Engineering Notes

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Design of a Natural Laminar Flow Airfoil for a Light Aircraft

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Introduction

A NEW natural laminar flow (NLF) airfoil, the NAL-NLF-208, has been designed for a light aircraft. It has been shown that the NAL-NLF-208 airfoil performs better than the Wortmann FX-60-177 airfoil because it is thicker and is estimated to give better aerodynamic performance (larger L/D) in the operating C_L range.

To take account of the difficulties in fabrication, the NAL-NLF-208 airfoil has been modified to incorporate appropriate bluntness at the trailing edge. A surface waviness (amplitude of 0.025% and wavelength of 4.1%, each of the local chord) superimposed on the blunted airfoil is shown to have no significant effect. It is concluded that the NAL-NLF-208 is robust with respect to performance and fabrication and could replace the Wortmann airfoil as a candidate for light aircraft after testing.

Content

For light aircraft, the Wortmann FX-60-177 airfoil, known for its good stalling characteristics, is used. This Note describes the design of an NLF airfoil designated as NAL-NLF-208, for the specifications $C_L = 0.3$, $R_N = 4.6\times10^6$, and $M = 0.16$. The C_L, R_N, and M represent the lift coefficient, Reynolds number, and Mach number, respectively. The performance of this airfoil is compared with that of the Wortmann airfoil for the same design conditions. The benefits of the NAL-NLF-208 are larger thickness and larger L/D ratios in the C_L range. The analysis of this airfoil has shown that the blunt trailing edge and surface waviness have no significant effect on the performance characteristics. Wind-tunnel testing of this airfoil is underway.

Design for Airfoils

The National Aeronautical Laboratory (NAL) has developed a design method for generating NLF airfoils for general-aviation application.[1,2] Briefly, one assumes a plausible pressure distribution that maintains an accelerated flow up to a chosen chordwise station x_1, provides a decelerating flow up to x_2 so as to trip the boundary layer, and then recovers to mainstream through a turbulent boundary layer without undue increase in drag and/or the threat of separation at the design conditions. This Note extends the design of roof top pressure distributions of Refs. 1 and 2 to concave pressure recoveries characterized by parameter γ in the turbulent region (Fig. 1). Goldstein's theory[3] is then used to obtain a symmetrical airfoil that supports such a flow. Parameters a,b,c,d,x_1,x_2, and γ (Fig. 1), which characterize the velocity distribution, are adjusted to obtain realistic airfoils that give efficient performance at the design conditions. More details of this method can be found in Ref. 1.

NAL-NLF-208 Airfoil vs Wortmann Airfoil

Making use of the preceding ideas, a symmetrical airfoil was designed for $C_L = 0.3$, $M = 0.16$, and $R_N = 4.6 \times 10^6$. The transition occurred at 49% of the chord according to Granville's criterion. It gave a drag value of $C_D = 0.00512$. A NASA camberline[4] with $C_L = 0.4$ and a constant load throughout was combined with this airfoil to give appropriate lift and pitching moment. The NAL-NLF-208 airfoil is shown in Fig. 2. Its performance is then compared with the Wortmann FX-60-177 for the same design conditions and is computed using the same NCSU code.[5] NCSU code is basically a panel method with the addition of viscous corrections. The transition is predicted by Granville's criterion, and the turbulent boundary-layer calculation is based on the work of Goradia and Nash.[7] All performance analysis on these airfoils used only this code.

Figure 3 illustrates the C_L, C_D, and $C_{M_{1/4}}$ curves for both airfoils. Note the following points. The lift coefficient C_L of the Wortmann airfoil is relatively larger than that of the NAL-NLF-208 because the former has a larger camber. However, the drag polars show the low drag values of the NAL-NLF-208 in the operating C_L range. The transition positions on the upper and lower surfaces of the airfoil are given in Fig. 4. The NAL-NLF-208 airfoil performs better because it maintains more laminar flow on both surfaces combined.

Futher analysis was done on these two airfoils under forced transition conditions. Wortmann's airfoil was tripped at 5.2 and 3.8% of chord on the upper and lower surfaces, respectively, whereas the NAL-NLF-208 was tripped at 4.5 and

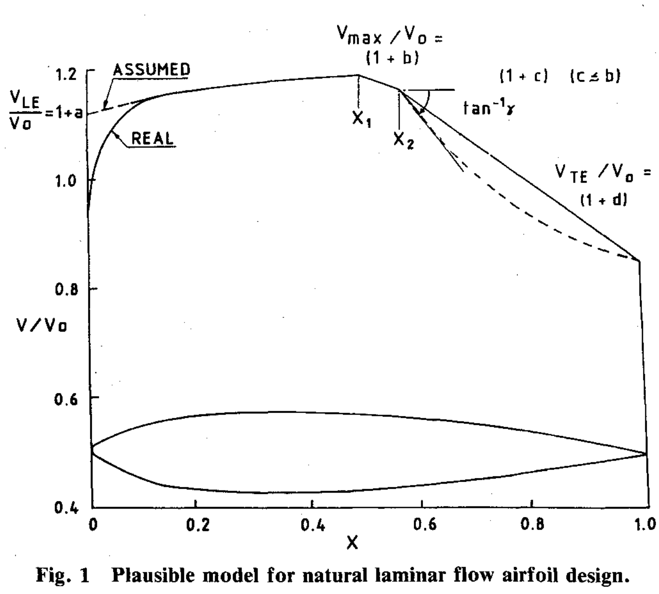

Fig. 1 Plausible model for natural laminar flow airfoil design.

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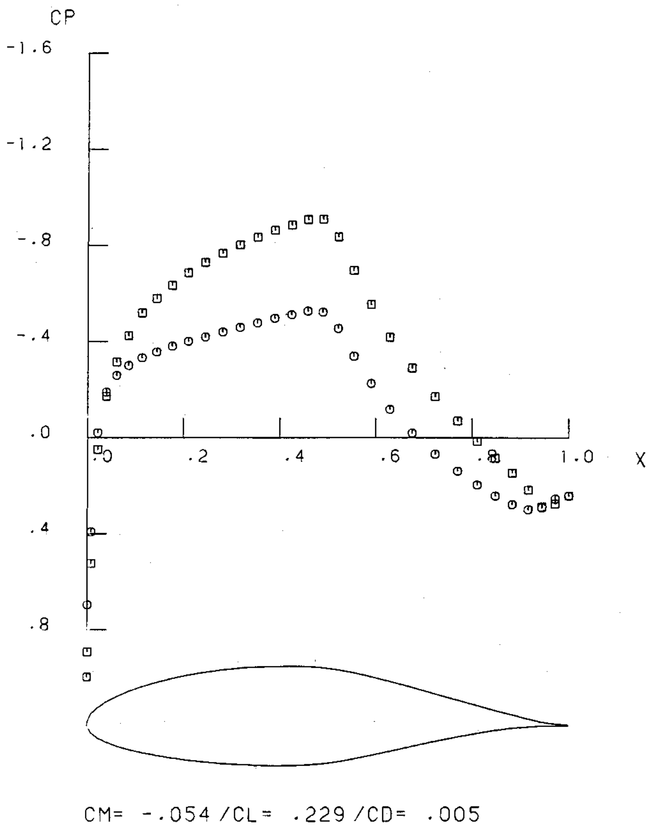

Fig. 2 NAL-NLF-208 Airfoil ($M = 0.16$, $R_N = 4.6 \times 10^6$, $\alpha = 0$).

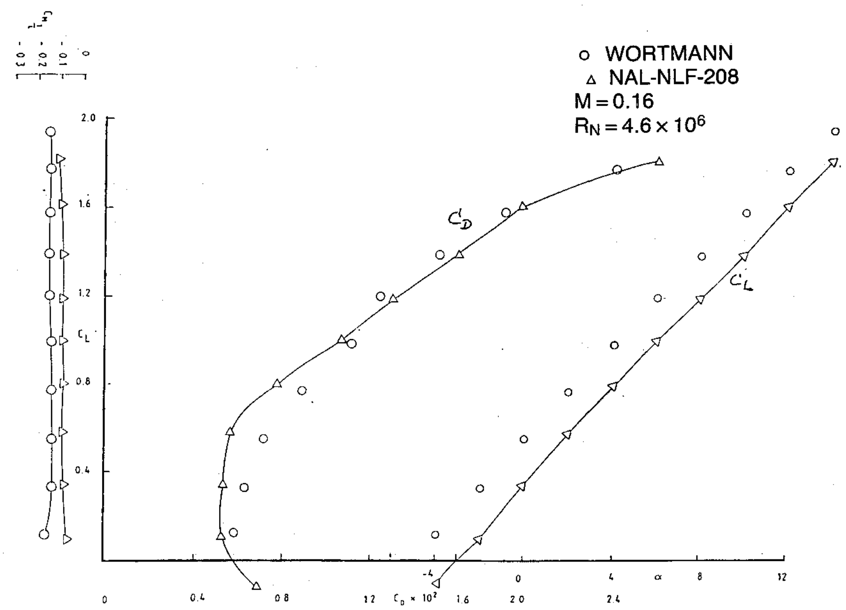

Fig. 3 The C_L, C_D, and $C_{M_{1/4}}$ curves for the NAL-NLF-208 and FX-60-177 airfoils.

5.4%, respectively. The drag performance of both airfoils was almost identical, and this was confirmed further by separate comparisons of the pressure drag and the skin-friction drag.

Analysis of the NAL-NLF-208 Airfoil with Trailing-Edge Bluntness and Surface Waviness

As suggested by the NAL fabricating group, finite trailing-edge bluntness was first incorporated on the NAL-NLF-208 airfoil. With this modification, the NAL-NLF-208 was analyzed using the NCSU code[5] at the same design conditions. The predictions of C_L, C_D and $C_{M_{1/4}}$ are quite good for low Mach numbers and moderate angles of attack. Extensive validation of this code with experimental results was carried out in Ref. 5. This code also accepts blunt trailing-edge coordinates. Note that the experimental values for the Wortmann airfoil at $R_N = 4.6 \times 10^6$ are not available for comparison.[6] The NAL airfoil (with and without bluntness) gave the same drag performance, whereas the modified airfoil showed better pitching moment.

A study of the influence of surface waviness was also suggested. Surface waviness (amplitude = 0.025% and wavelength = 4.1% each of the local chord) was superposed on the

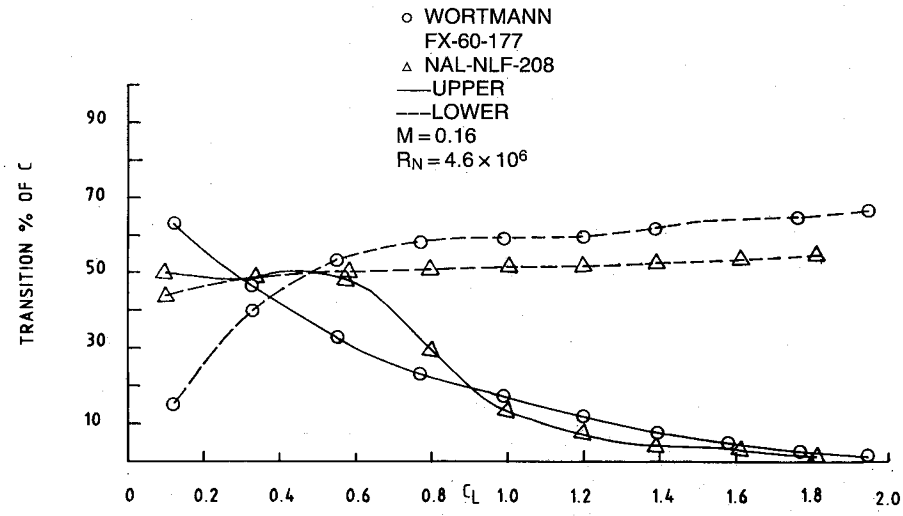

Fig. 4 Transition of the NAL-NLF-208 and FX-60-177 airfoils.

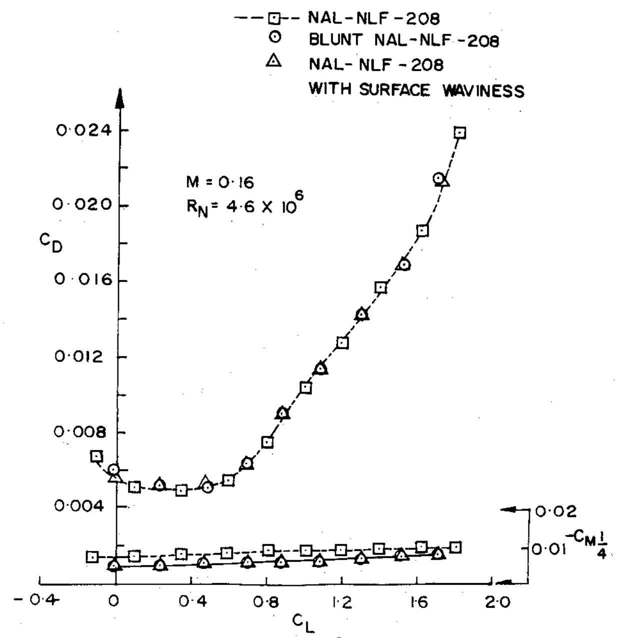

Fig. 5 Drag polars for the NAL-NLF-208 and the modified NAL-NLF-208.

NAL-NLF-208. As can be seen in Fig. 5, this waviness had no significant effect on the NAL-NLF-208 airfoil.

Conclusion

The analysis presented points out that the NAL-NLF-208 airfoil (with bluntness) is robust in performance and is practically feasible. Wind-tunnel and flight testing of this airfoil are worth pursuing.

Acknowledgment

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Measurements and Implications of Vortex Motions Using Two Flow-Visualization Techniques

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Introduction

VORTEX flows represent a challenge in aircraft design because they occur at many different scales and are important for almost every aspect of vehicle performance, stability, control, and maneuverability. This is especially true for highly maneuverable fighter aircraft, which may have extensive regions of complex, turbulent, off-surface vortex flow for which there are no reliable computational design methods. In

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