WIND-TUNNEL INVESTIGATION OF AN NACA 23012 AIRFOIL WITH 30-PERCENT-CHORD VENETIAN-BLIND FLAPS

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SUMMARY

An investigation has been made in the NACA 7-10-foot wind tunnel of an NACA 23012 airfoil with 30-percent-chord venetian-blind flaps having one, two, three, and four slats of Clark Y section. The three-slat arrangement was aerodynamically the best of those tested but showed practically no improvement over the comparable arrangement used in the preliminary tests published in NACA Report No. 689. The multiple-slat flaps gave slightly higher lift coefficients than the one-slat (Fowler) flap but gave considerably greater pitching-moment coefficients. An analysis of test data indicates that substitution of a thicker and more cambered section for the Clark Y slats should improve the aerodynamic and the structural characteristics of the venetian-blind flap.

INTRODUCTION

The NACA is undertaking an extensive investigation of various wing-flap combinations for improving safety and performance in flight. One promising combination developed to date by the NACA is the venetian-blind flap (reference 1), which gave higher maximum lift coefficients and lower drag coefficients at moderate high lift coefficients than any flap previously tested by the NACA (references 1 and 2).

A further development of the 30-percent-chord venetian-blind flap hinged at the trailing edge of the wing appeared promising. In the present investigation various arrangements were tested to determine the effect of number of the slats and chords of the slats used to form the flap, of the slot gap between the slats, and of the position of the slats with respect to each other and to the wing.

The characteristics of an NACA slotted flap and of a plain wing are included for comparison.

MODELS

MAIN AIRFOIL

The basic wing, or plain airfoil, was built to the NACA 23012 profile and has a chord of 3 feet and a span of 7 feet. The wing was constructed of laminated mahogany and tempered wallboard with a steel trailing-edge plate. It was specially made for these tests. The cut-out required for the retraction of the one-slat (Fowler) 30-percent-chord venetian-blind flap was retained in all the models.
the two-slat combination composed of two 15-percent-chord slats, the three-slat combination composed of three 10-percent-chord slats, and the four-slat combination composed of four 7.5-percent-chord slats. In the tests the one-slat (Fowler) flap is considered to be the limiting case of the venetian-blind flap.

Equal slot gaps of \(\frac{1}{4}\), \(\frac{1}{4}\), and \(\frac{2}{4}\) percent of the wing chord were used. These slot gaps were measured from the slat nose-hinge point to the chord line of the immediately preceding slat or main airfoil. The slot gap defined is not the minimum air gap between two adjacent slats or between the first slat and the main airfoil but is the distance between the slat-hinge axis (at the slat nose) and the chord line of the preceding slat or main airfoil.

**TESTS**

The models were mounted in the closed test section of the NACA 7- by 10-foot wind tunnel so as to span the jet completely except for small clearances at each end. (See reference 3.) The main airfoil was rigidly attached to the balance frame by torque tubes, which extended through the upper and the lower boundaries of the tunnel. The angle of attack of the model was set from outside the tunnel by rotating the torque tubes with a calibrated drive. Approximately two-dimensional flow is obtained with this type of installation and the section characteristics of the model under test may be determined.

A dynamic pressure of 16.37 pounds per square foot was maintained for all the tests, which corresponds to a velocity of 80 miles per hour under standard atmospheric conditions and to an average test Reynolds number of about 2,100,000. Because of the turbulence in the wind tunnel, the effective Reynolds number \(R_e\) was approximately 3,500,000. For all tests, \(R_e\) is based on the chord of the airfoil with the flap fully retracted and on a turbulence factor of 1.6 for the tunnel.

Each venetian-blind flap combination was tested through a complete range of slat deflections with 1.5-percent-chord slot gaps. The optimum slat deflections were then tested again with equal slot gaps of 0.5- and 2.5-percent chord. An angle-of-attack range from \(-6^\circ\) to the angle of attack for maximum lift was covered in \(2^\circ\) increments for each test. Lift, drag, and pitching moment were measured at each angle of attack.

No tests were made of a plain wing; the plain-wing data used herein are taken from reference 3.

**RESULTS AND DISCUSSION**

**SYMBOLS**

Test results are presented in standard section nondimensional coefficient form, corrected as in reference 3. The following symbols are used:

\[
\begin{align*}
  c_l & \quad \text{section lift coefficient} \quad (l/qc) \\
  c_{l_{\text{max}}} & \quad \text{effective section maximum lift coefficient for complete airplane} \\
  c_d & \quad \text{section profile-drag coefficient} \quad (d/qc) \\
  c_m & \quad \text{section pitching-moment coefficient about aerodynamic center of plain airfoil} \quad (m_{(e,c)}/q_c) \\
  l & \quad \text{section lift} \\
  d_o & \quad \text{section profile drag} \\
  m_{(e,c)} & \quad \text{section pitching moment} \\
  q & \quad \text{dynamic pressure} \quad \left(\frac{1}{2}pV^2\right) \\
  c & \quad \text{chord of basic airfoil with flap retracted} \\
  \alpha_0 & \quad \text{angle of attack for infinite aspect ratio} \\
  \delta & \quad \text{deflection of individual slats} \\
  \frac{1}{f} & \quad \text{slat position} \\
  \theta & \quad \text{deflection of individual slat} \\
  \sigma_0 & \quad \pm 0.1^\circ \\
  c_{l_{\text{max}}} & \quad \pm 0.0006 \\
  c_{l_{\text{max}}} & \quad \pm 0.03 \\
  \alpha_0 & \quad \pm 0.2^\circ \\
  \delta & \quad \pm 0.03 \\
  \theta & \quad \pm 0.0003 \\
  \sigma_0 & \quad \pm 0.001
\end{align*}
\]

**PRECISION**

The accuracy of the various measurements in the tests is believed to be within the following limits:

The accuracy of \(\delta\) refers to the deflection of the slat relative to the preceding slat and may be an additive error for successive slats, giving a maximum possible error of \(\pm 0.8^\circ\) for \(\delta_{sl}\) in the four-slat combination.

No tare tests were run to determine the effect of slat-hinge fittings on profile drag and the data are not corrected for this effect. Each slat required a separate set of fittings and the tare drag probably increased with the number of slats.

**VENETIAN-BLIND FLAP ARRANGEMENT**

**Maximum-lift characteristics.**—In order to determine the optimum venetian-blind flap arrangements from consideration of maximum lift, the various arrangements have been compared in figure 2 on the basis of increase of section maximum lift coefficients \(\Delta c_{l_{\text{max}}}\) due to slat deflections. The value of \(\Delta c_{l_{\text{max}}}\) is the difference between the section maximum lift coefficient of the wing with the flap extended and the section maximum lift coefficient of the plain wing.

The values of \(\Delta c_{l_{\text{max}}}\) for the two- and the three-slat arrangements increase almost linearly over the one-slat arrangement giving \(\Delta c_{l_{\text{max}}}\) of 1.75, 1.80, and 1.85 for
the one-, the two-, and the three-slat arrangements, respectively. The three-slat arrangement was the optimum of those tested and its value of $\Delta c_{\text{max}}$ was slightly above that of the comparable three-slat arrangement of reference 1, which gave a value of $\Delta c_{\text{max}}$ of 1.80 for slightly different slat locations and profile-drag coefficient and lowest maximum lift coefficient.

The three-slat arrangement with optimum slat deflections and with a set of differential slot gaps consisting of a 0.015c slot gap between the main wing and the first slat and 0.005c slot gaps between the other

deflections. The $\Delta c_{\text{max}}$ of the four-slat optimum arrangement was 1.84, indicating that a further increase in the number of slats would probably give no improvement in high-lift characteristics.

Differential deflection of slats with the last slat set at 50° proved optimum for the two-, the three-, and the four-slat arrangements and, as the number of slats composing the flap increased, the differential deflection between slats decreased for optimum arrangements.

The effect of slot gap on the increment of maximum lift coefficient is shown in figure 3. The effect of slot gap on other aerodynamic section characteristics is shown in figure 4. For all arrangements the 0.015c slot gap was optimum for maximum lift and low profile drag; the 0.005c slot gap was next best; and the 0.025c slot gap was least desirable with large increases in

![Diagram showing the effect of slot gap on maximum lift coefficient.](image-url)
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In consideration of possible increase in the angle of attack, a support at 90° in the rear of the wing is recommended with a careful consideration of the maximum lift coefficient for the individual section of the wing. The shape of the section should be oblong, and the lift coefficient should be obtained at a point where the section is adequate for the Reynolds number. The angle of attack for the maximum lift is approximately 2°. The effect of the angle of attack on the lift coefficient is given in the figure.

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coefficient of 2.5, the two-slat arrangement had the least drag, giving 27 percent less drag coefficient than the best slotted flap of reference 3 at the same \( c_l \); and, at a \( c_l \) of 3.0, the three-slat arrangement had the lowest drag coefficient, the two-, the four-, and the one-slat combinations, respectively, giving successively higher drag coefficients. As an example of the high variable profile-drag coefficient at high lift coefficient, the profile-drag coefficient of the three-slat combination increased 31 percent for an increase in lift coefficient of only 0.1 in going from \( c_l \) of 3.3 to 3.4.

Comparison of pitching moments.—The venetian-blind flap arrangements gave large pitching-moment coefficients, which increased with the number of slats. The four-slat arrangements, however, gave only slightly higher pitching-moment coefficients than the three-slat arrangement. The optimum three-slat arrangement gave a pitching-moment coefficient of 0.76 at \( c_{l_{\text{max}}} \), which was 10 percent greater than the pitching-moment coefficient of the one-slat (Fowler) flap at its maximum lift coefficient.

In order to give a more comprehensive comparison of maximum lift coefficients of flaps with different values of pitching-moment coefficient, the effect of tail loads required to balance the pitching-moment coefficients should be considered in determining the net or the effective maximum lift coefficient. Figure 6 gives a comparison of the effective maximum lift coefficients of several flaps for varying tail lengths. For simplicity in the computation of \( c_{l_{\text{max}}} \), the center of gravity was assumed to be at the aerodynamic center of the wing with the flap fully retracted. The following formula was used:

\[
c_{l_{\text{max}}} = \frac{c_{l_{\text{max}}}}{\text{tail length}} + \frac{(c_{m_{\text{a.e.c.}}})_{l_{\text{max}}}}{\text{tail length}}
\]

The large pitching-moment coefficients of the venetian-blind flaps made no difference in relative values of \( c_{l_{\text{max}}} \) of the various flaps and, for tail lengths of 1 to 5 airfoil chord lengths (conventional length is about 2½ to 3 chord lengths), the three-slat arrangement was still optimum and the two- and the four-slat arrangements gave slightly higher values of \( c_{l_{\text{max}}} \) than the one-slat, or Fowler flap, arrangement.

Slotted flap 2-h of reference 3 gave considerably lower effective \( c_{l_{\text{max}}} \) than the venetian-blind flap arrangements shown. Although the slotted flap had a chord of only 0.256c as compared with 0.30c for the venetian-blind flap, the comparison is valid in view of the fact that tests have shown a chord of about 0.25c to produce very nearly the same \( c_{l_{\text{max}}} \) as a chord of 0.40c for the slotted flap. (See reference 5.)
CONCLUSIONS

The best arrangement of the venturi-blind gaps tested were those that the best venturi-blind gaps did not give the significant higher results than the best comparative arrangement with the use of more or less of the high pressure. However, that improvement in high- and low-speed conditions was the single most (power) improvement and the duration was not as significant a higher result in the multiple-speed losses as in the reference. The duration of the previous investigation reported in Reference 1.

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REFERENCES


