RESEARCH MEMORANDUM

LOW-SPEED LATERAL CONTROL CHARACTERISTICS OF AN UNSWEPT WING WITH HEXAGONAL AIRFOIL SECTIONS AND ASPECT RATIO 4.0 AT A REYNOLDS NUMBER OF $6.2 \times 10^6$

By William M. Hadaway

Langley Aeronautical Laboratory
Langley Field, Va.

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LOW-SPEED LATERAL CONTROL CHARACTERISTICS OF AN UNSWPT WING WITH HEXAGONAL AIRFOIL SECTIONS AND ASPECT RATIO 4.0 AT A REYNOLDS NUMBER OF 6.2 x 10^6

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SUMMARY

A lateral-control investigation has been made in the Langley 19-foot pressure tunnel of an unswept wing having 6-percent-thick hexagonal airfoil sections, aspect ratio 4.0, and taper ratio 0.625. The wing was mounted on a circular fuselage with a fineness ratio of 10 to 1. Characteristics of both a 0.40 semispan outboard aileron and a 0.79 semispan aileron were investigated at a Reynolds number of 6.2 x 10^6. The effects of 0.79 semispan leading-edge flaps and 0.39 semispan trailing-edge flaps were also determined. The data include aileron normal-force, hinge-moment, and aileron balance-chamber-pressure measurements as well as force measurements by the standard six-component balance system. A theoretical aileron effectiveness value $C_{l_A}$ of 0.00132 compared with an experimental value of 0.00150 for the plain wing equipped with the 0.40 semispan aileron. Comparisons of the rates of change of the hinge moment with aileron deflection and angle of attack as well as $C_{l_A}$ of the unswept wing with those of an unswept wing of aspect ratio 2.5 having the same wing area, taper ratio, and airfoil section are also presented herein.

INTRODUCTION

As part of the study of the low-speed characteristics of wings suitable for supersonic speeds, a lateral-control investigation has been made of an unswept, modified double wedge wing of aspect ratio 4.0 in the Langley 19-foot pressure tunnel at high Reynolds numbers and low Mach numbers. Lateral-control investigations have been conducted previously for wings of similar plan form and airfoil section (NACA investigations conducted at the Ames Laboratory by Ben H. Johnson, Jr., and Fred A. Demele and by Noel K. Delany and Nora-Lee F. Hayter and at the Langley Laboratory by James E. Fitzpatrick and Robert L. Woods); however, there is a scarcity of data pertaining to aileron hinge moments, aileron normal
forces, and aileron balance-chamber pressures. This paper presentsorce measurements as well as aileron hinge moments, normal forces, and
balance-chamber pressures. The tests included measurements of both a
0.79 semispan and an outboard 0.40 semispan aileron. The effects of
leading-edge droop and part-span trailing-edge flaps on the outboard
aileron effectiveness were also investigated. All tests were made with
a cylindrical fuselage attached to the wing. No analysis is presented
herein.

SYMBOLS AND COEFFICIENTS

The data are referred to wind axes with the origin at 25 percent
of the mean aerodynamic chord projected to the plane of symmetry.
Symbols and coefficients are defined as follows:

- \( S \) wing area
- \( A \) aspect ratio
- \( \lambda \) taper ratio
- \( \delta_n \) deflection of nose flap, deg
- \( \delta_f \) deflection of trailing-edge flap, deg
- \( \delta_a \) deflection of aileron, deg (positive when trailing edge is
down)
- \( C_L \) lift coefficient, \( \text{Lift}/qS \)
- \( C_m \) pitching-moment coefficient, \( \text{Pitching moment}/qSc \)
- \( C_n \) yawing-moment coefficient, \( \text{Yawning moment}/qSb \)
- \( C_{\text{ha}} \) aileron hinge-moment coefficient, \( \text{Hinge moment}/2M_aq \)
- \( C_t \) rolling-moment coefficient, \( \text{Rolling moment}/qSb \)
- \( P_R \) resultant pressure coefficient in aileron balance chamber
corrected to complete sealed condition,

\[
\left( \frac{\text{Pressure below seal} - \text{pressure above seal}}{Kq} \right)_{\text{ave}}
\]
- \( K \):

\[
K = \left( \frac{\text{Pressure difference across seal}}{\text{Pressure difference across vents}} \right)_{\text{ave}}
\]
q \quad \text{dynamic pressure, } \rho V^2/2, \text{ lb/sq ft} \\
\bar{c} \quad \text{mean aerodynamic chord, } \frac{2}{b} \int_0^b c^2 dy \\
b \quad \text{wing span, ft} \\
b_a \quad \text{aileron span, ft} \\
M_a \quad \text{moment area of aileron behind hinge line, taken about hinge axis, } \frac{1}{2} \int_0^{b_a} c_a^2 dy, \text{ cu ft} \\
c_a \quad \text{aileron chord behind and perpendicular to aileron hinge line, ft} \\
V \quad \text{free-stream velocity, ft/sec} \\
\rho \quad \text{density of air, slugs/cu ft} \\
c \quad \text{local wing chord, ft} \\
\alpha \quad \text{angle of attack of wing root chord, deg} \\
C_{h\alpha} \quad \text{rate of change of aileron hinge-moment coefficient with angle of attack at } \delta_a = 0^\circ \\
C_{h\delta} \quad \text{rate of change of aileron hinge-moment coefficient with aileron deflection at } \delta_a = 0^\circ \\
P_{R\delta} \quad \text{rate of change of pressure coefficient with aileron deflection at } \delta_a = 0^\circ \\
P_{R\alpha} \quad \text{rate of change of pressure coefficient with angle of attack at } \delta_a = 0^\circ \\
C_{l\delta} \quad \text{rate of change of rolling-moment coefficient with aileron deflection at } \delta_a = 0^\circ \\
C_{N_a} \quad \text{aileron normal-force coefficient, Normal force}/qS_a \\
S_a \quad \text{aileron area behind hinge line, sq ft} \\
R \quad \text{Reynolds number, } \rho Vc/\mu \\
\mu \quad \text{coefficient of viscosity, slugs/ft sec}
MODEL AND TEST APPARATUS

Details of the wing model, fuselage, and aileron are presented in figure 1. The 6-percent-thick solid-steel wing had an aspect ratio of 4.0, a taper ratio of 0.625, and a sweep angle of 0° at the 50-percent chord line and had neither dihedral nor twist. The symmetrical hexagonal airfoil section had 11.42° leading- and trailing-edge angles and the upper and lower surfaces of each wing section were parallel between the 0.30 chord line and the 0.70 chord line. The wing was equipped with rounded tips. The fuselage was of circular cross section and had a fineness ratio of 10 to 1. The wing-fuselage combination was used throughout this investigation and the wing was mounted on the fuselage longitudinal center line at 0° incidence. No fillets were used at the wing-fuselage juncture.

The leading edge of the wing could be drooped from 0.16b/2 to 0.95b/2. The plain aileron was a constant 25 percent of the wing chord and extended from 0.16b/2 to 0.95b/2 on the left wing. The aileron was split at 0.55b/2, and the outboard and inboard segments could be deflected individually or together.

The inboard aileron could also be deflected in combination with the inboard flap on the right wing to simulate 0.39b/2 trailing-edge flaps as can be seen in the photograph presented in figure 2.

Four strain-gage beams, two on each segment, connected the aileron to the wing. The aileron hinge moments and aileron normal forces were measured by resistance-type strain gages mounted on each of the four beams.

A flexible seal was installed between the wing and the aileron from 0.16b/2 to 0.95b/2. Four pressure orifices above and four below the aileron seal were installed at various spanwise stations in the basic wing just forward of each aileron segment and were connected by flexible tubing to a manometer board for the determination of pressure differences across the seal during the tests. The right wing was not equipped with a seal between the wing proper and the flap.

The photograph of the test setup (fig. 2) shows the three-support system employed during these tests.

Tests

The tests were made in the Langley 19-foot pressure tunnel with the air in the tunnel compressed to approximately 2$\frac{1}{3}$ atmospheres. The
outboard 0.40b/2 aileron was deflected at various angles on both the plain wing and the wing having 0.79b/2 leading-edge flaps and 0.39b/2 trailing-edge flaps deflected. The 0.79b/2 aileron was deflected only on the plain-wing configuration.

The leading-edge flaps were deflected 30° in combination with the part-span trailing-edge flaps deflected 50°. The deflection angles were chosen to permit a comparison with data obtained from an unswept wing of aspect ratio 2.5 having the same wing area, taper ratio, and airfoil section as that of the subject wing. These flap deflections were considered representative of the most favorable deflection angles tested for a wing of similar airfoil section and aspect ratio (ref. 1).

Measurements of moments and forces, aileron loads, hinge moments, and aileron balance-chamber pressure were made for each configuration through the angle-of-attack range from -4° to approximately 25° and for various aileron deflections from -25° to +25°. A dynamic pressure of 80 pounds per square foot, corresponding to a Reynolds number of 6.20 x 10⁶ and a Mach number of 0.15, was maintained for most of the test conditions. Aileron hinge moments and normal forces exceeded the limits of the measuring instrument for a few maximum negative aileron deflection angles at low angles of attack and maximum positive aileron deflections at high angles of attack; therefore, for these angles the dynamic pressure was lowered to 60 pounds per square foot, which corresponded to a Reynolds number of 5.36 x 10⁶ and a Mach number of 0.13. This small Reynolds number change had no apparent effect on the trends and magnitudes of the data presented.

CORRECTIONS TO DATA

The lift and pitching-moment coefficients (fig. 3) have been corrected for air-stream misalignment and for support tare and interference effects. The dynamic pressure has been corrected for blockage in the test section. Jet-boundary corrections, based on the method of reference 2, have been applied to the angle of attack but were found to be negligible for the pitching-moment coefficient, yawing-moment coefficient, and rolling-moment coefficient and were not applied.

Variations of rolling-moment and yawing-moment coefficients at $\delta_a = 0^\circ$ through the angle-of-attack range were obtained for both the plain wing and the wing with leading- and trailing-edge flaps deflected. A check run, made for the plain-wing configuration, showed little change in the magnitude of moment-coefficient variations (fig. 4). The moment coefficient of both plain-wing runs at $\delta_a = 0^\circ$ were averaged and applied as tares to the rolling-moment and yawing-moment data. Similarly, the yawing- and rolling-moment coefficients of the leading- and trailing-edge flap configurations at $\delta_a = 0^\circ$ were applied as tares to the
flapped configuration data. The moment coefficients indicated at 
$\delta_a = 0^\circ$ are due to air-stream misalignment across the tunnel test 
section and possible slight model asymmetry.

A calibration of the aileron-seal leakage before the tests were 
made indicated that average ratios $K$ of pressure differences across 
the seal were 0.871 and 0.844 of the pressure differences across the 
vents for the full-span and the outboard aileron, respectively. The 
same seal was used for all tests and the two conversion factors $K$ 
were used to convert the pressure differences across the seal to pres-
sure differences across the vents in order to approximate a balance 
chamber with a perfect seal. The seal leakage was attributed to the 
discontinuity of the seal along the aileron spar at the strain-gage 
beam position and the openings around the ends of the 0.79b/2 aileron 
and at the split section dividing the two aileron segments.

After the tests had been completed, another seal calibration 
indicated $K$ values to be less than 3 percent lower than on the previ-
ous calibration for both the 0.79b/2 and the outboard 0.40b/2 aileron. 
This percentage is considered to be within the accuracy of the calibra-
tion and it has been determined that the small differences in seal 
calibrations had a negligible effect on the $\rho_r$ values corrected to 
a perfect sealed condition.

RESULTS

The basic aileron data are presented in figures 5 to 7 and the 
results have been summarized in figure 8. The outboard aileron effec-
tiveness $C_{18}$ of the plain wing at an angle of attack of $0^\circ$ was calcu-
lated to be 0.00132 from the method of reference 3 as compared with 
the experimental value of 0.00150. The addition of leading- and 
trailing-edge flaps decreased the experimental $C_{18}$ slightly in the 
angle-of-attack range below $6^\circ$ and increased $C_{18}$ for angles of attack 
greater than $6^\circ$ (fig. 8). The aileron effectiveness of the plain wing 
was increased substantially by the use of the 0.79b/2 aileron at all 
angles of attack for which $C_{18}$ was measured. The aileron effective-
ness of the outboard aileron with leading- and trailing-edge flaps 
deflected, however, was greater beyond an angle of attack of approxi-
mately 12$^\circ$ than that of the plain wing with either 0.79b/2 aileron or 
outboard 0.40b/2 aileron.

A comparison of aileron effectiveness values for the unswept wing 
of aspect ratio 4.0 with an unswept wing of aspect ratio 2.5 having the 
same wing area, taper ratio, and airfoil section is presented in figure 9.
As expected, the aileron effectiveness of the aspect ratio 4.0 wing is greater than that of the aspect ratio 2.5 wing through most of the linear lift range for all three test configurations.

Comparisons of $C_{h\alpha}$ and $C_{h\phi}$ values of both wings are presented in figures 10 and 11.

Langley Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va.

REFERENCES


Figure 1.- Geometry of the model and aileron details. All dimensions are in inches unless otherwise noted. \( A, 4.0 \); \( S, 28 \) square feet; \( \lambda, 0.625 \).
Figure 2: Model mounted on three-support system in the Langley 19-foot pressure tunnel with full-span leading-edge flaps and part-span trailing-edge flaps deflected. Front view.
Figure 3.- Comparisons of lift and pitching-moment coefficient of the subject aspect ratio 4.0 wing with that of a wing of aspect ratio 2.5 having the same wing area, taper ratio, and airfoil section. $\alpha_f = 50^\circ$; $\alpha_n = 30^\circ$. 
Figure 4.- Static rolling-moment and yawning-moment coefficients with and without leading- and trailing-edge flaps deflected and the tares applied to the data. $\delta_a = 0^\circ$. 
(a) Variation of $C_n$ and $C_l$ with $\alpha$.

Figure 5.- Variation of $C_n$, $C_l$, $C_{h_{\alpha}}$, $P_R$, and $C_{N_{\alpha}}$ with $\alpha$; 0.40$b/2$ outboard aileron. Plain wing.
(b) Variation of $C_{ha}$ with $\alpha$.

Figure 5.- Continued.
(c) Variation of $P_R$ and $C_{N_B}$ with $\alpha$.

Figure 5.- Concluded.
Figure 6. Variation of $C_n$, $C_l$, $C_{h_{a}}$, $P_R$, and $C_{N_a}$ with $\alpha$; 0.79b/2 aileron. Plain wing.
(b) Variation of $C_{ha}$ with $\alpha$.

Figure 6.- Continued.
Figure 6.- Concluded.

(c) Variation of $P_R$ and $C_{Na}$ with $\alpha$. 
(a) Variation of $C_n$ and $C_\ell$ with $\alpha$.

Figure 7. - Variation of $C_n$, $C_\ell$, $C_{h_e}$, $P_R$, and $C_{N_e}$ with angle of attack; 0.79b/2 leading-edge flaps, 0.39b/2 trailing-edge flaps, 0.40b/2 outboard aileron. $\delta_f = 50^\circ$; $\delta_n = 30^\circ$. 
(b) Variation of $C_{h_0}$ with $\alpha$.

Figure 7.- Continued.
(c) Variation of $P_R$ and $C_{N_a}$ with $\alpha$.

Figure 7.- Concluded.
Figure 8.- The effects of aileron span and leading- and trailing-edge flaps on the aileron hinge moment and effectiveness parameters $C_{I_{h_{a}}}$, $C_{h_{a}}$, $C_{h_{u}}$, $P_{R_{a}}$, $P_{R_{u}}$. 
Figure 9.—Comparison of aileron effectiveness $C_{l\delta}$ of the subject aspect ratio 4.0 wing with that of a wing of aspect ratio 2.5 having the same area, taper ratio, and airfoil section.
Figure 10.- Comparison of $C_{h\alpha}$ of the subject aspect ratio 4.0 wing with that of a wing of aspect ratio 2.5 having the same area, taper ratio, and airfoil section.
Figure 11. Comparison of $C_{h\theta}$ of the subject aspect ratio 4.0 wing with that of a wing of aspect ratio 2.5 having the same area, taper ratio, and airfoil section.