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RESEARCH MEMORANDUM

COMPARISON OF THE AERODYNAMIC CHARACTERISTICS OF
THE NACA 0010 AND 0010-64 AIRFOIL SECTIONS
AT HIGH SUBSONIC MACH NUMBERS

By Perry P. Polentz

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUMCOMPARISON OF THE AERODYNAMIC CHARACTERISTICS OF
THE NACA 0010 AND 0010-64 AIRFOIL SECTIONS
AT HIGH SUBSONIC MACH NUMBERS

By Perry P. Polentz

SUMMARY

A wind-tunnel investigation has been conducted to determine the lift, drag, and pitching-moment characteristics of the NACA 0010 and 0010-64 airfoil sections at Mach numbers up to 0.91 and Reynolds numbers between 1.0×10^6 and 1.9×10^6 . The results are compared to illustrate the effects of varying the chordwise location of maximum thickness from 30-percent to 40-percent chord on the principal high-speed characteristics of the sections.

A virtually unchanged Mach number for lift divergence, a decrease in lift-curve slope of approximately 10 percent, and a reduced maximum lift coefficient at Mach numbers below 0.70 were associated with the more rearward location of maximum thickness. The Mach number for drag divergence was increased about 0.05 at lift coefficients up to 0.4, but the rate of drag rise above the Mach number for drag divergence was not appreciably changed. Pitching moment was affected to a negligible degree.

INTRODUCTION

The characteristics at high Mach numbers are available for relatively few airfoil sections of the NACA 4-digit series. The present experimental investigation was undertaken to obtain such data for the NACA 0010 and 0010-64 airfoil sections at Mach numbers ranging up to 0.91. A further purpose was to appraise the effect of varying the position of maximum thickness from 30-percent chord for the NACA 0010 profile to 40-percent chord for the NACA 0010-64 profile.

NOTATION

a_0 section lift-curve slope, per degree
 c_d section drag coefficient

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c_l	section lift coefficient
$c_{l_{max}}$	maximum section lift coefficient
$c_{m_{c/4}}$	section quarter-chord pitching-moment coefficient
M	Mach number of free stream
M_d	Mach number for drag divergence
M_l	Mach number for lift divergence
α_0	section angle of attack, degrees

APPARATUS AND TESTS

The tests were conducted in the Ames 1- by 3-1/2-foot high-speed wind tunnel. This tunnel is a two-dimensional, closed-return type having a rectangular test section of the indicated cross-sectional dimensions, and is provided with sufficient power to obtain choked flow in the presence of any model. Its contraction ratio is 16.1:1. Atmospheric air, maintained at barometric pressure in the settling chamber, forms the working substance.

Lift and pitching-moment data are obtained by use of a method similar to that described in reference 1 from measurements of the reactions on the tunnel floor and ceiling of forces experienced by the airfoil. Drag is determined from wake-survey measurements made with a rake of total-head tubes. By use of these methods it is possible to seal completely the gap between the sides of the tunnel and the ends of the airfoil, and ensure that two-dimensional flow is obtained over the entire surface without interference with force measurements.

Scale drawings of the profiles tested are reproduced in figure 1, and the corresponding coordinates are tabulated in table I, from which it will be noted that the point of maximum thickness is located at 30-percent chord for the NACA 0010 airfoil section and at 40 percent for the NACA 0010-64. (The significance of the airfoil notation used is explained in reference 2.) The chord length employed for the tests was 6 inches; the models were mounted at the center line of the tunnel and spanned the 1-foot dimension. The airfoils were fabricated of aluminum alloy, the deviation from nominal dimensions being held to 0.002-inch maximum. All surfaces were carefully polished to a mirror-like finish.

The Mach number of the tests was varied from 0.3 minimum to a maximum value lying between 0.75 and 0.91, the exact range depending upon the angle of attack but being sufficient to encompass the lift stall up to Mach numbers of the order of 0.8. Data were secured for angles of attack between -2° and 12° at increments of 2° , and at -1°

and 1° . Reynolds numbers of the investigation varied from 1.0×10^6 minimum to 1.9×10^6 maximum.

The results obtained in the wind tunnel have been corrected by the method of reference 3 to account for the constriction in the channel caused by the model and by the wake. The magnitude of these corrections increases both with Mach number and with angle of attack, but, in general, amounts to less than 2 percent of the values reported. This same reference demonstrates that no correction is possible for data obtained at the choking Mach number. Dashed lines are used on the figures to indicate measurements made in the vicinity of this Mach number which are of doubtful validity.

RESULTS AND DISCUSSION

Lift, drag, and pitching-moment coefficients for the NACA 0010 and 0010-64 airfoil sections are presented as functions of Mach number in figures 2, 3, and 4. An indication of the accuracy of the lift and pitching-moment measurements is afforded by the symmetry of the curves at low lift coefficients. Owing to such variables as stream angularity, model asymmetry, and errors in setting the angle of attack in the wind tunnel, discrepancies equivalent to as much as 0.2° in angle of attack may be observed.

Lift as a function of angle of attack is shown for various Mach numbers for the two airfoil sections in figure 5. Comparison of the principal lift parameters is provided in figures 6 and 7. Figure 6 discloses that no significant difference exists for the lift-divergence Mach numbers of the two profiles. (Lift-divergence Mach number is arbitrarily defined as that Mach number at which the first point of inflection occurs in the lift coefficient versus Mach number curve.) Figure 7 shows lift-curve slope and maximum lift coefficient as a function of Mach number for the two sections.

The loss of lift-curve slope for the NACA 0010-64 section compared to the NACA 0010 observed in figure 7, approximately 10 percent at Mach numbers below 0.7, cannot be attributed entirely to the differing maximum-thickness locations of the two profiles. Reference 4 indicates that some of this deterioration results from the increased trailing-edge angle of the NACA 0010-64 profile ($17^\circ 54'$ as compared with $13^\circ 22'$ for the NACA 0010). The present data do not permit a separate evaluation of the effect of this geometric variable, but the general conclusion is indicated that shifting the maximum thickness to 40-percent chord decreases the lift-curve slope at all Mach numbers for which data were obtained.

Figure 7 also demonstrates that the maximum lift coefficient of the NACA 0010-64 airfoil section, compared to the NACA 0010, is appreciably smaller to approximately 0.7 Mach number; but that differences beyond this value are inconsequential. Reference 4, on the other hand, indicates

that the maximum lift coefficient at Mach numbers above 0.7 would be reduced by the increase in the trailing-edge angle. By virtue of these facts, it seems evident that some increase of maximum lift coefficient, above 0.7 Mach number, results from the rearward shift of maximum-thickness location.

Drag-divergence Mach number (defined as the Mach number at which, for a constant angle of attack, the slope of the curve of drag coefficient versus Mach number equals 0.10) is plotted in figure 8 as a function of section lift coefficient. The advantage of the more rearward maximum-thickness location is here clearly evident, the Mach number for drag divergence being increased about 0.05 at lift coefficients up to 0.4. According to reference 4, however, some of this gain accrues from the change in trailing-edge angle.

Further evidence of the effect of the rearward shift of the maximum thickness on drag appears in figure 9, which illustrates the variation of drag coefficient with lift coefficient for the two profiles. A point-by-point comparison between the (a) and (b) portions of this figure at Mach numbers above that for drag divergence will quickly demonstrate that the NACA 0010-64 profile has much smaller drag coefficients than does the NACA 0010, but an approximately equal rate of drag rise with increasing lift coefficient. Reference to figure 3 shows that the reduction of drag stems primarily from the delayed drag rise of the NACA 0010-64 section as compared to that of the NACA 0010 section.

In figure 10 is seen the variation of pitching-moment coefficient with lift coefficient for the two airfoil sections, and the change with Mach number of the slopes of these curves at zero lift is illustrated by the plots of figure 11. The variation of the slopes displayed by both profiles at the higher Mach numbers is undesirably great, and it will be observed that moving the point of maximum thickness from 30-percent chord to 40-percent chord provides little improvement.

CONCLUSIONS

A comparison of the experimental lift, drag, and pitching-moment characteristics of the NACA 0010 and 0010-64 airfoil sections at Mach numbers up to 0.91 provides the following conclusions relative to changing the maximum-thickness position from 30-percent to 40-percent chord:

1. The lift-curve slope decreased approximately 10 percent throughout the Mach number range of the investigation, the Mach number for lift divergence was practically unaffected, and the maximum lift coefficient was reduced at Mach numbers below 0.70.
2. The drag-divergence Mach number increased approximately 0.05 at lift coefficients up to 0.4. The rate of drag rise with increasing Mach number above that for drag divergence was virtually unchanged.

3. The variation with Mach number of the slopes of the pitching-moment versus lift-coefficient curves (measured at zero lift) was practically unaffected.

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

REFERENCES

1. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA Rep. 824, 1945.
2. Stack, John, and von Doenhoff, Albert E.: Tests of 16 Related Airfoils at High Speeds. NACA Rep. 492, 1934.
3. Allen, H. Julian, and Vincenti, Walter G.: Wall Interference in a Two-Dimensional-Flow Wind Tunnel, With Consideration of the Effect of Compressibility. NACA Rep. 782, 1944.
4. Summers, James L., and Graham, Donald J.: Effects of Systematic Changes of Trailing-Edge Angle and Leading-Edge Radius on the Variation With Mach Number of the Aerodynamic Characteristics of a 10-Percent-Chord-Thick NACA Airfoil Section. NACA RM A9G18, 1949.

TABLE I.— COORDINATES OF THE NACA AIRFOILS TESTED

[Stations and ordinates given in percent of airfoil chord]

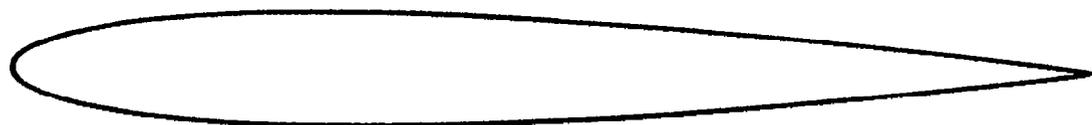
NACA 0010 SECTION

Upper and lower surface	
Station	Ordinate
0	0
1.250	1.578
2.500	2.178
5.000	2.962
7.500	3.500
10.000	3.902
15.000	4.455
20.000	4.782
25.000	4.952
30.000	5.002
40.000	4.837
50.000	4.412
60.000	3.803
70.000	3.053
80.000	2.187
90.000	1.207
95.000	.672
100.000	.105
L.E. radius, 1.10 percent c	

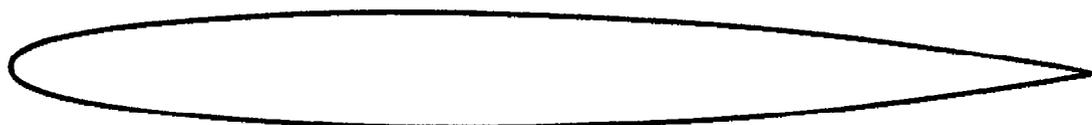
NACA 0010-64 SECTION

Upper and lower surface	
Station	Ordinate
0	0
1.250	1.511
2.500	2.044
5.000	2.722
7.500	3.178
10.000	3.533
15.000	4.056
20.000	4.411
25.000	4.666
30.000	4.856
40.000	5.000
50.000	4.856
60.000	4.433
70.000	3.733
80.000	2.767
90.000	1.556
95.000	.856
100.000	.100
L.E. radius, 1.10 percent c	





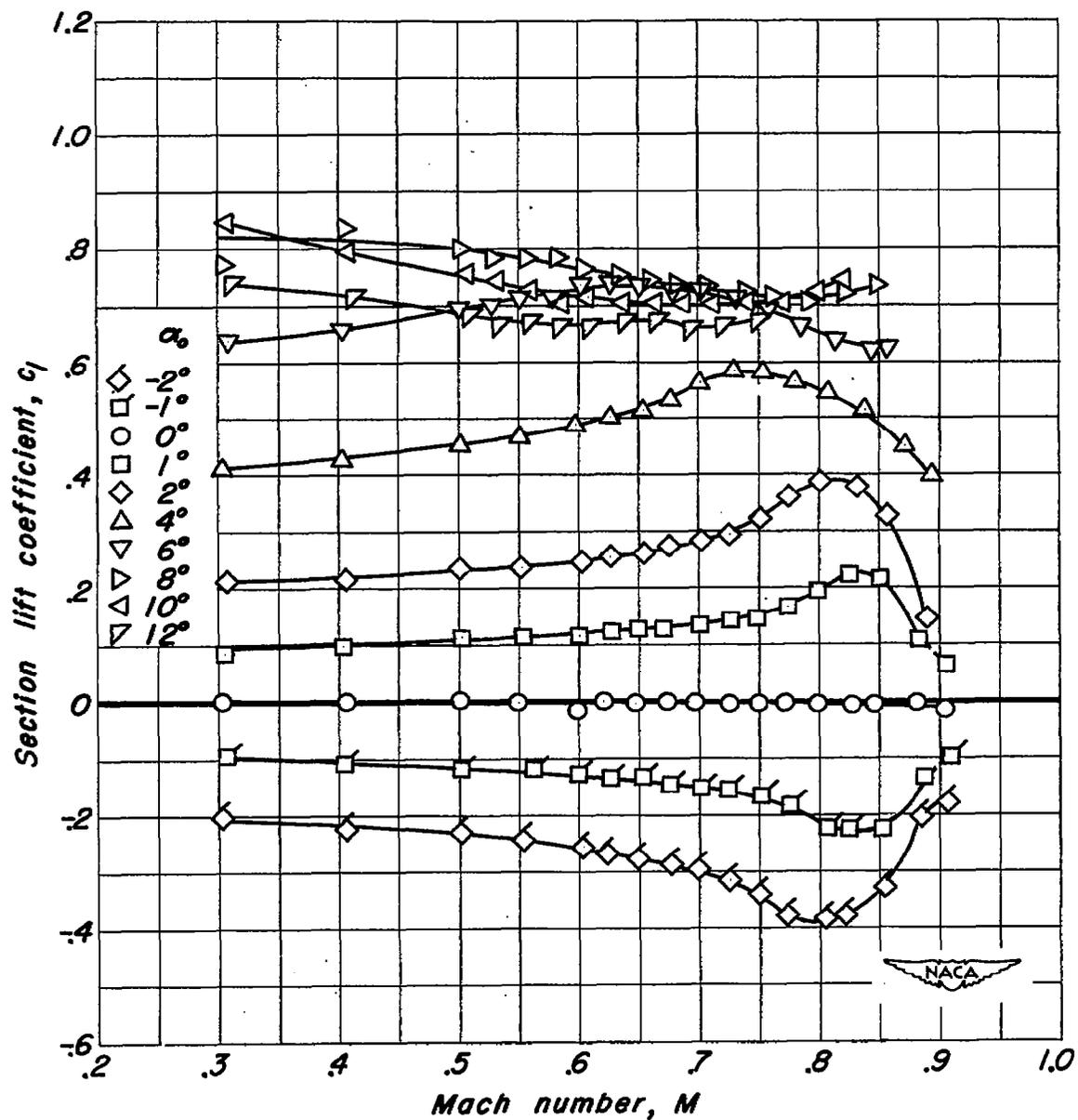
NACA 0010



NACA 0010-64

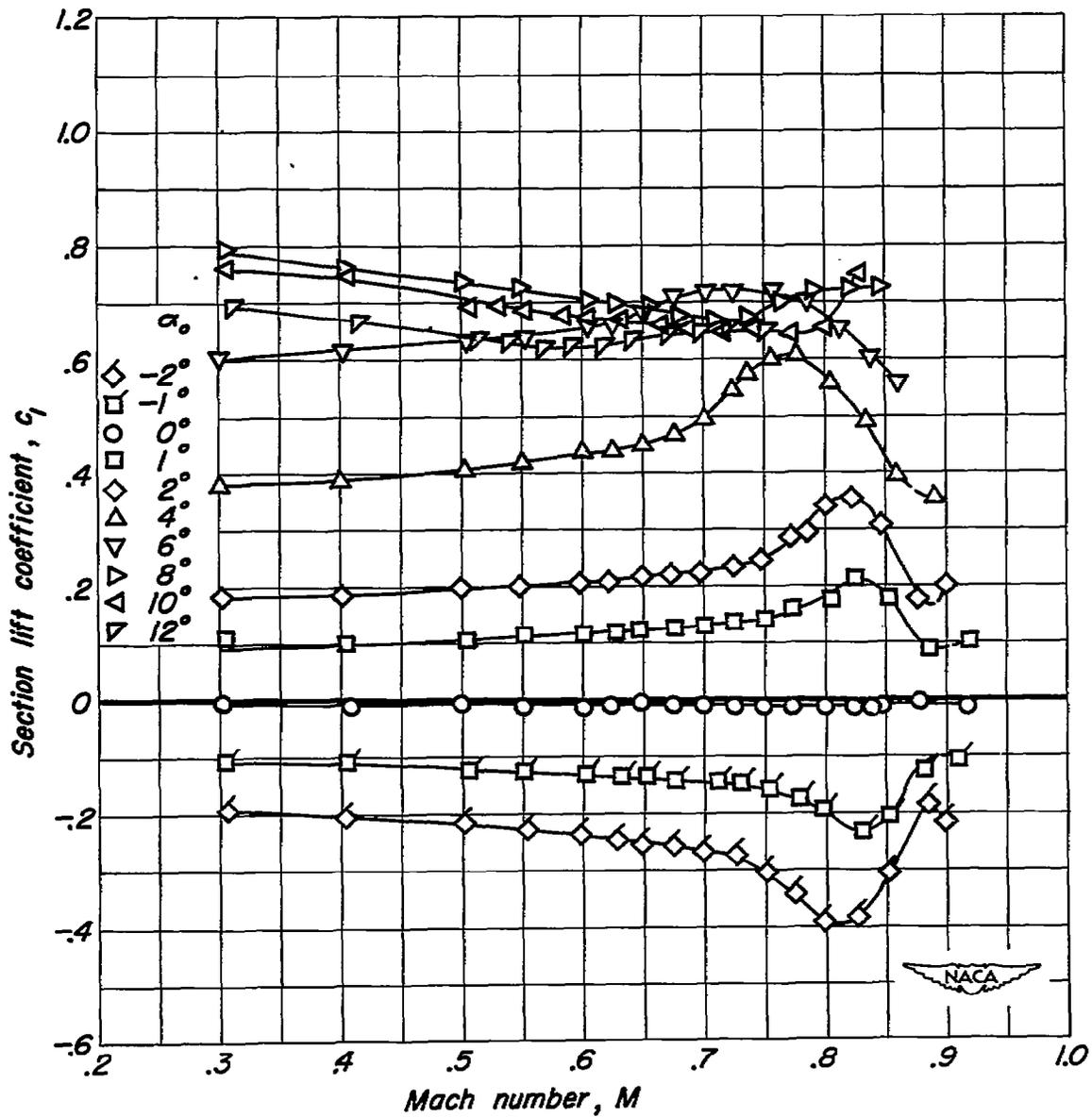


Figure 1.— Profiles of the NACA 0010 and 0010-64 airfoil sections.



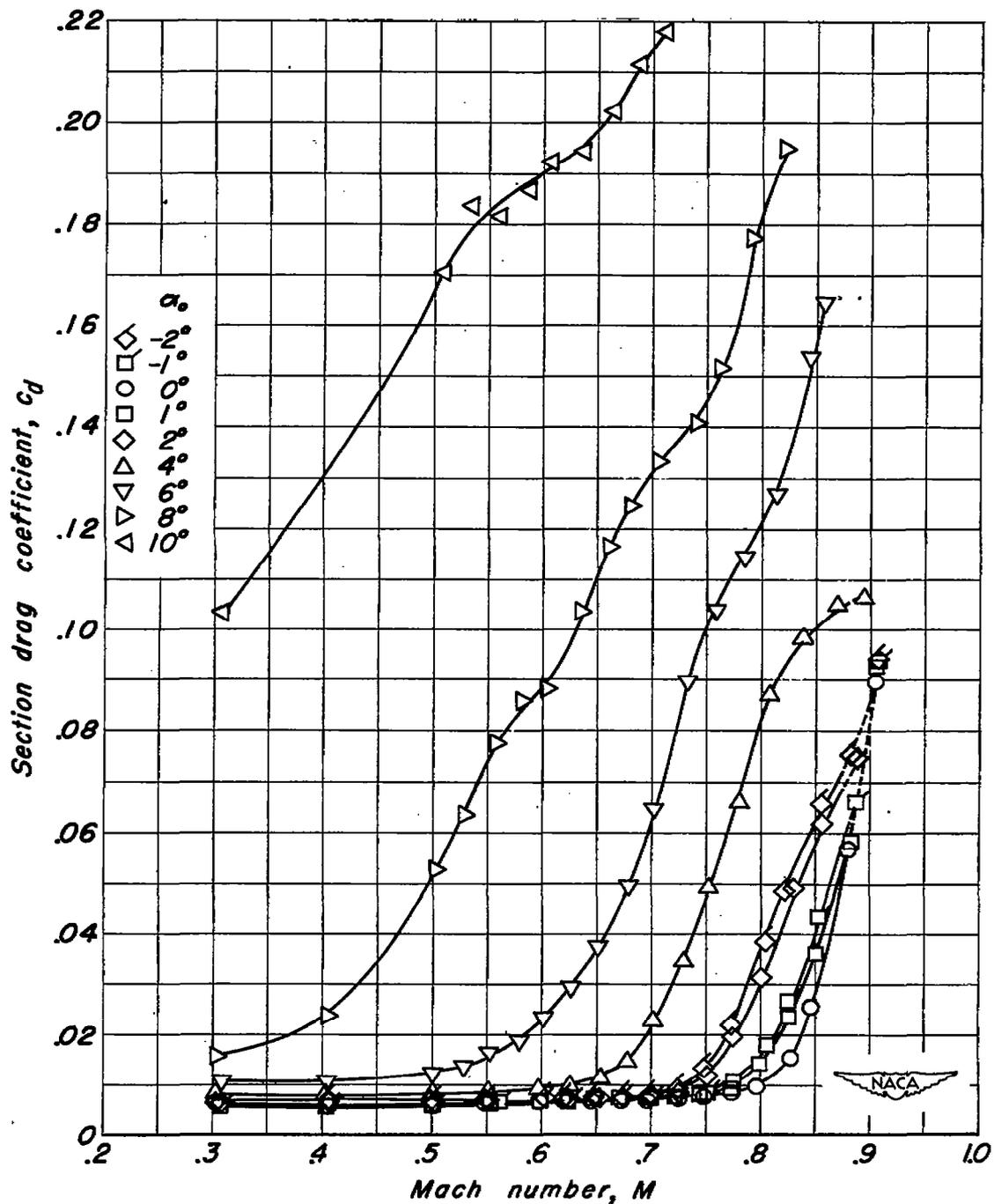
(a) NACA 0010 airfoil section.

Figure 2.—Variation of section lift coefficient with Mach number at various angles of attack.



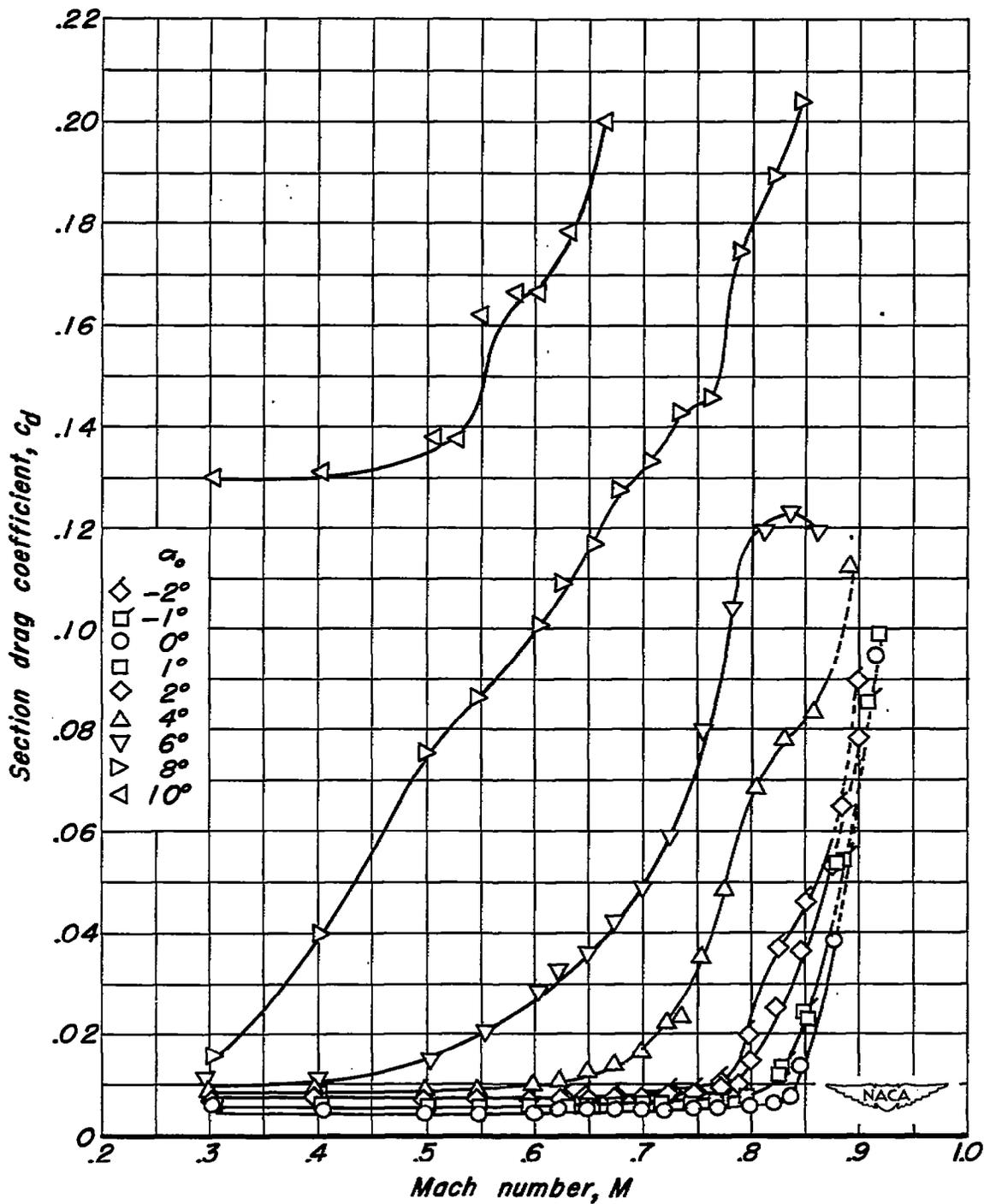
(b) NACA 0010-64 airfoil section.

Figure 2.-Concluded.



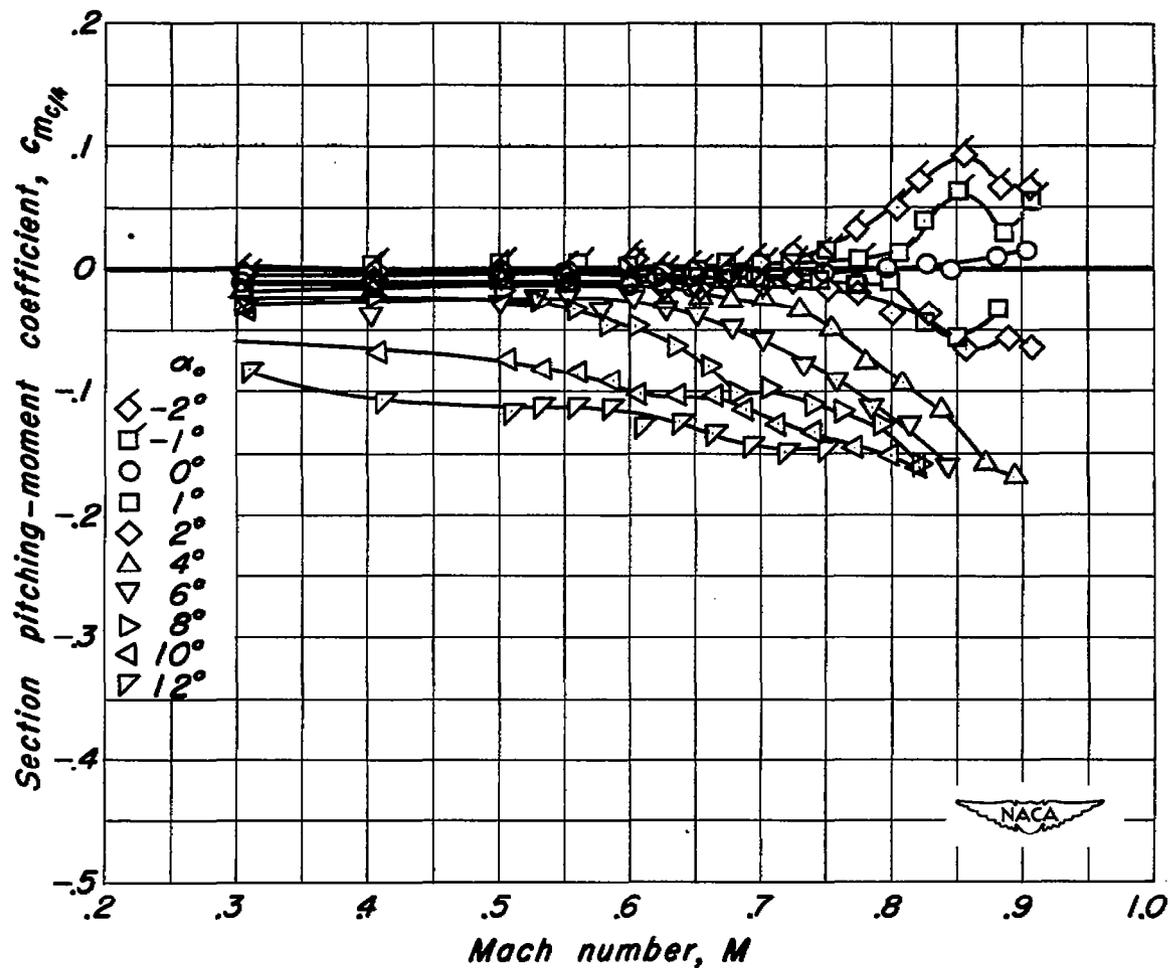
(a) NACA 0010 airfoil section.

Figure 3.—Variation of section drag coefficient with Mach number at various angles of attack.



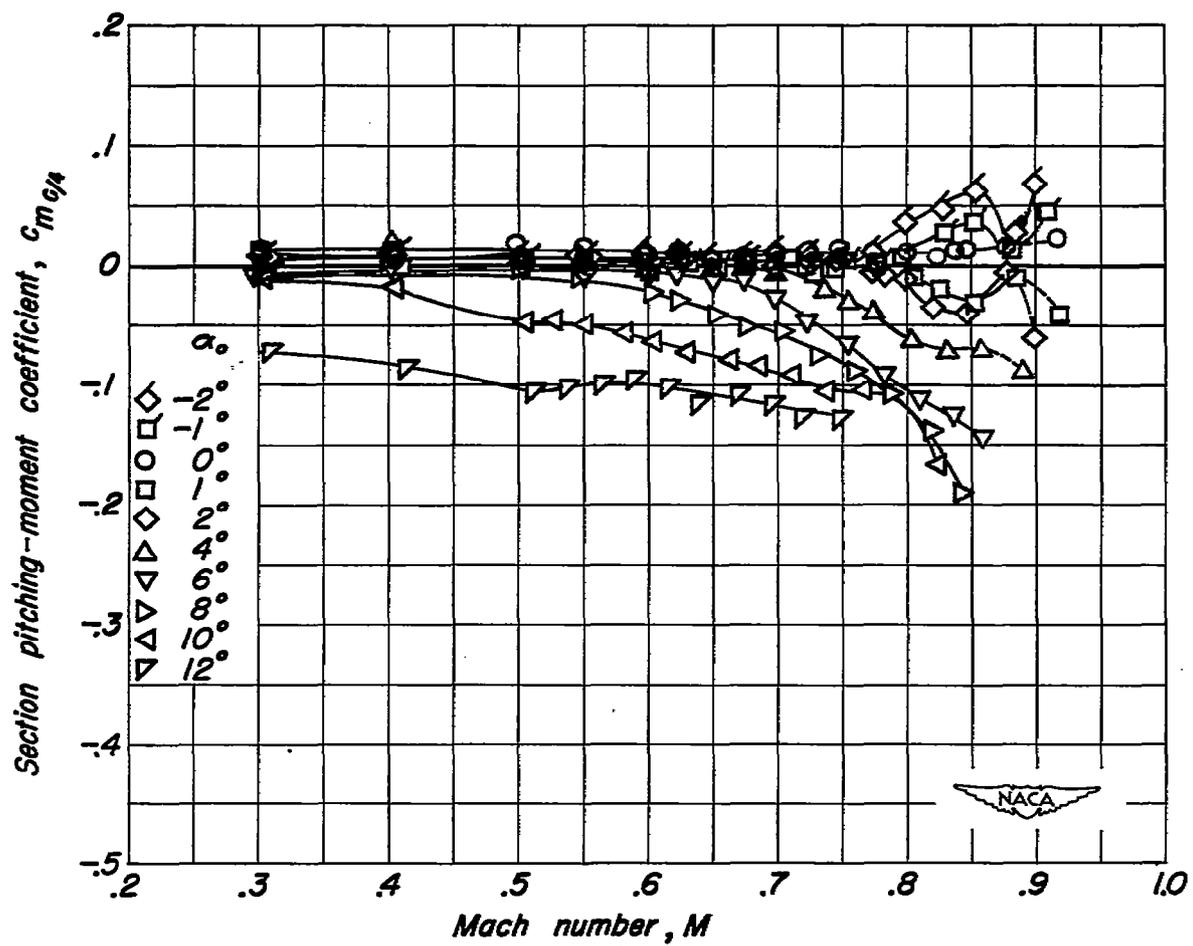
(b) NACA 0010-64 airfoil section.

Figure 3.- Concluded.



(a) NACA 0010 airfoil section.

Figure 4.—Variation of section quarter-chord pitching-moment coefficient with Mach number at various angles of attack.



(b) NACA 0010-64 airfoil section.

Figure 4.- Concluded.

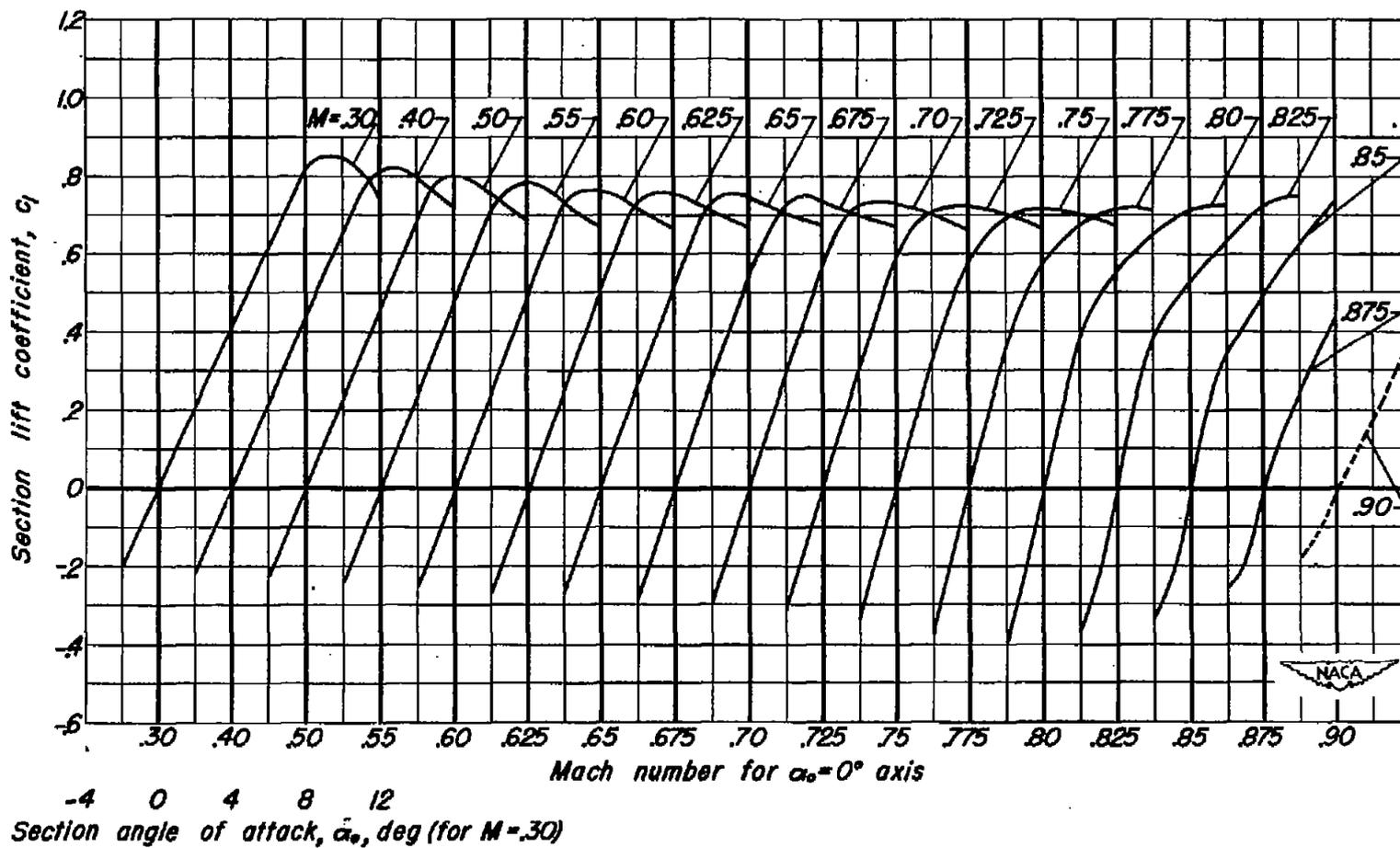
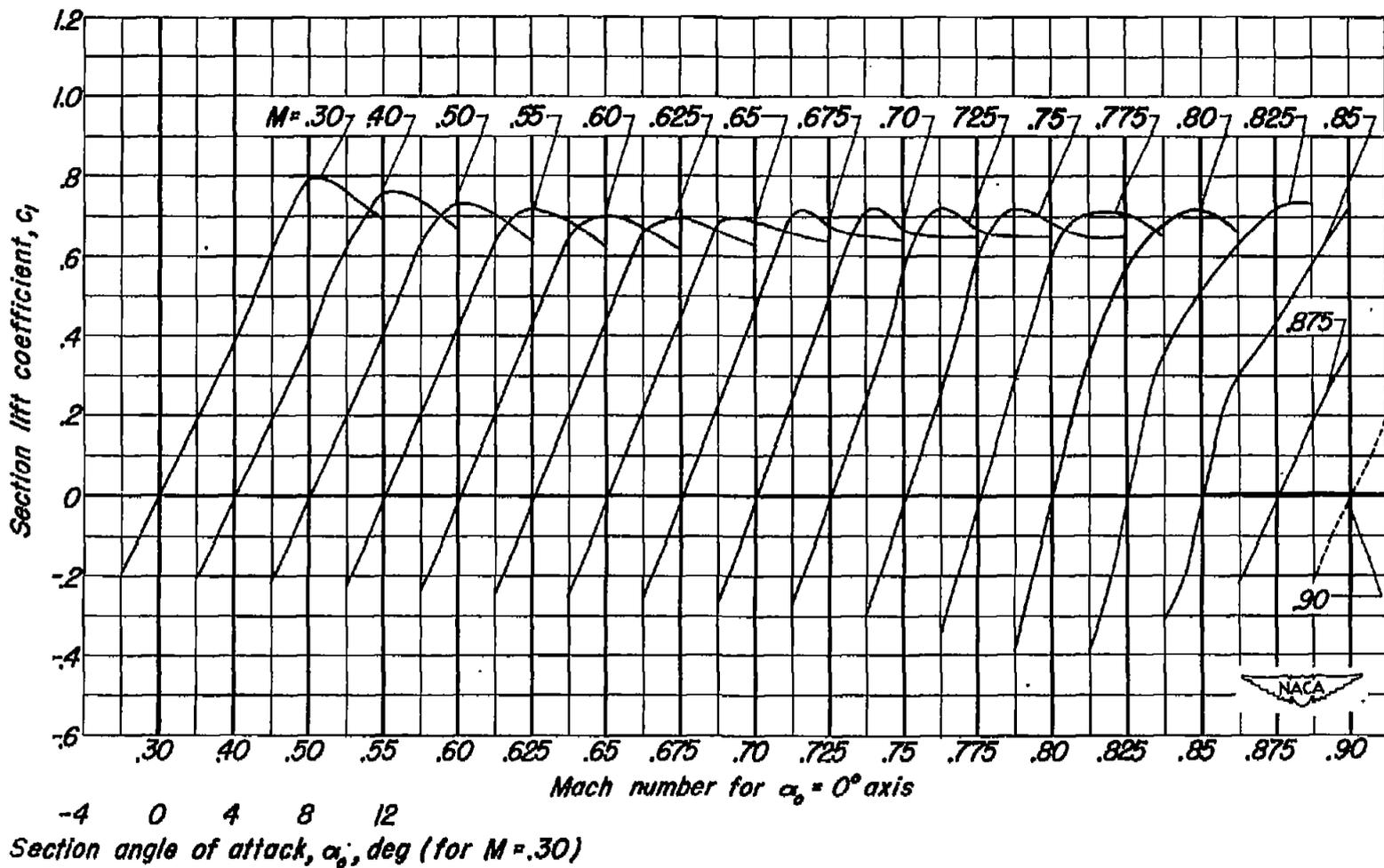


Figure 5.-Variation of the section lift coefficient with angle of attack at various Mach numbers.



(b) NACA 0010-64 airfoil section.

Figure 5.- Concluded.

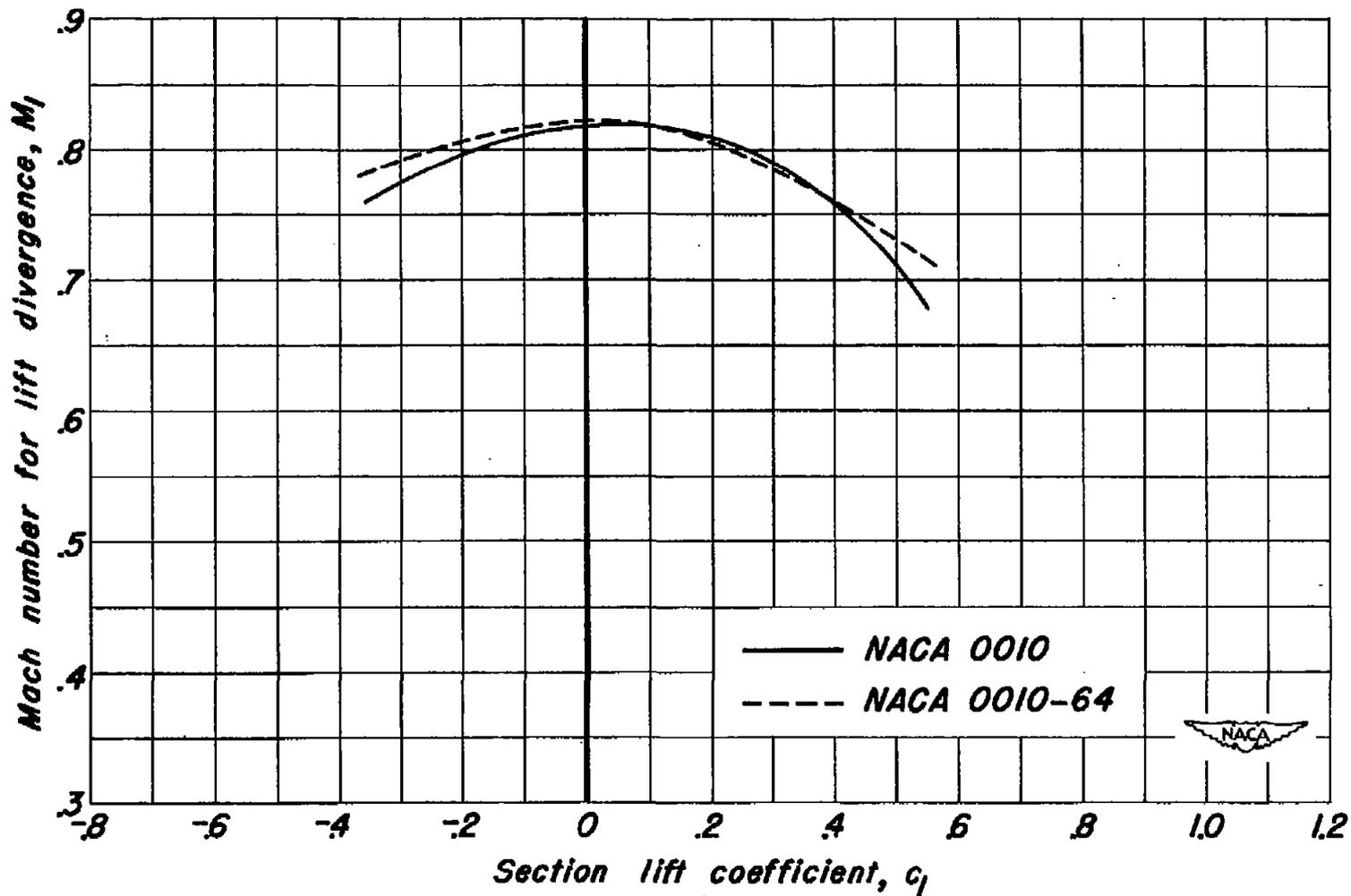


Figure 6.- Comparison of the variation of the Mach number for lift divergence with section lift coefficient for the NACA 0010 and 0010-64 airfoil sections.

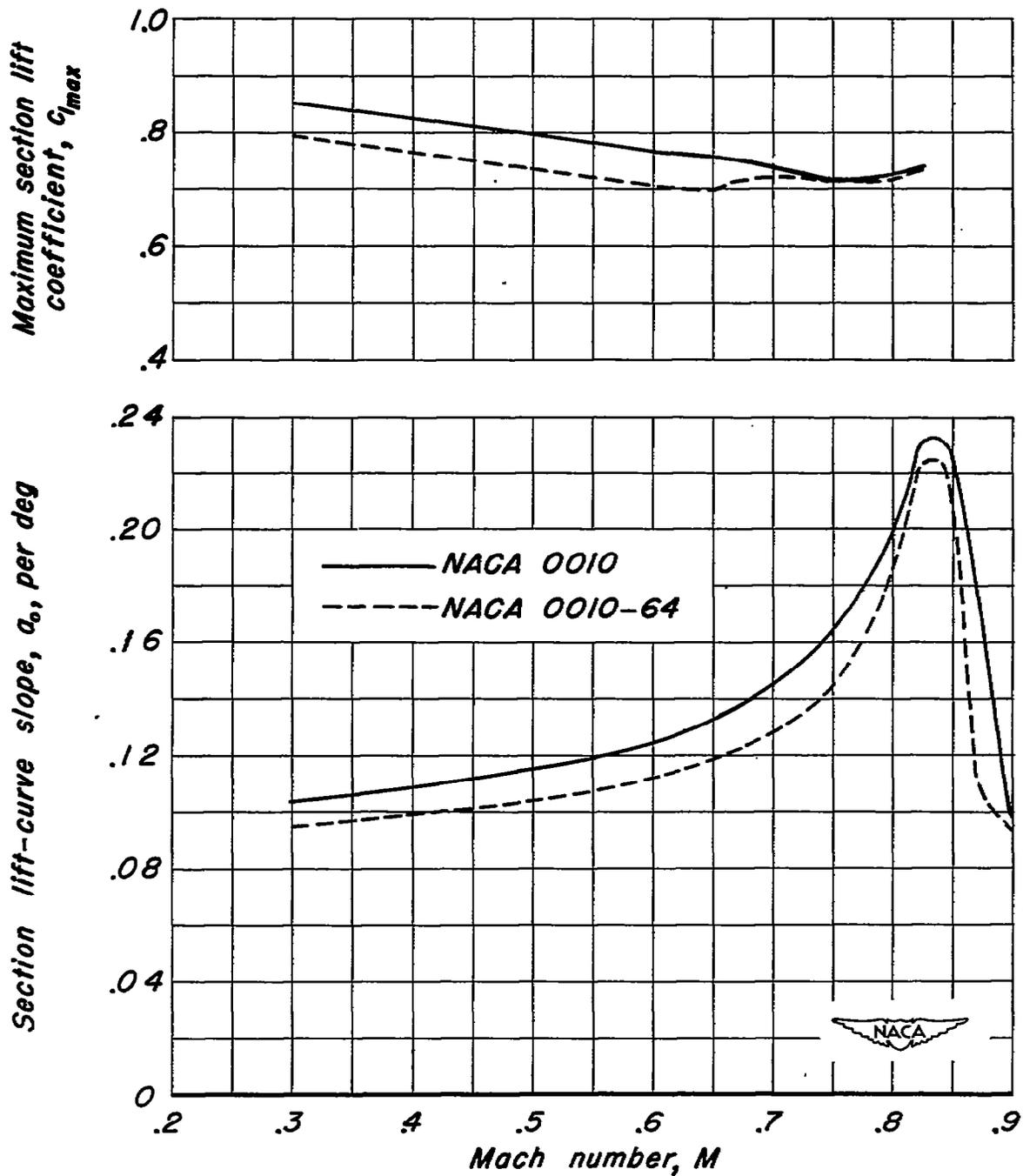


Figure 7.— Comparison of the variations of the maximum section lift coefficient and section lift-curve slope with Mach number for the NACA 0010 and 0010-64 airfoil sections.

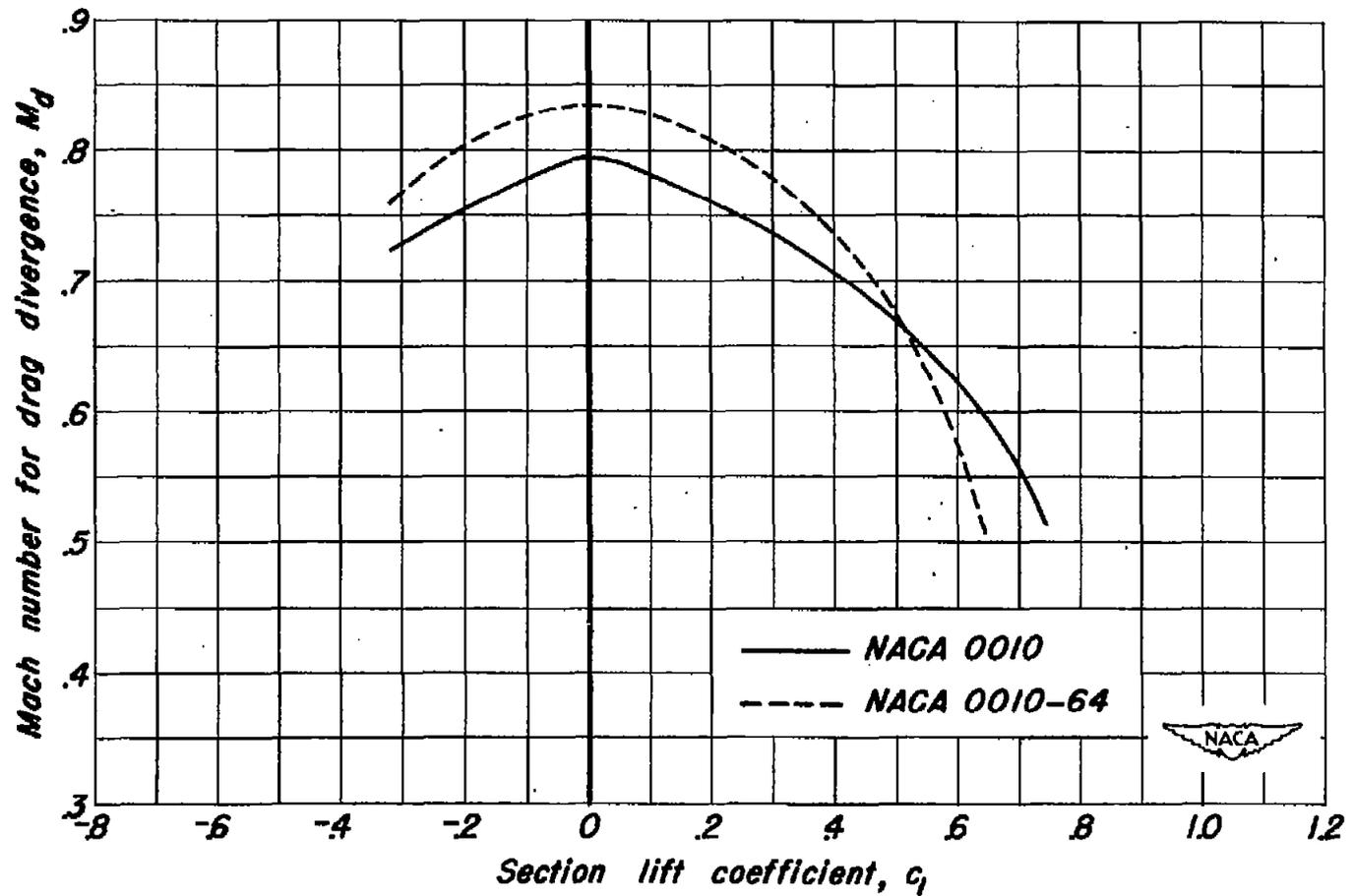
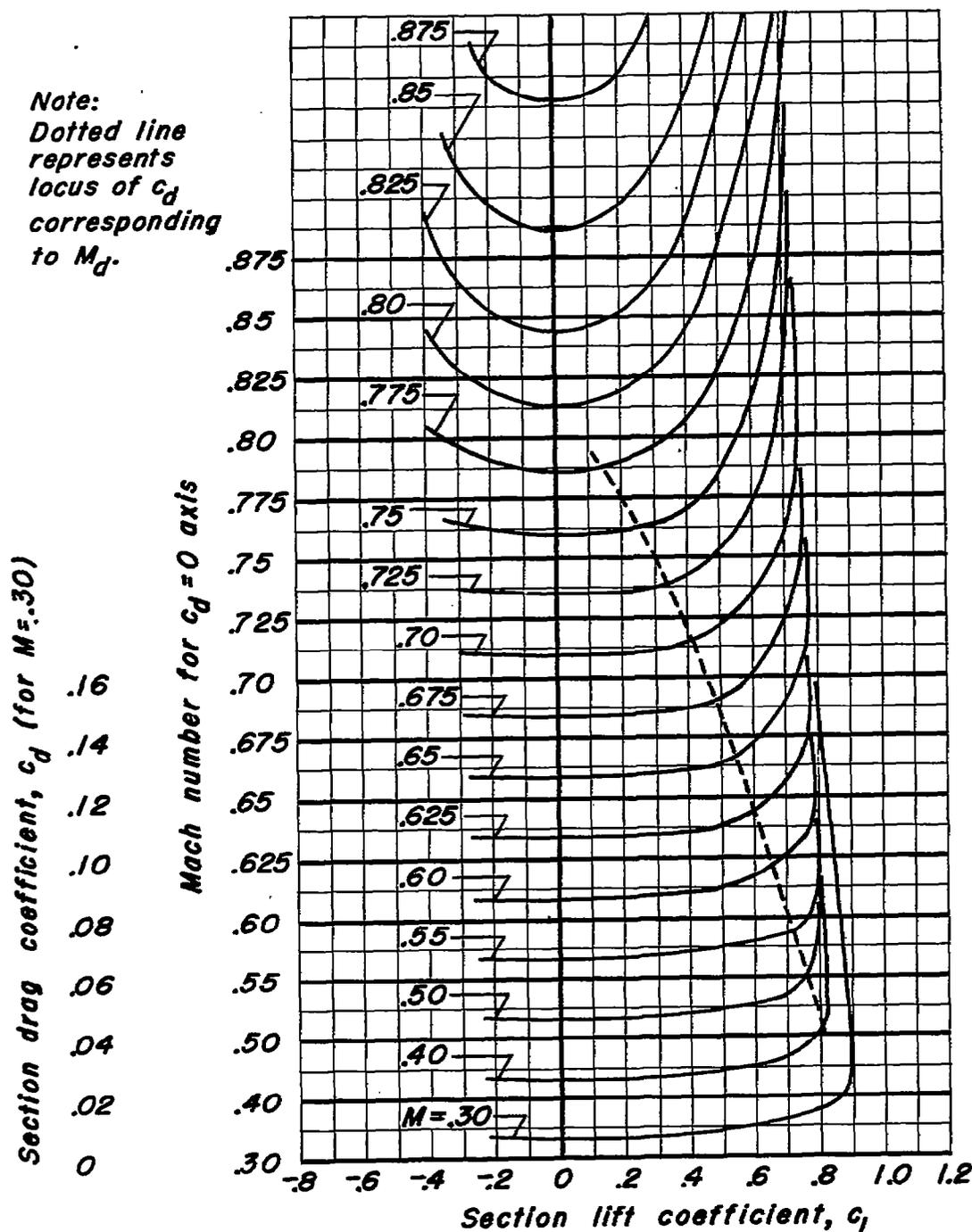


Figure 8.—Comparison of the variation of the Mach number for drag divergence with section lift coefficient for the NACA 0010 and 0010-64 airfoil sections.

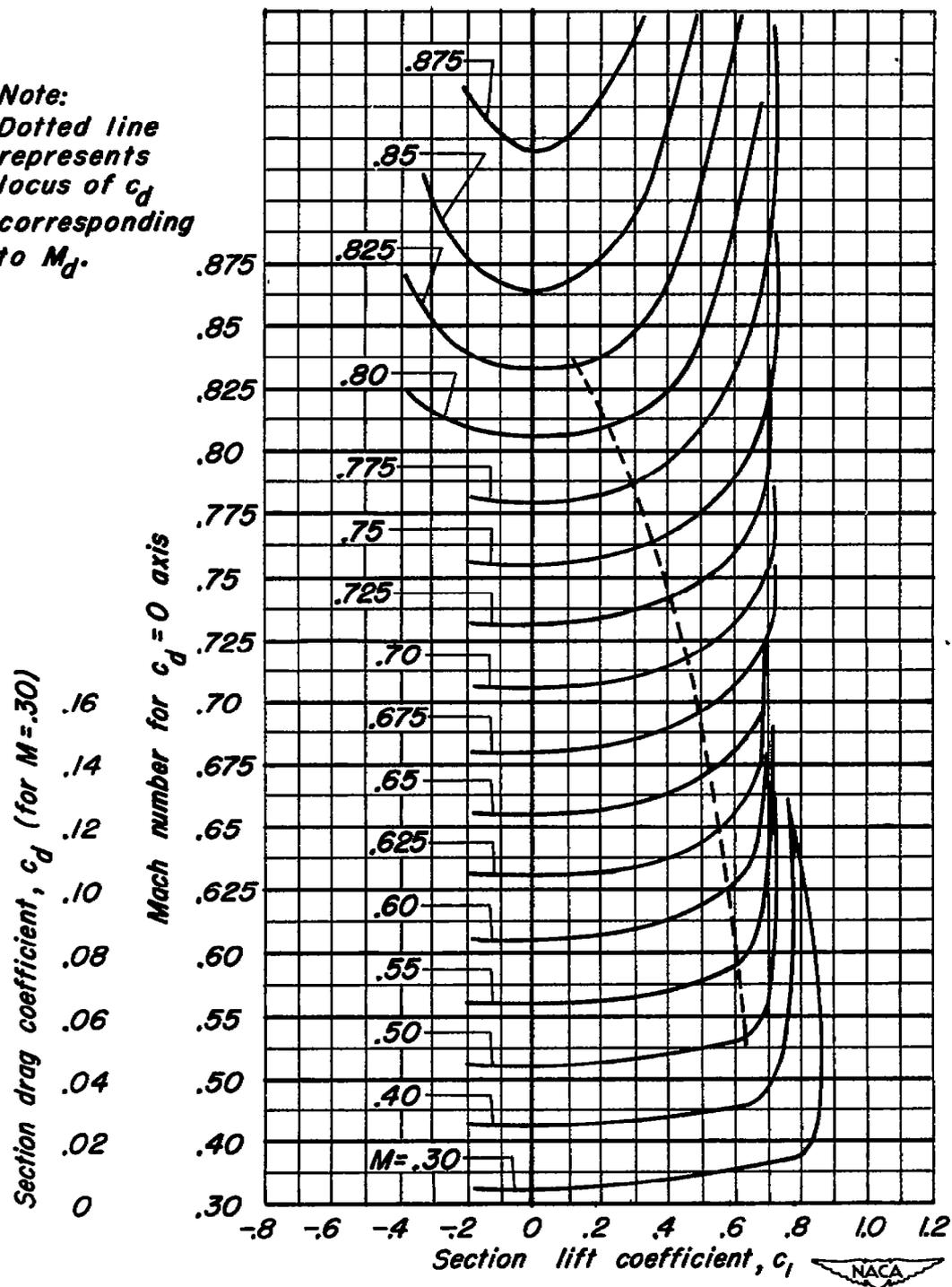


(a) NACA 0010 airfoil section.



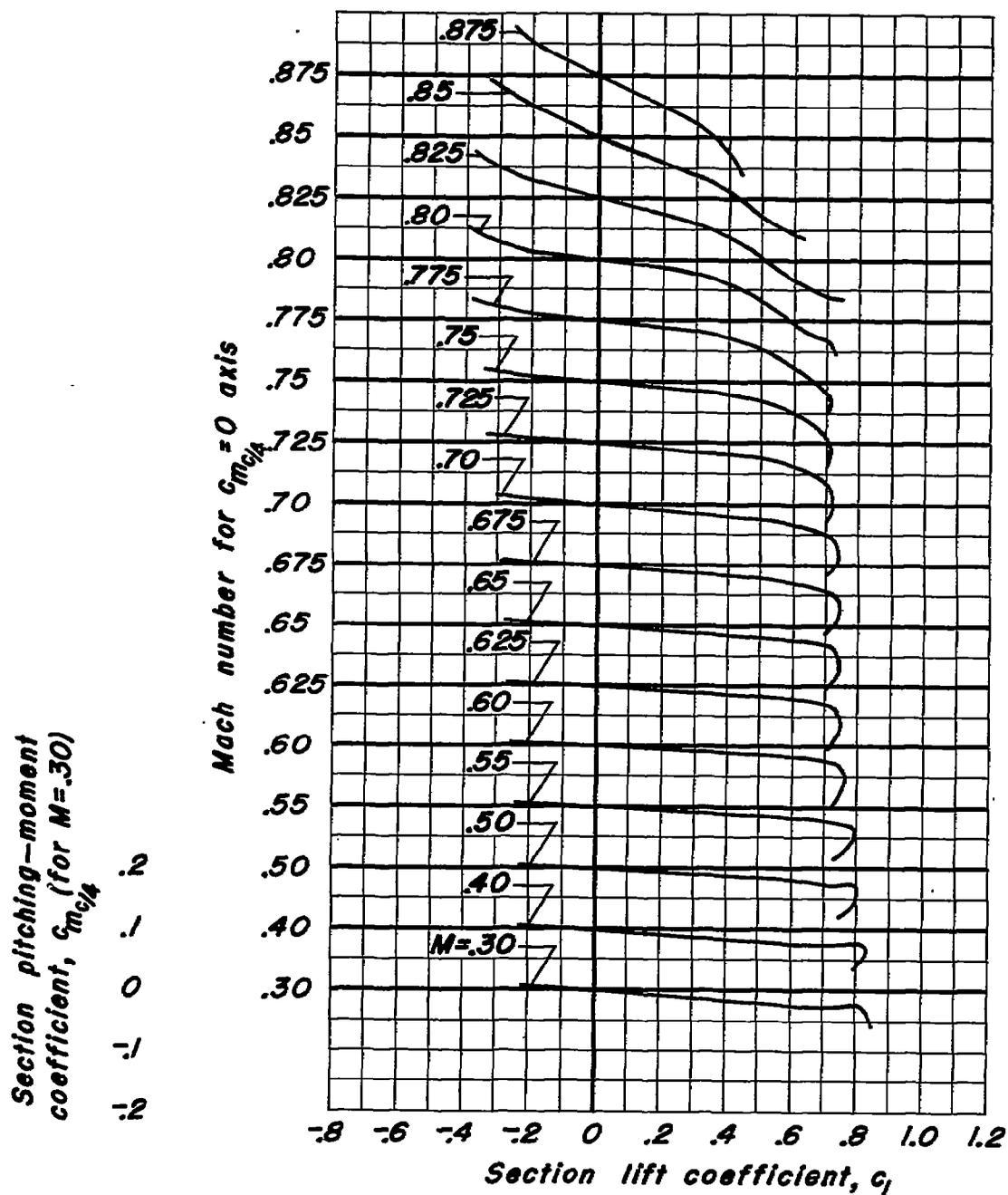
Figure 9.—Variation of the section drag coefficient with lift coefficient at various Mach numbers.

Note:
Dotted line
represents
locus of c_d
corresponding
to M_d .



(b) NACA 0010-64 airfoil section.

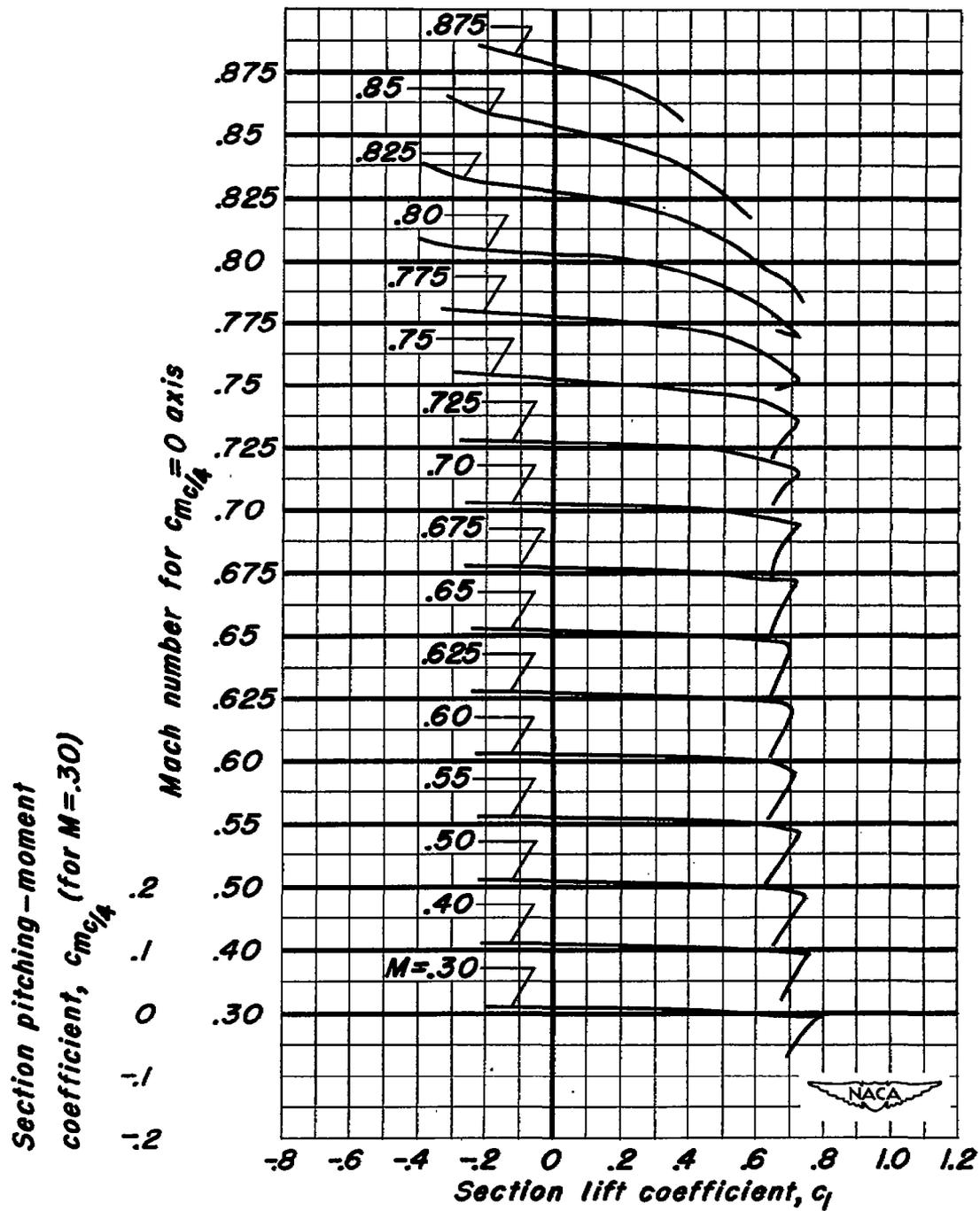
Figure 9.- Concluded.



(a) NACA 0010 airfoil section.



Figure 10.—Variation of the section quarter-chord pitching-moment coefficient with lift coefficient at various Mach numbers.



(b) NACA 0010-64 airfoil section.

Figure 10.- Concluded.

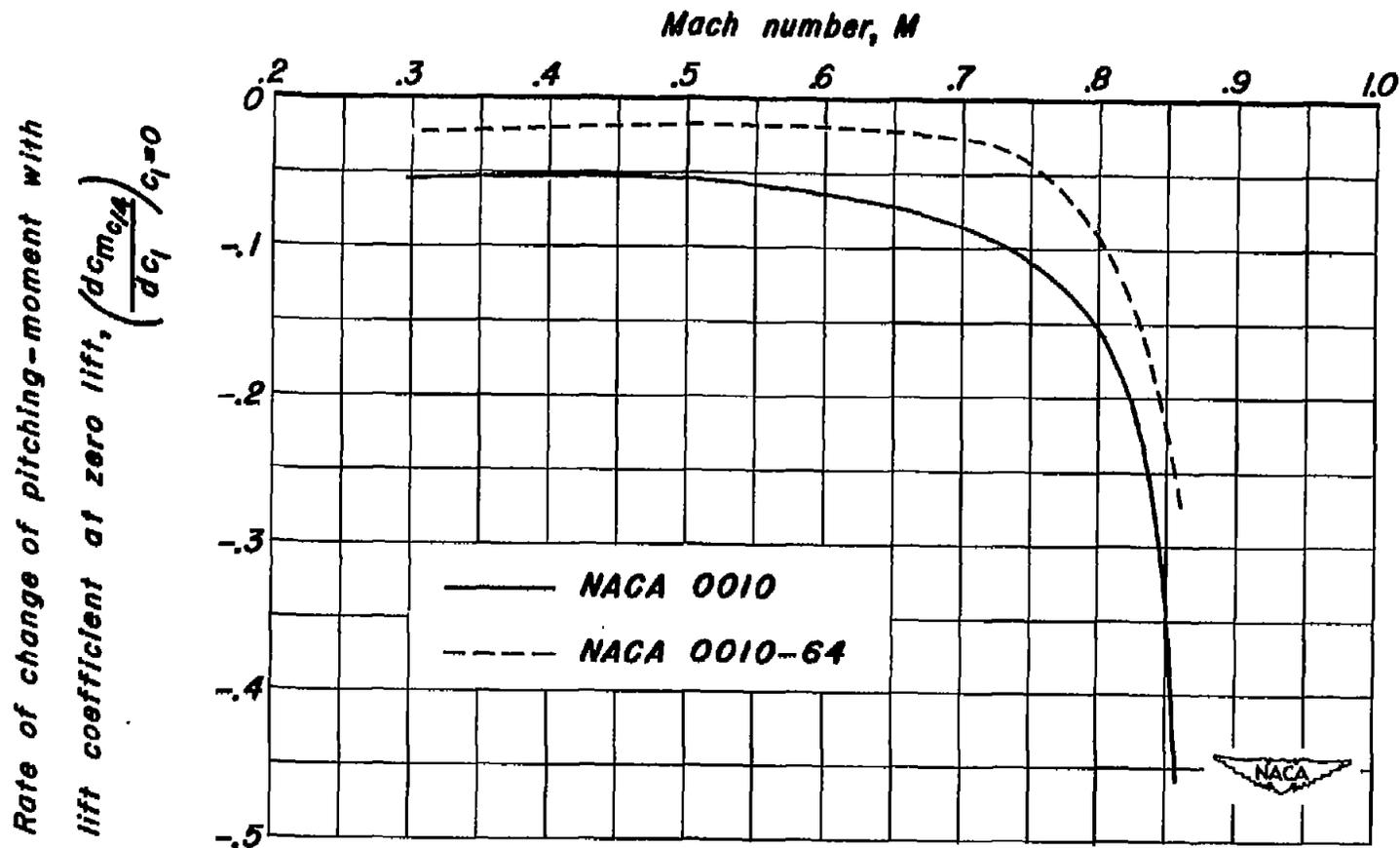


Figure 11.— Comparison of the variation with Mach number of the rate of change of section quarter-chord pitching-moment coefficient with lift coefficient, of the NACA 0010 and 0010-64 airfoil sections.