A GOOD AIRFOIL FOR SMALL RC MODELS

by Jef Raskin

INTRODUCTION

When I started building really small RC models, I wondered what kind of airfoils should be used. Based on consulting other experts, using computer and wind tunnel data, and building and flying models to test the results, I found a good general-purpose airfoil; it is certainly better than those found on many kits and ARFs.

But it's not for all models, just for certain small ones.

JUST HOW SMALL IS SMALL?

"Small" is a relative term. For example, the largest model plane is small compared to a Boeing 747. This makes it important to say exactly what we mean by "small" models. Aerodynamicists talk in terms of the "Reynolds number" (no apostrophe, it is named after the 19th century scientist, Osborne Reynolds). The Reynolds number (abbreviated Re) is very easy to compute for a model airplane flying under typical conditions (near sea level, mild or cold temperatures). A quick definition: a wing's chord is the distance from the wing's leading edge to its trailing edge, measured parallel to the direction of flight. To get a value of Re close enough for modeling purposes, just multiply the plane's speed times the wing chord times a magic number. Here's the magic numbers for both Imperial and Metric measurements.

Re = speed in miles per hour * chord in inches * 770
Re = speed in meters per second * chord in centimeters * 680

If your wing tapers, then it will have different Re at different places along its span. The sidebar can help you estimate the speed of your model.

Here are some examples. A plane with a chord of 6 inches that flies at 20 mph -- typical of some park flyers -- has Re = 100,000 (we usually work only to two significant digits when using Re). An indoor RC plane I fly has a chord of 3 inches and flies at 6 mph. Re = 14,000.

Now that we know about Re, we can be precise about small. Your plane is "small" in the sense discussed in this article if its Re is less than 50,000. So the plane with Re = 100,000 is not small in our sense, while the plane with Re = 14,000 is small. There is a lower limit, too. I don't know if this airfoil is effective below Re = 1500. But few of us fly that small and that slow (1 inch chord at 2 mph give a Re of about 1500).

[Illustration: photos some available designs with their Reynolds numbers. Choose models in the general ranges as follows. Re > 100,000; Re = 40,000; Re = 20,000; Re = 10,000 (Henry Pasquet's photos will show some of these last).]

THE GOOD, THE BAD, AND THE EASY

If you ask an aerodynamicist for a "good" airfoil, you'll get a question right back, "What do you mean by 'good'?" There are many properties that we can specify, and we can't have everything we want. For example, the airfoil described in this article is very efficient but, while it is fine for inside maneuvers such as a simple
loop, it is not good for more advanced aerobatics such as flying inverted or an outside loop. It would probably not be optimal in a load-lifting competition. Not only that, but some attributes of a wing are not controlled by the airfoil. For example, a strongly tapered wing may have a nasty stall with any airfoil. So what is good and bad about this particular airfoil?

· It has a good lift-to-drag ratio (L/D). A better L/D means that the wing produces relatively little drag (boo, hiss) for a given amount of lift (cheers!) Good L/D also means a flatter, longer glide
· It is easy to lay out in any size
· It can be built easily and lightly
· It doesn't have an abrupt stall
· Its behavior is the same across a wide range of Re
· It is close to scale appearance for many early airplanes.

What is bad about it?
· It does not like to fly inverted
· It may require external bracing or use in a biplane structure to keep the weight low
· It is not scale-looking in cross-section for most post-WWI aircraft.

HOW THIN IS THIN?

It's been known for years that a conventional airfoil

[ Illustration: just copy this illustration in whatever style desired. But do not change the shape. It is probably best to use it as is.]

is not best for small models and that a thin, curved sheet of balsa, foam, or other light material is better. Somewhere between $Re = 50,000$ and $Re = 100,000$ conventional airfoils become superior (just where the changeover occurs for any particular design depends on many factors, too complex to discuss here). Very thick airfoils, for example, one with a thickness-to-chord ratio of 20%, don't become effective until $Re$ is well over 100,000.
The lift we can get from different kinds of airfoils changes dramatically at different Reynolds numbers. This chart will give you a feel for how differently they can behave. At very low Re, a flat plate is best, at higher Re a curved plate is best, and finally a "conventional" airfoil is best. As the curves for the airfoils are dependent on the particular airfoil used and other factors, this chart cannot be used quantitatively.

So, for our purposes, we want a thin airfoil. Once again, we have to be precise with a relative term. We must ask: How thin is thin? We can't just give a number, such as 1/32 inch or 0.5 mm, because a larger wing can have a larger absolute thickness and still be a "thin" airfoil. To solve this kind of problem, wing thickness is expressed as a percentage of the chord length.

Thin for our purposes means at most 3% of the chord of the wing. So if your wing has a chord of 9 inches, then the thickness would be at most 0.27 inches or about 1/4". Thinner, down to about 1%, is better aerodynamically. Getting thinner than 1% probably confers no aerodynamic benefit. Here is what our 3% thick, curved sheet airfoil looks like.

and here is our airfoil at 1% thickness.

[Illustrations: These drawings (3% and 1%) are accurate illustrations of the airfoils discussed, they should be used as is.]

WHAT ABOUT SPARS?

Thin wings are often weak, and one way of strengthening them is to add spars. But spars which change the shape of the airfoil can lower the quality of the airfoil. Many light-weight models are made with leading and trailing edge spars with a thin covering over ribs between the spars.

[Illustration: a photo of any model with this kind of wing. The early "Bleriot" ARF electric models are a good example. Perhaps a detail of the Megatech Merlin wing. ]

Their airfoil looks like this

The spars (whether they are round, square, or some other shape) spoil some of the advantage of the thin-sheet airfoil. Spars in the middle of the wing (instead or along with those shown) are also harmful. They are less harmful on the bottom than on the top of the wing. I do not have any numerical data on how much extra drag or lift lost such spars cause

Ribs are less of a problem because they are aligned in the direction of flight.

It is more efficient aerodynamically, and lighter, to use external rigging (as some early aircraft and indoor
rubber-powered models do). At our low Reynolds numbers, the drag of a few fine wires (I use thin Kevlar fishing line) is negligible. Larger, faster models and real aircraft have to be very careful about such drag-inducing parts. We do not.

HOW MUCH SHOULD A THIN WING BE CURVED?

For thin airfoils, camber is a measure of just how high the highest point in the curve is. As with thickness, we measure camber as a percentage of chord. The airfoil this article recommends has 4% camber. Interestingly, this is the camber that the Wright brothers also found most efficient in their miniature wind tunnel. Their wind tunnel models had Re in our "small" range! The Wright brothers discovered that other airplane designers of their time were typically using too much camber. In an eerie parallel, that's what I found, too. Most small RC models are designed with too much camber!

Now that we know how thin a wing should be, and how much camber it should have, we can ask: What curve should we use? A simple circular arc of 4% camber is not bad. Because we the high point of a circular arc is in the center, we say that it has its high point at 50% (of chord length). Research shows, however, that it is better to put the high point further forward, and optimal seems to be at 40% of the chord. Below I'll show you how to lay out this kind of airfoil with compass and ruler (or a computer).

BUILDING PRACTICAL THIN WINGS

Materials and methods (to be written) and sources (to be found)

REAL-WORLD EXAMPLE

I have built a number of models with this airfoil, and all flew well. But lots of models fly well: The real test came when I flew the same airplane (the MiniStik, sold by Bob Selman Designs: Re = 21,000) with its stock 6% camber airfoil and then with this 4% camber airfoil. With the new wing, the plane climbed faster, had a better glide, penetrated the wind more effectively, and maintained altitude at a noticeably lower throttle setting (half throttle instead of 3/4 throttle). Nothing was changed but the wing section, all the wings were made out of curved sheet foam.

To find the MiniStik's Re, I had to know the speed of the model. A sidebar shows how to calculate this. You can also time the model's flight over a measured distance (average upwind and downwind runs) or use a radar gun.

DRAWING THE AIRFOIL

The illustrations of airfoils above show the proper curve.

Here's how to draw the curve.

1. Lay out a horizontal straight line the length of the desired chord. In this example, I will use 3 inches (drawings not actual size).
2. Draw a vertical line, 4% of the length of the chord, that rises from the horizontal line at 40% of its length.

\[ 40\% \text{ of chord (L)} = 0.12 \quad 4\% \text{ of chord (T)} \]

3. Place the arc of a circle from the top of the vertical line to the leading and another arc from the same place that goes to the trailing edge. This is easy with a good computer drawing package (I use Ashlar's "Graphite").

It is harder to do this with a compass, ruler, and pocket calculator, but not all that hard. Extend the vertical line down from the top of the short line segment the distance that you get from the formula. The values shown are for our 3" chord example. Set the compass to the length of this line and draw the front arc.

\[ \frac{(T+L) + (L+L)}{2T} \]

4. Now do the same for the rear arc, using the given formula for the radius of the rear arc. This drawing is not to scale.
SIDEBAR: It's Easy to Measure Chord, but How Fast Does My Model Fly?

You can make a good estimate of your model's flying speed for the purposes of this article by first dividing the weight of the model (in grams) by the wing area (in square centimeters), multiplying that by 160, and then taking the square root of your result. This gives, approximately, the plane's flying speed in meters per second. The conversion factors given here are approximate, but more than accurate enough for airfoil choice.

\[
\text{Speed in meters per second} = \sqrt{\frac{160 \times \text{weight in grams}}{\text{wing area in sq. cm}}}
\]

To convert from ounces to grams, multiply the number of ounces by 28.3
To convert from square inches to square centimeters, multiply the number of square inches by 6.45.
To convert from meters per second to miles per hour, multiply the speed in meters per second by 2.24

For the example of the MiniStik the chord is 3" (7.6 cm), the area is 300 sq. cm. = 0.03 sq m and the weight is 32 g. This gives a speed according to our formula of about 4.1 m/s, and a Re of 680 \times 4.1 \times 7.6 = 21,000 which is in the middle of our range for "small".

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