

MAE 457 Group Project 2: Design, Build, Fly

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1.2	
CG	Center of Gravity location
h_n	Stick-Fixed Neutral Point
K_n	Static Margin
$C_{L_{trim}}$	Lift Coefficient about Trimmed Flight
Λ_{0_w}	Sweep Angle of Wing [degrees]
Λ_{0_t}	Sweep Angle of Horizontal Tail [degrees]
Λ_{0_v}	Sweep Angle of Vertical Tail [degrees]
i_w	Incidence Angle of Wing [degrees]
i_t	Incidence Angle of Tail [degrees]
Γ	Dihedral Angle [degrees]
α_{trim}	Angle of Attack about Trim

I Introduction

This project was conducted to create a miniature glider capable of flying in stable and trimmed flight. This glider must be able to fit within a square of 12 x 12 inches. Additionally, alongside creating the glider, the center of gravity, CG , must be calculated, alongside the stick-fixed neutral point, h_n , static margin, K_n and the coefficient of lift about trim.

It was mainly recommended to create the glider out of balsa wood. Our group decided instead to mainly 3D print the separate parts of the glider and put them all together. It would allow for the tangible testing of multiple different designs as well as easier manufacturing of more intricate designs such as specific airfoils and fuselages. The tradeoff is the weight, but even so, the more specific designs allow for additional lift, thus counteracting that added weight.

II Design

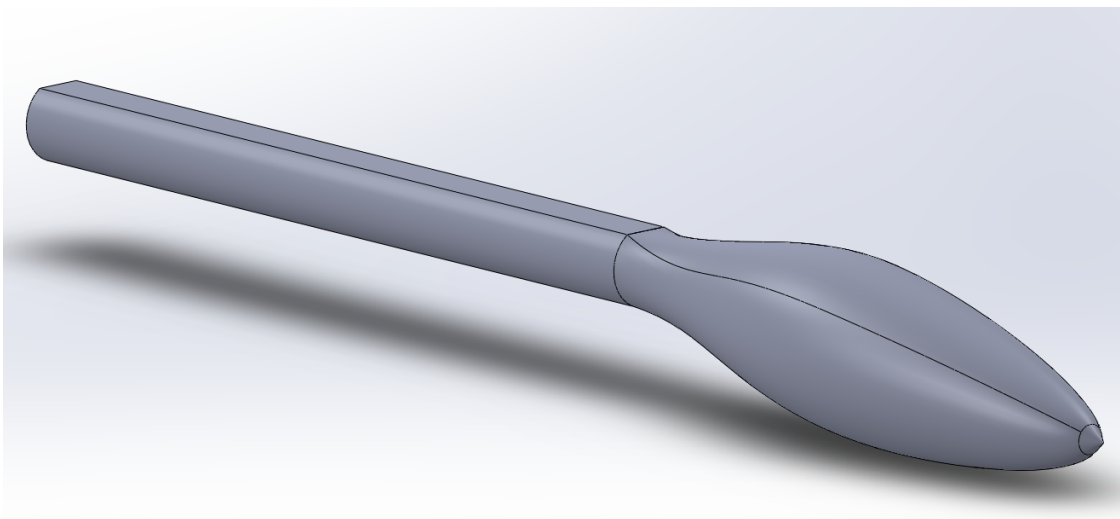


Fig. 1 Isometric View of Fuselage CAD Model

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The first aspect of the model was the fuselage. This fuselage was based around gliders such as the Jonker JS3 Rapture due to their high lift at a low angle of attack and drag coefficient. The easiest way to describe this model is like a dragonfly without any wings. It has a long nose which is smoothed out to allow for a easier slipstream conditions. The remainder of the fuselage is raised from the base of the nose and maintains a consistent cylindrical shape. The top portion of this length was smoothed out to allow for the wings attachment, as will be discussed later. This design is also easy to throw if pinched an inch behind the nose.

As far as measurements go, the nose holds a rough max diameter of 0.95 inches and a length of 3.5 inches. Meanwhile, the rest of the fuselage span remains 4.5 inches with the cylindrical design having a diameter of 0.4 inches. In total, the fuselage holds a length of 8 inches, which was decided to keep with a consistent wing span and to allow the aerodynamic effects to flow across the body.

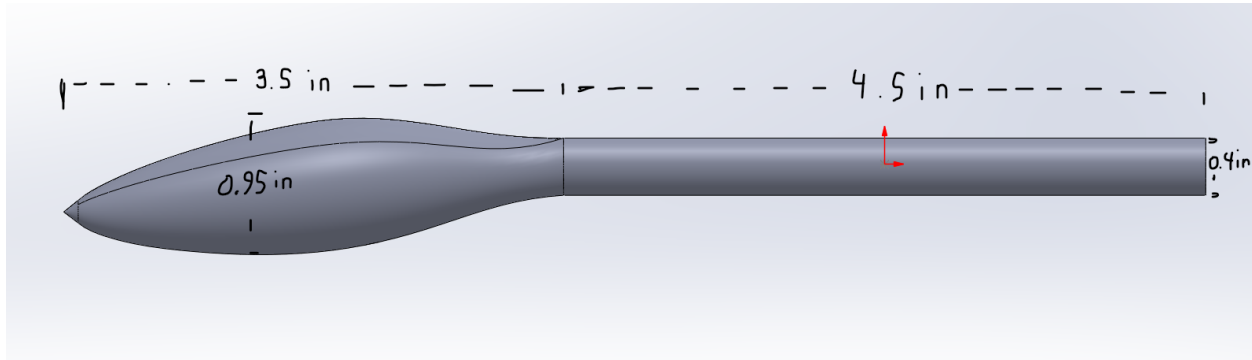


Fig. 2 Side View of Fuselage CAD Model

Next are the wings. For this model, NACA 0006 airfoils were decided upon. This was due to the fact they garnered a lift coefficient at 0.4 at lower drag coefficients and angle of attacks when compared to other airfoils like NACA 0010 or NACA 0015. It was also chosen because there is zero camber at the beginning of the chord. With the wings designed as uniform as well, that allows for zero twist upon the wings and the glider. The different airfoils were compared using [1]. This website also provided the coordinates used to create the airfoil in Solidworks as a CAD design.

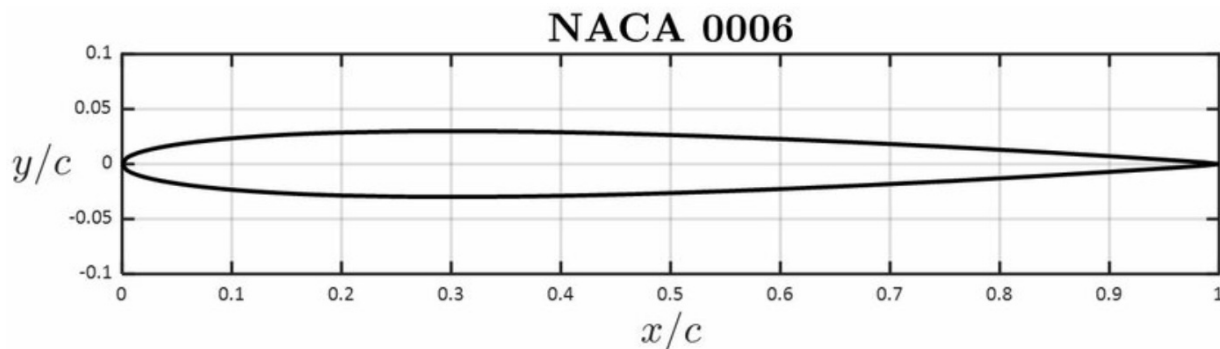


Fig. 3 NACA 0006 Airfoil[2]

With the design in place did came the necessary measurements to coincide with the glider. The span of each wing measures out to be 5.5 inches, allowing for a total wing span of 11 inches for the plane. This was chosen given it fit within the design specifications of having wings less than 12 inches while still maintaining as much lift as possible with a longer span. The wings hold an aspect ratio of 0.5, with a tip chord of 1 inch and a tip chord of 2 inches. The wing shape itself is trapezoidal, having a straight trailing edge and a swept leading edge with a sweeping angle of 9.8° . This was to reduce the weight of the wings and reduce induced drag (thus increasing spanwise lift).

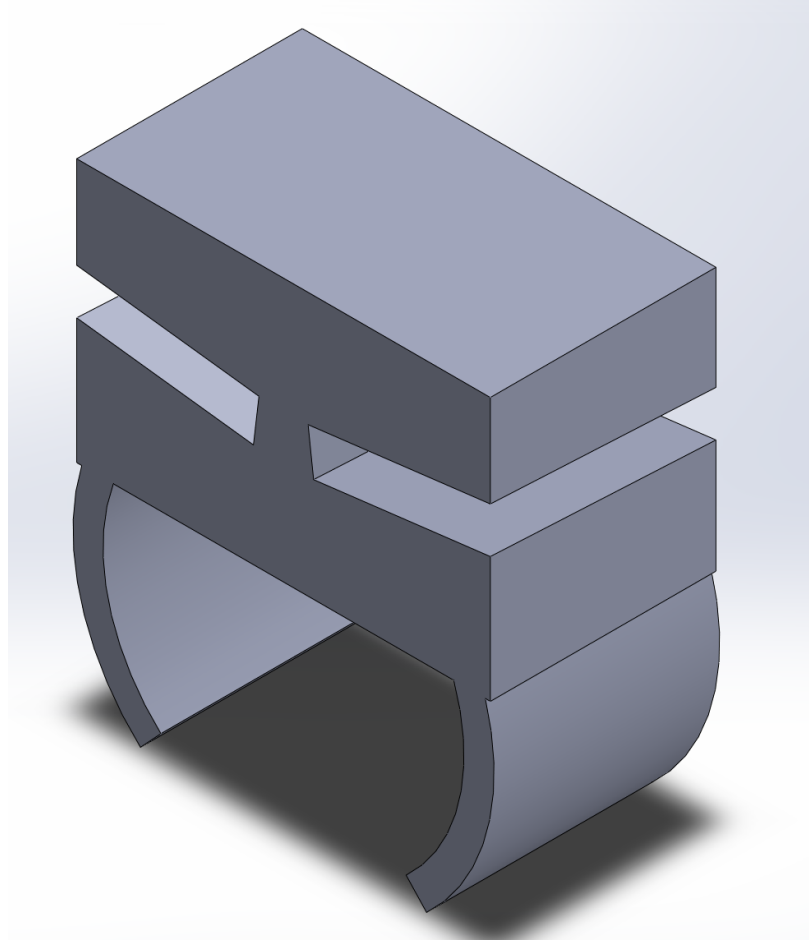


Fig. 4 Isometric View of Wing Clip CAD

To properly connect the wing to the plane, a wing clips were designed and 3D printed. The clip itself is through the half rings centered at the bottom of the design. This is where the design would clip onto the top of the fuselage behind the nose. Having the clips make the plane modular, allowing the wings to be moved back and forth with ease during construction to best determine wing location while still remaining sturdy to hold the wings in place during flight.

As far as measurements go, the rings hold an inner radius of 0.22 inches and an outer radius of 0.28 inches. Meanwhile, the top part of the clip holds a height of 0.35 inches, a length of 0.55 inches, and a thickness of 0.3 inches. Meanwhile, the notches which hold the wings have a depth of 0.24 inches and a width of 0.05 inches.

The last notable design choice of this clip is the position of the notches which hold the wings in place. They are set up to have a dihedral angle of 7 degrees and an incidence angle of 3 degrees.

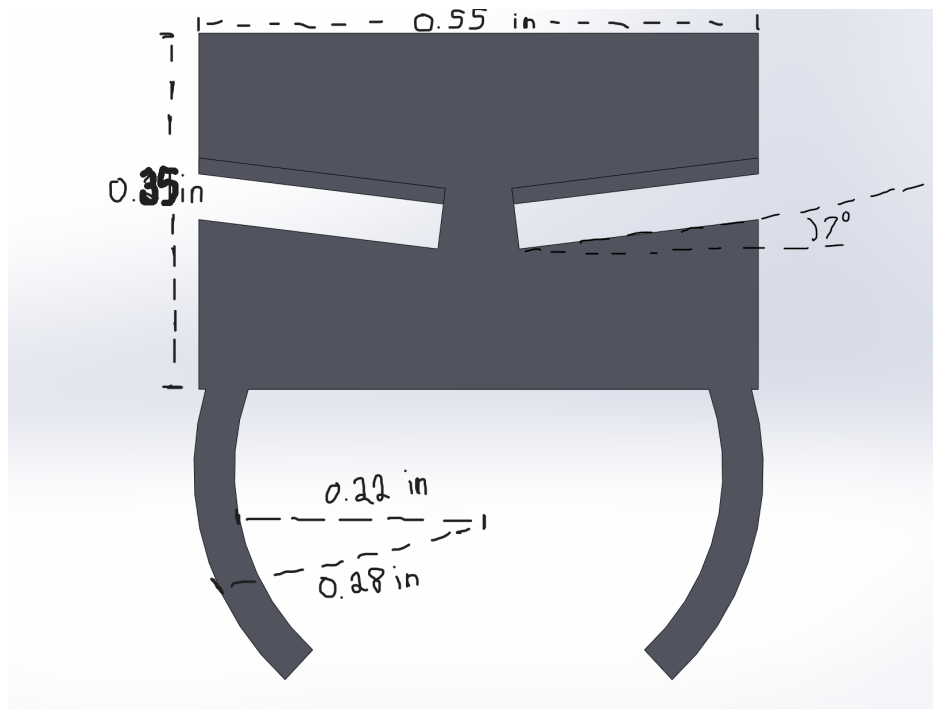


Fig. 5 Forward View of Wing Clip CAD

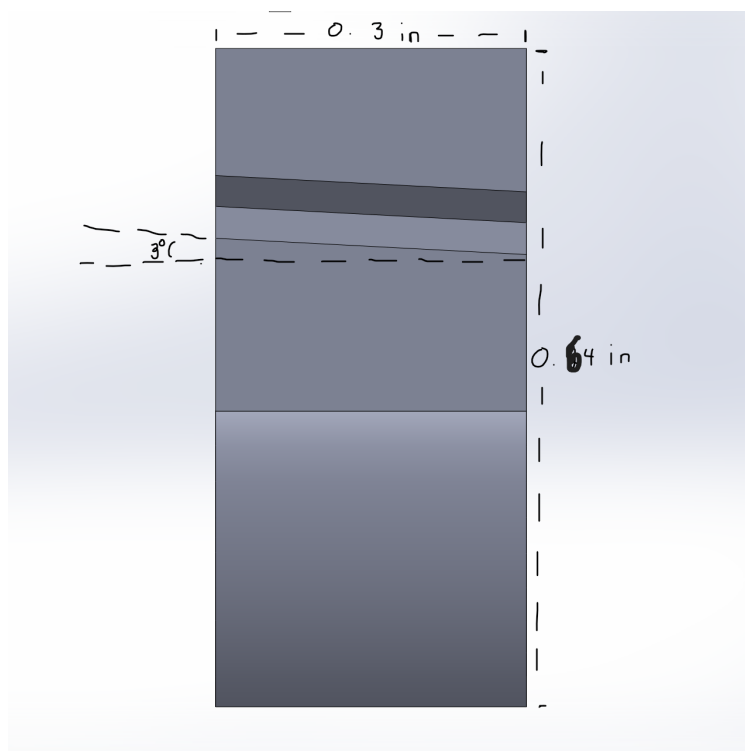


Fig. 6 Side View of Wing Clip CAD

The tail is made similarly to the wings. A NACA 0010 airfoil is used instead of NACA 0006 to add a little more weight on the back of the fuselage to counter the nose. Each of the airfoils for the tail were made with roughly half the

tip and root chord of the horizontal wings. Specifically, the vertical tail and the horizontal tail was made with a root chord of 0.97 inches and a tip chord of 0.48 inches, allowing for a taper ratio of 0.49. Similar to the horizontal wing, the trailing edge remains straight while the leading edge is swept. The horizontal tail LE sweep angle is 11.3° , whereas for the vertical tail 14° .

The biggest difference between the horizontal and the vertical tail is their span. Where the horizontal tail has a span of 2.5 inches, the vertical tail has a span of only 2 inches.

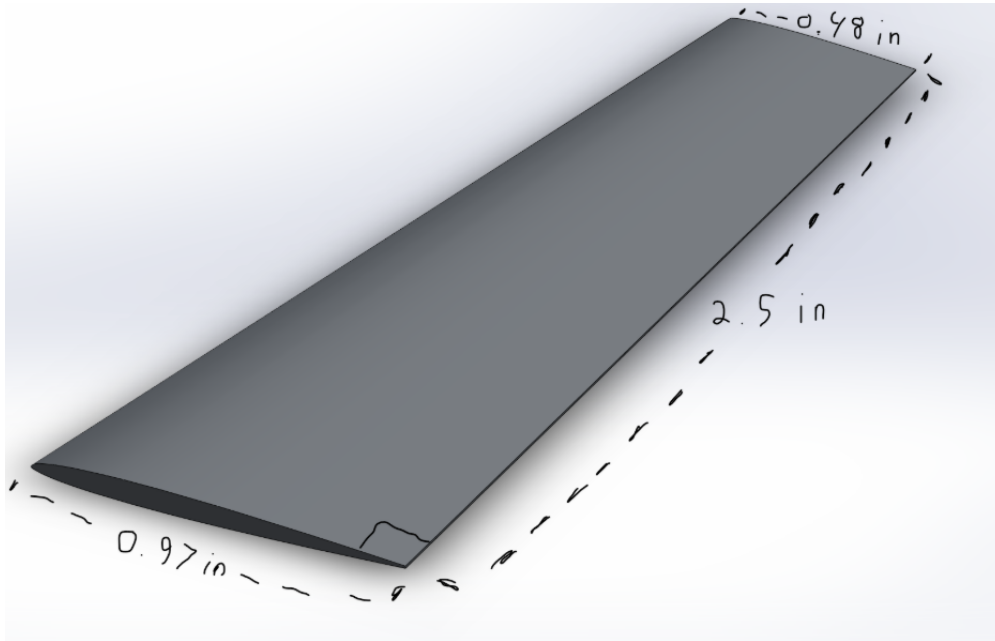


Fig. 7 Isometric View of Horizontal Tail CAD

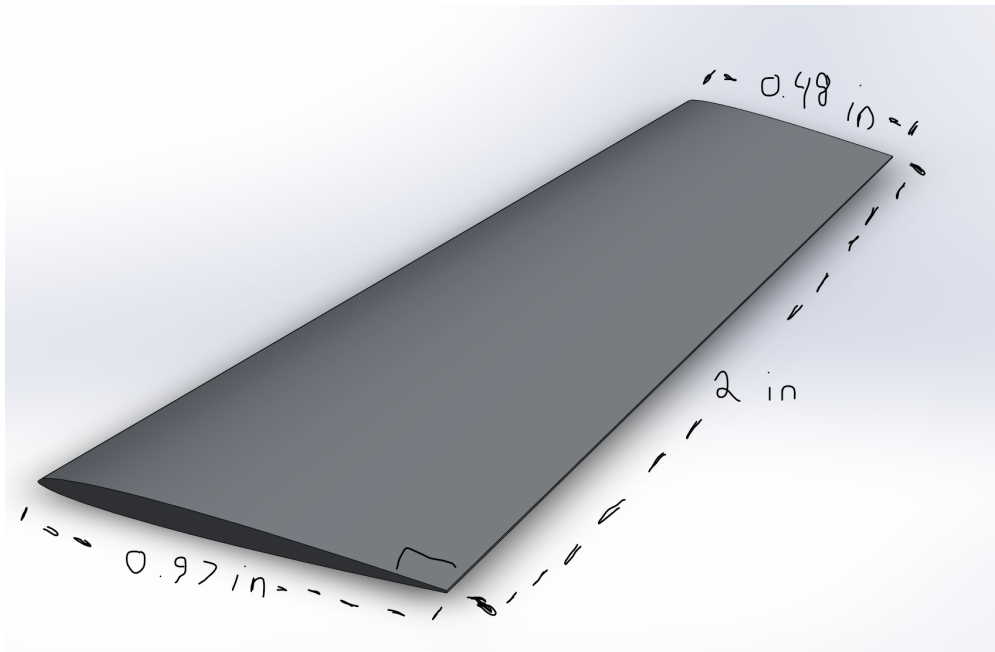


Fig. 8 Isometric View of Vertical Tail CAD

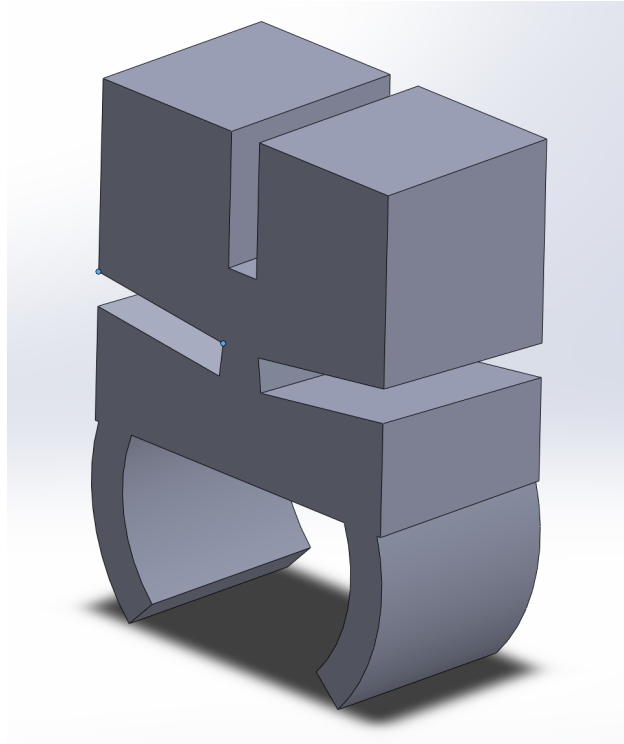


Fig. 9 Isometric View of Tail Clip CAD

Lastly there is the tail clip. This has similar dimensions to the horizontal tail clip, with the same radius for the wing and the same measurements for the notch to hold the wings. The main difference is that an additional notch is added to the top in order to fit the vertical tail. This notch is 0.2 inches deep and 0.05 inches wide. Once again, this is wide enough to fit the 3D printed airfoil while still remaining inside the clip during flight.

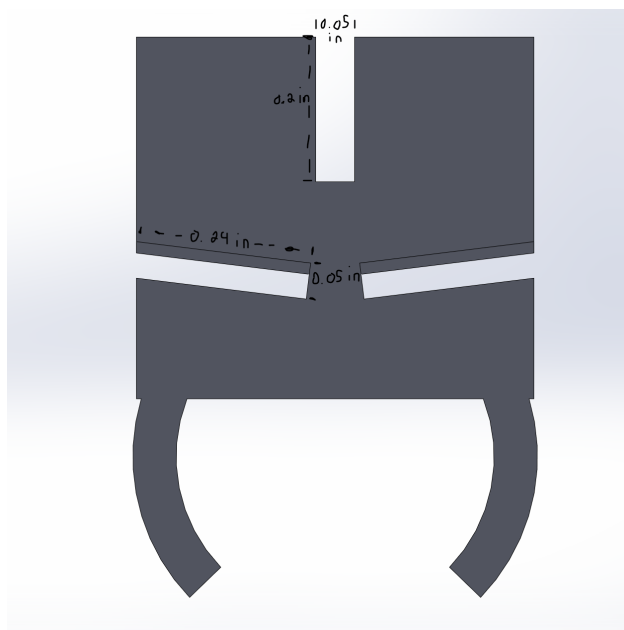


Fig. 10 Front View of Tail Clip CAD

With all of the main parts to the plane designed could the manufacturing process start.

III Manufacturing and Design Iteration

The design process was an iterative process. It was highly unlikely our model would have been perfect with the first design given the high weight of the 3D printed material (at least when compared to a simple balsa wood glider) and the modular design of the wings. In fact, besides fuselage length, wing shape, and wing span, most other measurements had slight alterations when iterating throughout the design process.

Our first full design was entirely 3D printed. The fuselage was 3D printed into halves between the left and right, where it was put together through the use of electrical tape. Though the fuselage was hollow, it had a thickness of 0.5 inches, thus making it heavier. The wing clips fit onto the fuselage, but were a little more loose than desired. The same can be said for the wings themselves upon the clips.



Fig. 11 Isometric View of First Glider

Needless to say, the first design was a failure. For starters, with the clips being loose, though they never fell off the fuselage, they did occasionally slide some centimeters down the fuselage during flight, causing the plane to be unstable. Next, the weight of the fuselage and the wings made it so the glider couldn't produce enough lift to glide more than a couple feet before nosediving and crashing. Finally, with the wings loose on the wing clips, some flights would have it so they would fall off the clips mid flight.

Fortunately, with the modular design of the glider, it was easy to rebuild. Test flights were numerous to ensure if issues in flight were caused by design issues or just bad throws. Additionally, the 3D printed material was surprisingly durable. There would be at least twenty flights before any damages were seen. Even so, a durable design couldn't makeup for the lack of lift.

Thus, the first iteration of the design came to address these issues. First, the fuselage was reprinted to have a much thinner infill, going from a thickness of 0.5 inches to 0.1 inches. Additionally, the measurements on the clips were decreased so that both the rings can fit tightly onto the fuselage and the notches would more tightly hold the wings. Lastly, for good measure, the fuselage halves were soldered/melted together for a more sturdy structure.

These changes were moderately successful. The glider experienced more lift, the clips remained on the fuselage, and the wings rarely fell off during flight (unless the glider was pitched instead of tossed like a dart). The glider did have more success in flying. Yet, there were still some issues. For starters, the glider had a tendency to yaw/turn drastically in one direction or another in unstable flight. This was likely due to the weight of the wings. Additionally, the weight of the glider meant it had to be thrown at an upwards angle in order for the glider to fly. Otherwise, it would nosedive or experience stalling, both of which effectively killing any momentum the glider has.

Thus, the second iteration needed to work around these. For the weight of the wing, it was decided the horizontal wings would be made of balsa wood instead of 3D printed material using the same measurements. Even though this removed the NACA 0006 airfoil design for the horizontal wings, the change was negligible due to the small size of both wings. Additionally, the fuselage was 3D printed as a whole instead of in two parts with the natural infill supports of the infill left inside the fuselage. Though this increased the weight of the fuselage, the weight increase was only by about two grams. This weight increase was made up with the increased stability and durability of the fuselage.

These changes to having a fuselage with internal supports and balsa wood wings allowed the glider to glide further distances and glide more consistently with varying throws. Though the gliding problem with varying throws was mostly resolved, the design change caused a new problem. Instead of the glider having a high yaw, it now had a high roll. If the glider was thrown even slightly off center, there would be a lift imbalance with the wings which would cause the glider to roll one way or the other. Once it initiated roll, the glider quickly plummeted.

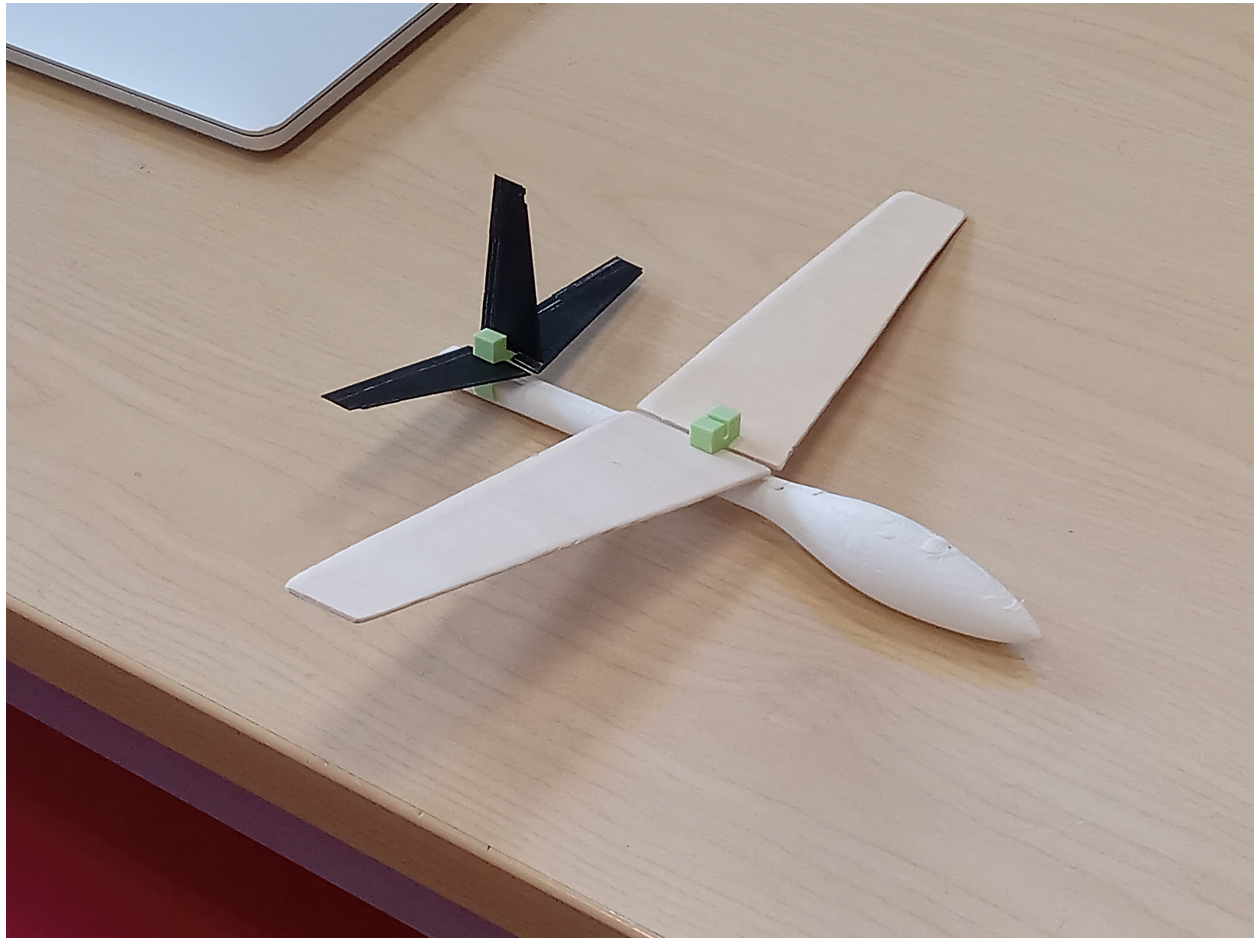


Fig. 12 Isometric View of Third Glider

So, the design was altered from this point. First, another horizontal tail was 3D printed and took the place of the vertical tail in the back. Second, another wing clip was added near the front of the fuselage. Though it allowed for the wings to be more firmly attached to the glider by holding them with two wing clips instead of one, that was not the main intention. Another clip was added in order to add another vertical tail. This did decrease the overall stability of the glider due to it being in front of the center of gravity, causing the trimmed gliding conditions to be more narrow depending on the throw. Despite this, the roll effect was removed. Though the additional vertical wing did add more weight, this weight was negligible given how small it is compared to the fuselage itself.

Due to time constraints, the glider needed to either be chosen between the third iteration with the roll effect or the fourth iteration with the additional vertical wing and decreased stability. Ultimately, it was decided to utilize the fourth iteration because of the flight in which the glider exhibited. Though the third iteration showcased more consistent and stable flight, that flight was never trimmed. Meanwhile, though the fourth iteration was more difficult to get it in a gliding phase based on how it was thrown, when it did glide the glider flew in stable and trimmed flight. Admittedly, it was a gamble to utilize the fourth design for the flight tests, but said gamble paid off in the end.

Thus, with the fourth design chosen as the final design for the glider, the final touches were made in ensuring the glider could hold it's best flight during testing. The wings and tail were super-glued to the wing clips to ensure they remained in place during testing. The minimal cracks in the fuselage were also soldered/welded together. A small counterweight was also added to the end of the fuselage. Additional test flights were taken after this point both to ensure the glider was capable of stable and trimmed flight as well as to determine who among the group would throw the glider during flight tests.

IV Three View Drawing

The final design of the glider is shown through the three-view images listed below. All of the measurements of the glider are included. These measurements include the spans, root and tip chords, mean aerodynamic chords, sweep, incidence, and dihedral angles of the wings and tails. Additionally, it illustrates the center of gravity and the neutral point with respect to the nose of the glider. For ease of viewing, the three-view drawing is separated into three images.

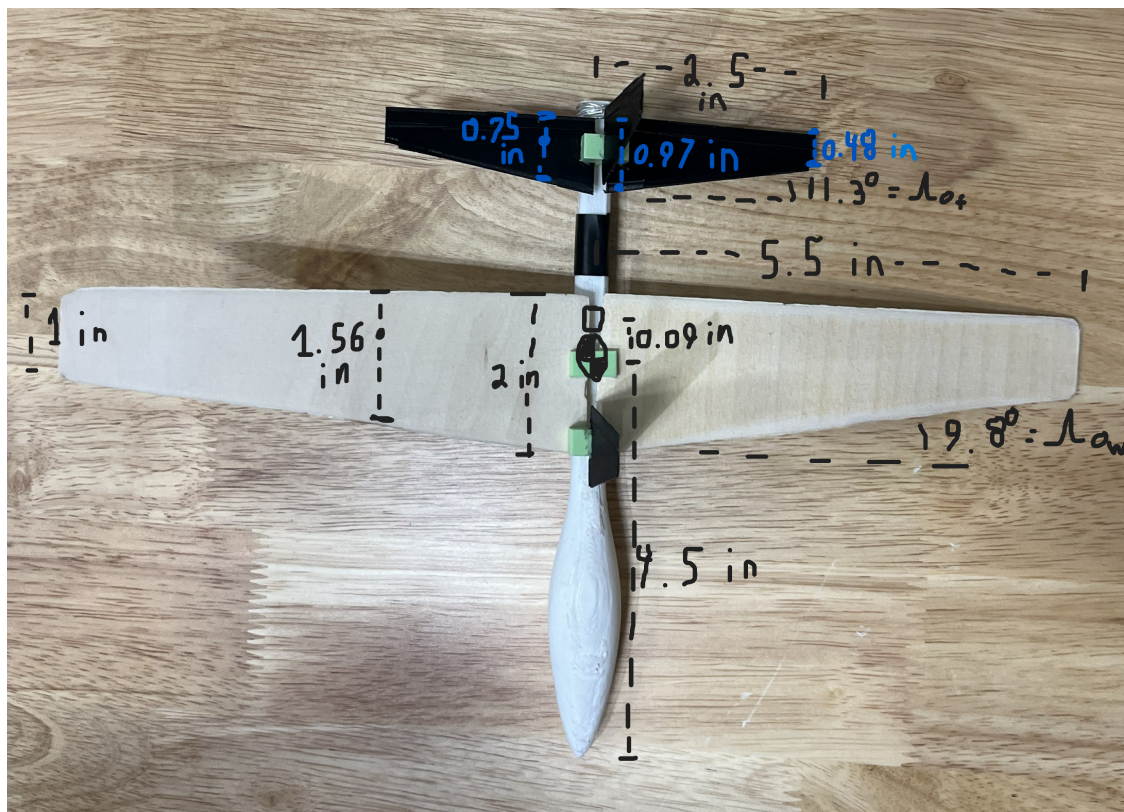


Fig. 13 Top View of Glider

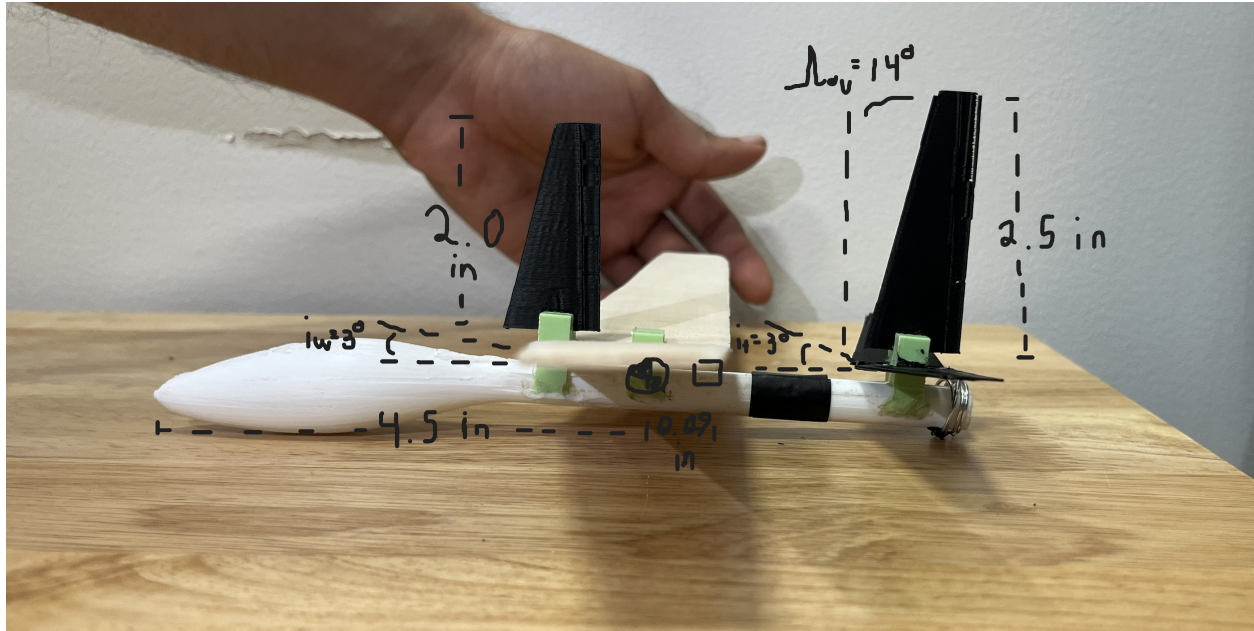


Fig. 14 Side View of Glider

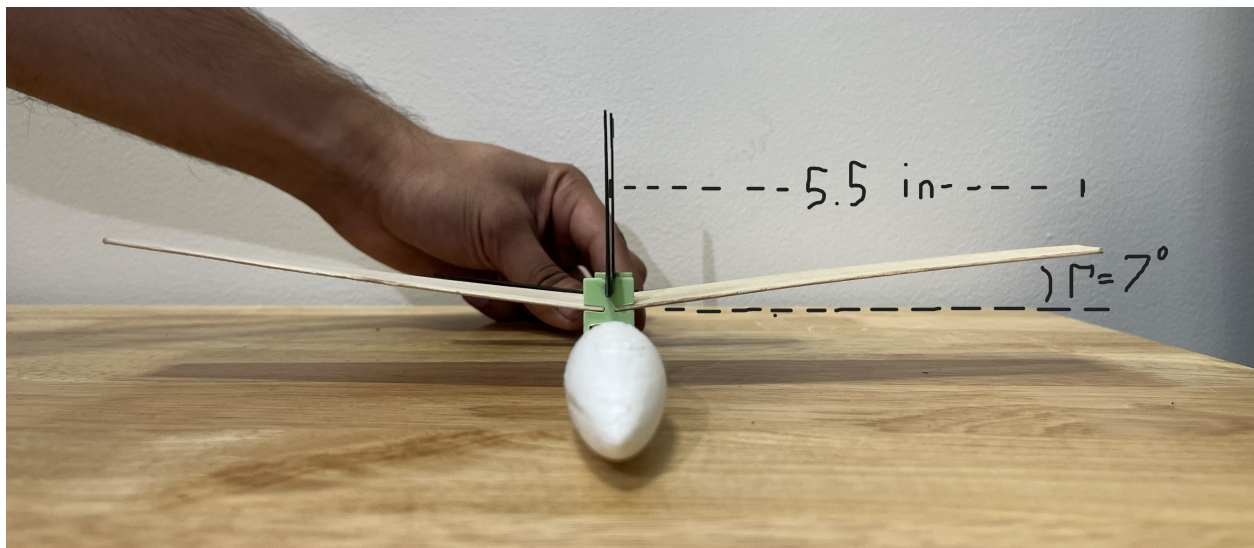


Fig. 15 Front View of Glider

V Calculations

To begin the calculations for our glider, we derived the CG location. This was done by weighing the components of our glider and measuring its distance from the nose. Based off of this, our glider's center of gravity location, CG , is 4.5 inches from the nose, and 1 inch from the wing's leading edge. This calculation was also verified with manual testing (attempting to balance the glider on a finger). The location for this was 1 inch from the wing's leading edge, roughly the same location as the back of the second wing clip.

With this measurement, our group decided to utilize AVL to estimate the stick-fixed neutral point, h_n static margin, K_n , and the lift coefficient at trim, $C_{l,trim}$. In doing so, we imported our measurements for the wings, horizontal tails, and vertical tails and modeled our glider. This is shown in Fig. 16.

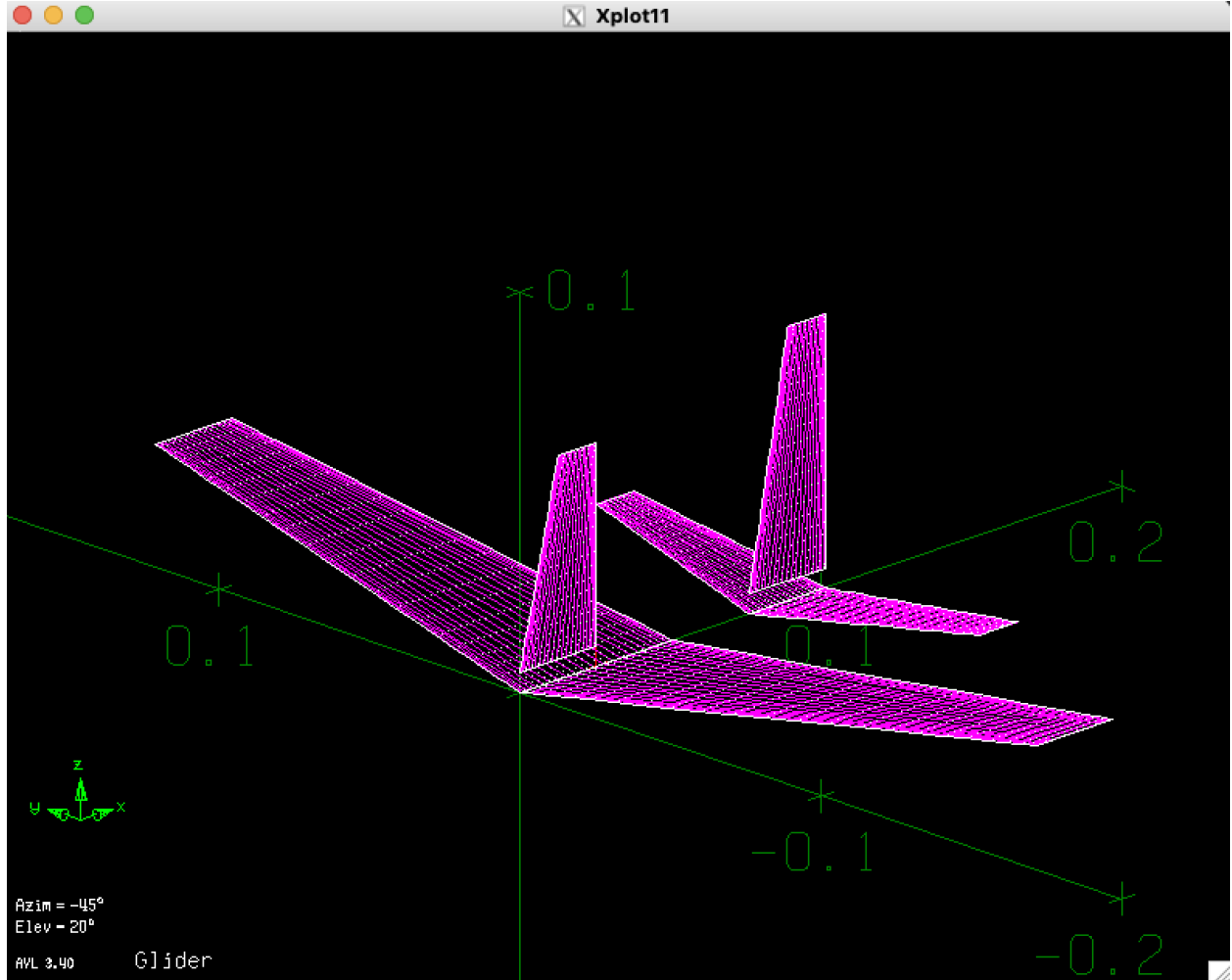


Fig. 16 AVL Geometry

Within AVL, we were unable to accurately model our fuselage, so the estimations presented are based on a simplified geometry that neglects the aerodynamic effects of the fuselage. The table with all of the desired parameters is shown below in Table 2.

Parameter	AVL Model
$C_{L_{trim}}$	0.00083
K_n	0.0587
α_{trim}	3.026°
$h_n(FromWingLE)$	1.0913 in
$CG(FromWingLE)$	1 in

Table 2 AVL Estimates

Based on the AVL output in Table 2, the trim configuration occurs at an angle of attack of $\alpha_{trim} = 3.026^\circ$, which is relatively low, but expected for a hand-launched glider. In this instance, the neutral point is located 1.0913 in behind the leading edge of the wing, whereas the CG location is at 1 inch behind the leading edge of the wing. This produces a positive static margin of $K_n = 0.0587$. This implies that the value of the static margin here is 5.9%, indicating that the

aircraft is statically stable, but only marginally so. However, the calculated lift coefficient, $C_{l,trim} = 0.00083$ appears to be very low for a hand-launched glider. This is likely due to some modeling limitations inherent in AVL, especially since the effect of the fuselage was disregarded in the analysis. As a result, while stability trends, such as the static margin and neutral point locations, are considered reliable, the absolute aerodynamic coefficients should be interpreted with caution.

VI Flight Test

After multiple iterations of the aircraft and numerous practice flights, our group took our glider to the real flight test. This occurred on Monday, April 28th at 1:30 PM in the bottom floor atrium of Engineering Building III. To qualify for the flight test, we had to check the dimensions of our glider to see if they met competition requirements. This was done by placing our aircraft into a 12 x 12 inch wooden box. After passing this, our glider was officially registered to fly. The flight test consisted of three attempts per group. A summary of each of those tests follows.

- **First Test:** The first flight test was the first time our glider has been tested in about 20 hours. Because of this, the wings of our aircraft were not in the correct location and so, upon launching, the wings fell off. We received a 1 out of 4 for this test.
- **Second Test:** The second flight test went marginally better as none of the wings fell off. However, trimmed flight was not achieved and the glider quickly fell to the ground after being launched. We received a 2 out of 4 for this test.
- **Third Test:** For the third flight test, our group had the option to wait in line again or immediately fly after our second test. We decided to choose the second option and immediately lined up for our third launch. This launch went perfectly and trimmed flight was achieved for a distance between 20–30 feet. We received a 4 out of 4 for this flight test.

Table 3 highlights the scores received for the three flight tests.

Test	Score
First Test	1/4
Second Test	2/4
Third Test	4/4

Table 3 Flight Test Scores

Based off of the scoring in the rubric, our group received a full 30 out of 30 points for the flight test.

References

- [1] airfoiltools, “NACA 0006 (naca0006-il),” , 2026. URL <http://airfoiltools.com/airfoil/details?airfoil=naca0006-il#polars>, website to compare NACA airfoils.
- [2] ResearchGate, “NACA 0006 Airfoil,” https://www.researchgate.net/figure/NACA-0006-Airfoil_fig14_333611443, n.d. Accessed: 2026-04-29.
- [3] Etkin, L. D., B. Reid, “Dynamics of Flight: Stability and Control,” *John Wiley Sons, Inc.*, Vol. 3, No. 177, 1996.