JOURNAL OF AIRCRAFT
Vol. 31, No. 6, November–December 1994

Study of an Airfoil with a Flap and Spoiler

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An experimental investigation of an airfoil with a spoiler and flap was carried out. Results of these studies are presented. The coefficient of lift was seen to decline sharply in the range of spoiler angles ranging from 0 to 15 deg, due to the early separation that the spoiler introduces on the airfoil. Experiments with wing-flap combinations for flap angles ranging from 0 to 45 deg showed that there is an optimum wing-flap gap for a wing-flap configuration. A considerable increase in the intensities of turbulences were seen at higher flap angles that should contribute to the sharp increase in the drag at the higher flap angles. A wake frequency spectrum for varying angles of attack has been made and is presented.

Nomenclature

C_d = drag coefficient
C_l = lift coefficient
S_c = Strouhal number
U_∞ = freestream velocity
$\sqrt{\overline{u'^2}}$ = rms of fluctuating velocity
α = angle of attack, deg
γ = angle of flap, deg
δ = angle of spoiler, deg

Introduction

PERFORMANCES of an airfoil with a spoiler and an airfoil with a spoiler and a flap has considerable practical significance in view of its application to wings of aircraft. Early experimental investigation of airfoil-spoiler configurations were carried out in the 1930s by Weick and Short.[1] Wentz and Ostowari[2] carried out considerable wind-tunnel studies on spoiler flow characteristics. Lee and Bodapati[3] carried out both theoretical and experimental investigations of the steady and unsteady flowfields around a deflected spoiler. Among other findings, they concluded that the effectiveness of a spoiler changes drastically with the presence of a flap. Bibere and Zumwalt[4] published some results on the flowfield measurements they carried out on an airfoil with a flap having large separation. They evaluated the flowfield on the upper side of the two-element airfoil using a splitter plate having 42 static pressure holes. In addition, wake turbulence intensities and the normal and shearing stresses due to turbulence were obtained by them.

The purpose of the present study has been to throw more light on the performance of an airfoil-spoiler-flap configuration, and to study the intensity of turbulence in the wake.

Model

A NACA 4424 airfoil was chosen to represent the wing model. To enable surface pressure measurements to be made on the airfoil, 20 pressure holes were drilled around the airfoil; 12 being on the upper surface and 8 on the lower surface. Fine tubes of 2 mm i.d. connected to these holes were taken through the airfoil to a multimanometer. The airfoil had a chord length of 90 mm and a span of 270 mm. A flat plate of brass 14 mm wide, 270 mm span, and 1 mm thick was hinged at 73% chord and formed the spoiler. The flap of 2 mm thickness, 22.5 mm wide, and 270 mm span was fabricated out of brass. Figure 1 shows the airfoil-spoiler-flap configuration, whereas Fig. 2 shows the end plates designed to hold the airfoil, the spoiler, and the flap together. The end plates were made from a 15-mm-thick brass plate. The spoiler, hinged at location A shown in the figure, had a locking spigot that moved inside the circumferential groove marked B, enabling the spoiler to be fixed at any desired angle with respect to the airfoil chord. The radial groove marked F in the figure permitted the movement of the flap along the groove so as to vary the airfoil-flap gap, and also permitted fixing the flap at the required flap angle.

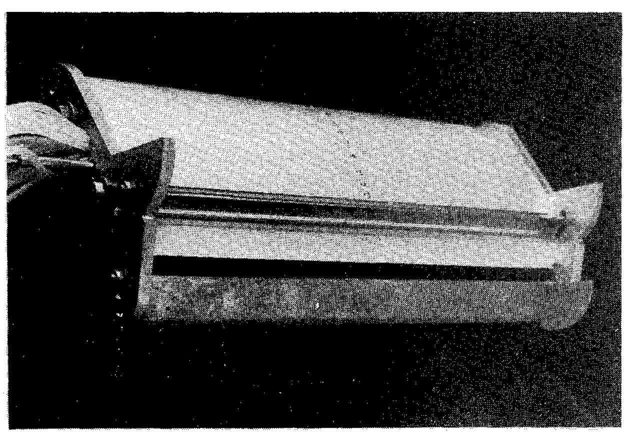

Fig. 1 Airfoil-spoiler-flap configuration.

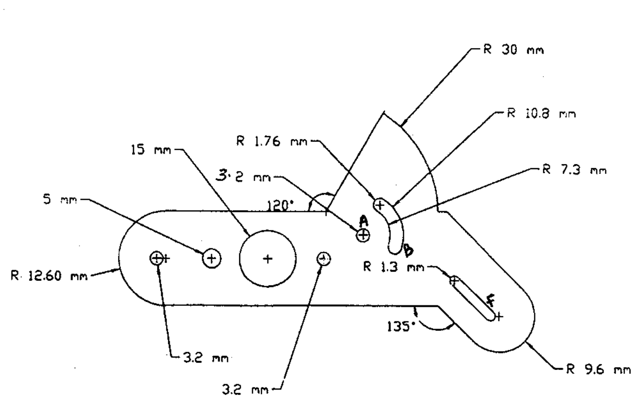

Fig. 2 End plates designed to hold the spoiler and the flap on to the airfoil.

Received July 25, 1993; revision received Feb. 15, 1994; accepted for publication March 7, 1994.

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The test facility consisted of a low-speed, open-circuit wind tunnel having a test section 300 mm octagonal × 450 mm long. The maximum test section speed was limited to 25 m/s. Instrumentation included a hot-wire anemometer and a dual-channel wave analyzer, besides multimanometers and pitot static tubes.

Experiments

The tunnel was run at a speed of 20 m/s corresponding to a Reynolds number of 1.15 × 10^5, based on airfoil chord. The experiments were conducted in two parts. The first part of the experiments were conducted with a spoiler to study the characteristics of the wing-spoiler configuration. Tests were conducted for spoiler angles of 0, 15, 30, 45, and 60 deg, and for airfoil angles of attack varying from −6 to +8 deg. The pressure distribution around the airfoil was obtained from the multimanometer connected to the pressure holes around the airfoil. The wake velocity profiles and the intensities of turbulences in the wake were obtained using a hot-wire anemometer. The turbulence intensity at each station in the wake was computed from the mean velocity and the rms value of the fluctuating velocity at that station. The total drag in each case was calculated from the wake velocity profiles obtained and by using the momentum equation. Experiments with the flap were carried out for flap angles of 0, 15, 30, and 45 deg, and the airfoil angles of attack varying from 0 to +8 deg, taking flap-gap to airfoil chord as a varying parameter. All experiments were carried out for the three flap-gap to airfoil chord ratios of 0.022, 0.044, and 0.066. In all cases, values of the airfoil surface pressure distribution, wake velocity profiles, and intensities of turbulence in the wake were noted.

A frequency spectrum of the wake was also taken using a wave analyzer.

Results and Discussion

Figure 3 shows the results of a test carried out with spoiler angles δ = 0, 15, 30, 45, and 60 deg for α varying from −6 to +8 deg. As can be seen, with an increase in spoiler angle there is a decrease in the lift coefficient. The results obtained confirm the results published by Lee and Bodapti.[5] Variation of the C_d with α, varying from −6 to +6 deg for spoiler angles of 15, 30, and 45 deg are presented in Fig. 4. The behavior should not be surprising because the configurations having the large spoiler angles would exhibit the characteristics of an unsymmetrical wedge in a uniform flow with its apex as the leading edge. Such a wedge when rotated about its apex or leading edge is bound to show an oscillatory drag characteristic. Figure 5 shows wake turbulence intensities obtained for spoiler angles of 30, 45, and 60 deg, for an angle of attack of 4 deg.

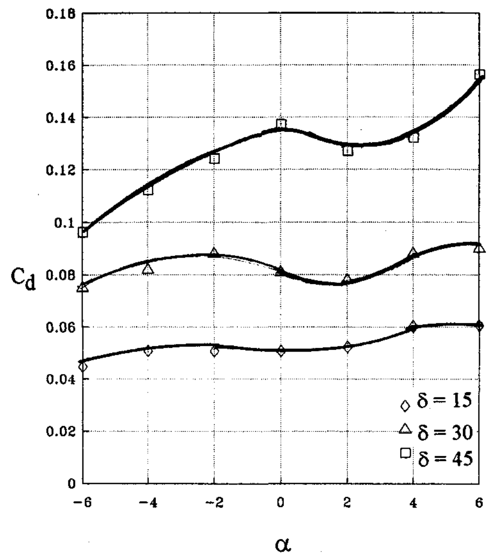

Fig. 4 Variation of drag coefficients with angle of attack.

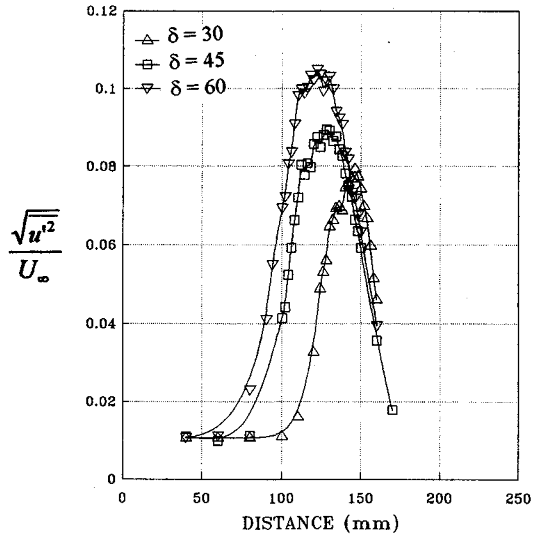

Fig. 5 Turbulence intensity profiles in the wake at 4-deg angle of attack.

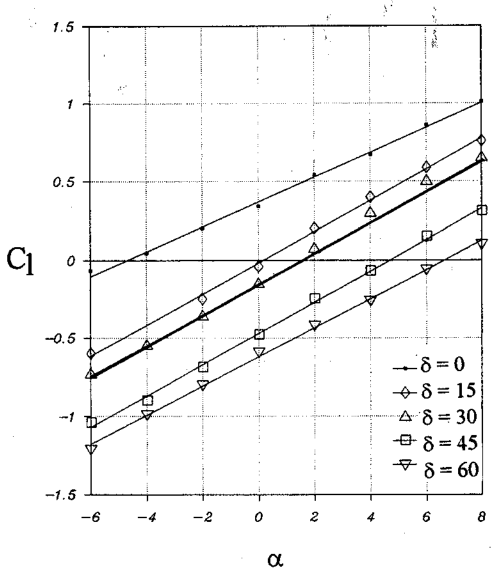

Fig. 3 Variation of lift coefficients with angle of attack.

Test results with flap-gap to chord ratios of 0.022, 0.044, and 0.066 are presented. Figures 6–8 show C_l vs α for flap angles of 0, 15, 30, and 45 deg, for flap-gap ratios of 0.022, 0.044, and 0.066. It can be noticed from these figures that the optimum gap-ratio for the configuration lies between 0.022–0.066. This is understandable because a very small gap-ratio would allow through the gap sufficient high-energy fluid to blow off the relatively low-energy fluid on the upper portion of the flap, causing separation. When the gap becomes too large, the pressure on the underside would decrease, leading to a loss in the lift force. Figure 9 shows the drag characteristic.

Turbulence intensity variations for flap angles of 15, 30, and 45 deg for an angle of attack of 4 deg, and gap-ratio of 0.044, is shown in Fig. 10. An increase in flap angles produces larger wake turbulences, both in magnitude and spread, with the increase in magnitude being higher at larger angles of flap. Results of frequency spectrum obtained in the wake of the airfoil with zero spoiler angle and flap removed is shown in Fig. 11, where α has been plotted against S_c, based on the airfoil chord.

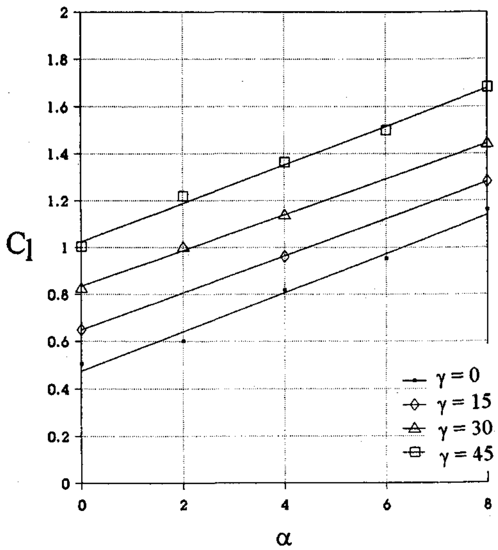

Fig. 6 Variation of lift coefficients with angle of attack for a gap-ratio of 0.022.

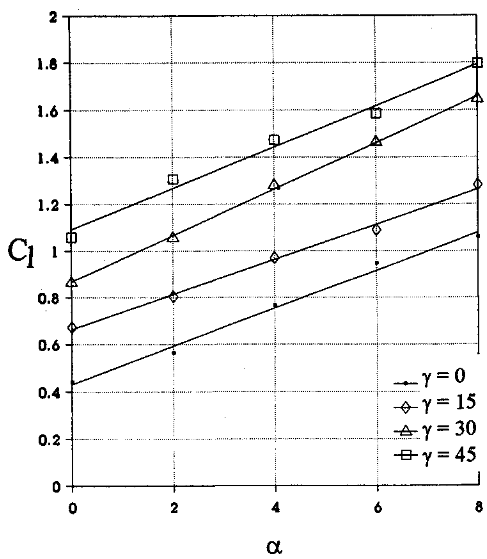

Fig. 7 Variation of lift coefficients with angle of attack for a gap-ratio of 0.044.

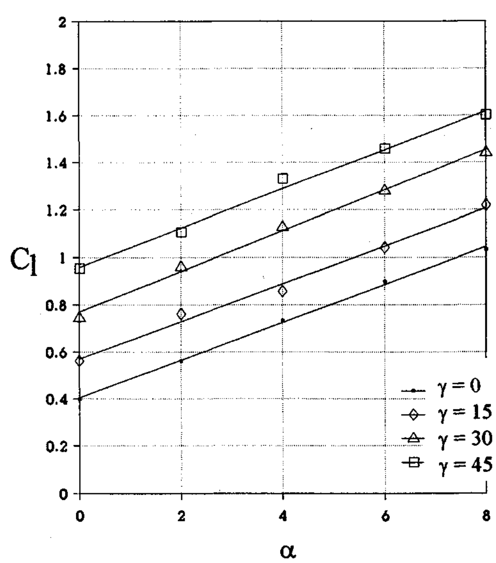

Fig. 8 Variation of lift coefficients with angle of attack for a gap-ratio of 0.066.

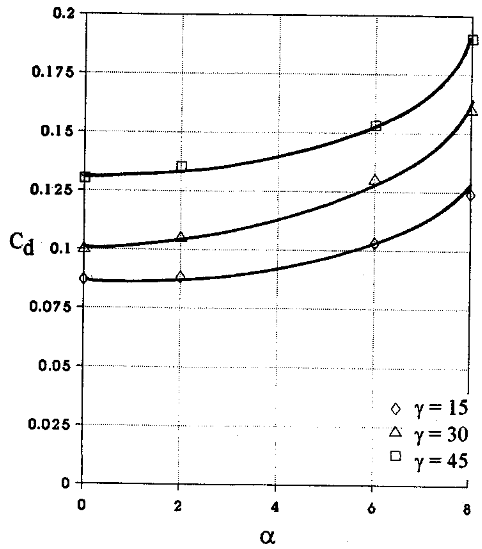

Fig. 9 Variation of drag coefficients with angle of attack for a gap-ratio of 0.044.

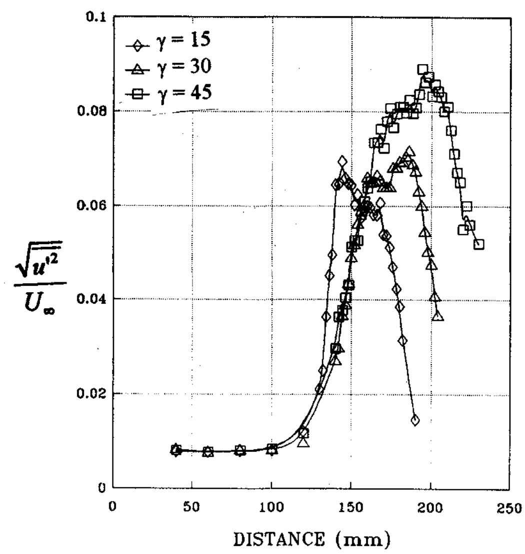

Fig. 10 Turbulence intensity profiles in the wake at 4-deg angle of attack and a gap-ratio of 0.044.

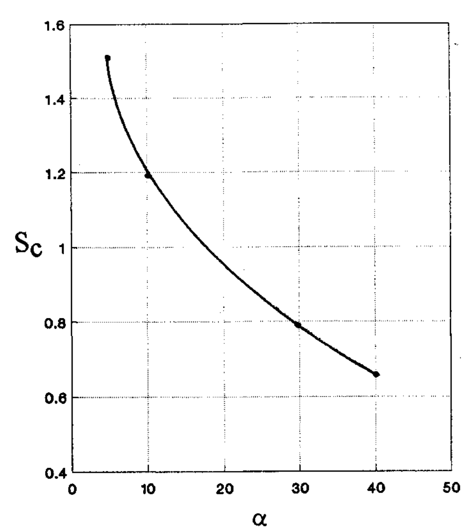

Fig. 11 Variation of Strouhal number with angle of attack.

Concluding Remarks

The decrease in the values of C_l for various α of the airfoil was seen to be large in the range of the spoiler angles varying from 0 to 15 deg. This should be due to the early separation of flow on the airfoil that the spoiler introduces at its lower angles. At higher spoiler angles, the negative lift contributed by the spoiler reduces the overall C_l, rather than any further effect from flow separation. Investigations are necessary to look into the transient behavior of the oscillatory flow downstream of the spoiler, to throw more light on any longitudinal periodic oscillatory forces that flow attachment and detachment would produce behind the spoiler as a consequence to separation.

Experiments with a wing-flap combination show that there is an optimum wing flap-gap to chord ratio for a configuration. The flowfield downstream of the flap-wing gap is complicated and needs considerable study if any theoretical basis to obtain an optimum gap is to be established. Considerable increase in the intensities of turbulences were seen with higher flap angles, which obviously contributed to the sharp increase in the drag at the higher flap angles.

Acknowledgments

We would like to acknowledge Khalfan Al Asmi and Saif Al Haddabi of the Mechanical Engineering Department for the valuable help they rendered.

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