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NASA TM X-398

Classification changed to declassified
effective 1 April 1963 under
authority of NASA CCN 2 by
J. J. Carroll

[redacted]
Change of Security Marking Dtd 2/15

N63-13904

TECHNICAL MEMORANDUM

code-1

X-398

A WIND-TUNNEL INVESTIGATION AT SUBSONIC AND LOW SUPERSONIC SPEEDS OF A RE-ENTRY VEHICLE WITH RETRACTABLE WINGS

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24P 553998

CLASSIFIED DOCUMENT - TITLE UNCLASSIFIED

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON February 1961

CONFIDENTIAL

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TECHNICAL MEMORANDUM X-398

A WIND-TUNNEL INVESTIGATION AT SUBSONIC AND LOW SUPERSONIC SPEEDS OF A RE-ENTRY VEHICLE WITH RETRACTABLE WINGS*

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SUMMARY

An experimental investigation was conducted to study the aerodynamic characteristics of a winged re-entry vehicle, with emphasis on the lift capabilities and lift-drag ratios necessary for a glide landing. A blunted half-cone body was fitted with wings of triangular plan form which were shaped to match the body contours when retracted. Static longitudinal and lateral characteristics were measured at Mach numbers of 0.25, 0.90, and 2.20 and angles of attack of from -8° to 22° and sideslip angles of from -6° to 16°.

Analysis indicated that the model with wings developed from the body had a sufficiently large lift-drag ratio to perform a safe glide landing.

INTRODUCTION

The problem of landing a vehicle capable of entry into the earth's atmosphere is vitally important for manned space flight. This problem is made difficult by the tremendous speed range from orbital velocity to a soft landing. Also, certain limitations imposed on the shape and size of the vehicle by the launch and high heating phases of the flight cannot be compromised. The vehicle, when mounted on the booster with appropriate fairings, should be nearly symmetrical to minimize aerodynamic moments, and should have the center of gravity near the thrust line. Further, the lateral area should be small to minimize the aerodynamic destabilizing effect of the vehicle on the booster. The aerodynamic heating encountered on entry requires that the vehicle have a blunt nose and no sharp corners or protuberances.

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*Title, Unclassified

Currently, three methods of vehicle recovery, or combinations of these methods, are being considered:

1. Terminal descent by parachute.
2. Terminal deceleration by retrorocket.
3. Controlled glide landing.

Of the three methods, the glide landing is the best for controlling impact point and avoiding local landing hazards. A vehicle of the glide-landing type will be the subject of this paper.

One solution to the problem of glide-landing a re-entry vehicle, compatible with the restrictions mentioned previously, would be to use auxiliary aerodynamic lifting surfaces which would be retracted during the critical high-speed part of the atmosphere entry. A compact body of simple geometric shape could then be used for the basic vehicle. If the wings were retracted, stagnation-point heating on the wings could be avoided and thermal contact between wing and body would permit the wing structure to be cooled by conduction. To evaluate the landing characteristics of a re-entry vehicle, many factors such as reliability and weight penalty must be considered. The scope of the present work is, however, limited to a study of the aerodynamic characteristics of a re-entry vehicle with retractable wings.

A blunted 13° half-cone designed to have hypersonic manuevering capabilities and to stay within the heating-rate limitations of current materials (ref. 1) was chosen for the basic vehicle shape. This shape seemed well suited for this study since wings of rather large area could be evolved from the conical part of the body. Hinges for extending the wings could be placed at the side edges of the flat body top, out of the region of highest local heating rates. There are a number of problems associated with this concept, such as interrupting the heat shield to extend the wings, but they appear to be within the scope of future technology.

Although this paper is primarily concerned with landing characteristics, data were obtained at Mach numbers of 0.90 and 2.20 as well as 0.25. These higher speeds are of interest since the wings may be extended subsequent to the high heating phase of the atmosphere entry, but at high altitude, to increase the glide distance and the time in the terminal glide.

NOTATION

The aerodynamic coefficients presented in this report are referenced to the stability axes system except the lift and drag which, of course, are referenced to the wind axes system. The moment reference location was 48 percent of the body length measured from the nose (fig. 1).

b wing span, ft

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_m pitching-moment coefficient, $\frac{\text{pitching moment}}{qSl}$

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

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

h altitude, ft

l body length, ft

M Mach number

q dynamic pressure, lb/sq ft

S reference area (projected area of wing and body), sq ft

V velocity, knots

α angle of attack measured from body cone axis, deg

β sideslip angle, deg

APPARATUS AND TEST PROCEDURE

The experimental investigation was conducted in the Ames 6- by 6-Foot Supersonic Wind Tunnel. This is a closed-return, continuous-operation wind tunnel in which both the Mach number and Reynolds number are variable. The model was mounted on a sting support system in the tunnel which permitted the model attitude to be varied during tunnel operation. A bent sting was used to obtain combined angles of attack and sideslip.

The entire test was performed at a constant Reynolds number of 2.0 million per foot. Data were obtained at Mach numbers of 0.25, 0.90, and 2.20 at angles of attack from -8° to 22° and also at sideslip angles from -6° to 16° with the angle of attack held constant at 10°.

The aerodynamic forces and moments were measured with a six-component strain-gage balance mounted in the model. The model angle of attack was measured by a gravity-actuated electrical transducer. Electrical outputs of the balance and model attitude transducer were automatically recorded and then converted to standard NASA coefficients by means of an electronic digital computer.

The models used in the investigations were basically blunted half-cone bodies with triangular plan-form wings which were developed from the body contours (figs. 1 and 2). The wing panels hinged about the intersections of the conical portion of the body and the flat top. The leading edges of the wing intersected the body just aft of the blunt nose. When retracted, the wings lay close against the lower body surface with the wing tips meeting at the plane of symmetry.

The body of Model I was a portion of a right-circular cone of 13° half angle. Wing panels on this model were then truly conic surfaces and, of course, highly cambered and twisted. The wing of this model is referred to as the conical wing. Flat wings of identical projected plan form were investigated for comparison with the conical wings. (See fig. 1 for model dimensions.)

Model II (fig. 1(b)) was similar to the first model except the wing was essentially flat from the hinge line to the 0.80 semispan ray. The wing was slightly twisted with 20 percent of the local span deflected down to the original conic surface; and the juncture of the flat and conic surface was rounded. This wing is referred to herein as the cambered wing. The body sides were cut down to match the contours of the cambered wing. As a result, the body was somewhat slab-sided with a base area approximately 12 percent less than that of Model I.

The wings used in the investigation were formed from flat stock and had half-round leading edges and square trailing edges. Because of the preliminary nature of this investigation, the wings were attached to the upper surface of the body with no attempt to simulate hinges or body recesses for wing retraction. The body with wings removed represented the vehicle with wings retracted.

RESULTS AND DISCUSSION

The results of this investigation show the longitudinal and lateral aerodynamic characteristics of the blunted half-cone body with and without wings. Two wing shapes with different amounts of camber and twist were tested as well as a flat wing which provided a basis for evaluating the performance of the cambered wings. The discussion is general since the models do not represent specific vehicle designs. Longitudinal and lateral aerodynamic characteristics of the basic half-cone body at Mach numbers of from 3 to 5 are presented in reference 1.

Comparison of the aerodynamic characteristics of Model I with the conical wing and with the flat wing (fig. 3) shows the lift effectiveness of the conical wing to be equal to that of the flat wing. Also, the model with the conical wing did not exhibit the pitch-up tendency shown with the flat wing at a Mach number of 0.25. The conical wing model had a rather large positive pitching-moment coefficient at zero lift which resulted in longitudinal trim at higher lift coefficients than for the flat-wing model. However, a serious drawback was the large drag penalty at low to moderate lift coefficients due to the excessive camber of the conical wing. At the highest lift coefficient at subsonic speeds (fig. 3), the beneficial effects of camber become evident by the lesser drag coefficient for the cambered wing model compared to the flat wing model. A further comparison of the flat and cambered wings is shown in the plot of lift-drag ratio versus lift coefficient (fig. 4). The drag penalty at moderate lift coefficients resulted in a lower lift-drag ratio for the conical-wing model than for the flat-wing model although this decrement decreased with further increase in lift coefficient. These results indicate the need for a modification to the wing shape to reduce the adverse effects of camber.

The reduction of wing camber and the body modification of Model II provided a significant drag reduction without affecting the characteristic of positive pitching moment at zero lift or the linear variation of pitching-moment coefficient with lift coefficient. The maximum lift-drag ratios obtained with Model II with the cambered wing (fig. 4) were equal to those of Model I with the flat wing except at a Mach number of 2.2 where Model II equaled or exceeded the flat-wing value only above a lift coefficient of 0.6. Changes in body shape to match the revised wing contours resulted in only small aerodynamic changes in the speed range of this investigation. The effects of these changes at hypersonic speed on the aerodynamic characteristics and aerodynamic heating of the body are unknown.

The contribution of the auxiliary wings to the static lateral and directional stability was determined in these tests for the model at a constant angle of attack of 10°, which was believed to be representative of the flight regime under consideration. The variations of rolling-moment, yawing-moment, and side-force coefficient with sideslip angle shown in figure 5 are almost linear with the exception of the yawing-moment variation for Model I with the conical wing. Model I was found to have a rather large positive dihedral effect because of the high wing position. A negative geometric dihedral angle was used in Model II to reduce this excessive roll stability. Addition of either the conical wing or the cambered wing increased the directional stability of the model except at a Mach number of 0.25 where the contribution of the cambered wing of Model II was negligible.

Calculations were made to evaluate the potential landing approach characteristics for Model II. A power-off glide landing approach technique is described in reference 2 for vehicles capable only of low lift-drag ratios. This glide approach technique consists of three phases: (1) steady glide at constant angle, (2) constant g pull-out, and (3) straight flight path to touchdown. It was shown in reference 2 that experienced pilots could perform this approach with accuracy and consistency. The profile of the approach calculated from the experimental data for Model II is shown in figure 6 for an assumed wing loading of 50 pounds per square foot which was determined from a conservative estimate of the vehicle weight for a 3-man, 14-day space mission. For comparison, the profile for the test airplane employed to check the approach technique of reference 2 is also shown in figure 6.

The landing profile of Model II (fig. 6) is similar to that of the test airplane differing mainly in a lower speed throughout the approach, a lower altitude for initiation of the flare, and a shorter length of the final approach phase. The final approach phase is of 11-seconds duration for both vehicles. In view of the similarity of the profiles and of the successful flights of the test airplane (ref. 2), it appears that with the same piloting techniques a vehicle with the configuration of Model II could be landed successfully at a selected point. As an additional consideration, the maximum lift-drag ratio for the test airplane and Model II was 2.8 and 3.2, respectively; reference 3 suggests a lift-drag ratio of 2.5 as the practical lower limit for flared landings.

It should be noted that the wing loading of the test airplane (fig. 6) was 75 psf as contrasted to a wing loading of 50 psf for Model II. With wing loading increased to 75 psf the glide approach performed near maximum lift-drag ratio by Model II would be somewhat faster but still would be slower than that of the test airplane (because of the higher lift coefficient for maximum lift-drag ratio for Model II). Variations of initial glide angle, flare initiation speed, and length of final approach for both the test airplane and Model II are restricted because of the low values of maximum lift-drag ratios. The approach profiles for

Model II could be limited by pilot visibility and landing-gear considerations (ref. 4); however, these considerations are beyond the scope of the present paper.

The model configuration tested was designed to achieve a maximum wing area with a wing evolved from the body contours, and the center of gravity was chosen so that the static margin at landing speed would be 3 percent of the body length. Experimental results (fig. 3) show that at a Mach number of 2.2 the model with wings retracted has a 14-percent static margin. Thus, it appears that the present configuration would have a serious control problem if the lift and drag are to be varied in the high speed (wings retracted) phase of the atmosphere entry. However, a vehicle of this type could be designed with a center-of-gravity location which would result in satisfactory longitudinal stability of the body at supersonic speeds and with a more rearward wing (reduced area) which would give equally satisfactory stability at subsonic speeds with the wings extended.

CONCLUDING REMARKS

An experimental investigation has been conducted to study the static aerodynamic characteristics of a winged re-entry vehicle at subsonic and supersonic speeds. The main objective of this investigation was to determine if satisfactory landing characteristics could be achieved by using retractable wings on a blunted half-cone body.

Results of the investigation showed that the wings evolved from the conical surface of the body developed lift capabilities and pitching-moment characteristics as good as those of a flat wing of identical plan form. The large drag penalty associated with the excessive camber and twist of the conical wing was substantially reduced by a simple configuration revision which reduced the extent of the camber and also reduced the base area at the expense of reduced volume of the body.

The model with reduced camber had sufficient lift and lift-drag ratios to perform a safe glide landing.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Sept. 27, 1960

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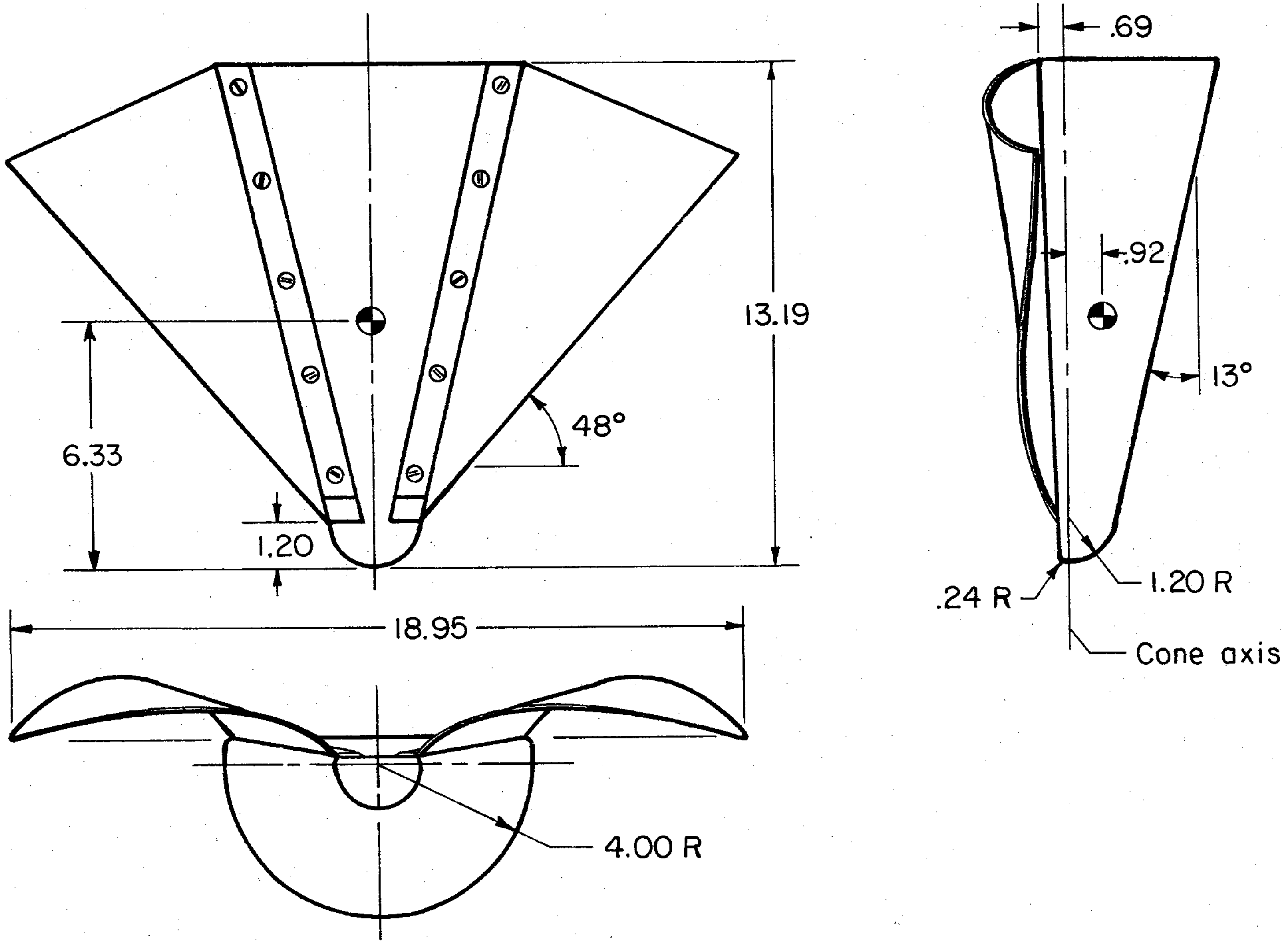
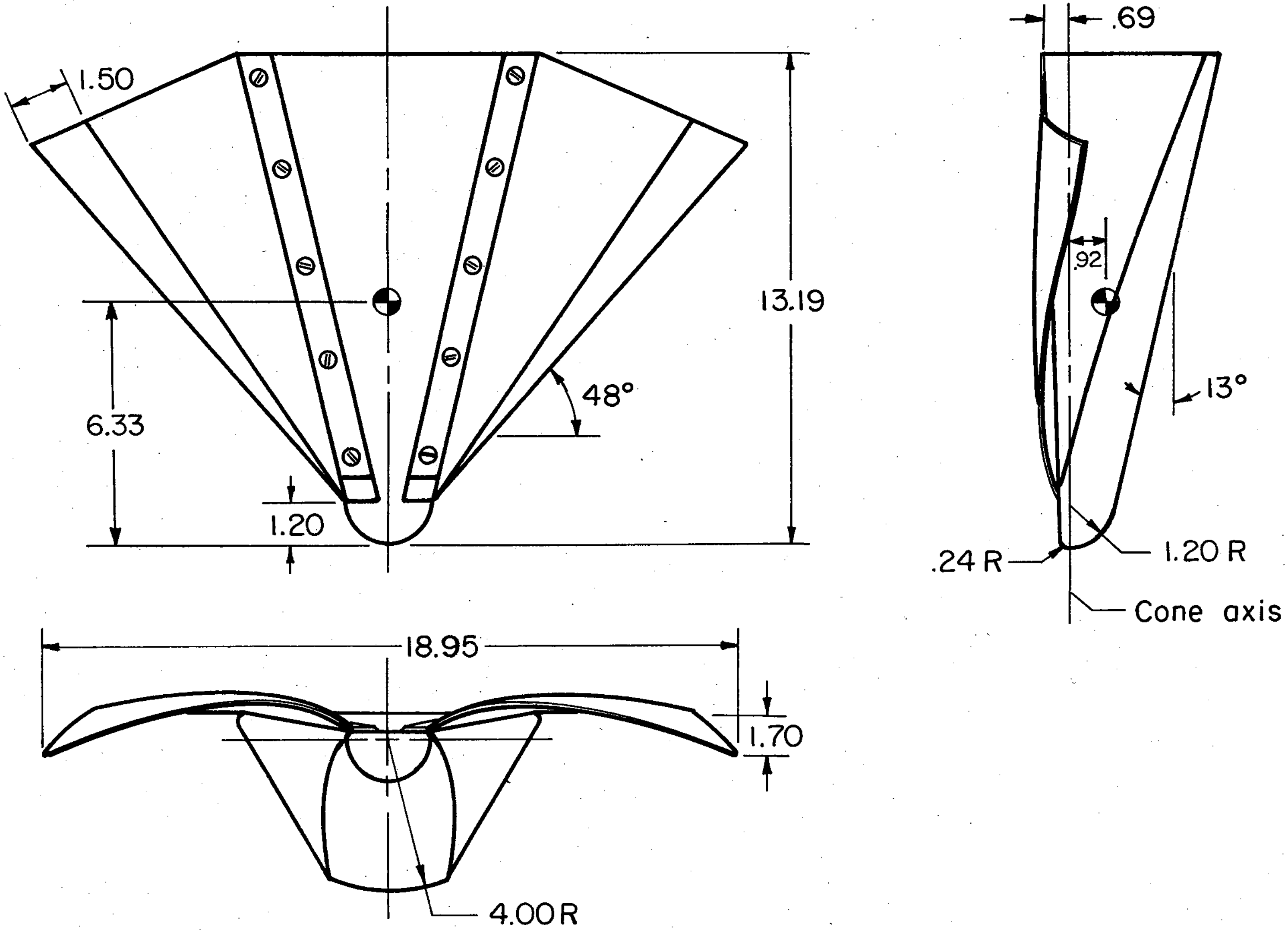


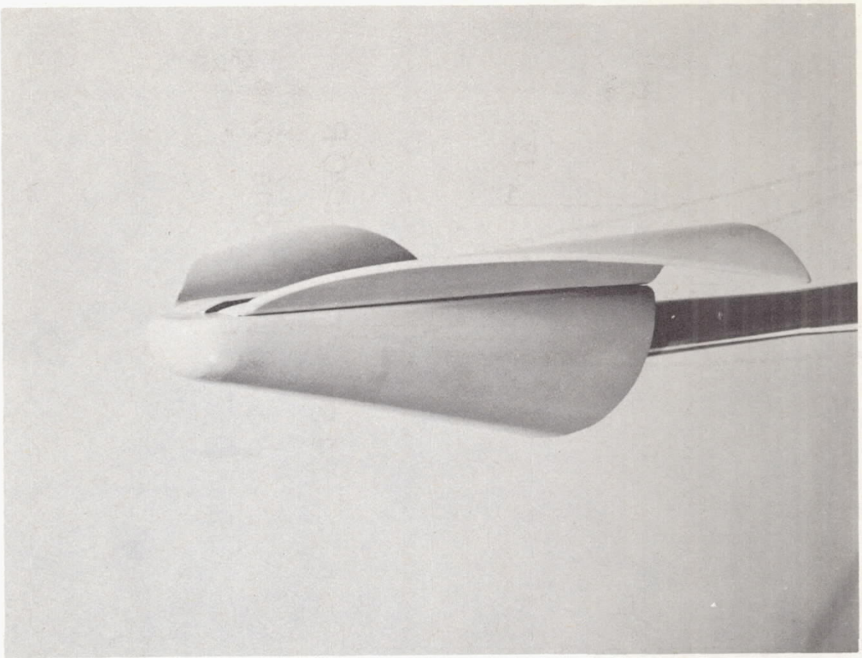
(a) Model I.

Figure 1.- Dimensional drawings of models; dimensions in inches.



(b) Model II.

Figure 1.- Concluded.



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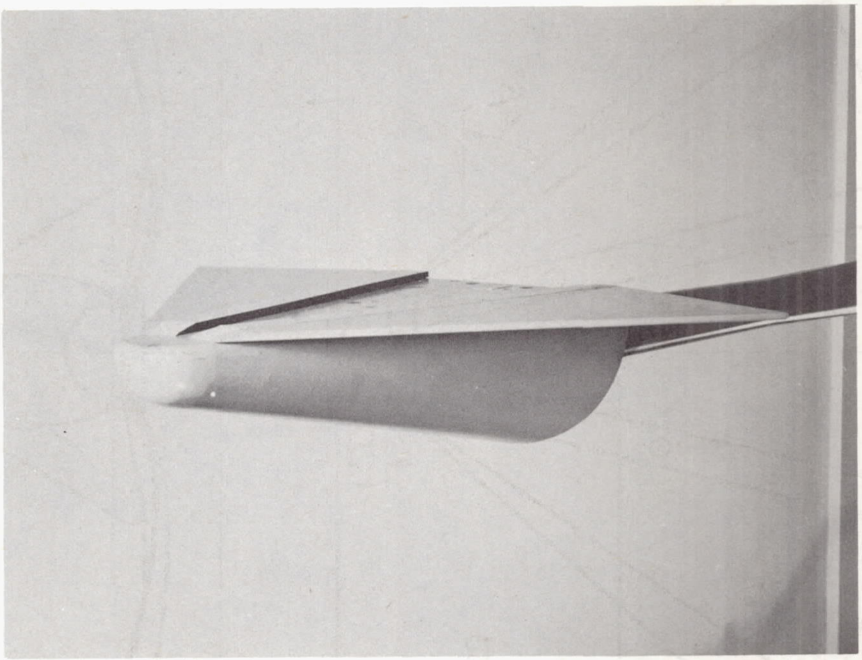
Conical wing



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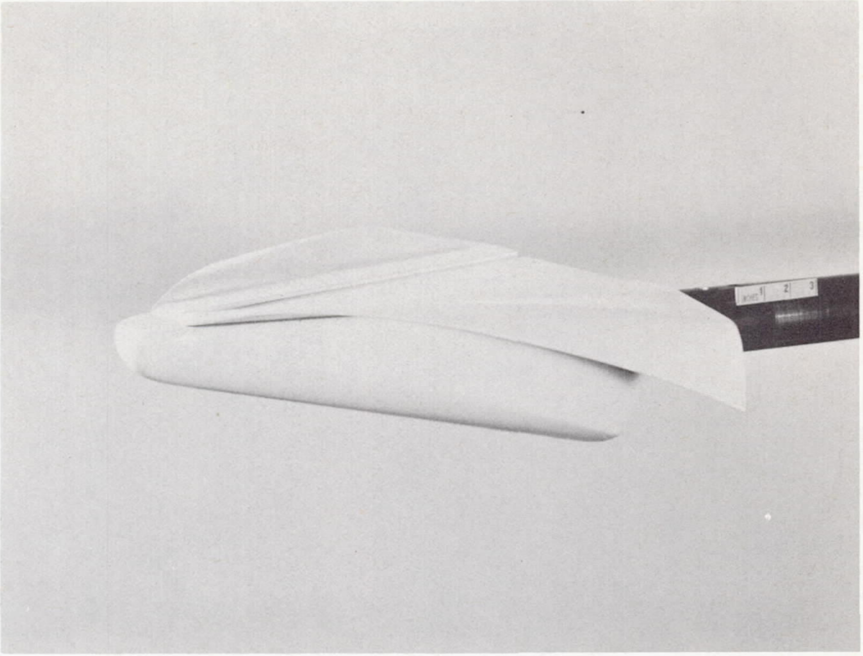
Flat wing

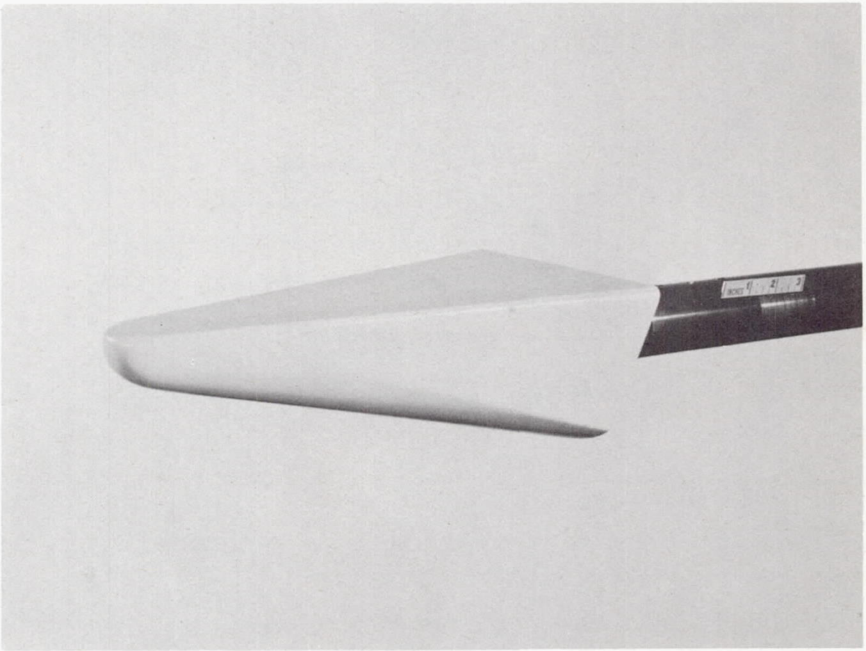
(a) Model I.

Figure 2.- Photographs of models.



Cambered wing

A-26937

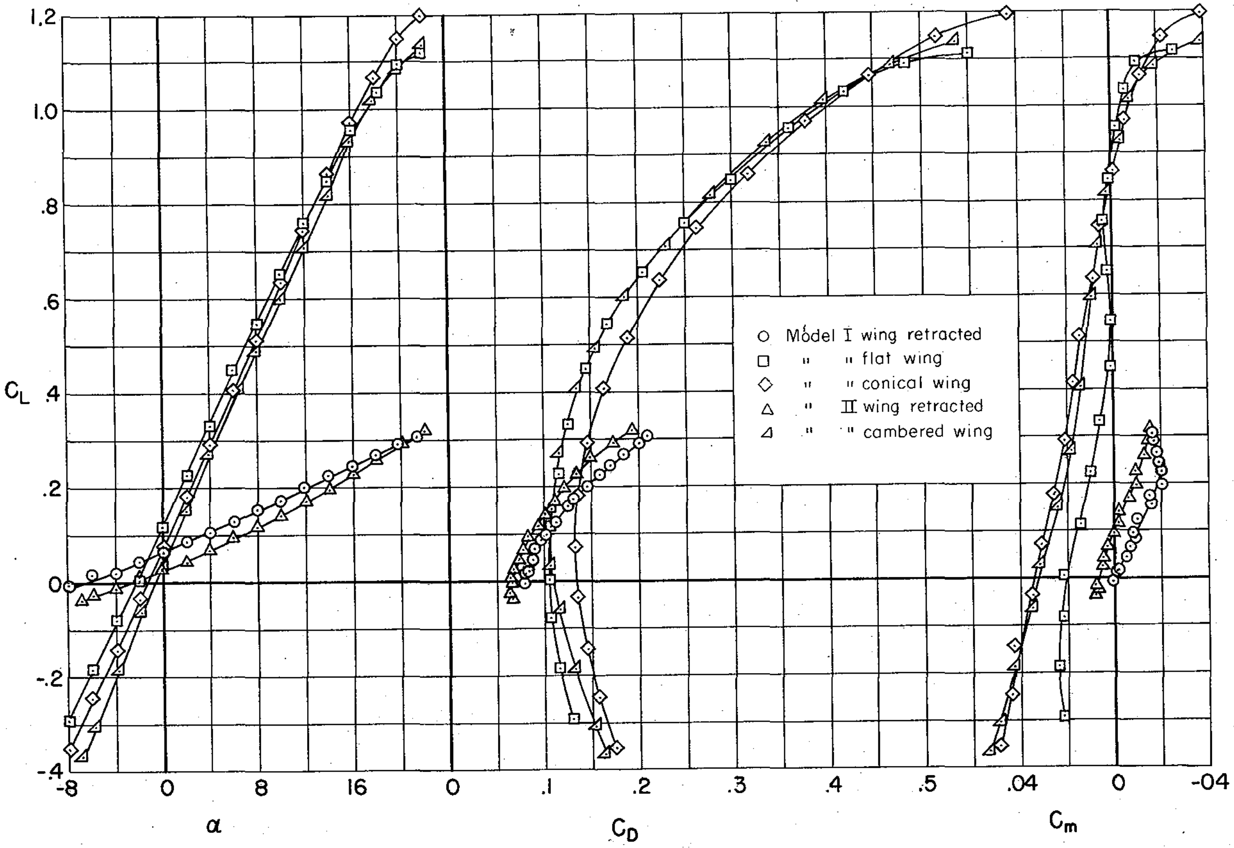


Body alone
(Wings retracted)

A-26938

(b) Model II.

Figure 2.- Concluded



(a) M = 0.25

Figure 3.- Variation of angle of attack, drag, and pitching-moment coefficient with lift coefficient.

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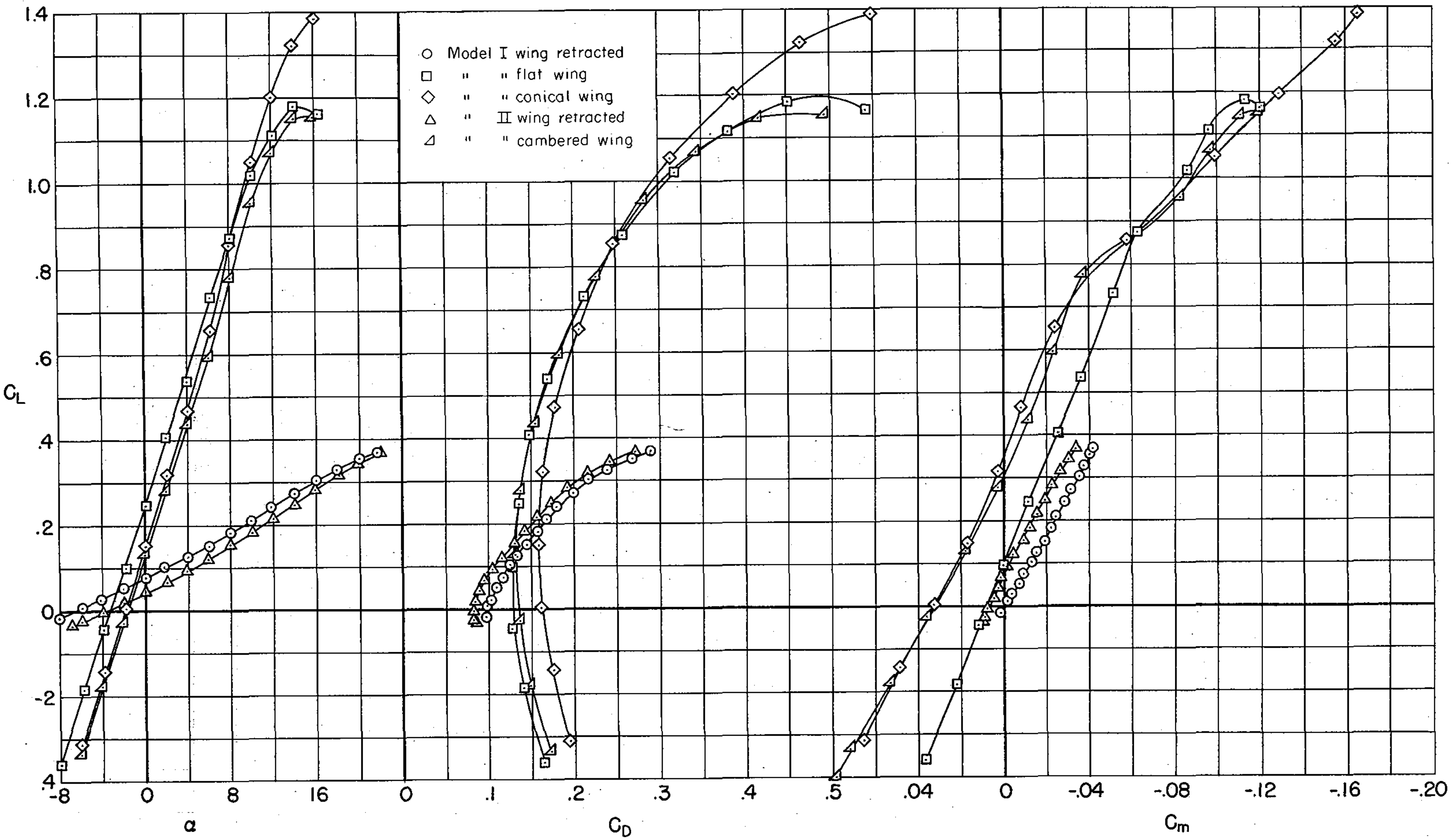

(b) M = 0.90

Figure 3.- Continued.

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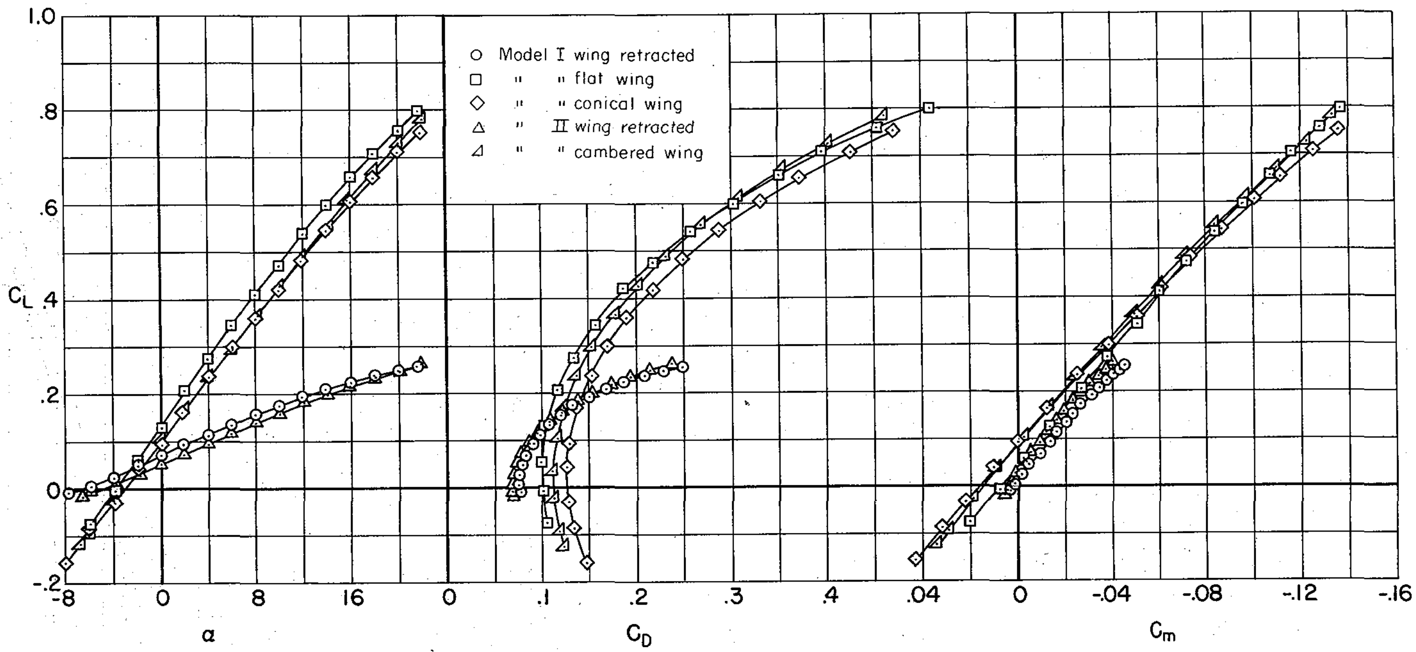

(c) M = 2.20

Figure 3.- Concluded.

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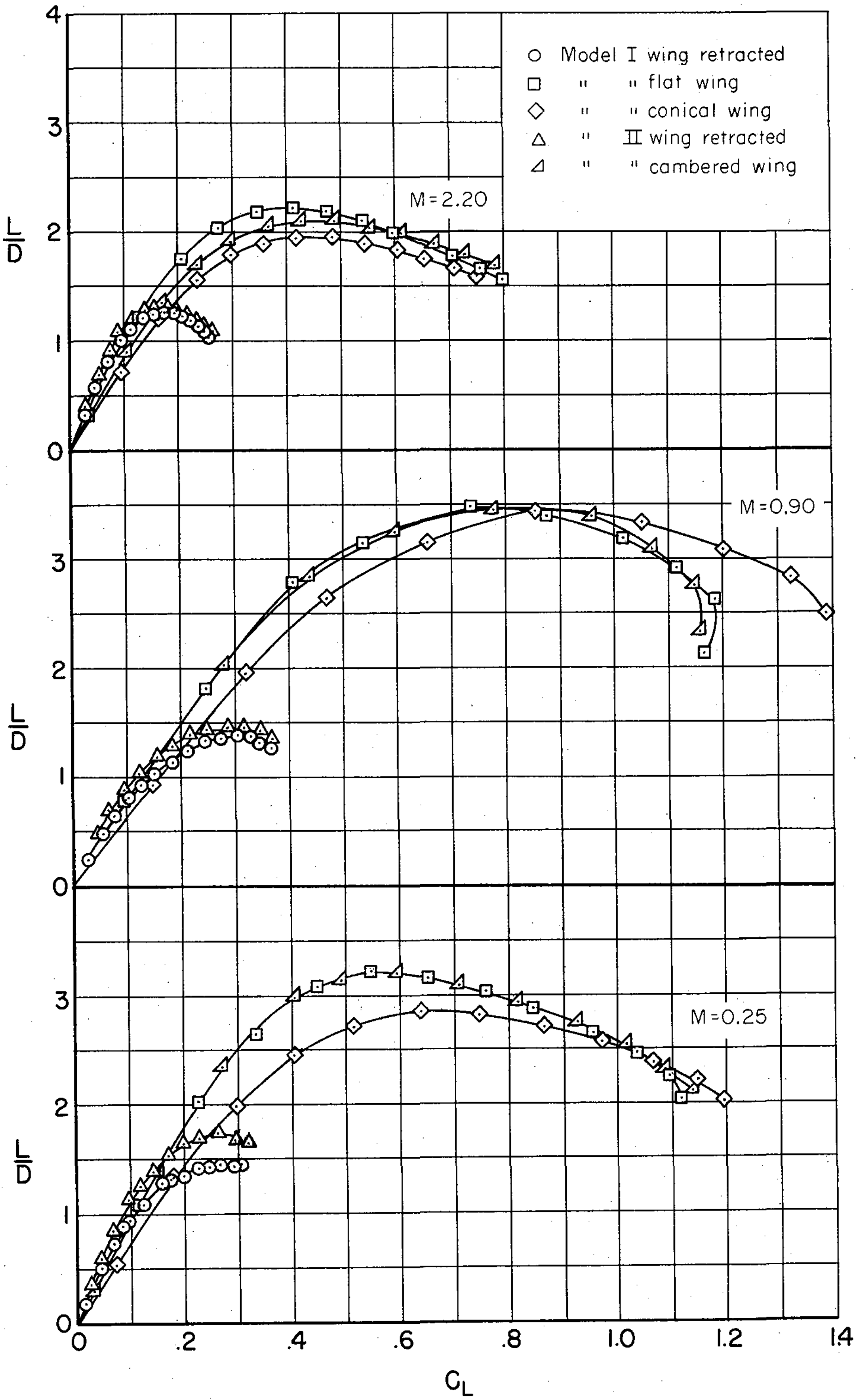
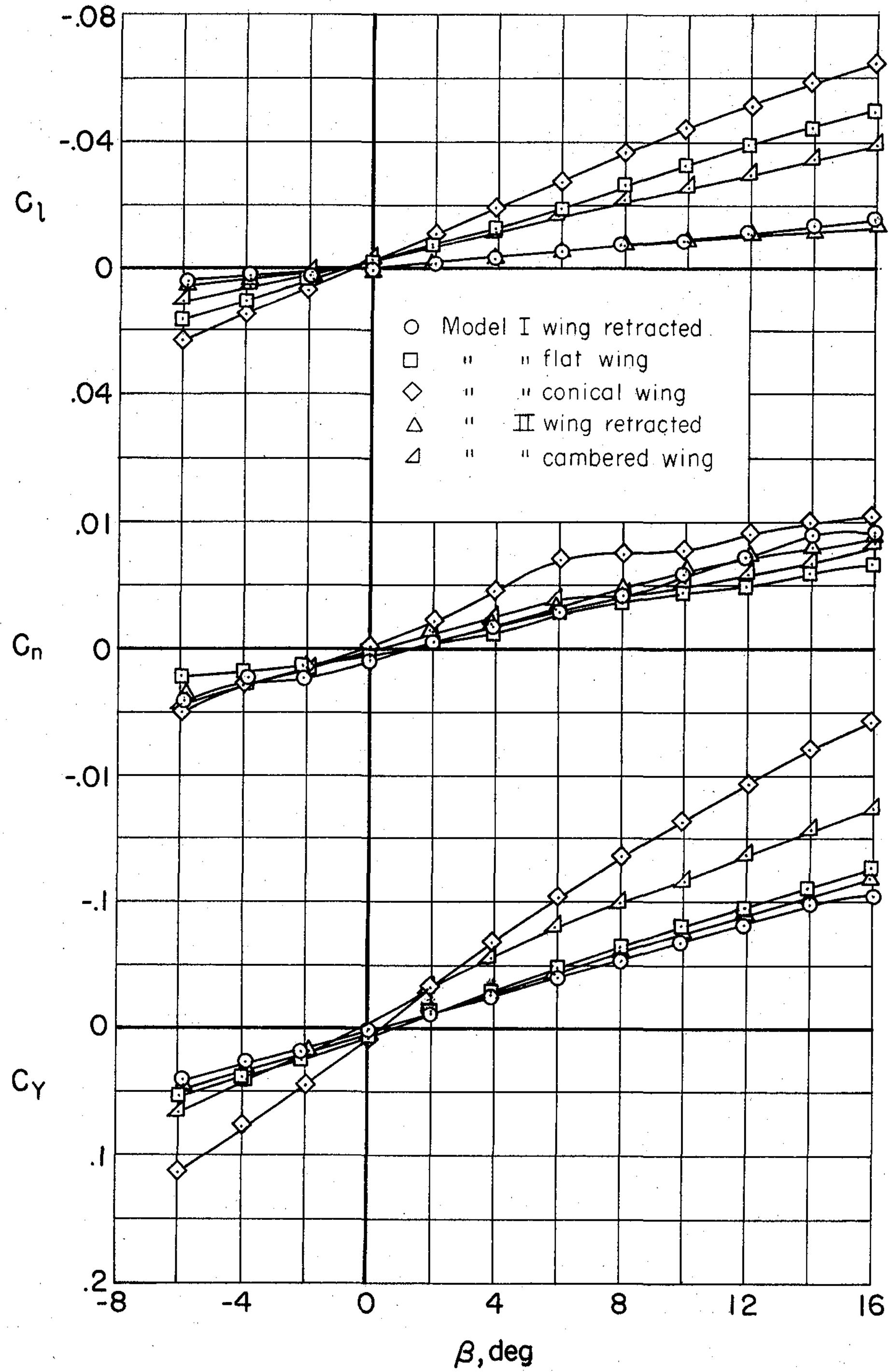
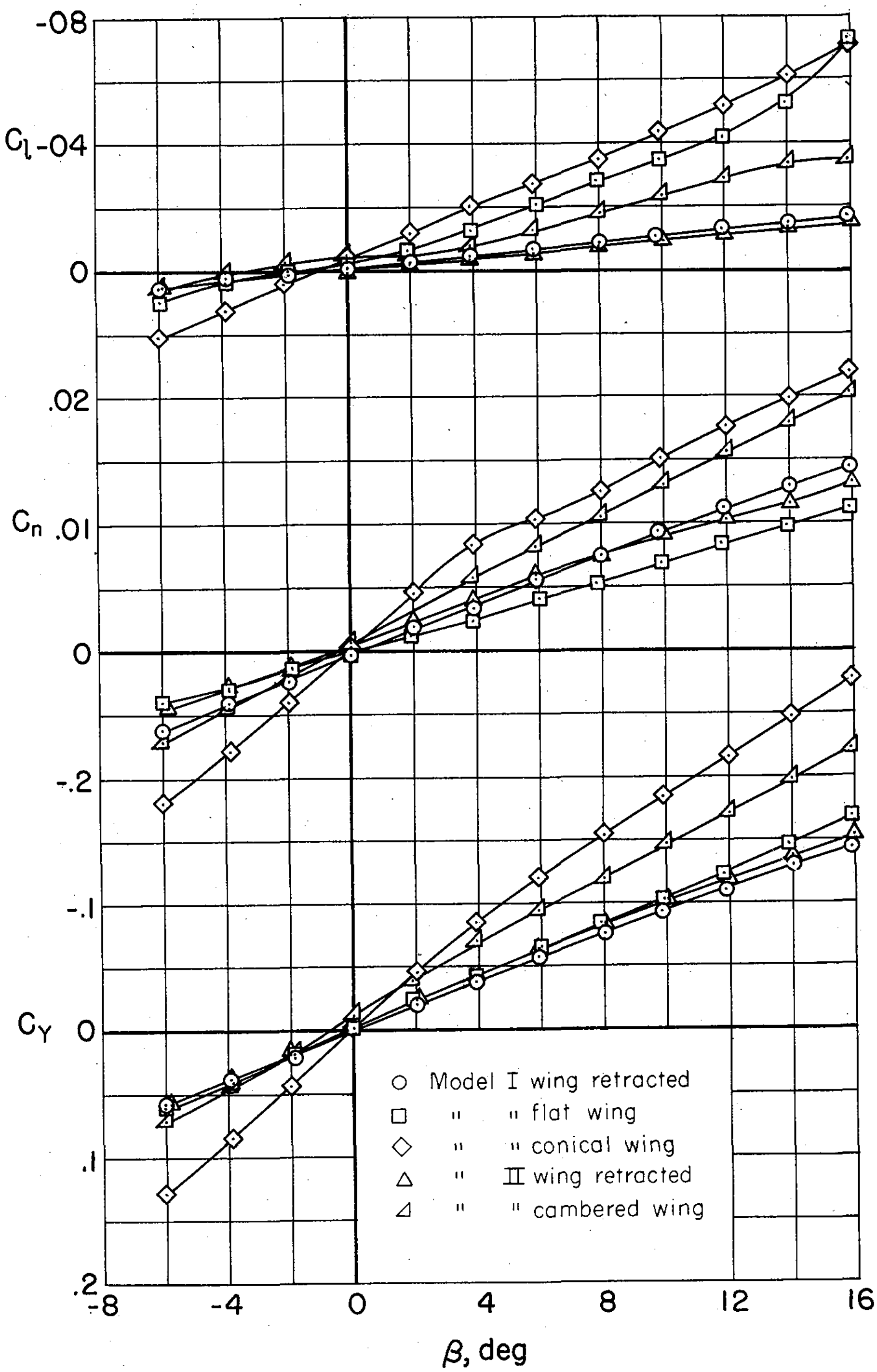


Figure 4.- Variation of lift-drag ratio with lift coefficient.



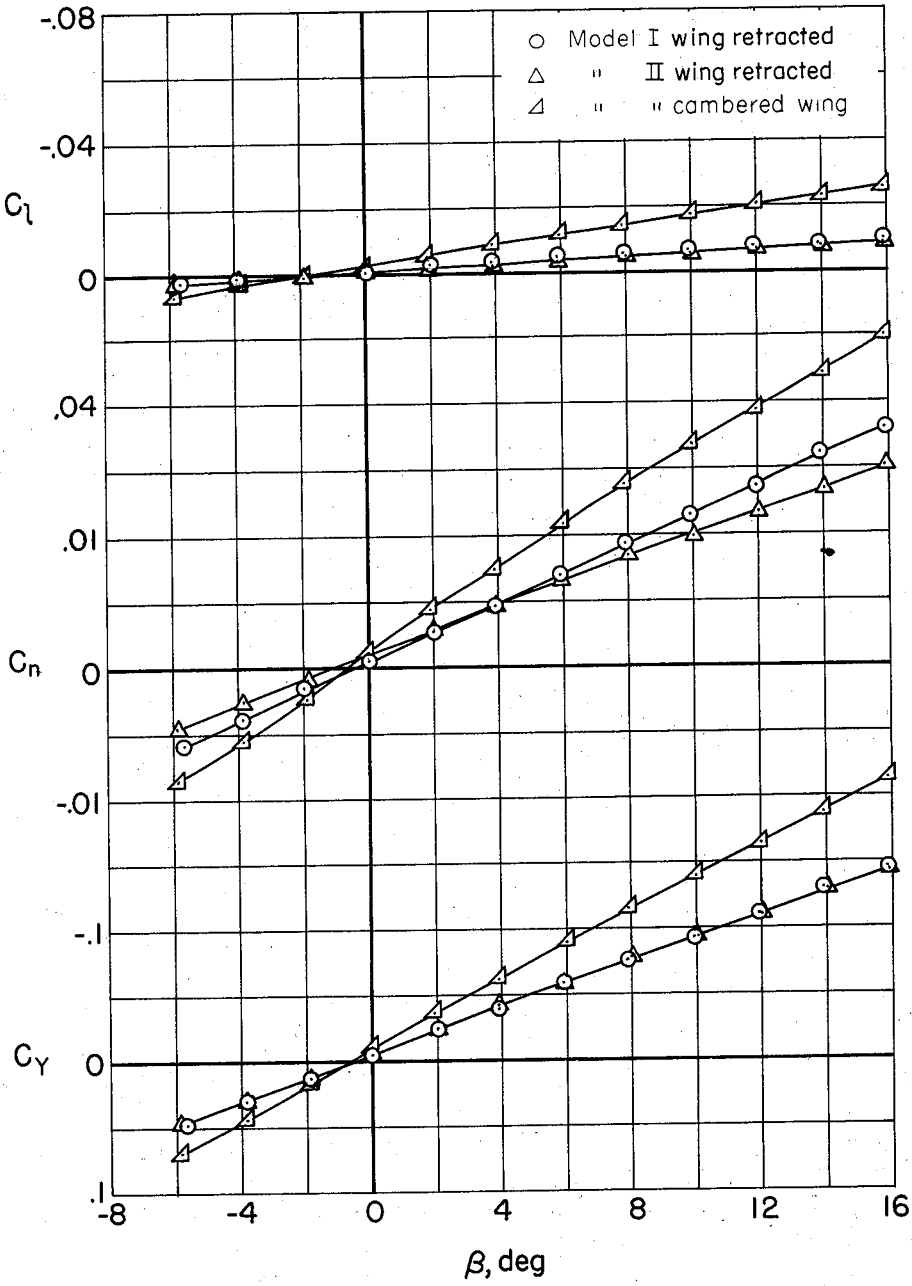
(a) M = 0.25

Figure 5.- Variation of rolling-moment, yawing-moment, and side-force coefficient with side-slip angle.



(b) M = 0.90

Figure 5.- Continued.



(c) M = 2.20

Figure 5.- Concluded.

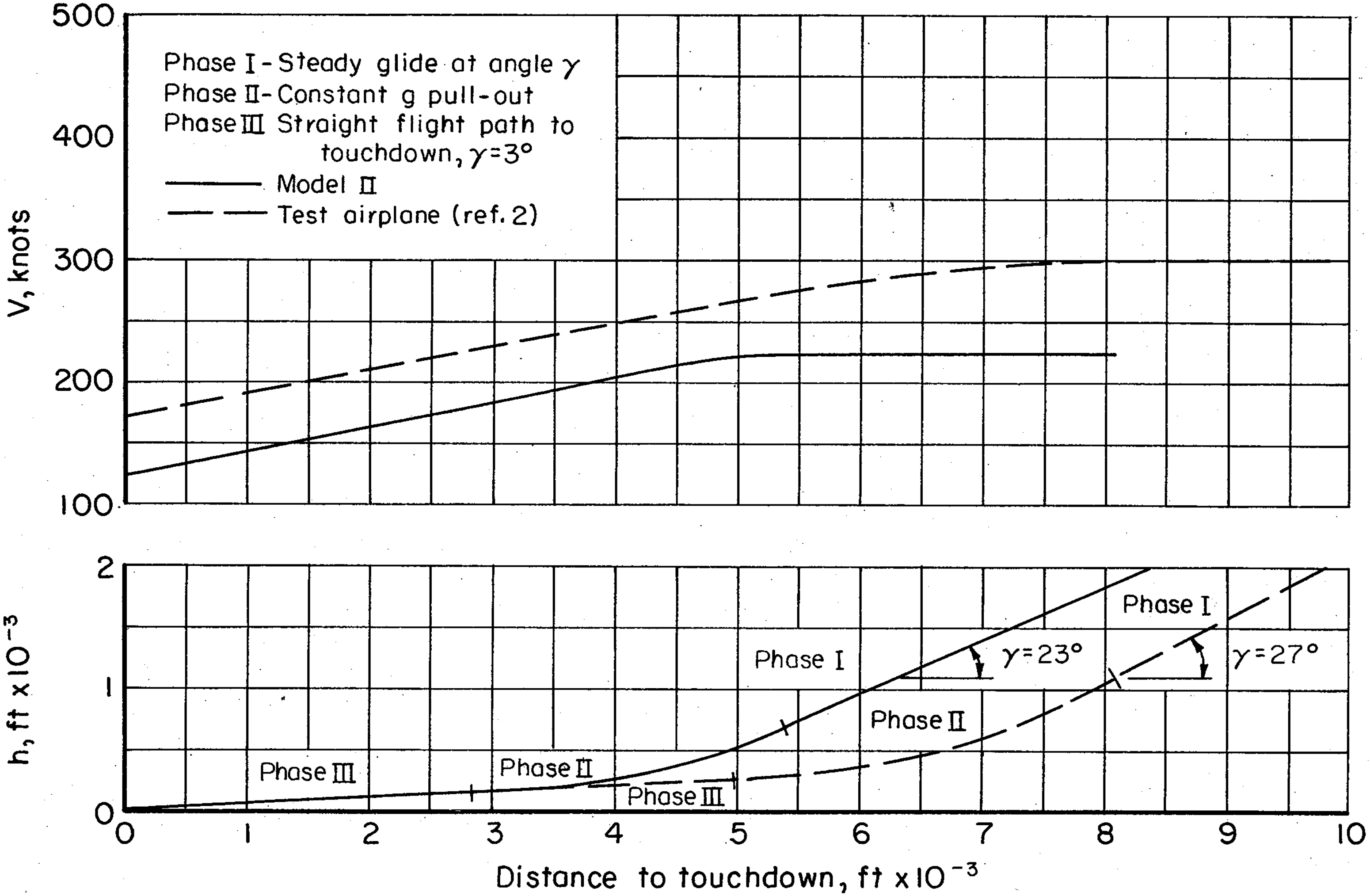


Figure 6.- Profile of speed and altitude versus distance from touchdown for Model II with an assumed wing loading at 50 pounds per square foot and for a test airplane with power off and a wing loading of 75 pounds per square foot.

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