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NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
AERODYNAMICS LABORATORY
WASHINGTON 7, D.C.

WIND-TUNNEL INVESTIGATION OF THE USE OF WING-TIP BLOWING
TO REDUCE DRAG FOR TAKE-OFF AND LANDING

by

Herbert E. White

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January 1963
SYMBOLS

b  span in feet
\bar{c}  mean chord in feet
C_\mu  blowing momentum coefficient \( C_\mu = \frac{wV_j}{gqS} \)
g  acceleration due to gravity in feet per second-squared
q  dynamic pressure \((pV^2/2)\) in pounds per square foot
R  Reynolds number \((pV\bar{c}/\mu)\)
S  area in square feet
V  airspeed in feet per second
V_j  jet exit velocity in feet per second, assuming isentropic expansion to atmospheric conditions
w  quantity of air in pounds per second
x  chordwise distance from \(\bar{c}/4\) to center of pressure
y  spanwise distance from wing root to center of lift
\mu  absolute coefficient of viscosity of air in pound-seconds per square foot
\rho  mass density of air in slugs per cubic foot

Angular Settings

\alpha  angle of attack in degrees (angle between wing chord line and relative wind vector)
\delta  flap deflection in degrees, measured in a plane perpendicular to the hinge line
\theta_j  angle of inclination of the jet sheet from the chordal plane, in degrees (measured about a chordwise line in the spanwise-blowing case and a spanwise line in the chordwise-blowing case; positive downward)
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SUMMARY

A wind-tunnel investigation was undertaken to determine the potential value of wing-tip blowing as a means of reducing drag of low-aspect-ratio wings during take-off. Both spanwise and chordwise blowing, parallel to, and inclined to the chordal plane, were investigated. The results indicate that the improvement in lift and drag characteristics for take-off by blowing is small at best, and does not justify the expenditure of power that is required. It is possible that the increase in lift from blowing, available with some configurations, might be useful for landing, where power considerations would not be prohibitive.

INTRODUCTION

One of the possible methods of reducing the magnitude of induced drag of a low-aspect-ratio surface is the application of a jet of air at the tip. There are, of course, a great number of possible configurations that the tip jet could take. The present test was undertaken to investigate the potential value of the principle, to determine which are the more promising of several configurations, and to compare this method of drag reduction with others.

The tests were authorized by the Bureau of Naval Weapons (Reference 1) and were conducted in September 1960.
MODEL AND EQUIPMENT

The model was a half-span wing panel constructed of mahogany over a steel frame. The general arrangement of the model is shown in Figure 1. A plenum chamber was provided at the tip. This was supplied with compressed air at pressures up to 100 psig, brought through the wind-tunnel strut and through tubes in the model. Two basic nozzles were constructed to attach to the plenum chamber. The first of these (the spanwise-blowing nozzle) consisted of a narrow slot which was arranged parallel to the chord of the wing and expelled air in a spanwise direction. The second nozzle (the chordwise-blowing nozzle) consisted of a spanwise extension of the basic wing, with a long, thin opening on the trailing edge parallel to the span. This nozzle expelled air aft and parallel to the chord. Sketches of the nozzles are shown in Figure 2.

To deflect the jets from the chordal plane, blocks were fitted which utilized the Coanda principle. The blocks were cut to geometric angles of 45° and 90°. The actual angles of jet deflection obtained were determined by analysis of the reaction force components.

The model was mounted in the wind tunnel with the chordal plane vertical. The reflection plane was provided by a "false floor" above, and faired into, the tunnel floor. A seal of carpet material was installed between the root rib of the model and the reflection plane. This seal was adjusted by shims to rest lightly against the reflection plane. Details of the model are shown in Figures 2 through 6.

TESTS

The tests were conducted in the Aerodynamics Laboratory Wind Tunnel 2, which is a subsonic atmospheric tunnel having an 8- by 10-foot test section.

Lift, drag, and pitching moment variation with angle of attack were measured for various combinations of jet distribution, jet direction, momentum coefficient, and flap deflection. At some jet directions, a full range of momentum coefficients could not be obtained because of the breakdown of Coanda effect at higher values. Increasing the turning radius of the deflection blocks for the chordwise-blowing nozzle
partially alleviated this problem. In order to cover the desired range of C\textsubscript{L} 's, it was necessary to use several different dynamic pressures: 4, 6, 9, 18, and 50 pounds per square foot, which correspond to Reynolds numbers of \(0.959 \times 10^5\), \(1.175 \times 10^6\), \(1.439 \times 10^6\), \(2.035 \times 10^6\), and \(3.392 \times 10^6\), respectively.

RESULTS

The reduction of the data to coefficient form was based on the following full-span model constants:
\[
S = 16.666 \text{ square feet} \\
b = 6.666 \text{ feet} \\
\bar{c} = 2.593 \text{ feet}
\]

The data were corrected for tunnel wall effects by the following equations:
\[
\Delta \alpha = 0.94 \, C_L \\
\Delta C_D = 0.0136 \, C_L^2
\]

The direct effects of the jet thrust on the load components have been subtracted out, so that the data presented show only the effects of aerodynamic changes on the wing brought about by the presence of the jet.

The results are shown in Figures 7 through 11. In addition to the lift, drag, and pitching moment, two other aerodynamic characteristics are represented. These are the chordwise location of the center of pressure and the spanwise center of lift. While the chordwise center of pressure is a generally understood term, the spanwise center of lift may require some definition. For this report, the spanwise center of lift has been defined as \(M_r/F_L\), where \(M_r\) is the moment at the root of the wing about an axis parallel to the wind and \(F_L\) is the wing lift.

The Reynolds number effect on the coefficients is shown in Figure 11.

DISCUSSION

Spanwise blowing parallel to the wing chordal plane results in an increase in \(C_L\) at each \(\alpha\), up to \(C_L\) values of about 0.5 (Figure 9a).
Higher values of \( C \) result in practically no change in \( C_L \), and a slight increase in \( C_D \). Evidently, then, a \( C \) of 0.5 is approximately the practical limit for increasing \( C_L \) by blowing with this configuration. Deflecting the spanwise-blowing jet downward (Figure 9) decreases the increment of \( C_L \) obtained by blowing. This decrease is progressive through the range of deflection angles investigated. The lift-curve slope is increased by blowing. However, for a given \( C_L \), the largest percentage increase in \( C_L \) is obtained at the lower \( C_L \)'s.

In the spanwise-blowing configuration, with \( \theta J = 0^\circ \), the \( C_L \) increases approximately linearly with \( C \) up to a \( C \) of about 0.5. At this \( C \), the \( C_L \) is increased about forty percent above the no-blowing value. Increasing \( C \) from 0.5 to 1.0, the maximum value tested, yields no further increase in \( C_L \).

Chordwise blowing at \( \theta J = 0^\circ \) has practically no effect on the wing drag (Figure 10a). Nor is the wing lift affected to any significant extent. For \( \theta J \) values other than 0, the wing drag increases without a compensating increase of lift.

Since pitching moment considerations are of secondary interest in this drag-reduction study, they will not be discussed except to state that in the chordwise-blowing configuration with \( \theta J = 37^\circ \), \( C_L \) has much more effect on pitching moment than it has in any of the other configurations.

The chordwise center of pressure and spanwise center of lift data presented give an indication of the distribution of lift on the wing. However, this indication is very rough and probably can at best only give a hint as to the direction of changes in the lift distribution.

A striking feature of spanwise blowing, although it is not important from the present point of view, is the discontinuity in the lift curve near \( \alpha = 0^\circ \), when \( \theta J = 0^\circ \). This discontinuity disappears at the other values of \( \theta J \) investigated. The tuft-mattress studies (Figures 7 and 8) show the change in circulation clearly.

CONCLUDING REMARKS

Since chordwise blowing seems to be at best ineffective, only spanwise blowing will be discussed further. Spanwise blowing at \( \theta J = 0^\circ \)
appears to be the most effective of the configurations investigated in improving the characteristics of the wing, but the energy of the jet is totally lost so far as the direct production of thrust (either along the horizontal or the vertical axis) is concerned. Deflecting the spanwise jet downward, while it reduces the beneficial effects on the wing aerodynamic characteristics, does make it possible to recover at least some of the jet thrust as lift. But this downward-deflected jet configuration also has this disadvantage: when the wing is at a positive angle of attack, the jet thrust produces a component of force in the drag direction.

Actually, the relative merits of the various tip-blowing configurations as drag-reduction devices are of small significance. A consideration of the power requirements for even the best of the configurations indicates that this power could better be used for the direct production of thrust at the tail pipe or the propeller.

Up to this point, the discussion has been confined to the merit of tip blowing for the purpose of drag reduction during take-off. We have seen that the improvement in wing aerodynamics does not justify the power expenditure from the standpoint of take-off improvement. However, the higher maximum $C_L$'s obtainable with blowing indicate the blowing might be desirable for the reduction of landing speed, in which case the expenditure of energy might not be a problem. It should be borne in mind, however, that the mechanical problems associated with the tip blowing may be so complex as to render it impractical.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
December 1962

REFERENCE
1. BUWPSINST 3920.1 R-12 of 2 Sep 1960
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September 20, 1960
Figure 7 - Tuft-Mattress Study of the Effect of Spanwise Blowing on Tip-Vortex Position

PSD-309,256

September 20, 1960
\[ \alpha = -5^\circ \]
\[ C_\mu \approx 0.13 \]
\[ \theta_J = 73^\circ \]

\[ \alpha = 5^\circ \]
\[ C_\mu \approx 0.13 \]
\[ \theta_J = 73^\circ \]

\[ \alpha = 10^\circ \]
\[ C_\mu \approx 0.13 \]
\[ \theta_J = 73^\circ \]

\[ \alpha = 20^\circ \]
\[ C_\mu \approx 0.13 \]
\[ \theta_J = 73^\circ \]

Figure 7 (Concluded)
Figure 8 - Tuft-Mattress Study of the Effect of Lateralwise Blowing on Tip-Vortex Position

α = -5°
C_μ ≈ 0.13
θ_j = 0

α = 10°
C_μ ≈ 0.08
θ_j = 0

α = 15°
C_μ ≈ 0.08
θ_j = 0

α = 20°
C_μ ≈ 0.08
θ_j = 0
\[ \alpha = -5^\circ \]
\[ C_\mu \approx 0.06 \]
\[ \theta_J = 37^\circ \]

\[ \alpha = 10^\circ \]
\[ C_\mu \approx 0.06 \]
\[ \theta_J = 37^\circ \]

\[ \alpha = 15^\circ \]
\[ C_\mu \approx 0.06 \]
\[ \theta_J = 37^\circ \]

\[ \alpha = 20^\circ \]
\[ C_\mu \approx 0.06 \]
\[ \theta_J = 37^\circ \]

\[ \alpha = -5^\circ \]
\[ C_\mu \approx 0.07 \]
\[ \theta_J = 64^\circ \]

\[ \alpha = 10^\circ \]
\[ C_\mu \approx 0.07 \]
\[ \theta_J = 64^\circ \]

\[ \alpha = 15^\circ \]
\[ C_\mu \approx 0.07 \]
\[ \theta_J = 64^\circ \]

\[ \alpha = 20^\circ \]
\[ C_\mu \approx 0.07 \]
\[ \theta_J = 64^\circ \]

Figure 8 (Concluded)

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September 20, 1960
Figure 9 - Effect of Spanwise Blowing on the Aerodynamic Characteristics of the Wing

(a) $\theta_s = 0^\circ$, $\delta_s = 0^\circ$
Figure 9 (Continued)

0 \leq \phi_y \leq 38.6^\circ, \beta = 0^\circ
Figure 10 - Effect of Chordwise Blowing on the Aerodynamic Characteristics of the Wing

(a) $\alpha_1 = 0^\circ$, $\delta_x = 0^\circ$
Figure 10 (Concluded)

\[ \theta_1 \theta_2 = 5.3^\circ; \theta_4 = 32^\circ \]
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