NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE EFFECTS OF A HIGHLY CAMBERED LOW-DRAG WING AND OF
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CHARACTERISTICS OF A TWIN-ENGINE PURSUIT AIRPLANE MODEL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Material Command, U. S. Army Air Forces

THE EFFECTS OF A HIGHLY CAMBERED LOW-DRAG WING AND OF AUXILIARY FLAPS ON THE HIGH-SPEED AERODYNAMIC CHARACTERISTICS OF A TWIN-ENGINE PURSUIT AIRPLANE MODEL

By Victor M. Ganzer

SUMMARY

This report presents the results of tests of a model of a twin-engine pursuit airplane. Two wings were investigated, an NACA 230-series wing and a highly cambered NACA 66-series wing. Auxiliary control flaps were tested in combination with each of the wings.

Data showing the comparison of the high-speed aerodynamic characteristics of the model when equipped with each of the wings, the effect of the auxiliary control flaps on the aerodynamic characteristics, and the elevator effectiveness for the model with the 66-series wing are presented.

INTRODUCTION

A model of a twin-engine pursuit airplane was tested previously in the high-speed wind tunnel at the Ames Aeronautical Laboratory to determine, among other things, the relative merits of an NACA 230-series wing and an NACA 66-series wing cambered for an optimum lift coefficient of 0.1 at the root (reference 1). Results of that investigation led to the belief that a more highly cambered 66-series wing might extend the usable Mach number range for the airplane even more than did the low-cambered wing.
Tests of a similar airplane model at high-speed indicated that auxiliary control flaps were effective in producing forces and moments tending to pull the airplane out of high-speed dives (reference 2). It was desired to determine if such auxiliary control flaps would be effective on the model reported herein and, if so, the optimum location of the flaps.

The specific purposes of the present investigation were as follows:

1. To compare the high-speed aerodynamic characteristics of the model having an NACA 230-series wing with those of a model having a highly cambered NACA 66-series wing

2. To determine the effectiveness, in producing pull-out forces and moments, of auxiliary control flaps in combination with the 230-series wing

3. To determine the effectiveness, in producing pull-out forces and moments, of auxiliary control flaps in combination with the highly cambered 66-series wing

4. To determine the variation of elevator effectiveness with Mach number for the model equipped with the highly cambered 66-series wing

The investigation was conducted in the Ames 16-foot high-speed wind tunnel at the request of the Air Material Command, U. S. Army Air Forces.

APPARATUS

A description of the model with the NACA 230-series wing and the large booms may be found in reference 1. The large booms were used in all of the present tests. A three-view drawing of the model is shown in figure 1 and a photograph of the wind-tunnel setup in figure 2. Some of the pertinent dimensions are given in the following table:
<table>
<thead>
<tr>
<th></th>
<th>230-series wing</th>
<th>Highly cambered 68-series wing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing area, sq ft</td>
<td>16.67</td>
<td>16.67</td>
</tr>
<tr>
<td>Mean aerodynamic chord, ft</td>
<td>1.525</td>
<td>1.525</td>
</tr>
<tr>
<td>Horizontal tail area, sq ft</td>
<td>3.623</td>
<td>3.623</td>
</tr>
<tr>
<td>Elevator area, sq ft</td>
<td>0.903</td>
<td>0.903</td>
</tr>
<tr>
<td>Tail length, 25 percent M.A.C. to elevator hinge line, ft</td>
<td>4.979</td>
<td>4.979</td>
</tr>
<tr>
<td>Wing section (constant chord part of wing)</td>
<td>NACA 23016</td>
<td>NACA 66.2-416 (a = 0.5)</td>
</tr>
<tr>
<td>Wing section, tip (2.17 in. inboard from wing tip)</td>
<td>NACA 4412</td>
<td>NACA 66.2-616 (a = 0.5)</td>
</tr>
<tr>
<td>Incidence, constant chord part of wing, degrees</td>
<td>2°</td>
<td>0°</td>
</tr>
<tr>
<td>Incidence, tip section</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>Stabilizer incidence</td>
<td>2° 0° and 2° (noted in figures)</td>
<td></td>
</tr>
</tbody>
</table>

Each of the auxiliary control flaps had a span of 12 inches and a constant chord of 1.32 inches (10 percent of the M.A.C.). The outboard flaps were mounted just outboard of the booms, as shown in figure 3; the inboard flaps between the booms and the fuselage. The hinge line was located at the various chordwise positions noted in the figures. The flap angle indicated was the angle between the flap and the lower surface of the wing.

**SYMBOLS**

Symbols used in this report are defined as follows:

\[ V \] free-stream velocity, feet per second
\( q \)  
free-stream dynamic pressure \( (\frac{1}{2} \rho V^2) \), pounds 
per square foot

\( M \)  
Mach number \( \left( \frac{V}{\text{velocity of sound}} \right) \)

\( S \)  
wing area, square feet

\( \text{M.A.C.} \)  
mean aerodynamic chord, feet

\( \text{CL} \)  
lift coefficient \( \left( \frac{\text{lift}}{\text{qs}} \right) \)

\( \text{CD} \)  
drag coefficient \( \left( \frac{\text{drag}}{\text{qs}} \right) \)

\( C_{\text{m.o.g.}} \)  
pitching-moment coefficient  
\( \left( \frac{\text{pitching moment about the center of gravity}}{\text{qs M.A.C.}} \right) \)

\( c_n \)  
section normal-force coefficient  
\( \left( \frac{\text{section normal force}}{\text{qs}} \right) \)  
(Positive when acting upward.)

\( c \)  
section chord, feet

\( \alpha \)  
angle of attack measured from the fuselage reference line, degrees

\( \Delta \text{CL} \)  
increment of lift coefficient due to the extension of the auxiliary flaps

\( \Delta \text{CD} \)  
increment of drag coefficient due to the extension of the auxiliary flaps

\( \Delta \text{C_m} \)  
increment of pitching-moment coefficient due to the extension of the auxiliary flaps or to the deflection of the elevator

\( P \)  
pressure coefficient  
\( \left( \frac{\text{local static pressure} - \text{free-stream static pressure}}{q} \right) \)

\( P_{\text{cr}} \)  
value of \( P \) at which the local velocity reaches the local velocity of sound
Corrections to the data for angle-of-attack, elevator deflection, trim and acceleration were made as follows:

\[ \delta_e \text{ correction} = 0.623 \text{ CL} \]

\[ \text{Drag co-efficient correction} = 0.01097 \text{ CL}^2 \]

\[ \text{Pitching-moment co-efficient correction} = 0.0155 \text{ CL} \]

No corrections for flow inclination or constriction were applied.

Presentation of Results

The results of the force and pressure measurements on the complete model with the 230-series wing and with the highly cambered 66-series wing are found in figures 4 to 10.
Data obtained from tests of auxiliary flaps on the 230-series wing are found in figures 11 to 19 and from tests of flaps on the 66-series wing in figures 20 to 27.

Data obtained from tests with the elevator deflected and from tests with the two stabilizer angles are shown in figures 28 and 29.

DISCUSSION

Comparative Characteristics of Model with NACA 230-Series Wing and of Model with Highly Cambered NACA 66-Series Wing

As shown in reference 1, the increase of static longitudinal stability, the shift of the lift coefficient for balance at constant elevator angle, and the reduction of the maximum lift coefficient at speeds above the critical seriously limit the speeds to which the airplane with the 230-series wing could be dived safely. The substitution of a 66-series wing, cambered for a lift coefficient of 0.1 at the root, extended by approximately 50 miles per hour the speed at which pull-outs from dives could be made without these changes of stability and lift coefficient for balance; but the maximum lift coefficient was considerably reduced at the test Reynolds numbers. It was suggested in reference 1 that a more highly cambered 66-series wing should make a greater maximum lift coefficient available than did the low-cambered 66-series wing, and might further increase the speed from which normal pull-outs from dives could be made.

The lift, drag, and pitching-moment characteristics of the model with the 230-series wing and with the highly cambered 66-series wing are shown in figures 4 to 6. As indicated in reference 1, high-speed longitudinal-control difficulties arise mainly from the increase of static longitudinal stability and the decrease of the lift coefficient for balance as the critical Mach number is exceeded. Figure 4(a) shows that the static longitudinal stability, \( \frac{\partial C_L}{\partial C_L} \), of the model with the 230-series wing increased from 0.085 at a Mach number of 0.491 to approximately 0.47 at a Mach number of 0.747, an increase of 450 percent. Through the same Mach number range the lift coefficient for balance with the elevator neutral decreased from 0.7 to 0.17.
The model equipped with the highly cambered 66-series wing experienced an increase of static longitudinal stability of only about 60 percent when the Mach number increased from 0.491 to 0.747 (fig. 5). This lesser change of stability should make the airplane with the highly cambered wing more controllable at high Mach numbers than it would be with the 230-series wing. The substitution of the 66-series wing also reduced the change of balance with Mach number. With this wing the lift coefficient for balance decreased from 0.65 at a Mach number of 0.491 to 0.3 at a Mach number of 0.747.

Figures 7(a) to 7(d) compare, directly, the aerodynamic characteristics of the models equipped with the two wings. It is evident from figure 7(c) that at lift coefficients of 0.5 and 0.7 the highly cambered 66-series wing resulted in less drag at high Mach numbers, while at a lift coefficient of 0.1 (fig. 7(b)) the model equipped with the 230-series wing showed less drag. Figure 7(d) shows that the model equipped with the 66-series wing attained higher Mach numbers before marked changes in the lift coefficient for balance or the static longitudinal stability occurred, especially at lift coefficients of 0.3, 0.5, and 0.7; these changes in lift coefficient and stability are indicated when the pitching-moment coefficient for a constant lift coefficient diverges sharply.

Pressure distributions over the 66-series wing are shown in figure 8; pressure distributions for the 230-series wing may be found in reference 1. Figure 9, which shows the critical Mach numbers of the wings as determined from the pressure distributions, illustrates the fact that the critical speed of the highly cambered 66-series wing was greater than that of the 230-series wing at positive angles of attack. The difference amounted to an increase of critical Mach number of about 0.125 at an angle of attack of 40° or to about 90 miles per hour at 20,000 feet altitude.

Figure 10 shows a comparison of selected characteristics for the 230-series wing, the low-cambered 66-series wing (reference 1), and the highly cambered 66-series wing. The Mach number at which the pitching-moment coefficient begins to decrease, when plotted as in figure 7(d), is considered the limiting usable Mach number; because if this Mach number were exceeded the decrement of the pitching-moment
coefficient (coupled with the increase of static longitu-
ducinal stability) would make pull-outs from dives difficult. The model, when equipped with the highly cambered 66-series wing, had a higher limit of usable Mach numbers at lift coefficients above 0.1 than did when equipped with the 230-series wing, and a higher limit for lift coefficients above 0.6 than did the model when equipped with the low-cambered 66-series wing. The maximum lift coefficient at a Mach number of 0.6 with the highly cambered 66-series wing was especially noteworthy, being about 1.34 as compared to 1.1 for the 230-series wing and 0.89 for the low-cambered 66-series wing (fig. 10). These maximum lift coefficients correspond to the following normal accelerations at various altitudes:

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>Highly cambered 66-series wing</th>
<th>230-series wing</th>
<th>Low-cambered 66-series wing</th>
</tr>
</thead>
<tbody>
<tr>
<td>40,000</td>
<td>2.24</td>
<td>1.83</td>
<td>1.48</td>
</tr>
<tr>
<td>30,000</td>
<td>3.57</td>
<td>2.93</td>
<td>2.37</td>
</tr>
<tr>
<td>20,000</td>
<td>5.24</td>
<td>4.55</td>
<td>3.68</td>
</tr>
<tr>
<td>10,000</td>
<td>8.27</td>
<td>6.79</td>
<td>5.50</td>
</tr>
</tbody>
</table>

This additional maximum lift coefficient is especially valuable for a high-altitude fighting airplane which may be required to develop large accelerations at high speed.

Auxiliary Control Flaps in Combination With the 230-Series Wing

Wind-tunnel tests of other models (reference 2) indicate that auxiliary control flaps of the type used in this test usually cause forces and moments to be developed which produce positive normal accelerations. The results of reference 1 and of the present tests indicate that the airplane will develop moment and stability changes at high Mach numbers which will oppose recovery from high-speed dives. The use of auxiliary control flaps should provide additional control for recovery from such dives.

Experience indicates that the use of flaps on the wing near the center of the span may result in tail buffeting and
shaking. Because of this consideration, most of the flaps tested in this investigation were installed outboard of the booms where the wing wake would have less effect on the tail.

Figures 11 to 16 show the additional pitching-moment coefficient and drag coefficient which resulted from the flaps at various locations. Using the criteria that the requirement for auxiliary control flaps is the development of positive (climbing) moments when the flaps are deflected, an analysis of the figures indicates that the 20-percent-chord location is the best location for the outboard flaps, and that a 45° flap opening gave almost as much additional pitching moment as did the 60° opening. Lift, drag, and pitching-moment characteristics of the model with the outboard 45° auxiliary flaps at 20 percent of the wing chord are presented in figure 17, and wing and flap pressure distributions are presented in figure 18. The figures show that at low lift coefficients positive pitching-moment-coefficient increments of as much as 0.1 may be expected from the use of these flaps. Assuming that the deflection of the flaps would have no effect on the floating angle of the elevator and using the data presented in figures 4(a) and 17, if the airplane were trimmed in a steady glide at a Mach number of 0.747 at 20,000 feet altitude (approximately 0.14), the extension of the flaps would produce a normal acceleration of about 1.9g with no force on the stick.

Section normal-force coefficients with the flaps retracted and with the flaps open are plotted in figure 19. These coefficients were obtained from the pressure distributions. The actual magnitude of the coefficients may be subject to some error, as the complete pressure distributions were faired from data obtained at only six points on each surface of the wing. However, the data show that the total section normal-force coefficients increased markedly when the flaps were deflected, especially at the higher Mach numbers and, as one would expect, the flaps affected the pressures on both the upper and lower surfaces of the wing. The data from force tests also show an increase of the effectiveness of the flaps at the high Mach numbers (fig. 11).
Auxiliary Control Flaps in Combination With the Highly Cambered 66-Series Wing

Tests of auxiliary control flaps outboard of the booms on the highly cambered 66-series wing showed that negative (diving) moments resulted from the flaps at high Mach numbers, rather than the desired climbing moments (fig. 20). Figures 19 and 22 to 24 show that the effect of the outboard flaps on the section normal-force coefficient, on the total lift coefficient, and on the moment of the wing was quite similar for the 230-series wing and for the highly cambered 66-series wing; hence it is surprising that the effectiveness of the flaps in producing positive pitching moments was not similar. It is possible that the difference in flap effectiveness was due to a difference in their effect on the downwash at the tail resulting from a difference in lift distribution.

The auxiliary control flaps mounted inboard of the booms on the 66-series wing gave the desired climbing moments. Data obtained from tests of inboard flaps at several flap angles are shown in figures 25 and 26, and the lift, drag, and pitching moment characteristics of the model with the inboard flaps at 30 percent chord at 30° are shown in figure 27. The climbing moment with the inboard flaps was undoubtedly due to the increased downwash at the tail caused by the increase of lift coefficient on that part of the wing just ahead of the tail.

Elevator Effectiveness

The effect of elevator deflection on the pitching-moment coefficient was determined for the model equipped with the highly cambered 66-series wing. The results of the tests with the elevator deflected are found in figure 28. The effectiveness of the elevator decreased as the Mach number increased above 0.7. The elevator effectiveness as determined with the 230-series wing on the model did not decrease appreciably as the Mach number exceeded 0.7, as is shown in reference 1. No reason for the loss of elevator effectiveness with the 66-series wing on the model is readily apparent, especially since the stabilizer effectiveness dCm/dit did not change appreciably as the Mach number increased (fig. 29).
CONCLUDING REMARKS:

1. The high-speed aerodynamic characteristics of the model were improved by the substitution of a highly cambered NACA 66-series wing for an NACA 230-series wing, especially with regard to the maximum lift coefficient at Mach numbers of about 0.6 (1.34 for the 66-series wing as compared to 1.1 for the 230-series wing), and the lift coefficient available for pull-outs from high-speed dives (0.56 for the 66-series wing as compared to 0.18 for the 230-series wing at a Mach number of 0.7).

2. The use of auxiliary control flaps on the 230-series wing, either outboard or inboard and outboard of the booms, resulted in forces and pitching moments which would tend to pull the airplane out of high-speed dives. The test results indicated that the extension of the outboard flaps at 20 percent of the wing chord to an angle of 45° would produce a normal acceleration of about 1.9g from a steady glide at a Mach number of 0.75.

3. Auxiliary control flaps inboard of the booms on the highly cambered 66-series wing were effective in producing forces and moments tending to pull the airplane out of high-speed dives, but flaps mounted outboard of the booms were not effective.

4. The elevator effectiveness when the model was equipped with the highly cambered 66-series wing decreased as the Mach number increased above 0.7.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.
REFERENCES


FIGURE 1.- THREE VIEW DRAWING OF THE $\frac{1}{6}$-SCALE MODEL OF A TWIN-ENGINE PURSUIT AIRPLANE.
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- Flaps retracted
- Flaps extended

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Flap angle
- 15°
- 30°
- 45°
FIGURE 27A
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