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Boundary-Layer Control on Wings Using Sound and Leading-Edge Serrations

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Abstract

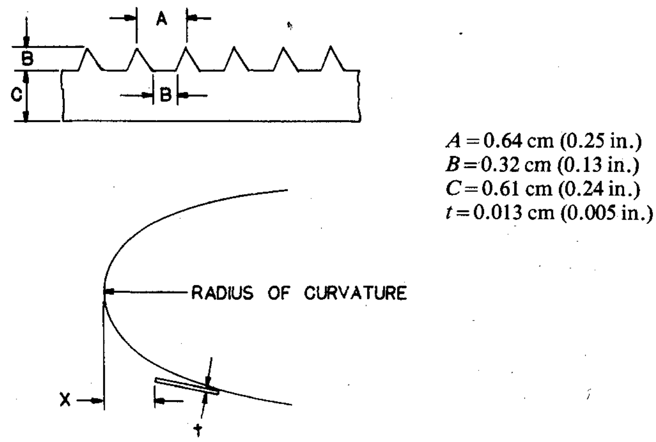
THIS study systematically examined the effect of leading-edge serrations, sound emitted from periodically spaced holes near the wing leading edge, and external sound upon the flow over two low-speed wings, one with camber (NACA 2412) and one without (NACA 0015). The main purpose of the study was to determine whether these techniques could be used to increase the lift coefficient of these wings. These techniques were all found to have a beneficial effect upon the aerodynamic properties of these airfoils. The first two techniques could be practically used to improve the low-speed lift and stall performance of light aircraft during takeoff and landing and could be used for stall/flutter suppression on rotor and propeller blades.

Contents

The experiments were performed in a subsonic wind tunnel with an open test section measuring 0.56×0.91 m in cross section. Two-dimensional airfoil sections fitted with end plates were placed in the center of the test section. The tests were performed over a chord Reynolds number range of 3-6×10^5. Surface pressures were measured at midspan on two of the models and the integrated pressures yielded the aerodynamic coefficients. The measured coefficients were corrected to second order using standard techniques[1] but the corrections could not be expected to be correct at the higher angles of attack, especially after stall had occurred.

Serrations which spanned the airfoils were glued to the bottom of the models for some tests (Fig. 1). The serrations were placed in the rapidly accelerating region between the stagnation point and the point of minimum pressure. The sectional aerodynamic coefficients were measured as a function of angle of attack α for the two airfoils, both with and without serrations. Measurements of the lift coefficient C_l, drag coefficient C_d, and quarter-chord pitching moment C_m are shown in Figs. 2 and 3.

The serrations modified the pressure distribution on the suction surface of the airfoils (Fig. 4) resulting in an increase of the slope of the C_l curve, compared to the basic airfoil, of 12% for the 0015 airfoil and 22% for the 2412 airfoil. The maximum lift was not increased for the 0015 airfoil but it was substantially increased for the 2412 airfoil. The zero-lift angle of attack was decreased for the latter airfoil but the stall angle was not changed for either airfoil. The serrations added no measurable drag for either airfoil but did decrease the pitching moment for the 2412 airfoil. These results are in contrast to those of Soderman[2] who found that serrations produced no change in the slope of the lift curve, but did produce an increase in the maximum lift and the stall angle for a symmetric laminar flow airfoil.



For 0015 airfoil, $R = 0.024c = 0.53$ cm (0.21 in.)
For 2412 airfoil, $R = 0.0158c = 0.48$ cm (0.19 in.)

Airfoil	A/R	B/R	C/R	X	X/R
NACA 2412	1.316	0.658	1.263	0.64 cm (0.25 in.)	1.316
NACA 0015	1.196	0.598	1.148	0.69 cm (0.27 in.)	1.196

Fig. 1 Serration geometry and location on models.

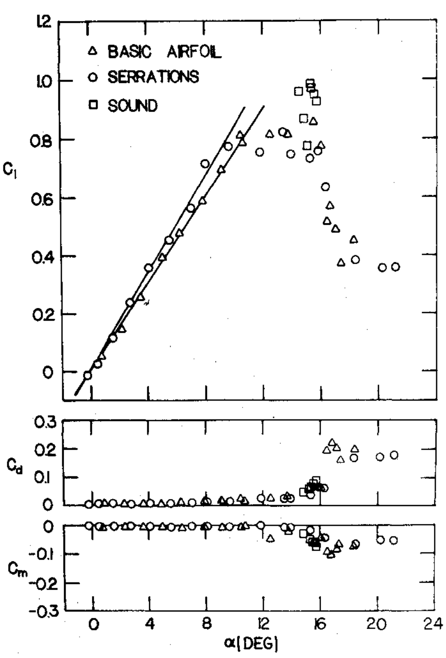


Fig. 2 Aerodynamic coefficients for NACA 0015 airfoil, $Re = 3.3 \times 10^5$.

The transition location was measured on the suction surface of the models and the serrations produced no noticeable change in its location. Therefore it was concluded that serrations do not bring about premature transition on the suction surface, in agreement with previous investigations.[2-4]

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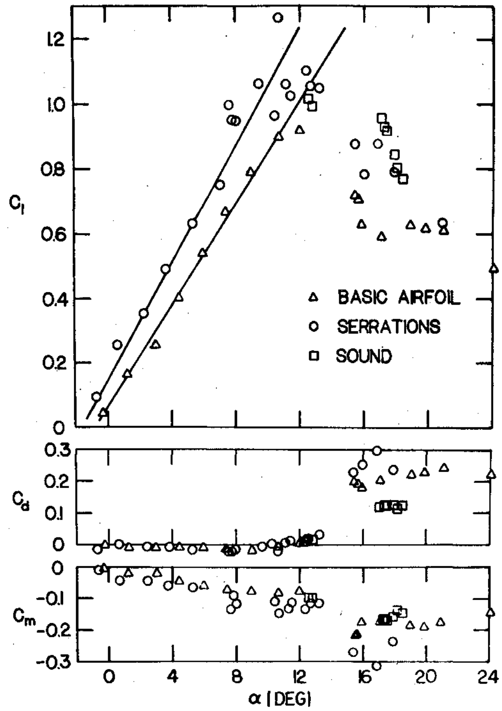

Fig. 3 Aerodynamic coefficients for NACA 2412 airfoil, $Re = 4.8 \times 10^5$ ($Re = 4.4\text{-}5.4 \times 10^5$ for sound).

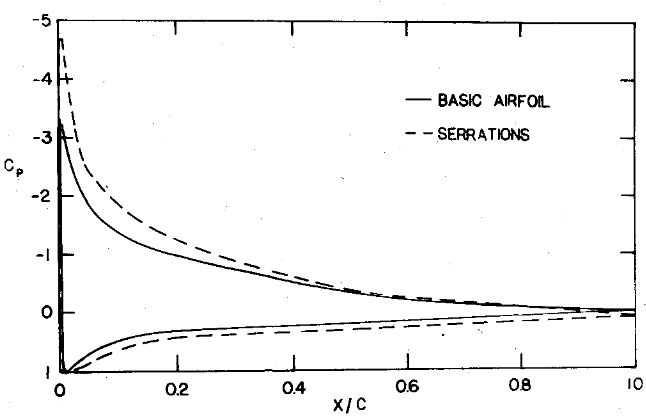

Fig. 4 Pressure distribution around NACA 2412 airfoil with and without serrations, $Re = 4.8 \times 10^5$, $\alpha = 10.63$ deg (basic airfoil, $C_l = 0.90$; with serrations, $C_l = 1.27$).

The serrations did not behave like roughness or vortex generators on the suction surface of an airfoil, which decrease the maximum lift and the slope of the lift curve and greatly increase the drag.[5] Instead serrations appear to act as "ideal vortex generators."

External sound, produced by a loudspeaker placed downstream and above the models, was examined as a means of stall suppression for low-speed airfoils. The tests were performed by placing the models at an angle of attack just above the stall angle and at a second higher angle and measuring the sound frequency and pressure level (SPL) required to produce some amount of flow attachment. Preliminary results have been previously reported.[6]

For a fixed α and sound frequency, partial attachment occurred at a minimum SPL which resulted in increased C_l and decreased C_d with concurrent changes in C_m (Figs. 2 and 3). The power savings caused by drag reduction was up to 2800 times greater than the speaker power. Further increases in SPL produced only modest changes in aerodynamic properties and full stall suppression could not be achieved nor could the stall angle be increased. The sound produced a large suction peak near the leading edge of the suction surface.[6] The extent of the suction peak diminished and the SPL required for partial attachment increased rapidly as α was increased. The SPL required for partial attachment at a constant C_l varied with frequency and was a minimum at a certain frequency.[6]

From a measurement of the location of boundary-layer transition on the suction surface of the models it was concluded that the sound did not cause premature transition. It had previously been suggested that sound initiated instabilities in the separated shear layer and that this was responsible for the reattachment of the flow.[7]

Sound of certain frequencies and intensity, emitted from small holes periodically spaced in the span direction near the leading edge on the suction surface of an 0015 model, was found to cause partial reattachment of the flow for α up to 5 deg above the stall angle. The SPL of the sound emitted from the holes which was required to reattach the flow was considerably lower (greater than 10 dB) than the SPL of external sound needed to reattach the same flow. In contrast to the serrations and external sound, internal sound moved the boundary-layer transition point forward. Internal sound also suppressed stall/flutter for α close to the stall angle.

The results presented represent relatively simple modifications that yield improved low-speed performance of the 2412 and 0015 airfoils over the Reynolds number range of $2\text{-}5 \times 10^5$. Additional testing will be required to determine the general applicability of the techniques for other airfoils and over greater Reynolds number ranges. Also, other serration sizes and locations need to be examined.

Acknowledgments

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