Tethered Electric Airplane Project

Designing Your Wing

Simplifications and Generalizations

Like many fields of study, Aerodynamics can be very complex. In order to provide a meaningful introduction in a limited period of time it is necessary to make a few simplifications and generalizations. Here are a few of the simplifications that we will make for designing our tethered electric airplane wing:

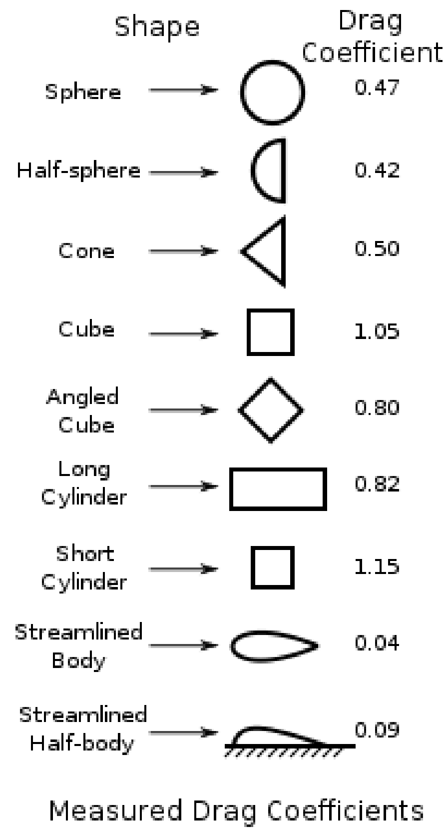
1) The airplane will be tested at room temperature at sea level
    a. These two factors affect the density of air. Hot days and high elevations reduce the air density, thus affecting lift and drag. Unless you're doing this project in the winter, outdoors, in Nepal, this is a fair assumption. Indoors, in Vancouver, it's perfect.
2) The airplane will be travelling at less than 360km/hr (assume 36 km/hr or 10 m/s)
    a. This means that our analysis can be based on incompressible fluid flow
        i. This greatly simplifies computer analysis as the fluid flows like a liquid
    b. Above Mach 0.3, the impact of air compression changes how air flows
        i. Note that fast jet airplanes have swept wings
            1. Swept wings may not be helpful at lower speeds
    c. The world record for a tethered airplane is 340km/hr. Let me know if you break it…
        i. https://www.youtube.com/watch?v=4vAw1CC4A3g
3) The airplane will have a rectangular wing of uniform cross section.
    a. No swept wings, no changes in shape over the length of the airfoil
    b. This works great for wings cut using a template on a hot wire cutter
    c. This greatly simplifies our analysis
4) The wing will be analysed separately from the propeller, fuselage and tail
    a. In reality each of these components interact with the airflow around the others
        i. The interaction is too complex to model at an introductory level
    b. Principles of drag reduction applied to the wing can be applied to other surfaces
5) We will consider a two-dimensional analysis of the airfoil
    a. Our model assumes an infinitely long wing
        i. Shorter wingspans with greater chord length deviate from this assumption
        ii. Wing tip vorticies and other 3D phenomena may have an impact on flight

Technical Terms

Every field of study has technical jargon. Aerodynamics is no different. Here are a few of the terms we will be using. Some definitions may be simplified.

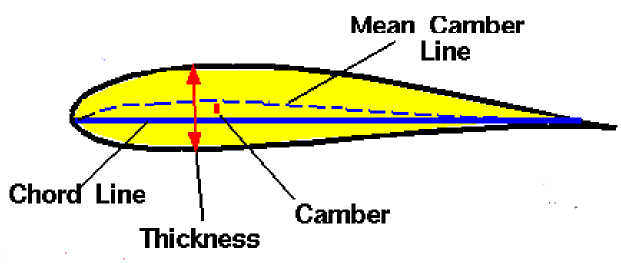
> **Reynolds Number (*Re*):** a number that allows us to compare the fluid flow in fluids of different densities, flowing at different speeds. Larger, faster airplanes will operate at higher Reynolds numbers. A Boeing 747 may have *Re*=2,000,000, a light plane around 4,700,000, and a housefly about 120. Our small, relatively slow plane will be closer to *Re*=60,000.

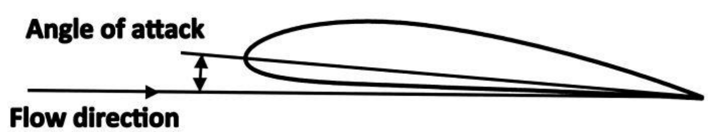
Coefficient of Drag (Cd): a number derived from testing the shape of an object that allows you to predict the force of aerodynamic drag acting on the object. The force of drag increases in a linear manner as Cd increases. The cross-sectional area of the object will also increase drag in a linear manner, however the drag force increases with the square of velocity. Maintaining a low Cd is important to going fast. (Figure, at right, from Wikipedia)



Coefficient of Lift (Cl): a number derived from testing the shape of an airfoil that allows you to predict the lifting force generated by the airfoil. As with Cd, lift increases linearly with Cl, but with the square of velocity. Where we refer to cross-sectional area in Cd, however, we refer to chord length in Cl.

Chord Length: the distance from the leading edge (front) of an airfoil to the trailing edge. (image, below, from NASA (edited))





Angle of Attack (α): the angle at which the airfoil cuts into the air. Changing the angle of attack can greatly affect the lift and drag coefficients of the airfoil. Small increases tend to increase lift, but large angles of attack can result in stall. (image, above, from Wikipedia)

NACA Airfoil: The predecessor to NASA, NACA was an American government body founded in 1915 to study aeronautics. As part of their testing they developed a database of hundreds of different airfoils and how they respond to wind tunnel testing. There are a number of online resources and software packages that refer to NACA airfoils.

Camber: A curve in an airfoil. See “mean camber line”, in above diagram.

Aspect Ratio: The ratio between the length of the wing (wingspan) and the chord length of the wing. A high aspect ratio wing (long wingspan, short chord) as seen in gliders will tend to be more efficient as wing tip vorticies will be less significant, however for faster, higher powered craft, long wings can become too flexible, and generate excessive parasitic drag.

Parasitic Drag: drag caused by the fluid flow of air as it interacts with the airplane. Parasitic drag should be minimized as it wastes energy.

Induced Drag: the drag caused by an airfoil creating lift. While induced drag should be kept to a minimum, it cannot be eliminated entirely as it is a necessary function of generating lift.

Bernoulli's Principle: high speed fluids are at a lower pressure than low speed fluids. This is used in the carburetor of engines, but also as a means of generating lift in an airfoil.

Useful Resources:

Aerodynamics, airfoils and airplanes are described extensively online, but often in very technical terms. Finding suitable introductory resources can be a challenge. Here are some that are relevant:

NASA Beginner's Guide to Aerodynamics:

https://www.grc.nasa.gov/www/k-12/airplane/bga.html

This was my "go to" resource for this project for years as it contained the FoilSim III virtual wind tunnel. Unfortunately most of the interactive parts of this project were written in Java, and have become almost impossible to use due to increased security settings. The text and references, however, continue to be useful.

Ideas Inspire Aerodynamics Lesson:

http://ideas-inspire.com/basic-aerodynamics-with-lesson/

Not specifically focussed on airfoils and wing design, but a good, general, backgrounder on how to get your airplane in the air and keep it there. Some excellent diagrams and ideas presented at the introductory level.

Wind Tunnel Free:

http://www.algorizk.com/

An app for iOS and Android that simulates fluid flow over a surface, and calculates lift and drag coefficients. Beautiful, interactive outputs… download from the relevant app store and explore. Paid versions with more advanced features are also available at reasonably low cost.

Model Aircraft Airfoils:

http://www.airfieldmodels.com/information_source/math_and_science_of_model_aircraft/rc_aircraft_design/plotting_airfoils/about_airfoils.htm

Some good tips on selecting an airfoil for a model plane.

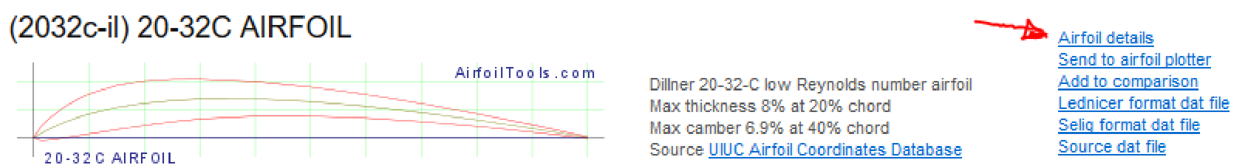
Airfoil Tools:

http://airfoiltools.com/

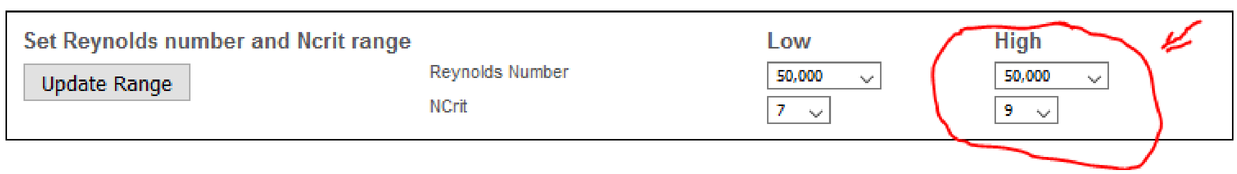
A website with a huge database of NACA airfoils, tools to compare them and print them. It will be used extensively on the following pages.

Choosing an Airfoil for Your Tethered Electric Airplane

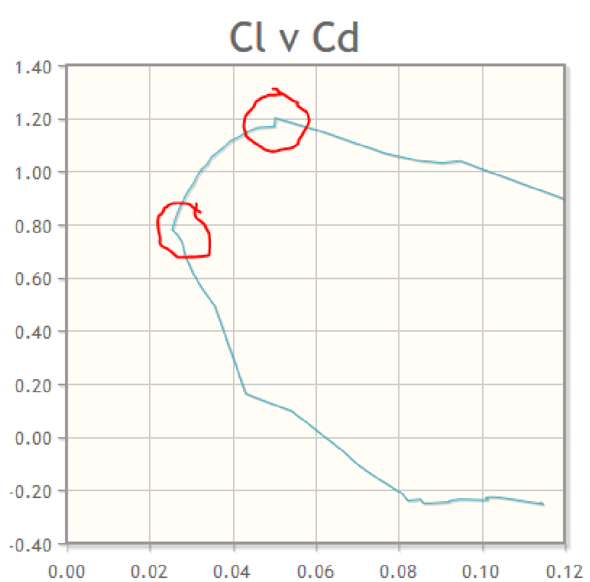
1) Go to http://airfoiltools.com/
2) Select “Airfoil Search” – click “Search”
   a. This should bring up a list of hundreds of airfoil designs.
   b. Note the first one, “20-32c Airfoil – Dillner 20-32-C Low Reynolds Number Airfoil”

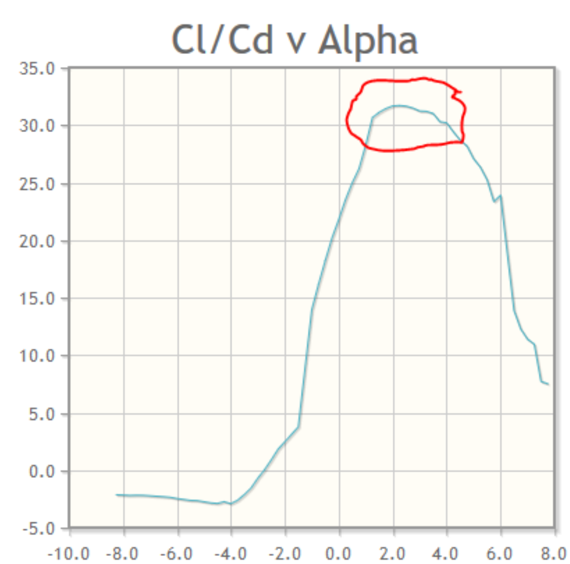


3) Click on “Airfoil Details”
4) Scroll Down to “Polars for 20-32C Airfoil” and set the High Reynolds Number to 50,000.
   a. This will simplify our charts to only look at airfoil performance at Re=50,000
      i. This is the closest approximation for most of our tethered electric airplanes
   b. Click “Update Range”

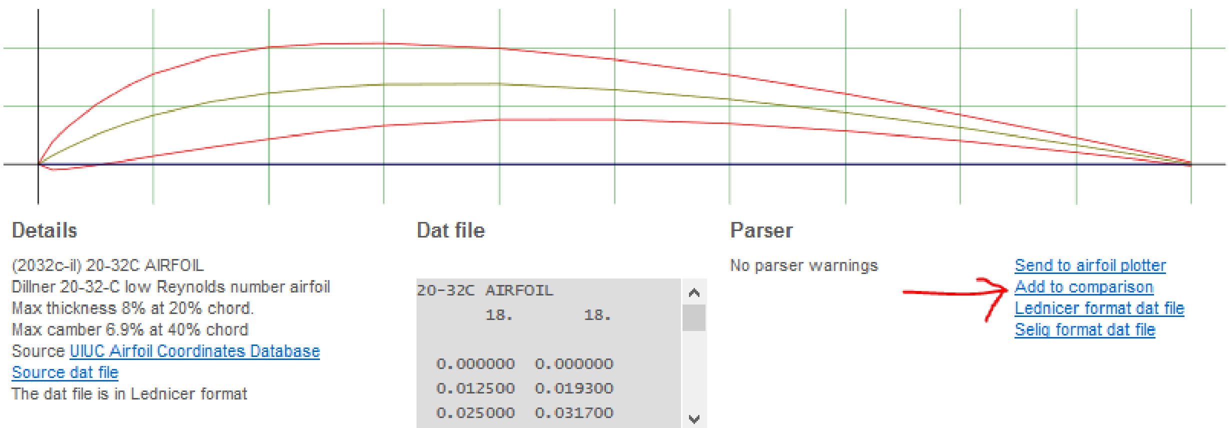


5) Observe the Chart “Cl vs Cd”. Shows the lift and drag coefficients over a range of different angles of attack. Cd is the horizontal axis, while Cl is the vertical. Note the minimum Cd is 0.025, while the maximum Cl is 1.2. Low Cd is good for going fast, while high Cl is good for heavy lift. Note, however, that a high Cl requires a higher Cd due to induced drag.



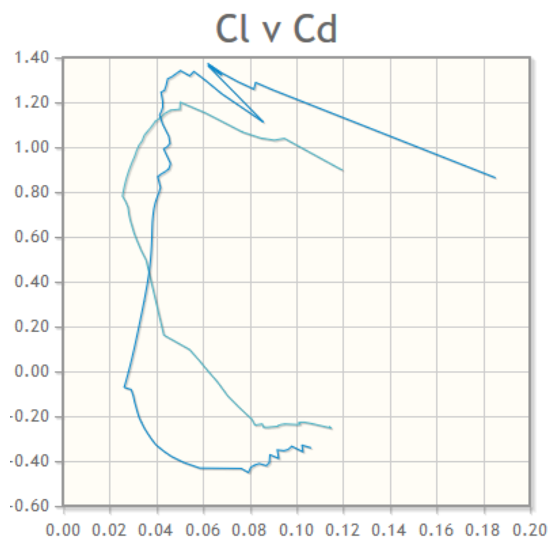


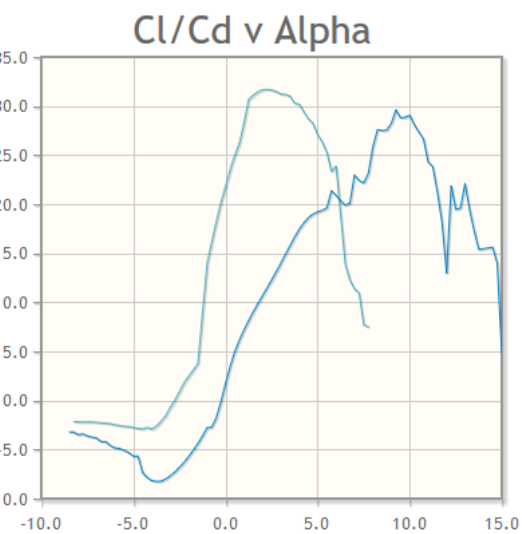
6) Note the chart “Cl/Cd vs Alpha”, immediately below the first chart. (shown here on the previous page). This helps identify the range of angles of attack over which the airfoil is efficiently producing lift. Peak performance occurs between 1° and 4° angle of attack.
    a. A high number for the Cl/Cd ratio is good
    b. Having a high number across a wide range of angles of attack is even better
        i. This means you don’t have to trim your airplane as perfectly to achieve performance
    c. Knowing a promising angle of attack can help you trim your plane. If you are flying this airfoil with an angle of attack greater than 4°, then you are likely approaching inefficiency.
    d. Note that the data stops at about 8°. This is because the wing has stalled and your airplane is crashing. Having a high stall angle can help keep your plane from stalling.
7) The “Cl vs Alpha” and “Cd vs Alpha” also let you analyze performance over various angles of attack. If you are designing purely for speed, then you want the lowest Cd over the greatest range of angle of attack.
8) Click on “Add to Comparison” (right underneath the drawing of the airfoil, see below)



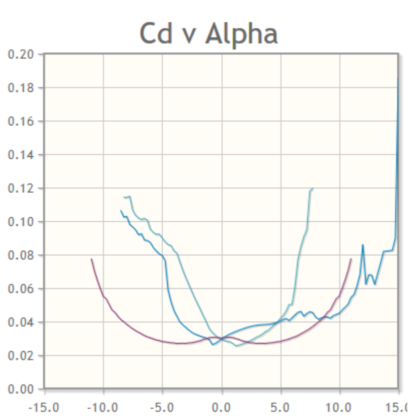
9) Click on “Airfoil Database Search” (under Applications… top right corner)
10) In the “Text Search” box, type “Clark Y” and press enter (or “Search”)
    a. The Clark Y is a very common airfoil for small airplanes and model aircraft
11) Select “Airfoil Details” for the (clarky-il) CLARK Y AIRFOIL.
12) Note that the drag polars are somewhat different for this airfoil, as would be expected given it has a different profile.
13) Click on the “add to comparison” option (as in step 8).
14) The drag polars will now show the comparison between the two airfoils. Unfortunately the colours for the two are very similar… the legend (above the plots) shows the Clark Y is the slightly darker blue line.

15) Observe Cl vs Cd and Cl/Cd vs Alpha (the Clark Y on these diagrams is the higher one with the zig zag in Cl vs Cd and the one "shifted to the right" on Cl/Cd vs Alpha)





16) Note that the Clark Y airfoil has:
    a. A higher maximum coefficient of lift – good for a heavy lift aircraft.
    b. Higher drag in the range midrange of lift… from about Cl=0.45 to Cl=1.15
    c. A positive Cl/Cd ratio from 0° to 15° while the 20-32 has a positive ratio from -2.5° to 7.5°. The Clark Y is able to generate lift over a wider range of angles of attack… it is a "more forgiving" airfoil… but it's peak lift/drag ratio is lower than for the 20-32.
        i. Will you trade off peak performance at a narrow range of operating conditions for "good" performance across a wide range of operating conditions?
17) So far we have looked at the 20-32 airfoil, a slightly "under cambered" airfoil (the bottom of the wing is concave) and the Clark Y, a roughly flat bottomed airfoil. Another common type of airfoil is the symmetric airfoil. Select "Airfoil Database Search" and try "NACA 0015". Add this airfoil to your comparison.
18) You'll notice that the NACA 0015 doesn't appear to be a strong contender in the Cl vs Cd or in the Cl/Cd vs Alpha charts, but note the Cd vs Alpha chart (at left, below).



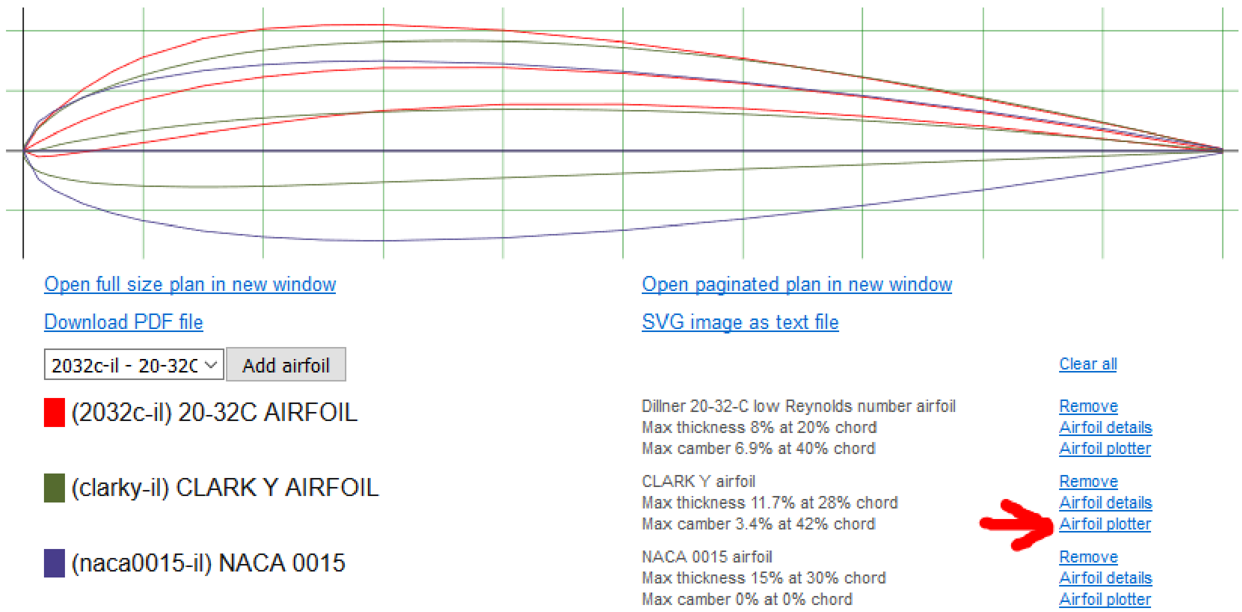
This shows the NACA 0015 having lower drag across the range of 2° to 8° angle of attack. That means this airfoil may result in a plane that is capable of flying faster than the other two airfoils. Since total lift is a function of both Cl and airspeed, and airspeed is squared, while Cl is linear, the lower drag may offer lift advantages over the other two airfoils with higher drag, IF your fuselage and propeller are designed to allow the aircraft to travel at higher speeds.

In short, there is no "one best" airfoil for this project… you may want to build one airfoil, test it on your plane, then consider a different design and test it. Try out a few different airfoils to see how they compare and get your plane flying early for more testing time!

Cutting Your Airfoil Templates

Once you have selected an airfoil complete the “airfoil design worksheet” and hand it in for marking.

Click “Airfoil Plotter” for your chosen airfoil. I’m choosing the “Clark Y” in this example.

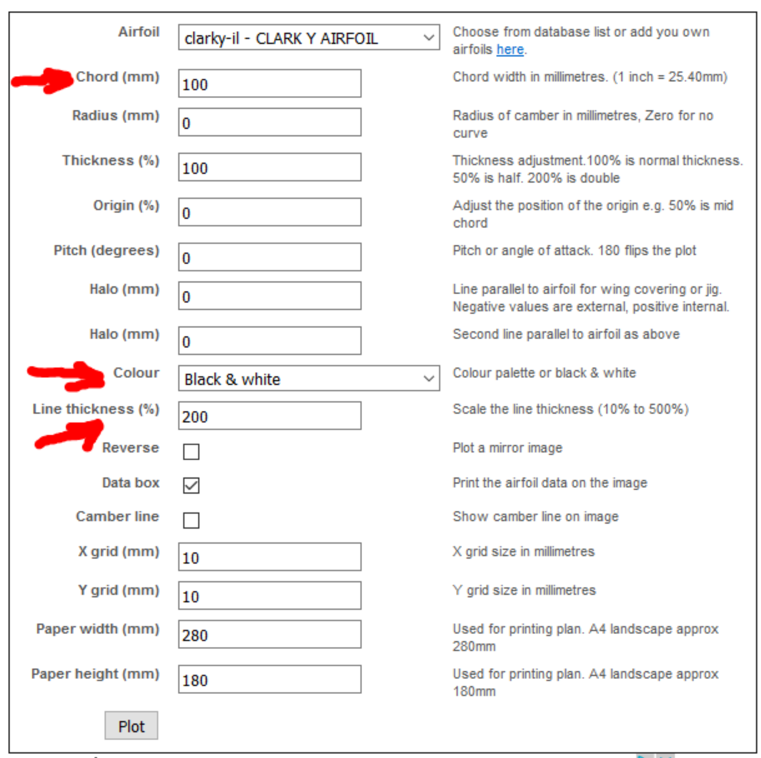


Adjust the “chord” setting to give the desired length of your airfoil from the leading edge to the trailing edge. Typical ranges are from about 90mm to 180mm. Note that the airfoil scales with the chord, so a longer airfoil will also be thicker. Short chords with long wingspans result in high aspect ratio wings, but airfoils that are too thin will need additional reinforcement to keep them from breaking.

Set the colour to “Black and White” and the Line Thickness to 200%, just to make your print out more visible.

Click on the “Plot” button to update your drawing, then “Download PDF File”.

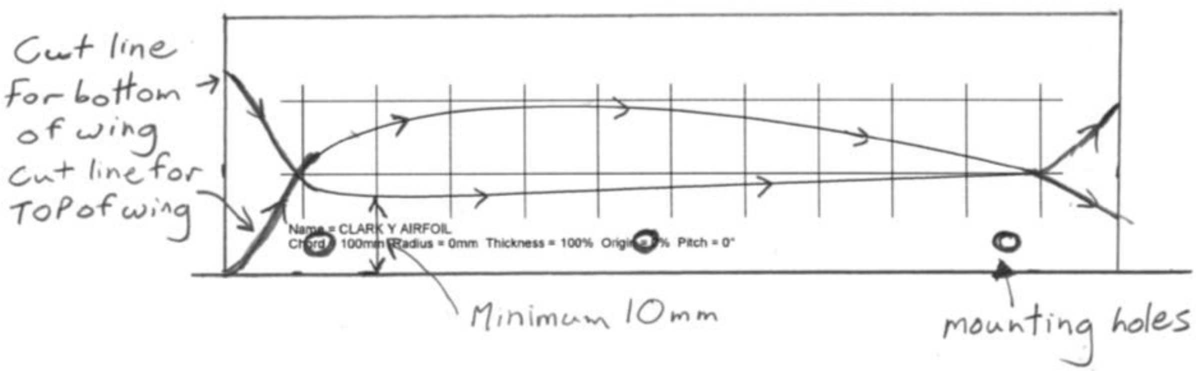
Save this file to your personal drive and print one copy at 100% scale.



This will be used to create your hot wire cutting template.

On your printed copy, use a pencil and ruler to draw a rectangular box around the airfoil. The front of the box should be 10-15mm in front of the leading edge, the back of the box should be 10-15mm behind the leading edge, and the bottom of the box must be at least 10mm below the lowest point on the airfoil.

Add “cut lines” for creating the top and bottom cutting templates. Mark three mounting holes below the bottom of the airfoil. The cut lines will guide your hot wire cutter, while the mounting holes will hold your template on to the styrafoam.

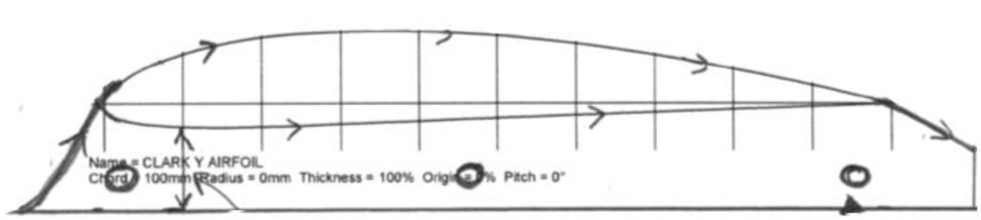


Make three photocopies of your template. You are going to need two TOP templates and two BOTTOM templates to cut your wing.

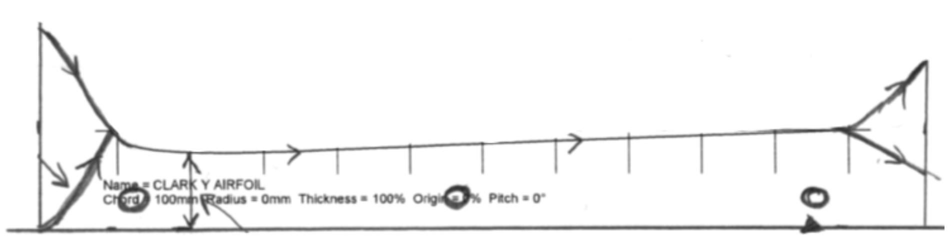
Cut out your templates and use glue stick to adhere them to a strip of 1/8” to ¼” thick hardboard.

Drill the three mounting holes in each template. Typically a 1/8” to 3/16” hole works well.

Cut two templates to form the top templates. These will be used for cutting the top side of the airfoil and should look something like this.



Cut two templates to form the bottom templates. These will be used for cutting the bottom side of the airfoil and should look something like this.



You are now prepared to cut your wing, using the instructions given in class.

Airfoil Design Worksheet

Names: ____________________ ____________________ ____________________

Airfoils we studied:

List at least two airfoils other than the three discussed in the handout

Handout airfoils: 20-32c
Clark Y
NACA 0015

Our airfoils: ____

____

____

We chose the ________________________________ airfoil for our plane.

Our airfoil has a maximum Cl of ___________________ at _________________ degrees angle of attack.

Our airfoil generates lift from __________________ to _________________ degrees angle of attack.

Our airfoil has a maximum Cl/Cd ratio of ____________________ at ________________ degrees.

We chose our airfoil because: (list at least three valid engineering design reasons)

1) ____

____

2) ____

____

3) ____

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