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RESEARCH MEMORANDUM

MAXIMUM-LIFT INVESTIGATION AT MACH NUMBERS FROM 0.05 TO 1.20 OF A WING WITH LEADING EDGE SWEPT BACK 42°

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RESEARCH MEMORANDUM

MAXIMUM-LIFT INVESTIGATION AT MACH NUMBERS FROM 0.05 TO 1.20 OF A WING WITH LEADING EDGE SWEPT BACK 42°

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SUMMARY

An investigation at subsonic and transonic speeds has been made in the Langley high-speed 7- by 10-foot tunnel to determine the aerodynamic characteristics of three geometrically similar wings which had 42° sweepback of the leading edge, aspect ratio 4, taper ratio 0.625, and NACA 64_1-112 airfoil sections at Mach numbers from 0.05 to 1.20. The Reynolds number varied from 350,000 to 5,000,000.

Maximum lift coefficient $C_{L_{max}}$ was greatly influenced by Mach number: $C_{L_{max}}$ decreased from a value of 1.02 at a Mach number of 0.10 to approximately 0.77 at a Mach number of 0.85, then increased to 1.19 at a Mach number of 1.10, after which it decreased with further increase in Mach number. The experimentally determined lift-curve slopes were in good agreement with estimated slopes.

The stability of the wing at all lift coefficients up to the stall increased with increase in Mach number.

INTRODUCTION

With the possibility of high-speed, high-altitude aircraft reaching or even exceeding the angle of attack for the aircraft's maximum lift in maneuvers, the effect of Mach number on maximum lift becomes important and will become of greater importance as the speeds flown continue to increase. Wind-tunnel and flight investigations up to a Mach number of approximately 0.80 showed large changes in the maximum lift coefficient with Mach number for unswept wings (references 1, 2, and 3). The use of swept wings on most high-speed aircraft makes it desirable and important to determine the effects of Mach number on the maximum lift coefficient for such wing plan forms.

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The effects of Mach number on the aerodynamic characteristics in pitch of a sweptback wing up to the stall, have been determined in the Langley high-speed 7- by 10-foot wind tunnel up to a Mach number of 0.98 and on the transonic bump up to a Mach number of 1.20. The models had a leading-edge sweep of 42°, an aspect ratio of 4, and a taper ratio of 0.625. The present investigation covered a Mach number range from 0.05 to 1.20 with the Reynolds number varying from 350,000 to 5,000,000.

The effects of Reynolds number at low Mach numbers for this model configuration have been reported in references 4 and 5 for a Reynolds number range from 1,700,000 to 9,500,000.

COEFFICIENTS AND SYMBOLS

C_L lift coefficient $\left(\frac{\text{Twice measured lift}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{Twice measured drag}}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{\text{Twice measured pitching moment about } 0.25\bar{c}}{qS\bar{c}}\right)$

R Reynolds number

M Mach number (V/a)

V stream velocity, feet per second

α angle of attack, degrees

q dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

ρ mass density of air, slugs per cubic foot

a velocity of sound, feet per second

S twice area of semispan wing, square feet

$\bar{c}$ wing mean aerodynamic chord, measured parallel to plane of symmetry, feet $\left(\frac{2}{S}\int_0^{b/2} c^2 dy\right)$

b — twice span of reflection-plane wing, feet

c — local wing chord parallel to plane of symmetry, feet

y — spanwise distance from plane of symmetry, feet

$C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha}$

$C_{L_{max}}$ — maximum lift coefficient

MODELS

Three geometrically similar models were used for this investigation (fig. 1). All three models had the leading edge swept back 42°, an aspect ratio of 4.01, and a taper ratio of 0.625. The wing airfoil sections normal to the 0.273 chord line were of NACA 64_1-112 profile. The 0.273 chord line of the swept wing is the quarter-chord line of a straight wing which has been rotated 40° about the quarter-chord point of its root chord (fig. 1). The airfoil sections parallel to the plane of symmetry had a maximum thickness of 9.6-percent chord located at approximately 38-percent chord. The wing tips were rounded off, beginning at the $0.975\frac{b}{2}$ station, in both plan form and cross section. The wings had no geometrical dihedral or twist.

The wings were made of bismuth and tin cast around steel inserts and polished to a smooth finish. The wings had small thin end plates fastened to the wing root sections, adjacent to the tunnel wall or reflection plane, to deflect away from the wing any spanwise flow of air into the tunnel through the clearance hole between the model and the reflection plane. The end plate extended about 6 percent of the root chord from the wing surface on the largest model and about 15 percent on the smaller models. No correction was made for the effect of these end plates; however, the effect is believed to be small.

TEST TECHNIQUE

The tests were made in the Langley high-speed 7- by 10-foot tunnel which is capable of reaching the choking Mach number. Model 1 was tested on the standard semispan setup. In this case the wing butt extended through a hole in the tunnel ceiling and was attached to the balance system and the tunnel ceiling served as a reflection plane. The power available limited the investigation of model 1 to a Mach number of 0.90.

In order to extend the investigation to a higher Mach number, model 2 was constructed and tested up to a Mach number of 0.98 on a small reflection plane built out from the tunnel side wall (reference 6). To make the investigation more complete, model 3 was tested on the transonic bump (reference 6) up to a Mach number of 1.20.

The tests were run through the angle-of-attack range up to the wing stall at various Mach numbers. In a few cases the power available was insufficient to obtain maximum lift. The variation of Reynolds number with Mach number for each of the models investigated is presented in figure 2.

RESULTS AND DISCUSSION

Lift characteristics.- The lift characteristics of the 42° sweptback wing models are presented in figures 3 to 5 and are summarized in figures 6 and 7.

The variation of $C_{L_{max}}$ with Reynolds number at low speeds is presented in figure 6. The data in this figure at and above a Reynolds number 1,700,000 are from reference 5 at Mach numbers varying from 0.07 to 0.22; those below 1,700,000 are from the present investigation. The maximum-lift value for $R = 1,650,000$ at $M = 0.2$ from the present investigation was not included in the curve of figure 6 because $C_{L_{max}}$ at this Mach number (0.2) was considerably lower than at a Mach number of 0.10 as is discussed later. The value of $C_{L_{max}}$ increased from 1.02 at $R = 1,000,000$ to 1.06 at $R = 8,000,000$; above $R = 8,000,000$ $C_{L_{max}}$ decreased. However, it should be noted that the data for Reynolds numbers in excess of 8,000,000 were obtained at a Mach number of approximately 0.2. It is believed that part of this decrease in $C_{L_{max}}$ is a Mach number effect rather than a Reynolds number effect since the curve of $C_{L_{max}}$ against Mach number (fig. 7) shows an appreciable decrease in $C_{L_{max}}$ at $M = 0.20$ as compared to the value obtained at $M = 0.10$. Below a Reynolds number of 1,000,000, $C_{L_{max}}$ drops off appreciably with decrease in Reynolds number.

The maximum lift coefficient for model 1 presented in figure 7 increased from a value of 1.00 at $M = 0.05$ to a value of 1.02 at $M = 0.10$, then decreased almost linearly with increase in Mach number to $C_L = 0.79$ at $M = 0.75$, reached a minimum at approximately $M = 0.85$, and then increased with further increase in Mach number. The increase in $C_{L_{max}}$ with increase in Mach number up to $M = 0.10$ is believed to be a Reynolds number effect. Beginning at a Mach number of approximately 0.10, Mach number effects completely overshadowed the Reynolds number effects and caused a large decrease in $C_{L_{max}}$ with increase in Mach number. Model 2, investigated on the side-wall reflection plane through a Mach number range from 0.20 to 0.98, showed the same trends as model 1. Part of the decrease in $C_{L_{max}}$ at the lower Mach numbers as compared to $C_{L_{max}}$ for model 1 was the result of the low Reynolds number of model 2. The value of $C_{L_{max}}$ (fig. 7) for model 2 reached a minimum value of 0.78 at a Mach number of 0.85 and then increased with further increase in Mach number. The maximum-lift values from the investigation of model 3 on the transonic bump showed about the same trend as model 2. The values of $C_{L_{max}}$ increased rapidly beginning at a Mach number approximately 0.90, reached a maximum value of 1.19 at $M = 1.10$, and then decreased with further increase in Mach number.

The reasons for the maximum-lift values varying with Mach number as they do are probably the same as those discussed in references 2 and 7. In brief, at subcritical Mach numbers the decrease in $C_{L_{max}}$ with increase in Mach number may be attributed to boundary-layer separation induced by the compressibility-steepened adverse-pressure gradient. The increase in $C_{L_{max}}$ beginning at a Mach number of approximately 0.90 is probably the result of a net gain from an increase in lift caused by an increasing area of supersonic flow on the front portion of the wing upper surface and a simultaneous loss in lift caused by a lowering of the peak pressure at the nose of the airfoil. Above a Mach number of approximately 1.10 the reduction in peak pressure near the leading edge probably overbalances the broadened supersonic area, thereby giving a decrease in $C_{L_{max}}$ with further increase in Mach number.

The variation of the lift-curve slope C_{L_α} with Mach number for the models investigated, along with a theoretical C_{L_α} curve computed from reference 8, are presented in figure 7. The curves for the three models are in very good agreement with each other and with the theoretical curve. The value of C_{L_α} increased with increased Mach number in the subcritical range, reached a maximum at approximately the critical Mach number for the wing, and then decreased with further increase in Mach number.

<u>Drag characteristics</u>.- The drag characteristics of model 1 from the standard reflection-plane setup and model 3 from the transonic bump are presented in figures 8 and 9 and are summarized in figure 10. The minimum drag coefficient at subcritical Mach numbers was approximately 0.005, with the drag rise beginning at a Mach number of approximately 0.90 (fig. 10). The extremely low Reynolds numbers at which

model 3 was tested were probably responsible for the drag rise coming at a lower Mach number than for model 1. The minimum drag coefficient leveled off above a Mach number of 1.0 at a value of approximately 0.040.

The maximum value of L/D of 27 for model 1 at $M = 0.10$ is in good agreement with the maximum value of L/D of 25 at $M = 0.10$ shown for the same wing in references 4 and 5. Maximum L/D decreased as the Mach number was increased up to approximately 0.40 Mach number, leveled off at a value of L/D of approximately 20, and then started to decrease rapidly again at a Mach number of approximately 0.80 (fig. 10). Maximum L/D for model 3 was in good agreement with that for model 1 in the overlapping Mach number range, considering the Reynolds number difference of the two models and the fact that the overlap was in a critical Mach number range. Above $M = 1.00$, maximum L/D was practically constant at a value of about 5.

The lift coefficient at which maximum L/D occurred was practically constant throughout the subcritical Mach number range at a value of approximately 0.20 (fig. 10). Above the critical Mach number, C_L for maximum L/D rose sharply with increase in Mach number to a value of 0.45 at a Mach number of 1.05, and then decreased slightly as the Mach number was further increased.

Pitching-moment characteristics.- The wing pitching-moment characteristics for this investigation are presented in figures 11, 12, and 13. Models 1, 2, and 3 had practically neutral stability $\left(\frac{\partial C_m}{\partial C_L} = 0\right)$ at moderate lift coefficients up to a Mach number of about 0.60. Above $M = 0.60$, the stability in the moderate lift-coefficient range increased considerably with increase in Mach number; similarly, at the higher Mach numbers, there was a definite increase in stability (rearward movement of longitudinal center of pressure) at the higher lift coefficients up to $C_{L_{max}}$. It is obvious from reference 4 and by comparisons of the pitching-moment curves for the three models of this investigation at the same Mach numbers that this increased stability is the result of an increase in Mach number rather than an increase in Reynolds number.

CONCLUSIONS

An investigation was made of three geometrically similar wings which had 42° sweepback of the leading edge, aspect ratio 4, taper ratio 0.625, and NACA 64_1-112 airfoil sections at Mach numbers between 0.05 and 1.20 to determine the effect of Mach number on the aerodynamic characteristics in pitch. The following conclusions were indicated:

1. Maximum lift coefficients were greatly affected by Mach number, decreasing from 1.02 to approximately 0.77 as the Mach number was increased from 0.10 to 0.85. Above a Mach number of 0.85, maximum lift coefficients increased with increase in Mach number up to a value of 1.19 at a Mach number of 1.10, then decreased with further increase in Mach number.

2. Above a Mach number of 0.10, Mach number had a greater effect than Reynolds number on the maximum lift coefficient.

3. At subcritical Mach numbers, the values of the experimentally determined lift-curve slopes were in good agreement with the values of the estimated lift-curve slope.

4. The drag rise for this model occurred at a Mach number of approximately 0.90.

5. The maximum value of the lift-to-drag ratio decreased from 27 at a Mach number of 0.10 to approximately 5 at a Mach number of 1.00.

6. The stability of the wing at all lift coefficients up to the stall increased with increase in Mach number.

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[redacted]

Model	$\bar{c}$, ft	$b/2$, ft	$S/2$, sq ft	Scale
1	1.157	2.275	2.580	1.000
2	.206	.407	.082	.178
3	.103	.203	.021	.089

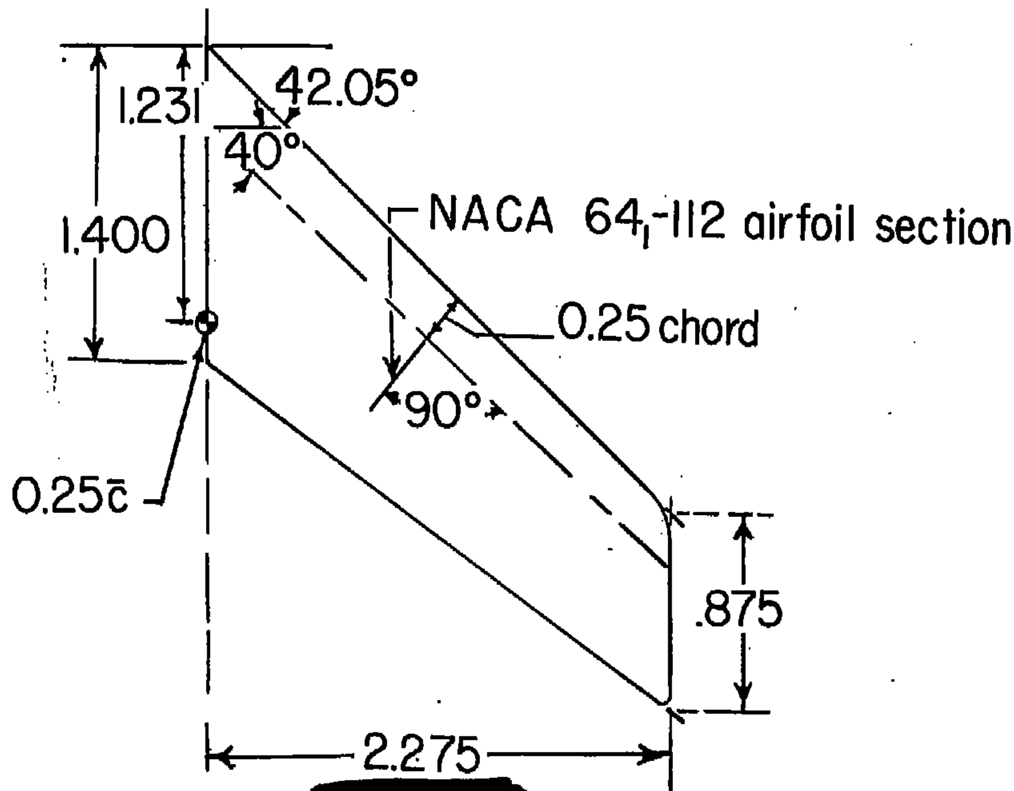

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Figure 1.- Plan form of 42° sweptback, aspect ratio 4.0, taper ratio 0.625 wing. (Dimensions on drawing for model 1 in feet.)

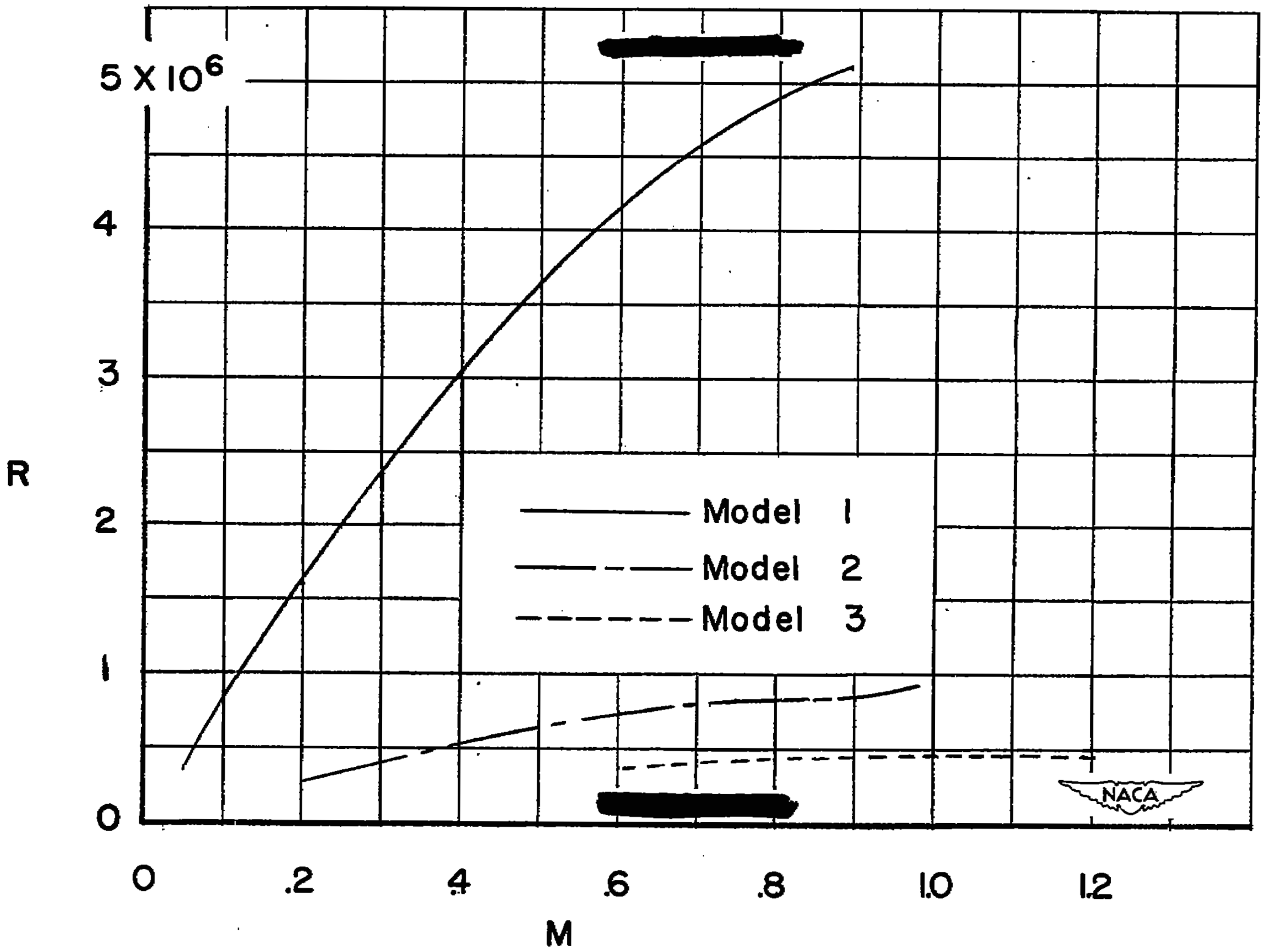

Figure 2.- Variation of Reynolds number with test Mach number.

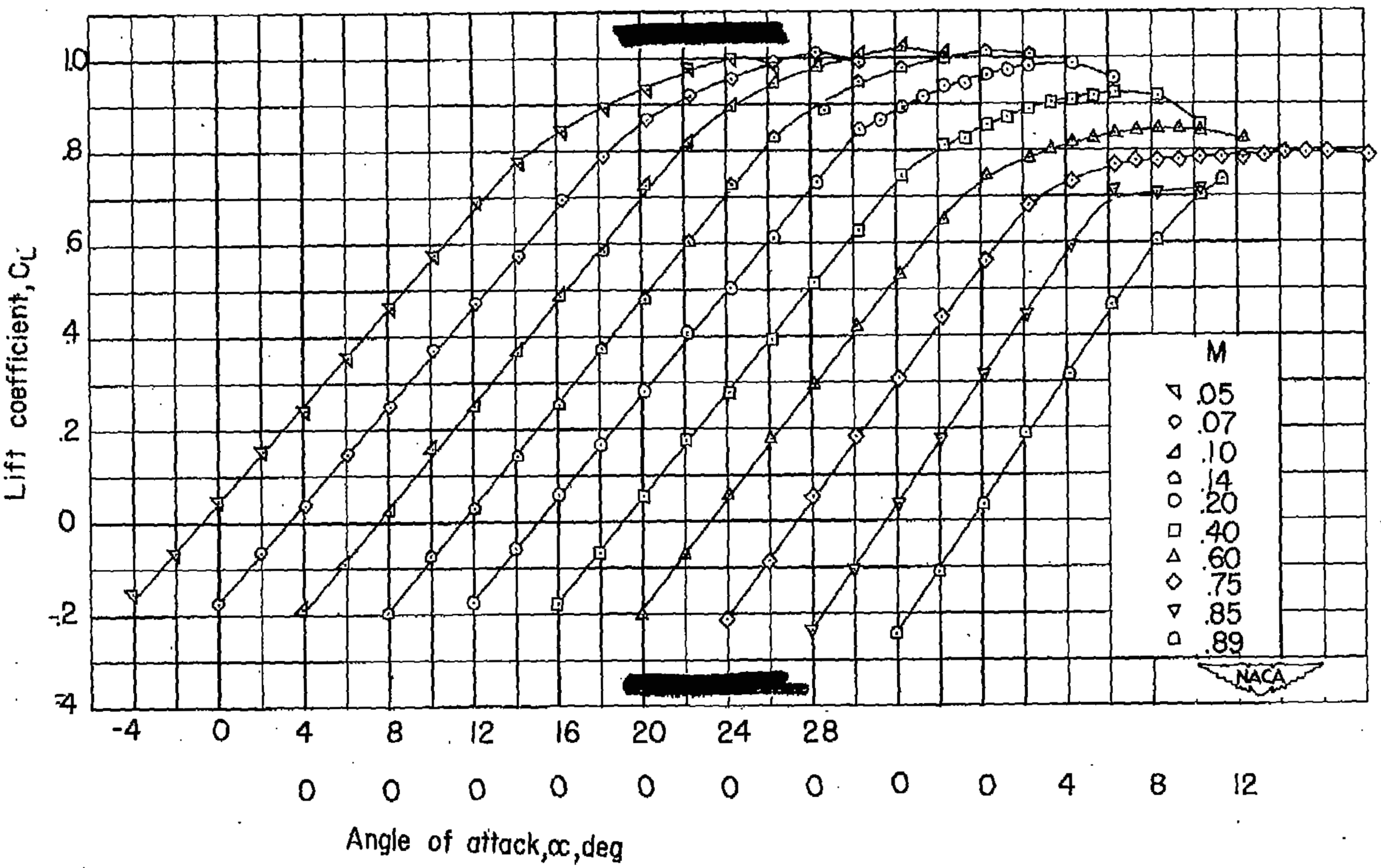

Figure 3.- Lift characteristics for various Mach numbers. 42° sweptback wing, model 1.

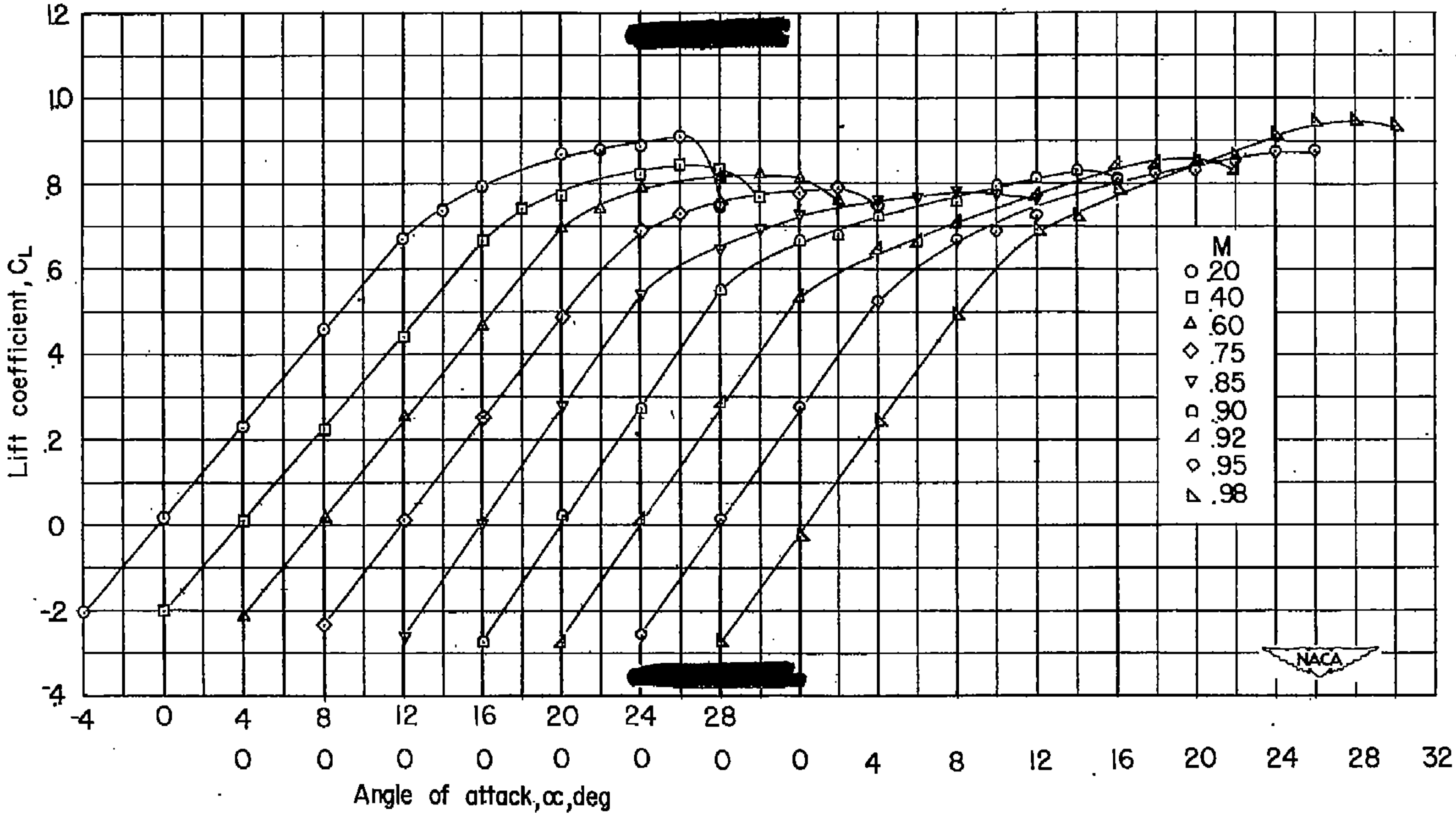

Figure 4.- Lift characteristics for various Mach numbers. 42° sweptback wing, model 2.

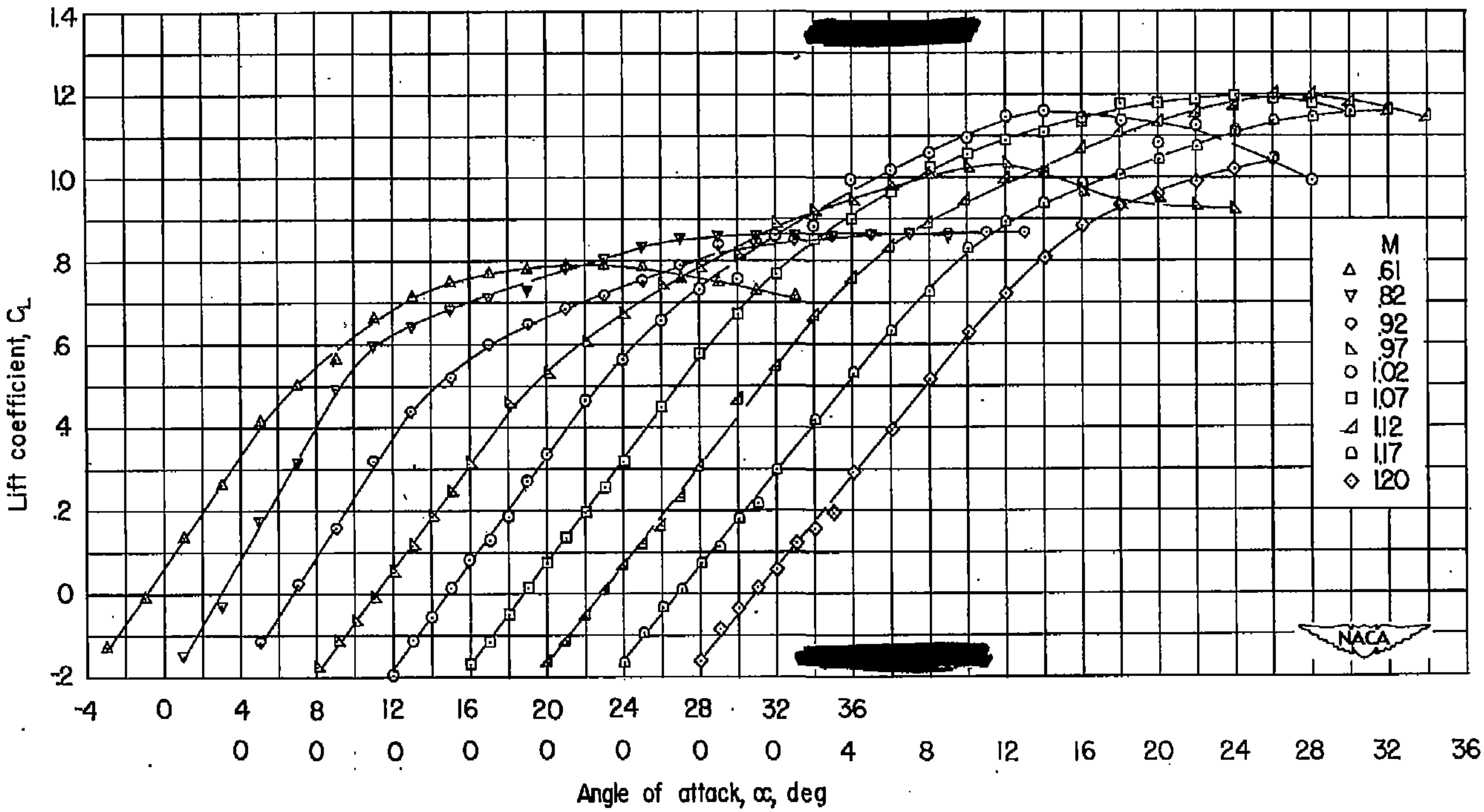

Figure 5.- Lift characteristics for various Mach numbers. 42° sweptback wing, model 3.

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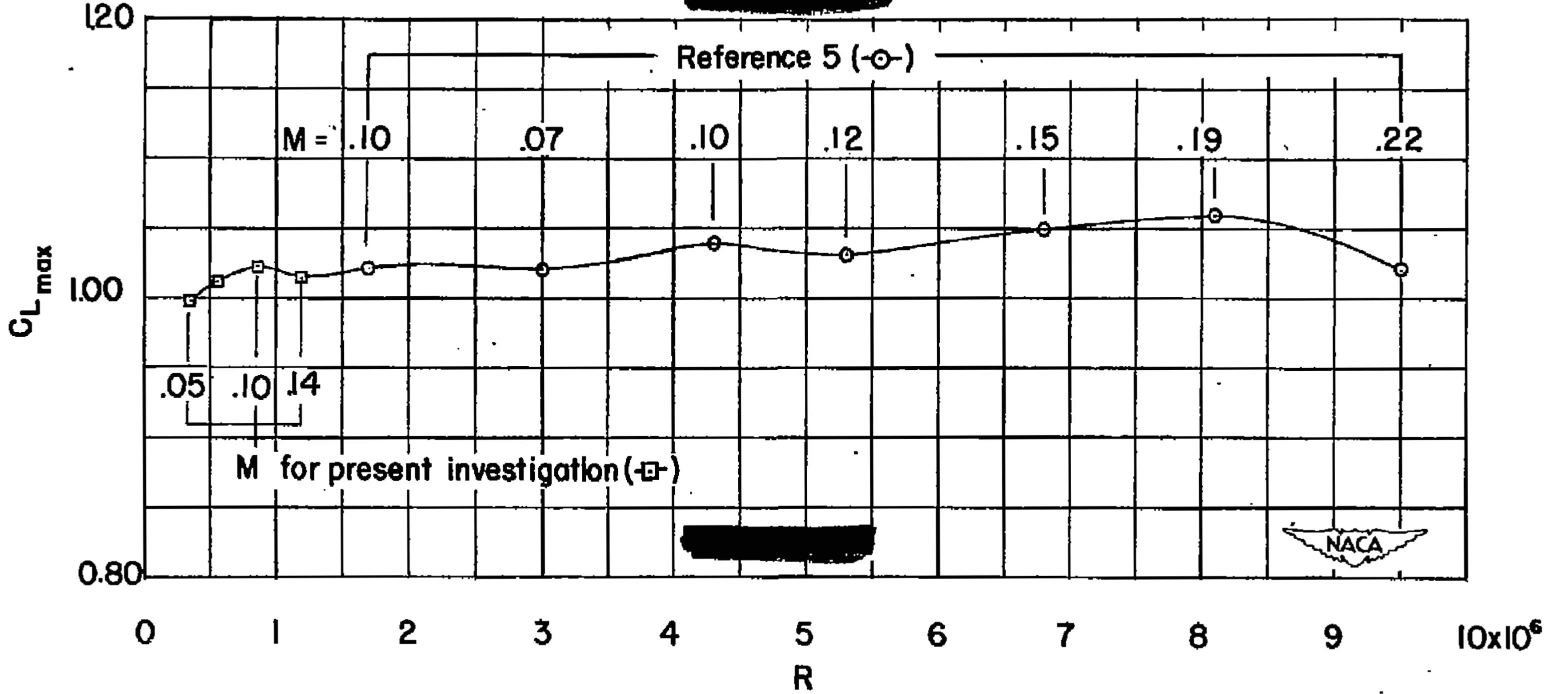

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Figure 6.- Variation of maximum lift coefficient with Reynolds number.

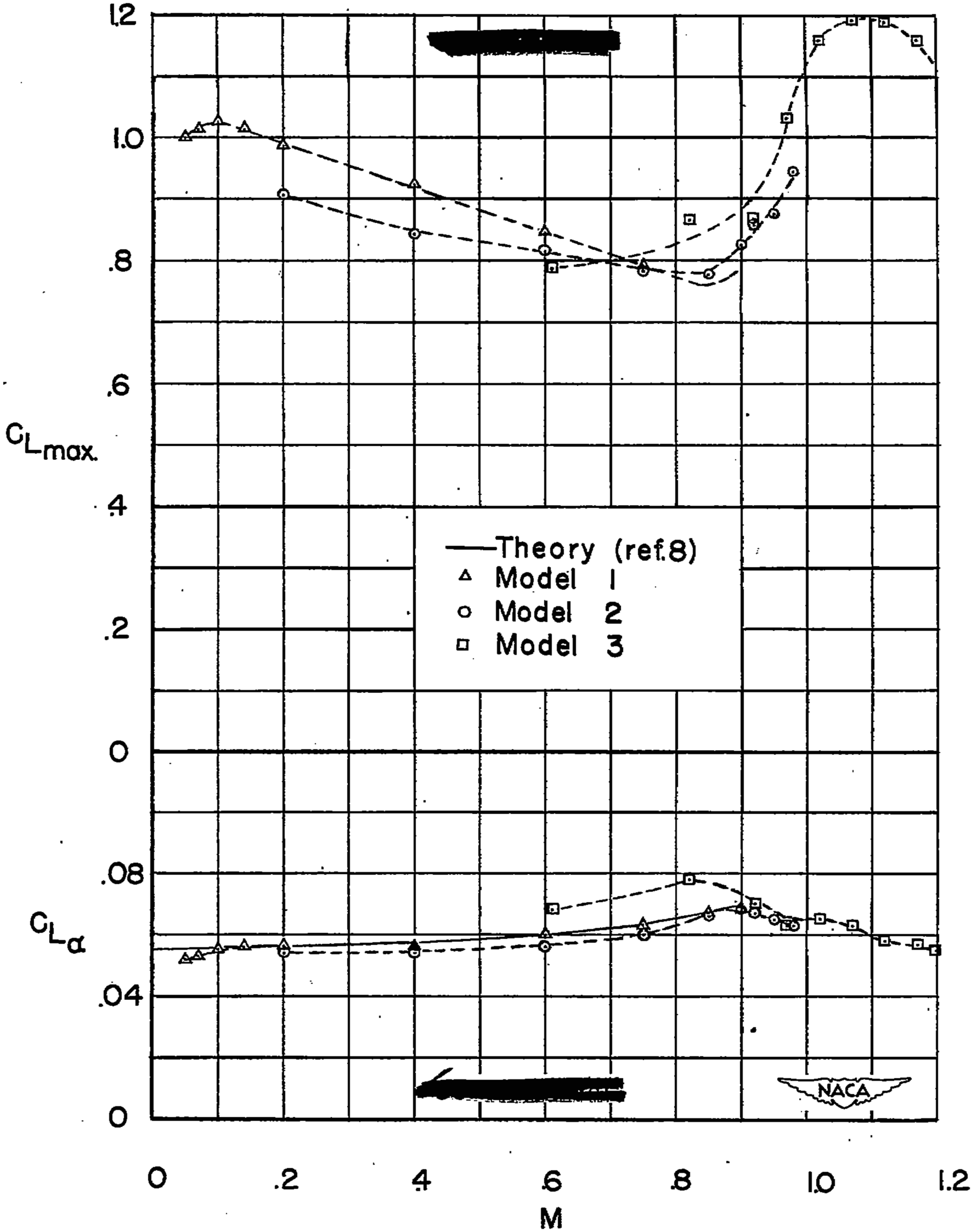

Figure 7.- Variation of lift-curve slope and maximum lift coefficient with Mach number.

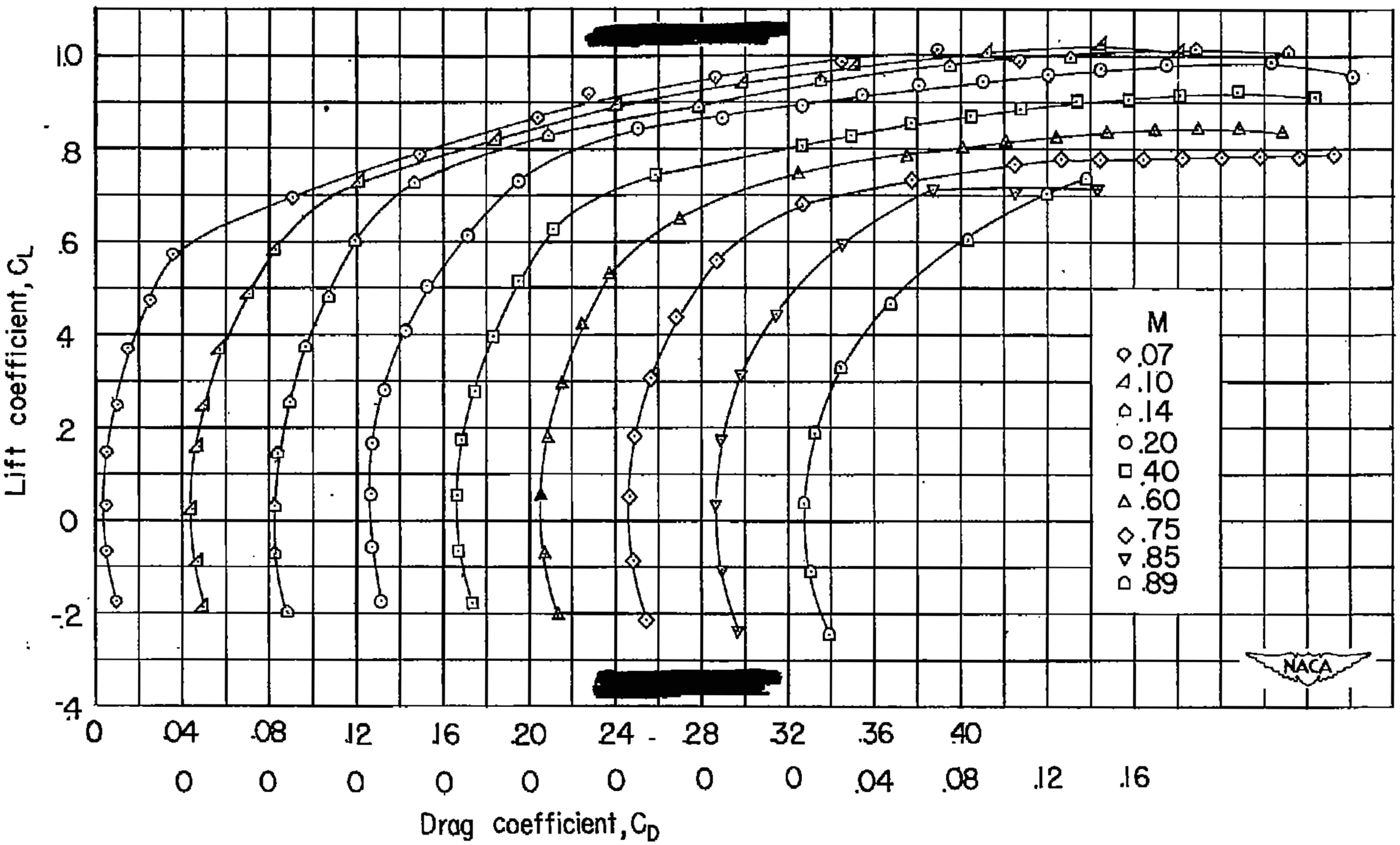

Figure 8.- Drag characteristics for various Mach numbers. 42° sweptback wing, model 1.

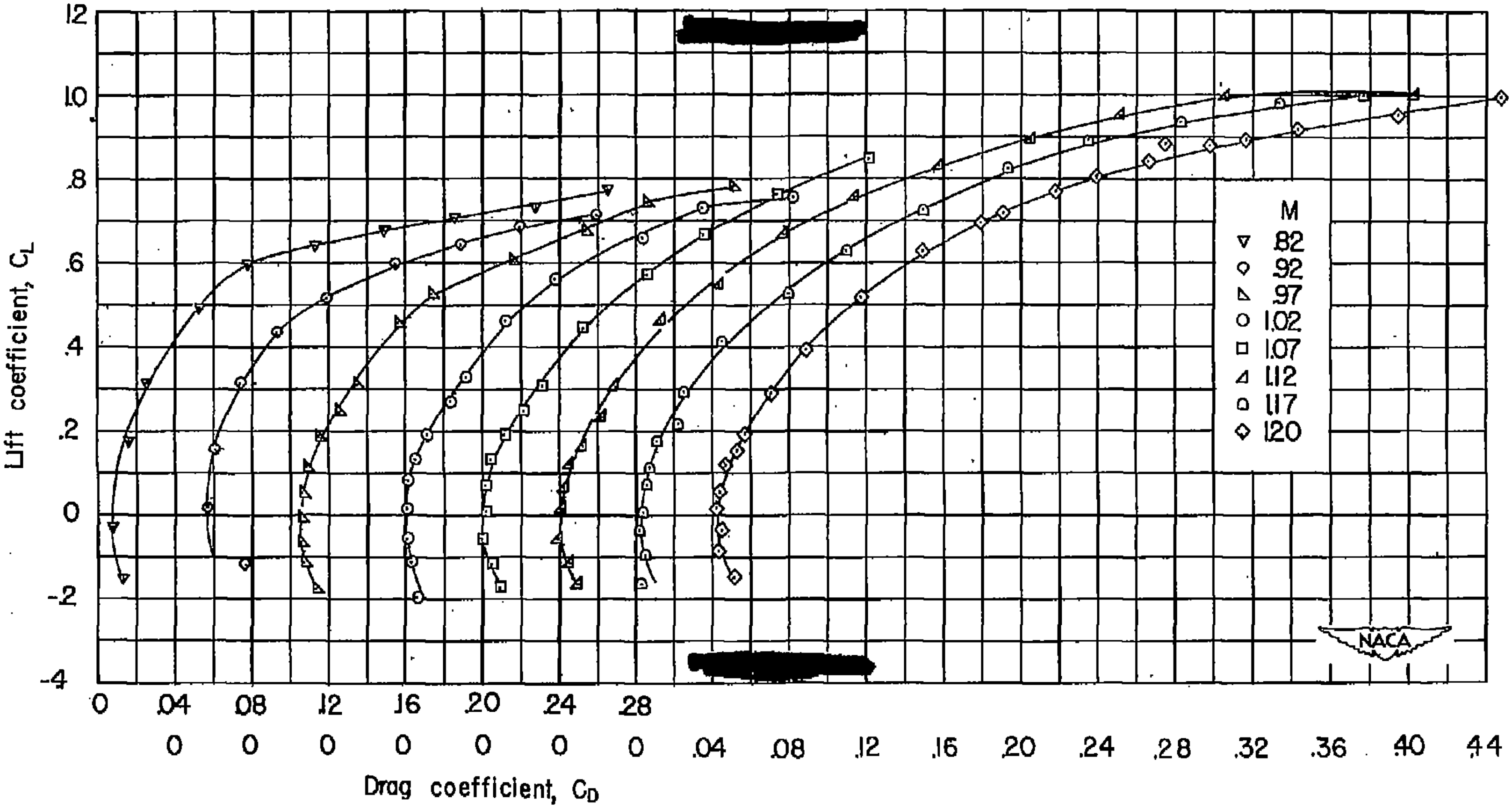

Figure 9.- Drag characteristics for various Mach numbers. 42° sweptback wing, model 3.

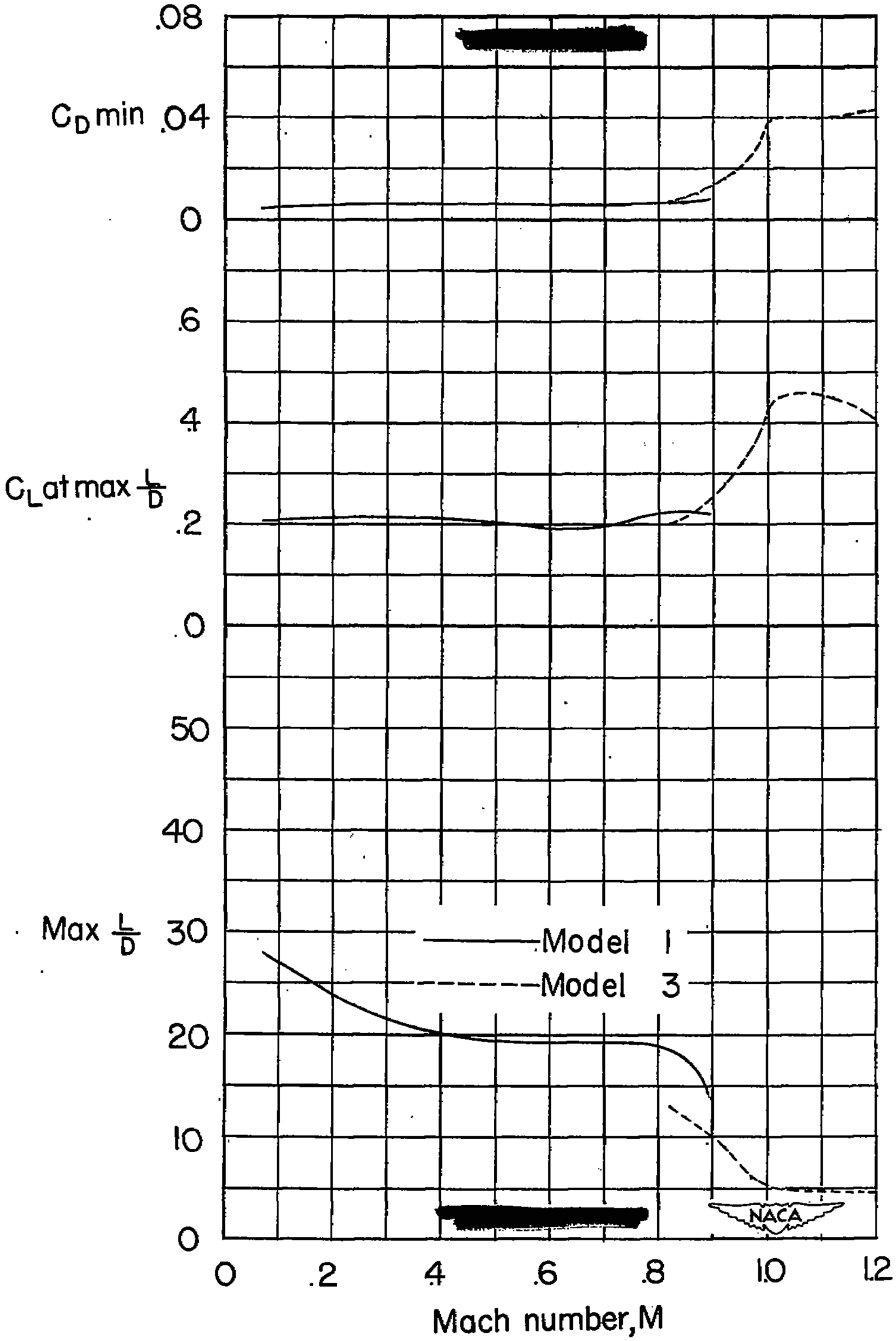

Figure 10.- Variation of some aerodynamic characteristics with Mach number.

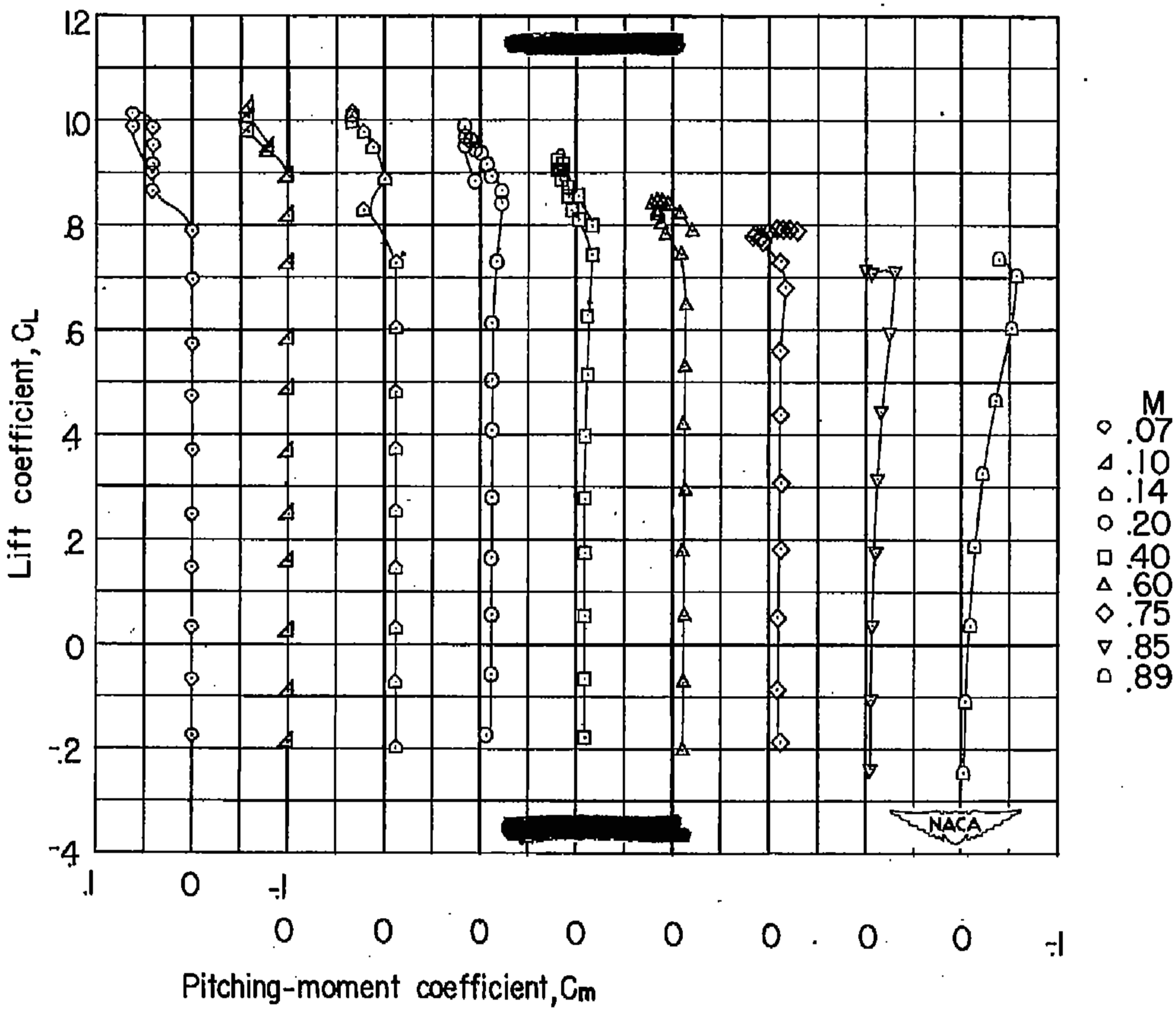

Figure 11.- Pitching-moment characteristics for various Mach numbers. 42° sweptback wing, model 1.

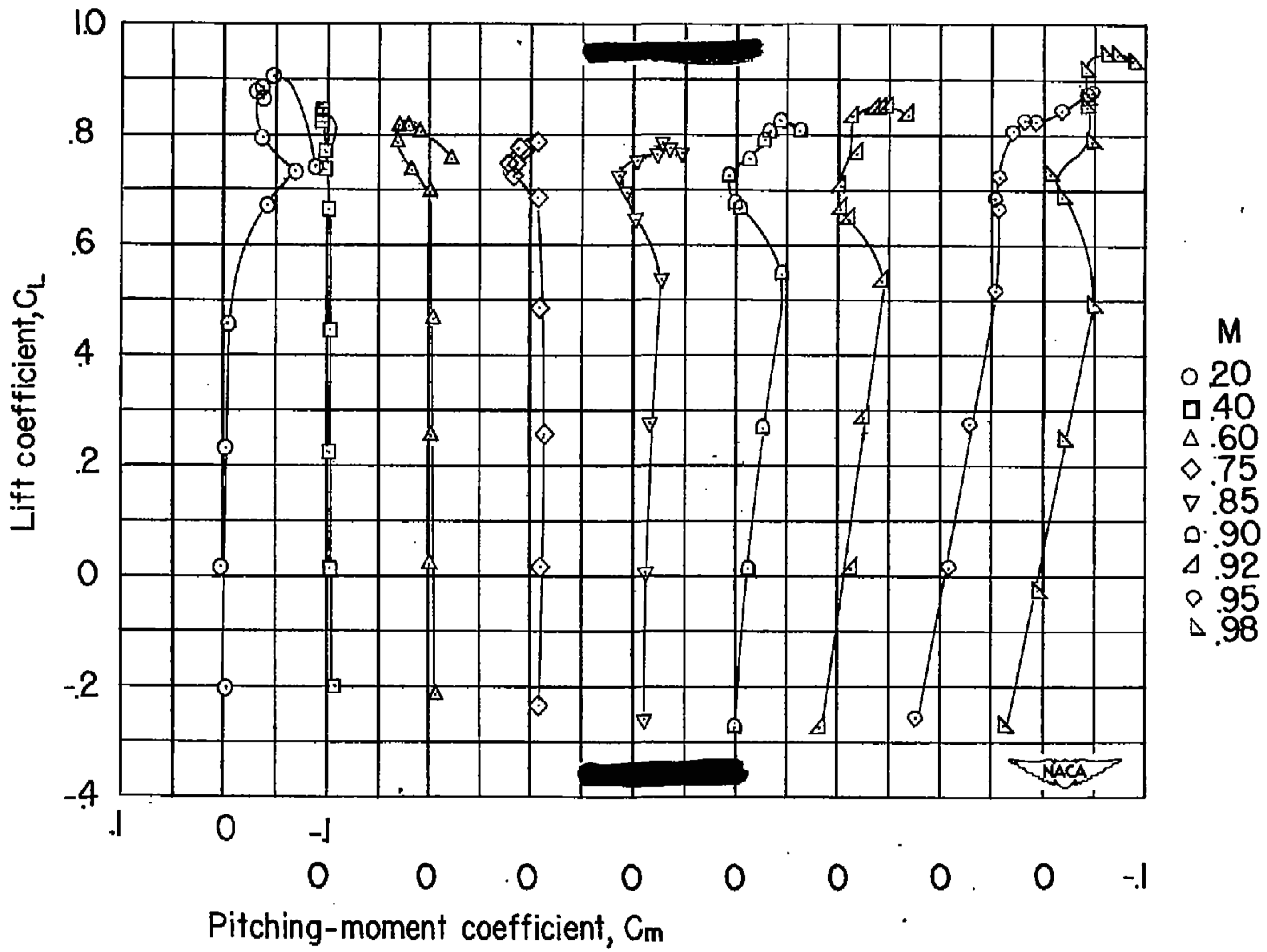

Figure 12.- Pitching-moment characteristics for various Mach numbers. 42° sweptback wing, model 2.

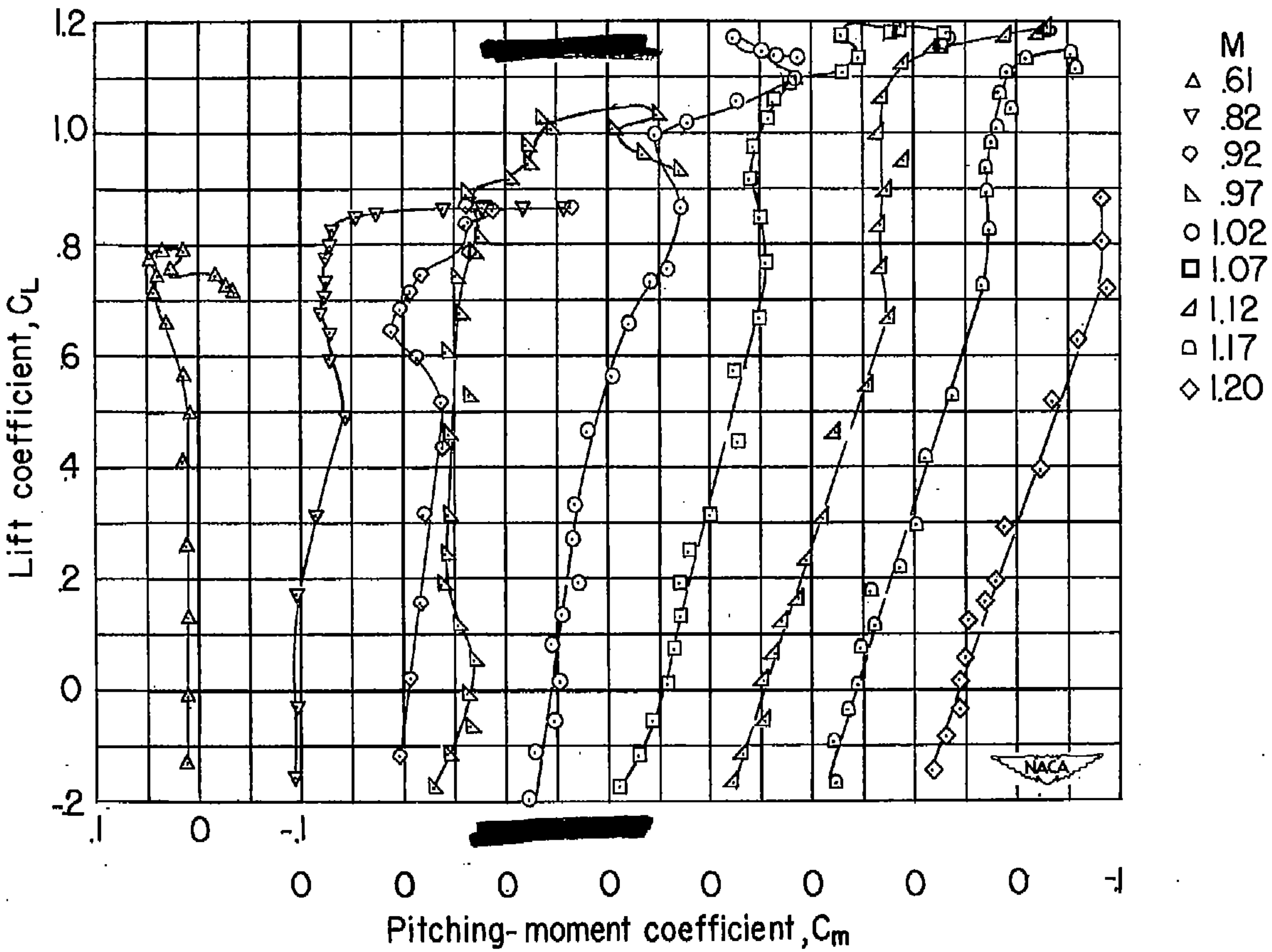

Figure 13.- Pitching-moment characteristics for various Mach numbers. 42° sweptback wing, model 3.

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