SECTION 2 – Dan Brown

Wing and tail geometries

The cross-sectional airfoil of our wing is the S1223 airfoil (the corresponding DAT file for this airfoil can be found here: https://m-selig.ae.illinois.edu/ads/coord/s1223.dat). This airfoil represents a two-dimensional analogue of our wing; viewing the wing from the side, will show a similar curvature and shape to the S1223 airfoil's curvature and shape.
Our wing is symmetrical with a wingspan of 24 inches (half-span of 12 inches), a taper of 2/3 (0.667 for estimation), and a root-chord of six (6) inches. Thus, the tip-chord is four (4) inches. The wing also has a dihedral of three (3) degrees (~0.0524 radians), and has no extra half-span (or other) partitions.

There are several reasons why we choose the above specifications for our wing. The S1223 airfoil is considered to be a high-lift airfoil (more information can be found about it here: https://m-selig.ae.illinois.edu/uiuc_lsat/Low-Speed-Airfoil-Data-V5.pdf), so choosing this particular airfoil as the cross-section for our wing made sense.
As for other specifications- we made those decisions based on two criteria: lift optimization and structural durability. In some cases, we had to compromise lift optimizing in order to make sure that the wing is durable and structurally sound, so that it will not come apart while flying or break during a bad landing.

In terms of lift-optimization, the best way to increase lift is to maximize the aspect ratio. The aspect ratio refers to the following ratio: wing-span^2/ area of the wing. The maximum allowed wingspan (due to limitation of the foam cutting machine) is 24 inches; thus, choosing the maximum wingspan makes sense when trying to get the most lift. The other way to maximize lift is to reduce the area of the wing, which can be done in several ways; most notably, this can be done by reducing the size of wing's chord and/or tapering the wing.

There is unfortunately no magic formula when deciding how large a wing's chord should be or by how much one should taper their wing. This is where the structural durability of the wing comes into question if either of those are too small. We ended up choosing a taper of 2/3 as an experimental taper ratio; choosing anything below that could have seriously compromised the integrity of the overall wing, especially near the tips. As for the chord-length, after running an analysis in Tornado, we found that setting the root-chord to four inches, only improved our CL overall for the wing by about 0.1 at most. Using a four inch chord would make the wing way too fragile and very thin at the trailing edge, meaning we would be sacrificing a great amount of wing durability for not much gain in terms of lift. Thus, we choose to keep the chord at six inches.

We then added a dihedral for the purpose of wing-stability. Having no dihedral means that a simple gust of wind, an improper turn, or other slight force on the wing could cause the aircraft to start doing barrel-rolls; a dihedral prevents this, but at the cost of lift-performance. So it is a matter of finding an angle that keeps the aircraft stable while also not hindering the lift capabilities of the wing too much. After researching multiple sources, small gliders seem to need a dihedral angle of about 5-8 degrees in order to be considered "stable". However these recommendations are not meant for more simplistic designed gliders that we were creating, and not necessarily needed for when doing test flights within an indoor space; so, we settled on a slightly smaller dihedral angle of three degrees.

Now that we covered the specifications of our wing and why we choose them, it is time to move on to the tail. The cross-section airfoil of our tail is the NACA 0006 airfoil (its corresponding DAT file can be found here: https://m-selig.ae.illinois.edu/ads/coord/naca0006.dat).

Our tail is symmetrical with a tail-span of 8 inches (half-span of 4 inches) with a root-chord of four (4) inches. The tail has no taper (taper is equal to one), no dihedral, and no extra half-span (or other) partitions.

The specific NACA airfoil for the tail was chosen because it is a very symmetric airfoil, and makes it easier to predict the required downward angle for stable flight. The other specifications for the tail are heavily based on the planform area of the wing, so before moving forward, it makes sense to calculate that.

Using the wing specifications, it is quite easy to calculate the planform area of the wing.
The formula we use for calculating this is the following:
$S_{\text{planform area}}$ = Wingspan * (tipchord + rootchord)/2

However, in our case, we can simplify this formula:
$S_{\text{planform area}}$ = Wingspan * (tipchord + rootchord)/2 = Wingspan * (rootchord*taper + rootchord)/2 =
= Wingspan * rootchord *(taper + 1)/2

Thus, we can now substitute our wing information into the formula:
$S_{\text{planform area}}$ = Wingspan * rootchord *(taper + 1)/2 = 24*6*(0.667+1)/2 = 120 in^2

Thus, our wing has a planform area of 120 square inches.

Using the specifications of our tail, it is quite easy to calculate the planform area of it.
Using the formula from above, we can now substitute in our tail information:
$S_{\text{planform area}}$ = tailspan * rootchord *(taper + 1)/2 = 8*4*(1+1)/2 = 32 in^2

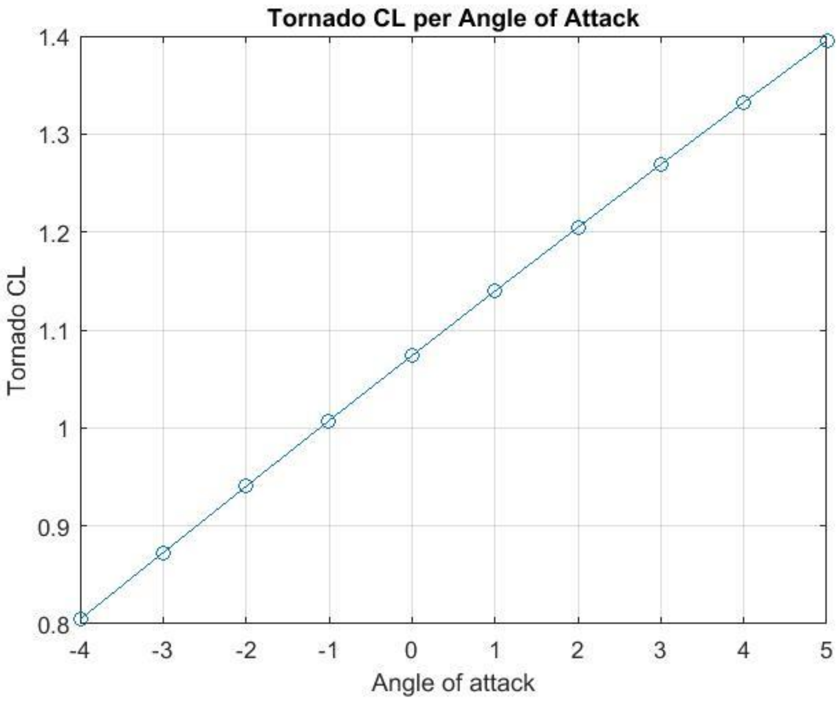
Thus, our actual tail has a planform area of 32 square inches.

For the tail, it is recommended to have a planform area of around 1/3 of the planform area of the wings (40 square inches in this case). Obviously, one can see that we choose a slightly smaller planform area. The reason for this is because of experimental reasons. We already decided that we wanted to make the tail have an 8 inch span, but having the chord be 5 inches seemed to make the tail look somewhat more square in shape. Most airplanes have tails that have a relatively long span compared to their chord, so we decided to just make the chord for the tail be four inches for that reason. Now, let's look at some of the theory behind our wing designs.

Theoretical results

Tornado:

The following graph was obtained by running tests in the Tornado program at different angles of attack. Each test was done as a static-state computation, using an airflow rate of 6.7 m/s.



Estimate for low Reynold's number case:

The following graph was obtained by getting results from the Xfoil program for the S1223 airfoil, and combining it with the Tornado results of our wing. More specifically, we obtained two different data sets from Xfoil- one data set represents the inviscid results at different angles of attack, while the other data set represents the viscid results. We then found the ratio between these data sets for each angle of attack. We then took this ratio and multiplied the corresponding Tornado result for that angle of attack. Here is an example to illustrate this method:

Xfoil results for S1223 *Inviscid*:

Angle of attack (aoa):	C_L
3.000	1.9390

Xfoil results for S1223 *Viscid*:

Angle of attack (aoa):	C_L
3.000	1.4152

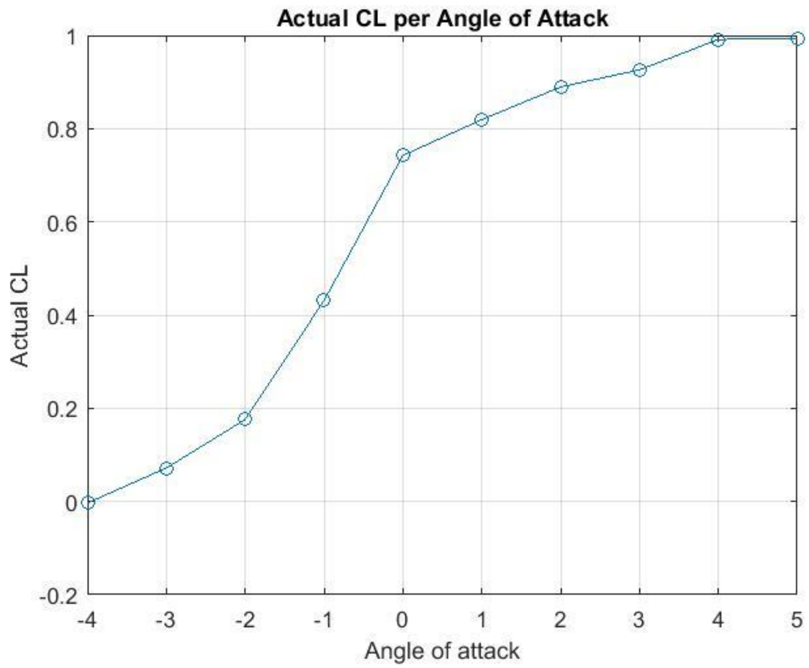
Thus, we now have a ratio at an angle of attack of three (3) degrees, which is: Viscid result$_{aoa = 3}$ / Inviscid$_{aoa = 3}$ = 1.4152/ 1.9390 = ~0.7298

Now, looking at the Tornado results, we obtained the following for this angle of attack:

Angle of attack (aoa):	C_L
3.000	1.269

So, our low Reynold's number estimate for the C_L at an angle of three (3) degrees is:
$C_{L\ estimate} = C_{L\ Tornado} * Ratio_{Viscid/Inviscid}$ = 1.269 * 0.7298 = 0.926

We then did this for each angle of attack; doing so, gave us the final set of values as depicted by the graph below, which shows the estimates of the C_L (lift coefficient) for the low Reynold's number case.



Drag coefficient:

The lift force for our wing becomes zero at around an angle of attack of -4 degrees. At -4 degrees, the Cd (drag coefficient) is: -0.00058. This is the value we will use as the Cd0.

Now for each angle of attack, to calculate the "real" drag coefficient, we will use this formula:
$Cd = Cd0 + Cdi = Cd0 + (C_L)^2_{aoa} / (3.14159*AR*e)$
Where Cd0 is the drag at the angle of attack where the lift force is zero, Cdi is the induced drag, AR is the aspect ratio, and where e, the efficiency factor, is assumed to be 0.9. The AR for wings is $span^2/area$*; the AR for our wing is:* $24^2/ 120 = 4.8$*.*

In order to use this formula, however, we must first find the CL of our wing at a certain angle of attack. Since this is all a theoretical estimation of the actual drag, as well as for the actual lift, we could simply take the CL values we obtained for the estimated low-Reynold's number case and plug them in. But, it is *better* to have an "over-estimate" of drag rather than an under-estimate; for this reason, it makes more sense to use the CL values that Tornado suggests, which are larger than the low-Reynold's number case, and thus, will suggest a higher estimate for induced drag and overall drag in general.

So, for example, at an angle of attack of five (5) degrees, our CL according to Tornado is 1.395.
Plugging this in, we get:
$Cd = Cd0 + Cdi = Cd0 + (C_L)^2_{5\,deg} / (3.14159*AR*e) = -0.00058 + (1.395^2 / 3.14159*4.8*0.9) =$
$= -0.00058 + (1.395^2 / 13.572) = 0.1428$

So, at an angle of five degrees, our Cd is 0.1428.

The following table summarizes the Cd of our wing at different angles of attack:

Angle of attack	Cd
-4.0	0.04711144015657088
-3.0	0.05553343307316783
-2.0	0.06457055115403348
-1.0	0.07419744814992835
0.0	0.08437981275346185
1.0	0.09511111795595838
2.0	0.10635615585431914
3.0	0.11807607860987587
4.0	0.13022850897275068
5.0	0.14280877765717362

SECTION 4 – Dan Brown

Flight test outcomes

The following shows a table of the results of the flight tests for our glider. Only distance and total flight time were recorded with accuracy. The height was recorded via an "eye-ball" estimation. The speed was calculated by simply doing distance/ time. The glide angle was calculated by doing arcTan(Drag/Lift).

Flight test 1:

Distance	total flight time	speed	height	calculated glide angle
35ft	2.23 sec	15.7 ft/s	15ft	8.177 degrees

Flight test 2:

Distance	total flight time	speed	height	calculated glide angle
42ft	3.15	13.3 ft/s	25ft	8.177 degrees

Flight test3:

Distance	total flight time	speed	height	calculated glide angle
60ft	2.49	24.1 ft/s	15ft	8.177 degrees

Flight test 4:

Distance	total flight time	speed	height	calculated glide angle
50ft	2.12	23.6 ft/s	15ft	8.177 degrees

SECTION 6 – Dan Brown

Conclusions

Overall, the glider that we have designed performed decently well. The wings produce a decent amount of lift and are sturdy for the most part; so they seem to be well designed. The overall idea of how the wings are attached to the fuselage is also well designed. However, if I had more time, I would redesign several different components/ aspects of the glider.

Firstly, the size of the fuselage could be changed to be of a smaller length. Due to time constraints, we decided to keep the fuselage at its current length of 1 yard. I would redesign this to be about 80% of the wingspan in order to reduce drag and reduce the weight of the glider. Although at its current size, the fuselage probably did not hinder the glider's performance; reducing its size could potentially increase performance and help the glider fly for a longer period of time.

Secondly, the tail is too simple of a design; it would make sense to do research on a tail-airfoil design that improves the general performance of the aircraft, not just act as a sort-of counter-balance lift device in order to keep the aircraft balanced. Most tails are made for this purpose, but there could be designs that offer less drag for instance. Furthermore, the overall construction of the tail could use improvements. Stabbing pop-sickle sticks through the tail and attaching them to the glider, caused an unforeseen consequence—a tilted tail. This caused our aircraft to start turning to the left during some of the test flights. Finding a more appropriate way to attach the tail, perhaps in similar way that we used to attach the wings of the glider to the fuselage could prove to be beneficial for the design of the glider.

Lastly, the overall construction of the glider is somewhat delicate. Since, in this section, I am discussing *any* redesign ideas- the most obvious one is to use better materials, and to find better ways of attaching all the components of the glider together. Tape, balsawood, and foam are great for prototypes or a class project, but not that great for gliders that are meant to be used outside of that scope. Imagine if we did the flight tests outdoors and it started to rain; the tape would peel off, and our glider would literally start falling apart.

Despite all these possible modifications and redesigns, we are still proud of how the glider actually performed. And, more importantly, due to the glider's performance, some of our design decisions now feel validated. We also have learned a lot from the process of designing and constructing it. So, next time, hopefully we, or whoever reads this report, will be able to use this knowledge, use these ideas for improvement to create an even better glider.