(10/31/1995) Taming the Sharp Stall of the NACA 23012 Airfoil

Summary: This paper discusses two methods that can be used to soften the notoriously sharp stall of the NACA 23012 airfoil, that is, use of vortex generators, or alternatively an upper surface build-up (reprofiling). We also discuss the mechanism of the stall on this airfoil, and explain why additional leading edge droop is ineffective for improving the stall of this airfoil.

Discussion: In the mid-1930's, following the work on the 4-digit airfoil series, NACA conducted a series of test on airfoil related to the 4-digit airfoils (same thickness distribution), but with the maximum camber placed unusually far forward. The object of the tests was to see if the airfoil Cm could be reduced to zero, which is not necessity for conventional airplanes anyway, as long as the Cm is kept reasonably low by moderately forward loading. Anyhow, these "zero C_m" airfoils were designed and tested, and the most widely used of these 5-digit airfoils is the ubiquitous and infamous NACA 23012 airfoil. It is 12% thick, with peak camber of 1.8%C located at the 15% position, rather than the usual 40%C position used the most of the popular 4-digit airfoils (2412, 4412, 4415, etc.). The mean line aft of .15C is a straight line, thus the only camber in this airfoil is in the first 15% of the chord length. Accordingly, we can describe the airfoil as being the NACA 0012 symmetrical section with the first 15% bent downwards (leading edge droop) approximately 1.8%. Actually, the effective droop is only about 1.4% due to the faulty "slope and radius" method of leading edge design used on all of the NACA airfoils, however the fact remains that the camber profile of this airfoil consists of leading edge drop only, with no conventional camber. The result of this is an airfoil with near-zero pitching moment coefficient (C_m). Further, since there is no negative camber in the airfoil, the maximum lift coefficient remains high and the induced drag is low, compared to the best known previous zero-C_m airfoil, Max Munk's 1924 M-6. The M-6 achieved zero C_m by reflexing (negative camber) the mean line from .60C to the trailing edge , effectively killing the nose-down pitching moment by applying a download on the trailing edge of the airfoil (figure 9). This however increases total induced drag, and reduces C_{lmax}. The camber profile of the M-6 in the first 60%C is conventional, however, so the M-6 does have a nice, soft stall.

Wind tunnel test results of the "new" zero-C_m airfoil, 23012, are summarized in NACA TR #537 of May 7, 1935 (see figure 1). Based on the fact that 23012 showed a moderately high C_{lmax}, very low C_m, and C_d no greater than 0012 symmetrical section, NACA pronounced this airfoil to be "markedly superior to well-known and commonly used sections", and recommended its wide usage in glowing terms. However the airfoil has a terrible sharp-stall characteristic, which NACA TR#537 failed to discuss, and that is downfall. This was noted briefly in Table II Airfoil Data of TR#537, so NACA knew of the existence of the sharp stall, and chose to ignore it. Sharp stall airfoils are bad enough single engine airplanes, but on prop driven twins with one engine out these airfoils are especially lethal, causing accidents such as described in figure 2. In fact, sharp stall are major reason that GA light twin fatality rates ironically exceed the fatality rates of GA light singles. We will not achieve true twin-engine reliability in prop-driven twins until we get rid of these sharp-stall airfoils. Prop-driven twins are limited by lateral control authority near V_{mc} due to effect of a "blown surface" aft of the operating engine. With sharp-stall airfoils, sudden uncommanded and uncontrollable upsets occur at relatively high V_{mc}. With soft-stall airfoils. Vmc is much lower, and in addition the roll tendency is controllable. Knowing what we know today, we realize that NACA, as soon as they learned of the bad stall characteristic of the 5-digit airfoils, should have terminated the project. Accepting the sharp stall merely to achieve zero Cm was a poor trade-off.

There are two types of airfoils that have sharp stalls, those with too little camber in the leading edge, and those with too much camber in the leading edge. Examples of the first group include most symmetrical sections, and low-cambered airfoils such as the later NACA 64-212. These airfoils experience complete and sudden flow separation from the very leading edge at the stall, and they can usually be improved by adding a small amount of leading edge droop. Airfoils of the second group, including 23012, experience complete flow separation on the top surface at the stall, from a point near the end of the leading edge droop, that is about .12C in the case of the 23012. The result is the same, however a sharp loss of lift, usually accompanied by loss of lateral control, and hysteresis loop requiring a substantial decrease of angle of attack (with considerable loss of altitude) before attached flow can be re-established.

Airfoils of the second group cannot be improved by adding leading edge droop, since they already have too much droop. For example, adding more droop to the 23012 airfoil results in the 33012 or 43012 airfoils, and these have stall characteristics as bad as or worse than 23012, from wind tunnel data (check it out). What is required is to ease the transition from the leading edge droop to the rest of the mean line, reducing the discontinuity in the mean line at that point. One effective and proven method is to install complete span-wise array of vortex generators on the surface at about .10C (fig. 3 deleted). These function by filling in the “low spot” on the wing downstream of the VG’s with a thicken boundary layer of energized turbulent air, discouraging flow separation. This fix is chip and effective, and should be required on all twin-engine prop commuters using 5-digit airfoils, which is the majority of the fleet. Also, don`t forget that the single engine airplanes with 5-digit airfoils can be benefit from this as well.

Another possible way to accomplishing the same fix is to reprofile the wings, filling in the low spot aft of the leading edge droop on the top of the surface with solid material such as foam and glass. This is quite common on experimental (homebuilt) airplanes, with both metal and composite wings. Figures 4, 5 and 6 describe this method. Notice that the section drag is actually decreases, in spite of the increased section thickness, due to the promotion laminar flow. Further, the zero-lift Cm remains about the same, so top speed is unaffected. This new profile could also be used to modify existing tooling on production airplanes. Of course, the better solution aerodynamically is to discard the 23012 airfoil completely, and use a modern low-Cm, soft-stall airfoil such a GA airfoil.

As stated above, the NACA 5-digit sections cannot be improved by adding leading edge droop, thus the NC State/NASA fix on the “Venture” airplane (figure 8) is a poor solution to the problem. I suspect that any improvement of the stall in this case is merely the result of the considerably aerodynamic twist that was introduced into the wing by this fix, delaying the tip stall. However, this causes a considerable loss of efficiency at high speed, and also raises the landing speed of the airplane, so it is not a good solution to the problem.