Curiosity Number 21. Comparison of some key airfoil geometric characteristics

W.H. Mason, August 8, 2017

This one came about due to some surprising results from a recent panel method code calculation. It led me to review some characteristics of airfoils. Specifically, I've collected typical values of the airfoil trailing edge thicknesses and included angles. For completeness I've included the leading edge radius values for some airfoils.

The root of this study arises because airfoils don't have zero thickness at the trailing edge, a razor blade is not a practical geometry. For inviscid calculations this causes a problem. Jameson extended the classical conformal transformation methods to include the trailing edge thickness.[1] Sometimes panel methods model thick trailing edge as a source. Drela wrote a paper describing an extension to the integral boundary layer method to handle thick trailing edges.[2] I thought that for a low order panel method you could just leave a hole at the trailing edge and nothing terrible happened. In most bases this is true. However, studying flap deflections for Curiosity 7 I revised this opinion somewhat. Nevertheless, it is worth looking at typical real airfoils.

Trailing edge thickness.

Figure 1 shows the trailing edge ordinate for several classes of airfoils as they change with the maximum thickness to chord ratio, *t/c* (the half thickness ay the trailing edge). I've included the NACA 4-digit airfoils, the NACA 6A-series airfoils, the NASA supercritical SC(2) airfoils from Harris, NASA TP 2969, the GAW(1) and GA(W)-2 airfoils that were also part of Whitcomb's work. Note that the original NACA 6-series airfoils specified a cusped zero thickness trailing edge, and the airframers pointed out the difficulty! The NACA 4-digit airfoils are the only airfoils shown here that have an analytic definition for the trailing edge thickness.

Looking at the figure, we see that the NACA 6A series airfoil trailing edges are a fraction of the thickness of the NACA 4-digit series. In contrast, the supercritical and GA(W) airfoils are more than twice as thick at the trailing edge as the NACA 4-digit series. As we'll see in Fig. 2, you can have a thicker trailing edge without a drag penalty. The trick being to reduce the included angle between the top upper and lower surfaces.

The trailing edge thickness for the NASA SC(2) airfoils gets a section in NASA TP 2969. Harris says that in the tunnel they found that a 0.7-percent-thick trailing edge could be used at transonic speeds without a significant subcritical drag penalty. Later on using CFD they found they could use "somewhat less than 0.7 percent" for the trailing edge thickness. He also states that it appeared that this value was connected to the boundary layer displacement thickness. He doesn't cite the work of Hoerner,[3] who connected base drag to the state of the boundary layer at the trailing edge, that would of course depend on the Reynolds number. His paper should be added to any collection of papers on thick trailing edges.

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[1] Antony Jameson, "Transonic Flow Calculations," VKI Lecture Series #87, 1976, published in 1978. See Section 5.2.

[2] Mark Drela, "Integral Boundary Layer Formulation for Blunt Trailing Edges," AIAA Paper 1989-2166, 1989.

[3] Sighard F. Hoerner, "Base Drag and Thick Trailing Edges," *Journal of the Aeronautical Sciences*, Oct. 1950, pp. 622-628.

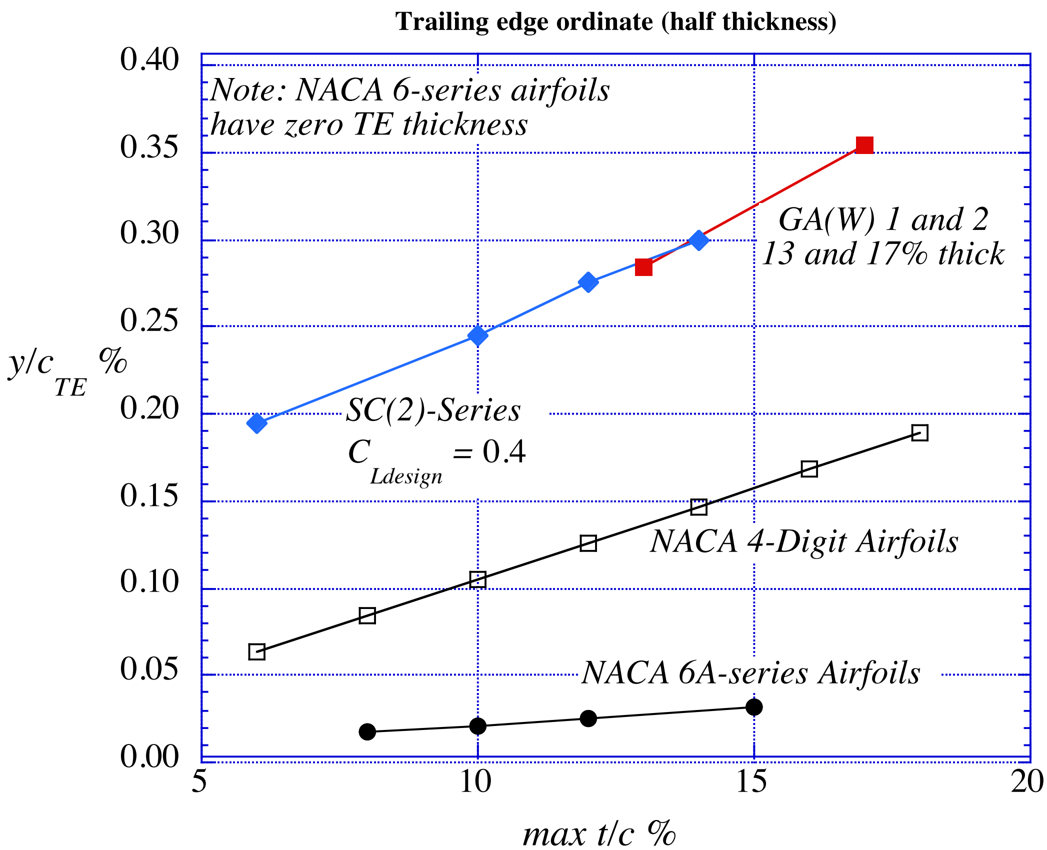

Figure 1. Airfoil trailing edge thicknesses for a variety of airfoils.

Included angle at the trailing edge.

Figure 2 shows the angle between the upper and lower surfaces for the same airfoils shown in Fig. 1. In this case the story is reversed. The supercritical airfoils have a much smaller included trailing edge angle than the classical NACA airfoils. The message is clear: allow the trailing edge thickness to be larger that the NACA 4-digit series, but make the upper and lower surfaces nearly parallel.

There's a little more to it than this, but this is a starting point for putting an airfoil together.

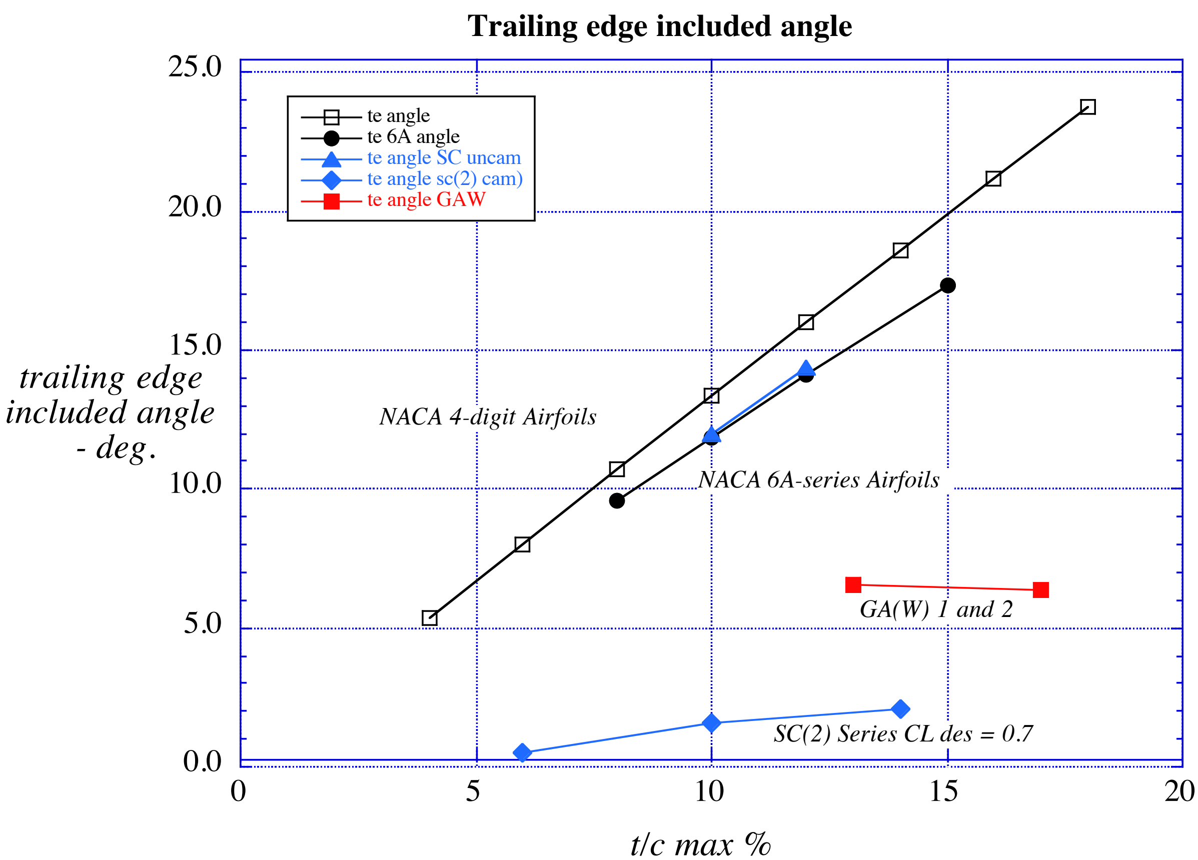

Figure 2. Trailing edge included angle for a variety of airfoils

Leading edge radius

To complete this survey I'm including the leading edge radius values of some airfoils. This shows that you can have a leading edge radius greater then the old NACA airfoils. Curiosity 20 presented some results showing that increasing the leading edge radius didn't result in an increase in basic parasite drag. There are several benefits of the increases radius. They include a reduced sensitivity to angle of attack and they also "fill out" the pressure distribution over the forward part of the airfoil. Figure 3 is a chart I put together many years ago providing a comparison of airfoil characteristics similar to the results presented in Figures 1 and 2. The figure concentrates on typical supersonic fighter values of thicknesses. Figure 4 is from the Harris report and shows the leading edge radius values for the SC(2) series of supercritical airfoils.

In this curiosity we've focused on subsonic flow. It's worth noting that a round leading edge is normally used at supersonic speeds too. Generally a 6A-series airfoil is used because the leading edge radius is low. This is especially true when the leading edge is supersonic. If the leading edge is subsonic the use of a larger leading edge radius does not lead to a significant drag penalty. I have done some tests (in the AEDC 16T no less) and compared CFD with DATCOM. If I run across the results I'll add a new curiosity.

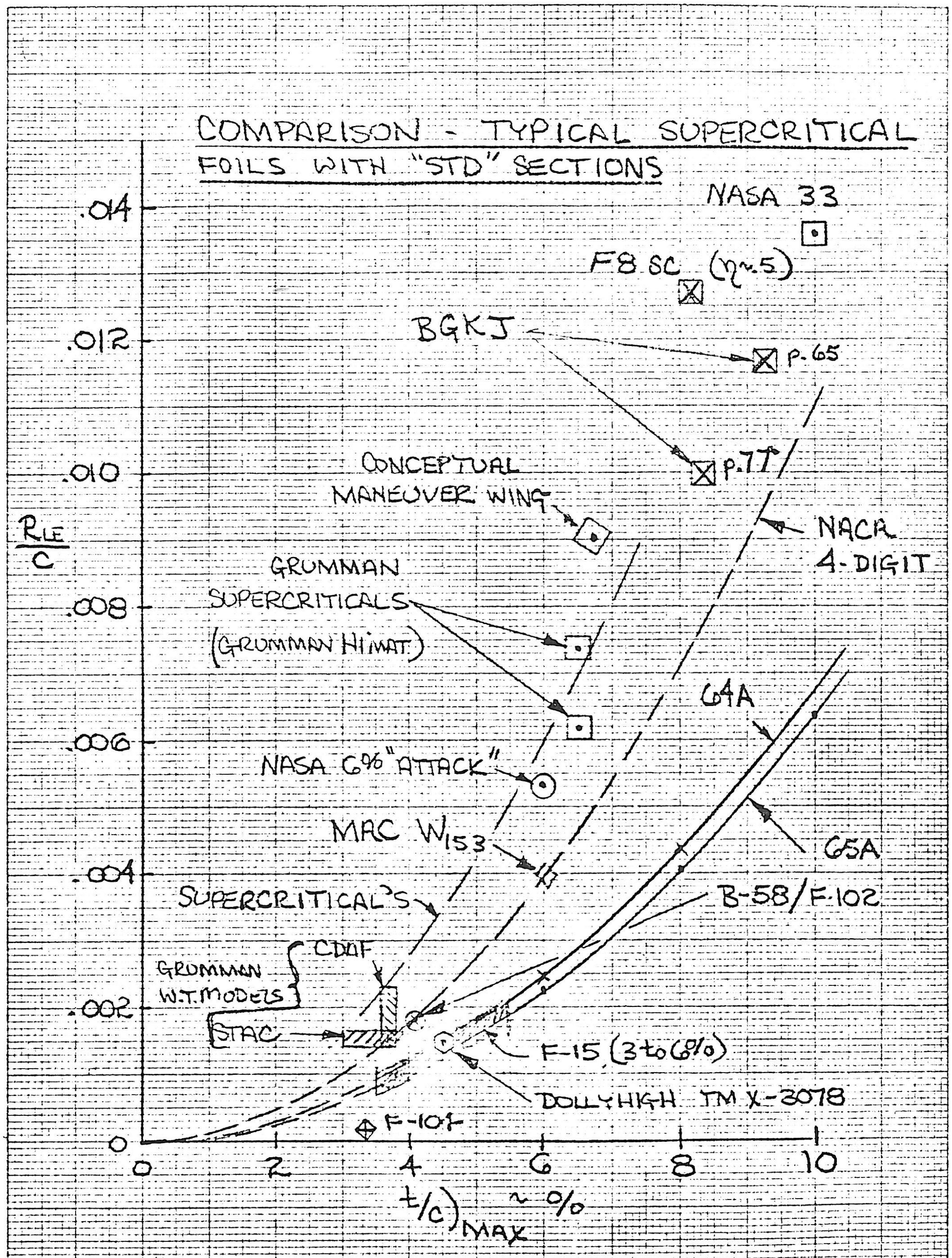

Figure 3. Leading edge radius values (assembled circa early 1980s) .

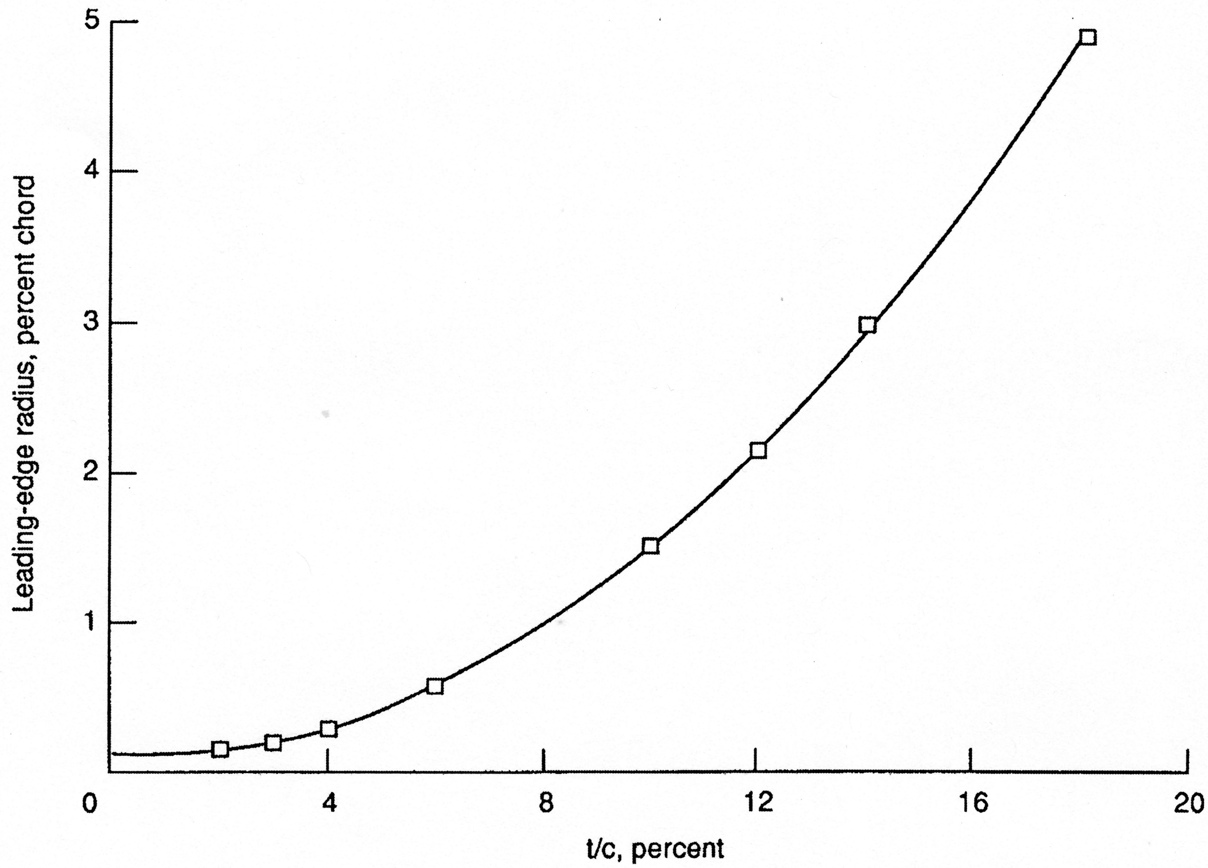

Figure 4. Leading edge radius values of SC(2) airfoils (from Harris, NASA TP 2969)

Takeaways:

Some basic subsonic airfoil guidelines have emerged from this comparison.

• The airfoil can have some trailing edge thickness (as it must!) and the included angle between the upper and lower surface should be small (for transonic airfoils Gregg and Henne found the divergent trailing edge airfoil provided further benefits).

• The leading edge radius can be larger than the classic NACA 4-digit series airfoils.

Something further that could be studied:

• Look at the surface curvature of the aft portion of airfoils.