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RESEARCH MEMORANDUM

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DAMPING IN ROLL OF STRAIGHT AND 45° SWEPT WINGS OF VARIOUS TAPER RATIOS DETERMINED AT HIGH SUBSONIC, TRANSONIC, AND SUPERSONIC SPEEDS WITH ROCKET-POWERED MODELS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

DAMPING IN ROLL OF STRAIGHT AND 45° SWEPT WINGS OF VARIOUS TAPER RATIOS DETERMINED AT HIGH SUBSONIC, TRANSONIC, AND SUPERSONIC SPEEDS WITH ROCKET-POWERED MODELS

By E. Claude Sanders, Jr.

SUMMARY

Rocket-powered flight tests have been conducted to determine the damping in roll of several wings of 0° and 45° quarter-chord-line sweep with various taper ratios. The Mach number range of these tests was from 0.8 to 1.45. Damping in roll decreased with decreasing taper ratio at approximately the same rate for swept and unswept wings, and was also decreased by sweeping the quarter-chord line. Experimental data were much lower than predicted by theory for the swept wings. The drag at zero lift was consistently of a lower magnitude for the 45° swept tapered series than for the unswept tapered series.

INTRODUCTION

The damping in roll of wings is of importance in the calculation of lateral stability and rolling performance of airplanes and missiles. The NACA has devised a simplified rocket-model technique, reference 1, utilizing canted nozzles to produce a torque, which allows a determination of damping in roll at high subsonic, transonic, and supersonic speeds at high Reynolds numbers. An investigation, utilizing the canted-nozzles technique, has been conducted to determine the effects of wing taper on the damping-in-roll characteristics of wings with 0° and 45° sweepback of the quarter-chord line. These wings had an aspect ratio of 3.71 with an NACA 65A006 airfoil section parallel to the model center line. The variation of the total drag with Mach number was obtained for each model. The test wings were mounted on identical bodies as described in reference 1.

The damping-in-roll coefficient and the total drag coefficient were obtained for each configuration at zero lift through a Mach number range of approximately 0.8 to 1.45, corresponding to Reynolds numbers from 3×10^6 to 11×10^6. The models were tested in flight at the Langley Pilotless Aircraft Research Station at Wallops Island, Va.

SYMBOLS

C_l	rolling-moment coefficient (L/qSb)
C_{l_p}	damping-in-roll derivative $\left(\dfrac{\Delta C_l}{\Delta \frac{pb}{2V}}\right)$
C_D	total-drag coefficient (D/qS)
D	total drag, pounds
L	rolling moment, foot-pounds
L_o	out-of-trim rolling moment, foot-pounds
T	torque, pound-feet
p	rolling angular velocity, radians per second
$\dot{p}$	rolling angular acceleration, radians per second^2
V	forward velocity, feet per second
q	dynamic pressure, pounds per square foot
M	Mach number
A	aspect ratio (b^2/S')
R	Reynolds number, based on the mean aerodynamic chord of included wing
λ	taper ratio, ratio of tip chord to chord at body center line
t/c	airfoil-section thickness ratio (parallel to center line)
Λ	angle of sweep of quarter-chord line, degrees

b	wing span (diameter of circle generated by wing tips), feet
S	total wing area, thrice the area of semispan wing (wing assumed to extend to model center line), square feet
S'	twice area of semispan wing (wing assumed to extend to model center line), square feet
I_X	moment of inertia about longitudinal axis, slug-feet^2
m_θ	torsional stiffness, inch-pounds per degree

Subscripts:

1	sustainer-on flight
2	coasting flight

MODELS AND APPARATUS

The models used in this investigation were identical to those reported in reference 1, except for wing design. The body consisted of a cylindrical, wooden fuselage with a spinsonde nose section (reference 2) and incorporated a sustaining rocket motor with canted nozzles. The test wings were attached with the 0.25 exposed mean aerodynamic chord located 12 inches from the rear of this basic fuselage in a three-wing arrangement. Wings tested in this investigation had taper ratios of 1.0, 0.5, 0.3, and 0, and aspect ratio of 3.71, NACA 65A006 airfoil section parallel to model center line, and the quarter-chord line swept 0° and 45°. A sketch of the model configuration and types of wing construction are shown in figure 1. Figure 2 shows sketches of the wings tested and a table of pertinent wing geometry. Comparative values of torsional stiffness for each wing are presented in this table. The wing was loaded about midspan and the twist was measured at the wing tip. The technique used is explained in reference 3; however, no correction for torsional stiffness has been applied to the results presented in this paper.

Each model was launched from a rail-type launcher at an elevation angle of approximately 70° to the horizontal and was accelerated to a Mach number of approximately 0.8 by means of a booster rocket motor which separated from the model when its fuel was exhausted. The model was then accelerated by an internal rocket motor with canted nozzles to a Mach number of approximately 1.45. Thus, a Mach number range of about 0.8 to 1.45 was covered corresponding to a Reynolds number range of 3×10^6 to 11×10^6 based on the mean aerodynamic chord of the wing.

The rate of roll and rolling acceleration were obtained by means of a spinsonde (reference 2) contained in the nose of the model. The flight path velocity and longitudinal acceleration were obtained with a CW Doppler radar set. Atmospheric measurements covering the altitude range of flight tests were obtained with radiosondes.

REDUCTION OF DATA

The damping-in-roll derivative was calculated by balancing the moments acting on the model. The torque nozzle and wing misalinement produced rolling moments which were balanced by the inertia moment and the damping moment produced by the wing and body. Moment equilibrium for one degree of freedom may be written

$$I_X\dot{p} - \frac{dL}{dp}p = T + L_o \tag{1}$$

Resolving equation (1) into coefficient form at the same Mach number for the accelerated and the decelerated portions of flight and solving them simultaneously for the damping-in-roll derivative yields

$$-C_{l_p} = \frac{\dfrac{T}{q_1} - \left(\dfrac{I_{X_1}\dot{p}_1}{q_1} - \dfrac{I_{X_2}\dot{p}_2}{q_2}\right)}{\dfrac{Sb^2}{2}\left(\dfrac{p_1}{V_1} - \dfrac{p_2}{V_2}\right)} \tag{2}$$

The complete analysis of this method for determining the damping-in-roll derivative may be found in reference 1.

The accuracy of C_{l_p}, C_D, and their component errors for these tests are estimated to be within the following limits:

Torque T, pound-feet	±2.50
Rolling angular velocity, radian per second	±1.00
Damping-in-roll derivative	±0.03
Total-drag coefficient C_D	±0.002
Mach number M	±0.010

The preceding estimations are based on individual model calculations. The agreement between results obtained for individual models in reference 1 was better than the estimated accuracy indicated for individual models in the high-subsonic and supersonic speed ranges. However, it may be expected that the accuracy of the results presented herein is better than the estimated accuracy throughout the entire speed range investigated since these models were not affected by the wing-dropping phenomenon (reference 4) in the transonic region. A more complete analysis of factors producing the error in C_{l_p} is reported in reference 1.

RESULTS AND DISCUSSION

The variation of damping in roll with Mach number is presented in figure 3. The damping in roll for all the unswept wings (fig. 3(a)) shows about the same general trend. There is a noticeable increase in C_{l_p} for these wings in going from the high subsonic region into the transonic region which is not evident in the swept-wing series (fig. 3(b)). The damping in roll for the swept wings was not appreciably affected by Mach number.

The damping-in-roll values from figure 3 have been replotted against taper ratio in figure 4 in the form of a ratio of damping in roll for any taper and sweep to the value of C_{l_p} at zero taper and sweep. This figure presents the effects of both taper and sweep on damping in roll. The reduction in experimental damping in roll with decreasing taper ratio is approximately the same for the swept wings as for the unswept wings as shown by curves faired through the experimental values. In both cases a reduction in taper ratio below 0.3 results in an appreciable reduction in damping in roll. This reduction is predicted by theory for unswept wings $(M = 1.29$ to $1.47)$ (reference 5) which is also shown in figure 3. Theory also exhibits a noticeable Mach number effect on C_{l_p} which is not evident in the experimental data over the supersonic range tested. However, the trend predicted by theory generally agrees better with experimental data at $M > 1.2$ than at transonic and lower supersonic speeds.

Theory is not available for the untapered 45° swept wing through this Mach number range; and therefore, the trend of theory for the swept wings could not be plotted in figure 3.

Sweeping the quarter-chord line 45° results in a reduction in C_{l_p} of approximately 30 percent in the supersonic range. This is apparent from a comparison of the swept tapered wings with the unswept tapered wings (fig. 4). A similar reduction in C_{l_p} is shown in reference 6 for the same change in sweepback on a wing with $A = 4$, $\lambda = 0.6$ and with NACA 65A006 airfoil section.

A comparison of the relative magnitudes of experimental and theoretical damping in roll is shown in figure 5. The theoretical values of C_{l_p} are higher than experimental values of C_{l_p}. This tendency, which has been noticed in previous investigations of damping-in-roll characteristics of other wing plan forms (references 1 and 7), is believed to be due to the combined effects of body influence, mutual interference effects between wings, section thickness, and wing twisting which was not taken into consideration in the theory for isolated wings (references 5, 8, and 9). The first two effects have been discussed for straight and swept untapered wings in reference 10.

The difference between theoretical and experimental values of C_{l_p} in the supersonic region for the unswept series can be almost entirely eliminated by applying an empirical correction factor (reference 11) developed for rectangular wings which is dependent upon thickness and aspect ratio.

There is a much greater difference, however, between theoretical and experimental damping in roll in the supersonic region in the case of the swept-wing series. The correction factor previously mentioned when applied to swept-wing values reduces the difference between experimental and theoretical values but does not eliminate it. This was also shown to be the case in reference 7 where the difference was attributed to aeroelastic effects for which there has been no correction applied to the present data.

The variations of total drag coefficient at zero lift with Mach number are presented in figure 6 for the models tested in this investigation. The drag coefficients for the 45° swept tapered wings (fig. 6(b)) were consistently lower than those obtained for the unswept tapered wings (fig. 6(a)) as would be expected. The effects of taper on drag did not show a consistent pattern in either the case of the unswept wings or the 45° swept wings. However, for the unswept wings, decreasing the taper ratio generally reduced the drag over the speed range but in the case of the 45° swept wings decreasing the taper ratio increased the drag at a Mach number of 1.0 although it had no effect at speeds beyond $M = 1.2$.

CONCLUSIONS

The following conclusions were drawn from tests of several wings of 0° and 45° swept quarter-chord line, aspect ratio 3.71, NACA 65A006 airfoil sections with various taper ratios:

1. Damping in roll for the unswept and swept tapered wings decreased with a decrease in taper ratio at approximately the same rate.

2. A reduction in taper ratio below 0.3 resulted in an appreciable loss in damping in roll.

3. Damping in roll was approximately 30 percent lower for the series swept 45° than for the unswept series.

4. Theoretical values of damping in roll were higher than experimental values of damping in roll.

5. Increasing the sweepback angle of the quarter-chord line from 0° to 45° decreased the total drag in the transonic and supersonic range.

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REFERENCES

1. Edmondson, James L., and Sanders, E. Claude, Jr.: A Free-Flight Technique for Measuring Damping in Roll by Use of Rocket-Powered Models and Some Initial Results for Rectangular Wings. NACA RM L9I01, 1949.

2. Harris, Orville R.: Determination of the Rate of Roll of Pilotless Aircraft Research Models by Means of Polarized Radio Waves. NACA TN 2023, 1950.

3. Broadbent, E. G., and Woodcock, D. L.: The Measurement of Structural Stiffness of Aircraft. R. & M. No. 2208, British A.R.C., 1945.

4. Stone, David G.: Wing-Dropping Characteristics of Some Straight and Swept Wings at Transonic Speeds as Determined with Rocket-Powered Models. NACA RM L50C01, 1950.

5. Harmon, Sidney M., and Jeffreys, Isabella: Theoretical Lift and Damping in Roll of Thin Wings with Arbitrary Sweep and Taper at Supersonic Speeds. Supersonic Leading and Trailing Edges. NACA TN 2114, 1950.

6. Lockwood, Vernard E.: Effects of Sweep at Transonic Speeds on the Damping-in-Roll Characteristics of Three Sweptback Wings Having an Aspect Ratio of 4. NACA RM L50J19, 1950.

7. Sanders, E. Claude, Jr., and Edmondson, James L.: Damping in Roll of Rocket-Powered Test Vehicles Having Swept, Tapered Wings of Low Aspect Ratio. NACA RM L51G06, 1951.

8. Malvestuto, Frank S., Jr., Margolis, Kenneth, and Ribner, Herbert S.: Theoretical Lift and Damping in Roll at Supersonic Speeds of Thin Sweptback Tapered Wings with Streamwise Tips, Subsonic Leading Edges, and Supersonic Trailing Edges. NACA Rep. 970, 1950. (Formerly NACA TN 1860.)

9. Bird, John D.: Some Theoretical Low-Speed Span Loading Characteristics of Swept Wings in Roll and Sideslip. NACA Rep. 969, 1950. (Formerly NACA TN 1839.)

10. Bland, William M., Jr., and Dietz, Albert E.: Some Effects of Fuselage Interference, Wing Interference, and Sweepback on the Damping in Roll of Untapered Wings as Determined by Techniques Employing Rocket-Propelled Vehicles. NACA RM L51D25, 1951.

11. Edmondson, James L.: Damping in Roll of Rectangular Wings of Several Aspect Ratios and NACA 65A-Series Airfoil Sections of Several Thickness Ratios at Transonic and Supersonic Speeds As Determined with Rocket-Powered Models. NACA RM L50E26, 1950.

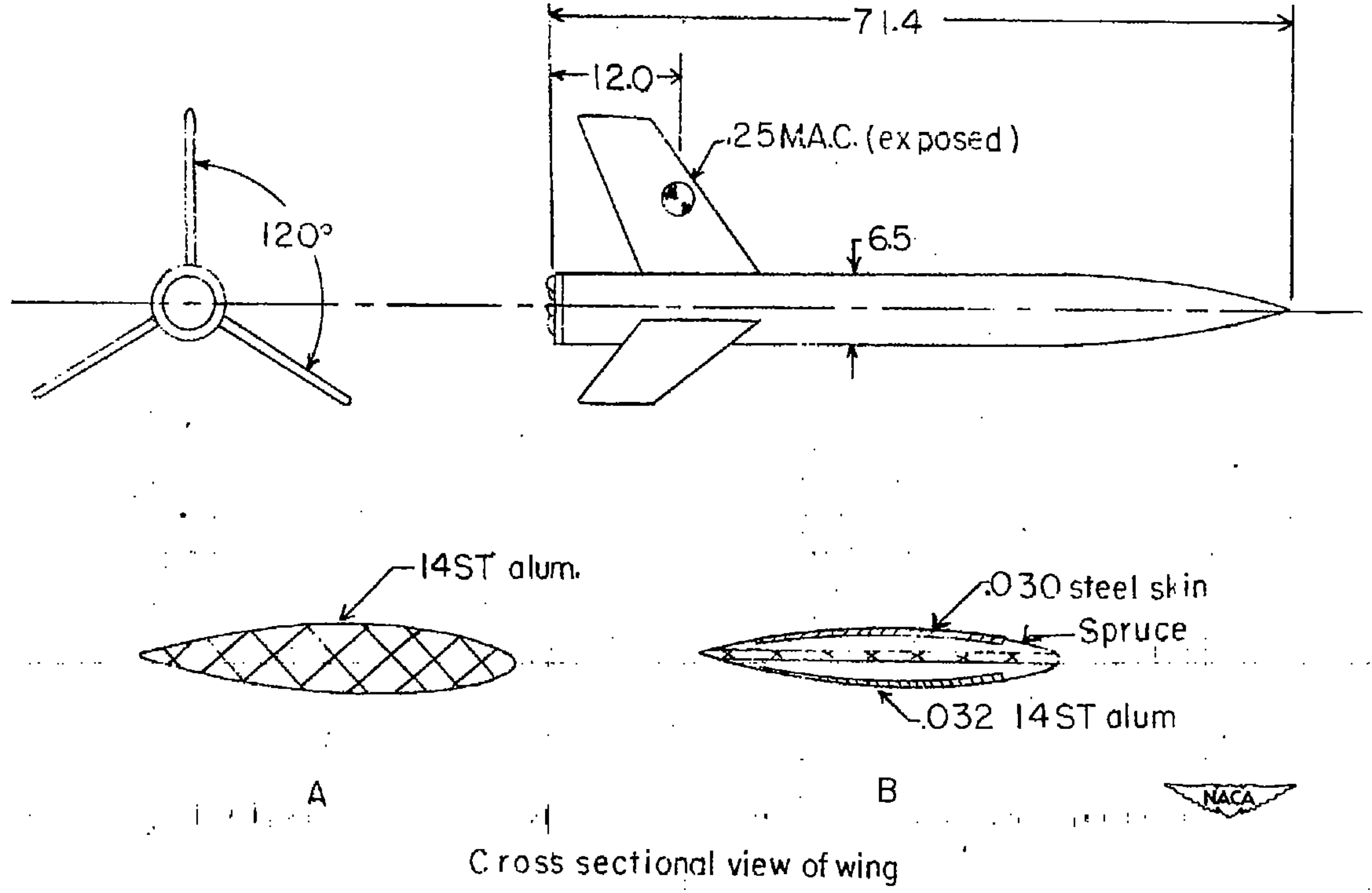


Figure 1.- General arrangement of models and types of wing construction. All dimensions in inches.

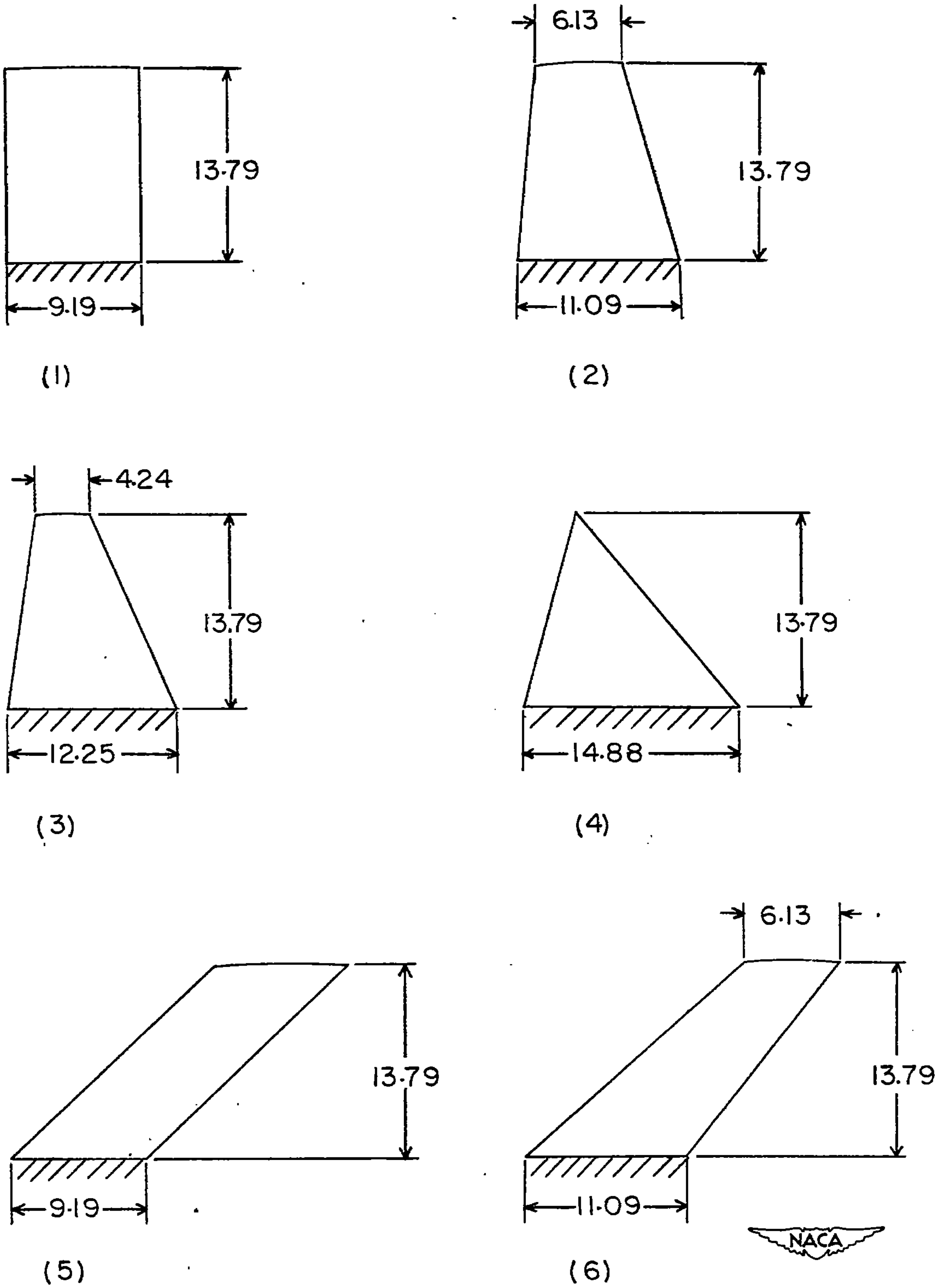
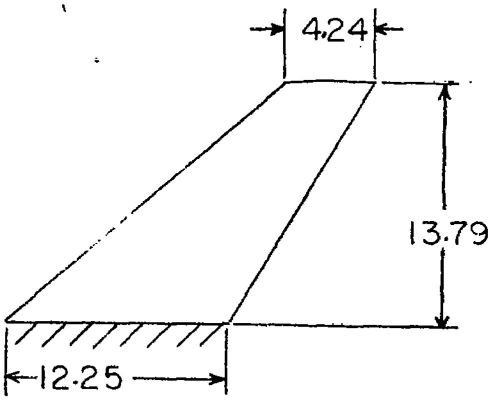


Figure 2.- Physical properties of test wings. All dimensions in inches.



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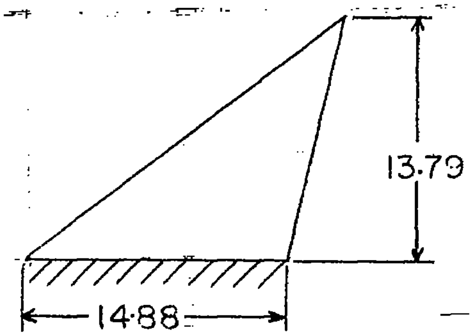


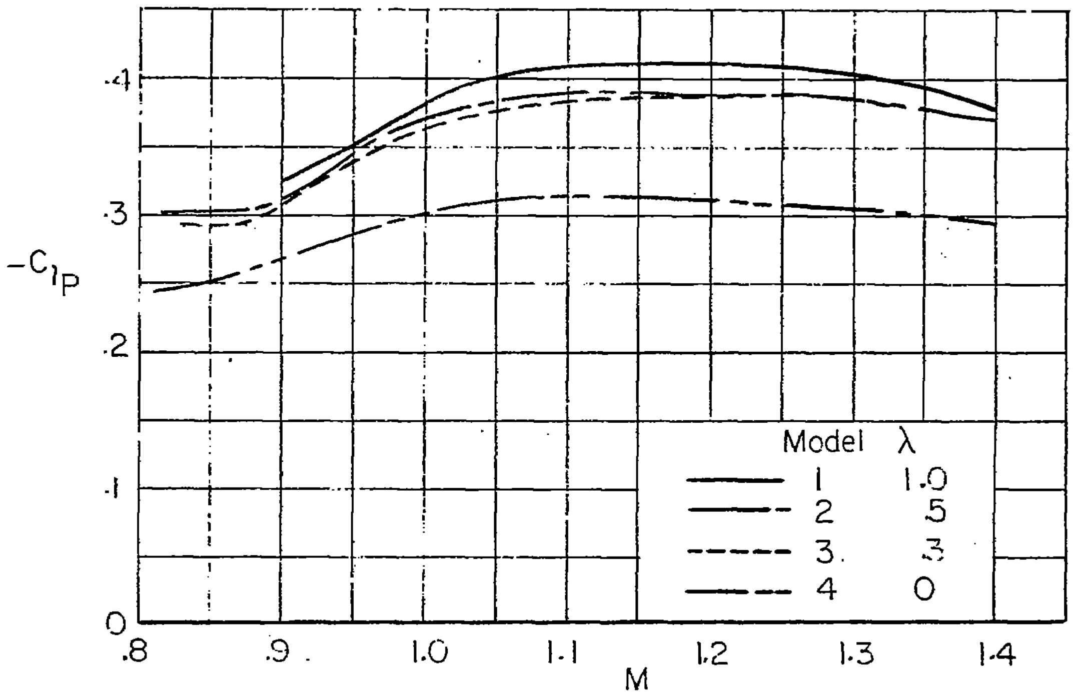
(8)

TABULATED WING DATA

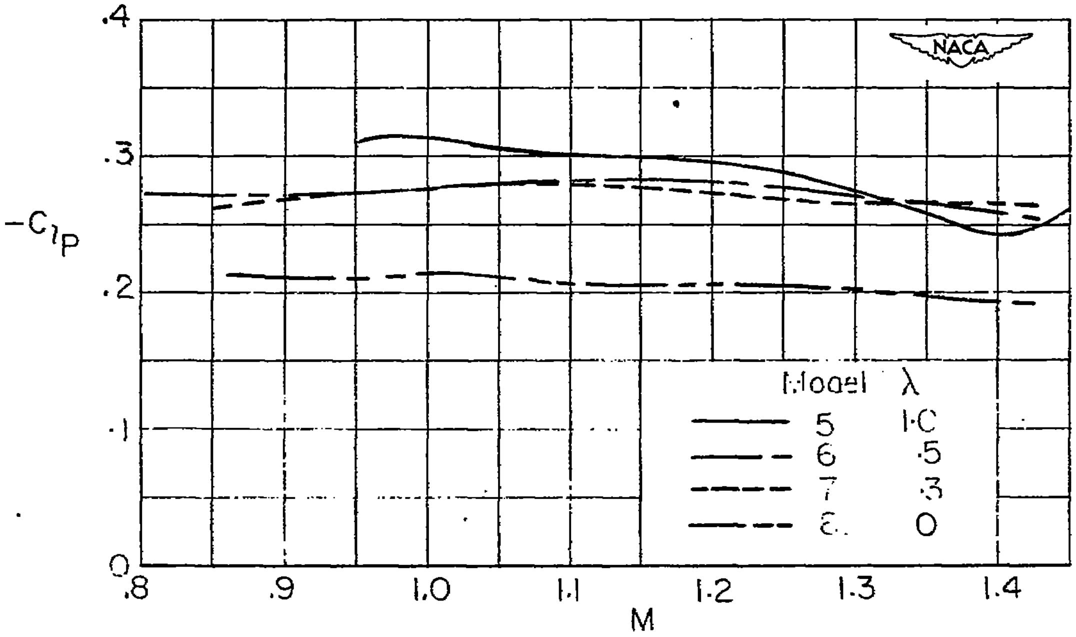
Area, S	3.25 sq.ft.
Aspect ratio	3.71
Airfoil section	NACA 65A006

Model	Sweep of quarter chord line	Taper ratio	Wing area (exp) sq ft	Type wing const.	m_θ in-lb/deg
1	0°	1.0	2.64	B	2271
2	0°	.5	2.46	A	2510
3	0°	.3	2.36	A	3060
4	0°	0	2.14	B	3400
5	45°	1.0	2.64	B	1569
6	45°	.5	2.46	A	1593
7	45°	.3	2.36	A	1921
8	45°	0	2.14	B	1250

Figure 2.- Concluded.



(a) Λ = 0°.



(b) Λ = 45°.

Figure 3.- Variation of damping in roll with Mach number.

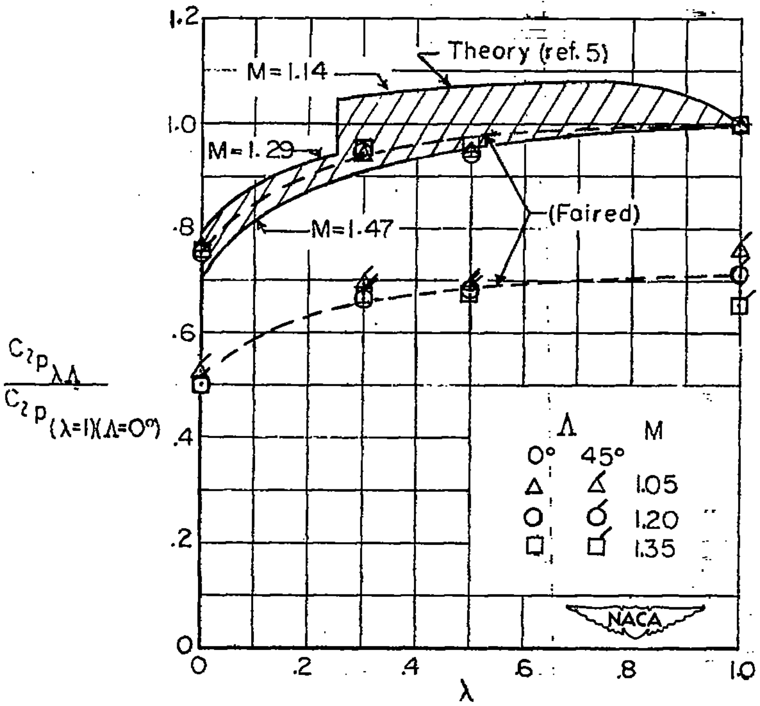


Figure 4.- Variation of C_{l_p} with taper ratio of a wing of arbitrary sweep and taper ratio normalized to the C_{l_p} of a rectangular wing.

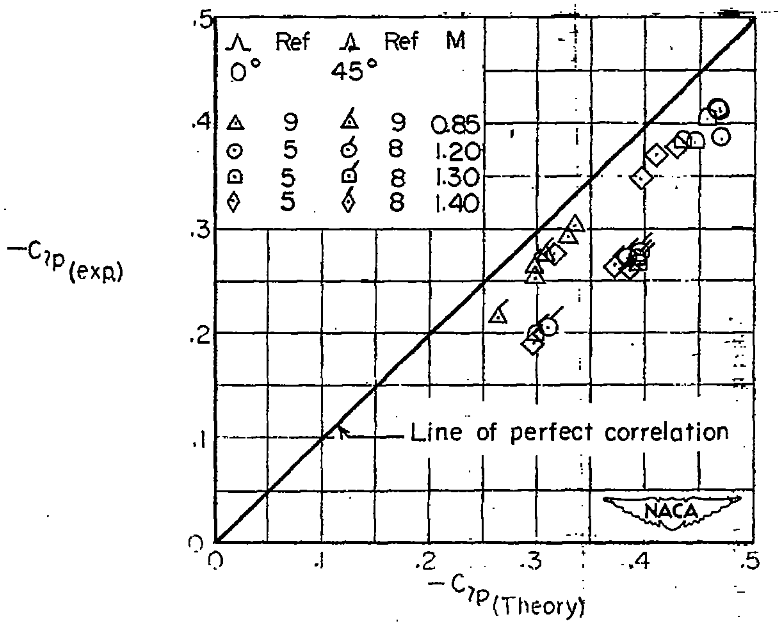
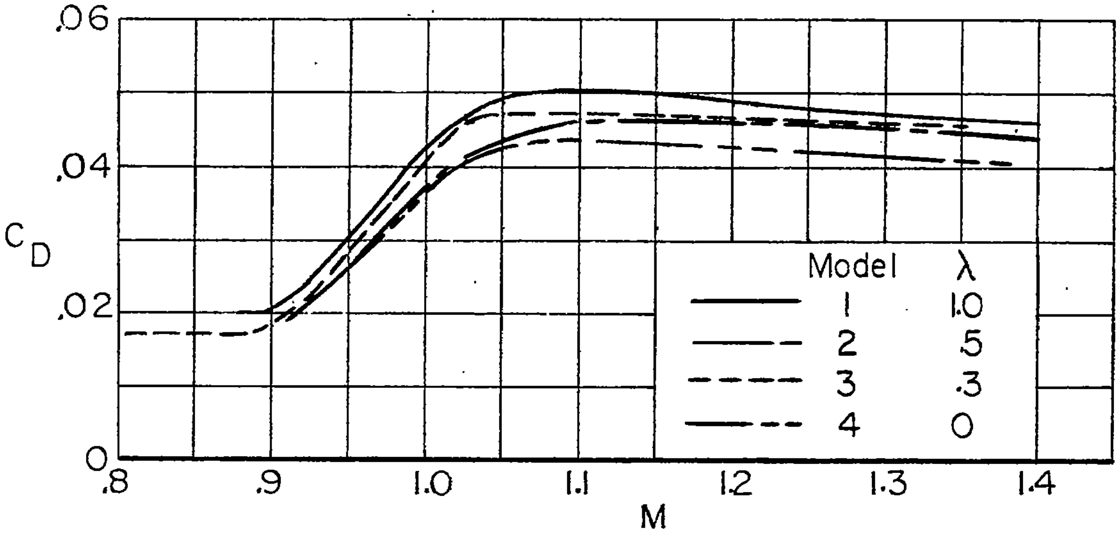
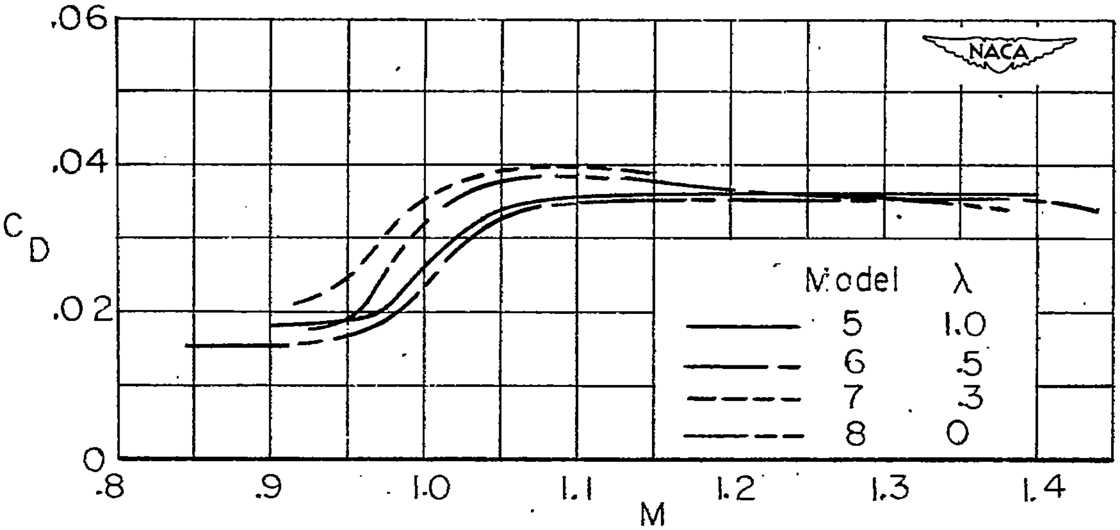


Figure 5.- Variation of experimental C_{l_p} with theory for tapered wings.



(a) $\Lambda = 0^{\circ}$.



(b) $\Lambda = 45^{\circ}$.

Figure 6.- Variation of total drag coefficient with Mach number.

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