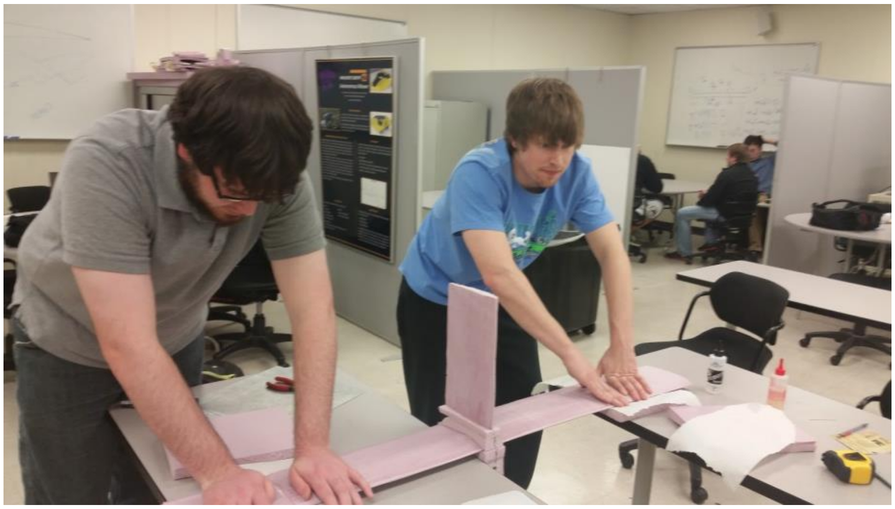
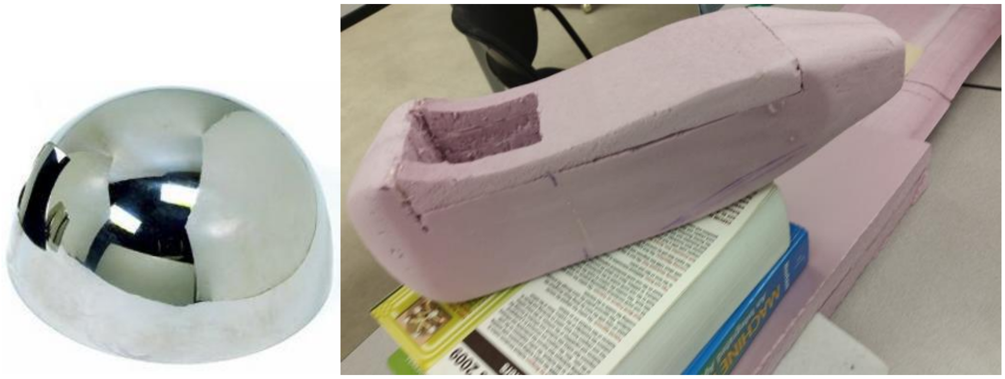


Figure 24. Tail Modification

A larger tail should help counter the pitching moment acting on the glider, making it more stable. While the increased span of the tail will add needed stability to the glider, other modifications must be done to ensure an acceptable margin of stability.

Fuselage Weight

Initial calculations for the glider's total weight was estimated to be roughly 2.31 lb. After construction, the glider turned out to weigh just 1.70 lb. While the lighter weight seemed like a benefit at first, the weight ended up being the prime reasoning behind the glider's upward pitching moment. The neutral point of our glider was clearly in front our our center of gravity. Our team decided to add 0.5 lb to the nose of our fuselage. The added weight should provide steady level glide throughout the flight path. Keeping the center of gravity of the glider in mind we decided to place the 0.5lb weight in the nose of the fuselage. This ensured that our center of gravity would move towards the front of the glider and further away from the neutral point. To construct our weight we decided to use a semicircular mold to form 0.5 lb worth of solder into a half-circle. The nose was then hollowed out and the solder slug was placed in the fuselage and attached using epoxy.



Figures 25 & 26. Nose Modification

<u>Wing deflection</u>

When designing our glider with a wing-span of 88 inches, we expected some downward deflection around wing tips. The drooping effect was magnified when we discovered our wing section cutouts were cut with a slight bow in them. The deflection didn't seem to hinder the flight of the glider to much during initial testing. Nevertheless, reducing the wing deflection should help recoup some of the lateral stability that was lost due to the drooping wing shape.

Our solution to this issue was to secure a piece of string along the top side of the entire span of the wing. With the glider project already over budget, we decided to use 10lb fishing string that was readily available in the measurements lab. We then punched a hole at each end of the wing, then used washers to secure the fishing line to the top side of the wing. In theory, the tightening of the string would cause the wing tips to bend upward and straighten out. The following figure shows a simple diagram of our wing deflection modification.

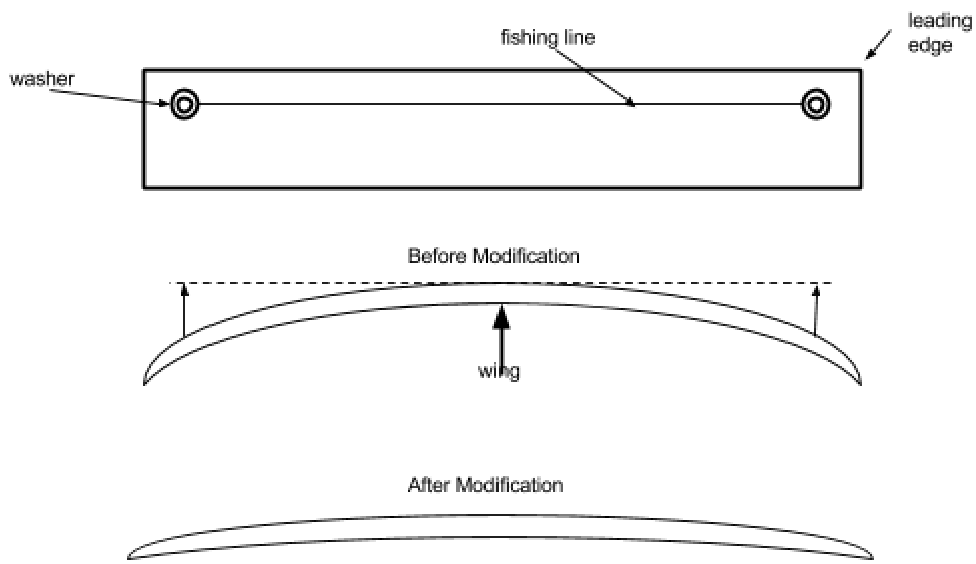


Figure 27. Wing Modification

One aspect we did not account for was the fishing lines elastic nature to stretch under tension. The wing did show some improvement after we attached the fishing line, but the properties of the line wouldn’t let us completely straighten the wing. With the last modifications complete, our glider was ready for its final test flights.

<u>Final Testing</u>

The glider final flight testing took place in the atrium of Rathbone hall. Our team choose to test the glider indoors to keep testing conditions as controlled as possible. Now that the glider was theoretically stable and ready for flight, we needed to see how the glider would react to various payload weights that it would be required to carry during the Weber arena launch. Using 1 ounce weights, we started with a payload of 2 ounces and incremented the payload by 2 ounces after each test flight until we reached the maximum payload of 16 ounces. Once all the test runs had been completed we determined an optimal payload range for steady glide. The glider responded the best to a payload range from 6-12 ounces. During this range, our glider performed rather consistently, flying roughly 60 feet when launched from a 6 foot height. The still frame photos below show the gliders launch height and glide angle from a test flight with an 8 ounce payload.

Figures 28 & 29. Final Flight Testing

With these flight dimension's along with the time was flight we were able to experimentally determine our glide parameters and compare them to the estimated parameters needed to successfully complete the flight at Weber arena. The following figure geometrically represents the still frame photos above with the measured glide speed and angle of attack.

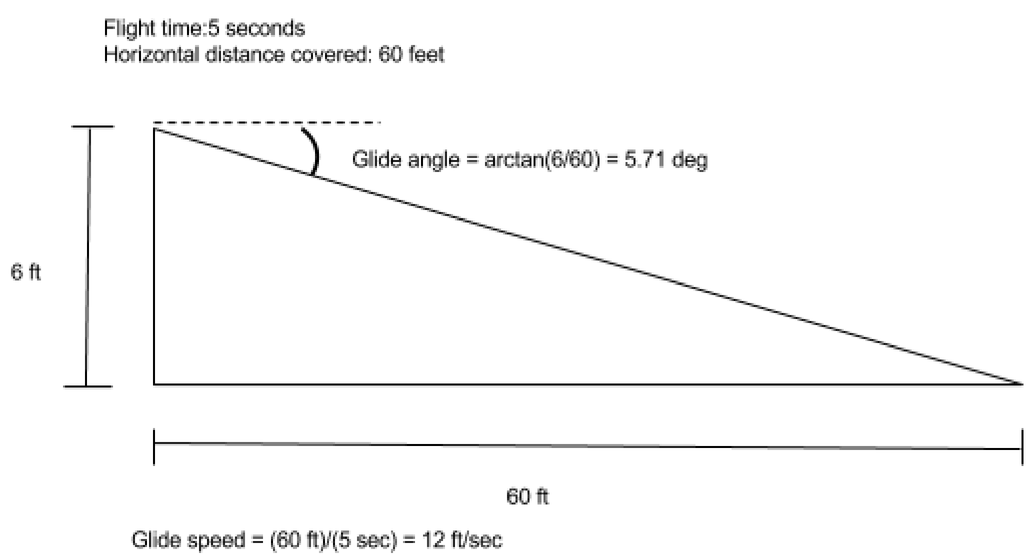


Figure 30. Measured Glide Parameters

The glide speed calculated during our final testing seemed to be a little slow when compared to our initial estimate of 22 ft/sec. However, the measured glide angle from the final testing matches up well with the estimated glide angle of 5.14 degrees, needed to complete the Weber arena flight. Given these flight parameters and assuming steady level glide along with similar flight conditions, our glider should perform well in the Weber arena glider challenge.

<u>Weber Throw</u>

Taking into account our teams calculations as well as the flight testing, we concluded that our glider would meet and possibly exceed the glide distance of 200 feet from an 18 foot high launching point. Unfortunately our glider toss did not go as predicted. As seen in the launch data below, we fell far short of the required flight distance.

Data sheet for Final Flight Testing of Glider Designs--Weber Arena
Fall 2014

		Vertical Elevation = 18.5 ft				
Team #	Flight Testing	Glide Characteristics (Comments)	Longitudinal Distance D (ft)	Lateral Distance L (ft)	Elevation Caught H (ft)	Flight Duration (Sec)
A5	Trial #1:	Nose stall glide, veer to right, crash	61	22	5 1/2	3.93
	Trial #2:					
	Trial #3:					

Figure 31. Final Flight Test Data

The short flight distance was mainly due to the stalling of our glider just after launch. Once the glider stalled it began to veer right and quickly descended towards the side wall of the area. Before anyone could stop the glider it collided with the side wall and was destroyed beyond repair. With the glider in pieces, we were forced to accept the 61 foot distance even though our glider matched that same distance when thrown from a mere 6 foot high launch point. Looking back on our final test results we began to wonder how our glider behaved so differently in the Weber arena toss. The only difference between our testing and the arena flight was the flight conditions. Final testing for the glider to place indoors in constant room temperature environment whereas the Weber flight was in an un-insulated indoor arena with a dirt floor.

On the evening of the flight the temperature inside the arena was very close to the outdoor temperature. While the air inside the arena may have been cooling as the sun set the dirt floor wouldn't of cooled near as quickly. According to Tom Benson of NASA's Glenn Research Center, conditions such as these can cause an updraft. In Benson's article, "Updrafts and Downdrafts", he explains how the warm ground can also warm the surrounding air.
The warm air would eventually rise creating an upward velocity as shown in the following figure.

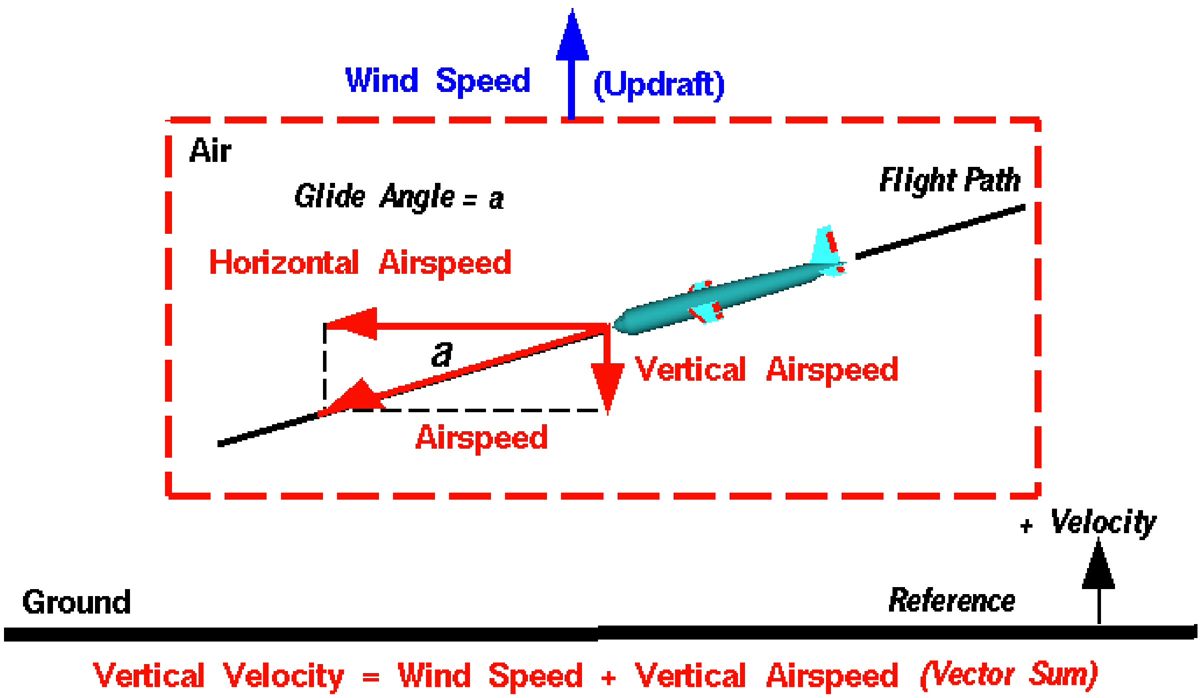


Figure 32. Effect of Updraft [3]

Although the effects of updraft would be minimal in a small scale flight such as this one, the updraft may have been sufficient enough to send the glider into stall. Along with the updraft effect, there may have been a slight cross wind in the area. The cross draft would explain our glider veering to the right after stalling. During final testing our glider seemed to slightly veer off towards the right but never to the magnitude of the Weber flight. Our glider was but one of many gliders that also veered off to the right after stalling. All in all, these effects would have not matter if our glider had been more laterally and longitudinally stable.

Evaluation

We were obviously disappointed with our glider's performance in the Weber Arena Flight Test. We were aware that our glider may have a longitudinal stability issue, but our most recent test flights led us to believe this issue had been corrected. Almost immediately after the Weber Arena launch, our glider began to pitch upward towards stall. This pitching indicates that our glider was indeed longitudinally unstable. After stalling, our glider curved severely to the right. However, we do not believe that lateral stability would have been an issue had the glider remained in level flight.

The longitudinal instability would be caused by the center of gravity of our glider being behind the neutral point. We measured our center of gravity to be about 15 inches behind our nose, and calculated our neutral point to be 20 inches behind the nose. Obviously, our calculations for the neutral point were not accurate. It is likely this inaccuracy was caused by errors in our initial estimations and build process. To improve the stability of our glider, we would need to move the center of gravity forward or neutral point backwards.

One way we could have accomplished these goals would have been to move our wings several inches backward. This move would have shifted our neutral point back as well. We also could have increased the weight in our nose, or moved this weight forward. This change would have shifted our center of gravity forward. We also could have increased the size of our tail even more. Again, this change would have shifted our neutral point back, but would also have shifted the center of gravity back as well.

Conclusion

Overall, our glider did not accomplish its main goal. However, our initial calculations indicated that our glider should have been able to glider the full 200 feet. We also believed that any errors in our construction had been corrected. We thought this because our final tests were mostly positive. In the end, we should have made more drastic modifications to ensure a larger safety factor.

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http://www.grc.nasa.gov/WWW/k-12/airplane/move4.html