NACA

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS AT HIGH AND LOW SUBSONIC MACH NUMBERS OF THE NACA 0012, 64_2-015, AND 64_3-018 AIRFOIL SECTIONS AT ANGLES OF ATTACK FROM -2° TO 30°

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation has been made in the Langley low-turbulence pressure tunnel of the aerodynamic characteristics of the NACA 0012, 64_2-015, and 64_3-018 airfoil sections. Data were obtained at Mach numbers from 0.3 to that for tunnel choke, at angles of attack from -2° to 30°, and with the surface of each airfoil smooth and with roughness applied at the leading edge. The Reynolds numbers of the tests ranged from 0.8×10^6 to 4.4×10^6. The results are presented as variations of lift, drag, and quarter-chord pitching-moment coefficients with Mach number.

INTRODUCTION

The trend of present helicopter designs toward higher forward speeds and higher rotor-blade speeds has resulted in a need for two-dimensional airfoil data throughout wide subsonic Mach number and angle-of-attack ranges. In order to supply this need, a number of NACA airfoil sections, which might be used for helicopter rotors, have been investigated in the Langley low-turbulence pressure tunnel. The results obtained with four of these sections are reported in reference 1. The results obtained with three additional sections, consisting of the NACA 0012, 64_2-015, and 64_3-018 airfoil sections, are presented herein.

The aerodynamic characteristics of the three airfoil sections were obtained at Mach numbers from 0.3 to that for tunnel choke, at angles of attack from -2° to 30°, and with the surface of each airfoil smooth and with roughness applied at the leading edge. The results are presented as variations of lift, drag, and quarter-chord pitching-moment coefficients with Mach number. In order to expedite publication of these basic data,

the preparation of charts having quantities other than the Mach number as the independent variable has been deferred, as has any discussion of the results.

SYMBOLS

c	airfoil chord
c_d	section drag coefficient
c_l	section lift coefficient
$c_{m_{c/4}}$	section quarter-chord pitching-moment coefficient
M	free-stream Mach number
R	Reynolds number based on airfoil chord
α	section angle of attack

APPARATUS, TESTS, AND METHODS

The present investigation was conducted in the Langley low-turbulence pressure tunnel with Freon-12 as the test medium. The investigation consisted of measurements of the lift, drag, and quarter-chord pitching moment of three two-dimensional airfoils at Mach numbers from 0.3 to that for tunnel choke and at angles of attack from -2° to 30°. The two-dimensional models consisted of the NACA 0012, 64_2-015, and 64_3-018 airfoil sections, the coordinates for which are presented in table I. The models were machined from solid aluminum alloy.

Data were obtained with the airfoil surfaces smooth and with roughness applied at the leading edge. For the tests with the model surfaces smooth, the surfaces were polished to a high degree of smoothness at the time of model installation in the tunnel. The drag coefficients measured, however, probably do not correspond to extensive regions of laminar flow since use of Freon-12 as a test medium makes unfeasible the almost continuous attention to model surface condition which is required in order to maintain extensive laminar layers. For the tests with roughness applied at the leading edge, the roughness consisted of 0.011-inch-diameter carborundum grains spread over a surface length of 8 percent of the chord back from the leading edge on the upper and lower surfaces. The grains were thinly spread to cover from 5 percent to 10 percent of this area.

The Reynolds numbers in the present tests ranged from 0.8×10^6 to 4.4×10^6. The variation of Reynolds number with Mach number is shown in figure 1 for both low (-2° to 14°) and high (11° to 30°) angles of attack. The difference in Reynolds numbers for the two angle-of-attack ranges resulted from the higher stagnation pressures used in the tests at the low angles of attack.

Additional information on the testing technique is contained in reference 1.

RESULTS

The variations of lift coefficient, drag coefficient, and quarter-chord pitching-moment coefficient with Mach number are presented in figures 2 to 4 for the three airfoil sections of the present investigation. As discussed in reference 1, corrections to the data have been applied for tunnel-wall effects and for converting the data (which were obtained with Freon-12 as the test medium) to equivalent air results. The variations of the aerodynamic characteristics with Mach number (figs. 2 to 4) for some angles of attack were obtained from cross plots and are presented as lines without data point symbols.

Based on the capability of the balance used to measure the lift and drag forces and the pitching moment, the accuracies of the measurements for various test conditions are indicated in the following table:

Accuracies of measurements			
M (approx.)	c_l	c_{d_o}	$c_{m_{c/4}}$
0.30	±0.013	±0.0030	±0.003
.67	±.003	±.0006	±.001
.85	±.002	±.0004	±.001

As can be seen, the accuracy in the measurement of drag is rather poor at low Mach numbers; however, at higher Mach numbers, in the region of the force break, the accuracy of the drag measurements is within acceptable limits. As in reference 1, the highest Mach numbers for which data are presented correspond to tunnel-choked conditions. The highest Mach number for which the data may be considered reliable is open to some

question. A Mach number 0.03 less than that for choke, at low and moderate angles of attack, has often been considered as a rough upper limit beyond which little confidence should be placed in the results. Results at high angles of attack are involved with unknown corrections which are still under study.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 23, 1954.

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REFERENCE

1. Wilson, Homer B., Jr., and Horton, Elmer A.: Aerodynamic Characteristics at High and Low Subsonic Mach Numbers of Four NACA 6-Series Airfoil Sections at Angles of Attack From -2° to 31°. NACA RM L53C20, 1953.

TABLE I

COORDINATES OF NACA AIRFOIL SECTIONS TESTED

(Dimensions given in percent chord)

Chordwise Station	Upper and lower surface ordinates		
	0012	64_2-015	64_3-018
0	0	0	0
.5	---	1.208	1.428
.75	---	1.456	1.720
1.25	1.894	1.842	2.177
2.5	2.615	2.528	3.005
5.0	3.555	3.504	4.186
7.5	4.200	4.240	5.076
10	4.683	4.842	5.803
15	5.345	5.785	6.942
20	5.738	6.480	7.782
25	5.941	6.985	8.391
30	6.002	7.319	8.789
35	---	7.482	8.979
40	5.803	7.473	8.952
45	---	7.224	8.630
50	5.294	6.810	8.114
55	---	6.266	7.445
60	4.563	5.620	6.658
65	---	4.895	5.782
70	3.664	4.113	4.842
75	---	3.296	3.866
80	2.623	2.472	2.888
85	---	1.677	1.951
90	1.448	.950	1.101
95	.807	.346	.400
100	.126	0	0
L. E. rad.	1.580	1.590	2.208

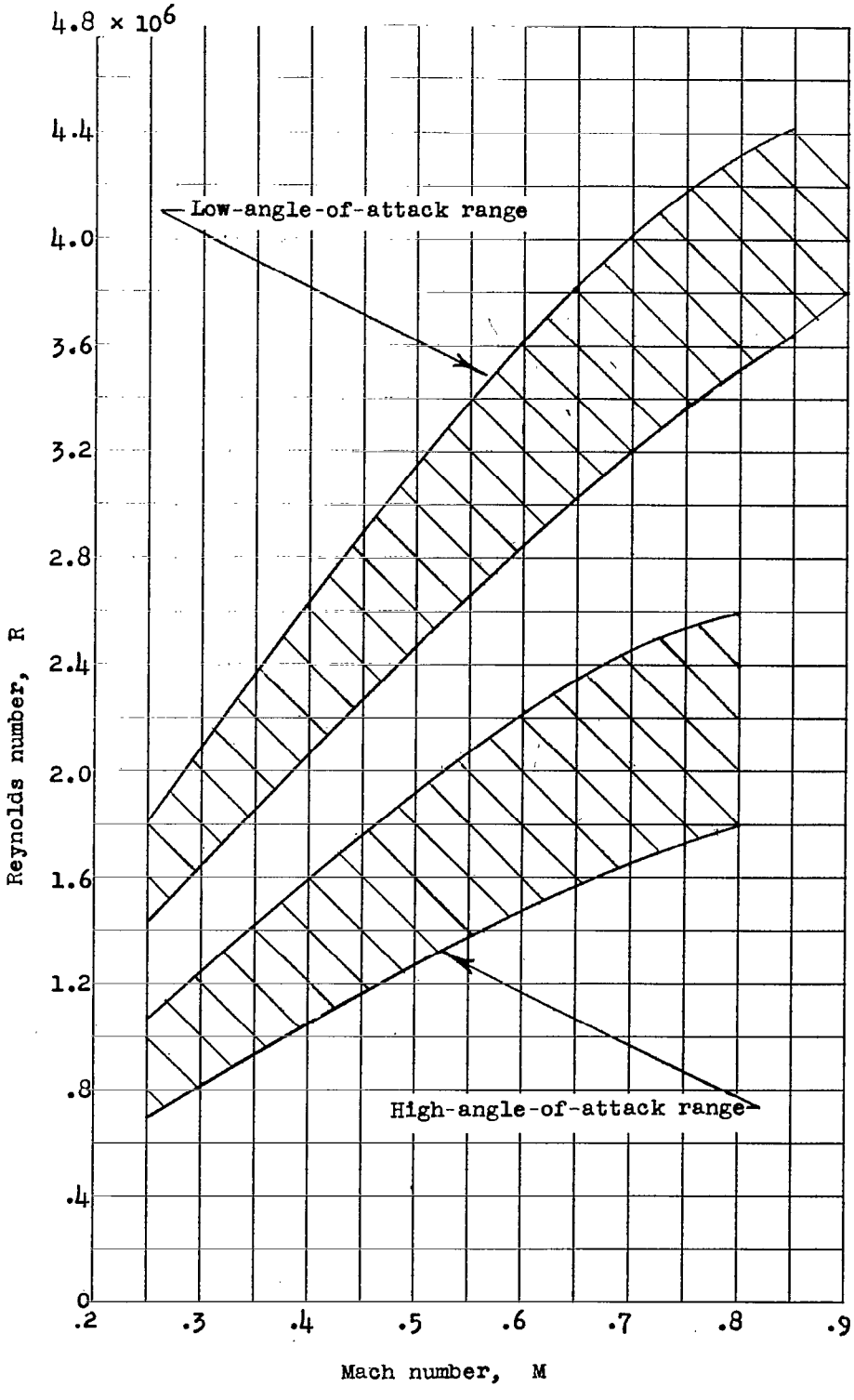
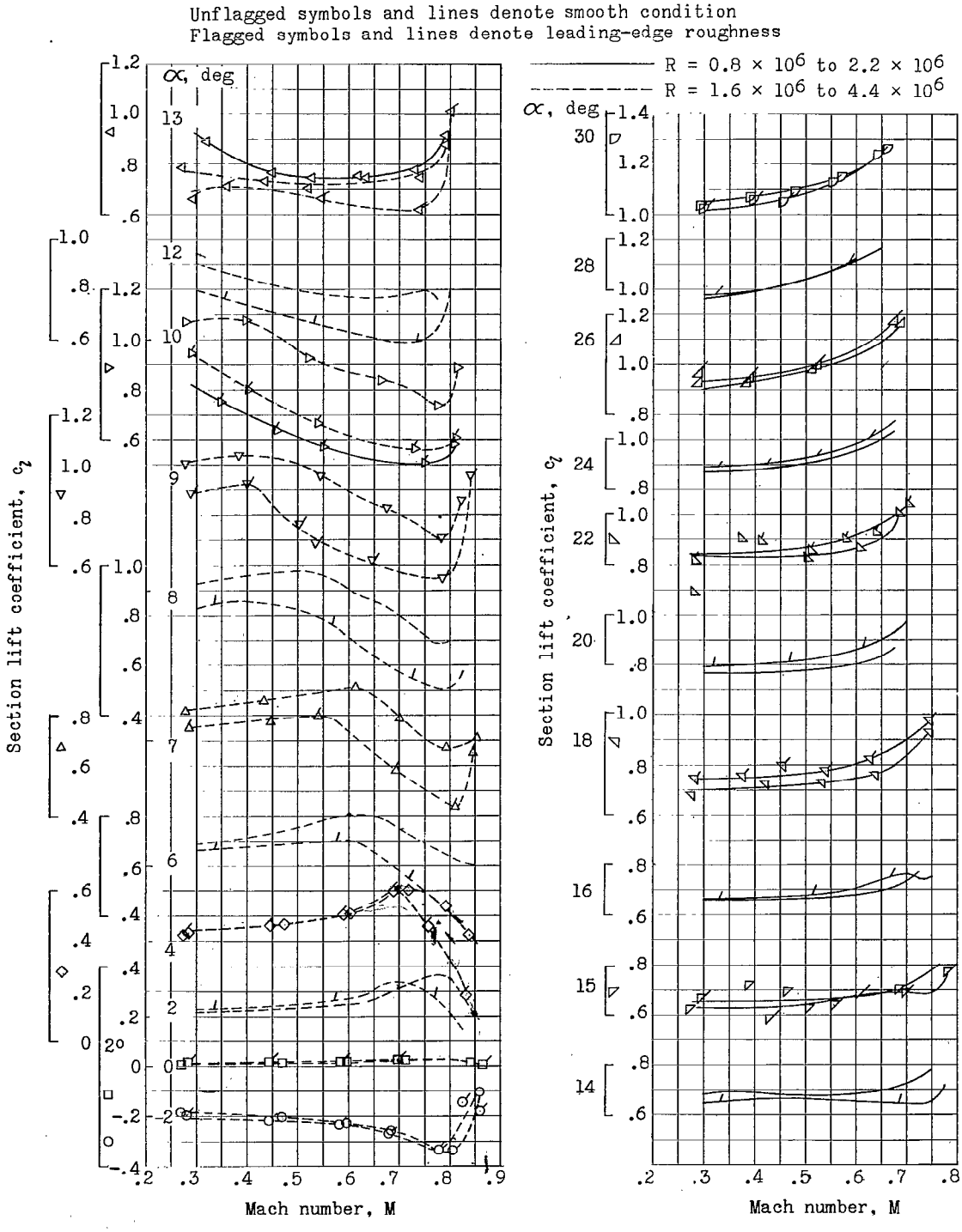
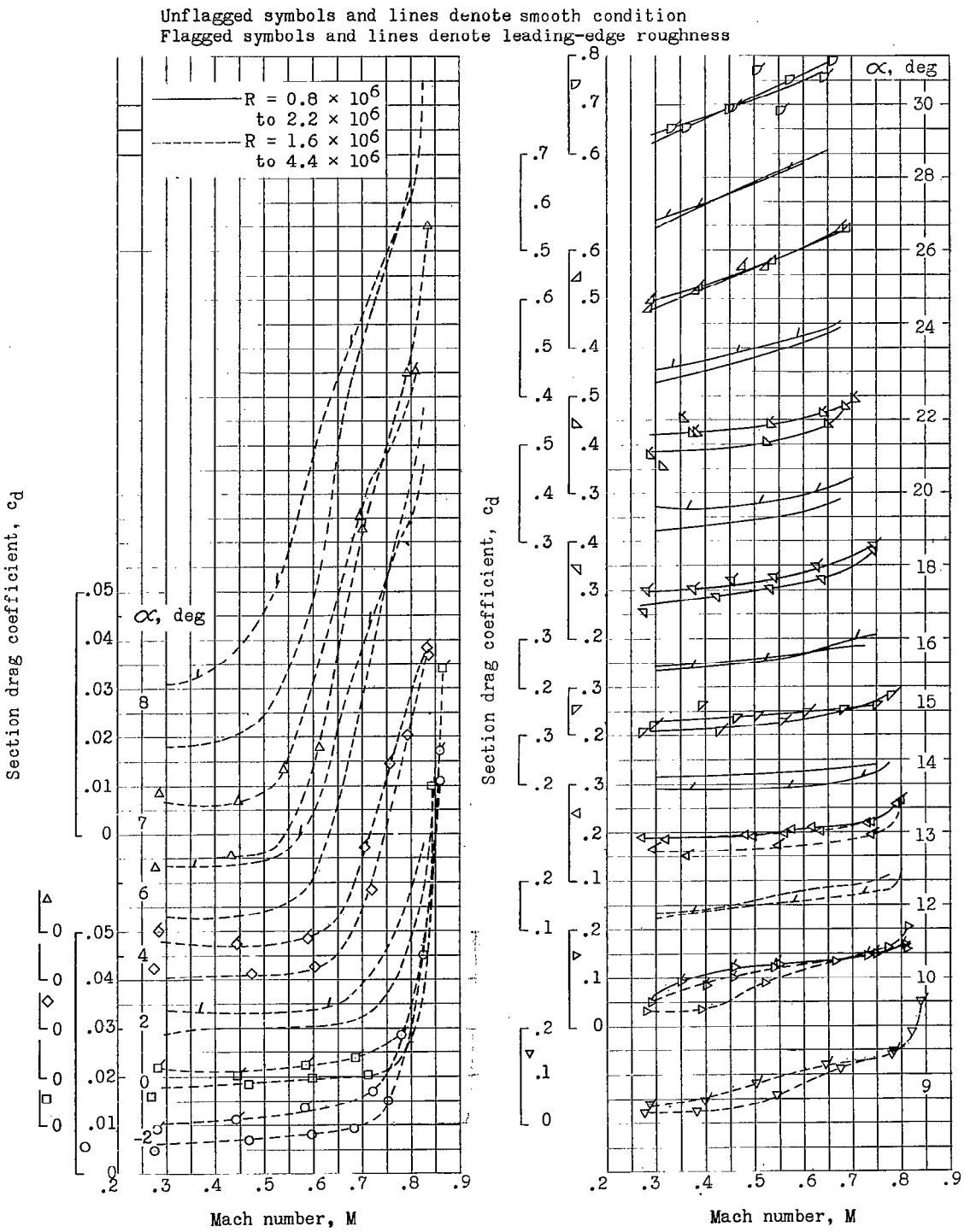


Figure 1.- Variation of Reynolds number with Mach number for two angle-of-attack ranges.



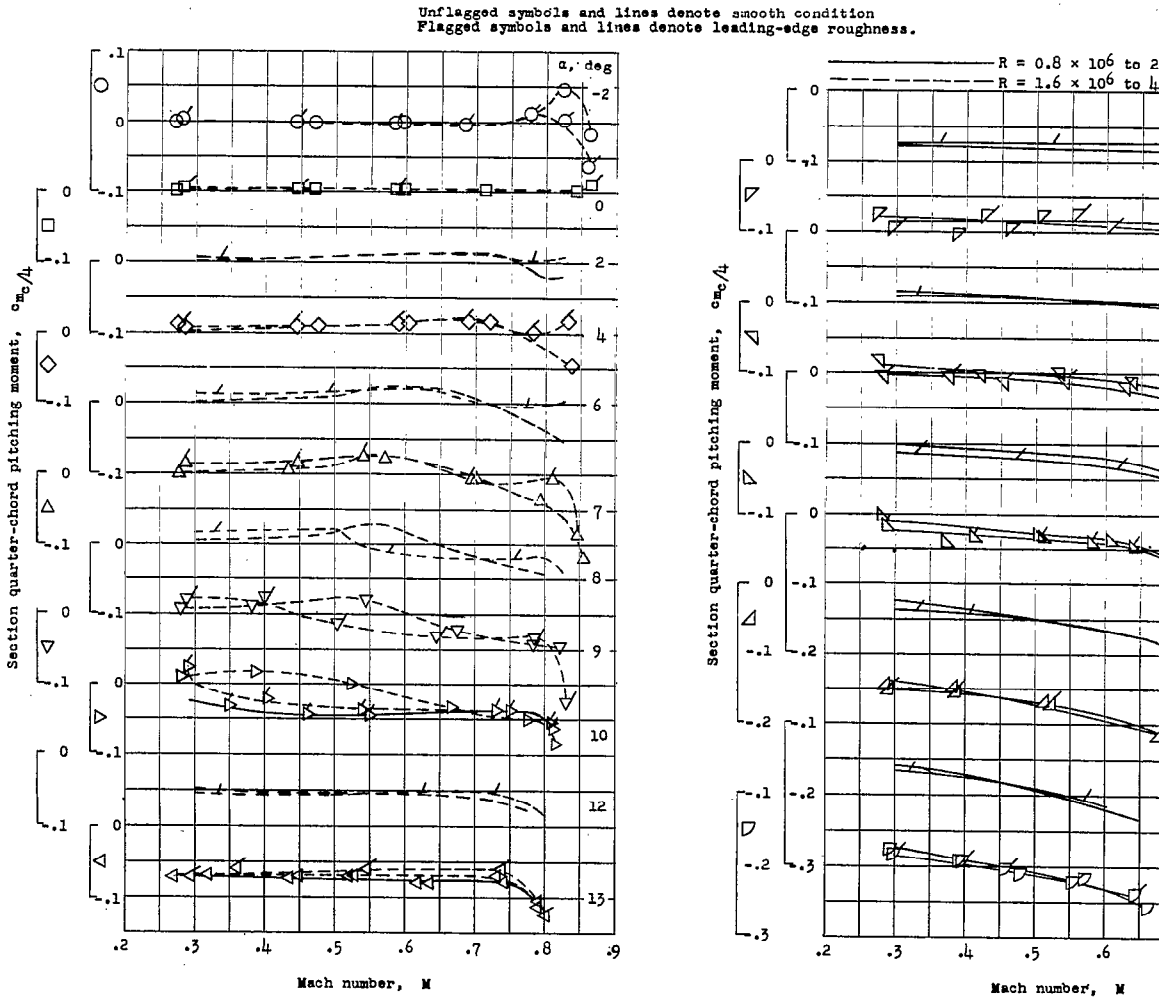
(a) Section lift coefficient.

Figure 2.- Aerodynamic characteristics at various angles of attack obtained with 1.0-foot chord NACA 0012 airfoil section.



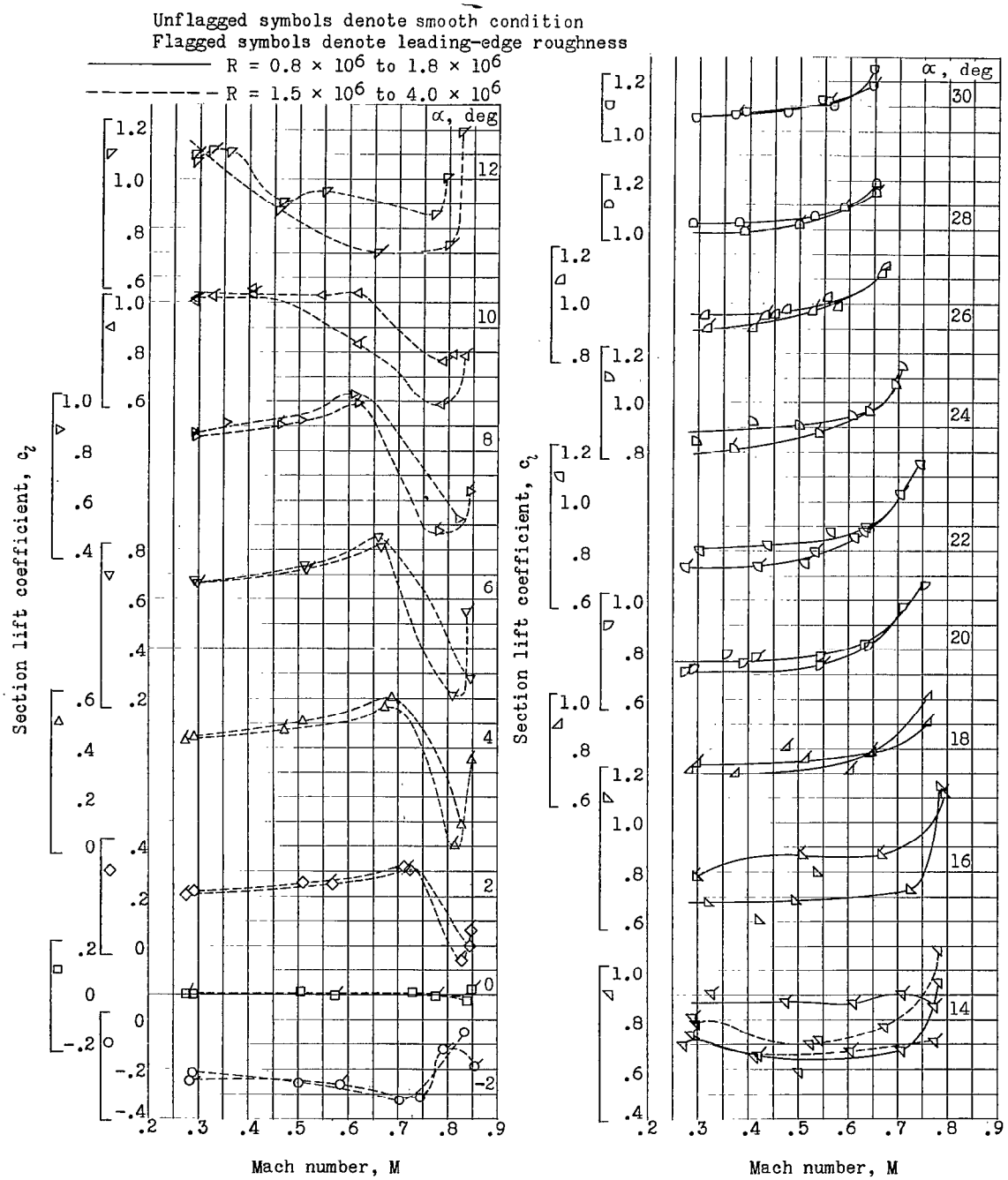
(b) Section drag coefficient.

Figure 2.- Continued.



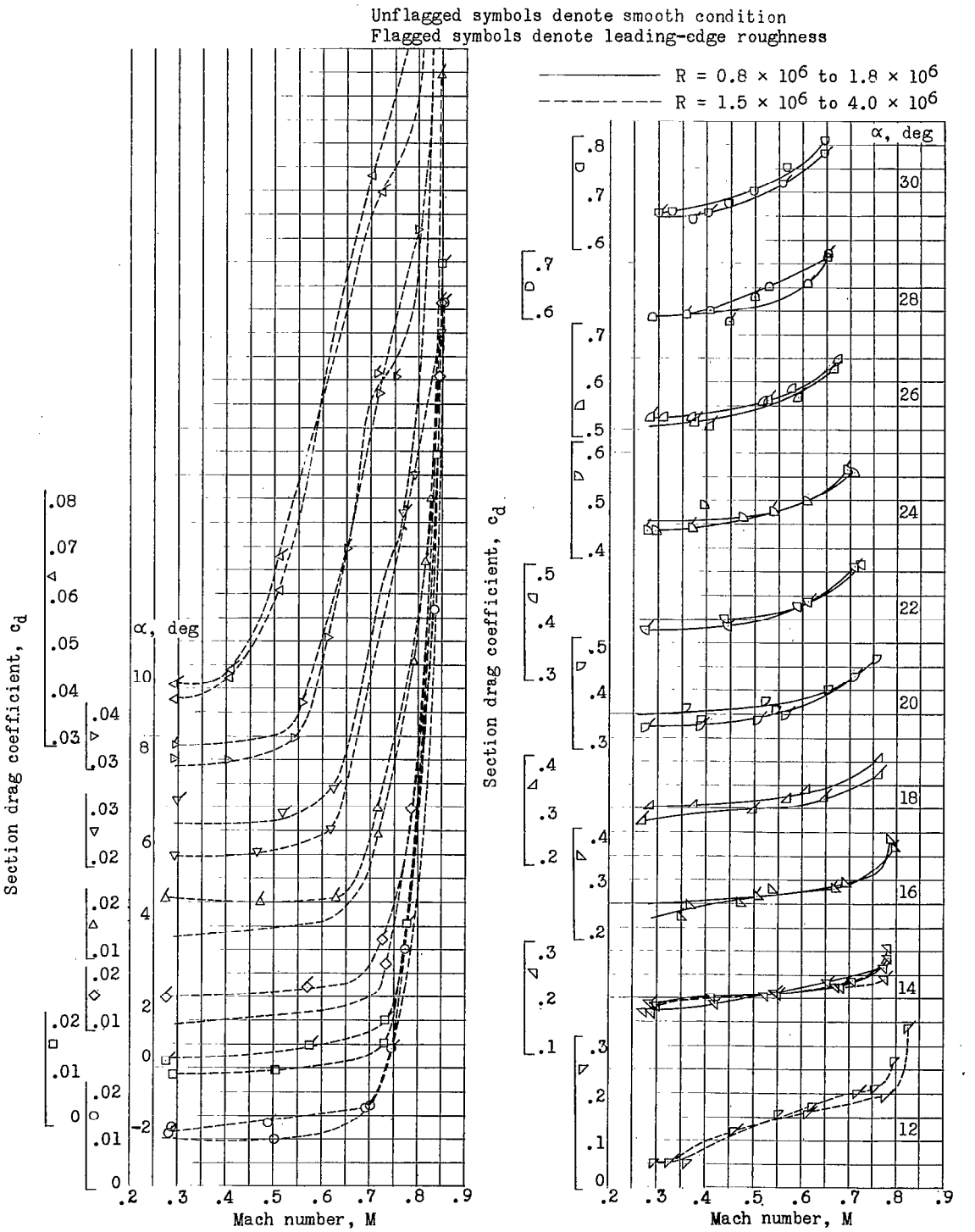
(c) Section quarter-chord pitching-moment coefficient.

Figure 2.- Concluded.



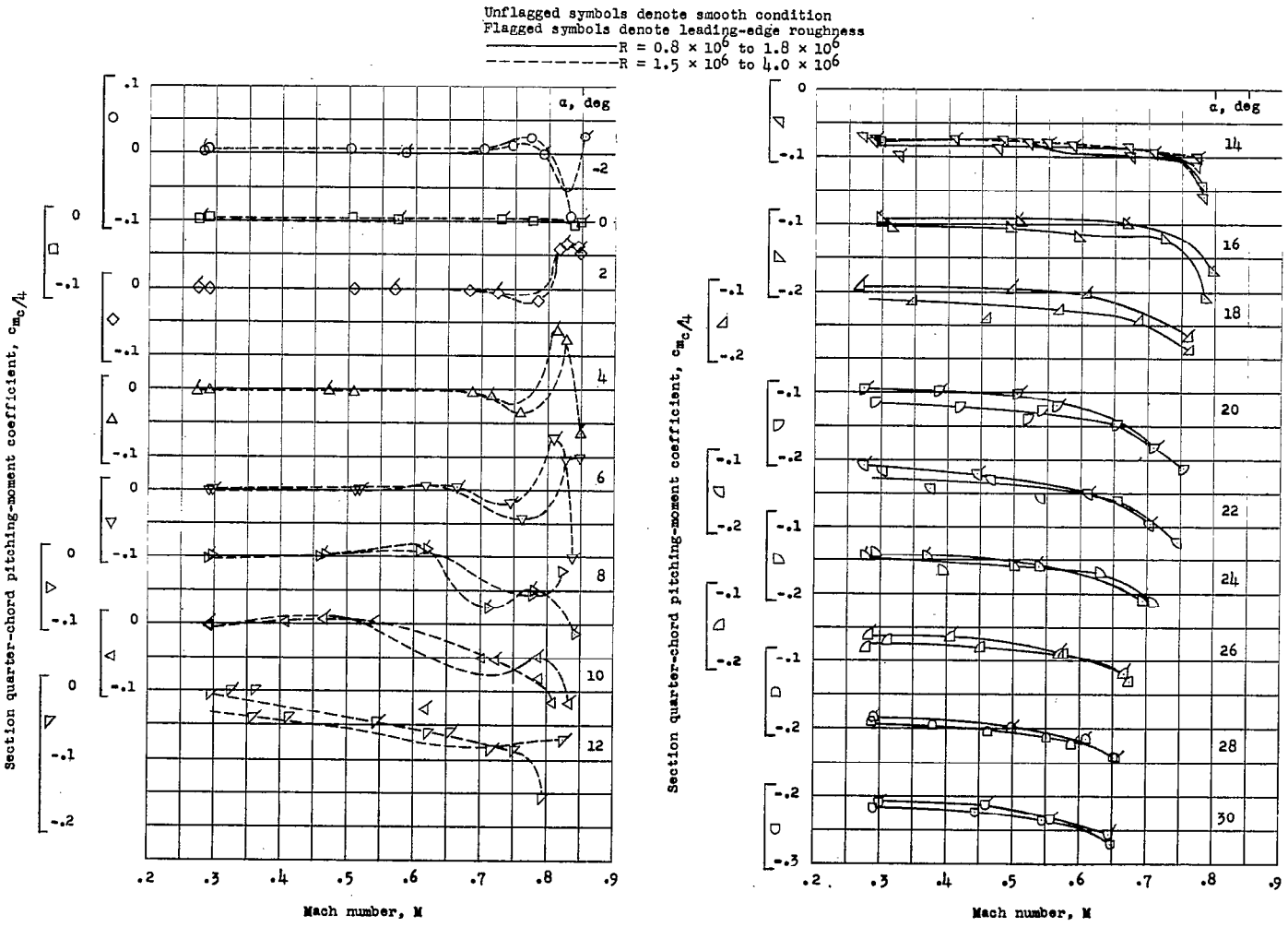
(a) Section lift coefficient.

Figure 3.- Aerodynamic characteristics at various angles of attack obtained with 1.0-foot chord NACA 64_2-015 airfoil section.



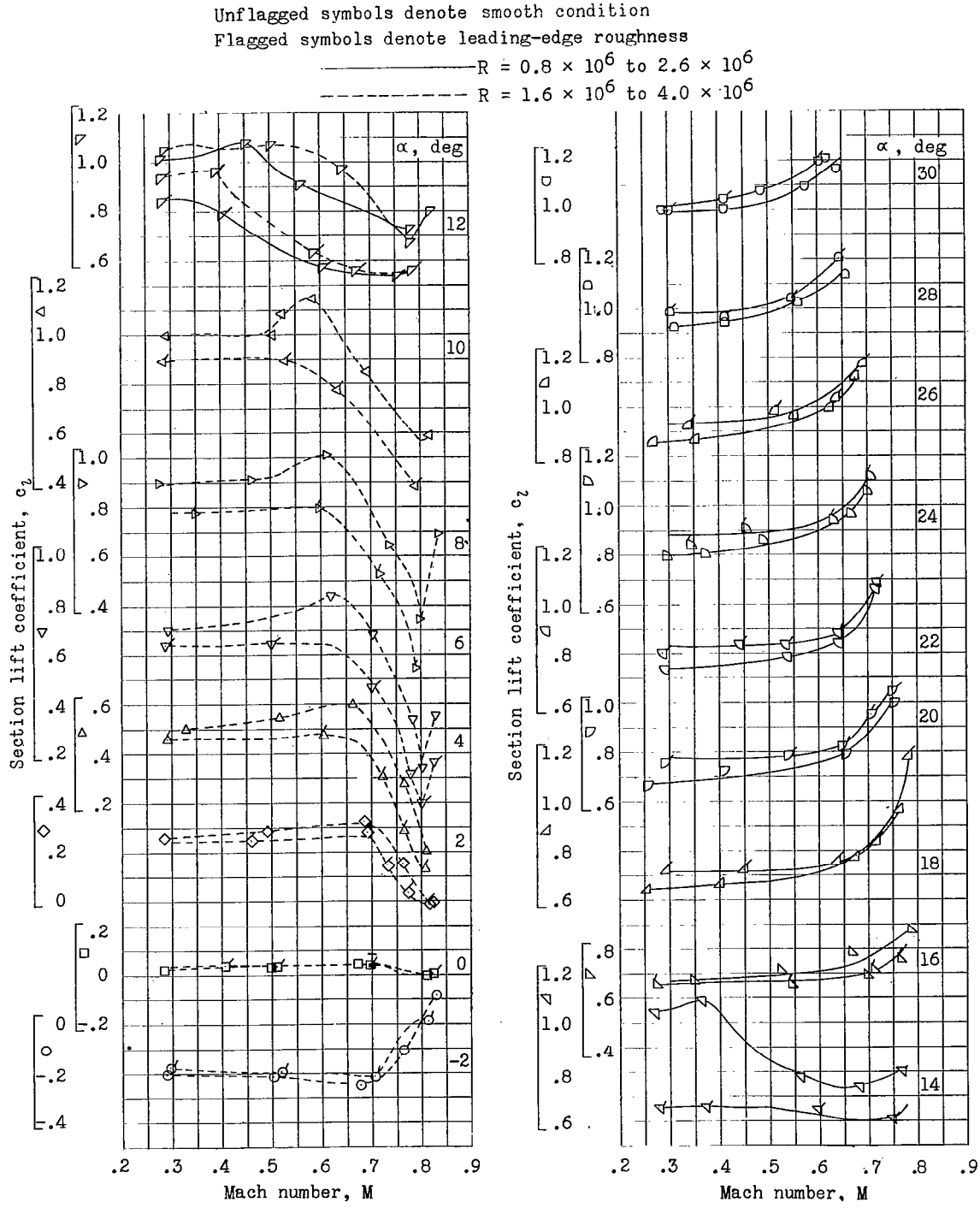
(b) Section drag coefficient.

Figure 3.- Continued.



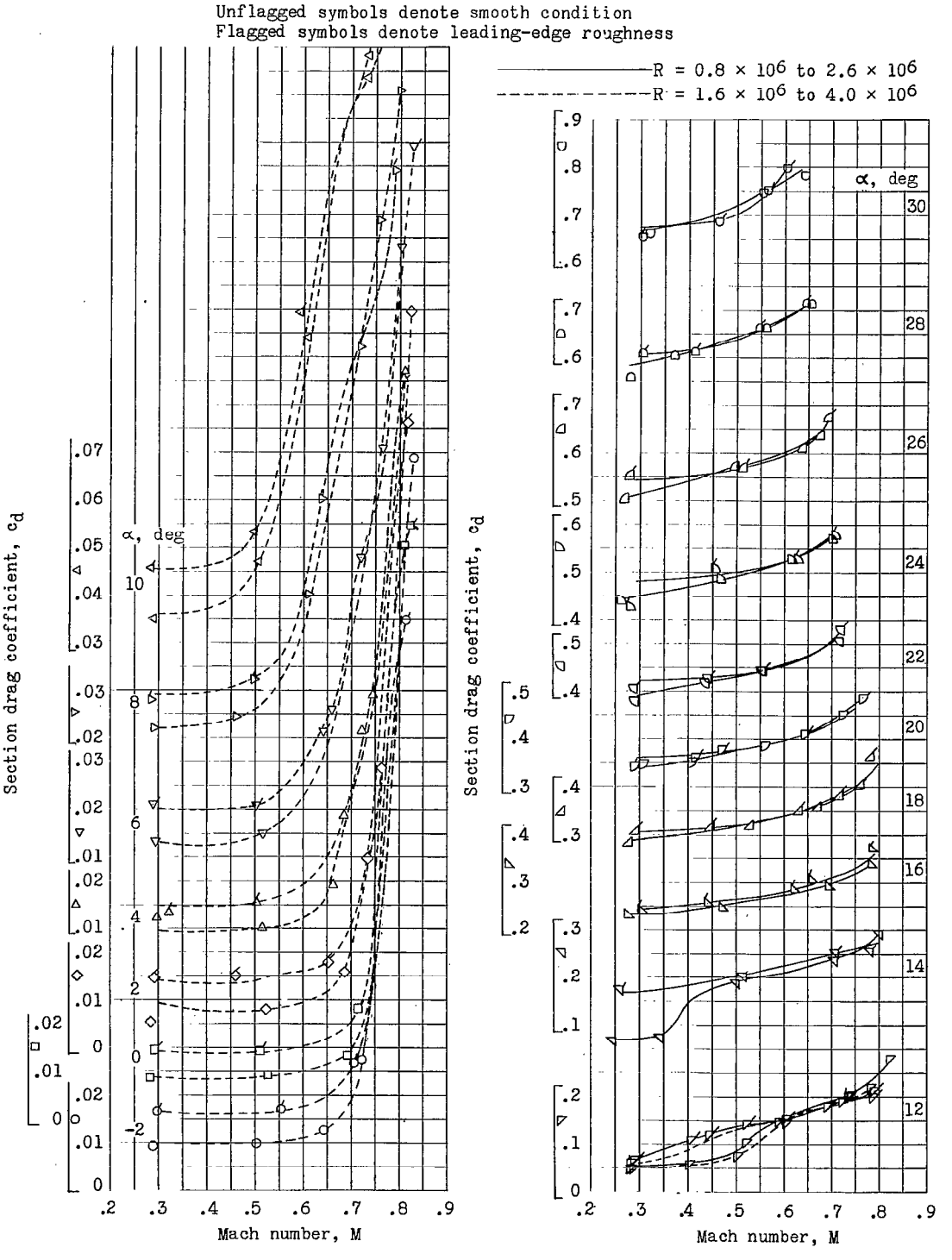
(c) Section quarter-chord pitching-moment coefficient.

Figure 3.- Concluded.



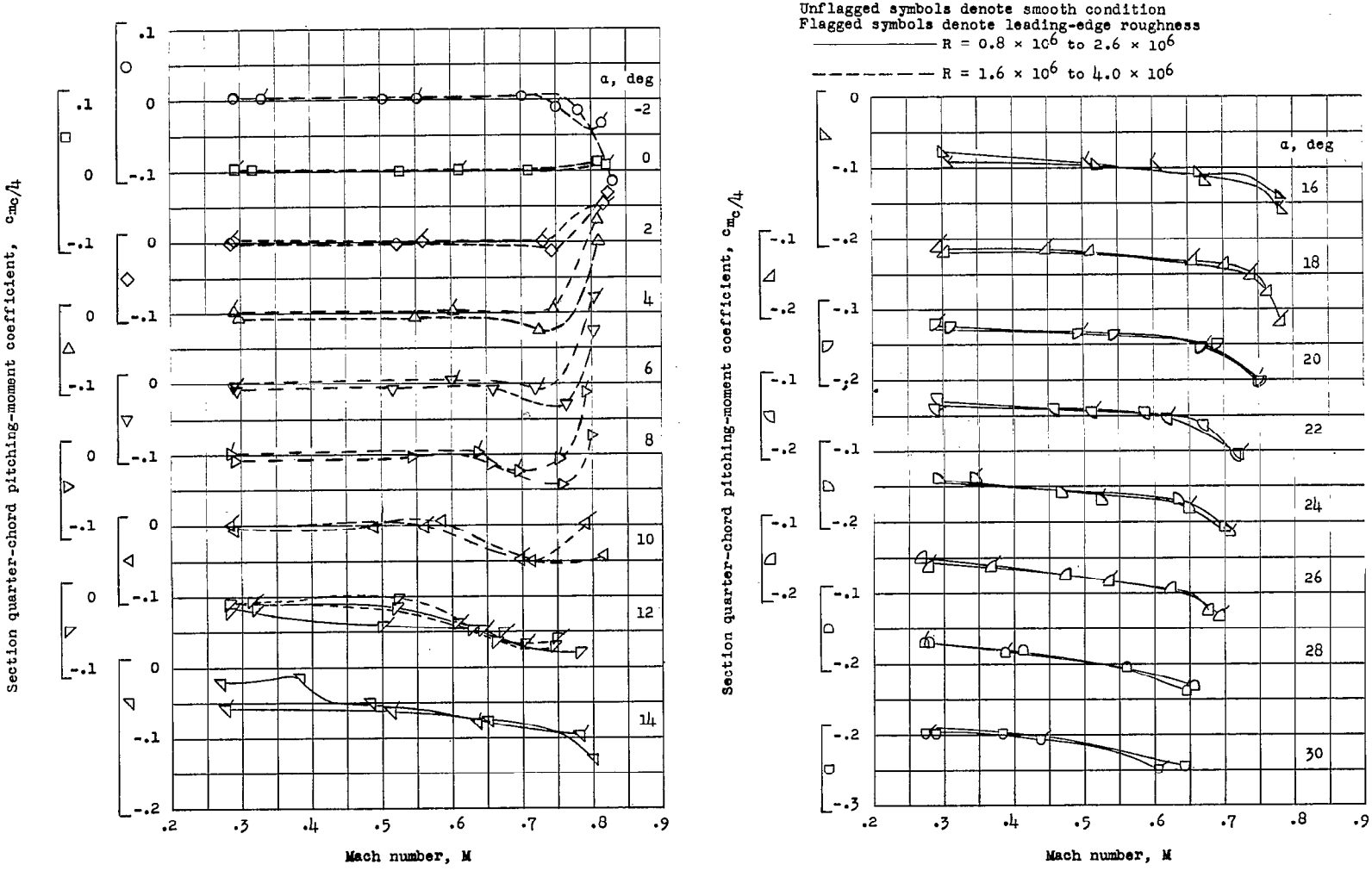
(a) Section lift coefficient.

Figure 4.- Aerodynamic characteristics at various angles of attack obtained with 1.0-foot chord NACA 64$_3$-018 airfoil section.



(b) Section drag coefficient.

Figure 4.- Continued.



(c) Section quarter-chord pitching-moment coefficient.

Figure 4.- Concluded.