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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION AT SUBSONIC AND TRANSONIC
SPEEDS OF THE AERODYNAMIC CHARACTERISTICS
OF A BIPLANE COMPOSED OF A SWEEPBACK
AND A SWEEPFORWARD WING
JOINED AT THE TIPS

By Jones F. Cahill and Dexter H. Stead

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

March 12, 1954

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SUMMARY

A preliminary investigation at subsonic and transonic speeds has been made of the aerodynamic characteristics of a wing-body configuration designated as a swept biplane which is composed of a sweptback and a sweptforward wing joined at the tips. Results show that a configuration of this plan form prevents the abrupt pitch-up normally encountered on monoplane swept wings. Drag data obtained at lift coefficients of 0 and 0.15 on a biplane configuration having airfoil sections 4 percent thick show that the drag coefficients at transonic speeds are approximately equal to those of a monoplane wing having the same sweep angle, aspect ratio, and taper ratio with airfoil sections 6 percent thick. Measurements of stresses in a similar biplane model have shown, however, that the stresses in the 4-percent-thick biplane are considerably higher than those in the 6-percent-thick monoplane and that the biplane requires sections approximately 8 to 10 percent thick in order to provide equal stresses.

INTRODUCTION

The use of a biplane composed of a sweptback and a sweptforward wing joined at the tips has been suggested as a possible means for avoiding some of the difficulties encountered with swept wings. The most appealing aspect of this wing arrangement is the possibility that the flow field behind the forward (sweptback) wing might influence the loading on the rear wing in such a way as to prevent pitch-up. As a partial justification for this conjecture, it can be seen that, if the

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forward wing is attached to the top of the fuselage and the rear wing to the bottom, the location of the rear wing root is similar to the low horizontal-tail locations which have been found effective in reducing pitch-up tendencies on swept-wing monoplanes. The possibility exists, however, that the use of such a configuration having two wing-fuselage junctures and requiring an attachment between the two wings might result in drag coefficients appreciably higher than those of a monoplane swept-wing configuration.

In order to obtain a preliminary indication of the characteristics of this type of wing arrangement which is designated as a swept biplane, an investigation has been conducted at subsonic and transonic speeds in the Langley low-turbulence pressure tunnel and in the 26-inch Langley transonic blowdown tunnel on two swept biplane models having an aspect ratio of 4, a taper ratio of 0.6, and with the leading edge of the forward wing swept back 45° and the trailing edge of the rearward wing swept forward 45° . The aspect ratio is defined on the basis of the combined area of both wings.

SYMBOLS

The results of this investigation are presented in the form of standard nondimensional coefficients. A list of symbols used in the present paper is presented as follows:

α	angle of attack, deg
β	angle of sideslip, deg
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$; moments measured about axes at 0.181 \bar{c} for monoplane and at 0.360 \bar{c} for biplane
$C_{l\beta}$	effective dihedral parameter at $\beta = 0^\circ$, $dC_l/d\beta$

q	dynamic pressure, lb/sq in.
S	total area of both wings, sq in.
\bar{c}	mean aerodynamic chord, in.; two wings are considered as a unit
b	wing span
X	distance between apexes of front and rear wing of biplane at center line
A	aspect ratio, b^2/S
λ	taper ratio
M	Mach number
R	Reynolds number, based on mean aerodynamic chord of a single wing

MODELS AND TESTS

Two models were used in this investigation, each having an aspect ratio of 4, a taper ratio of 0.6, and with the leading edge of the forward wing swept back 45° and the trailing edge of the rearward wing swept forward 45° . The aspect ratio is defined on the basis of the combined area of the two wings.

A rather crude model (model A) was constructed for exploratory tests at subsonic speeds in the Langley low-turbulence pressure tunnel. Freon-12 was used as a testing medium in order to attain high subsonic Mach numbers in these tests. Photographs of model A are shown in figure 1 and a drawing showing the details is presented in figure 2. The wings were made from 1/8-inch-thick steel plate with the leading edges arbitrarily rounded and the trailing edges beveled to a sharp edge. The 1/8-inch thickness provided a thickness ratio of 4.0 percent at the root and 6.6 percent at the tip. The two wings were attached to the top and bottom of a body of revolution as shown in figure 2. The tips of the wings were welded together and resulted in the formation of a sharp V at the juncture. Fairings were added to cover the sharp discontinuities at the wing-fuselage junctures, but no attempt was made to design efficient fillets. Lift, drag, and pitching moments were measured for this model through a range of lift coefficients up to approximately 0.9 at Mach numbers of 0.2, 0.76, and 0.90 and rolling moments

were measured through a range of sideslip angle from -7° to 6° for several angles of attack at a Mach number of 0.8.

Photographs and a drawing of model B, constructed for tests at transonic speeds in the 26-inch Langley transonic blowdown tunnel, are shown in figures 3 and 4, respectively. The fuselage of this model was constructed with a nearly rectangular cross section in order to provide approximately perpendicular junctures at the wing-fuselage intersections without fillets. The body sides only were modified in accordance with the transonic area rule (ref. 1) in order to provide a constant value of the total cross-sectional area of wing and fuselage from the rear of the body nose section to the base of the body. The two wings for each side of the model were constructed in a single piece and bent around a $3/16$ -inch diameter at the tips, thus providing a separation between the wings of approximately five times the wing thickness. The wings had NACA 65A004 airfoil sections and had no twist or incidence with respect to the body center line. Tests were made of model B in the 26-inch Langley transonic blowdown tunnel to determine the drag at lift coefficients of 0 and 0.15 through a range of Mach number from 0.7 to 1.27. The Reynolds numbers corresponding to these Mach numbers varied from approximately 1.0×10^6 to 1.2×10^6 .

Data from the Langley low-turbulence pressure tunnel have been corrected for tunnel blockage and boundary-induced upwash effects. These data were then converted from Freon-12 to air conditions by the method presented in reference 2. For all data presented, the chord forces have been adjusted to the condition of free-stream static pressure on the base. No jet boundary corrections have been applied to the data obtained in the 26-inch Langley transonic blowdown tunnel inasmuch as the investigation of reference 3 has shown that, for models of the size tested, the boundary effects are very small except for reflected shocks. Reflections of the body bow wave were observed to strike the model forward of the body base at Mach numbers between about 1.04 and 1.19. Drag measurements were made at only one Mach number within this range ($M = 1.15$). It is believed that the drag coefficients presented at this Mach number are not greatly affected by the reflected shock because the model has no boattail and because the chord force has been adjusted to the condition of free-stream static pressure on the base.

RESULTS AND DISCUSSION

Subsonic Tests

Lift, drag, and pitching-moment data obtained from subsonic tests of model A in the Langley low-turbulence pressure tunnel are presented in figure 5 for Mach numbers of 0.2, 0.76, and 0.9. Pitching-moment

data are shown in figure 5(a) for a monoplane swept wing having the same sweep angle, aspect ratio, and taper ratio as the biplane model (data taken from ref. 4 and unpublished low-speed data). A comparison of these data shows that no pitch-up was obtained for the biplane model at any of the Mach numbers tested, whereas unstable pitching moments were measured for the monoplane model at lift coefficients above about 0.6. Although the pitching moments of the biplane model are not linear in any of the cases shown, the nonlinearities observed are considered to be of minor importance in comparison with the violent pitch-up obtained for the monoplane swept wing. These data are presented for moment axes located at 0.1813 for the monoplane swept wing and at 36.0 percent of the total wing length (distance between the front and rear apexes at the body center line) for the biplane wing. These moment axes provide a minimum value of the static margin of -0.05 at low lift coefficients for each model. It should be noted that the stability of the biplane at low lift coefficients shows a decrease as the Mach number is increased in contrast to the conventional increase shown by the monoplane wing. The minimum value of the static margin used, therefore, occurs at a Mach number of 0.9 for the biplane and at 0.2 for the monoplane.

The explanation of the lack of pitch-up on the biplane configuration can probably be found in an examination of the model geometry and the effects of the flow field behind the forward wing on the loading of the rear wing. Severe tip separation would be expected on the forward wing and an examination of tufts on model A confirmed this expectation. This loss in load at the tip cannot result in large pitch-up tendencies, however, since the tip is near the moment center of the configuration. The rear wing is, in general, in the downwash field of the front wing so that its angle of attack is generally less than that of the forward wing and, therefore, it would be expected to stall at a higher model angle of attack. The vortices shed from the forward wing also contribute a lateral component to the flow over the rear wing which opposes the spanwise flow in the boundary layer toward the root of the rear wing and, therefore, also tends to delay the premature stall usually encountered at the root of sweptforward wings. The primary factor contributing to the prevention of pitch-up on this configuration, however, is probably a phenomenon similar to that observed for low horizontal tails behind swept-back wings. Since the center of the principal trailing vortex shed from a swept wing follows a path approximately parallel to the flow direction, increases in angle of attack move the center of the vortex and its associated large downwash angles progressively farther from the rearmost portions of the rear wing. This variation of downwash angle with angle of attack permits the rear wing (or a low horizontal tail) to provide a large stabilizing contribution to the pitching moment.

The lift and drag data (figs. 5(b) and (c)) show that the lift-curve slope is considerably lower and the drag coefficients are considerably higher for the biplane configuration than would be expected for a monoplane

swept wing having the same sweep angle and aspect ratio. (See ref. 4.) These differences are attributed principally to the inefficient airfoil section and to the aerodynamically poor junctures at the tips and at the wing-fuselage intersections of the model A biplane. Model B, unlike model A, was designed with smooth junctures and with an efficient airfoil section. Drag data for model B at lift coefficients of 0 and 0.15 are presented in a later section of this paper.

Effective dihedral data ($C_{l\beta}$), obtained from measurements of rolling-moment coefficients for sideslip angles from -7° to 6° at a Mach number of 0.8, are shown in figure 6. These data show a low stable value of $C_{l\beta}$ of approximately -0.00075 except for lift coefficients between 0.6 and 0.8 where $C_{l\beta}$ becomes slightly unstable. For this range of lift coefficient, the value of $C_{l\beta}$ was positive only for sideslip angles from -4° to 4° , beyond which a stable slope was observed. Data from reference 5 for a monoplane swept wing having the same sweep angle and aspect ratio as the biplane wing, on the other hand, show a variation of $C_{l\beta}$ from 0 at zero lift to -0.002 at a lift coefficient of 0.4 and then an increase to a positive value at a lift coefficient of 0.75 followed by a return to stable values. The small variation of $C_{l\beta}$ with lift coefficient for the biplane indicates that the variations caused by the sweptback and the sweptforward wing tend to compensate for each other. It would be expected that any desirable value of $C_{l\beta}$ could be attained by the use of geometric dihedral on the biplane and that this dihedral effect would show only a small variation through the lift-coefficient range.

Transonic Tests

The purpose of tests on model B was to determine the drag characteristics of this type of wing configuration at transonic speeds. The design of model B was based on the assumption that a large structural advantage would result from the attachment of the two wings at the tips and, therefore, permit the use of airfoil sections having thickness ratios less than those required for a monoplane swept wing having the same sweep angle and aspect ratio. An analysis of unpublished data obtained by the Langley Structures Research Division on stress measurements for a biplane model similar to the test model shows, however, that stresses in the 4-percent-thick biplane are considerably higher than those in the 6-percent-thick monoplane used for comparison purposes and that airfoil sections approximately 8 to 10 percent thick would be required to provide equal stresses. The small structural advantage which actually exists for the biplane configuration, therefore, consists of a decrease in the volume of structure required to provide equal stresses in solid wings. The high stresses in the 4-percent-thick wings made it necessary to limit tests of this model to low angles of attack.

Drag coefficients measured at zero lift and at a lift coefficient of 0.15 for the model B biplane are presented in figure 7. These data have been compared with results obtained for a model of a monoplane 45° sweptback wing that is 6 percent thick and has an aspect ratio of 4, a taper ratio of 0.6, and a body indentation which provided a constant value of total cross-sectional area from the rear of the body nose section to the base (ref. 6). These data show that the drag coefficients of the 4-percent-thick biplane wing at transonic speeds are very nearly equal to those of the 6-percent-thick monoplane wing at both lift coefficients. Although these data appear to indicate a higher value of drag due to lift for the biplane model at subsonic speeds, primarily as a result of a lower zero-lift drag coefficient, it is believed that the difference in level of zero-lift drag coefficient between the two configurations is partially a result of probable differences in transition location on the two test models. In any event, the data obtained on model B in the present investigation do not cover a large enough lift-coefficient range to provide an adequate evaluation of drag due to lift, and it would be expected, on the basis of subsonic biplane theory, that the induced drag of the biplane would be slightly less than that of a monoplane swept wing having the same span-loading and flying at the same speed.

As pointed out previously, the comparison shown in figure 7 is not a true comparison of the drags of structurally comparable airplanes having biplane and monoplane wings and some increase in drag would be anticipated as a result of using the thicker sections required to make the stresses in the biplane equal to those in the monoplane. However, data presented in references 7 and 8 show that, by application of the transonic area rule, swept wing-body combinations having wing thickness ratios of the order of magnitude required for the biplane configuration can be designed to give very low pressure drags at transonic and low supersonic speeds. For the particular case shown in reference 8, the minimum drag coefficient was increased by only 0.007 (from 0.012 to 0.019) by an increase in Mach number from 0.8 to 1.10 for a wing-body combination having wing thickness ratios which varied across the span from 12 percent to 3 percent. It is likely, therefore, that proper application of the area rule can partially compensate for increased drag rise of the higher thickness ratios of the biplane configuration. Since the chord of each of the biplane wings is only half that of the monoplane wing used for comparison purposes, application of the area rule results in smaller body indentations than those required for the monoplane. This fact might permit in some cases the use of basic body shapes having smaller frontal areas for the biplane configuration.

Additional Design Considerations

In addition to the prevention of pitch-up obtained with this configuration, indications of several other possible advantages can be found from the geometry of the configuration and from stress measurements. Because of its long forward and rearward length, this wing arrangement seems particularly suited for use on tailless airplanes; pitch damping should be high and controls near the root of the rear wing could provide longitudinal control. The use of high-lift flaps on the forward wing would require positive elevator loads for trimming and, therefore, produce increases in trimmed maximum lift since most of the area of the forward wing is ahead of probable center-of-gravity locations. The effectiveness of ailerons on the rear wing should be maintained up to very high lift coefficients since an examination of tufts on model A at low speeds showed that the tip regions of the rear wing remained completely unseparated up to the highest angles of attack investigated (28°). An examination of deflections occurring in the structural model investigated shows that the biplane configuration having airfoil sections 8 to 10 percent thick should provide aeroelastic distortions smaller than those of the monoplane swept wing having sections 6 percent thick.

CONCLUDING REMARKS

A preliminary investigation at subsonic and transonic speeds has been made of the aerodynamic characteristics of a wing-body configuration designated as a swept biplane which is composed of a sweptback and a sweptforward wing joined at the tips. Results show that a configuration of this plan form prevents the abrupt pitch-up normally encountered on monoplane swept wings. Drag data obtained at lift coefficients of 0 and 0.15 on a biplane configuration having airfoil sections 4 percent thick show that the drag coefficients at transonic speeds are approximately equal to those of a monoplane wing having the same sweep angle, aspect ratio, and taper ratio with airfoil sections 6 percent thick. Measurements of stresses in a similar biplane model, however, show that the stresses in the 4-percent-thick biplane are considerably

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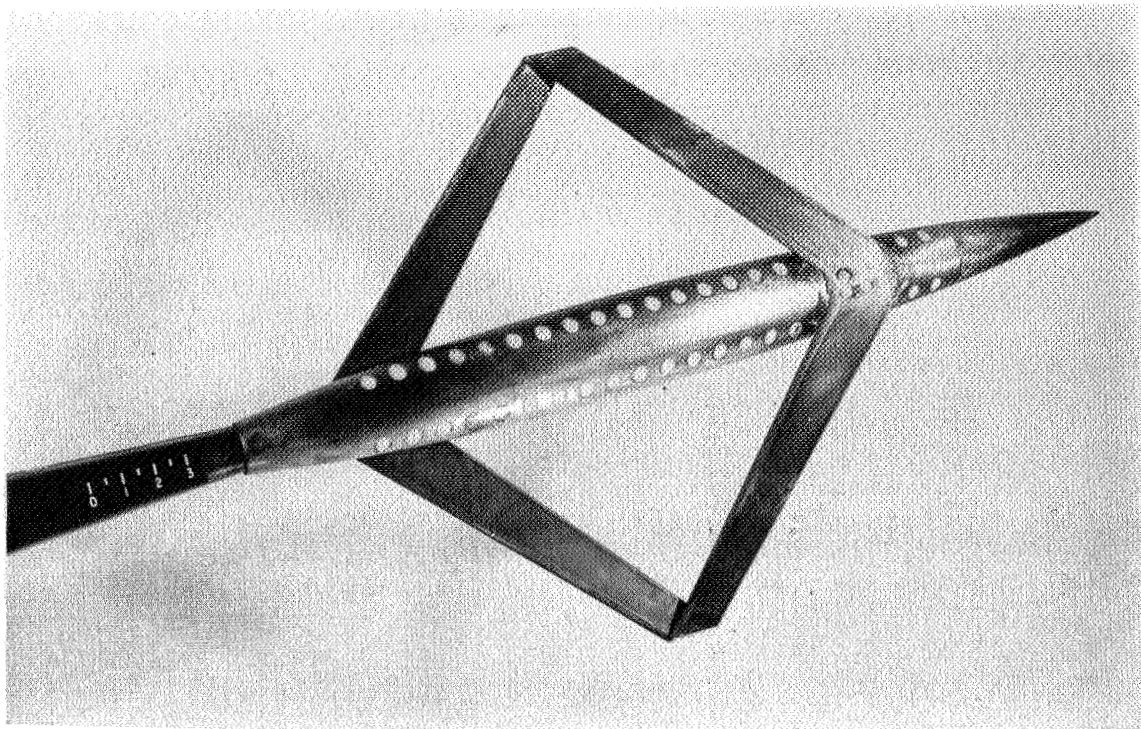
higher than those in the 6-percent-thick monoplane and that the biplane requires sections approximately 8 to 10 percent thick in order to provide equal stresses.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 10, 1953.

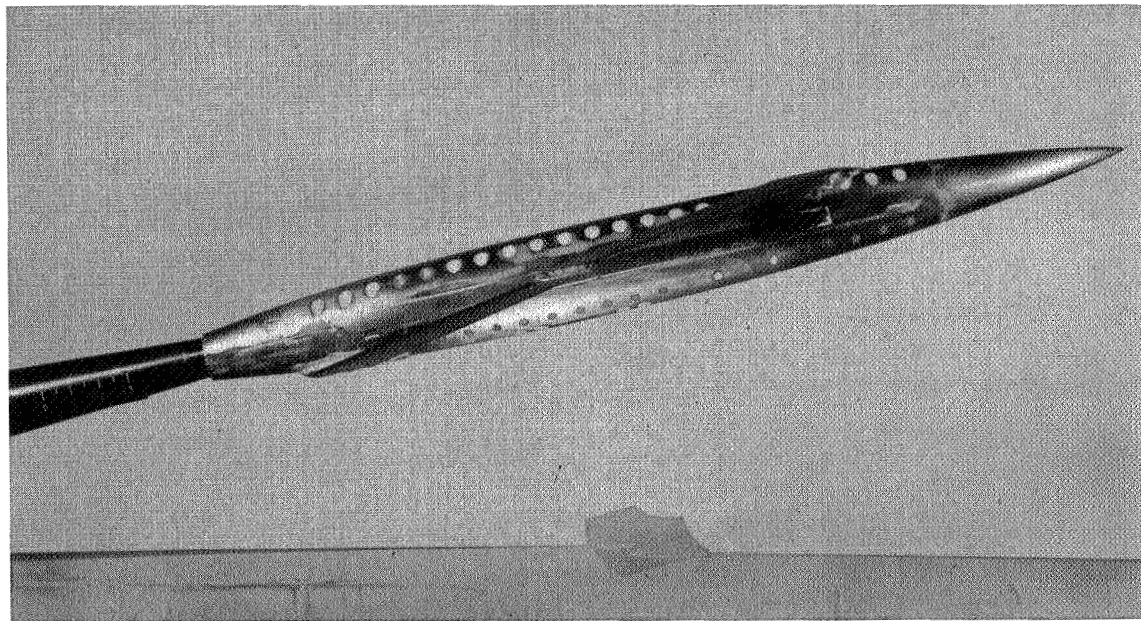
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Figure 1.- Photographs of swept biplane, model A.

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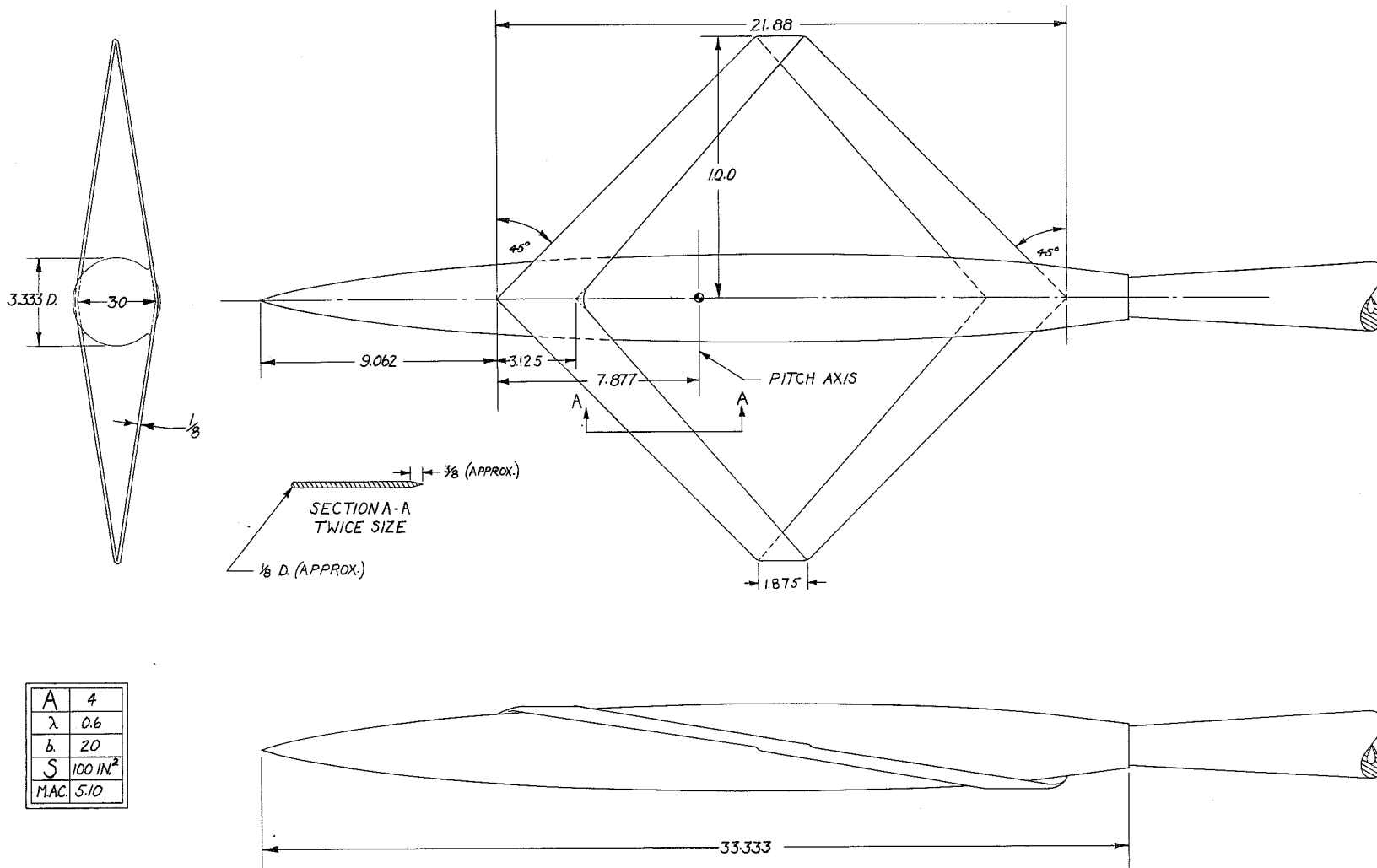
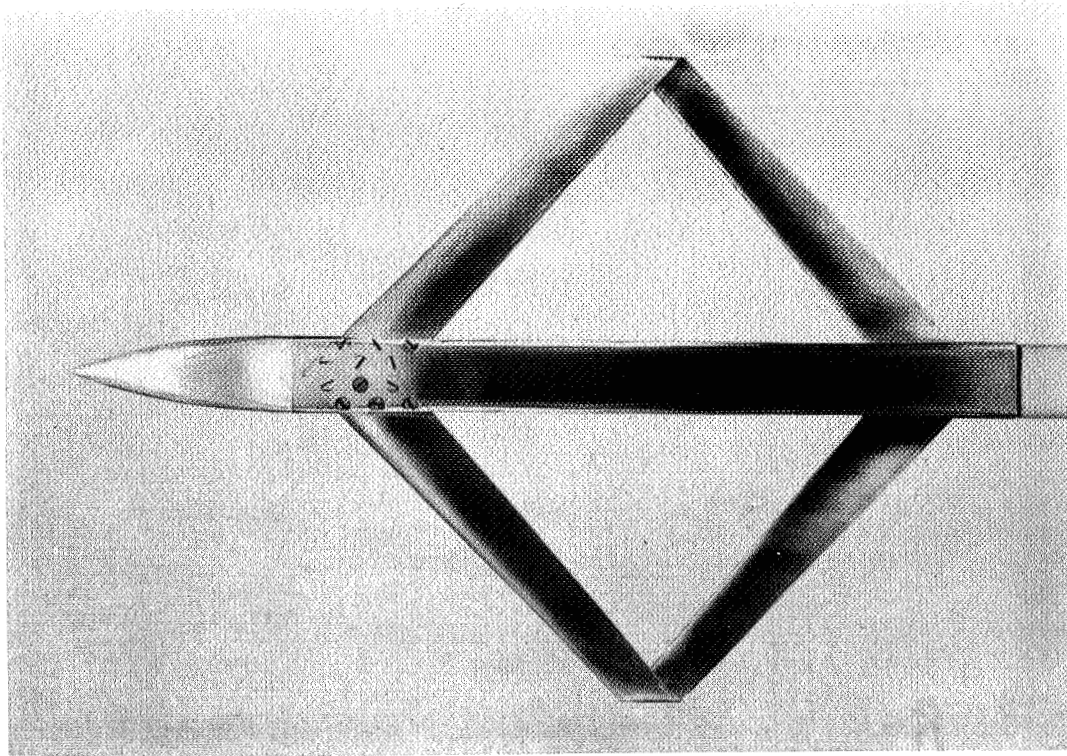


Figure 2.- Drawing of swept biplane, model A. Dimensions are in inches unless otherwise noted.



L-80966

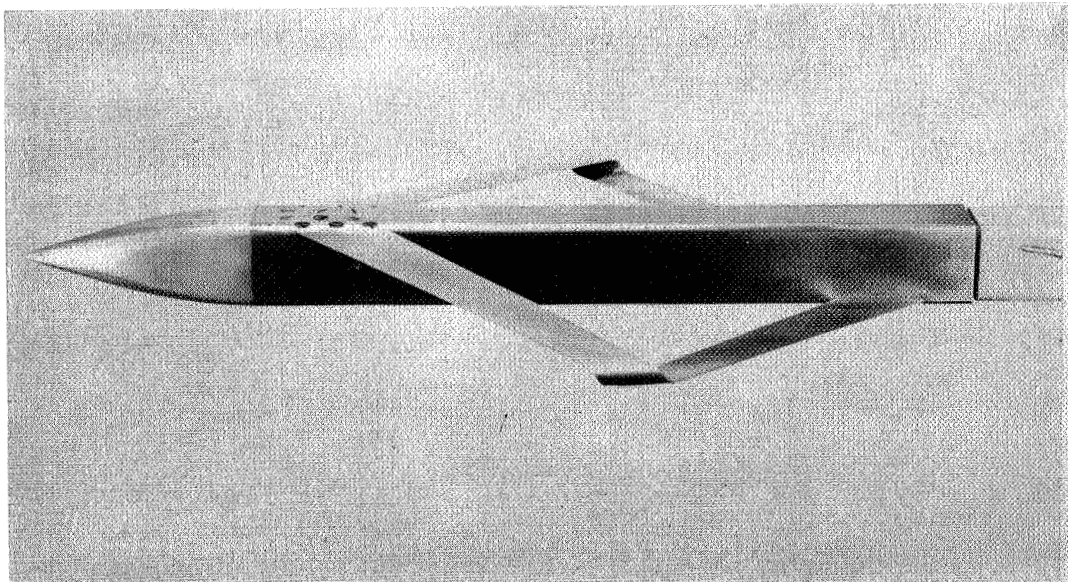
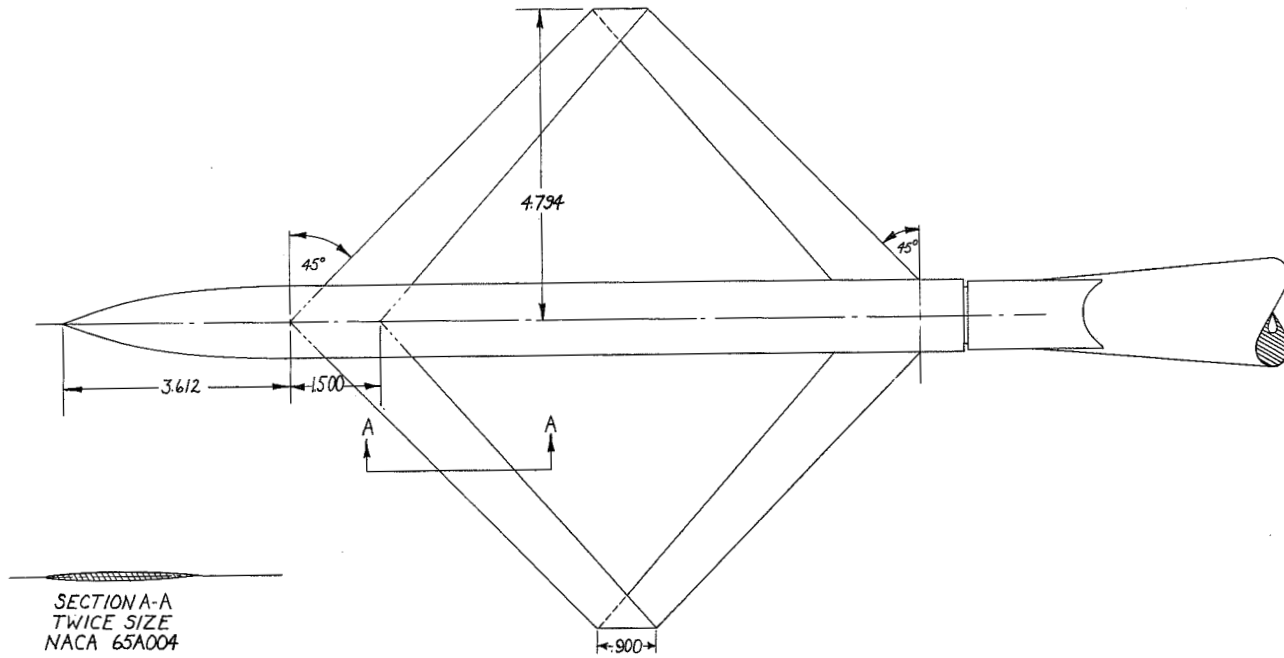
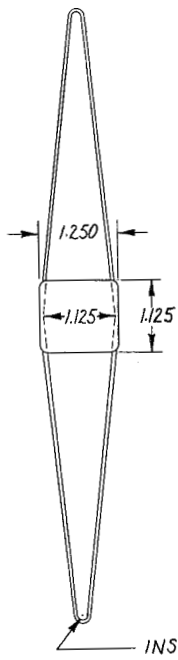


Figure 3.- Photographs of swept biplane, model B. L-80965

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A	4
λ	0.6
b	9.588
S	2296 IN. ²
M.A.C.	2.445

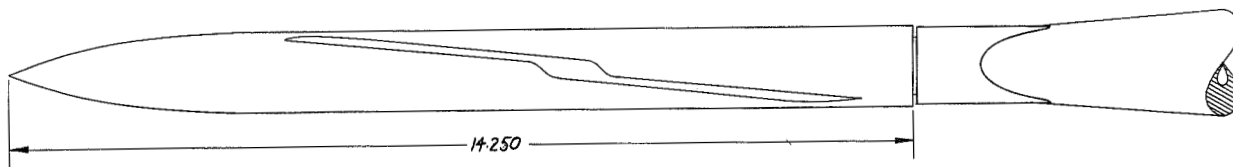
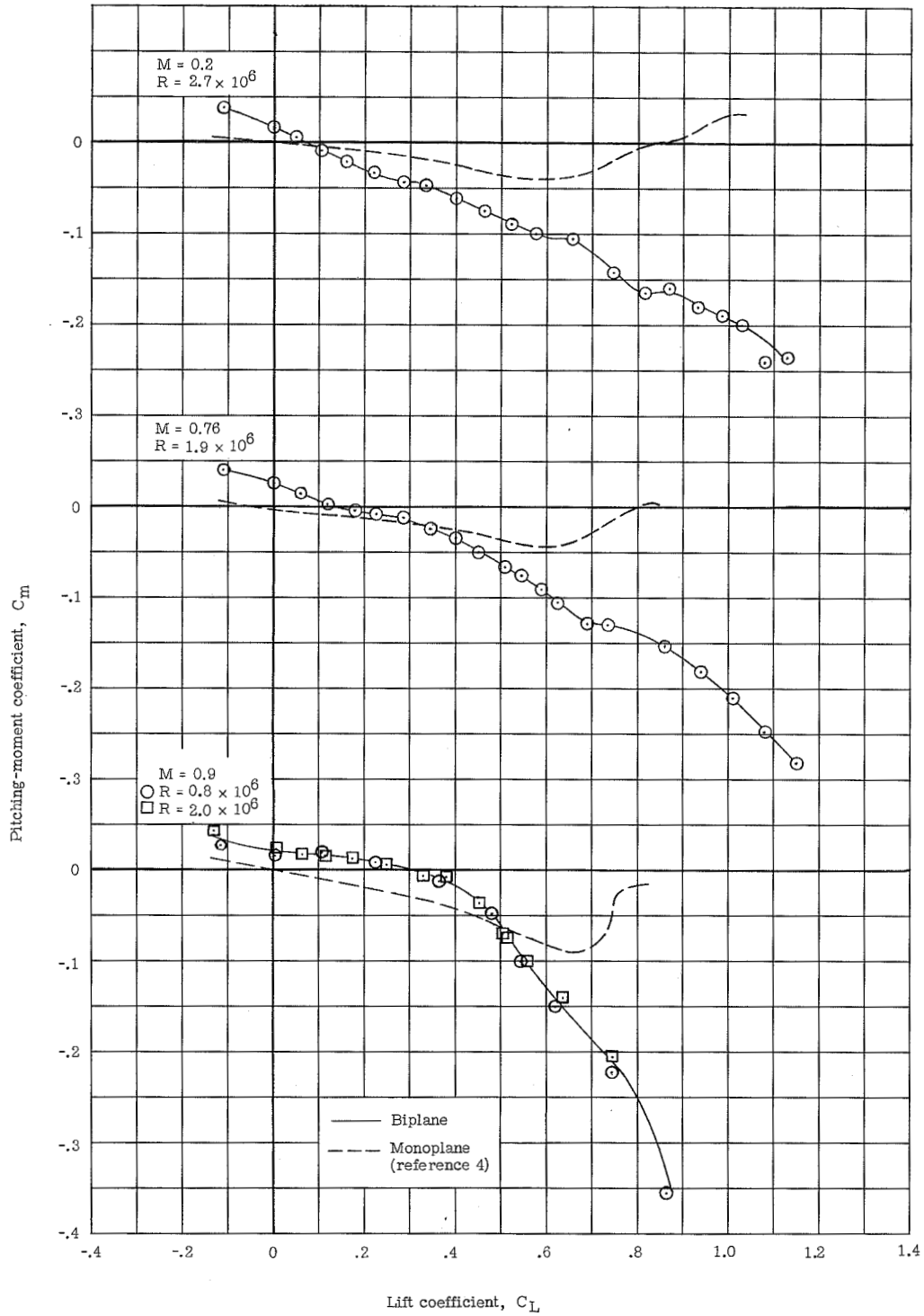
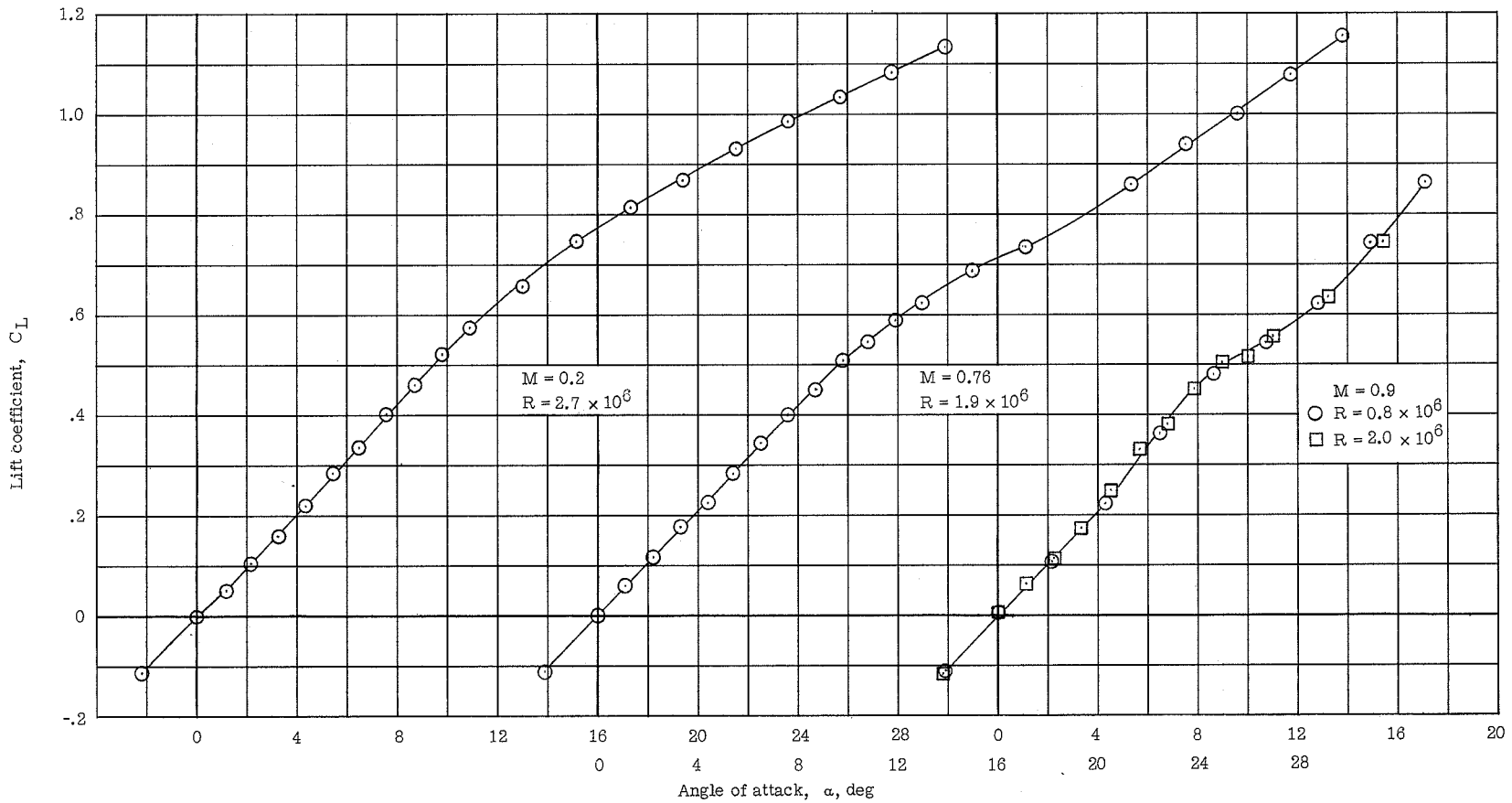


Figure 4.- Drawing of swept biplane, model B. Dimensions are in inches unless otherwise noted.



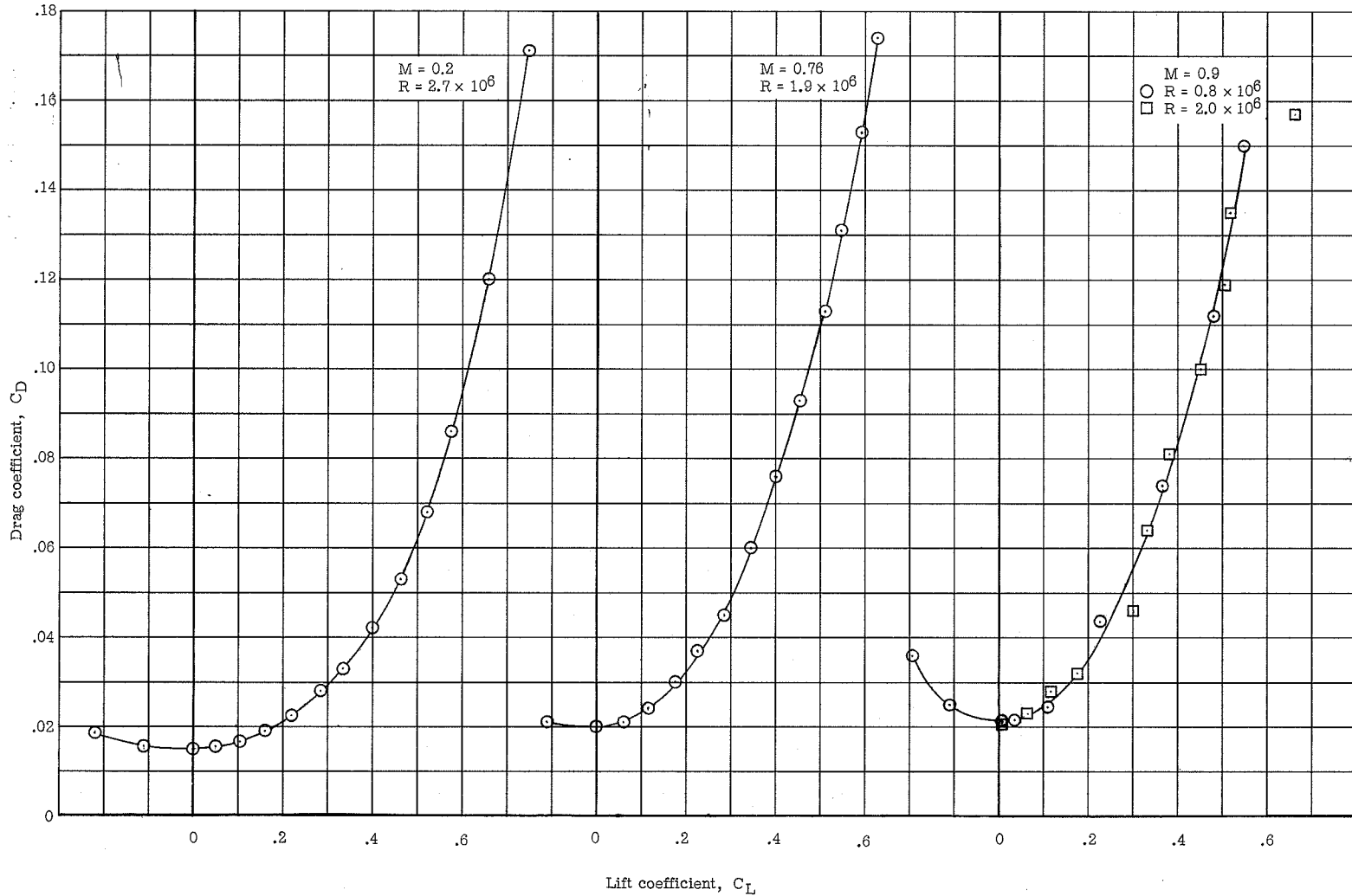
(a) Pitching moment.

Figure 5.- Subsonic aerodynamic characteristics of swept biplane-fuselage combination (model A).



(b) Lift.

Figure 5.- Continued.



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(c) Drag.

Figure 5.- Concluded.

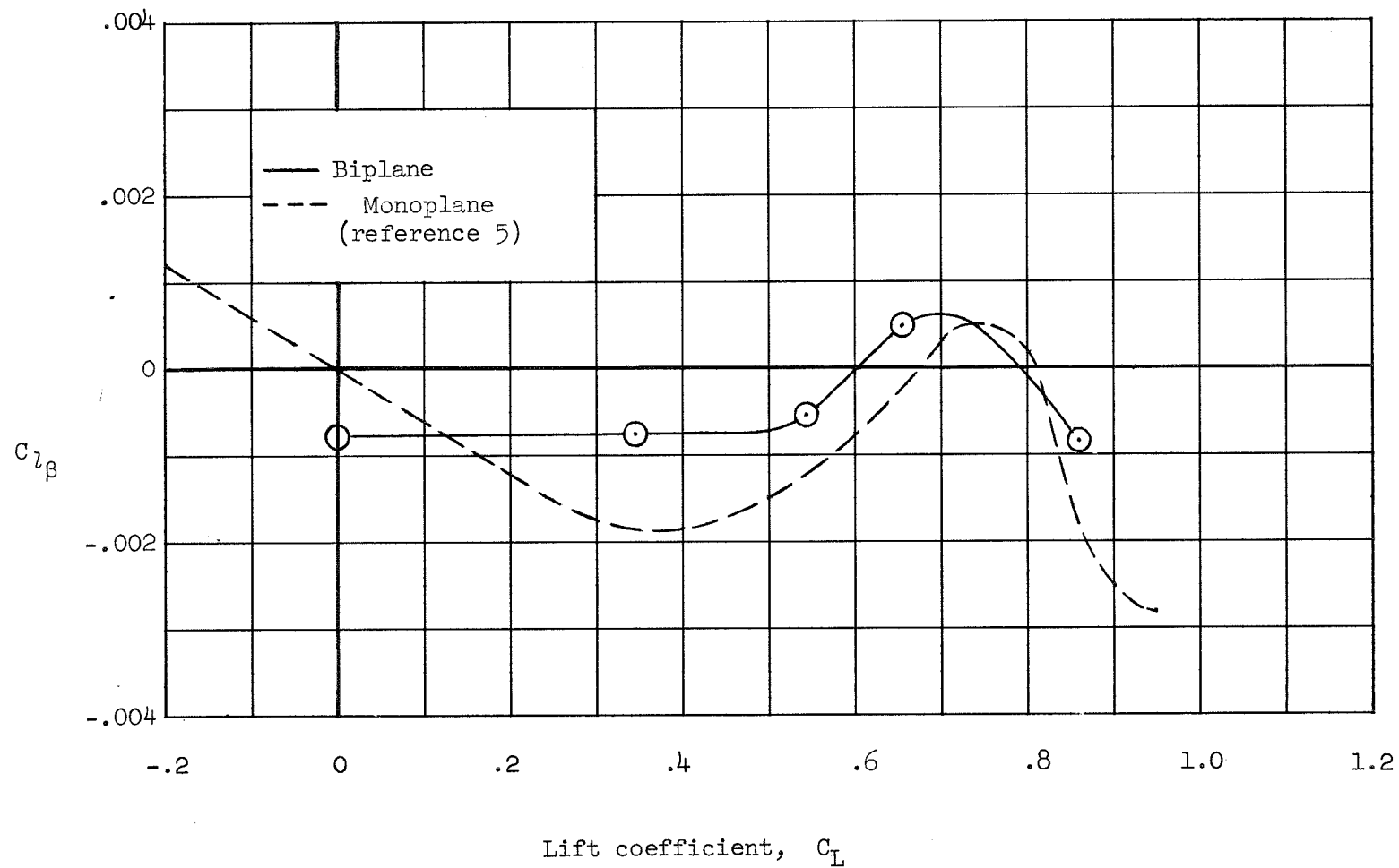


Figure 6.- Variation of effective dihedral parameter $C_{l\beta}$ with lift coefficient for swept biplane-fuselage combination (model A). Mach number, 0.8.

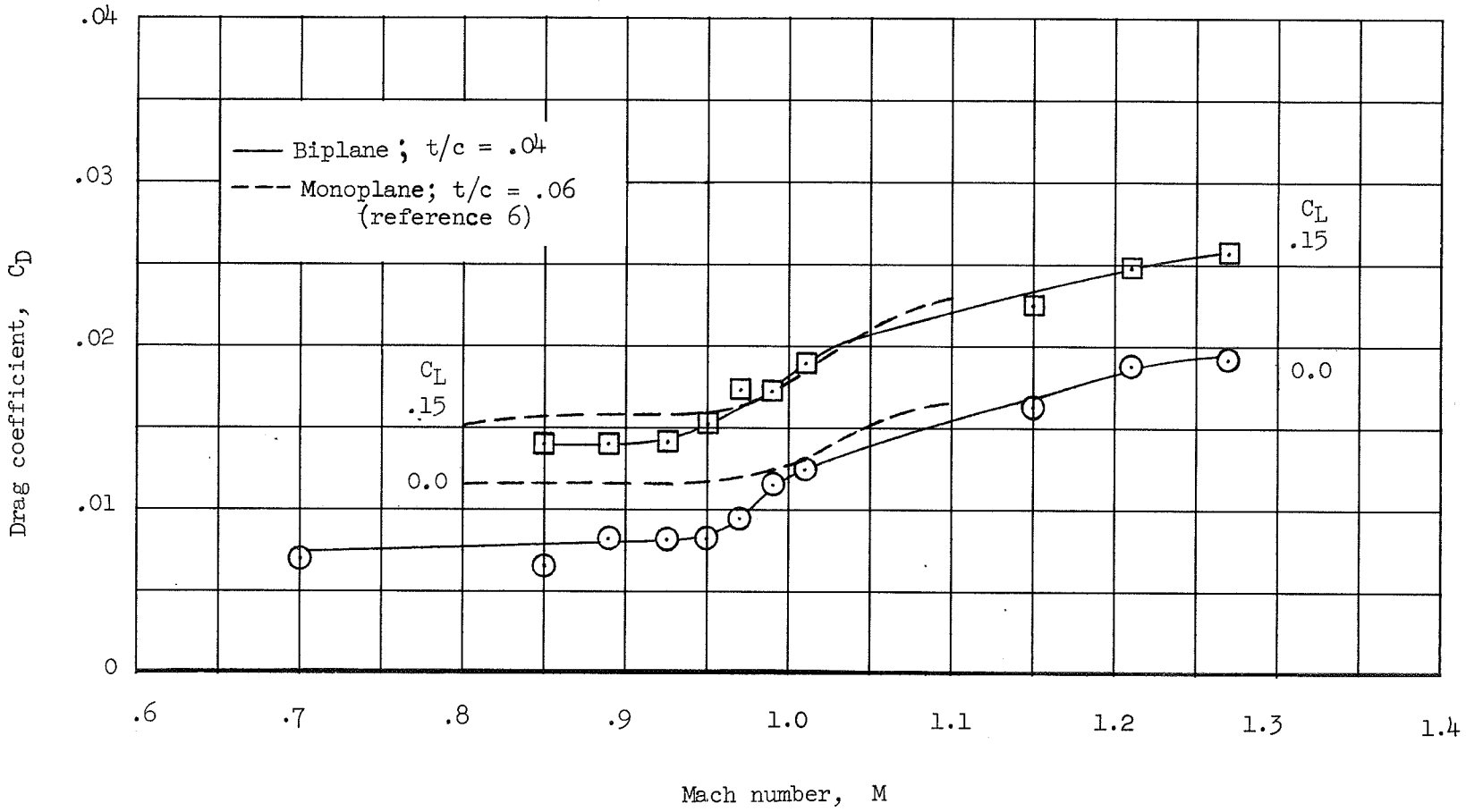


Figure 7.- Variation of drag coefficient with Mach number for swept biplane-fuselage combination (model B).

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