WHAT'S NEW IN LOW SPEED AIRFOILS?

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FOR THE PAST 20 years, the question, "What's new in low speed aerodynamics research?" could be answered very simply with two words — "nothing much". Now, however, the light aircraft designer will be pleased to know that the picture is changing. Back from a long journey into the vast reaches of outer space (where they didn't find much but a bunch of lifeless rocks), NASA, by popular demand, is beginning to get its feet back where it all started — here in the good ole troposphere. To stay alive and obtain congressional funding, the various government laboratories are very eager to put their ears to the ground and listen to what the taxpayers desire. They are discovering we are willing to pay just so much to search for the illusive "life in outer space" which many will admit is a major impetus behind the space program. We do want and demand better, more efficient and quieter air transportation — especially in the short-haul and general aviation areas. None can complain about the great progress and present state of the art in long distance mass air transport — except for the traffic problem in a few large terminal areas, perhaps. But the need is great for improvements in short-haul and inter-urban air transport technology. Fortunately, given enough time, our good old system usually comes to the rescue where there is a real need, and it is beginning to do so with at least a few token efforts in the low speed aerodynamics flight regime.

What are some new developments which might interest the custom aircraft designer and builder? This question was posed recently to a number of government laboratories and universities doing government sponsored aerodynamics research. Everyone contacted was most helpful and cooperative. The typical reply went something like this, "Glad to be of assistance. You EAA folks are about the only ones willing to try something new. The light plane manufacturers, for various reasons, are reluctant to try new concepts which might increase their financial or liability exposure." So, here's what's new in airfoils.

AIRFOILS

NASA is developing airfoils which achieve excellent performance in both low speed and high speed cruise flight conditions. In the past there were the laminar flow airfoils which exhibited extremely low drag "buckets" at cruise (design lift coefficient) if the wing surface could be made very smooth and kept free of the tiniest speck of dirt. Not only did they degrade severely in real life conditions, but they also had poor maximum lift capabilities and non-gentle stall characteristics.

The first breakthrough was the GA(W)-1 airfoil developed by NASA with the aid of elaborate digital computer programs and fluid flow theories not available to earlier aerodynamicists. Both wind tunnel and actual flight tests on a full scale airplane were conducted verifying the outstanding performance predicted by the computer. Then the GA(W)-2 was developed and is currently being tested.

Before the results of these tests are discussed, let us talk about some aerodynamic terms which you will need to understand to grasp the significance of the data.

REYNOLDS NUMBER

Reynolds number is an important parameter which must be considered in all aerodynamics discussions. It is not really too complicated to become familiar with, so hang in there. Reynolds number is a quantity representing scaling effect. It is described by an equation containing four parameters: airfoil size (usually wing chord), velocity, viscosity and air density.

$$R = \frac{\text{Vel x chord x density}}{\text{viscosity}}$$

The higher the velocity, the larger the wing chord, the higher the air density and the lower the air viscosity, the larger is the Reynolds number. For sea level standard conditions, it is very easy to find Reynolds number by using the equation:

$$R = 780 \text{ V(in mi/hr) x chord(in inches)}$$

As an example, let us find the Reynolds number for a STOL airplane having a 50 inch chord flying at 40 mph.

$$R = 780 \times 40 \text{ mph} \times 50 \text{ in.} = 1{,}560{,}000 \text{ or } 1.56 \times 10^6$$

Now, let us find the Reynolds number of John Shinn's 135 hp T-18 at full throttle at sea level as measured in the Pazmany efficiency contest.

$$R = 780 \times 198 \text{ mph} \times 50 \text{ in.} = 7.8 \times 10^6$$

So, the area of interest for typical homebuilt airplanes is from about 1.5 to 10 million. Hang gliders and ultra lights have Reynolds numbers much lower than one million and NASA cautions that the new GA(W)1 & 2 airfoils do not perform well at Reynolds numbers under 1 million.

Reynolds number affects maximum lift coefficient, L/D, lift curve slope and angle of attack at stall. A fairly good generalization worth remembering is that all these get better at high Reynolds numbers and worse at low Reynolds numbers. Thus we can see that a larger chord wing will have a higher maximum lift coefficient, a lower L/D at conditions of our interest, a higher lift curve slope and stall at a higher angle of attack than a small chord wing at the same conditions. This explains why some tiny airplanes don't fly too well at

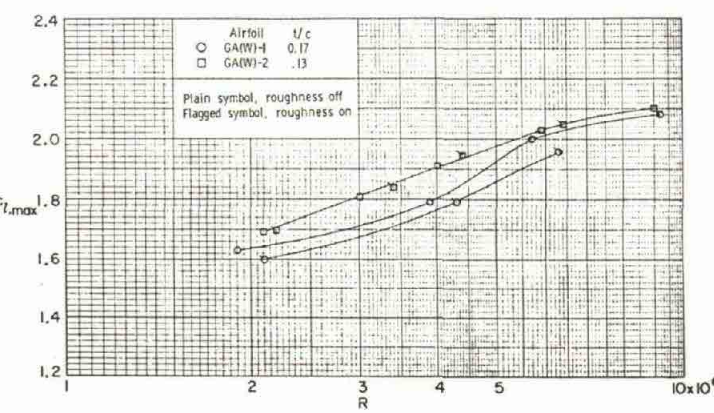


FIGURE 1 — Variation of maximum section lift coefficient with Reynolds number for GA(W)-1 and GA(W)-2 airfoils. M = 0.15.

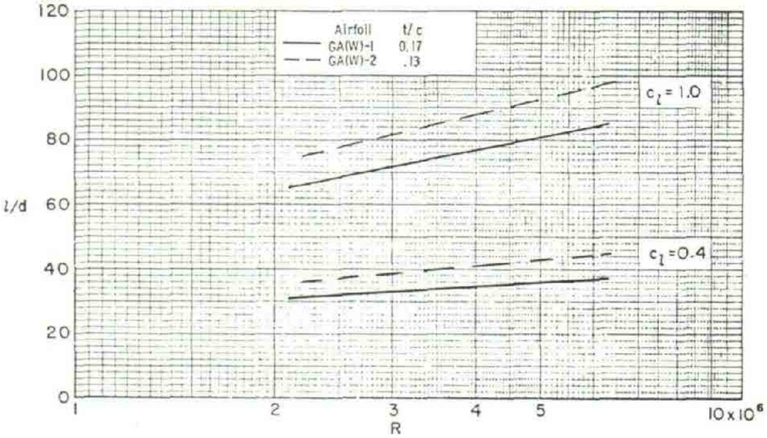


FIGURE 2 — Variation of lift-drag ratio with Reynolds number for GA(W)-1 and GA(W)-2 airfoils. M = 0.15; transition fixed at x/c = 0.075.

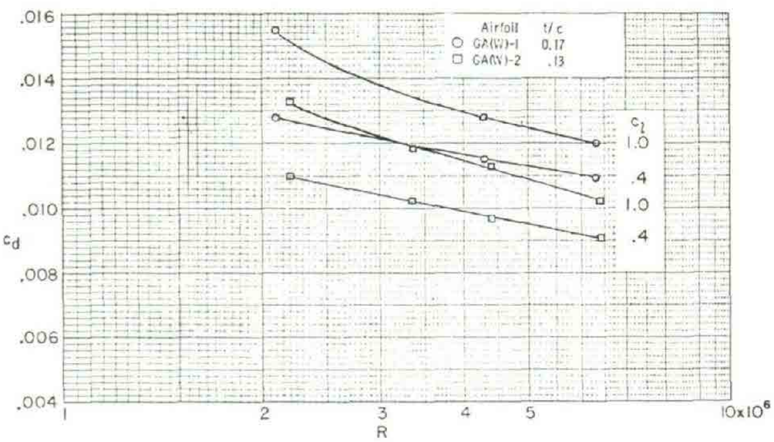


FIGURE 2b — Variation of drag coefficient with Reynolds number for GA(W)1 and GA(W)-2 airfoils. M = 0.15; transition fixed at x/c = 0.075.

low speed and why model airplane flight test results may be difficult to extrapolate and apply to a full-size airplane. Figure 1 shows the effect of Reynolds number on maximum lift coefficient for various airfoil sections while Figure 2 shows its effect on L/D.

ASPECT RATIO

Another important airplane parameter is aspect ratio, abbreviated AR, or sometimes just A. It is defined as wing span (b) divided by mean (or average) chord $\bar{c}$ and by the following equation where S is wing area:

$$AR = b/\bar{c} = b^2/S$$

As an example, a T-18 has a span of 20' 10" and chord of 50 inches.

$$AR = 250 \text{ in}/50 \text{ in} = 5$$

On the other hand, a J-3 Piper Cub has a span of 35' 4" and chord of 63 inches. Its AR is thus 6.7.

Aspect ratio has a direct effect on induced drag which is highest at high lift coefficients. Thus, AR is an important consideration mainly for high C_L flight conditions, like climb, take-off and landing. STOLs thus usually have high AR wings. It is less important at cruise where induced drag is low.

STALL SPEED

One more thing to keep in mind before discussing the data on the new airfoils is the equation for calculating stall speed. Now that nearly everybody has a pocket calculator, you can solve this equation readily:

$$\text{For sea level, } V_s = 19.78\sqrt{\frac{W \text{ (in pounds)}}{C_L \times S \text{ (area in sq. ft.)}}}$$

As an example we shall find the stall speed of an 1100 pound J-3 Cub with a C_L max of 1.62 and 180 ft.² wing area.

$$V_s = 19.78\sqrt{\frac{1100}{1.62 \times 180}} = 38 \text{ mph}$$

(If your calculator does not have a square root function, simply guess at the square root, multiply it by itself and if too large or small, make another approximation and try again. In just a few tries you can zero in on the answer.)

For a T-18 with the laminar 63A-412 airfoil the maximum C_L is only 1.3, wing area is 87 ft.² and gross weight is 1400 pounds. Without flaps the stall speed is 69.6 mph. With full flaps, the maximum C_L is 1.6 so the stall speed is 63 mph. If you want to calculate the maximum coefficient of lift for a flying airplane, rearrange the above equation and insert actual stall speed.

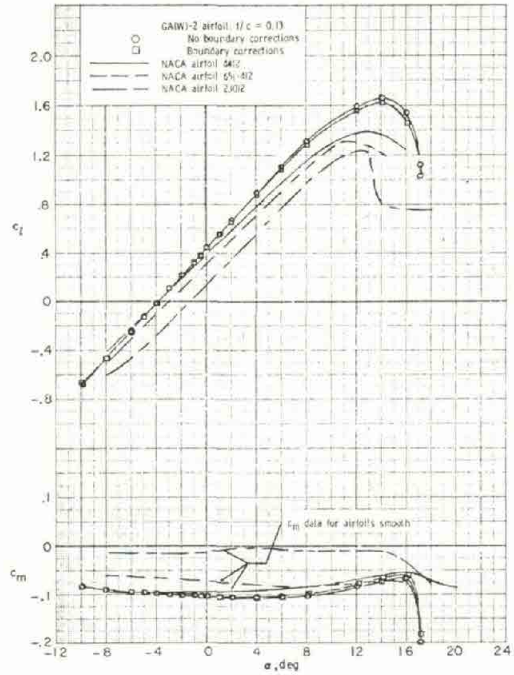
$$C_L = \frac{W \text{ (in lbs.)} \times 391.2}{S \text{ (in sq. ft.)} (V \text{ in mph})^2}$$

WIND TUNNEL DATA

Aerodynamic characteristics data supplied for an airfoil by NASA is normally what is called "section" data. It is measured at a specific Reynolds number on a section of airfoil extending between the walls of a wind tunnel with no tip circulation permitted. Thus, it is considered two dimensional or 2-D flow data. When a wing is put on a real airplane with a finite aspect ratio, there are necessarily wing tip losses, so the actual airfoil performance is always less than the published 2-D data indicates. The big question facing a designer is the amount to degrade section data for a specific application. There are mathematical techniques available to help the engineer estimate tip loss effects as a function of Reynolds number, wing taper ratio, tip shape and aspect ratio, but determining 3-D performance is not an exact science. The most reliable data is 3-D data taken in a full scale wind tunnel or full scale flight test on a comparable configuration wing. NASA development test programs on the GA(W)-1 and GA(W)-2 airfoils are beginning to provide this much needed information.

GA(W)-1 AIRFOIL

Dr. Richard T. Whitcomb of NASA Langley Research Center has become widely known for his developments of the area rule and the super-critical wing for use on transonic and high subsonic cruise aircraft. Engineers evaluating airfoils for use on a Piper Seneca being equipped with a new wing for research purposes noted that the supercritical airfoil had good characteristics at low speed and might be suitable for the ATLIT (Advanced Technology Light Twin). Dr. Whitcomb said he could modify it slightly for a light twin and retain the 17% thickness. This was done and that is how the GA(W)-1 (General Aviation-Whitcomb) airfoil originated. The Seneca-ATLIT wing was designed by Robertson STOL, built by Piper and tested by Kansas University under NASA contract. The aircraft has just completed wind tunnel tests at Langley — with winglets installed. Section (2-D) wind tunnel tests on the basic GA(W)-1 airfoil at a Reynolds number of 6 million gave a max C_L of about 2.0.



(a) Lift and moment data.

FIGURE 3 — Comparison of section characteristics of NASA GA(W)-2 airfoil and NACA 4412, 23012, and 651-412 airfoils. M = 0.15; R ≈ 6.0 x 10^0; wraparound roughness to 0.08c surface length (no. 60 grit).

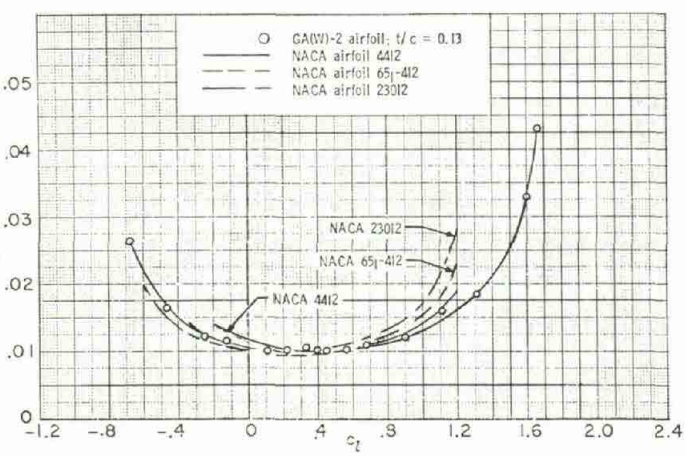


FIGURE 4 — Drag polars.

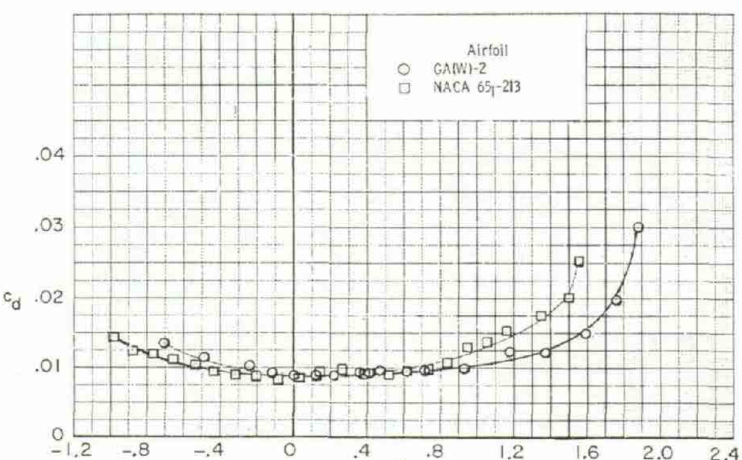


FIGURE 5 — Drag polars.

Full span Fowler flaps were tested on the GA(W)-1 in the wind tunnel at R of 1 million. 2-D max C_L incremental increase with full span flaps was 1.57. When the GA(W)-1 wing of AR 9 was put on the ATLIT Seneca with full span Fowler flaps, actual in-flight max C_L increase was measured at 1.36. This is 86.6% of the 2-D value. Normally, a span efficiency of about 0.8 is expected for this aspect ratio. Maximum C_L obtained on the Seneca with 40° deflection of full span flaps was just over 3. They had predicted 2.8 so the engine nacelle interference was not as severe as expected.

GA(W)-2 AIRFOIL

Most well designed airfoils when operating near their design lift coefficients (.4 for the GA(W)-1 & 2) have a drag coefficient which is directly proportional to their thickness. In an effort to maintain the excellent maximum lift performance of the GA(W)-1 while reducing the fairly high cruise drag of its 17% thick section, NASA designed a 13% thick airfoil and designated it the GA(W)-2. The camber was kept the same, and the thickness at all stations was reduced by the ratio of 13/17. Wind tunnel and full scale flight tests of a GA(W)-2 airfoil showed that its performance was exceptionally good.

Its maximum lift coefficient is higher and the drag is much lower. For instance, at a low Reynolds number (2.1 million) and high lift coefficient (1.25) representing landing or climb conditions, the GA(W)-2 airfoil section has 27% less drag and it has 6% higher maximum lift coefficient (1.7). At a Reynolds number of 6.3 million and a lift coefficient of 0.4 representing cruise conditions, the GA(W)-2 has 20% less drag.

Not only does the GA(W)-2 compare favorably with the GA(W)-1 but also favorably with older 4412, 23012 and the laminar 65_1-412 when subjected to the same amount of leading edge roughness. Figures 3 and 4 show a comparison of these airfoil section characteristics when subjected to extensive roughness wrapped around the leading edge and extending back to 8% of chord. Notice the sharp stall and low maximum lift of the 23012. The GA(W)-2 has 15% more lift than even the excellent old 4412.

Figure 5 shows comparison of the drag of the laminar 65_1-213 and the GA(W)-2, each with small (0.05 inch wide) roughness strips at a Reynolds number of 6 million and mach 0.15. Both airfoils have the same drag at 0.4 design lift coefficient but the laminar section has far greater drag at high lift coefficients. Thus they would have equal performance at cruise, but the GA(W)-2 would climb much better.

Some engineers have objected to the rather large negative pitching moment of the GA(W)-1 and 2 airfoils. This is caused by the large amount of camber near the trailing edge which loads the aft part of the airfoil and moves the center of pressure aft. This more rearward cp location can be allowed for in the location of the cg of a new design, but might be a bit of a problem for application to an existing design if the cg could not be moved aft and more down load would thus need to be carried by the tail. The large amount of aft camber is primarily responsible for the high maximum lift coefficient of the GA(W)-2.

For a modified 63-212 airfoil which the author was working with, when camber like that of the GA(W)-2 was added aft of the rear spar (80% c), the NASA computer program showed a 30% increase in lift before separation. At the same time, the cruise drag at 0.4 C_L remained unchanged.

With a full span Fowler flap, the measured 2-D maximum C_L is comparable to that for the GA(W)-1. Research programs on the GA(W)-1 and GA(W)-2 airfoils have been conducted under NASA sponsorship by Wichita State University in Kansas and Ohio State University. University of Kansas did the initial ATLIT work with the actual airframe modification being done by Robertson. Ohio State has modified a Beech Sundowner wing to the GA(W)-2 airfoil. The existing 15% thick Sundowner wing had new ribs cemented to the exterior skin and aluminum sheet wrapped around these. The chord had to be extended to reduce the thickness to 13% for the GA(W)-2 airfoil. Unfortunately, high lift devices are not provided due to the add-on nature of the modification. The purpose is to measure airfoil L/D. Ohio State offers a relatively inexpensive computer evaluation service for new airplane designs. If you would like your design analyzed, contact Dr. G. M. Gregorek, Ohio State University, 330 Case Rd., GA/ADAC, Columbus, Ohio 43220.

WINGLETS

There is considerable optimism about the potential of winglets. If properly designed, they can reduce high speed drag about 5 to 10%. They offer the most benefit at high lift coefficients and therefore help during climb. Flight tests are to be conducted on a Boeing KC-135. Engineers familiar with winglets emphasize that they need to be installed at the proper angle of incidence to be of value. Also, it is important that a wing on which winglets are used is designed to carry the proper loading over the outboard region. The Seneca tests will supply valuable winglet information for designers.

NASA tests on the effects of different wing tip shape show that there is very little difference in wing performance regardless of tip shape. Tip shape does affect the dispersion of sprays on agricultural aircraft and tests being conducted in this area might produce some helpful data.

In a flight test of a Cessna 172 by a private owner in California with one regular straight tip and one new drooped tip, the pilot reported that the airplane flew hands off and feet off indicating no difference in performance between the tips.

SURFACE EFFECTS

Flight tests on the Sundowner revealed two interesting pieces of information. At a Reynolds number of 6 million, the section L/D (2-D) was slightly higher than that measured in the wind tunnel for the rough condition. This was attributed to the very smooth skin wrapped over top of the Sundowner wing. Secondly, waviness tests revealed that a wave on the bottom surface at 30% of chord produced more drag increase than the same wave on the top surface. Waviness measurements were first made on a number of different production aircraft. Based on the statistical average of these data, a wave was simulated on the Sundowner wing skin of 1/16 inch amplitude and a peak to peak length of 8 inches. The lower surface wave probably triggered turbulent flow breaking up the boundary layer and causing a sharp increase in drag whereas the upper surface boundary layer was probably already broken up ahead of the wave so the wave caused little drag increase.

NEW AIRFOIL DESIGNATION SYSTEM

NASA is considering adopting a new designation system for airfoils. They are dividing the new subsonic airfoils into various families with designation prefixes relating to the application. For instance, the low speed family is designated LS, the medium speed family is designated MS and the supercritical family SC. The GA(W)-1 has been redesignated the LS(1)-0417. The 1 indicates that it is the first of the series, 04 indicates a design lift coefficient of 0.4 and 17 is maximum thickness in the percent of chord. The GA(W)-2 is the LS(1)-0413 since it is the same as the LS(1)-0417 except for thickness. NASA is also developing other sections with different thickness ratios and design lift coefficients.

Anyone can scale an airfoil section to change the thickness very simply. It is not proper to just scale down the upper and lower surface coordinates. This would also change the camber which should remain unchanged. The camber at each station must be determined and taken out making a symmetrical airfoil before the thickness is scaled up or down. Then it is put back in after the thickness has been changed. Now multiply the ratio of the new thickness to the old thickness, i.e. 13/17 if a 17% section is being reduced to 13%. So 13/17 x 7.0 = 5.35. Midpoint is 5.35/2 = 2.676. Adding the 0.5 camber to 2.676 gives the new upper surface coordinate of 3.176 and subtracting 0.5 from 2.676 gives the lower surface coordinate of 2.176. This scaling technique has given excellent results, according to NASA, for small thickness changes with airfoils from 12% to 18% thick, but occasionally can cause problems in stall characteristics.

CONCLUSIONS

What might the light aircraft designer gain from the most recent NASA research? There seems to be unanimous agreement among the aerodynamicists doing the research that the GA(W)-2 airfoil offers excellent performance benefits for the custom built class of aircraft. It outperforms the GA(W)-1 at both high speed and low speed conditions — only slightly at low speed and considerably at high speeds. If a thicker section is desired for structural reasons and minimum speed performance is favored, the GA(W)-1 is a good selection. Coordinates of the GA(W)-2 airfoil are given in the December 75 issue of *SPORT AVIATION*. You can obtain a NASA report on the GA(W)-2 for $4.25 from NASA, Scientific and Technical Information Facility, P.O. Box 8757, BWE Airport, MD 21240. The report is TMX-72697, entitled, "Low Speed Aerodynamic Characteristics of a 13-Percent Thick Airfoil Section Designed for General Aviation" by R. J. McGhee, W. D. Beasley and D. M. Somers.

This article has addressed only one area of NASA research of interest to the light aircraft designer. There is also much work being done in such areas as stall-spin research, drag reduction, crash survival, composite materials and structures. We are pleased to hear of plans for additional exciting projects. We've come a long way since the poverty of the space age but much additional research is needed.