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RESEARCH MEMORANDUM

TESTS OF LIFTING SURFACES ON CONICAL AND CYLINDRICAL PORTIONS OF A BODY AT SUBSONIC MACH NUMBERS AND AT A MACH NUMBER OF 1.2

By Robert S. Osborne and John B. Wright

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RESEARCH MEMORANDUM

TESTS OF LIFTING SURFACES ON CONICAL AND CYLINDRICAL PORTIONS OF A BODY AT SUBSONIC MACH NUMBERS AND AT A MACH NUMBER OF 1.2

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SUMMARY

Tests of low-aspect-ratio triangular-plan-form lifting surfaces located on the conical and on the cylindrical portions of a body have been made at a Mach number of 1.2 and at several subsonic speeds in order to determine if aerodynamic characteristics of such surfaces at supersonic speeds could be improved by locating them in the subsonic conical-flow field resulting from employment of a cone with the proper apex angle.

The lift-curve slopes were much smaller for the surfaces when located on the cone than when on the cylinder. In the conical location the drag coefficients of the surfaces remained subcritical through the Mach number range tested, whereas for the cylindrical position supercritical values were obtained at a Mach number of 1.2. Lower drag for a given lift with the surfaces on the cone at a Mach number of 1.2 indicated that at low supersonic speeds improved aerodynamic characteristics could be obtained for the lifting surfaces by locating them in the subsonic conical-flow field. In any practical application of this result, however, the high body drag accompanying the use of the large cone apex angle required and the small region of useable subsonic conical flow must be considered.

INTRODUCTION

One problem in the performance and control of aircraft and missiles at supersonic Mach numbers is the loss in lift effectiveness and increase in drag of lifting surfaces caused by shock formation. Now it is well known that in the field of flow about a cone at supersonic free-stream

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Mach numbers, subsonic Mach numbers result from the employment of the proper cone apex angle. Although such cone apex angles are large and result in high values of body drag, it would be desirable to know if lifting surfaces designed to operate subcritically in this region of local subsonic flow would exhibit better lift and drag characteristics in comparison with operation in the supercritical free-stream field.

In a preliminary test to determine if the cone position were advantageous, the lift and drag of a low-aspect-ratio triangular-plan-form lifting surface with simple airfoil sections mounted on the conical and on the cylindrical portions of a body were measured. The investigation was made with a sting-supported model having an internal balance at a Mach number of 1.2 and at several subsonic Mach numbers from 0.6 to 0.85 in the Langley 8-foot high-speed tunnel.

SYMBOLS

M	free-stream Mach number
C_L	lift coefficient
C_D	drag coefficient
ΔC_L	incremental lift coefficient of lifting surface $\left(C_{L_{\text{Body + Surface}}} - C_{L_{\text{Body}}}\right)$
ΔC_D	incremental drag coefficient of lifting surface $\left(C_{D_{\text{Body + Surface}}} - C_{D_{\text{Body}}}\right)$
i	angle of incidence of lifting surface with respect to body center line, degrees
α	angle of attack of body center line, degrees
θ	angle measured from body center line, degrees

Subscripts:

s	cone surface
w	shock

APPARATUS AND TEST

Model and Design

The exact geometry of the flow pattern over cones at supersonic speeds depends on the stream Mach number and the cone apex angle. Figure 1 defines the various regions of flow that may exist over a cone at supersonic Mach numbers. These data, as well as other theoretical conical-flow data presented, were taken from reference 1 wherein the complete characteristics of conical flow are tabulated for many cone angles and Mach numbers.

For these tests, the flow in Region II was chosen as the most desirable of the four possible types because it permits subsonic velocities in the area to be occupied by the lifting surfaces while keeping the cone apex angle as small as possible. The conical-flow field was computed and interpolated at a stream Mach number of 1.2 for a cone with a semiapex angle of 17.5°. The results are shown in figure 2 for any cross section at $\alpha = 0^{\circ}$. Radiating lines from the apex of the cone represent constant Mach number values in the field. The area, then, between the sonic line and the surface of the cone is a region of subsonic flow, and a lifting surface placed in this region therefore should experience subsonic-flow phenomena while the stream Mach number is supersonic. Surfaces placed on the cylindrical portion of the body behind the cone, however, are in a region where a Mach number of approximately 1.2 should exist throughout the field.

A cylinder and cone were constructed to attach to the forward part of a body of revolution. A drawing of the arrangement is shown in figure 3(a). Simple airfoil sections were used for the lifting surfaces. The details of these surfaces are shown in figure 4. The airfoil sections were composed of flat sides with flat taper to the leading edge and to the trailing edge, rounded leading edges, and faired edges from flat to flat. The leading edge of the surface was swept back 40°, and kept as far behind the cone apex as possible in order to allow the three-dimensional conical flow to be established before the effects of the surface were introduced. The trailing-edge sweep was 0°. One set of surfaces only was built to fit interchangeably on the cone or the cylinder (figs. 3(b) and 3(c)) and have the same exposed area (0.095 sq ft) in either position. There was no filleting and no gap at either the surface-cone or surface-cylinder junctions. Changes in angle of incidence were accomplished by rotating the surfaces about the leading edge as shown in figure 4.

The data in reference 1, and, consequently, the flow field as presented in figure 2, are based on the assumption that the cone is semi-infinite. Since this is not the case for these tests, a deterioration of the conical-flow phenomenon would be expected as the cylindrical portion of the body is approached. It is probable, therefore, that the tips of the surfaces lie in a region of accelerating supersonic flow and that completely subsonic phenomena are not present in this cone position. However, a large portion of the area of the surfaces is in a subsonic region, and comparison with the surfaces in a completely supersonic region will still provide information on the general effects.

The short dashed lines in figure 2 illustrate the flow direction through the field of the cone. It is evident that a greater effective sweep exists with the surface on the cone than with the surface on the cylindrical portion. An approximate mean value of the angle of flow at the leading edge of the airfoil relative to the undisturbed flow direction is 8°, and the effective sweep of the leading edge of the surface on the cone is therefore approximately 48°.

Tunnel and Model Support System

The Langley 8-foot high-speed tunnel is of the closed-throat single-return type. A wall liner in the tunnel provided a supersonic test section designed for a Mach number of 1.2 downstream of the minimum section. The stream Mach number in the region of the surfaces tested varied from the design value by only ± 0.01. The supersonic test section was also used to test the model subsonically, and for this condition the highest Mach number which could be attained before the tunnel choked was 0.852.

The model was attached to a strain-gage balance which was enclosed within the hollow body of revolution. The downstream end of the balance formed a tapered sting which was attached to a telescoping support tube through couplings used to vary the angle of attack. The support tube was fixed axially in the center of the tunnel by two sets of support struts projecting from the tunnel walls. The general arrangement is shown in figure 3(d).

Tests and Methods

The tests were conducted at angles of attack of approximately 0° and with surface incidences of -2.5°, 0°, 2.5°, and 5° through a subsonic Mach number range from 0.6 to 0.852 and at the supersonic Mach number of 1.2. The Reynolds number based on a lifting-surface mean aerodynamic chord of 2.31 inches ranged from 0.65×10^{6} at a Mach number of 0.6 to 0.73×10^{6} at a Mach number of 1.2.

Tests were made of the basic body with cylinder and cone (fig. 3(a)), of the body with the surfaces on the cone (fig. 3(b)), and of the body with the surfaces on the cylinder (fig. 3(c)). A strain-gage balance within the body was used to measure the lift and drag forces on the body free from any aerodynamic forces on the sting support. With a system of this type, the only tare is the interference effect of the sting support on the body. Previous tare measurements on a similar configuration have indicated that the effect on lift is negligible and that the drag coefficient based on the exposed lifting-surface area used in the present tests is decreased approximately 0.03. However, since the body was used only as a basis for comparison in the present tests, tares have been neglected. Aerodynamic loads caused bending of the sting so that the resulting model angles of attack had to be observed at each test point by means of an optical light reflection instrument. Lift and drag coefficients are based on the exposed area of the surfaces.

PRECISION OF DATA

The maximum probable errors in the data presented herein have been estimated and are listed in the following table:

	Error
C_L	±0.01
C_D	±0.002
α, degree	±0.1
i, degree	±0.1

The variation of the error in lift and drag coefficients with Mach number is probably small.

RESULTS AND DISCUSSION

Lift and drag coefficients for the various configurations at each test Mach number were plotted against angle of attack; for example, see figures 5 and 6 for a Mach number of 1.2. These data were interpolated and extrapolated using straight-line fairing to obtain values at an angle of attack of 0°. These data are presented as a function of Mach number in figures 7 and 8.

In order to compare the characteristics of the surfaces in the two locations, body-alone data were subtracted from body-with-surface data at an angle of attack of 0° in order to obtain incremental values for the surfaces alone. These values, then, necessarily contain any effects of surface-body interference, which is not disadvantageous since surface-body interference would certainly be a factor to be considered in evaluating the relative merits of the two surface locations. These data as a function of surface incidence are presented in figures 9 to 12.

It is evident that the lift effectiveness of the surfaces at a Mach number of 1.2 (fig. 9) is much greater for the cylindrical position. The slope of the lift curve for the conical position is 0.049, while for the cylindrical position it is 0.085. At subsonic Mach numbers (fig. 10), the lift-curve slopes are also much greater for the surfaces in the cylindrical position. The increase of lift-curve slope with Mach number is small as would be expected of a surface having a plan form approximately that of a low-aspect-ratio triangular wing. The lower values of lift-curve slope with the surfaces in the conical position are probably due to substream dynamic pressure, greater effective sweep, and a smaller effective aspect ratio for the surfaces in this location.

In an effort to predict the lift-curve slopes, the aspect ratios of the surfaces in each position were calculated using the exposed semispans indicated in figures 3(b) and 3(c) and the exposed area. Using these values of aspect ratio and assuming the effective local Mach number to be 0.94 in the case of the surfaces on the cone at a Mach number of 1.2 (fig. 2), the Weissinger method presented in reference 2 yielded values from 92 to 107 percent of those measured for all Mach numbers and surface locations except for the surfaces on the cylinder at a Mach number of 1.2. For this case, the supersonic triangular-wing theory of reference 3 predicted a value 108 percent of that measured. For all test conditions, therefore, a theoretical method could be employed to predict adequately the measured results.

The drag of the surfaces at a Mach number of 1.2 (fig. 11) is much larger for the cylindrical location and indicates that a drag rise has probably occurred for this condition, but not for the surfaces in the conical-flow field. This drag rise is more evident in figure 12, which presents the drag data for all Mach numbers tested. In order to confirm these data the approximate drag-rise Mach numbers of the surfaces in each location were calculated by assuming an airfoil-section critical Mach number of 0.70, correcting for aspect ratio by a method in reference 4, applying the usual cosine factor to account for sweepback, and assuming the drag rise to occur at a Mach number 0.05 higher than the critical Mach number. The resulting drag-rise Mach numbers were 1.16 for the surfaces on the cone and 1.00 for the surfaces on the cylinder. Since the effective Mach numbers at the surface locations are approximately 0.94 for the conical case and 1.2 for the cylindrical case, it becomes obvious that a drag rise would be expected for the cylindrical case, but not for the conical location.

Since the minimum drag for the surfaces on the cone at all Mach numbers (fig. 12) is lower than would be expected from a consideration of skin friction alone, it must be assumed that there is a definite favorable surface-body interference effect on the drag with the surfaces in this position. This effect is not obvious for the cylindrical location. The greater increase of drag coefficient with increase in incidence of the surfaces in the cylindrical position is due to the increased lift of the surfaces in this position.

The variations of lift coefficient with drag coefficient for the surfaces in the two locations at a Mach number of 1.2 are presented in figure 13. It is evident that for the lift-coefficient range tested, the delay in the drag rise and the favorable surface-body interference effect on the drag realized by moving the surfaces from a cylindrical to a conical location on the body have resulted in a considerable saving in drag for a given lift. At subsonic free-stream Mach numbers such a comparison would not reveal any definite advantage of one location over the other.

It is indicated, then, that placing the surfaces in the subsonic conical-flow field does delay the adverse effects of compressibility at supersonic Mach numbers and does result in an advantage for this location. However, in a practical application of these results, such as the design of control surfaces for aircraft or missiles, other factors must be considered. High body drags are associated with the comparatively large cone apex angles required to produce the subsonic conical-flow field. For instance, if the semiapex angle of the cone were reduced from the present 17.5° to an angle of 10°, the area of subsonic flow over the cone would not exist, but the body drag would be reduced approximately 58 percent. This reduction in body drag would be on the order of 600 percent of the reduction in surface drag realized by locating the surfaces in the subcritical conical-flow field instead of on the cylindrical portion of the body. Also, it is clear from figure 2 that the region of subsonic conical flow is small and that the use of surfaces large enough to take advantage of the lower drag for a given lift may not be practicable.

CONCLUSIONS

The following may be concluded from tests of low-aspect-ratio triangular-plan-form lifting surfaces located on the conical and on the cylindrical portions of a body at a Mach number of 1.2 and at several subsonic Mach numbers:

1. Much lower lift-curve slopes were indicated for the surfaces when on the cone than when on the cylinder. Subcritical drag

coefficients were obtained at all Mach numbers tested for the surfaces when on the cone, whereas supercritical values were obtained for the surfaces when on the cylinder at a Mach number of 1.2.

2. Considerably lower drag for a given lift for the surfaces in the conical location at a Mach number of 1.2 indicated that at supersonic free-stream Mach numbers an improvement in the aerodynamic characteristics of lifting surfaces could be obtained by locating them in the subsonic conical-flow field. However, in taking advantage of this result in practical applications, the higher body drag associated with the comparatively large cone apex angle required and the small region of useable subsonic conical flow must be considered.

3. Theoretical methods could be used to predict adequately the lift-curve slopes of the surfaces in both locations at all Mach numbers tested.

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2. DeYoung, John: Theoretical Additional Span Loading Characteristics of Wings with Arbitrary Sweep, Aspect Ratio, and Taper Ratio. NACA TN 1491, 1947.

3. Brown, Clinton E.: Theoretical Lift and Drag of Thin Triangular Wings at Supersonic Speeds. NACA Rep. 839, 1946.

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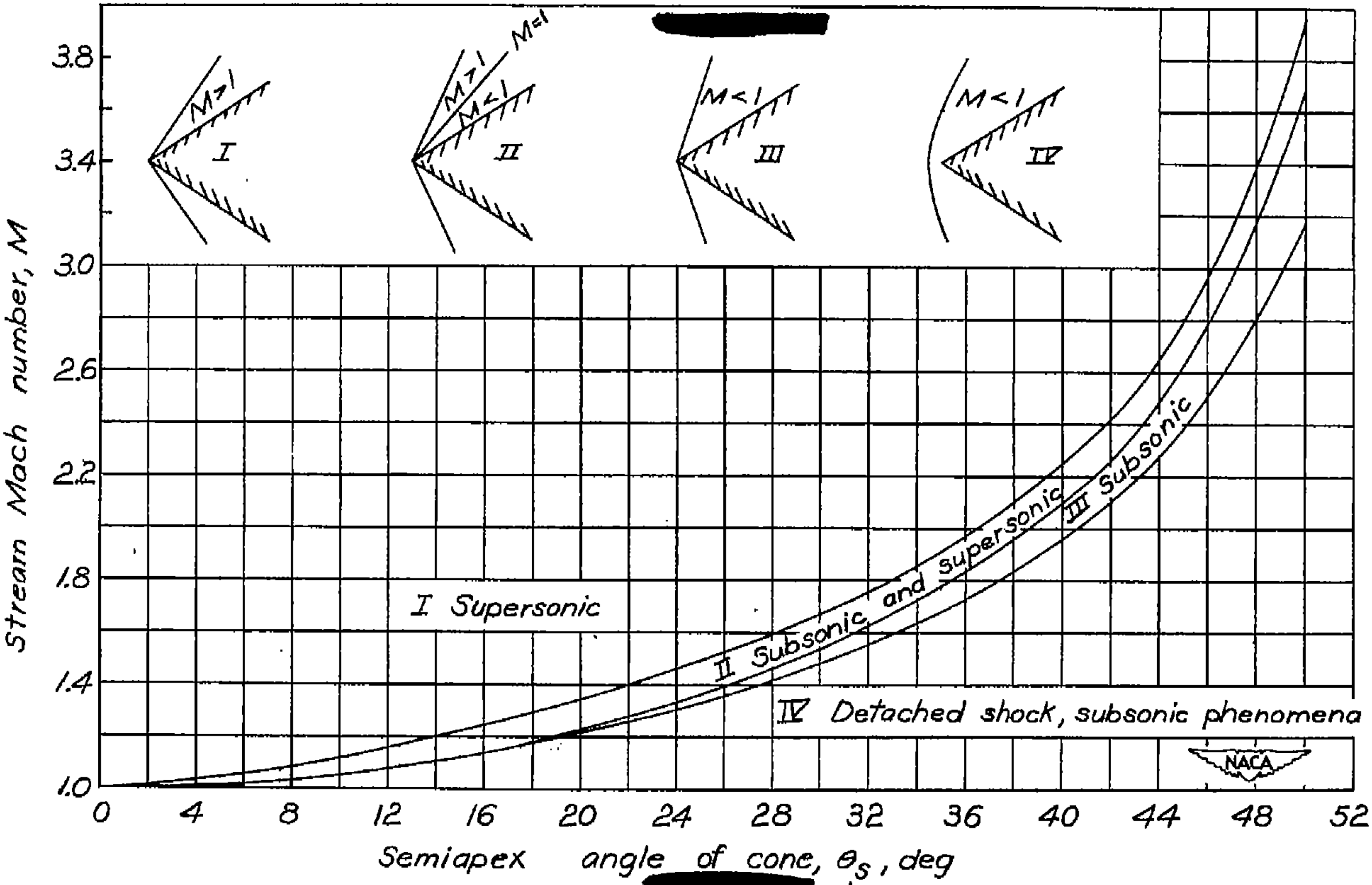

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Figure 1.– Regions of flow over cones.

[redacted]

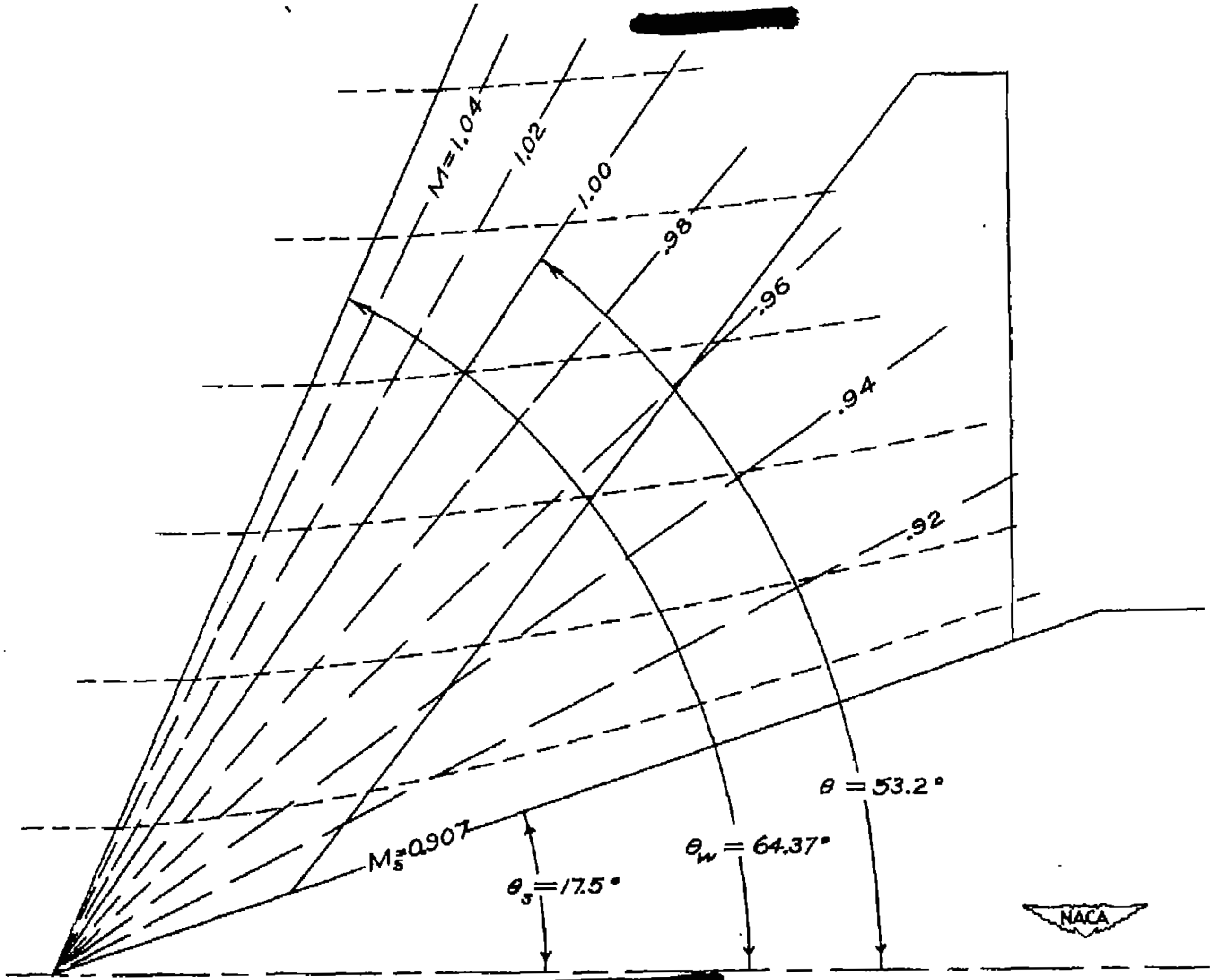

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Figure 2.– Flow field about cone with $\theta_s = 17.5^\circ$: M = 1.2. (Lifting surface on cone also shown.)

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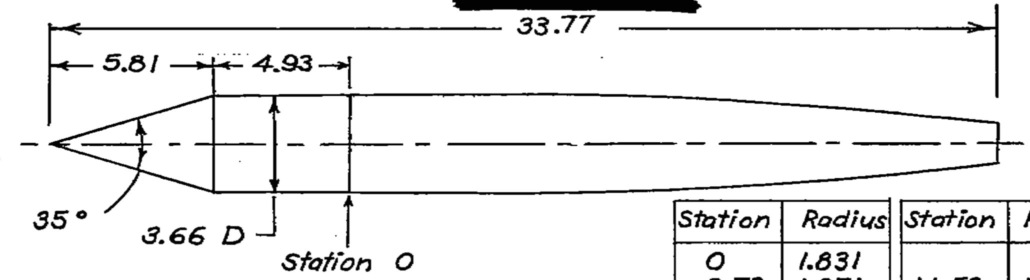
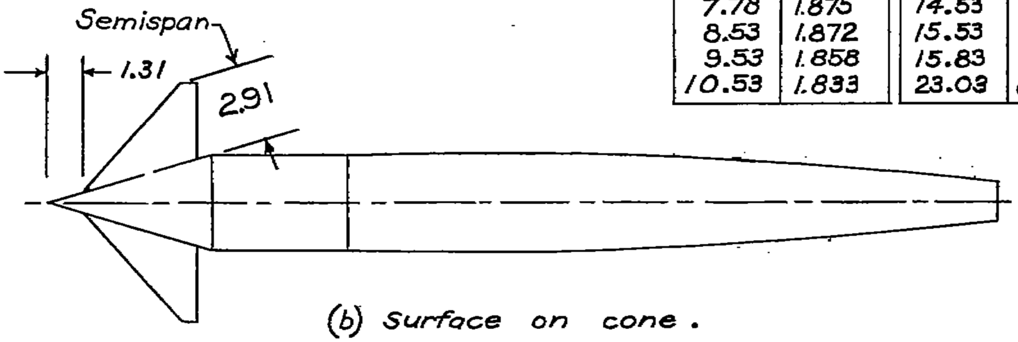
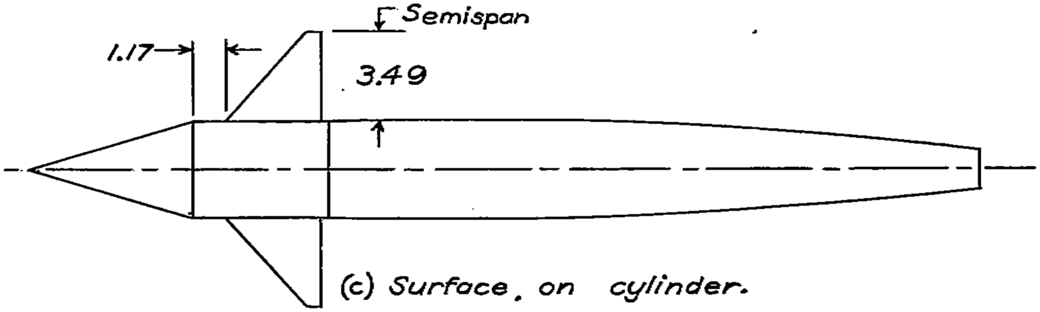


(a) Basic body.

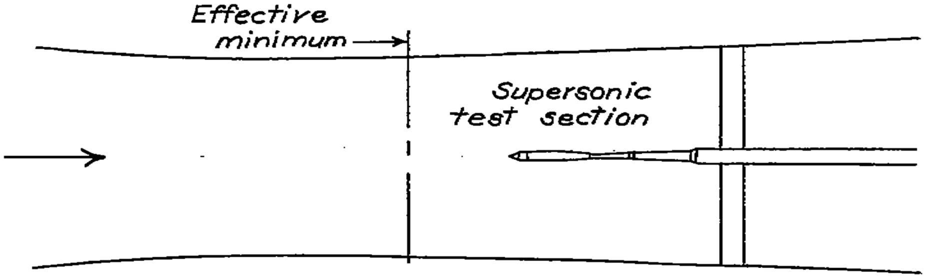
Station	Radius	Station	Radius
0	1.831		
0.53	1.851	11.53	1.794
1.53	1.871	12.53	1.743
2.53	1.875	13.53	1.679
7.78	1.875	14.53	1.602
8.53	1.872	15.53	1.513
9.53	1.858	15.83	1.484
10.53	1.833	23.03	0.780



(b) Surface on cone.



(c) Surface, on cylinder.



(d) Tunnel arrangement.

[redacted]

Figure 3.– Model details and arrangement in the Langley 8-foot high-speed tunnel. All dimensions in inches.

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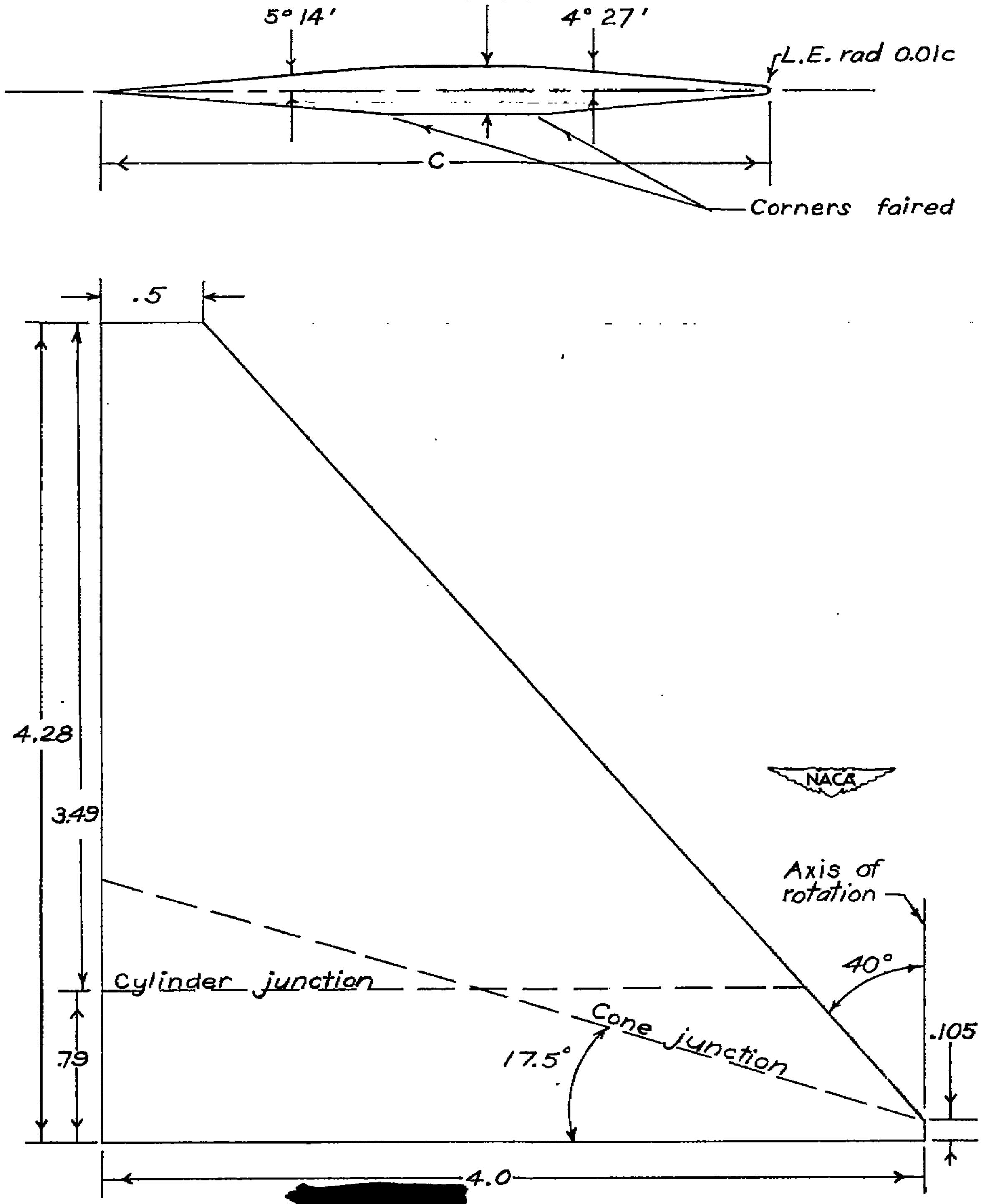

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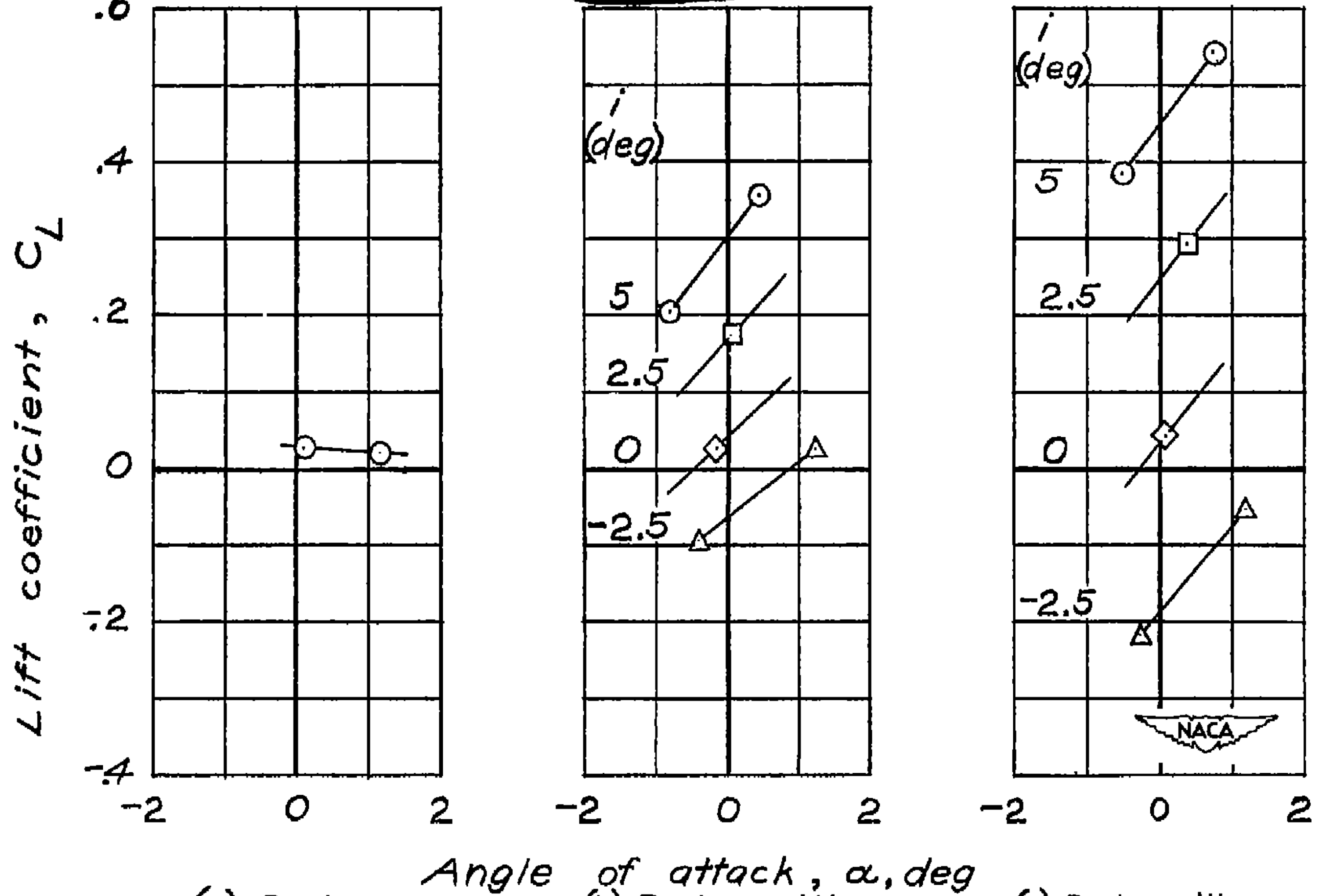
Figure 4.- Details of lifting surface. All dimensions in inches

[redacted]



(a) Body.

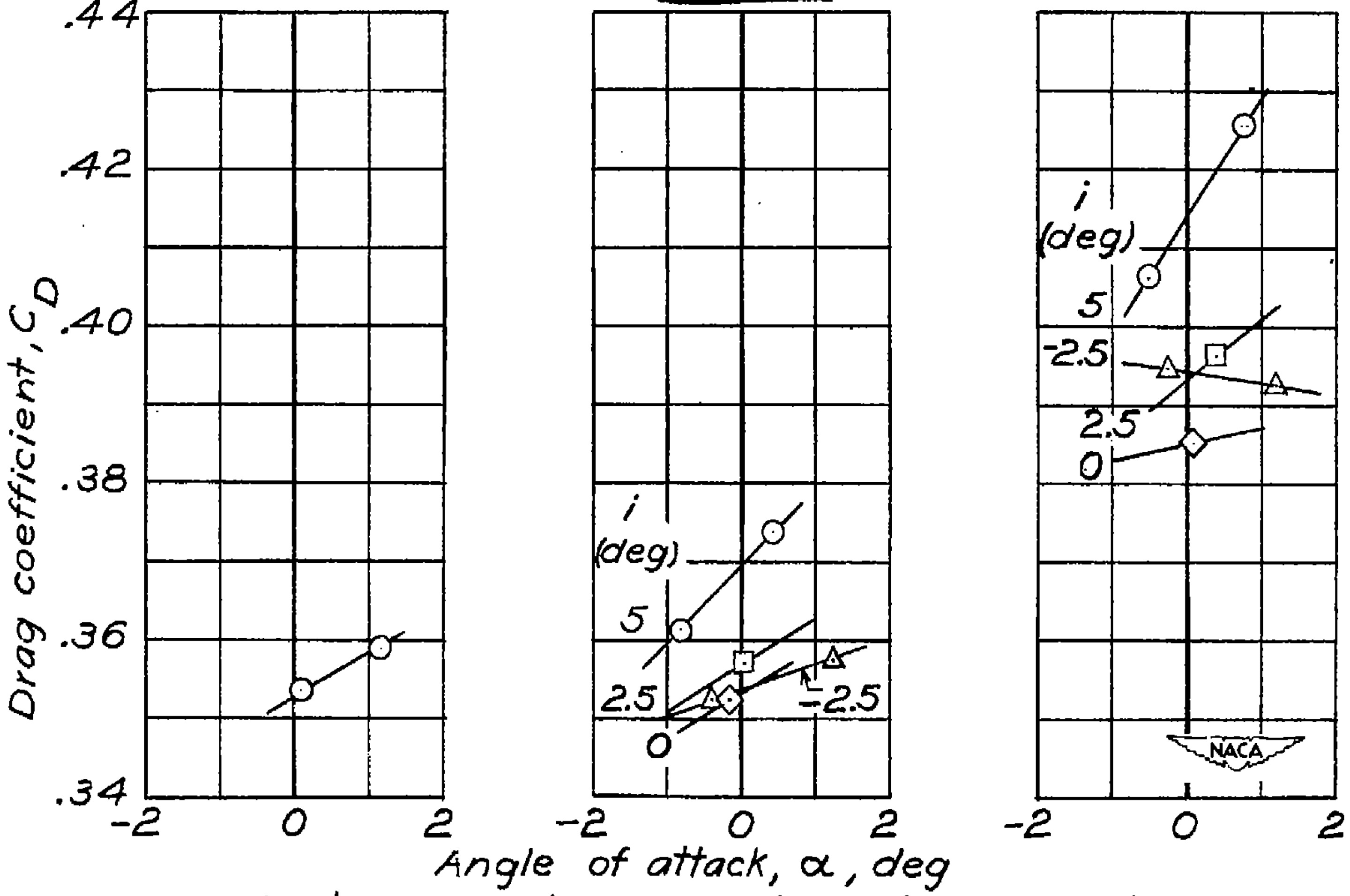
(b) Body with surface on cone.

(c) Body with surface on cylinder.

[redacted]

Figure 5.- Variation of lift coefficient with angle of attack and surface incidence for various test arrangements. M = 1.2.

[redacted]



(a) Body.

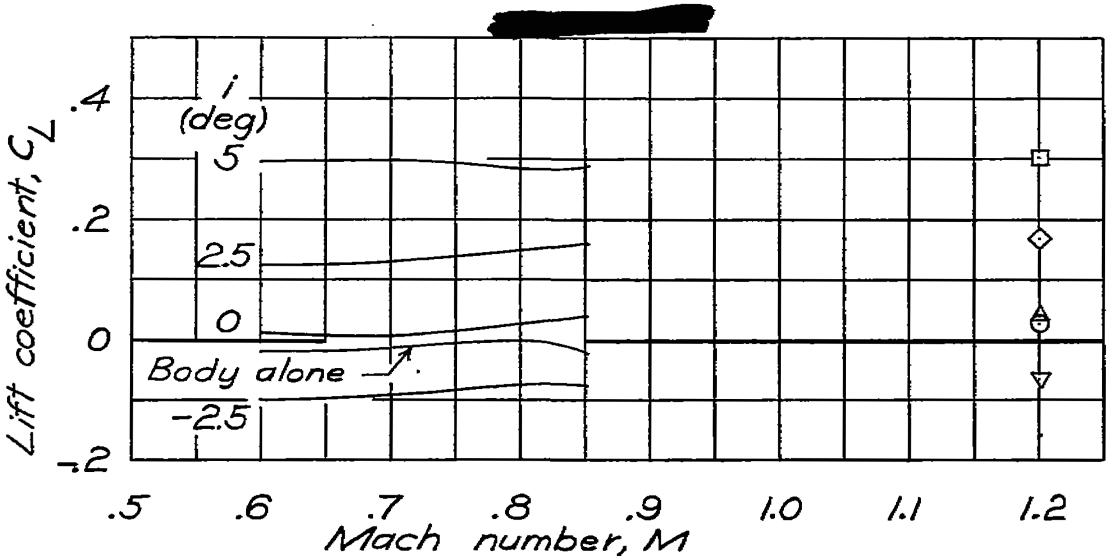
(b) Body with surface on cone.

[redacted]

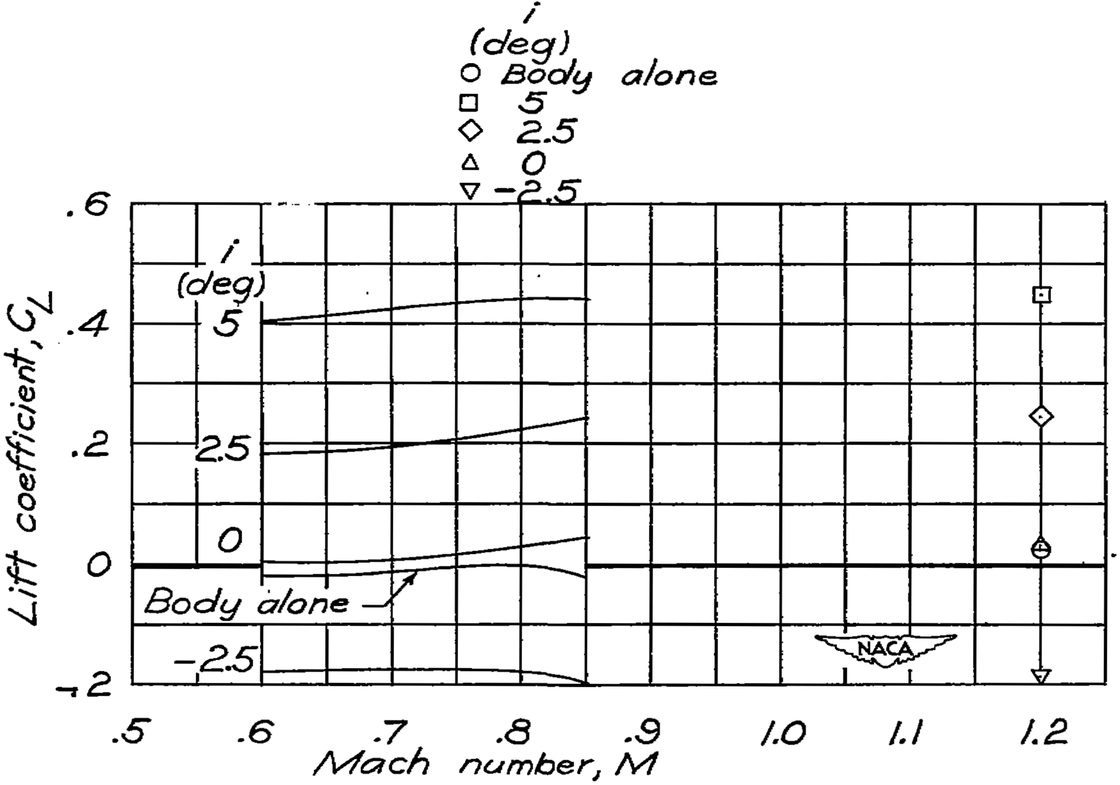
(c) Body with surface on cylinder.

Figure 6.– Variation of drag coefficient with angle of attack and surface incidence for various test arrangements. M = 1.2.

[redacted]



(a) Surface on cone.



(b) Surface on cylinder.

[redacted]

Figure 7.– Variation of lift coefficient with Mach number for various test arrangements. $\alpha = 0^{\circ}$.

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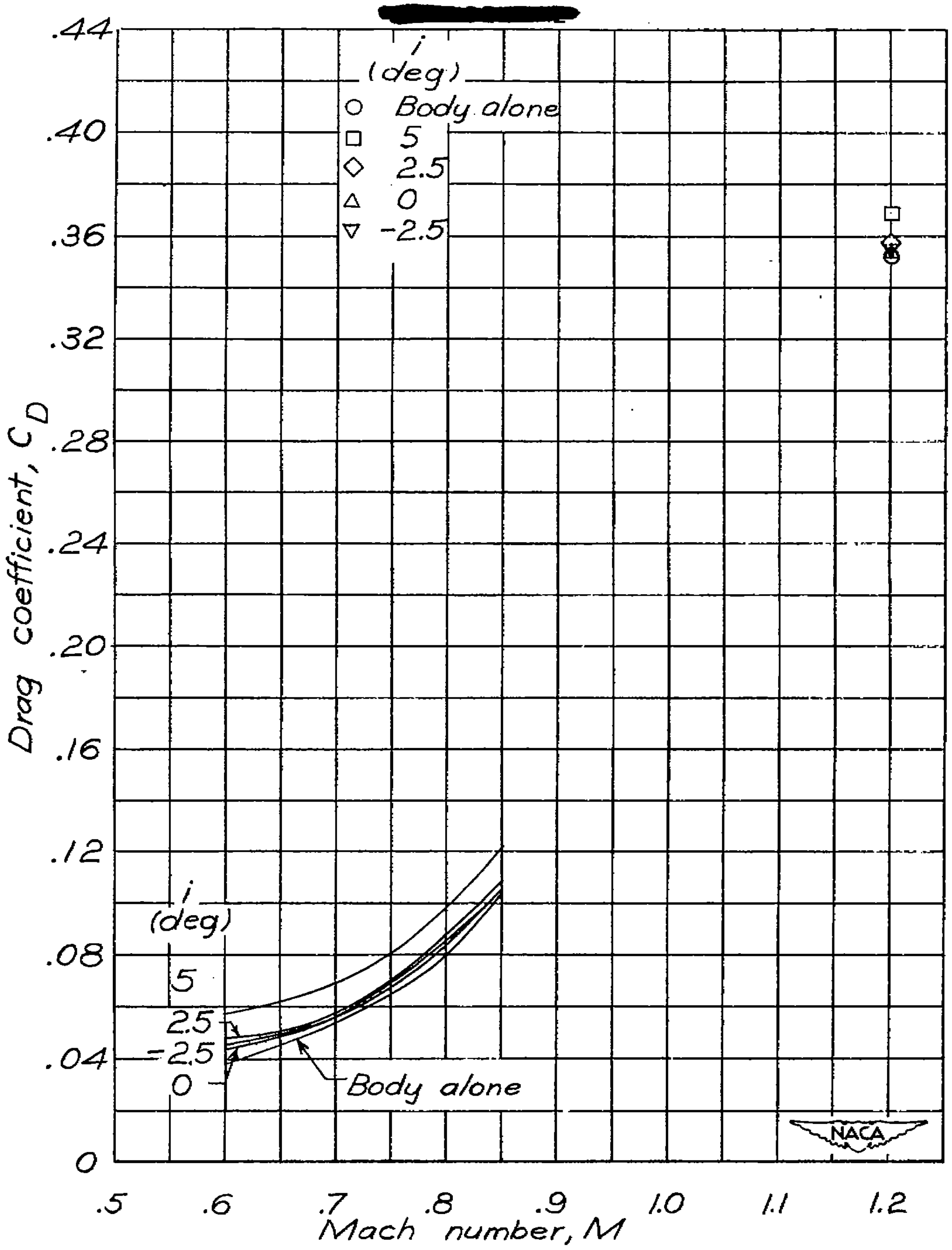
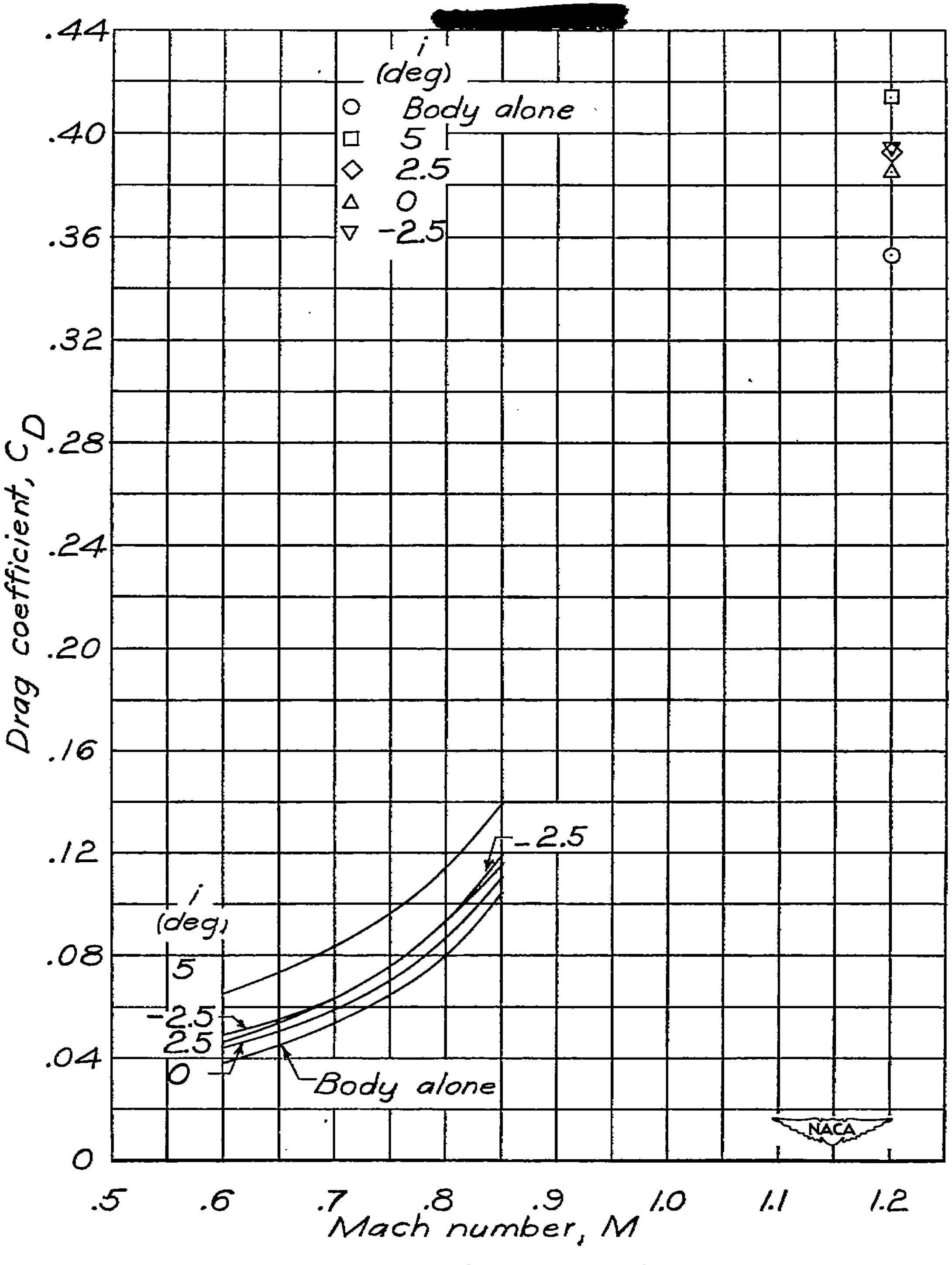


(a) Surface on cone.

[redacted]

Figure 8.- Variation of drag coefficient with Mach number for various test arrangements. $\alpha = 0^\circ$.

[redacted]



(b) Surface on cylinder.

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Figure 8.— Concluded.

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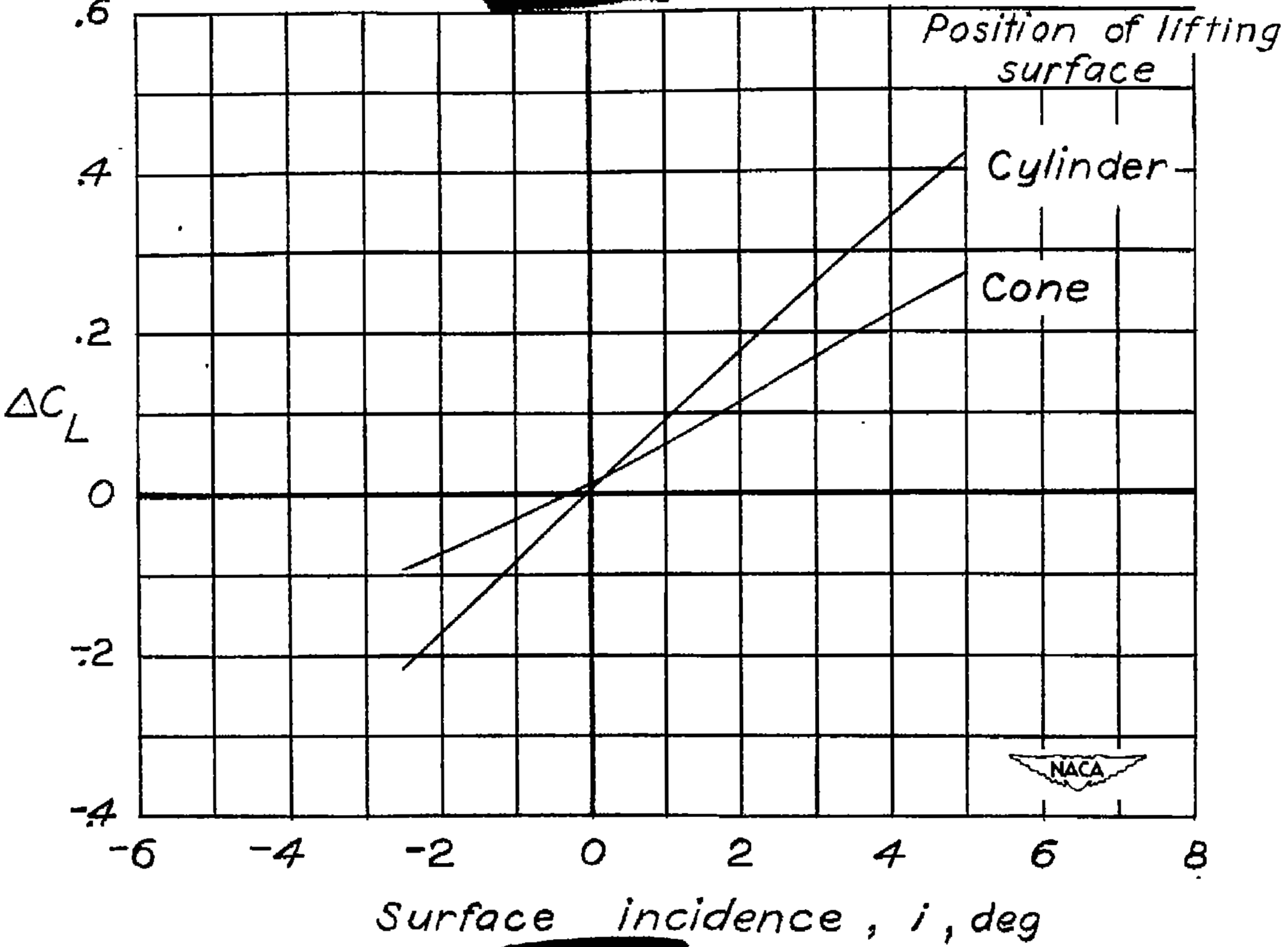

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Figure 9.– Variation of incremental lift coefficient of lifting surface with surface incidence. $\alpha = 0^{\circ}$; $M = 1.2$.

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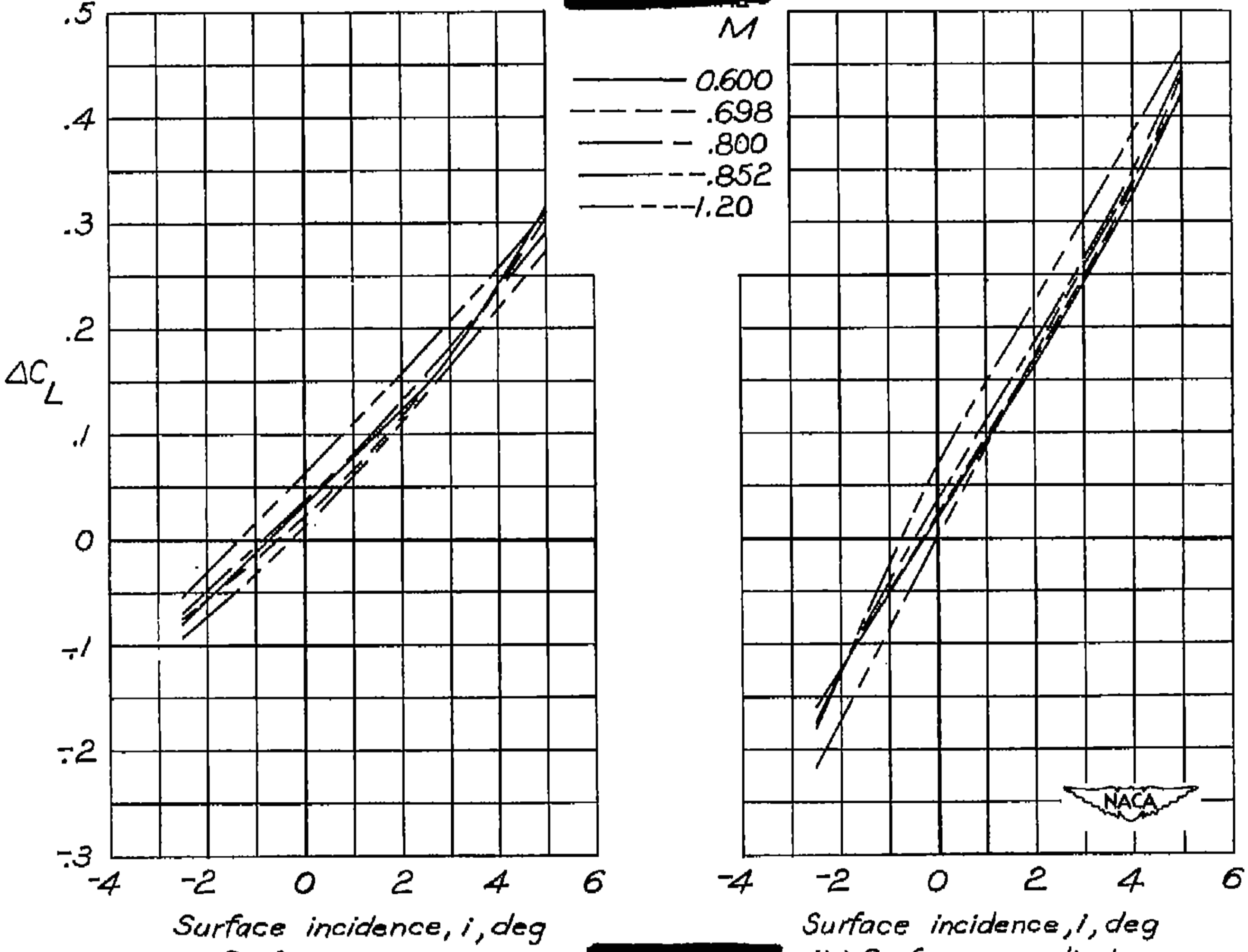


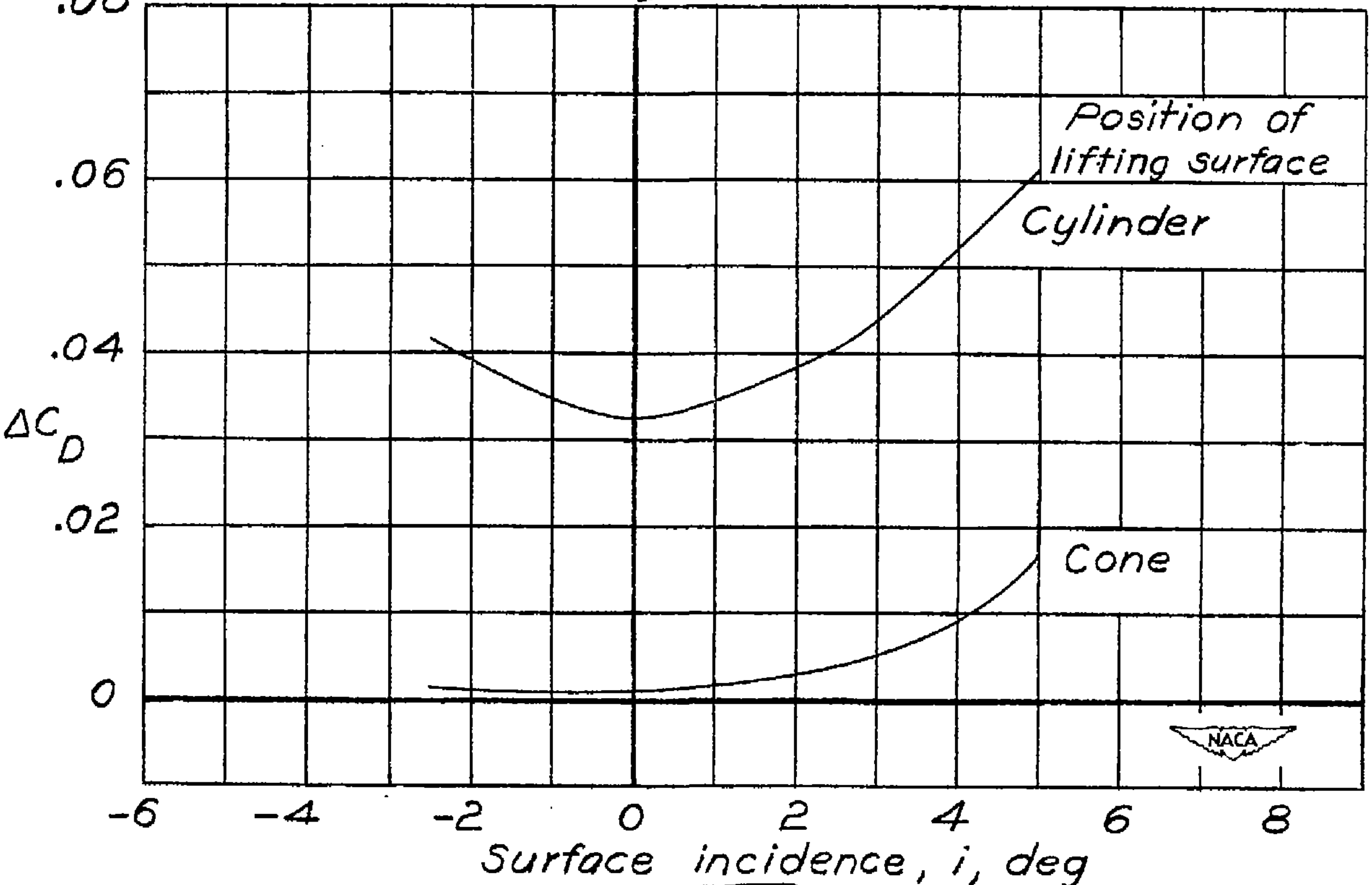
(a) Surface on cone.

[redacted]

(b) Surface on cylinder.

Figure 10.- Variation of incremental lift coefficient of lifting surface with surface incidence for various Mach numbers. $\alpha = 0^\circ$.

[redacted]



[redacted]

Figure 11.– Variation of incremental drag coefficient of lifting surface with surface incidence. $\alpha = 0^\circ$; $M = 1.2$.

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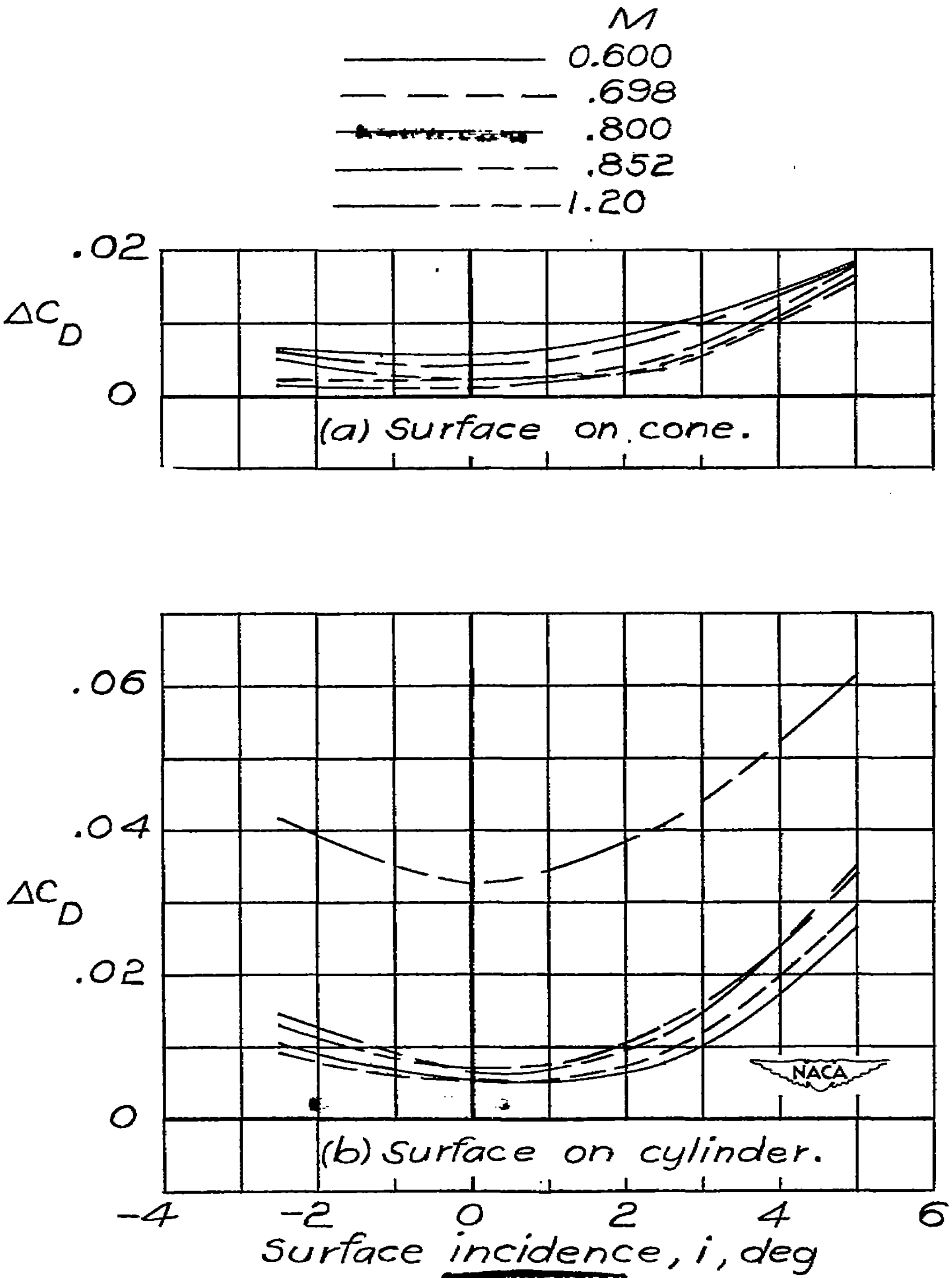

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Figure 12.– Variation of incremental drag coefficient of lifting surface with surface incidence for various Mach numbers. $\alpha = 0^\circ$.

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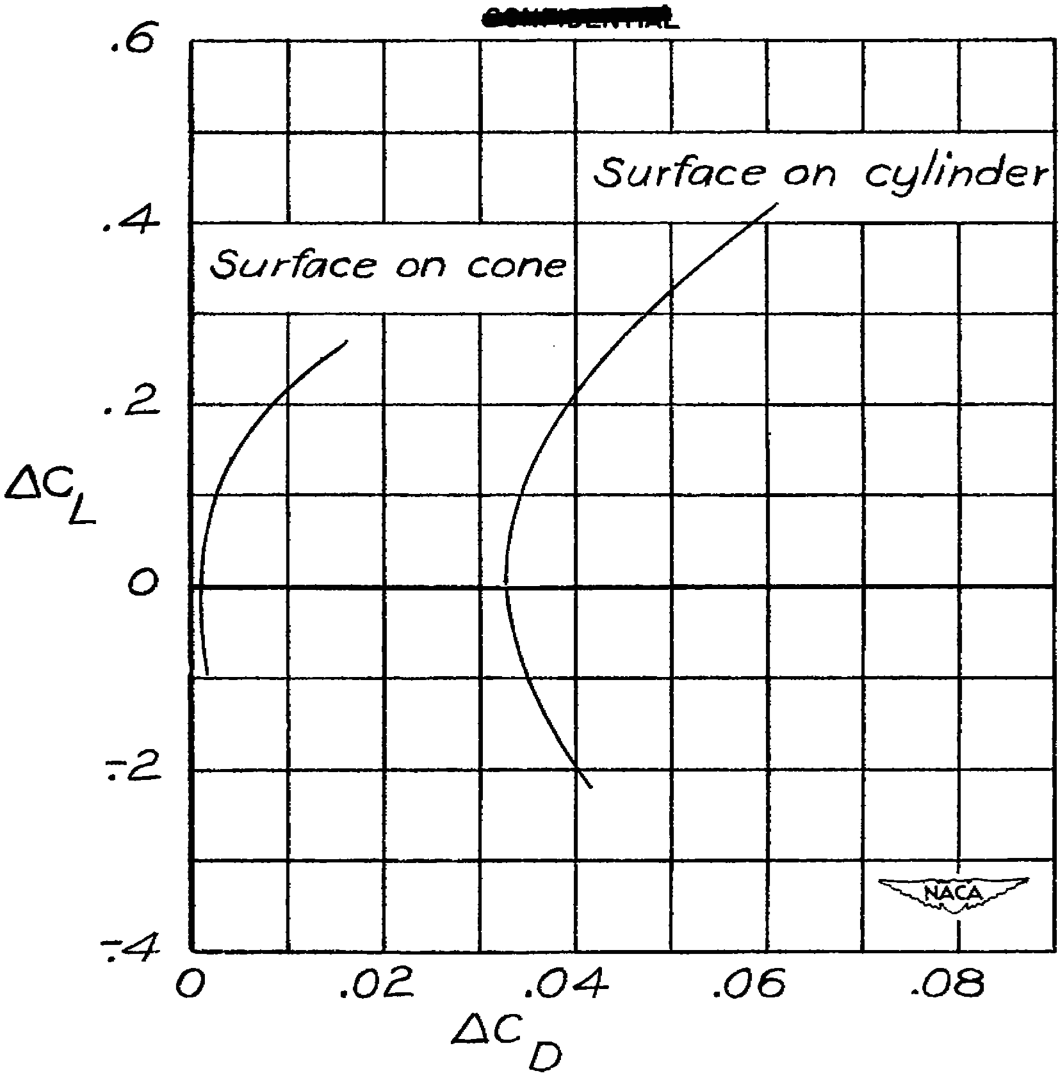

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Figure 13.— Variation of incremental lift coefficient with incremental drag coefficient for lifting surface. $\alpha = 0^{\circ}$; $M = 1.2$.

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