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EFFECT OF REYNOLDS NUMBER AND ENGINE NACELLES ON THE STALLING CHARACTERISTICS OF A MODEL OF A TWIN-ENGINE LIGHT AIRPLANE

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16. Abstract

The investigation was made on a 1/18-scale model of a twin-engine light airplane. Static longitudinal, lateral, and directional characteristics were obtained at 0° and $\pm 5^{\circ}$ sideslip at a Mach number of about 0.2. The angle of attack varied from about 20° at a Reynolds number of 0.39×10^{6} to 13° at a Reynolds number of 3.7×10^{6}, based on the reference chord. The effect of fixed transition, vertical and horizontal tails, and nacelle fillets was studied.

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SUMMARY

An investigation has been made in the Langley low-turbulence pressure tunnel to determine the effect of Reynolds number on the stall characteristics of a 1/18-scale model of a twin-engine light airplane. The investigation was made at a Mach number of about 0.2 over a Reynolds number range from about 0.39×10^6 to 3.7×10^6, based on the reference chord. Static longitudinal, lateral, and directional characteristics were obtained with and without twin nacelles.

The investigation showed that maximum lift coefficients increased with Reynolds number with the nacelles on or off. The presence of the nacelles on the model caused a reduction in lift at all Reynolds numbers. The maximum lift coefficients of the model without nacelles agreed favorably with results obtained on a version of the full-scale single-engine airplane, but the lift coefficients for the model with nacelles on were less than those obtained on the twin-engine airplane. The configurations with and without nacelles were longitudinally stable, the tail providing large pitch-down moments above maximum lift. The model with the nacelles off had positive dihedral effect (negative values of C_{l_β}) throughout the angle-of-attack and Reynolds number range of the investigation; and the model with the nacelles on had a positive dihedral effect at low Reynolds numbers, but at Reynolds numbers of approximately 3×10^6 and at angles of attack greater than 8°, the model had a negative dihedral effect. These results are in qualitative agreement with those obtained in previous tests of the full-scale airplanes. The model possessed directional stability with nacelles on and off.

INTRODUCTION

For several years, the National Aeronautics and Space Administration has been conducting a program to evaluate the flying qualities of a number of general aviation airplanes. The results of these investigations are reported in references 1 to 6. Tests at the NASA Flight Research Center and in the Langley full-scale tunnel have indicated some unfavorable aerodynamic characteristics in the stall angle-of-attack range for the configuration reported in reference 2. For example, the data of reference 2 show a strong rolling tendency in the angle-of-attack range near maximum lift which is thought to result from the asymmetric flow generated by propellers rotating in the same direction. During the time period after these adverse effects were discovered, it was desired to document many of the aerodynamic parameters including the dynamic derivatives at stall and for this purpose a 1/6-scale model of the airplane was constructed and statically tested in the Langley full-scale tunnel. The results of these tests show major differences in the maximum lift and effective dihedral between the model and the airplane. The data of the 1/6-scale model were obtained at a Reynolds number of 0.7×10^6 based on the mean aerodynamic chord whereas the airplane data were obtained at a Reynolds number of 2.96×10^6. An examination of available airfoil section lift data (refs. 7 and 8) indicates a rapid increase in the maximum section lift coefficients with Reynolds number, which probably explains the difference in maximum lift coefficient between the model and airplane; however, the Reynolds number effect on maximum lift coefficient cannot be used to explain the differences noted in dihedral effect. To resolve both of these questions, a small model was constructed for tests in the Langley low-turbulence pressure tunnel covering the range of Reynolds numbers of the previous two investigations. The results of these tests are presented herein.

SYMBOLS

The data contained herein are referred to the stability axis system as shown in figure 1. The model moment center is located longitudinally at 0.10 of the mean aerodynamic chord and vertically 0.20 of the mean aerodynamic chord below the horizontal reference line. The symbols are defined as follows:

b wing span, 0.6096 m

C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

$C_{l_\beta} = \frac{\Delta C_l}{\Delta \beta}$, determined from $\beta = \pm 5^\circ$ (effective dihedral parameter)

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

$C_{n_\beta} = \frac{\Delta C_n}{\Delta \beta}$, determined from $\beta = \pm 5^{\circ}$

C_Y side-force coefficient, $\frac{\text{Side force}}{qS}$

$C_{Y_\beta} = \frac{\Delta C_Y}{\Delta \beta}$, determined from $\beta = \pm 5^{\circ}$

$\bar{c}$ mean aerodynamic chord, 0.0847 m

c_l section lift coefficient, $\frac{\text{Lift}}{qS}$

i_t horizontal-tail incidence, positive when trailing edge is down, deg

q free-stream dynamic pressure

R Reynolds number based on $\bar{c}$

S wing area, 0.05104 m^2

V_∞ free-stream velocity

α angle of attack of fuselage reference line, deg

β angle of sideslip, positive when nose is to the left, deg

Subscript:

max maximum

Model nomenclature:

B body

F nacelle fillet

H horizontal tail

N nacelle

V vertical tail

W wing

MODEL

The model tested was a 1/18-scale version of the light twin-engine low-wing airplane described in references 2 and 3. A three-view drawing of the model is presented in figure 2 and photographs of the model mounted in the Langley low-turbulence pressure tunnel are presented in figure 3. The model had a wing span of 0.6096 m, a mean aerodynamic chord of 0.0847 m, a wing area of 0.05104 m^2, and an aspect ratio of 7.28 based on the projection of the outboard leading edge through the fuselage. The wing had a NACA 64_2A215 airfoil section, a 2° incidence with respect to the fuselage reference line, and a dihedral angle of 5°. The wing leading edge between the fuselage and the engine nacelle was swept back 20°. With the engine nacelle removed, the sweptback leading edge extended to approximately 29 percent of the semispan. The outboard panel of the wing was unswept.

The model was supported by a sting which resulted in increasing the width and depth of the fuselage as shown in figure 3. This modification also reduced the exposed tail area as the overall dimensions were maintained.

Incidence change in the horizontal tail was obtained by replacing the complete tail with one having a built-in incidence. Filler blocks were also provided for use when the vertical and horizontal tail were removed.

TESTS

The investigation was made in the Langley low-turbulence pressure tunnel at a Mach number of approximately 0.2. The tests were made at several Reynolds numbers from 0.39×10^6 to 3.7×10^6 based on the mean aerodynamic chord. The model was tested at sideslip angles of 0° and $\pm 5^{\circ}$ up to angles of attack of 20° at low Reynolds number decreasing to 12° at highest Reynolds number because of loads. Transition strips approximately 0.2 cm wide of No. 240 grit were attached to the fuselage, nacelles, and surfaces as shown in figure 3. The grit was located 0.5 cm behind the leading-edge surfaces, about 2.5 cm behind the nose of the fuselage and on nacelles about 4.3 cm behind the nose. (It will be noted that fig. 3 shows grit applied around the leading edge but only a narrow strip on the upper and lower surface was actually used in the investigation.)

MEASUREMENTS AND CORRECTIONS

The aerodynamic forces and moments were measured by means of a six-component, electrical strain-gage balance housed within the model. Corrections were applied to the measured angles of attack and sideslip for the deflections of the sting and balance under load. Jet boundary and blockage corrections calculated by the methods of references 9 and 10, respectively, have been applied to the data. The axial force was adjusted to a condition of free-stream static pressure at the base of the model.

PRESENTATION OF DATA

Data obtained in the present investigation as well as data obtained in previous investigations are presented in the following figures:

	Figure
Summary of previous investigations	4 and 5
Longitudinal characteristics:	
Effect of Reynolds number	6
Effect of engine nacelles	7
Effect of Reynolds number on maximum lift	8
Effect of horizontal tail	9
Lateral characteristics:	
Effect of Reynolds number	10
Effect of engine nacelles and transition	11
Effect of nacelle fillet and tail	12

DISCUSSION

Summary of Previous Results

Recent wind-tunnel investigations of a twin-engine light airplane and a 1/6-scale model have disclosed considerable differences in the aerodynamic characteristics at angles of attack near stall. Most significant of these differences are the maximum lift coefficient $C_{L,max}$ and a reversal of the effective dihedral parameter C_{l_β} as illustrated in figure 4. These data show the maximum lift coefficients of the model are well below the values determined for the airplane and the effective dihedral parameter of the model remained negative, whereas that of the airplane became positive at high angles of attack. The differences in lift characteristics might well be assumed to be associated with the differences in the Reynolds number of the investigations because two-dimensional data obtained from references 7 and 8 show large increases in maximum section lift coefficient $c_{l,max}$ in the range of Reynolds number under consideration as indicated in figure 5. Whether this increase in Reynolds number is also responsible for the reversal of effective dihedral is of great concern. The present investigation was initiated to determine whether the differences observed in effective dihedral were due to Reynolds number, geometric differences between the configurations, or a combination of both.

Present Investigation

Longitudinal characteristics.- The effects of varying the Reynolds number on the aerodynamic characteristics at zero sideslip are shown in figure 6(a) for the complete model and in figure 6(b) with the engine nacelles removed. The test results show, as would be expected from the section characteristics, an increase in $C_{L,max}$ with Reynolds number. Significant increases in lift were noted between Reynolds numbers of 0.39×10^6 and 1.91×10^6 with nacelles on and off. The maximum lift data with the nacelles off correlate well with the data obtained from the single-engine airplane investigation of reference 3 but the data with the nacelles on are considerably below the values obtained in tunnel tests of the twin-engine airplane (ref. 2) as shown in figures 6(a) and 8. The effect of engine nacelles is better illustrated in figure 7; at all Reynolds numbers the presence of the nacelle caused a reduction in the maximum lift coefficient compared with the plain wing. It is apparent from the breaks in the lift and the axial-force curves that the addition of nacelles causes a separation to occur at a lower angle of attack (approximately 4° lower). A brief tuft study of the model showed that early separation occurred on the wing near the trailing edge between the fuselage and the nacelles where there is a region of stream-tube expansion.

The effect of the horizontal tail on the aerodynamic characteristics in pitch is shown in figure 9 for the wing configuration with nacelles on. Longitudinal stability existed for tail-on configurations and the tail produced large nose-down pitching moments at the higher angles of attack.

Lateral-directional characteristics.- The effects of Reynolds number, model configuration, and fixed boundary-layer transition strips on the characteristics in sideslip are shown in figures 10, 11, and 12. These results show the effective dihedral parameter C_{l_β} with the nacelles on is sensitive to Reynolds number at high angles of attack. The data of figure 10(a) show the model with nacelles off having favorable dihedral effect (negative values of C_{l_β}) throughout the angle of attack and Reynolds number range as would be expected from the results of single-engine airplane tests of reference 4. In contrast, the model with nacelles on although giving negative values of C_{l_β} at lower