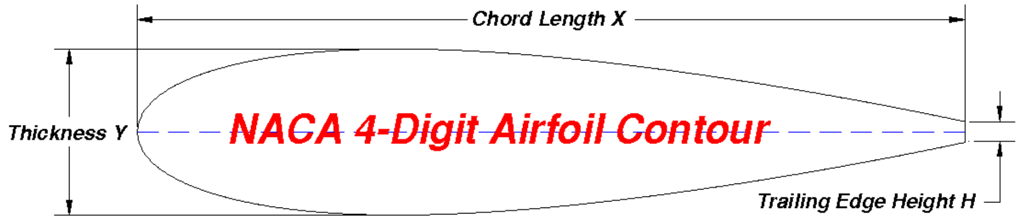
NACA 4-Digit Airfoils for Stunters, Part II

The Lost Byte Method of Making Wing Rib Templates

by Larry Cunningham



Airfoil Dimension Parameters

The Equation

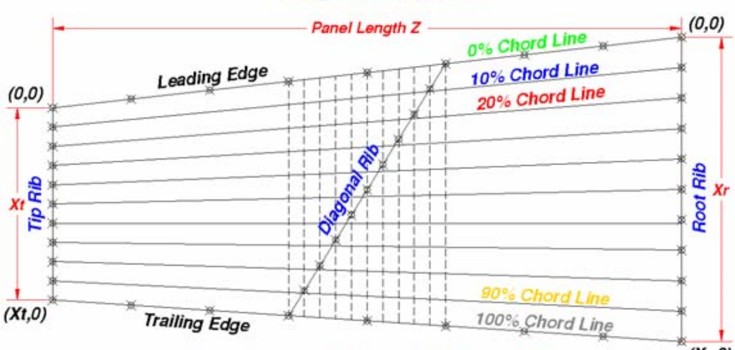
Part I of this article revealed the 5th order polynomial equation for symmetrical NACA 4-digit airfoils and described techniques of scaling and interpolation to generate usable plots for rib templates.

The requirement for non-zero trailing edge height was handled by "chopping off" the aft airfoil edge at the desired height and rescaling its chord (horizontal length) accordingly. I neglected to mention that this technique moves the high point of the airfoil aft slightly; as a practical matter this is of no serious consequence with an attached flap (why we wanted a non-zero trailing edge height in the first place).

A "Hot Wire"Cutter

I used the analogy of a hot wire foam wing cutter to argue that interpolation of vertical (**y**) coordinates would rightfully occur on lines between points on root and tip airfoils which are at the same percentage of chord. It was shown graphically that simple interpolation could be applied to both horizontal (**x**) and vertical (**y**) coordinates of root and tip airfoils to plot ribs parallel to the root and tip.

Wing Panel Top View



Linear Interpolation and Diagonal Ribs

Diagonal Ribs

Now, what about those infamous "geodesic" ribs, which are placed diagonally? As could be expected, things get a bit more complicated.

In general, chord percentage points on the angled rib **will not fall** on chord percentage lines drawn between the root and tip airfoils as they do for parallel ribs.

But things aren't all that bad. Simple geometry and linear interpolation can be applied to yield a slightly more complicated but more general method.

The *Airfoil* Object

I will revive the *Airfoil* computing object described in Part 1, which can compute and return a scaled point (**x,y**) on [the top surface] of a symmetrical NACA 4-digit airfoil, which can deal with a non-zero trailing edge height as well:

(**x,y**) = *Airfoil*(**X,T,H,P,N**)

(**x,y**) are horizontal and vertical coordinates, respectively, and the input parameters for *Airfoil* are defined as follows:

X	scaled chord length of the finished airfoil
T	maximum thickness of the finished airfoil
H	trailing edge height of the finished airfoil
P	the total number of evenly spaced points in my plot
N	the index of a point (x,y) I am querying

Airfoil computes a specific point (number **N** of **P** points) on the top surface of a symmetrical NACA 4-digit airfoil of a given chord length (**X**), maximum thickness (**T**), and trailing edge height (**H**). Each point ($\mathbf{x_N}$, $\mathbf{y_N}$) has a companion point ($\mathbf{x_N}$, $\mathbf{-y_N}$) for the bottom surface of the symmetrical airfoil.

As a matter of convenience, the *Airfoil* object will also return a 0th point, ($\mathbf{x_0,y_0}$) = (**0,0**) representing a leading edge point and ($\mathbf{x_{P+1}}$, $\mathbf{y_{P+1}}$) = (**X,0**) representing a trailing edge point. Part III of this article will reveal more detail for computer algorithms; for now, I want to deal with it in a completely abstract manner.

Index N (of P points)	Point (x,y)	Corresponding Position
$N \le 0$	**(0,0)**	leading edge
$1 \le N \le P$	**(XN/P,$\mathbf{y_N}$)**	scaled ($\mathbf{x_N,y_N}$) airfoil point
$N = P$	**(X,H/2)**	trailing edge at height **H**
$N > P$	**(X,0)**	trailing edge at thickness 0

Since all points are evenly spaced on the horizontal axis, **N/P** with $0 \le N \le P$ represents represents the normalized horizontal (**x**) distance from the leading edge of the airfoil, and **N/P** can be multiplied by **X** (total chord length) to obtain the actual scaled distance $\mathbf{x_N}$, or by 100 to obtain the percentage of chord distance.

My method for parallel ribs called *Airfoil* twice to obtain coordinates for points at each specific percentage of chord length (point number **N** of **P** total points) on the root and tip airfoils, then applied linear interpolation to both **x** and **y** values to find a point on a [parallel] an interpolated rib at a specified distance **Z** from the root.

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Linear Interpolation

$$V = R + (Z/L)(T - R)$$

where **V** = interpolated value
R = value at Root
T = value at Tip
Z = rib distance from Root
L = Root to Tip length
and **Z/L** is a normalized distance **D**

Linear interpolation of values between root and tip airfoil points is defined by the equation for **V**, as shown above.

Notation Conventions

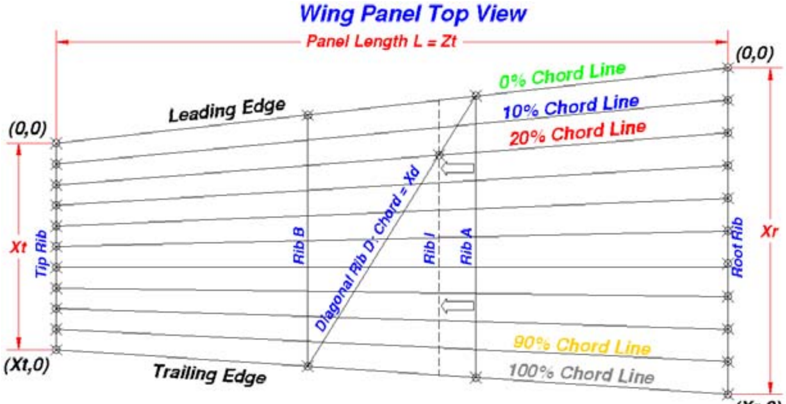
To clarify exactly which parameters I am referring to, I want to define some parameter symbols and subscripts which correspond to specific rib positions:

Parameter Symbols	
X	chord of finished rib
Z	distance from **Root** airfoil
S	leading edge sweep
P	total points in **Rib D** plot
p	total points in **Rib I** plot

Subscript Conventions	
r	**Root Rib** (parallel)
t	**Tip Rib** (parallel)
d	**Rib D** (diagonal, general case)
a	**Rib A** (parallel), intersects with **Rib D**'s leading edge
b	**Rib B** (parallel), intersects with **Rib D**'s trailing edge
I	**Rib I** (parallel), interpolated between **A** and **B**
N	Point number index $(0 \le N \le P+1)$, diagonal **Rib D**
n	Point number index $(0 \le n \le p+1)$, interpolared **Rib I**

My method for parallel ribs called ***Airfoil*** twice to obtain coordinates for points at each specific percentage of chord length (point number **N** of **P** total points) on the root and tip airfoils, then applied linear interpolation to both **x** and **y** values to find a point on a [parallel] an interpolated rib at a specified distance **Z** from the root.

Wing Panel Top View



Diagonal Rib D Point in Interpolated Rib I

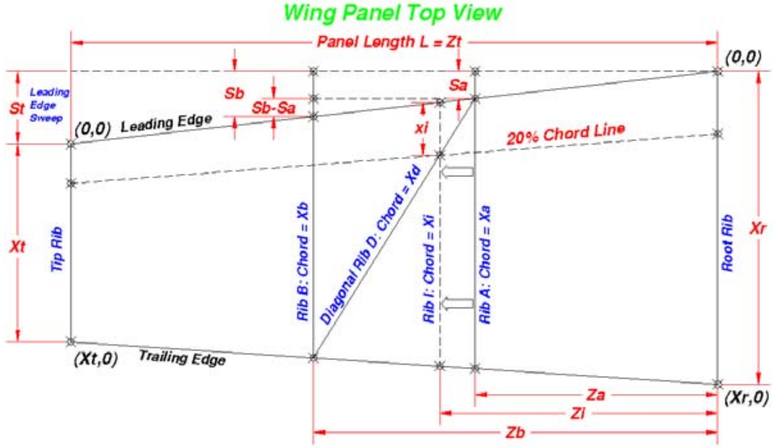
Chord lengths of parallel Ribs **A**, **B**, and **I** are easily calculated by linear interpolation as follows, where $\mathbf{Z_t = L}$, the wing panel length:

$$X_a = X_r + (Z_a/Z_t)(X_t-X_r)$$
$$X_b = X_r + (Z_b/Z_t)(X_t-X_r)$$
$$X_i = X_r + (Z_i/Z_t)(X_t-X_r)$$

Diagonal Rib Geometry

More detail on diagonal rib geometry is shown in the next illustration. Finding the chord length $\mathbf{X_d}$ of the diagonal rib requires more information: leading edge sweep $\mathbf{S_t}$ is involved ($\mathbf{S_r}$=0).

Wing Panel Top View



Diagonal Rib D Geometry

We invoke the **Pythagorean** theorem on right triangles next: $\mathbf{X_d}$ is the hypotenuse of a right angle triangle, whose other sides are $\mathbf{(Z_b\text{-}Z_a)}$ and $\mathbf{(X_b\text{+}S_b\text{-}S_a)}$:

$$X_d = \sqrt{(Z_b - Z_b)^2 - (X_b + S_b - S_a)^2}$$

The **x** coordinate for each point **N** of **P** points in diagonal **Rib D** is again:

$$X_n = X_d(N/P)$$

So much for the hard part!

The **y** coordinate for each point in **Rib D** has to be found as **y** for a point in a parallel **Rib I** which **Rib D** intersects with.

Points for Plotting

If there are **P** total points in the plot, we will be dealing with **P** different instances of **Rib I**, which lies between **Rib A** and **Rib B** $(Z_a \le Z_i \le Z_b)$. To find distance $\mathbf{Z_i}$, chord length $\mathbf{X_i}$, and the distance $\mathbf{x_i}$ (horizontal distance from the leading edge of **Rib I** to its intersection with diagonal **Rib D**) we apply linear interpolation again, multiple times:

$$Z_i = Z_a + (N/P)(Z_b-Z_a)$$
$$X_i = X_a + (N/P)(X_b-X_a)$$
$$x_i = (N/P)X_i$$

(Note that $\mathbf{x_i}$ varies linearly from **0** at the leading edge of **Ribs D** and **A** to $\mathbf{X_d}$ at the trailing edge of **Ribs D and B**.)

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Knowing x_i and X_i for each instance of **Rib I**, we can determine the index **n** of a point in **Rib I** we are looking for. Think of the quantity x_i/X_i as a normalized distance on the chord of **Rib I** (which it is).

And how accurate do we want to be? If you would be satisfied with 6 decimal places, we'll assume that there are a cool million points in the plot for **Rib I**, (**p** = 1,000,000), so that we can find the index **n** value as follows:

$$n = p(x_i/X_i)$$

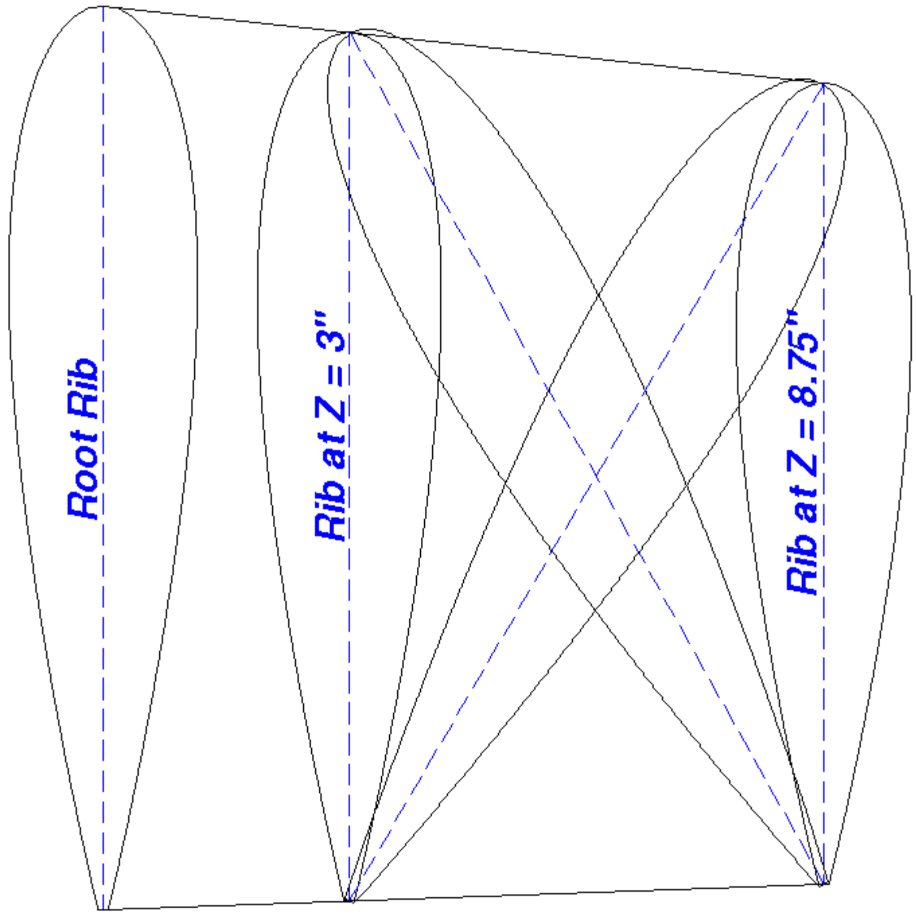
All that remains to do is to compute the **y** value we need. We know everything we need to feed the *Airfoil* object, and to do the interpolation of **y** in **Rib I** between **Ribs A** and **B**!

Here are some example airfoil plots for diagonal ribs layed at 60 degrees, on a wing with a 28" panel length, root chord and thickness of 11 and 2.3 inches, respectively, tip chord and thickness of 7 and 1.75 inches, respectively, a leading edge sweep of 3 inches and a trailing edge height of 1/8 inch. For this example, Z_a = **3.0** and Z_b = **8.75** inches.

Diagonal Ribs from Stuntrib

Calculating 500 plot points with StuntRib for each airfoil in this example (total 2500 points), output as a **.DXF** file, only required about one second on my old 66 MHZ '486 computer.

The .DXF files were imported directly into **AutoCAD** for annotation and plotting.



Diagonal Rib Airfoils

And aren't they pretty? By taking advantage of the computer, we benefit from its extreme accuracy. The more general method developed here can be applied to ribs in virtually any position in configurations with wing panel geometries involving <u>backward</u>, <u>forward</u>, or <u>no</u> sweep of both leading and trailing edges.

<u>Important:</u> Leading edge sweep **S** is an active parameter now. Diagonal ribs generated by the StuntRib program will **not** fit correctly unless you build the specified sweep into your wing!

Next time, I will wrap this up with some information about the software algorithms used, and fascinate you with some more ideas for putting the computer to work further.

Elliptical Thickness Tapers

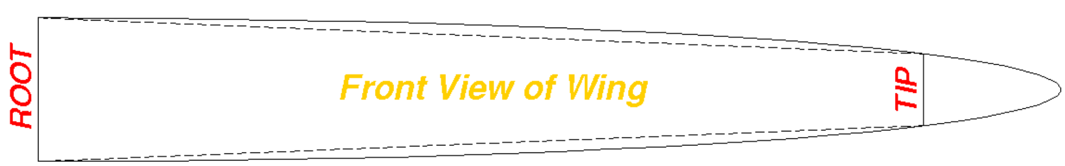
Meanwhile, permit me to to tease you with a simple enhancement, to support either **linear** or the pretty **elliptical** interpolation on airfoil thickness, as illustrated below. It turns out that if you simply square all parameters in the equation for linear interpolation, you have the equation for elliptical interpolation.

This illustrates how a computer program can easily do things which are difficult or impossible by other means. **Good luck** on trying to make an **elliptical** thickness taper by sanding a stack of ribs or cutting templates out of a foam wing!

-Larry Cunningham

Elliptical Interpolation:
$V^2 = R^2 + (Z^2/L^2)(T^2-R^2)$

where
V = interpolated value
R = value at Root
T = value at Tip
Z = rib distance from Root
L = Root to Tip Length



Elliptical vs Linear Taper on Airfoil Thickness