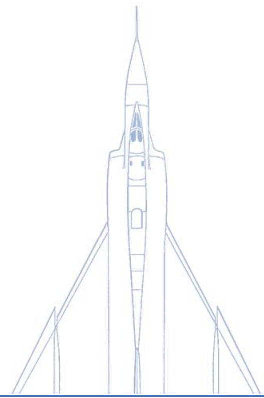

HOW TO BUILD A SIMPLE GLIDER

The Official Unofficial Guide to the 2018 RUAT Glider Competition

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Foreword

We’ve come along way in the last hundred years or so. We went from believing manned flight was an impossible feat to strapping people into a tube filled with a few million tons of explosives and sending them into outer space. There is a common modern understanding that one can make anything fly if they try hard enough. The issue arises with how to make it fly *well*. This guide will take you through the design and construction of a simple glider using little more than standard Newtonian mechanics. It will teach you how to make something fly. We’ll leave the flying *well* condition to the 4 year undergraduate degree that most of you are in the process of completing. Please strongly note that this guide does reorder various design steps and prescribes various variable to ensure suitability for a first year students.

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Introduction

A glider has four principle components that are considered the minimum recommended components in order to fly: a wing, fuselage, horizontal tail and vertical tail. These can be seen in Figure 1. As you gain more knowledge about flight and aerospace design, you will likely encounter many more components such as winglets, canards, ailerons, flaps and many more. Each of these have their own unique advantages and uses, but this guide will focus on the four listed above.

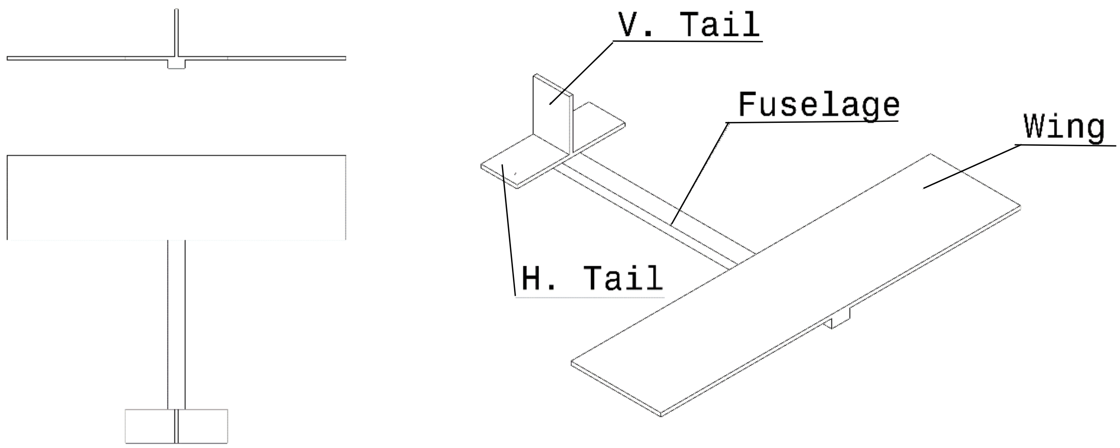

Figure 1: Simple Glider with Labelled Key Components

While designing each of these components, this guide will consistently relate back to the following key design principles.

1. Maintain the C.G. at most 25% away from the front edge of the wing
2. Keep the glider low-weight

As long as these two principles are followed (and the first is much more important than the second) the glider should fly.

Step 1: Let's make a Wing

Theory

The main purpose of wings is to generate lift while minimizing drag.

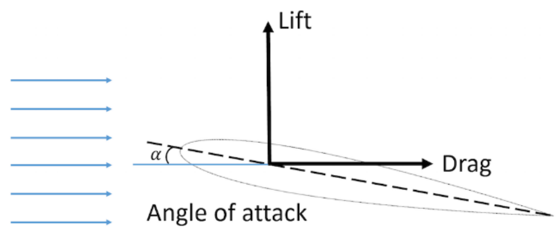

Figure 2: Lift and Drag

The formula for lift and drag are as follows

$$L = \frac{1}{2}\rho V^2 S C_L$$

$$D = \frac{1}{2}\rho V^2 S\left(C_{Do} + \frac{C_L^2 \bar{c}}{\pi e b}\right)$$

Where L is lift, ρ is the density of air (~1.225 at sea level), V is velocity, S is wing area, C_L is the lift coefficient, which is essentially a measure of how well each wing cross section can generate lift, C_{Do} is the parasitic drag coefficient (or zero lift Drag Coefficient), $\bar{c}$ is the average cord length (or wing width), π is the number 3.141592653…, e is the Span/Oswald efficiency factor (typically 07-0.9) and b is the wingspan.

Based on these two equations, it would appear as though we have a problem. We want more lift. The easiest way to do this is by increasing our wing area S. The problem the problem is that if we increase our chord $\bar{c}$, we also get more drag, which we don't want. Luckily, the other way to increase the area is by increasing wingspan b. As we can see from the equation, this actually *decreases* our drag which is exactly what we want. There is a balance when picking your values of b and $\bar{c}$, but in general your aspect ratio, $AR = b/\bar{c}$, should be greater than or equal to 7. The main limiting factors are wing structural capabilities and various higher level aerodynamic effects.

The next thing to look at the lift coefficient. This number is not actually a constant, but rather a variable that changes with your angle of attack α, which is the different between your wing angle and the flight path. This value is also dependant on your *airfoil,* which is the cross-sectional shape of your wing. A typical graph of the AIRFOIL section c_l is given bellow. Please note that an airfoil section c_l and a wing C_L are NOT the same thing, and are related by any of the three equations bellow. If you're wondering why there are three different equations for the same thing, welcome to aerospace engineering.

$\left(C_L = \frac{c_l}{1+\frac{c_l}{\pi AR}}\right)$[1] or $\left(C_L = \frac{c_l}{1+\frac{c_l}{\pi e AR}}\right)$[2] or $\left(C_L = c_l\left(\frac{AR}{AR+2}\right)\right)$[3]

[1] From the NASA Website
[2] From the Anderson Introduction to Flight Textbook
[3] From Professor Bramesfeld's Notes which he claims is definitely way better than NASA's version

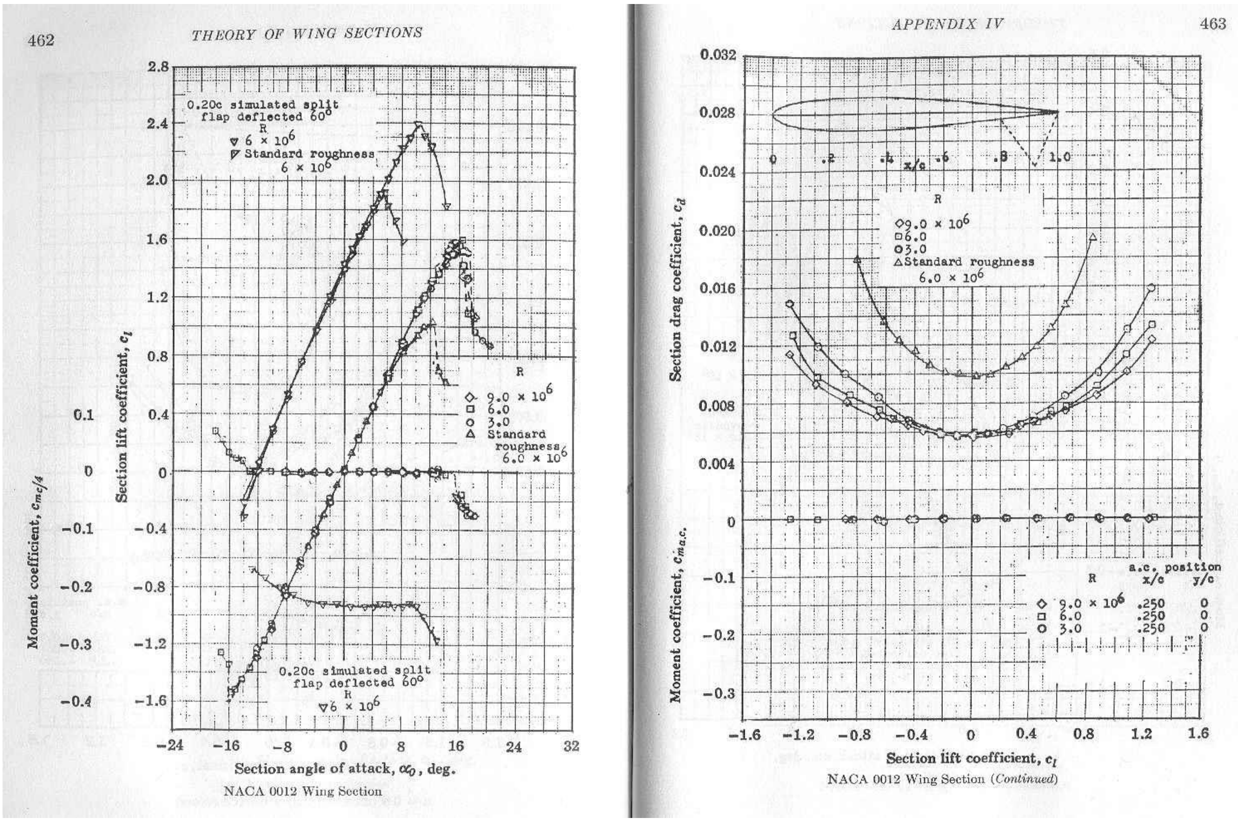

Figure 3: Airfoil properties of the NACA 0012

The key difference between c_l and C_L is that the first is measured for a 2D shape and the 2nd is for a full 3D wing with fun aerodynamic effects like downwash and vortices that you'll learn about in class. For now, the equations should suffice. Similarly, to the section lift coefficient c_l, the also exists a section lift c_d. This, however, is a fine approximation for the actual wing C_D.

Based on the figure above, it can be seen that the relationship of c_l to angle of attack α is roughly linear, until it reaches a point where the lift starts to rapidly decrease called stall. In the pre-stall region, the $c_l - \alpha$ relationship can be modelled as follows

$$c_l = c_{l\alpha}\alpha + c_{l\alpha 0}$$

Where $c_{l\alpha}$ is the lift-curve slope and $c_{l\alpha 0}$ is the lift coefficient at 0 angle of attack, which is 0 for symmetric airfoils. This is the equation is the equation of a line similar to $y = mx + b$ which you are all familiar with.

For gliders, the key principle of airfoil selection is maximizing your lift to drag ration where

$$\frac{L}{D} = \frac{c_l}{c_d}$$

The last parameter that will need to be calculated is the parasitic drag. This drag is composed of 2 components, the pressure drag and the skin friction drag where

$$C_{Do} = C_{DP} + C_{Df}$$

At low speeds, the pressure drag is typically much more dominant than the skin friction drag. The pressure drag coefficient for various shapes can be calculated using the following graph

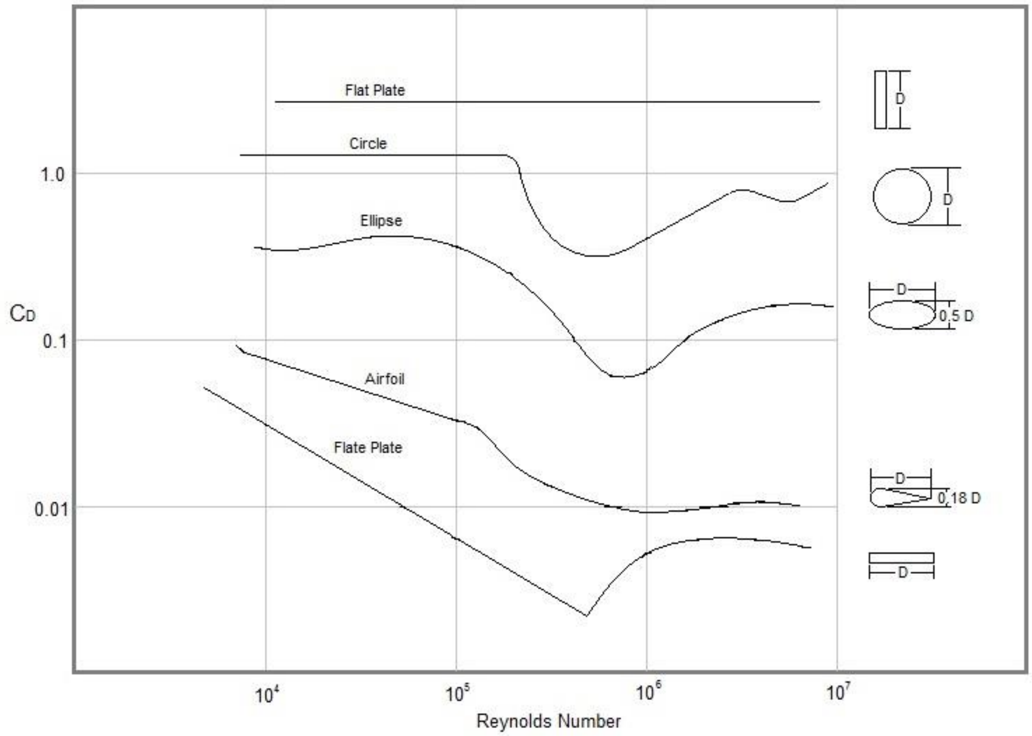

Figure 4: Pressure Drag Coefficient of Various shapes

Note that the figure uses C_D, but it should be C_{DP} to follow our notation. The value Re along the x axis is the Reynold's number which can be calculated as

$$Re = \frac{\rho V \bar{c}}{\mu}$$

Where ρ is the density or air, V is the velocity, $\bar{c}$ is the average cord, and μ is the dynamic viscosity of air, which is approx. $1.789 \cdot 10^{-5} \frac{Kg}{m \cdot s}$ at sea level.

The skin friction drag coefficient can be calculated using the following formulas. For laminar flow,

$$C_{Df} = \frac{1.328}{\sqrt{Re}}$$

And for turbulent flow

$$C_{Df} = \frac{0.074}{\sqrt[5]{Re}}$$

For our purposes, turbulent flow is a safe assumption.

Example

Now that we've covered the theory, we can design our wing given the competition requirements. The two main forces in the y direction are lift and weight. The tail will also produce a force in this direction which you should consider in your own analysis, but we're going to neglect it for now. If we want to gain altitude, want the lift to be higher than the weight. Design is an iterative process, so often time we prescribe an estimate value for something, then once we get a real value, you can substitute it in later. This is why calculation are often done using MatLab or excel that way parameters can be adjusted easily. Let's begin by assuming a final weight of 500g. For this example, we're going to be launching the glider from a flat surface spring with a Δx of 0.5m and a k of 50$\frac{N}{m}$. Please reference the competition guidelines for the true competition spring parameters and launch parameters.

Under idea conditions (no friction assumption) the glider launch velocity will be given by conservation of energy. In your calculations, you will likely wish to consider drag and friction as well.

$$\frac{1}{2}kx^2 = \frac{1}{2}mv^2 \tag{1.1}$$

Velocity can then be solved as follows

$$v = \sqrt{\frac{kx^2}{m}} \tag{1.2}$$

$$v = \sqrt{\frac{50 \cdot 0.5^2}{0.5}}$$

$$v = 5\frac{m}{s}$$

We can now create an equation to specify the design space of our wing. We'll use a flat plate airfoil to keep things simple.

$$W \leq L = \frac{1}{2}\rho S C_L v^2 \tag{1.3}$$

Where for a flat plate $c_{l\alpha} = 2\pi,\ c_{l\alpha 0} = 0$ and α is in radians

$$C_L = \frac{c_l}{1 + \frac{c_l}{\pi e AR}} = \frac{c_{l\alpha}\alpha + c_{l\alpha 0}}{1 + \frac{c_{l\alpha}\alpha + c_{l\alpha 0}}{\pi e AR}} = \frac{2\pi\alpha}{1 + \frac{2\alpha}{eAR}} \tag{1.4}$$

Combining 1.3 and 1.4, subbing in $W = 0.5kg,\ \rho = 1.225,\ v = 5$ and assuming $e = 0.7,\ S = b\bar{c},\ AR = \frac{b}{\bar{c}}$ we get the following

$$5.197 \cdot 10^{-3} \leq \frac{\alpha}{1 + \frac{2\alpha\bar{c}}{0.7b}} b\bar{c} \tag{1.5}$$

Since we're launching in line with the flight path, $\alpha = 0$ and our lift would consequently be 0 at launch. Let's preangle our wings at $3°$ or 0.05236 rad. We'll also prescribe our b to be the max 0.75m giving us the equation.

$$0.1323 \leq \frac{\bar{c}}{1 + 0.199\bar{c}} \tag{1.6}$$

This can be rearranged to

$$\bar{c} \geq 13.55\ cm$$

Which would give us an aspect ration of

$$AR = \frac{b}{\bar{c}} = \frac{0.75}{0.1355} = 5.53$$

This is a little lower than we would hope. We can reduce the cord requirement in a few different ways such as changing the airfoil, having a higher preset α, or reducing the weight. For a glider, the aspect ratio should typically be at least 7 to minimize your drag.

This method is a very rudimentary way of sizing a wing. The number of prescribed variables can be reduced by including more constraint equations such as maximizing lift to drag ratio. If a closed for equation for range can be developed, this can if fact be used the best form of constraint equation as well. These are left up to the teams.

Step 2: Let's design a Tail

Theory

The job of the horizontal tail is to make sure that when the glider pitches up or down (rotates up or down relative to the flight path) it returns to a neutral position. Consider the 2D glider with a symmetrical tail airfoil at three different angles of attack shown in Figure 5.

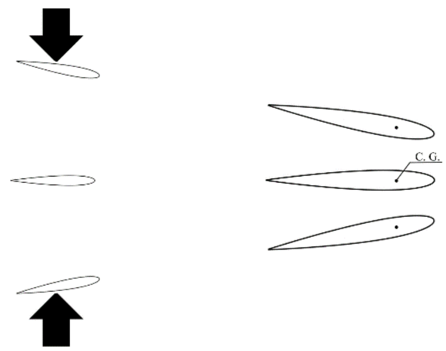

Figure 5: Horizontal Tail Effect

When the glider begins to pitch down, the tail sees a negative angle of attack, resulting in a negative lift, thus creating a moment about the C.G. in the counter clockwise direction acting to rotate the glider back to neutral. When the glider begins to pitch up, the tail sees a positive angle of attack, resulting in a positive lift, thus creating a moment about the C.G. in the clockwise direction acting to rotate the glider back to neutral. As can be seen the primary function of the horizontal tail is to create a restorative force when the glider pitches up or down.

Now the question remain, how big should the tail be. As we learned before, a bigger tail will result in a bigger tail lift, or restorative force. If this force is too strong, the glider will simply overshoot the neutral position and continue to pitch up and down in an oscillatory fashion forever as seen in Figure 6.

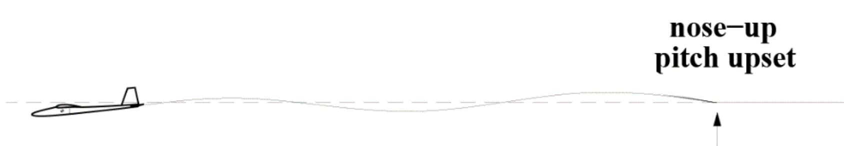

Figure 6: Effects of Oversizing a horizontal tail

On the other hand, if the tail is too small, the restorative force won't be enough and the glider will never return to it's original flight path as seen in Figure 7.

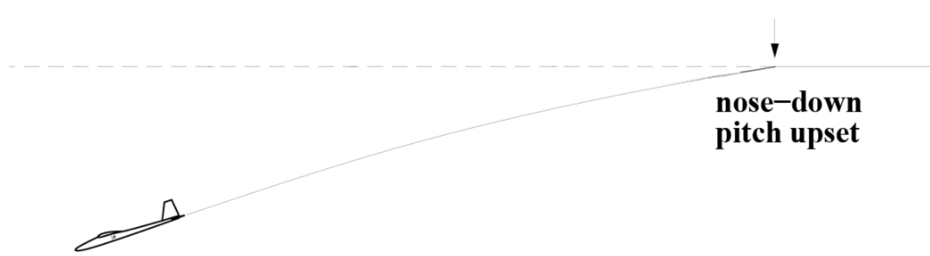

Figure 7: Effects of Under sizing a horizontal tail

The full stability analysis of an aircraft can get quite complicated. In general however, as long as the center of gravity is located between the leading edge of the wing and the 25% cord point, a simple equation can be used to size the horizontal tail.

$$V_h = \frac{S_h l_h}{S\bar{c}}$$

Where V_h is the horizontal tail effectiveness coefficient, S_h is the area of the horizontal tail, l_h is the distance between the C.G. and the aerodynamic center of the horizontal tail (usually ~25% od the tail cord), S is the area of the wing and $\bar{c}$ is the average wing cord length.

The values of V_h are around 0.3 to 0.6 for most aircrafts. Given that your gliders will have no active controls, higher values will be preferable ranging even potentially up to 0.8.

The principles of the vertical tail are exactly the same as the horizontal tail. The vertical tail effectiveness coefficient V_v has the following formula.

$$V_v = \frac{S_v l_v}{S\bar{c}}$$

Typical values for V_v are 0.02 to 0.05 for most aircrafts, and once again, designing on the slightly higher side won't hurt.

These values only apply to T-Tails and standard tail configurations. Other tail configurations such as the V tail exist as well, each with their own benefits and disadvantages. The final tail configuration is up to the student, but design considerations for other configurations shall not be presented here.

For the purposes of the competition, you should be fine calculating your tail lift and drag the same way as the wing, but it should be noted that in reality this is not the case. When the air leaves the wings, it is very turbulent and actually leaves at a certain downwashed negative angle. This will change the way the tail behaves. To minimize these effects, the tail should be positioned farther back from the wing.

Example

Our simplistically designed wings from the above example had a wingspan b of 0.75 m and a cord c of 0.1355m. This gives us the following wing area

$$S = 0.75 * 0.1355 = 0.102m^2$$

Setting V_h to 0.7, we get

$$V_h = 0.7 = \frac{S_h l_h}{S\bar{c}} = \frac{S_h l_h}{0.102 \cdot 0.1355}$$

$$9.6747 * 10^{-3} = S_h l_h$$

The value of $S_h l_h$ is quite import. As each of these parameters increase, you'll need more weight at the front to balance your glider at the quarter cord point. l_h increases the moment arm, and S_h increases the moment force. An optimization can be done to determine the optimal values. Once the value for S_h has been found, you can optimize for AR to find your span and chord, or simply use a similar ratio to the wing. A similar process can be followed for the vertical tail.

Step 3: Let’s design a Fuselage

Theory

The fuselage’s main purpose is to connect the wing and tail and house the payload. It should be designed as small and light as possible. The drag of the fuselage and be calculated the same way as with the wing. Since it’s lift will likely be 0, only the skin friction and pressure drag must be considered. When positioning the payload, it should likely be as forward as possible to help maintain the overall C.G. at or in front of the 25% cord point. At low speeds the pressure drag will likely be much greater than the skin friction drag.

Step 4: Let's Talk About Stability

As long as the tail is designed correctly, and the C.G. is in the correct location, the glider should be stable. That being said, there are other ways to enhance stability. These methods are not required by any means, but can be used if desired.

Dihedral

The first of these is dihedral. Adding a dihedral angle means slightly rotating the wings upwards when attaching them to the fuselage as seen in Figure 8.

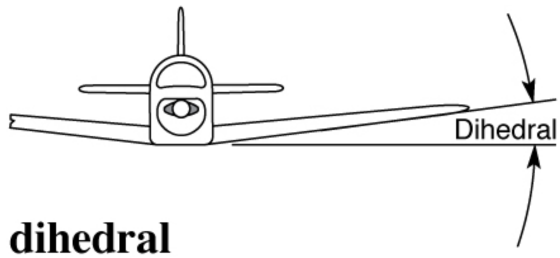

Figure 8: Dihedral

This helps to increase the roll stability. As seen in Figure 9, when the glider begins to roll in one direction, one wing will begin to produce more lift than the other. This will create a moment imbalance and cause the aircraft to rotate back to the neutral position.

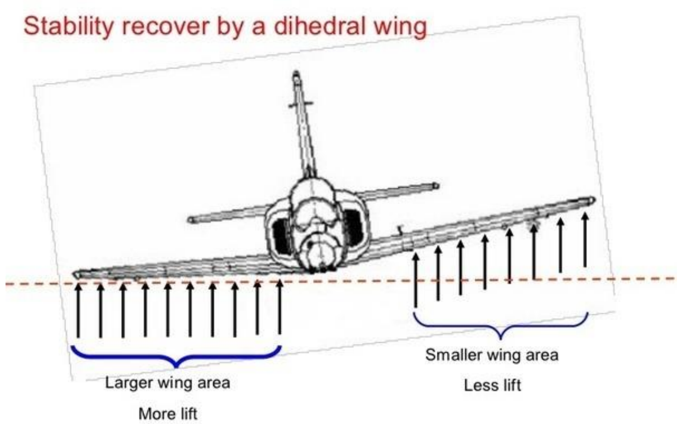

Figure 9: Roll Recovery Via Dihedral

If the dihedral angle is too large, the this will cause the aircraft to over-rotate and go into a spiral, if it is too small, the aircraft will not return to it's original flight path. Dihedral sizing can be done using the following equation

$$B = \frac{l_v Y}{C_L b}$$

Where Y is the dihedral angle in degrees. For spiral stability, B should be greater than 5 (but not too much greater). For Roll control, $V_V B$ should be between 0.1 and 0.2.

Other factors help determine the stability of the aircraft such as deciding whether to place the fuselage above or below the wings. These decisions and considerations are left for the reader to explore.

Electronics

MicroProcessors

The electronics components of the glider will likely require a microprocessor to run. If you have absolutely 0 experience with electronics and find the task of making the electronics extremely daunting, then the recommended processor is an Arduino Uno (https://www.digikey.ca/products/en?keywords=%091050-1041-ND).

Figure 10: Arduino Uno

This processor will allow you to get your setup with no soldering. If you are slightly more keen on learning the systems that many student teams use, we recommend the Arduino Pro Micro (https://www.digikey.ca/products/en?keywords=1568-1061-ND). This is a smaller, lighter processor that will be much easier to incorporate into your gliders. (Note, if you have access to an FTDI cable through a student team or other, you may choose to get a Arduino Pro Mini instead)

Figure 11: SparkFun Pro Micro

If you really want to minimize your footprint, there are other smaller devices available online like the Beetle (https://www.digikey.ca/products/en?keywords=1738-1016-ND), but please note, we've never tested or used this device before, and therefor it or similar devices should not be used without reviewing it's requirements.

Figure 12: DFRobot Beetle

Altitude Determination

There are a variety of ways to determine altitude. Some of which are more accurate than others. No matter which way you choose, you will need some form of sensor. Deciding which sensor to choose is up to the students. Based on our review, there are sensors available that can range from as low as under $5 to up to $100. More expensive does not necessarily mean better, the key deciding factor will be choosing a sensor that is appropriate for a low altitude (<5-10m) indoors application. Remember to consider the availability of Arduino libraries for the sensor that you choose. If you pick a sensor with plenty of content available online, the coding required for the project will be very minimal.

Position Determination

For an indoor application, this can get rather complicated. The are many ways to accomplish this feat, much more than for the altitude determination. The complexity of this problem is up to the students and the degree of accuracy which they wish to achieve. "Position" is not a directly measurable quantity. Students will be required to use a sensor to measure something else that can be related through math and physics to give them an estimate of their distance travelled. There is no one right answer to this problem and we expect to see a large variety of different potential solutions.

Example

Here is an example electronics configuration

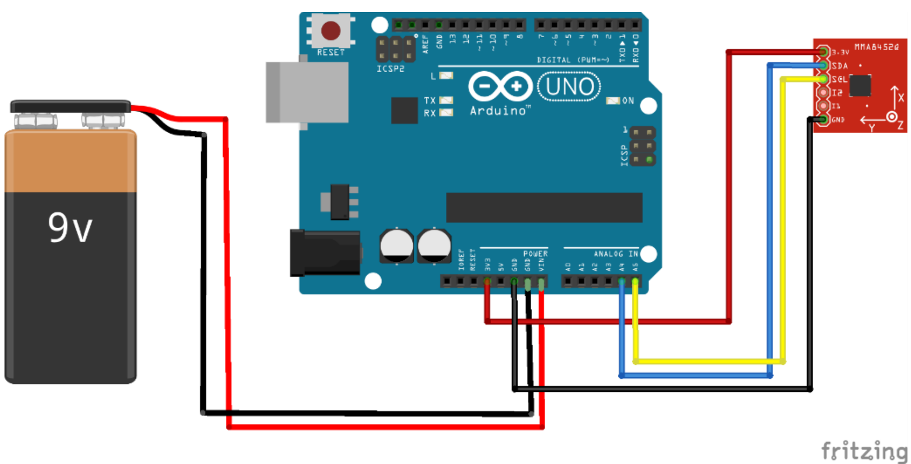

Figure 13: Example Electronics Configuration