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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF A 1/15-SCALE MODEL OF THE NORTHROP MX-775A MISSILE

By E. Ray Phelps and Frank A. Lazzeroni

Ames Aeronautical Laboratory
Moffett Field, Calif.

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SUMMARY

This report presents the results of a wind-tunnel investigation conducted to determine the control effectiveness and the variations of forces and moments as functions of angles of attack and sideslip for a 1/15-scale model of the MX-775A missile. The major portion of the data presented is for Mach numbers of 0.85, 0.92, 1.30, 1.40, and 1.70 at a Reynolds number of 2.20 million. A limited amount of data is presented at these same Mach numbers for a Reynolds number of 1.10 million to indicate the effects of Reynolds number. The aerodynamic characteristics of the model in sideslip are presented for Mach numbers of 0.85 and 1.40 only.

The results indicate that within the range of this investigation the effectiveness of the control surfaces was sufficient to permit longitudinal balance of the missile up to a lift coefficient of about 0.35 at a subsonic Mach number of 0.85 with both midspan control surfaces deflected -9° while maintaining longitudinal stability. Increasing the Mach number from subsonic to supersonic speeds caused an increase in longitudinal stability and a decrease in control effectiveness requiring a -18° deflection of both midspan control surfaces to balance the missile at a lift coefficient of about 0.15. The effectiveness of the surfaces as lateral controls is sufficient to hold wings level to sideslip angles of 5° with 7° differential deflection of the two midspan control surfaces at a Mach number of 0.85 and with 4° differential deflection at a Mach number of 1.40.

INTRODUCTION

The Northrop MX-775A is a long-range, ground-to-ground missile. The missile is to fly at high subsonic speeds during the major portion of the flight, followed by an increase in speed to supersonic Mach numbers during the final approach to the target. In view of the difficult aerodynamic design considerations engendered thereby, a request was made by Northrop Aircraft Company, Inc., through the United States Air Force, for a wind-tunnel investigation of a 1/15-scale model of the missile. The lift-drag characteristics, a prime factor in long-range flight, and the longitudinal trimming capacities of the control surfaces throughout the speed range were of paramount concern. In addition, the characteristics of the missile at supersonic speeds with the wing tips blown away (clipped-wing version) were of interest since it was believed that removal of the wing tips would improve the characteristics in the terminal dive. This report presents the results of the investigation conducted at both subsonic and supersonic speeds in the Ames 6- by 6-foot supersonic wind tunnel.

NOTATION

All force coefficients defined herein have been resolved to the wind axes. The rolling-moment coefficients have been referred to the body axes for tests of the model at zero sideslip and to the stability axes for tests of the model in sideslip. All other moment coefficients have been referred to the stability axes. The origins of the three systems of axes were located on the body center line at the point defined by the projection of the quarter point of the mean aerodynamic chord.

A.R.	aspect ratio $\left(\frac{b^2}{S}\right)$
b	wing span, feet
c	local wing chord measured parallel to plane of symmetry, feet
$\bar{c}$	wing mean aerodynamic chord $\left(\frac{\int_0^{b/2} c^2dy}{\int_0^{b/2} c\ dy}\right)$, feet
C_L	lift coefficient $\left(\frac{\text{lift}}{qS}\right)$
C_D	drag coefficient $\left(\frac{\text{drag}}{qS}\right)$
C_m	pitching-moment coefficient $\left(\frac{\text{pitching moment}}{qS\bar{c}}\right)$
C_l	rolling-moment coefficient $\left(\frac{\text{rolling moment}}{qSb}\right)$

C_Y	cross-wind-force coefficient $\left(\frac{\text{cross-wind force}}{qS}\right)$
C_n	yawing-moment coefficient $\left(\frac{\text{yawing moment}}{qSb}\right)$
L/D	lift-drag ratio
M	free-stream Mach number
q	free-stream dynamic pressure, pounds per square foot
R	Reynolds number based on mean aerodynamic chord
S	total projected wing area, including area formed by extending leading and trailing edges to plane of symmetry, square feet
x, y, z	Cartesian coordinates for wing plan form in directions longitudinal, lateral, and normal to plan form, respectively, feet
α	angle of attack of body axis, degrees
α_i	wing incidence angle measured between chord plane and body axis, degrees
β	angle of sideslip, degrees
δ	angle between wing chord and control surface chord, measured in a plane perpendicular to the control-surface hinge line, positive for downward deflection with respect to wing, degrees

APPARATUS AND EQUIPMENT

Wind Tunnel

The experimental investigation was conducted in the Ames 6- by 6-foot supersonic wind tunnel. In this wind tunnel, the Mach number can be continuously varied from 0.60 to the choking Mach number and from 1.15 to 2.00. The stagnation pressure can be continuously varied from 2 to 20 pounds per square inch absolute. To prevent the formation of condensation shock waves, the absolute humidity was maintained at a value of less than 0.0003 pound of water per pound of air. Further information regarding this wind tunnel is presented in reference 1.

Model

The model used in the present wind-tunnel investigation was a complete 1/15-scale model of the MX-775A missile. The wing was untwisted, had a leading-edge sweep of 48.39°, and was composed, in planes parallel to the plane of symmetry, of 6-percent-thick, cambered airfoil sections, the ordinates for which are given in table I. To produce the clipped-wing configuration, the wing tips were made removable outboard of the 80-percent semispan station. A photograph of the model mounted in the wind tunnel is shown in figure 1 and a three-view drawing of the model is shown in figure 2.

The wing panels were fitted with adjustable control surfaces, as shown in figures 2 and 3, to permit the determination of longitudinal- and lateral-control characteristics. The midspan control surfaces are intended to provide the primary longitudinal and lateral control depending, respectively, upon whether the surfaces are deflected together or differentially. The outboard surfaces, which were represented on the model by a flap installed on the left panel only, were designed as longitudinal trimmers. Inboard flaps were provided on the model to obtain information as to the effect of these flaps on the lift characteristics.

The geometric characteristics of the model are presented below. In determining these characteristics, the outboard extremity of the wing was considered to lie in the streamwise plane through the point of tangency between the tip fairing and the leading edge, as shown in figure 3.

Total wing area, S, square feet	
Standard wing	1.45
Clipped wing	1.25
Aspect ratio	
Standard wing	5.5
Clipped wing	4.1
Taper ratio	
Standard wing	0.40
Clipped wing	0.52

The wing and tail surfaces were constructed of steel and the body of steel and wood. All external surfaces were polished.

Model Support

The model was supported in the wind tunnel by a sting bent 5° and having a diameter at the base of the model of about 50 percent of the maximum body diameter. The sting support system allowed a model angle-of-attack range of -12.5° to 22.5° in the horizontal plane.

Balance

The aerodynamic forces and moments on the model were measured by means of a four-component strain-gage balance, of the type described in reference 2, enclosed within the body of the model. The balance is so designed that each force and moment component is measured by one strain gage only and each gage is supported by ball bearings so that interaction between the various gages is minimized. The forces and moments as measured by means of the balance were transmitted to recording-type galvanometers. The force and moment measuring system was calibrated by applying known loads on the model.

TESTS AND PROCEDURES

Tests of the model were conducted through a range of subsonic and supersonic Mach numbers with various combinations of control-surface deflections for the standard-wing version and with controls undeflected for the clipped-wing version. Lift, drag, pitching- and rolling-moment measurements were made at Mach numbers of 0.85, 0.92, 1.30, 1.40, and 1.70. Both the standard- and clipped-wing configurations were tested at the same Reynolds number per unit length but, due to the difference in reference length, the resulting Reynolds numbers based on the mean aerodynamic chord were 2.20 million and 2.33 million, respectively. A few additional tests for the standard-wing version with controls undeflected were made at a Reynolds number of 1.10 million for the purpose of determining the effect of Reynolds number. A limited investigation of the lateral and directional characteristics of the standard-wing model was also conducted.

The majority of the tests to determine the effectiveness of the midspan and outboard control surfaces were made with the surfaces deflected on the left wing panel only. The results of a limited investigation through the range of Mach numbers showed no appreciable interaction between control surfaces on opposite wing panels on the lift, drag, or pitching-moment, the incremental effects of the deflection of two control surfaces (one on each wing panel) being twice those for the deflection of one control surface within experimental accuracy. It was possible, therefore, to reduce the number of tests by investigating the characteristics of a single control to obtain simultaneously pitching-moment and rolling-moment data.

Reduction of Data

The test data have been reduced to standard NACA coefficient form with all coefficients based upon the geometry of the appropriate wing configuration. Factors which could affect the accuracy of these results and the corrections applied are discussed in the following paragraphs:

Angles of attack and sideslip.- The determination of the angles of attack and sideslip of the model under load necessitated that several corrections be applied to the measured angles as determined from static calibrations. Corrections were applied for the angular deflection of the sting and balance due to aerodynamic loads and for the free angular movement resulting from internal clearances in both the balance and sting support mechanism.

Tunnel-wall interference.- Corrections to the data obtained at subsonic speeds necessitated by the effects of the tunnel walls were made according to the method of reference 3. These corrections, which were added to the measured data, are as follows:

$$\Delta\alpha = 0.339\ C_L$$

$$\Delta C_D = 0.0059\ {C_L}^2$$

The effects of constriction of the flow due to the presence of the model were taken into account by the method of reference 4. This correction was calculated for conditions of zero angle of attack and was applied throughout the angle-of-attack range.

No corrections to the data for tunnel-wall effects were made at supersonic speeds, although these effects may be present to a slight degree at $M = 1.30$, because the reflected bow wave intersected the left wing tip at about 70 percent of the tip chord as shown by schlieren photographs.

Stream variations.- A survey of the 6- by 6-foot supersonic wind tunnel at supersonic speeds (reference 1) has shown the presence of some inclination and curvature of the stream in vertical planes but little in horizontal planes. To minimize the effects of these stream irregularities, the model was mounted with the wing in a vertical plane for tests in which longitudinal data were obtained and in a horizontal plane for the tests in which lateral data were measured.

The model was tested in both upright and inverted positions to determine possible effects of stream inclination or curvature on the longitudinal characteristics. Examination of the data revealed a shift in pitching-moment coefficient which was shown by theoretical calculations to be due to stream-angle variations of 0.1° to 0.2° over the streamwise length of the wing. The data presented herein are for the model in the upright position and are uncorrected for this stream curvature. Therefore, the pitching-moment coefficients are too large by 0.005 at $M = 0.85$ and 0.92; 0.004 at $M = 1.30$; 0.002 at $M = 1.40$; and 0.001 at $M = 1.70$. Comparison of the data for the model tested in upright and inverted positions indicated that the stream irregularities had little effect on the force coefficients. The error in lift coefficient did not exceed about 0.01 at subsonic speeds and diminished with increasing supersonic speeds to within the precision of the data. The error in drag coefficient did not exceed about 0.001 throughout the speed range.

The deviation of rolling-moment coefficients from zero at conditions of supposedly zero rolling moments was probably caused by a combination of stream irregularities and model asymmetry. The incremental rolling moments should be unaffected, however.

The wind-tunnel survey also indicated axial static-pressure variations at supersonic speeds in the test section of sufficient magnitude to affect slightly the drag results. Therefore, a correction as a function of Mach number was added to the measured drag at supersonic speeds to take into account the longitudinal buoyant force. At subsonic speeds, the longitudinal variation of static pressure in the vicinity of the model is not known accurately at the present time, but a preliminary survey has indicated that the variation is less than 2 percent of the dynamic pressure. No correction for this effect was made.

Support interference.- At subsonic speeds, it was believed possible that the foredrag as well as the base drag of the model might be appreciably affected by support interference in view of the severe boattailing of the model. To determine the magnitude of this effect, the body alone was tested at subsonic and supersonic speeds both on a small sting with diameter equal to about 25 percent of the maximum body diameter and on the standard sting which had a diameter of about 50 percent of the maximum body diameter. Total drag and base pressure were measured in both cases. The foredrag data for the body were unaffected by the difference in sting diameters, indicating that the effect of support interference was confined to a change in base pressure. A base-pressure correction to adjust the pressure at the base to free-stream pressure was made for all the experimental data presented herein.

Precision of Data

Excluding the previously mentioned effects of stream irregularities, the data are believed to have the following accuracy as evidenced by the ability to repeat data within these limits after an elapsed time of about two weeks:

Quantity	Accuracy
Lift coefficient	±0.005
Drag coefficient[1]	±.0010
Pitching-moment coefficient	±.001
Rolling-moment coefficient	±.001
Angle of attack	±.1°
Mach number	±.01
Reynolds number	$\pm .03 \times 10^6$

Although no analysis was made for the precision of the lateral data, the accuracy of the cross-wind-force coefficients is believed to correspond to that of the lift coefficients, the accuracy of the yawing moment to that of the pitching moment, and the accuracy of the angles of sideslip to that of the angles of attack.

RESULTS

Static Longitudinal Stability and Control Characteristics

Basic experimental data for the MX-775A model with several deflections of the left midspan control surface are presented in figure 4. As explained in a preceding section, these data are uncorrected for the induced twist and camber effects due to existing variations of stream angle over the wing. These data indicate that the variation of pitching-moment coefficient with control-surface deflection was essentially linear throughout the range of deflection angles tested.

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[1] The accuracy of the drag coefficient at M = 0.92 is ±0.0020. The drag accuracy at this Mach number as shown by consecutive tests is impaired by a very large variation of model base drag with Mach number in this speed range.

Based upon the results obtained with deflection of the left midspan control surface only, it is estimated that the stability of the missile with the center of gravity at the quarter point of the mean aerodynamic chord will be slightly positive in the balanced condition at $M = 0.85$ for lift coefficients less than about 0.4. With increasing Mach number, the stability at constant lift coefficient increased, reached a maximum value at $M = 1.30$, and decreased with further increase in Mach number to $M = 1.70$. It can be seen that about 9° deflection of the two midspan control surfaces is required to provide longitudinal balance at $M = 0.85$ at a lift coefficient of 0.35 and it is estimated that 18° deflection of the two midspan control surfaces is required to balance at a lift coefficient of about 0.15 at supersonic speeds. The large deflection angles required for balance are due to a combination of the large negative pitching moment at zero lift, resulting primarily from the use of cambered wing sections, and to the decreased control effectiveness at supersonic speeds.

An examination of figure 5 discloses the effects of left midspan control-surface deflections upon the aerodynamic characteristics of the model with both inboard flaps deflected 3° downward. It may be noted that the deflection of the inboard surfaces had little effect on the pitching-moment effectiveness of the midspan control surfaces.

Figure 6 shows the effect of left midspan control-surface deflections upon the aerodynamic characteristics of the model with the left outboard control surface deflected 6° upward. From a comparison with figure 4, the outboard control surface can be seen to exhibit in general only about one-half the pitching-moment effectiveness of the midspan surface.

Reynolds Number Effects

The effects of Reynolds number are shown in figure 7 where the relationships between the lift coefficient and the angle of attack, drag, and pitching-moment coefficients are presented for the two relatively low test Reynolds numbers. It can be seen that the model exhibited a slightly higher lift-curve slope at the lower Reynolds number. At subsonic speeds, the stability of the model was unaffected although the pitching moments were more negative at the lower Reynolds number.

Lateral-Control Characteristics

The results of a brief investigation of the lateral characteristics of the model are presented in figure 8 with the cross-wind-force, yawing-moment, and rolling-moment coefficients shown as functions of angle of sideslip for two Mach numbers. Examination of the results shown in figures 4 and 8 indicates that the model is laterally and directionally stable and that about 7° and 4° differential deflection of the midspan control surfaces is required to balance the rolling moments produced by an angle of sideslip of 5° for the subsonic and supersonic Mach numbers, respectively.

Clipped-Wing Configuration Characteristics

It has been suggested that it may be desirable to reduce the span of the wing of the MX-775A missile in its terminal dive by blowing off the wing tips in order to improve the aerodynamic characteristics. Several tests were made with the model altered to simulate the missile in this condition. These results are labeled "clipped-wing" configuration characteristics. The lift coefficient as a function of angle of attack and the relationship between lift and drag are shown for this configuration in figure 9.

Longitudinal stability.- The characteristic of primary concern is the pitching-moment-coefficient variation with lift coefficient which is shown in figure 10 together with data for the standard-wing configuration for comparison purposes. The data for the clipped wing are given both for the original center-of-gravity position which is located at 43.2 percent of the clipped-wing mean aerodynamic chord and for the center of gravity shifted to the 25-percent clipped-wing mean aerodynamic chord. The data show that the removal of the wing tips results in a stability decrease to almost neutral longitudinal stability at supersonic speeds for lift coefficients less than about 0.4 and marked instability at subsonic speeds. Removal of the wing tips, therefore, materially improves the maneuvering characteristics in the terminal dive at supersonic speeds if the center-of-gravity position remains fixed and the control characteristics remain unchanged.

Lift-drag characteristics.- A comparison of the lift-drag characteristics as a function of lift coefficient for the two wing configurations is shown in figure 11. An examination of the data reveals that the clipped-wing configuration suffered a decrease in maximum lift-drag ratio of about 22 percent at subsonic speeds, 9 percent at M = 1.3 and 1.4, and 5 percent at M = 1.7 from the values obtained with the standard-wing configuration. The maximum lift-drag ratios occurred at lift coefficients of 0.30 to 0.35.

CONCLUSIONS

Tests of a 1/15-scale model of the MX-775A missile have been conducted at Mach numbers of 0.85 and 0.92 and from 1.30 to 1.70 for Reynolds numbers of 2.20 million. The results indicate that the missile was longitudinally stable at $M = 0.85$ when balanced at a lift coefficient of about 0.35 with both midspan control surfaces deflected -9°. Increasing the Mach number from subsonic to supersonic speeds caused an increase in longitudinal stability and a decrease in control effectiveness requiring a -18° deflection of both midspan surfaces to balance at a lift coefficient of about 0.15. The effectiveness of the surfaces as lateral controls is sufficiently great to permit wings-level flight with a differential deflection of the control surfaces of 7° and 4° for sideslip angles of 5° at Mach numbers of 0.85 and 1.40, respectively.

An investigation of the clipped-wing version of the missile shows that a marked improvement in the maneuvering characteristics of the missile in the terminal dive can be obtained by blowing off the wing tips and retaining the same center of gravity position if the control characteristics remain unchanged.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

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1. Frick, Charles W., and Olson, Robert N.: Flow Studies in the Asymmetric Adjustable Nozzle of the Ames 6- by 6-foot Supersonic Wind Tunnel. NACA RM A9E24, 1949.

2. Olson, Robert N., and Mead, Merrill H.: Aerodynamic Study of a Wing-Fuselage Combination Employing a Wing Swept Back 63°.- Effectiveness of an Elevon as a Longitudinal Control and the Effects of Camber and Twist on the Maximum Lift-Drag Ratio at Supersonic Speeds. NACA RM A50A31a, 1950.

3. Silverstein, Abe, and White, James A.: Wind-Tunnel Interference with Particular Reference to Off-Center Positions of the Wing and to the Downwash at the Tail. NACA TR 547, 1936.

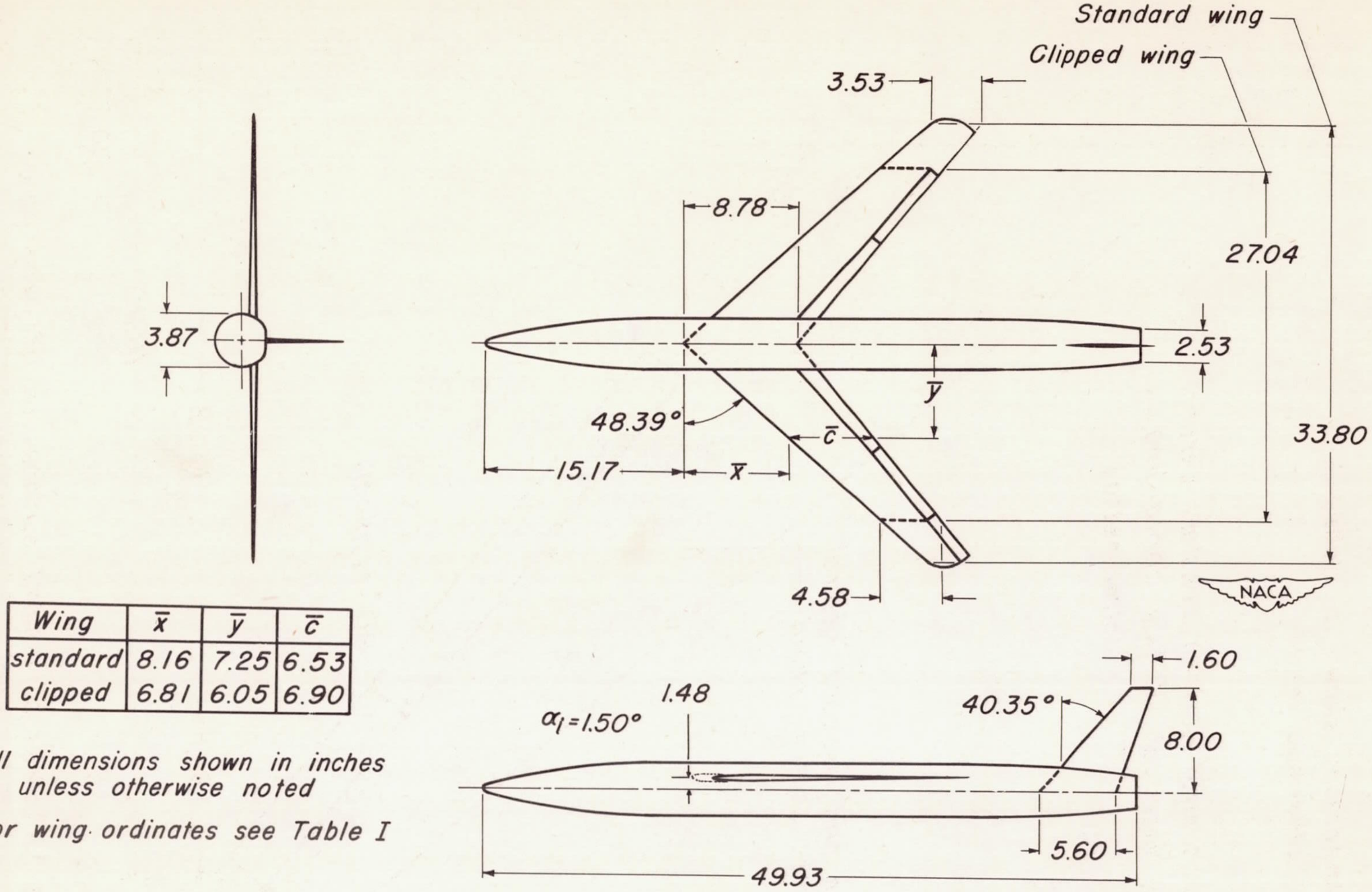
4. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA Rep. 995, 1950. (Formerly NACA RM A7B28)

TABLE I. - AIRFOIL ORDINATES

[Stations and ordinates given in percent of local chord, measured parallel to plane of symmetry]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	-0.785	0	-0.912
.116	-.533	.116	-1.158
.234	-.410	.234	-1.267
.351	-.314	.351	-1.345
.585	-.150	.585	-1.446
.878	.018	.878	-1.543
1.461	.267	1.461	-1.685
2.915	.681	2.915	-1.937
5.806	1.240	5.806	-2.275
8.672	1.631	8.672	-2.485
11.514	1.932	11.514	-2.646
17.126	2.344	17.126	-2.847
22.647	2.625	22.647	-2.958
28.076	2.822	28.076	-3.015
33.417	2.946	33.417	-3.023
38.672	2.996	38.672	-3.006
40.562	2.998	40.562	-2.998
43.843	2.977	43.843	-2.977
48.931	2.876	48.931	-2.876
53.940	2.686	53.940	-2.686
58.113	2.467	58.113	-2.467
Straight line to trailing-edge			
100	0	100	0
Leading-edge radius: 0.444			

Figure 1.- The 1/15-scale MX-775A model mounted in the Ames 6- by 6-foot supersonic wind tunnel.



Wing	$\bar{x}$	$\bar{y}$	$\bar{c}$
standard	8.16	7.25	6.53
clipped	6.81	6.05	6.90

All dimensions shown in inches unless otherwise noted

For wing ordinates see Table I

Figure 2.- Three-view drawing of 1/15-scale MX-775A model.

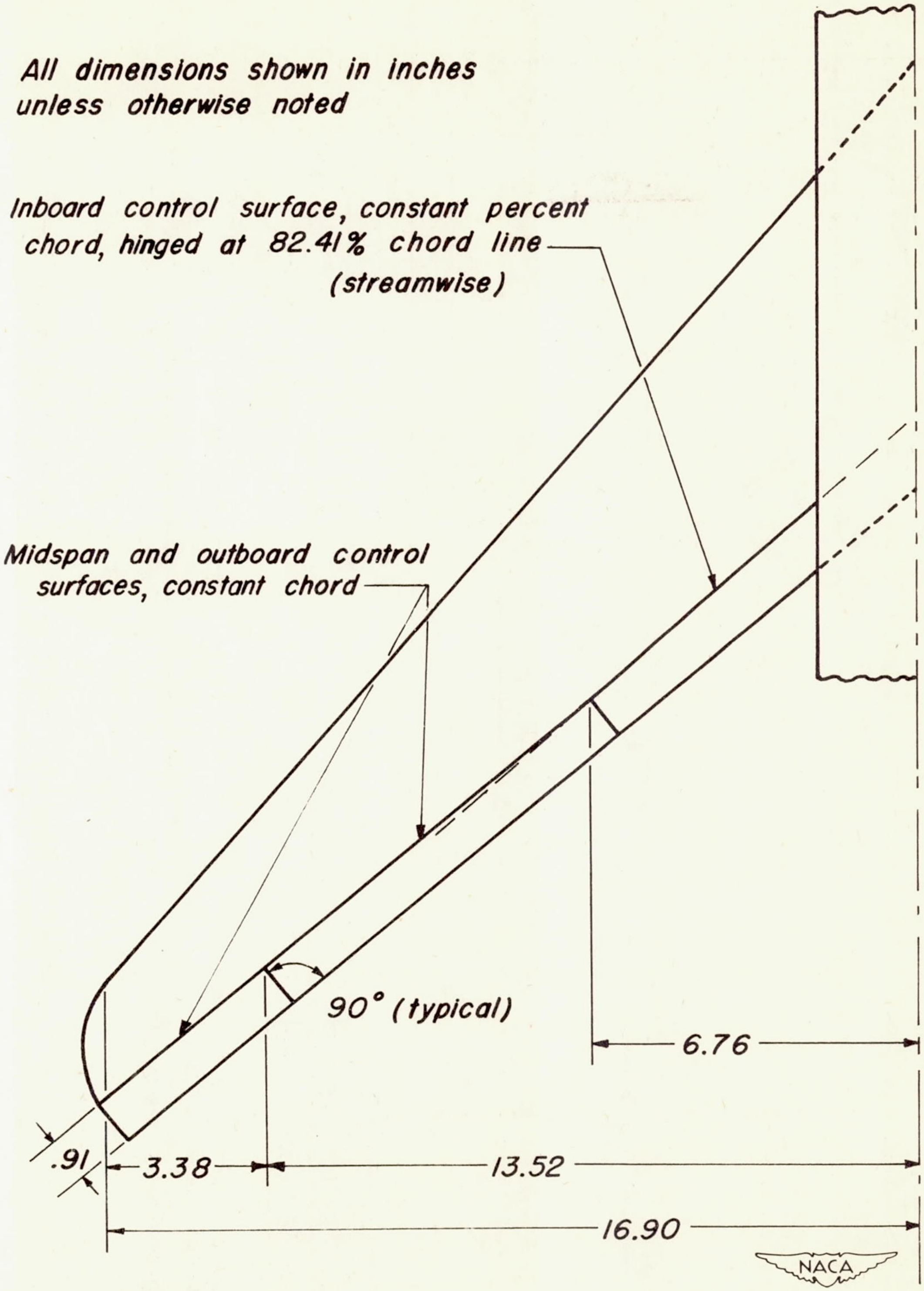
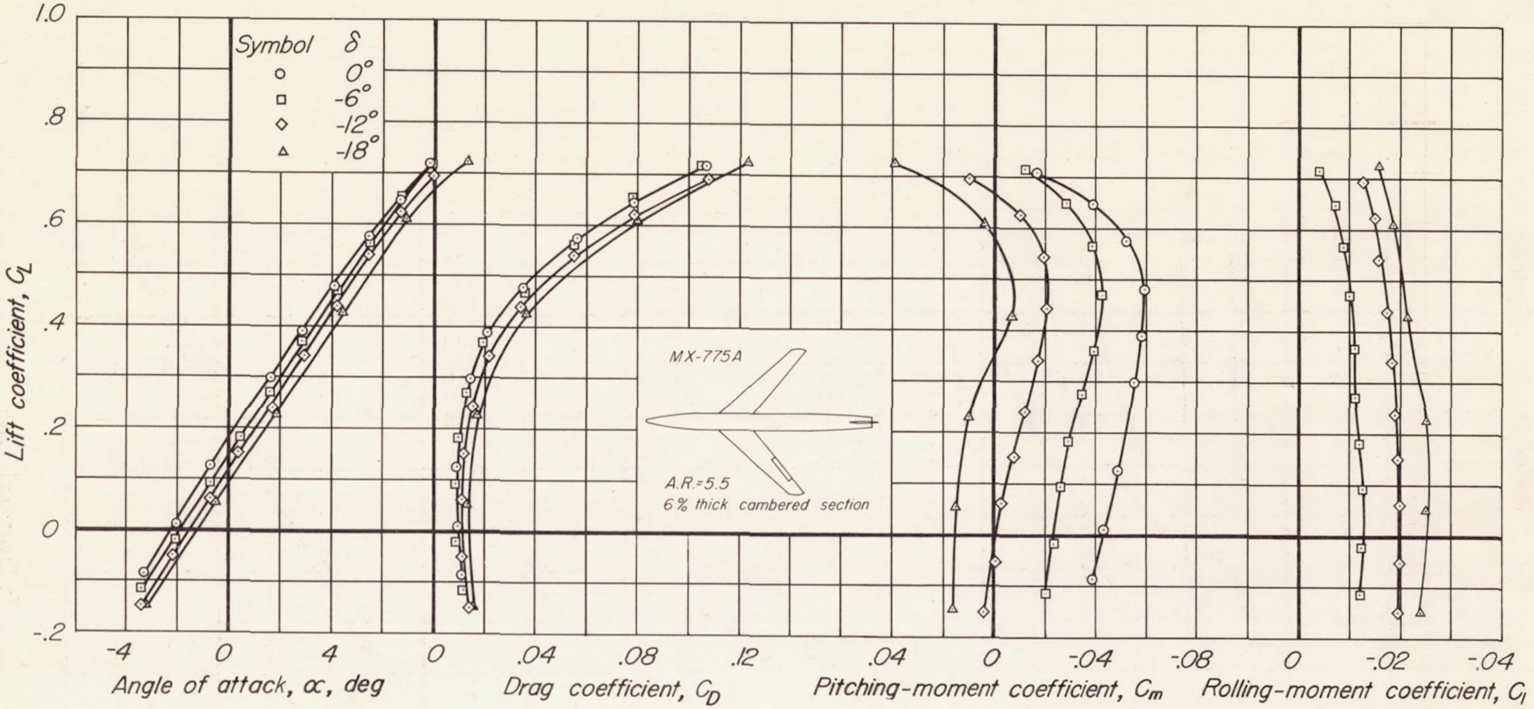
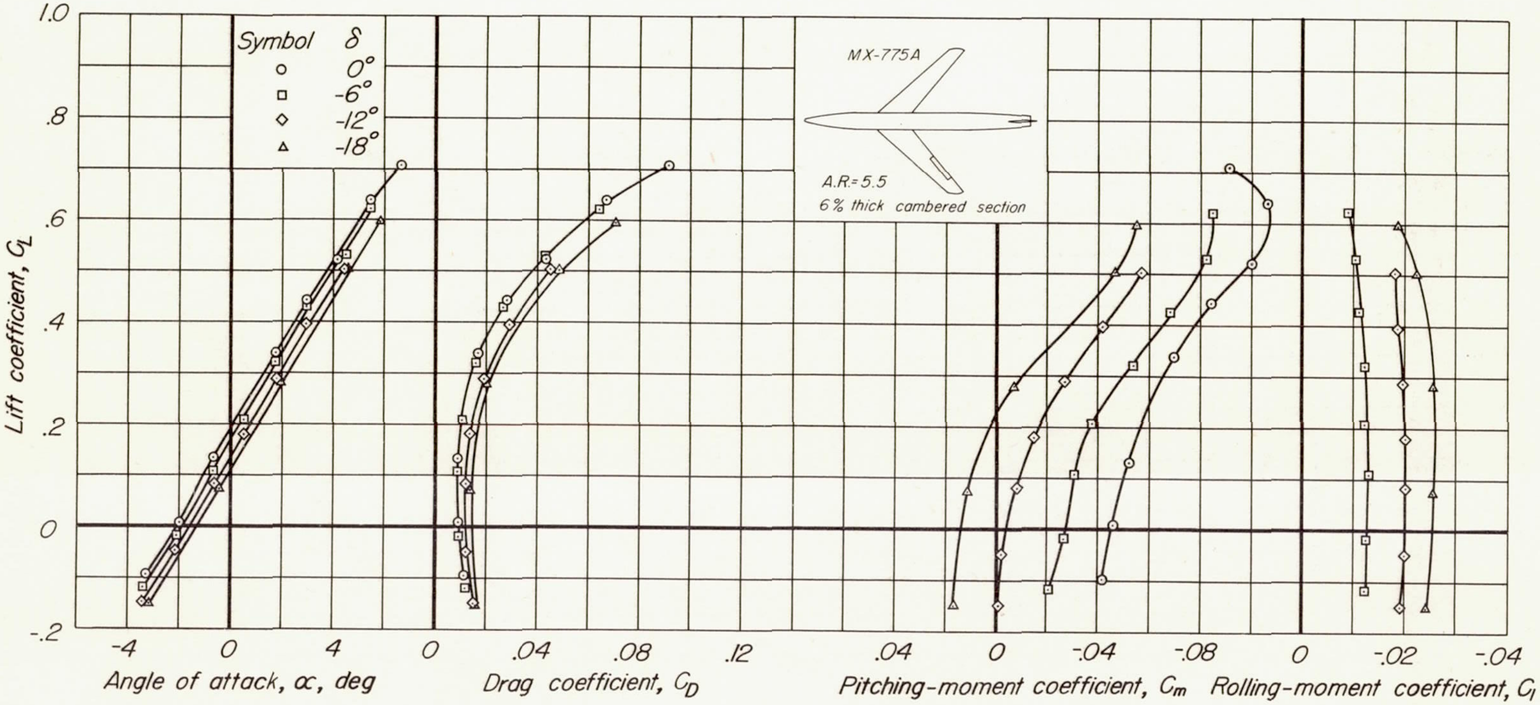


Figure 3.- Details of control surfaces on left wing panel of 1/15-scale MX-775A model.



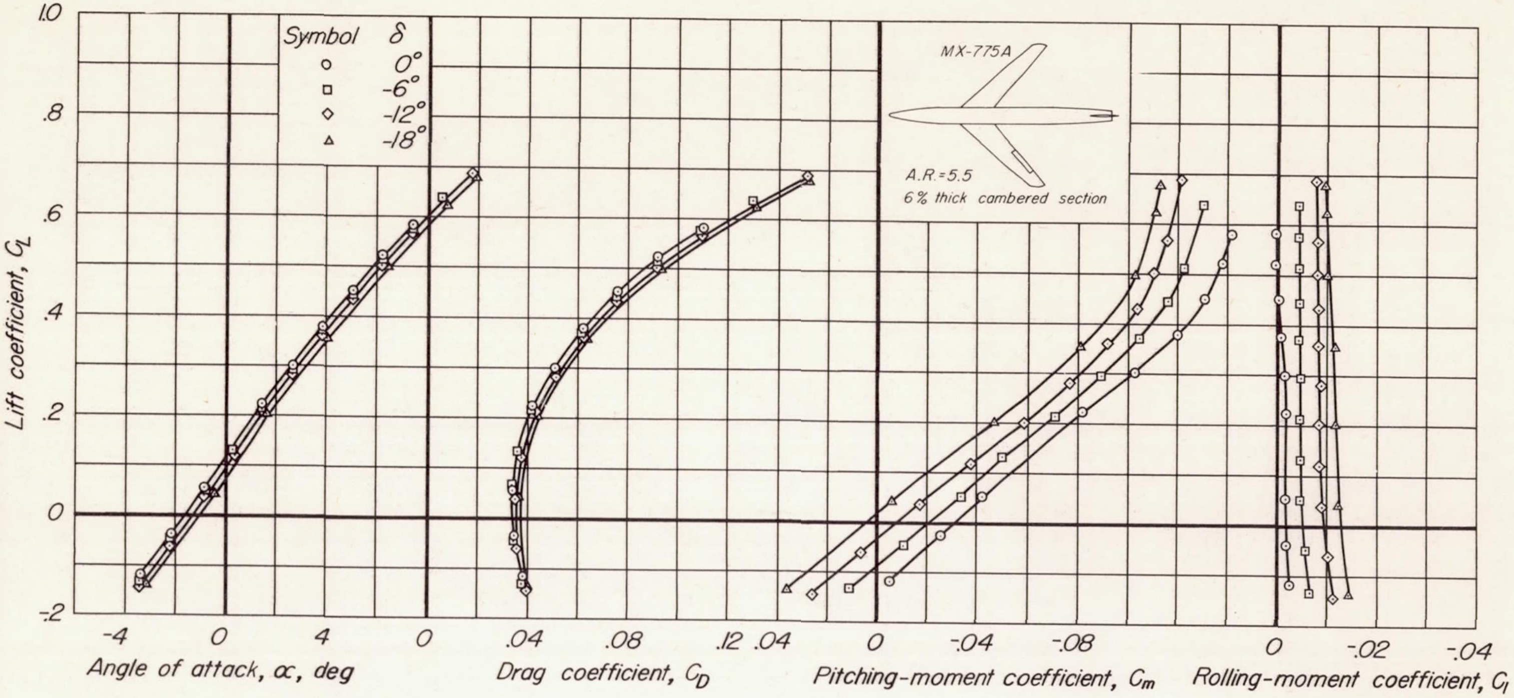
(a) M=0.85

Figure 4.- The effect of left midspan control-surface deflections, δ, on the aerodynamic characteristics of the 1/15-scale MX-775A model. Reynolds number, 2.20 million.



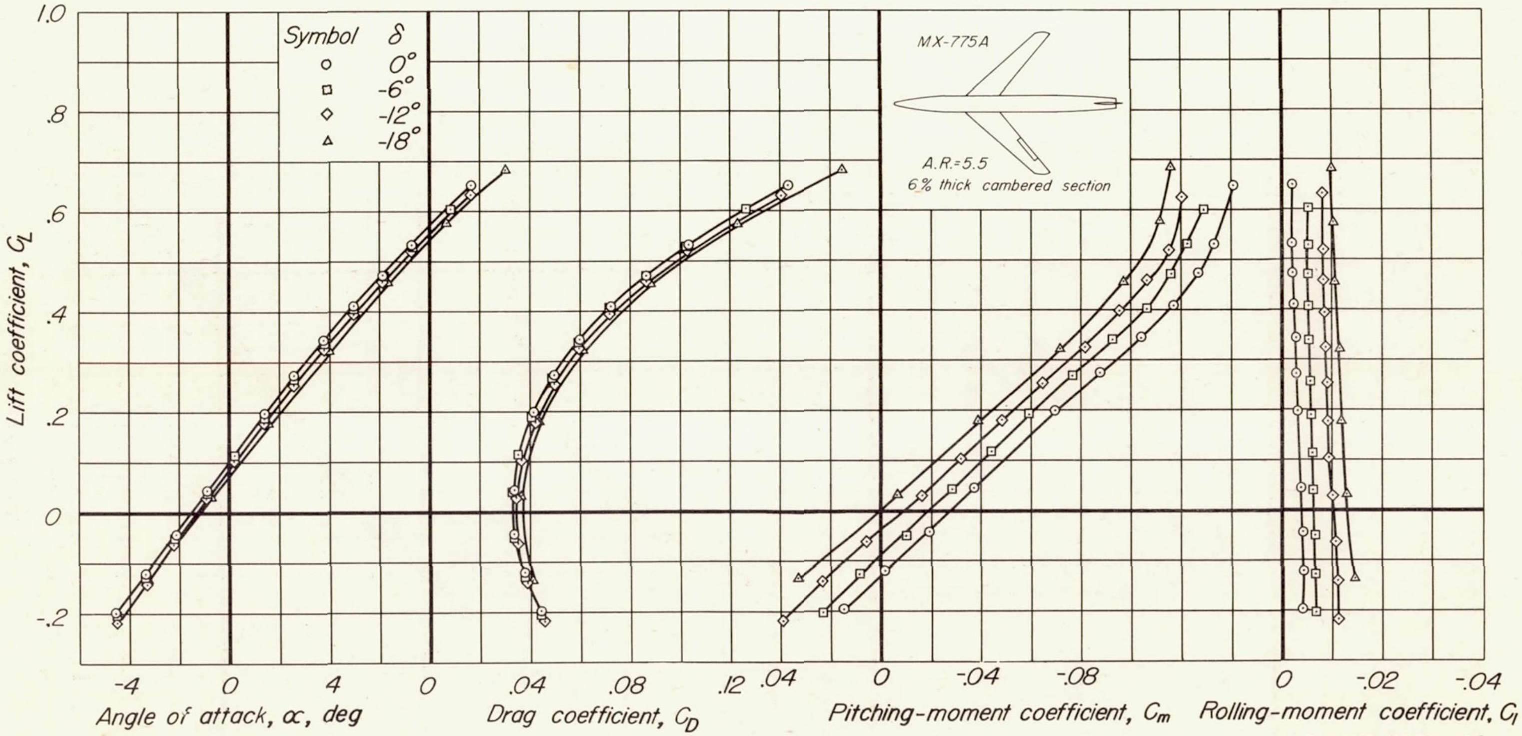
(b) M=0.92

Figure 4.- Continued.



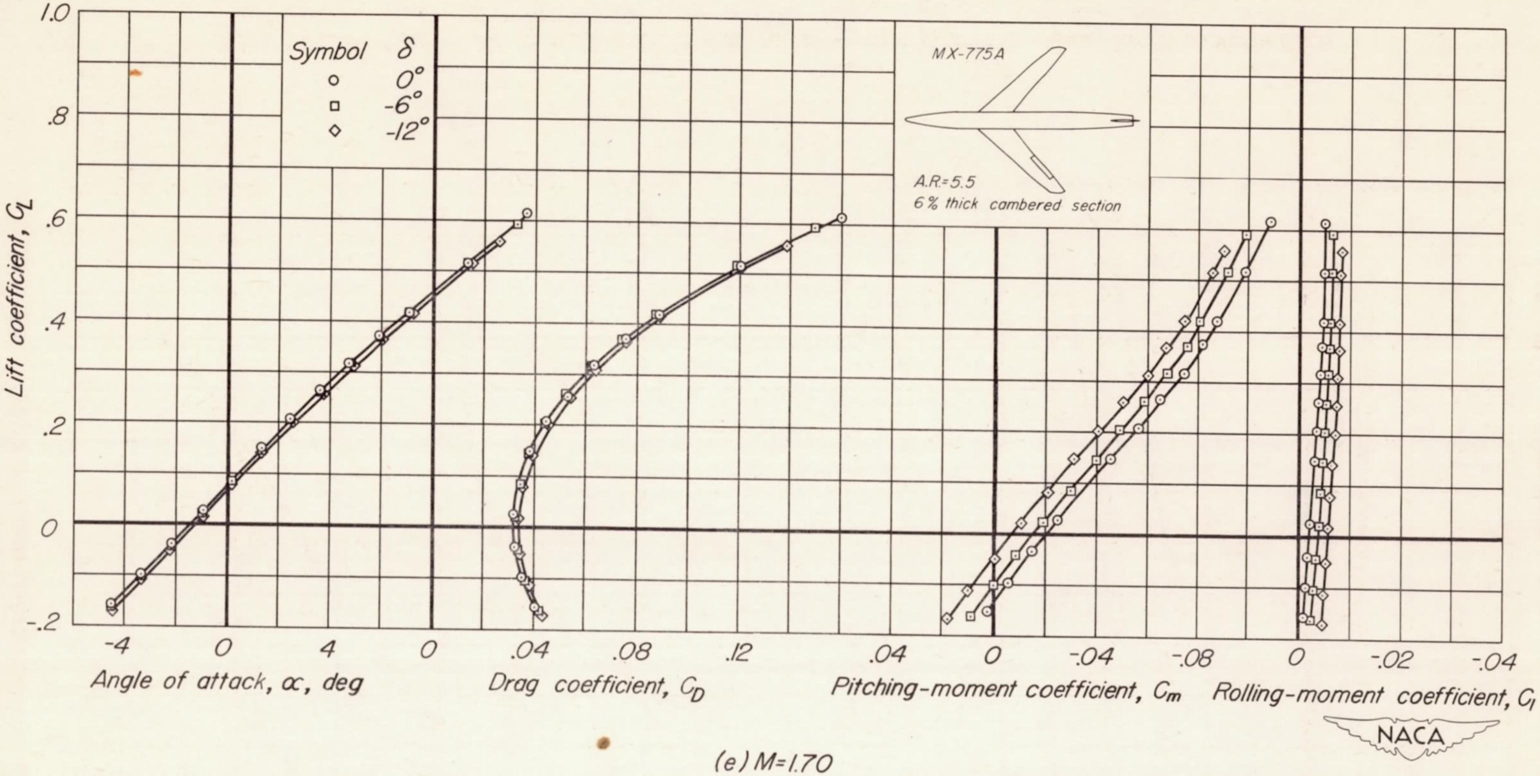
(c) M=1.30

Figure 4.- Continued.



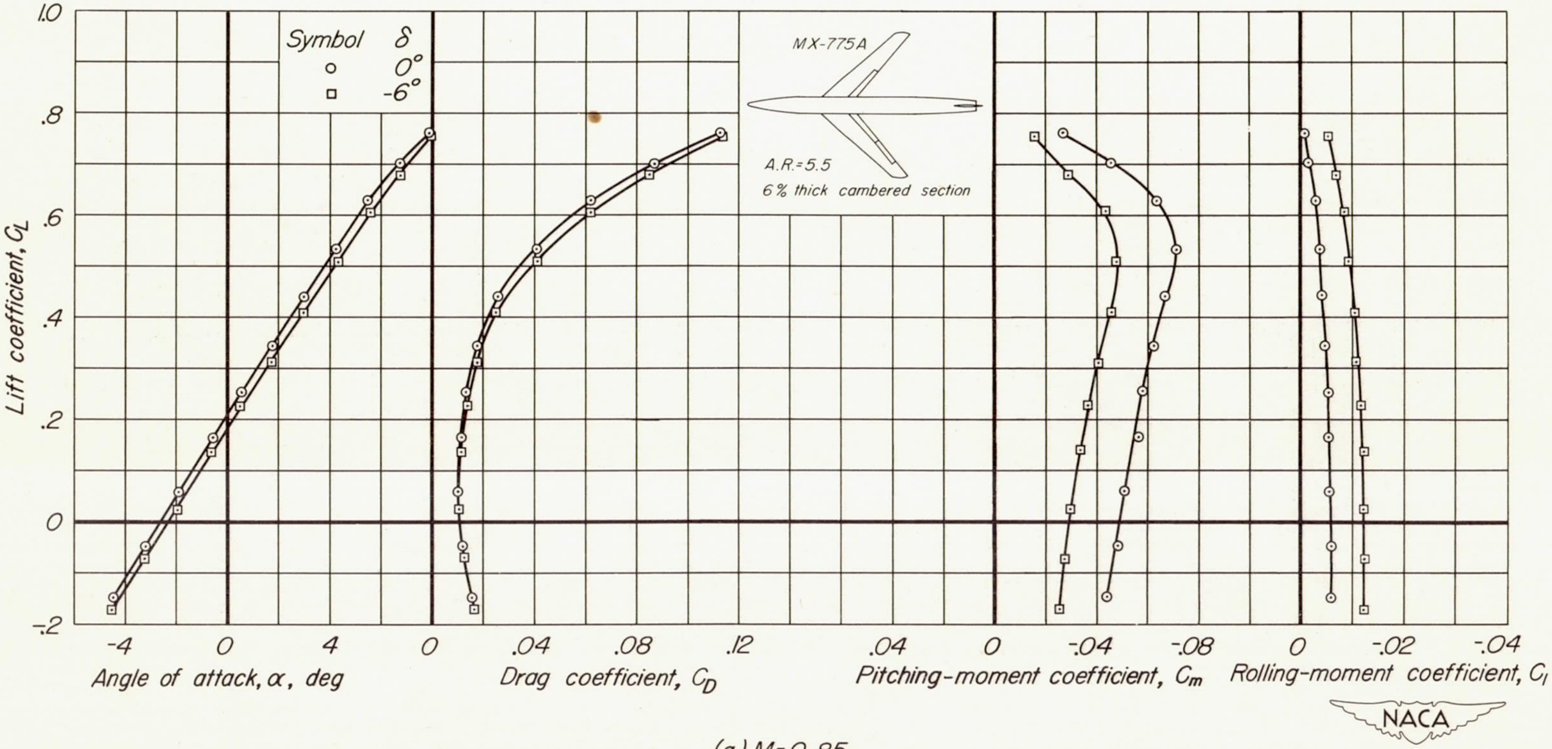
(d) M=1.40

Figure 4.- Continued.



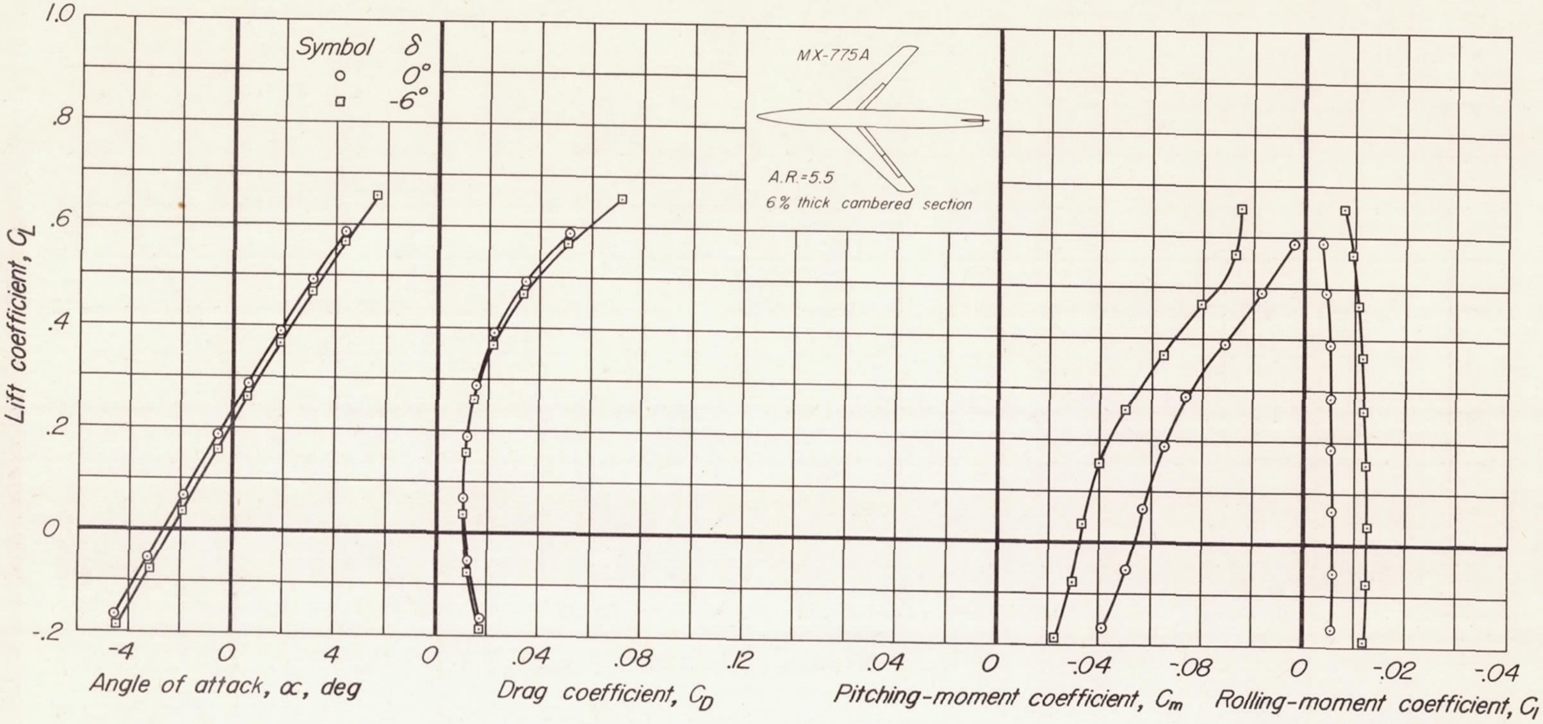
(e) M=1.70

Figure 4.- Concluded.



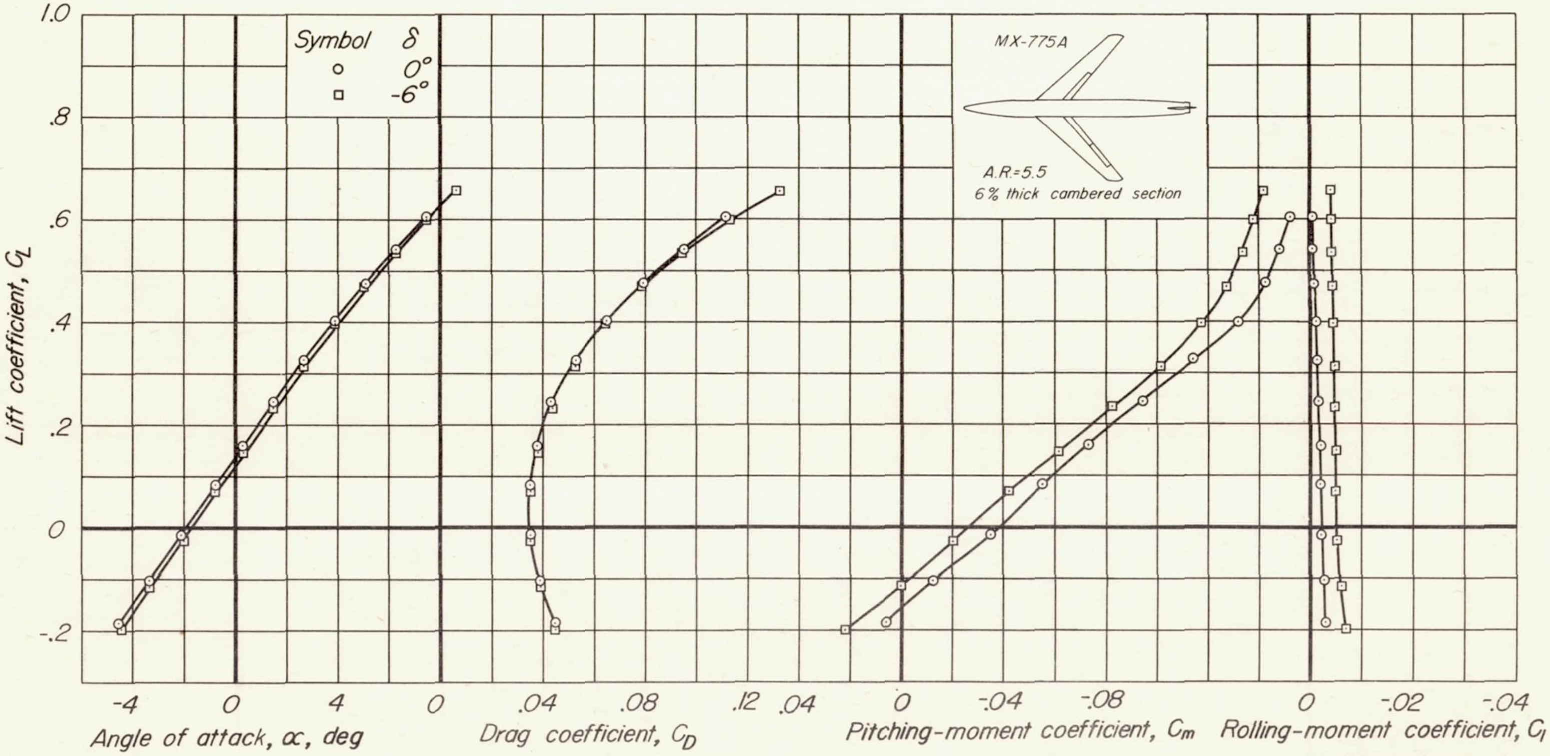
(a) M=0.85

Figure 5.- The effect of left midspan control-surface deflections, δ, on the aerodynamic characteristics of the 1/15-scale MX-775A model; both inboard control surfaces deflected downward 3°. Reynolds number, 2.20 million.



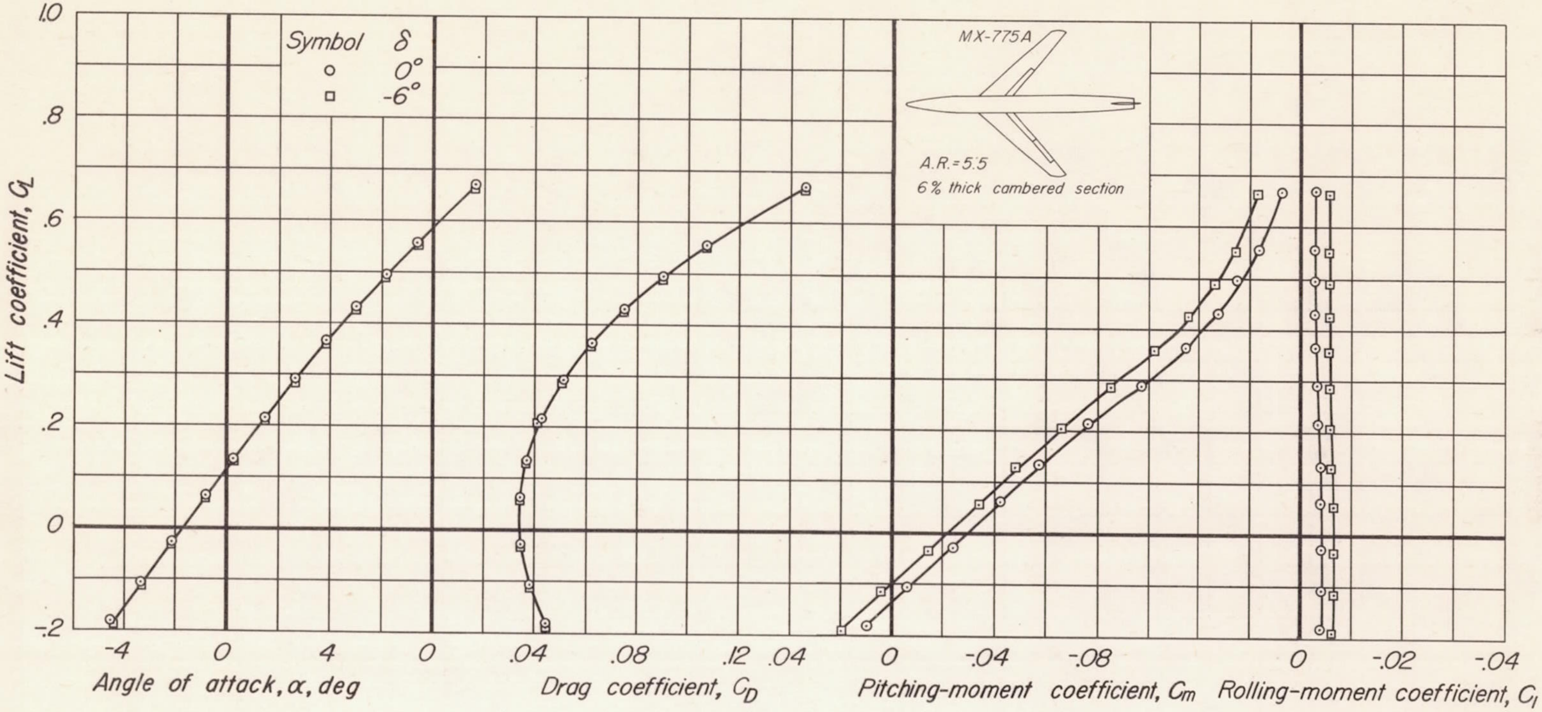
(b) M=0.92

Figure 5.- Continued.



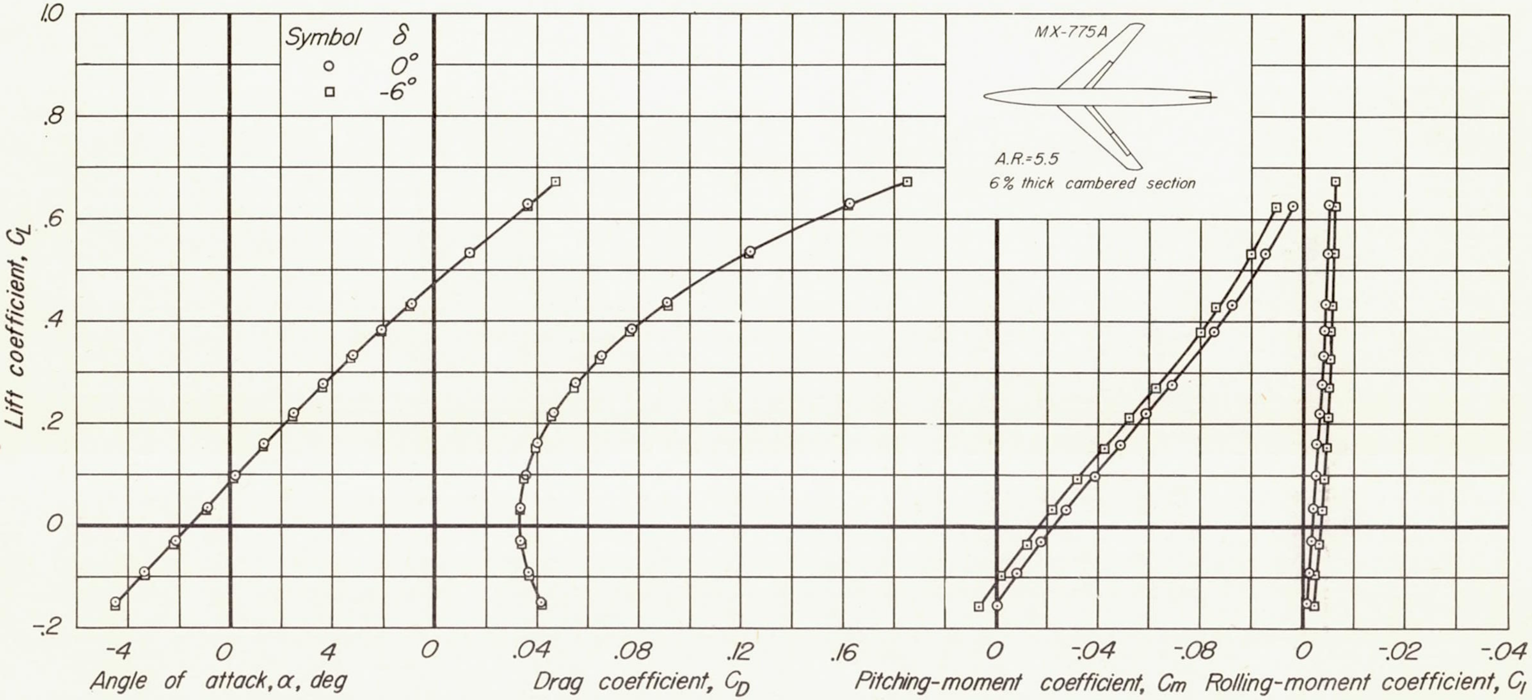
(c) M=1.30

Figure 5.- Continued.



(d) M=1.40

Figure 5.- Continued.



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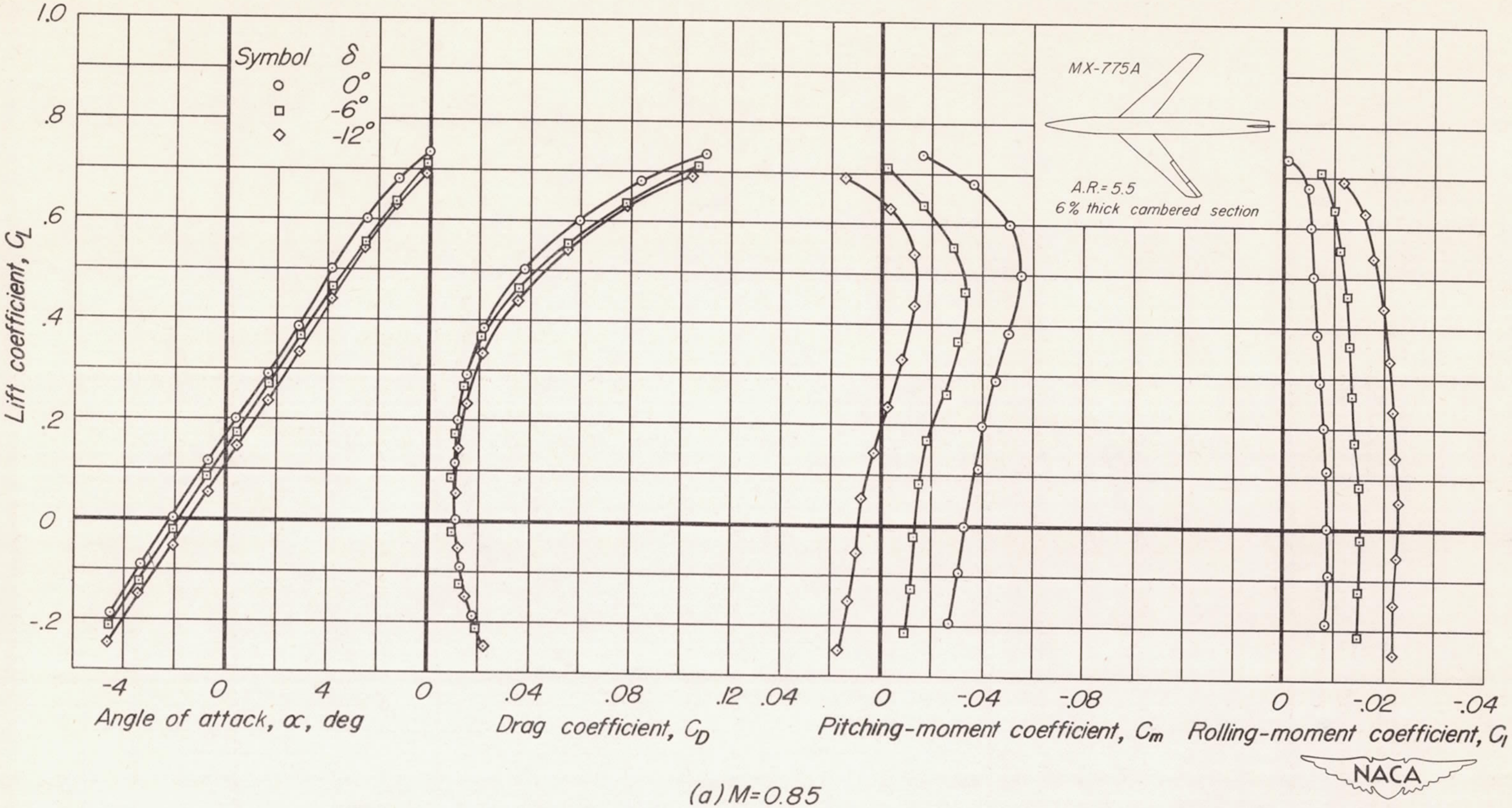
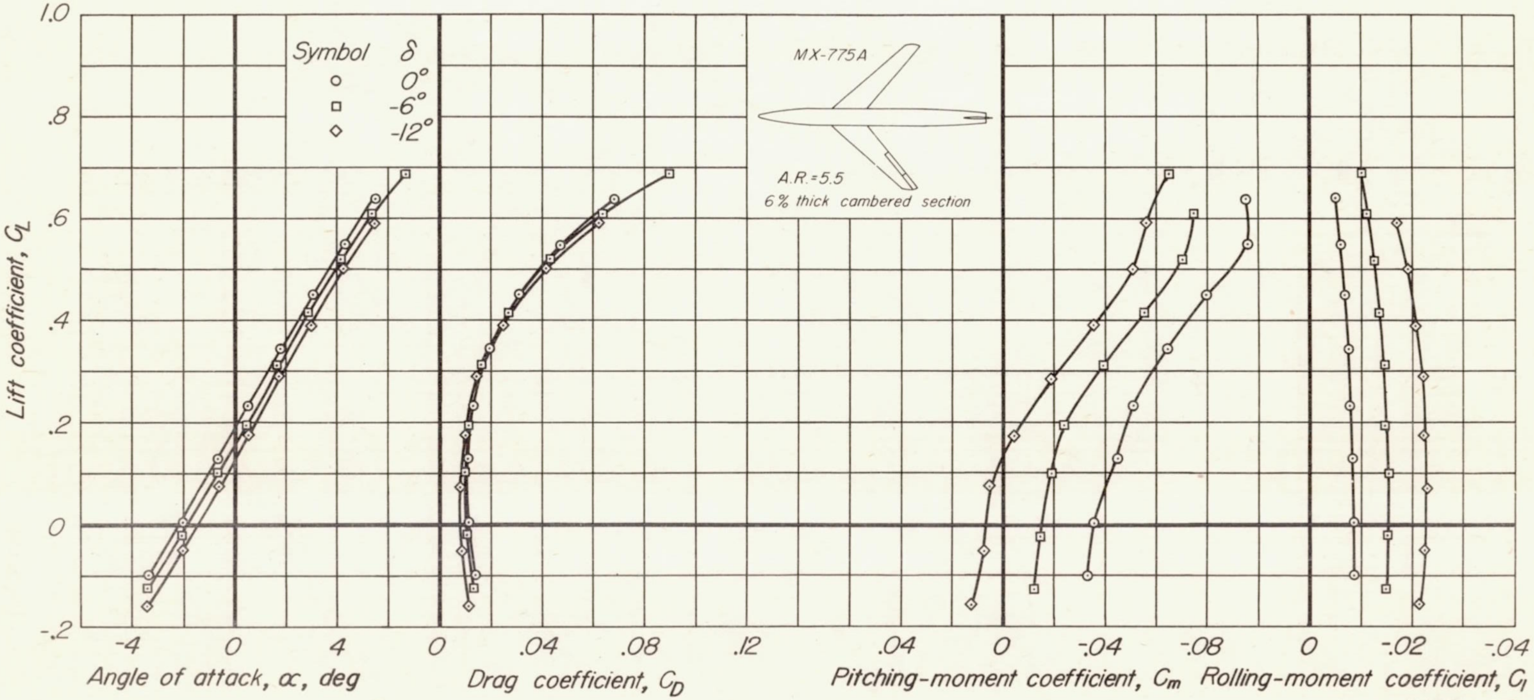
(e) M=1.70

Figure 5.- Concluded.



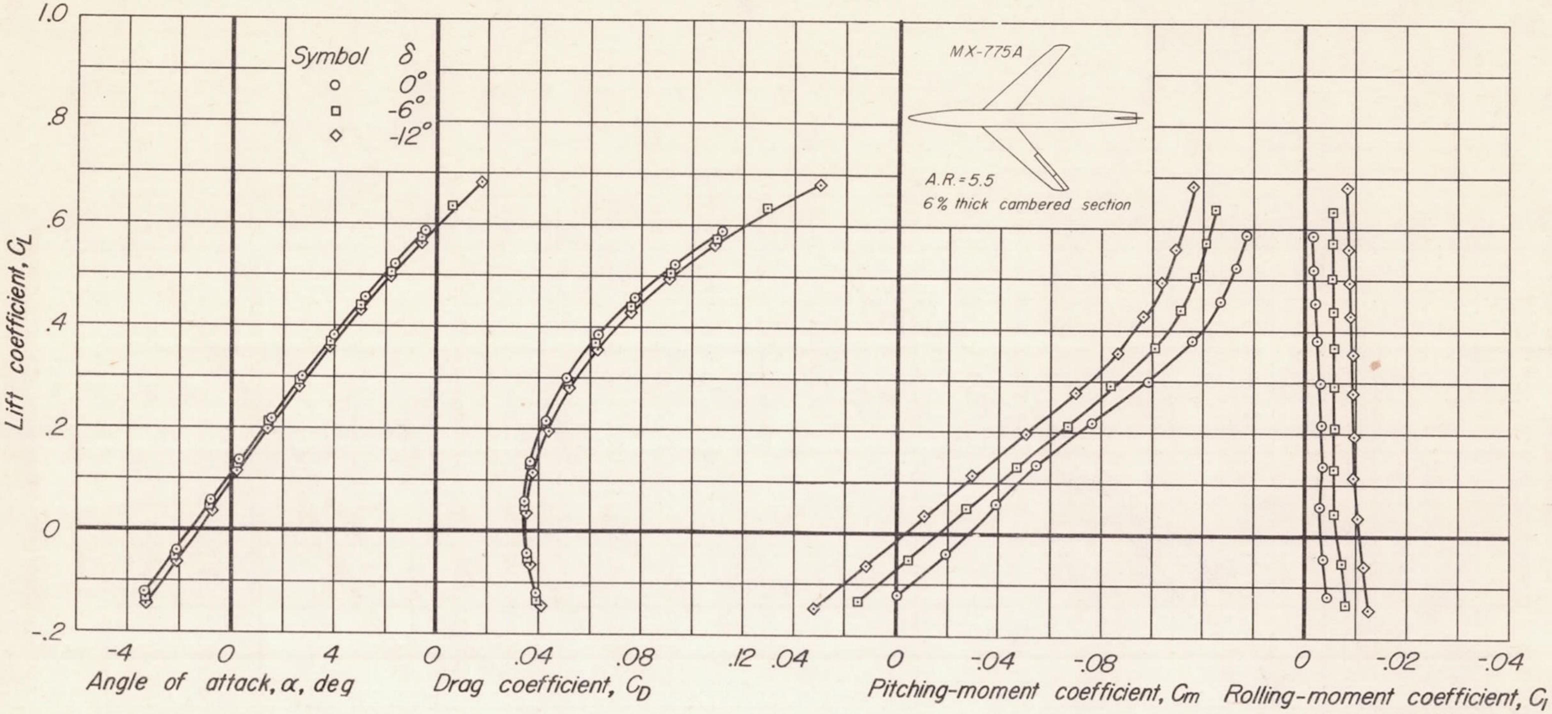
(a) M=0.85

Figure 6.- The effect of left midspan control-surface deflections, δ, on the aerodynamic characteristics of the 1/15-scale MX-775A model; left outboard control surface deflected upward 6°. Reynolds number, 2.20 million.



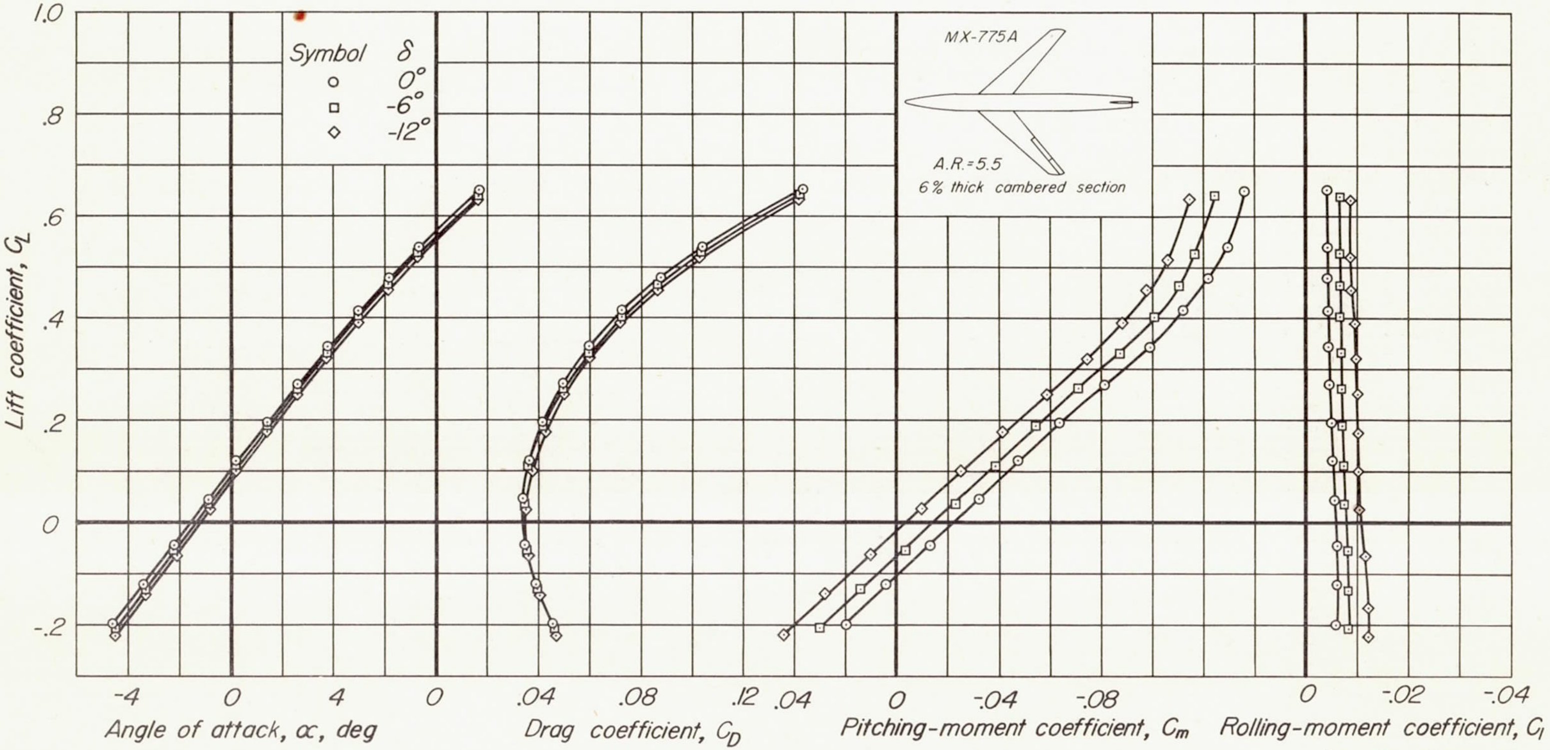
(b) M=0.92

Figure 6.- Continued.



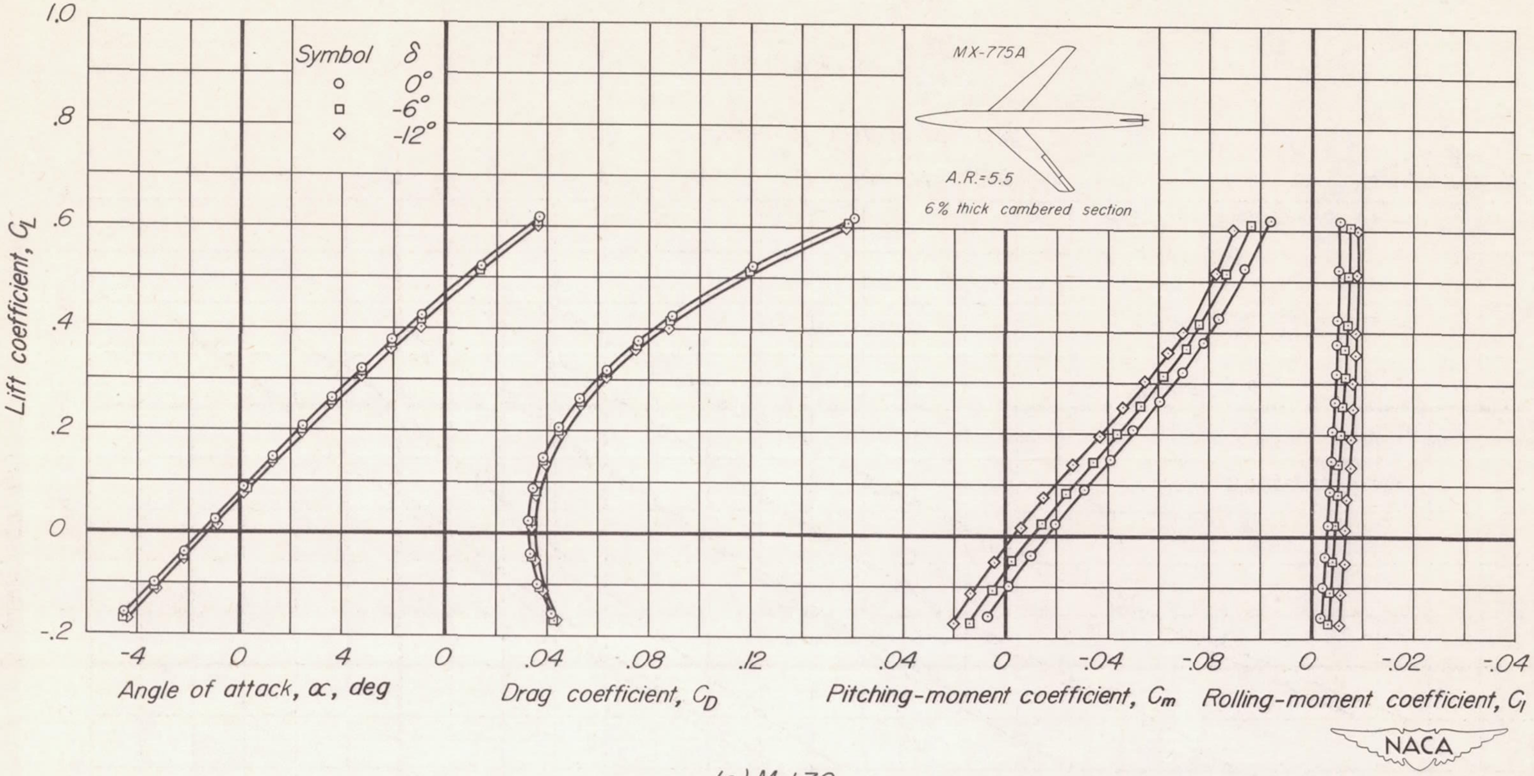
(c) M=1.30

Figure 6.- Continued.



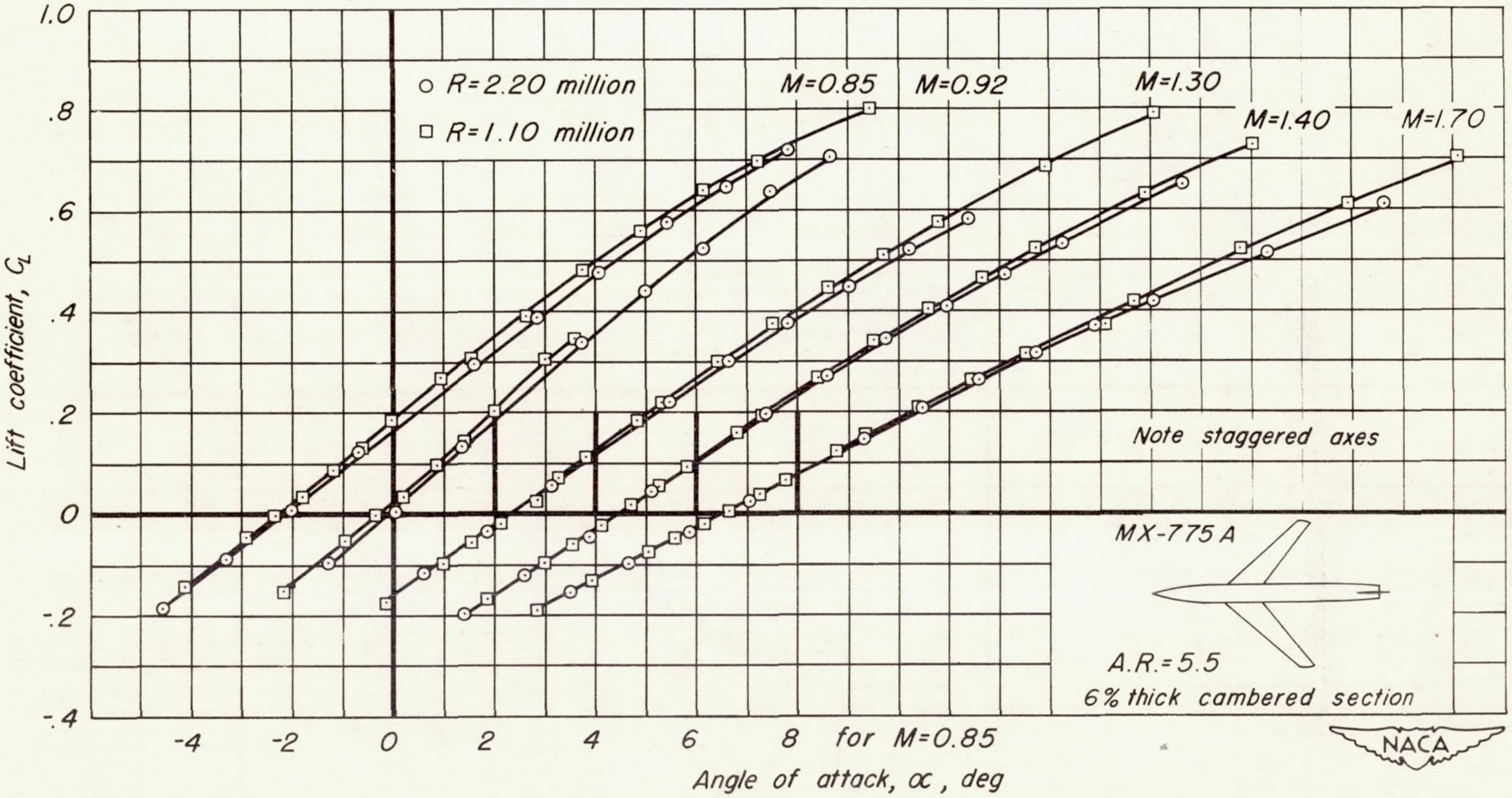
(d) M=1.40

Figure 6.- Continued.



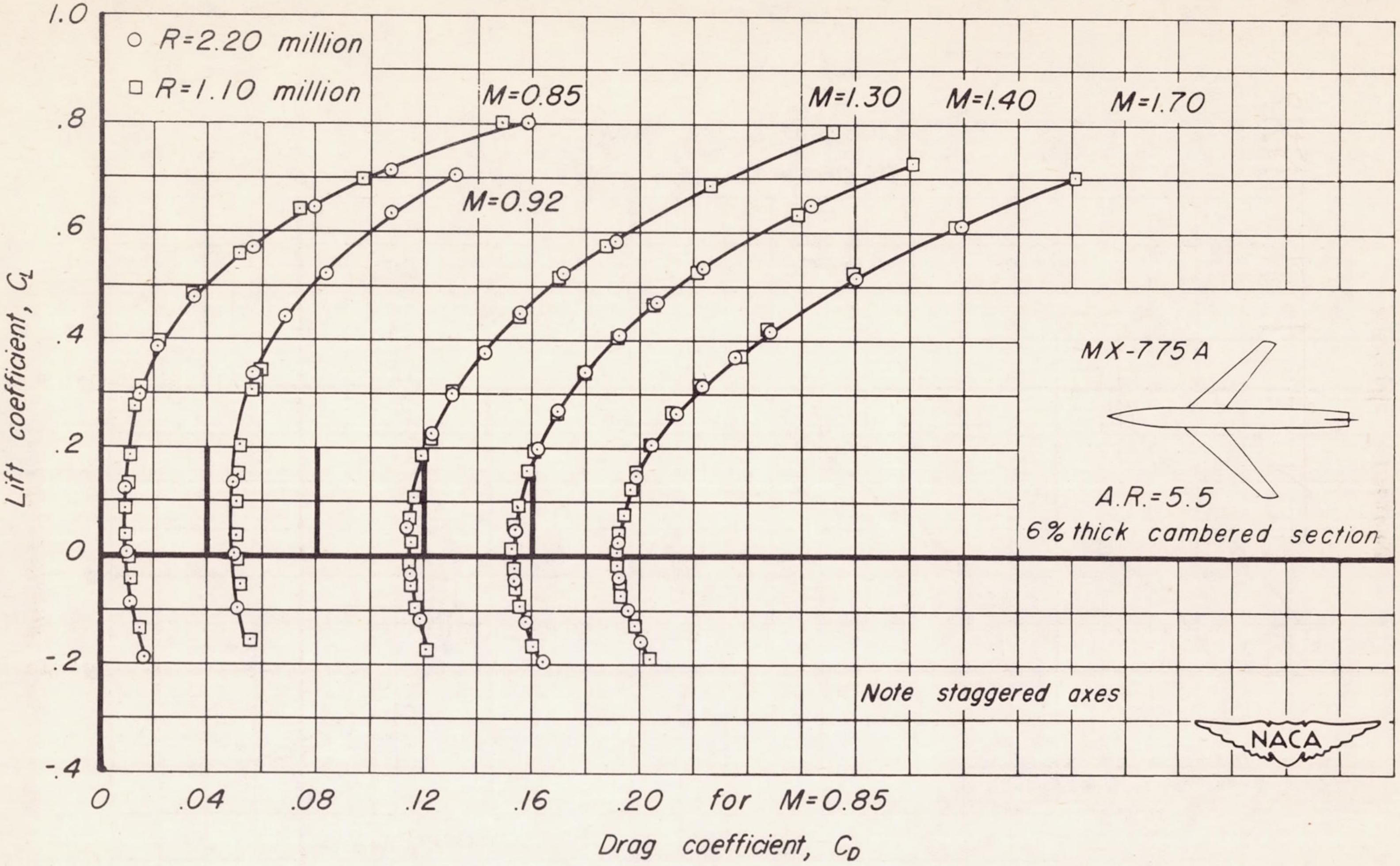
(e) M=1.70

Figure 6.- Concluded.



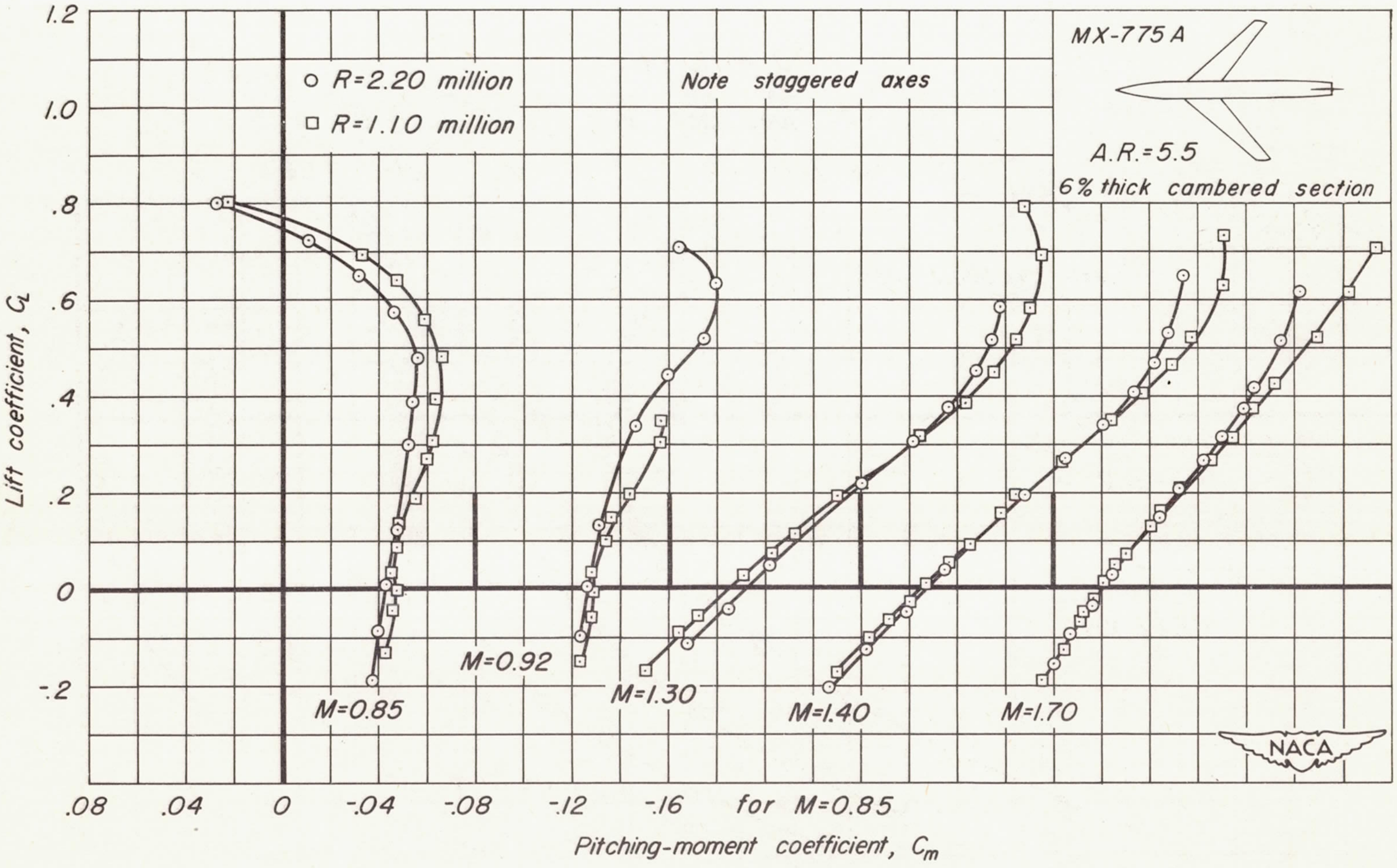
(a) C_L vs α

Figure 7.– The effect of Reynolds number on the aerodynamic characteristics of the 1/15-scale MX-775A model at various Mach numbers.



(b) C_L vs C_D

Figure 7.- Continued.



(c) C_L vs C_m

Figure 7. - Concluded.

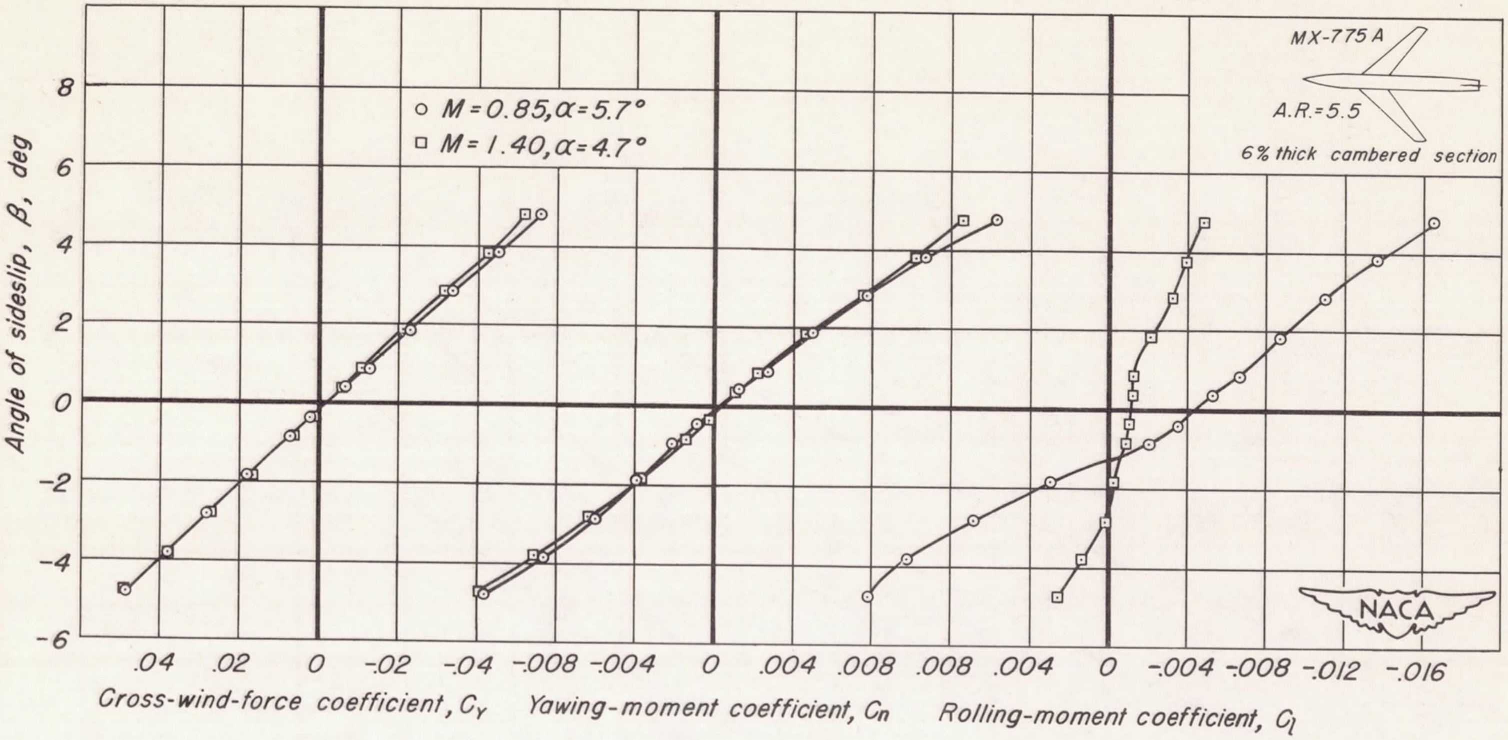
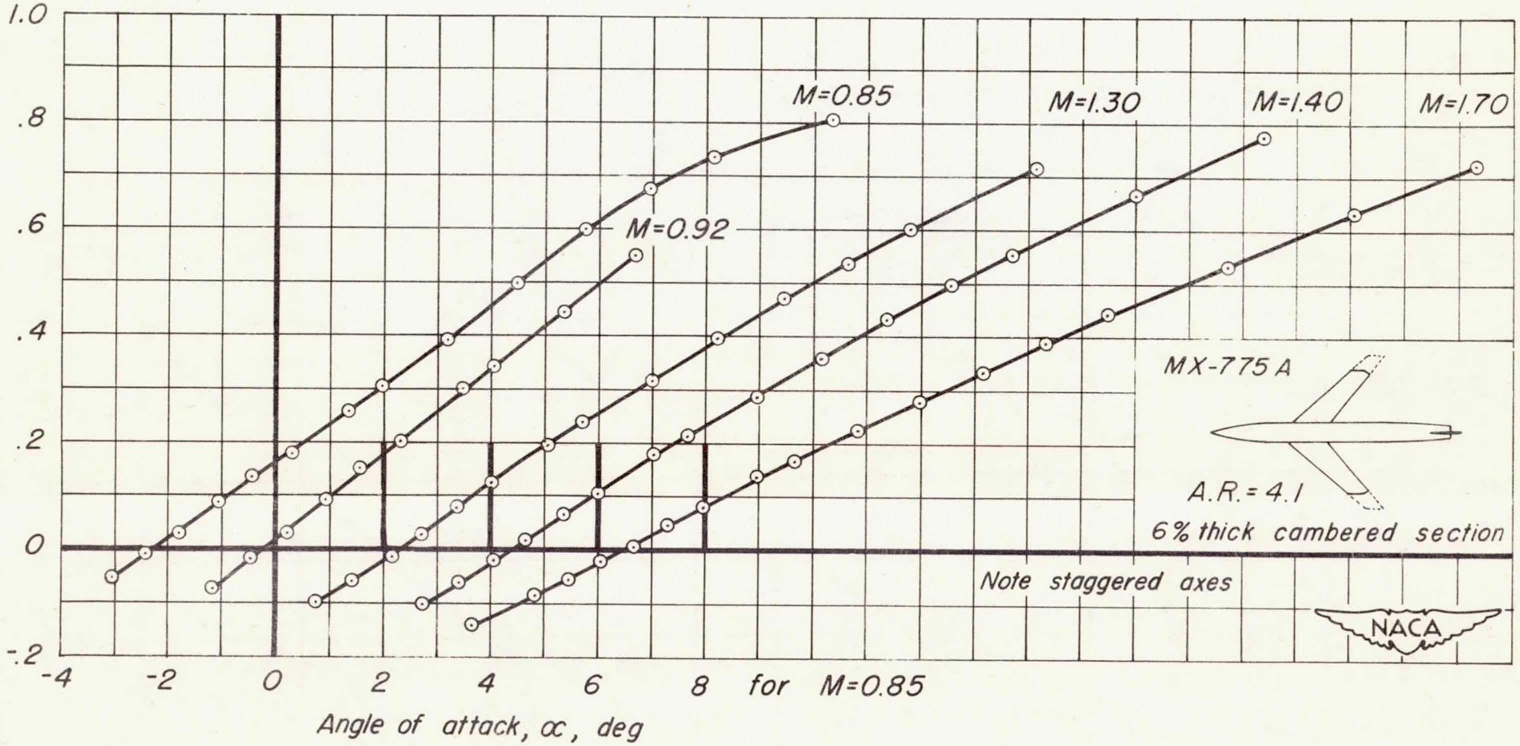
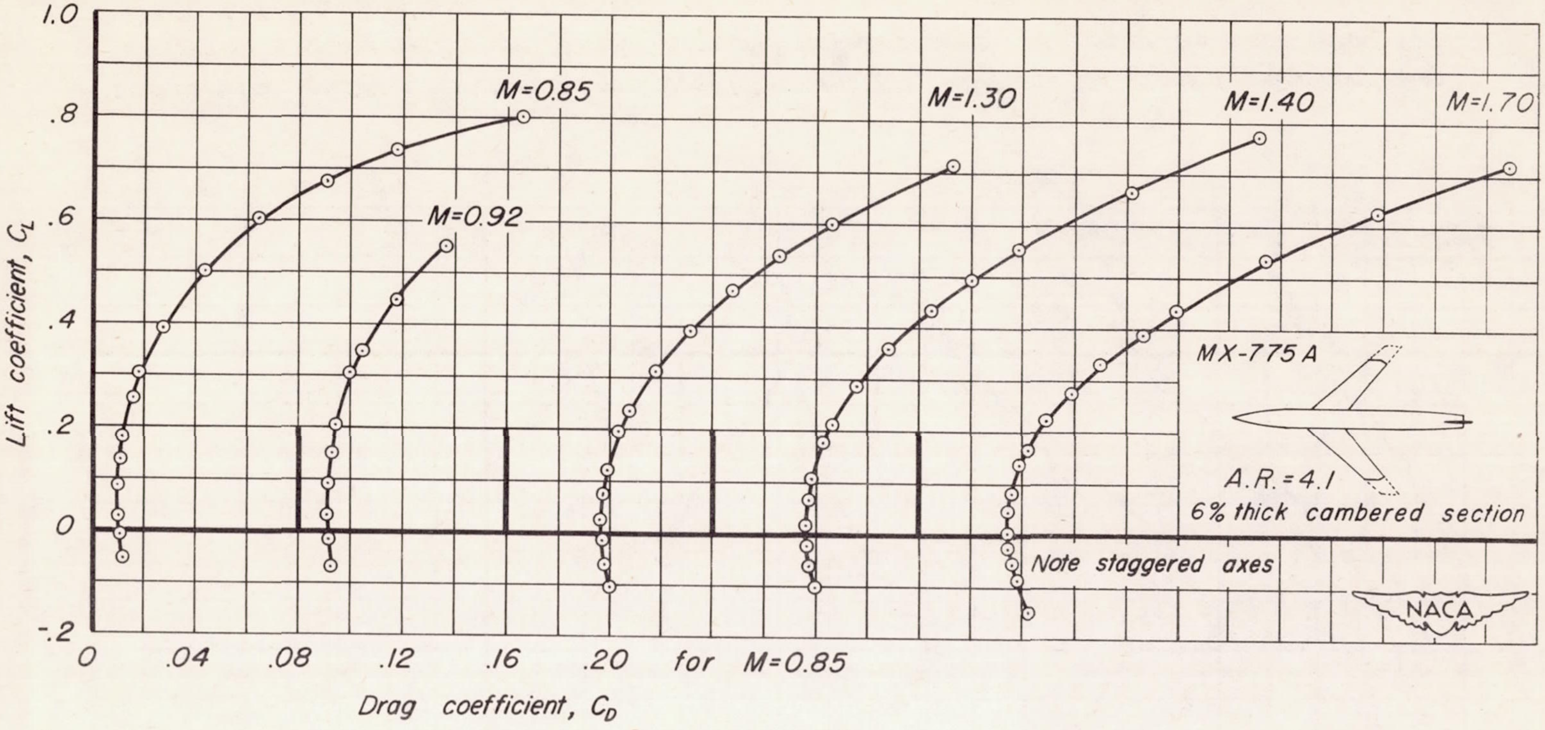


Figure 8.– The effect of sideslip angle, β, on the lateral characteristics of the 1/15-scale MX-775A model. Reynolds number, 2.20 million.



(a) C_L vs α

Figure 9.- The effect of Mach number on the lift and drag characteristics of the clipped-wing configuration of the 1/15-scale MX-775A model. Reynolds number, 2.33 million.



(b) C_L vs C_D

Figure 9.- Concluded.

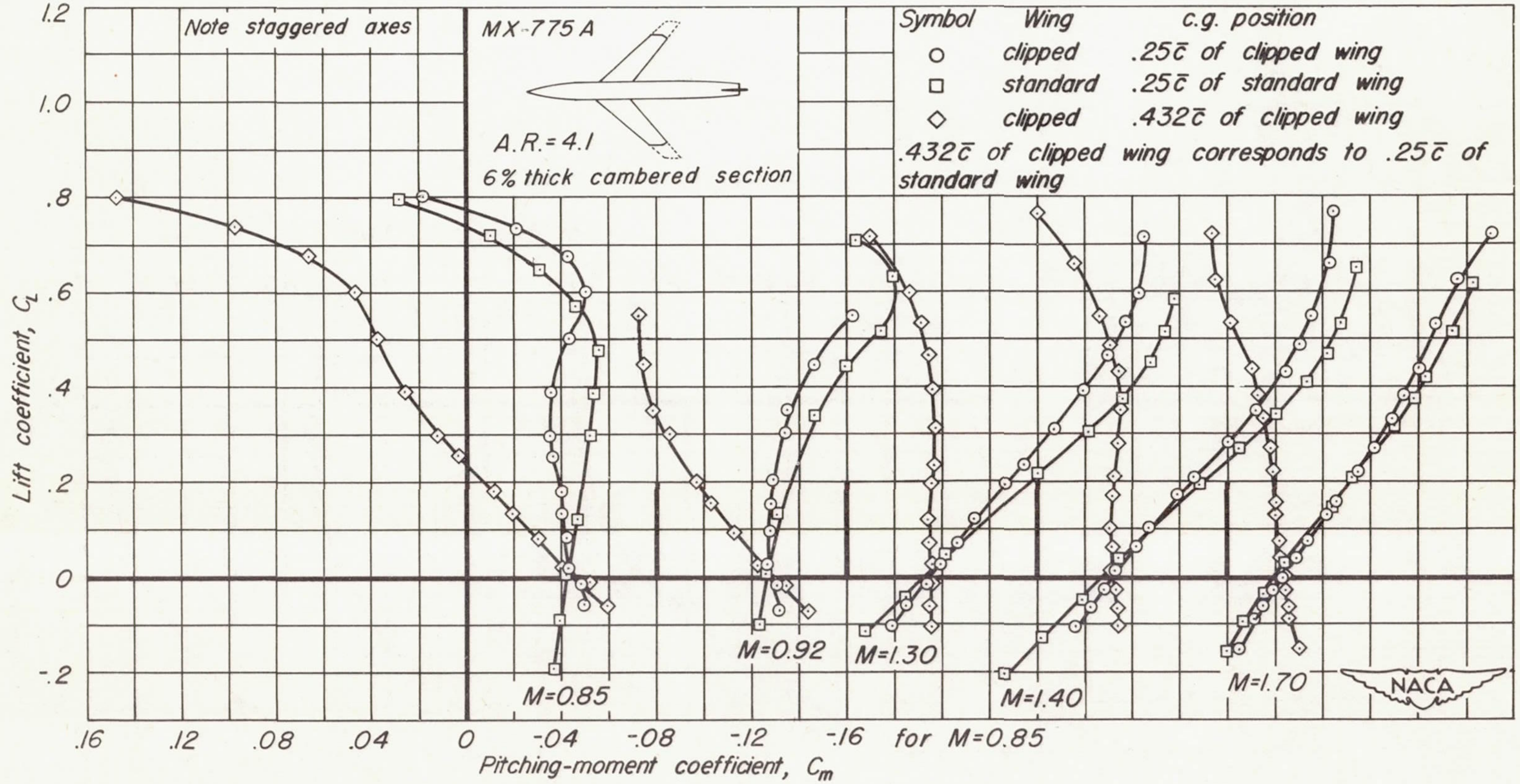


Figure 10.- The variation of pitching-moment coefficient with lift coefficient for standard and clipped-wing configurations of the 1/15-scale MX-775A model. Reynolds number, based on the mean aerodynamic chord of the standard wing, 2.20 million.

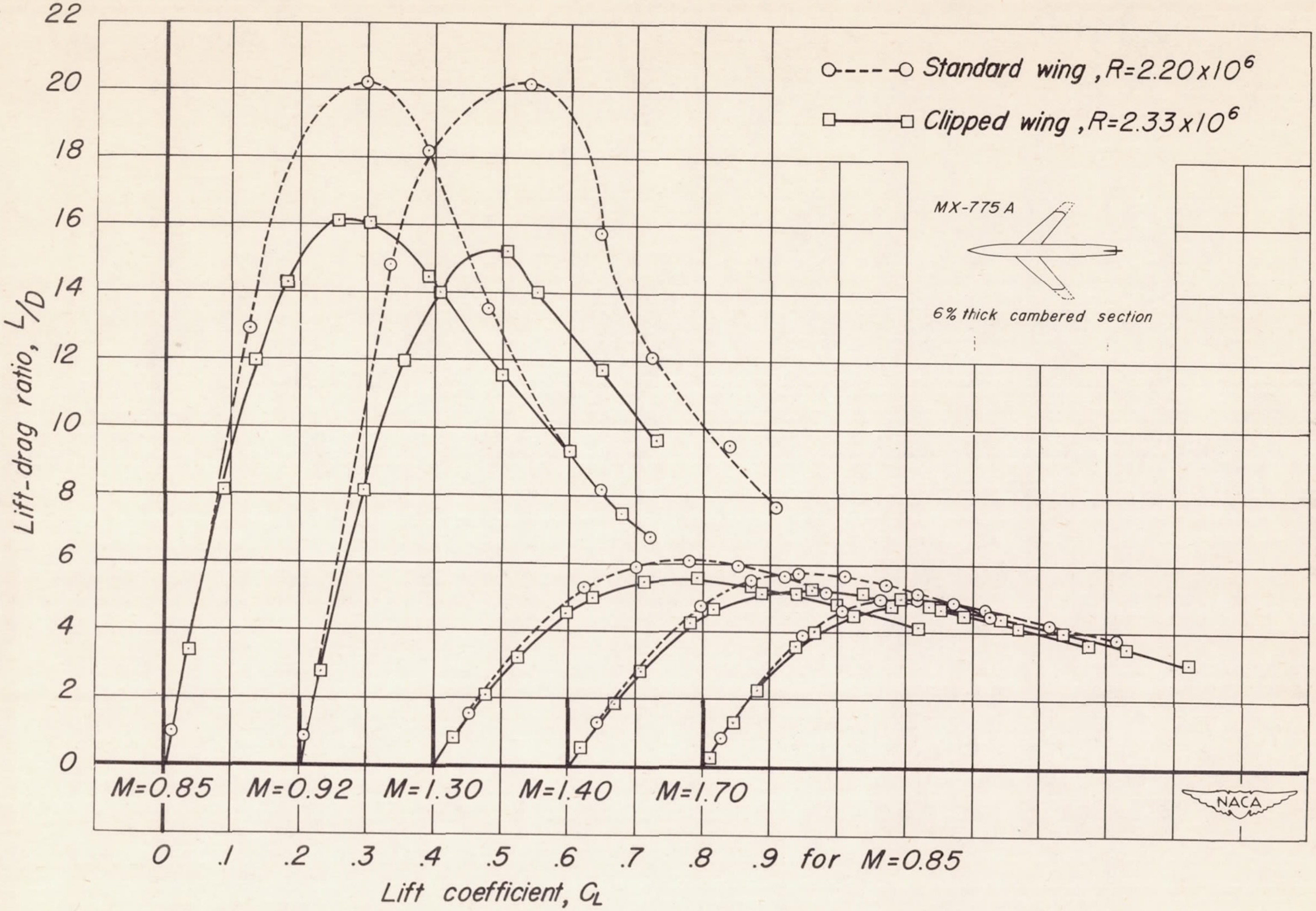


Figure 11. - The effect of Mach number on the lift-drag characteristics of the standard- and clipped-wing configurations of the 1/15-scale MX-775A model.

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