TN-1998

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 1998

AERODYNAMIC CHARACTERISTICS OF THE NACA 8-H-12 AIRFOIL SECTION AT SIX REYNOLDS NUMBERS FROM 1.8×10^6 TO 11.0×10^6

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Washington
December 1949

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AERODYNAMIC CHARACTERISTICS OF THE NACA 8-H-12 AIRFOIL SECTION AT SIX REYNOLDS NUMBERS FROM 1.8×10^6 TO 11.0×10^6

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SUMMARY

An investigation has been conducted in the Langley two-dimensional low-turbulence pressure tunnel to determine the aerodynamic characteristics of the NACA 8-H-12 airfoil section at four Reynolds numbers from 3.0×10^6 to 11.0×10^6. The section lift, drag, and pitching-moment characteristics are presented for both the smooth and rough surface condition at these four Reynolds numbers, together with previously published results for the same section at Reynolds numbers of 1.8×10^6 and 2.6×10^6. Some of the more important aerodynamic characteristics of the NACA 8-H-12 airfoil are compared with those of two sections commonly used in rotor-blade design, the NACA 0012 and NACA 23012.

The data indicate that no unusual scale effects on lift, drag, and pitching moment are present for the smooth NACA 8-H-12 airfoil within the range of Reynolds number from 1.8×10^6 to 11.0×10^6. In general, this is also true for the airfoil with leading-edge roughness.

The maximum lift coefficient of the smooth NACA 8-H-12 airfoil is lower than those for the NACA 23012 and NACA 0012 sections over the range of Reynolds number tested. Leading-edge roughness on the NACA 8-H-12 airfoil, however, has a less detrimental effect on the maximum lift coefficient than it does on the other two airfoils. The value of the drag coefficient at the design lift coefficient is lower than that for either the NACA 0012 or NACA 23012 section.

INTRODUCTION

Several low-drag airfoil sections have been derived solely for use in rotor blades of rotating-wing aircraft. References 1, 2, and 3 present aerodynamic data for a number of such sections designed to give near-zero pitching moments about the aerodynamic center, low drag over the range of lift coefficient most useful for normal operation, and moderate drag at higher lift coefficients. Because of the present interest in rotors of larger dimensions, it was considered desirable to investigate the aerodynamic characteristics of one of the more promising of these airfoils at Reynolds numbers higher than those at which the former investigations were conducted. The NACA 8-H-12 airfoil was selected on the basis of the generally favorable data given for this airfoil at the lower Reynolds numbers of reference 2. The aerodynamic results for this airfoil, initially tested in the Langley two-dimensional low-turbulence tunnel at Reynolds numbers of 1.8×10^6 and 2.6×10^6, have therefore been extended to include data for Reynolds numbers of 3.0×10^6, 6.0×10^6, 9.0×10^6, and 11.0×10^6 in the present investigation.

The data given in the present paper were obtained from measurements of the lift, drag, and pitching moments for both smooth and rough surface conditions at the six Reynolds numbers. For comparison, some of the more important aerodynamic parameters of two sections frequently used in rotor blades, the NACA 0012 and NACA 23012, are included. The basic aerodynamic data from which these parameters were taken are given in reference 4.

COEFFICIENTS AND SYMBOLS

c	chord
c_d	section drag coefficient
c_l	section lift coefficient
c_{l_i}	design section lift coefficient
$c_{l_{max}}$	maximum section lift coefficient
$c_{m_{ac}}$	section pitching-moment coefficient about the aerodynamic center
c_{m_p}	section pitching-moment coefficient about the axis on which the airfoil model was pivoted
$dc_l/d\alpha_o$	slope of section lift curve per degree

R	Reynolds number
x	distance along chord from leading edge
y	distance perpendicular to chord
α_0	section angle of attack, degrees
α_{l_0}	section angle of zero lift, degrees

MODEL AND TESTS

The 24-inch-chord model of the NACA 8-H-12 airfoil was constructed of laminated mahogany. For tests in the smooth condition, the surfaces of the model were lacquered and then sanded in a chordwise direction with No. 400 carborundum paper until aerodynamically smooth. For tests with standard roughness, carborundum grains of 0.011-inch diameter were applied over a surface length of 0.08c to each surface measured from the airfoil leading edge. The grains were sparsely spread to cover from 5 to 10 percent of the area. The model completely spanned the smaller dimension of the 3- by $7\frac{1}{2}$-foot rectangular test section of the Langley two-dimensional low-turbulence pressure tunnel. The model was pivoted at 0.25c in the chordwise direction and, because of the strength requirements of this particular model, at a vertical distance of 1/2 inch above the chord line. The gaps between the tunnel walls and the ends of the model were sealed to prevent air leakage. Ordinates for the NACA 8-H-12 airfoil section are given in table I.

The tests consisted of measurements of the lift, drag, and pitching-moment coefficients at Reynolds numbers of 3.0×10^6, 6.0×10^6, 9.0×10^6, and 11.0×10^6. Lift was obtained from the resultant of the integrated pressure distributions along the floor and ceiling of the tunnel test section. Drag was obtained by means of the wake-survey method, and pitching moments were measured with a torque balance. For variations in Reynolds number, the density of the air within the tunnel was changed over a pressure range of 2 to 10 atmospheres. The maximum Mach number attained during the tests was less than 0.13, therefore the results may be considered to be relatively free of compressibility effects. Detailed information on the tunnel and its operation can be found in reference 5.

RESULTS AND DISCUSSION

The results of the present tests, together with the lower Reynolds number data of reference 2 for the NACA 8-H-12 airfoil, are shown in figure 1 as standard plots of section lift, drag, and pitching-moment coefficients for both the smooth airfoil and the airfoil with roughened leading edge. In addition, some of the more important aerodynamic characteristics of the NACA 8-H-12 airfoil, along with those of the NACA 0012 and NACA 23012 sections for comparison (from reference 4), are shown plotted against Reynolds number in figure 2.

In connection with the comparison of the data of reference 2 with those of the present investigation, it should be noted that the surface length of roughness employed in the present investigation was different from that employed in the tests of reference 2. Roughness was applied to the leading edge for the tests of reference 2 for a surface length of 0.02c along each surface measured from the leading edge as compared with 0.08c for the present tests.

Corrections for tunnel-wall interference have been made to all data procured from the tunnel by the following equations (developed in reference 5) in which the primed quantities represent those measured in the tunnel:

$$\alpha_o = 1.015\alpha_o'$$

$$c_d = 0.992c_d'$$

$$c_l = 0.977c_l'$$

$$c_{m_p} = 0.992c_{m_p}'$$

Lift.- The maximum section lift coefficient of the smooth NACA 8-H-12 airfoil increases from 1.25 to 1.48 as the Reynolds number is increased from 1.8×10^6 to 11.0×10^6 (figs. 1(a) and 2(a)). Between Reynolds numbers of 1.8×10^6 and 3.0×10^6 the maximum lift remains relatively constant. The largest increment in maximum lift coefficient resulting from increases in the Reynolds number occurs between 3.0×10^6 and 6.0×10^6, with smaller increases occurring up to a Reynolds number of 11.0×10^6. The shape of the lift curve near maximum lift is very desirable for all Reynolds numbers. The lift-curve slope of the smooth airfoil, measured from approximately zero lift to slightly above the experimental design lift, increases from a value of 0.098 to approximately 0.112 per degree as the Reynolds number is increased from 1.8×10^6 to 11.0×10^6 (fig. 2(a)). The measured angle of zero lift for the airfoil in the smooth condition varies only about $\frac{1}{2}^{\circ}$ over the range of Reynolds number covered in this investigation (fig. 2(a)).

For the NACA 8-H-12 airfoil with roughened leading edge, there appears to be a relatively insignificant variation of the maximum lift with Reynolds number; the decrement in maximum lift due to surface roughness therefore increases with Reynolds number (fig. 1(a)). The amount of variation of the lift-curve slope with Reynolds number is small when the leading edge is roughened (fig. 2(b)). In comparison with the data for the smooth condition, the addition of roughness causes the angle of zero lift to become slightly more negative at the lower Reynolds number and approximately 0.7° more negative at the higher Reynolds numbers so that there is substantially no variation of the angle of zero lift with Reynolds number for the rough condition.

For the smooth condition, the maximum section lift coefficient of the NACA 8-H-12 section is somewhat less than those of the NACA 0012 and NACA 23012 sections at corresponding Reynolds numbers (fig. 2(a)). The difference between the maximum lift coefficients of the NACA 8-H-12 and the NACA 0012 section is smallest at the lowest Reynolds number, becomes a maximum at a Reynolds number of 3.0×10^6, then diminishes as the Reynolds number is increased to 9.0×10^6. In comparison with the NACA 23012 airfoil, the difference is again smallest at the lowest Reynolds number, increases to a maximum at a Reynolds number of 3.0×10^6, but remains relatively fixed up to a Reynolds number of 9.0×10^6.

At corresponding Reynolds numbers, the decrement in maximum lift coefficient due to roughness is not as great for the NACA 8-H-12 section as for either the NACA 0012 or NACA 23012 airfoils, with the result that the maximum lift coefficient for the NACA 8-H-12 section at corresponding Reynolds numbers exceeds that for the NACA 0012 section and is only slightly less than that for the NACA 23012 airfoil (fig. 2(b)). The NACA 8-H-12 airfoil section, moreover, stalls in a manner which is much less abrupt than that of the two other sections mentioned, for both the smooth and rough conditions and for all corresponding Reynolds numbers within the range for which data are given (fig. 1(a) and reference 4).

Drag.- For the smooth airfoil there appears to be, in most cases, some reduction in the extent of the low-drag range of lift coefficient with increasing Reynolds number (fig. 1(b)). This trend is characteristic of NACA 6-series airfoils (references 4 and 6). For most of the lift coefficients shown, the drag coefficient outside the low-drag range becomes lower in magnitude as the Reynolds number is increased. For the airfoil with roughened leading edge there is, of course, a complete absence of a region of low drag corresponding to extensive laminar layers. In the region where the drag rises rapidly with increase in lift coefficient, increasing the Reynolds number causes some slight decrease in the drag of the airfoil with roughened leading edge. The apparent adverse scale effect between Reynolds numbers of 2.6×10^6 and 3.0×10^6 may be attributed to the fact that the data at Reynolds numbers of 1.8×10^6 and 2.6×10^6 (reference 2) were obtained by employing a smaller extent of roughness than was used in the present investigation.

The drag coefficient at the experimental design lift coefficient, the value at the center of the low-drag region of the drag-lift curve, is plotted in figures 2(a) and 2(b) as a function of Reynolds number for the NACA 8-H-12 section. The values of the experimental design lift coefficient selected for the smooth and rough surface conditions of the NACA 8-H-12 airfoil are 0.52 and 0.22, respectively. The data show that the drag of the smooth section at design lift, although it remains relatively constant between Reynolds numbers of 3.0×10^6 and 6.0×10^6, decreases in general as the Reynolds number is increased from 1.8×10^6 to 11.0×10^6. In the rough surface condition the drag remains nearly constant up to a Reynolds number of 3.0×10^6 and then decreases progressively as the Reynolds number is increased from 3.0×10^6 to 11.0×10^6 (fig. 2(b)).

In figure 2 the section drag coefficient at the experimental section design lift coefficient is also shown plotted against Reynolds number for the NACA 0012 and NACA 23012 airfoils. The drag coefficient at design lift coefficient for the NACA 8-H-12 airfoil section is less than that for either the NACA 0012 or the NACA 23012 section in the smooth condition (fig. 2(a)). This can be attributed to the larger region of laminar flow prevailing on the NACA 8-H-12 airfoil in the smooth condition. When roughness is applied, however, this advantage of lower drag for the NACA 8-H-12 section is retained only at the lower Reynolds numbers and is lost at a Reynolds number of 6.0×10^6, where the drag coefficients for the three airfoil sections are equal (fig. 2(b)).

Pitching moment.- Pitching moments were measured about the horizontal axis on which the model was pivoted, and from these values, the position of the aerodynamic center and the pitching-moment coefficients about the aerodynamic center were calculated. The section moment coefficients about the pivot position c_{m_p} and about the aerodynamic center $c_{m_{ac}}$ are plotted in figures 1(a) and 1(b), respectively, for the airfoil in both the smooth and rough conditions. The positions of the aerodynamic center are tabulated in fig. 1(b). The positions of the aerodynamic center for the two lower Reynolds numbers (reference 2) have been recalculated and are somewhat different from the values given in reference 2.

Pitching moments about the aerodynamic center for the smooth airfoil are slightly positive for all six Reynolds numbers. Generally, the value of the pitching moment seems to become somewhat more positive as the Reynolds number is increased. Roughness has the effect of decreasing in magnitude the value of the moment coefficient about the aerodynamic center and of shortening the range of lift coefficient over which the moment-curve slope is constant.

The position of the aerodynamic center shows an appreciable forward shift as the Reynolds number is increased from 1.8×10^6 to 2.6×10^6 for the smooth airfoil and from 1.8×10^6 to 3.0×10^6 for the airfoil with leading-edge roughness; increases in the Reynolds number above these values had little effect. Within the range of Reynolds number from 3.0×10^6 to 11.0×10^6, the position of the aerodynamic center is farther forward for the rough than for the smooth surface condition.

CONCLUSIONS

The results of the present investigation of the NACA 8-H-12 airfoil section through a range of Reynolds number from 3.0×10^6 to 11.0×10^6, together with those obtained from a previous investigation of this airfoil at Reynolds numbers of 1.8×10^6 and 2.6×10^6, indicate the following conclusions:

1. No unusual scale effects on lift, drag, or pitching moment were present for the smooth NACA 8-H-12 airfoil over the range of Reynolds number from 1.8×10^6 to 11.0×10^6. This was also true for the airfoil with roughened leading edge except for an apparent adverse scale effect on the drag between Reynolds numbers of 2.6×10^6 and 3.0×10^6, which may be attributed to a difference in the extent of roughness employed at these Reynolds numbers.

2. The values of the pitching-moment coefficient about the aerodynamic center were somewhat positive and increased in magnitude with increasing Reynolds number for the smooth NACA 8-H-12 airfoil. Roughening the leading edge caused the value of the pitching moment about the aerodynamic center to decrease in magnitude.

3. The position of the aerodynamic center had a pronounced forward movement between Reynolds numbers of 1.8×10^6 and 2.6×10^6 for the smooth section, and between 1.8×10^6 and 3.0×10^6 for the section with roughened leading edge.

4. For the smooth condition, the NACA 8-H-12 airfoil had a lower maximum lift coefficient than either the NACA 23012 or the NACA 0012 sections at comparable Reynolds numbers. The addition of leading-edge roughness, however, affected the NACA 8-H-12 airfoil less adversely than the other two sections. The drag coefficient of the NACA 8-H-12 airfoil measured at the design lift was, in general, lower than that of the NACA 0012 and the NACA 23012 sections for both surface conditions.

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National Advisory Committee for Aeronautics
Langley Air Force Base, Va., November 8, 1949

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TABLE I

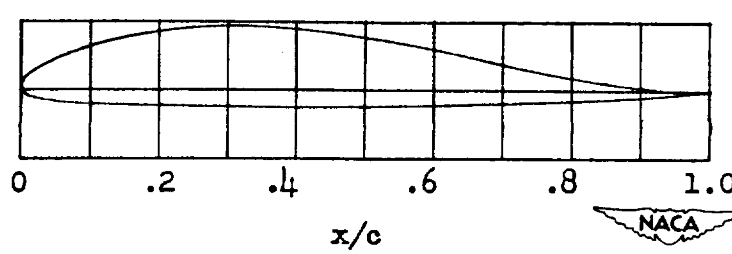
ORDINATES FOR THE

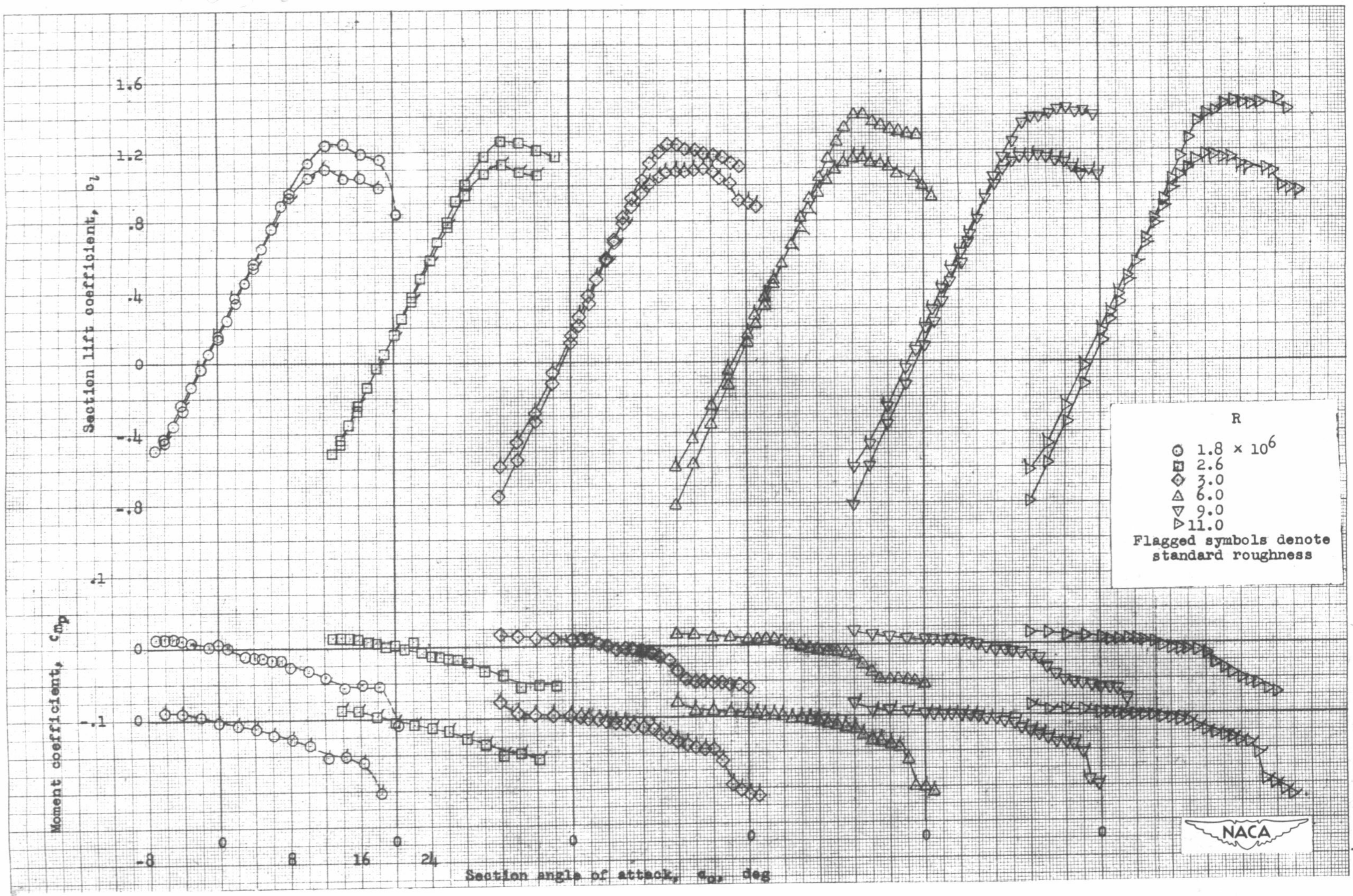
NACA 8-H-12 AIRFOIL SECTION

[Stations and ordinates given in percent of airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.147	1.229	.853	-.819
.358	1.520	1.142	-.946
.804	2.006	1.696	-1.128
1.980	2.941	3.020	-1.415
4.424	4.312	5.576	-1.736
6.914	5.380	8.086	-1.920
9.427	6.263	10.573	-2.059
14.497	7.626	15.503	-2.242
19.607	8.605	20.393	-2.351
24.754	9.243	25.246	-2.417
29.969	9.533	30.031	-2.455
35.174	9.432	34.826	-2.490
40.292	9.030	39.708	-2.494
45.360	8.420	44.640	-2.476
50.390	7.666	49.610	-2.436
55.387	6.795	54.613	-2.377
60.358	5.846	59.642	-2.290
65.311	4.850	64.689	-2.178
70.250	3.838	69.750	-2.034
75.184	2.838	74.816	-1.860
80.118	1.895	79.882	-1.645
85.060	1.046	84.940	-1.384
90.016	.343	89.984	-1.051
94.995	-.119	95.005	-.629
100.000	0	100.000	0

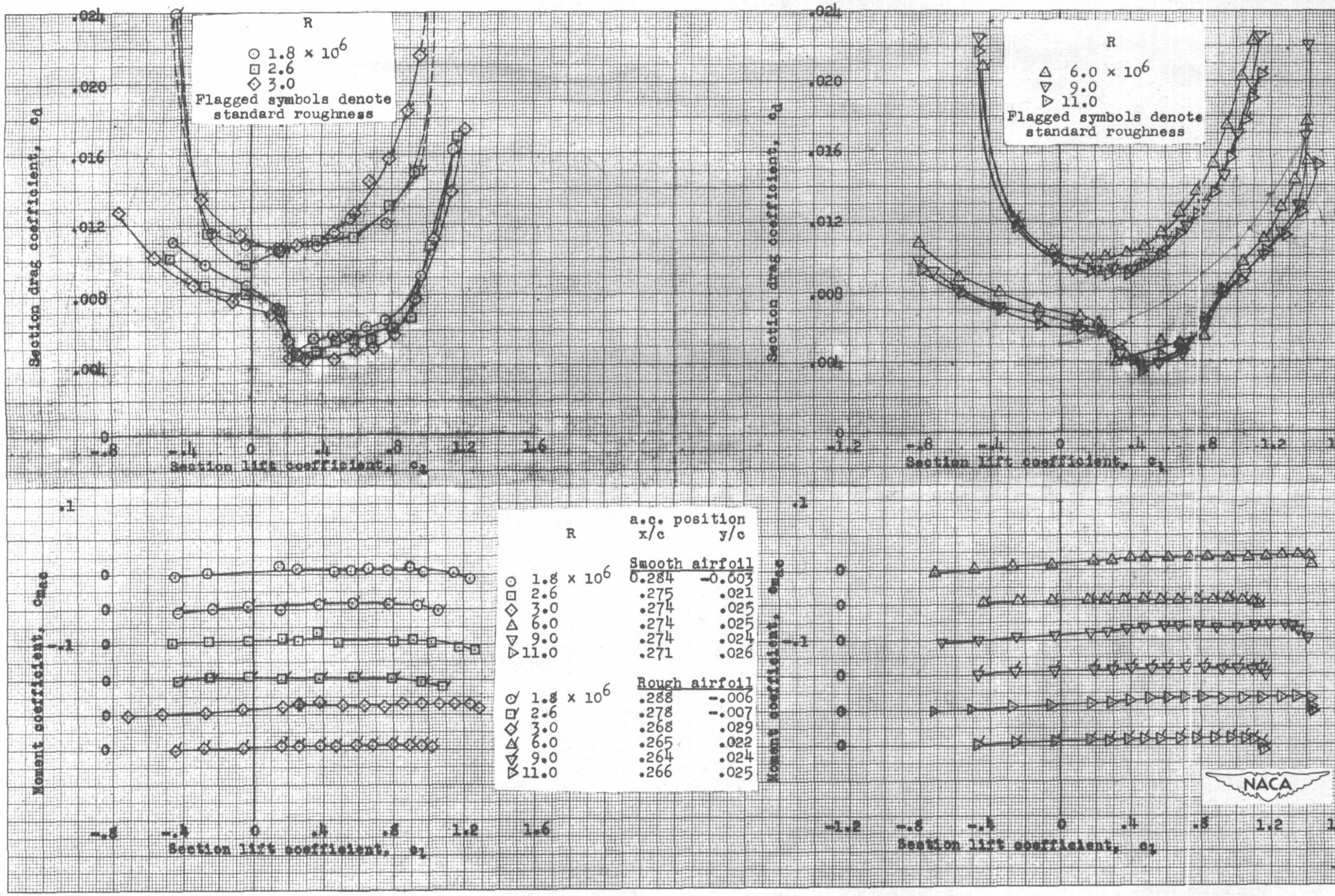
L.E. radius: 1.325
Slope of radius through L.E.: 0.344





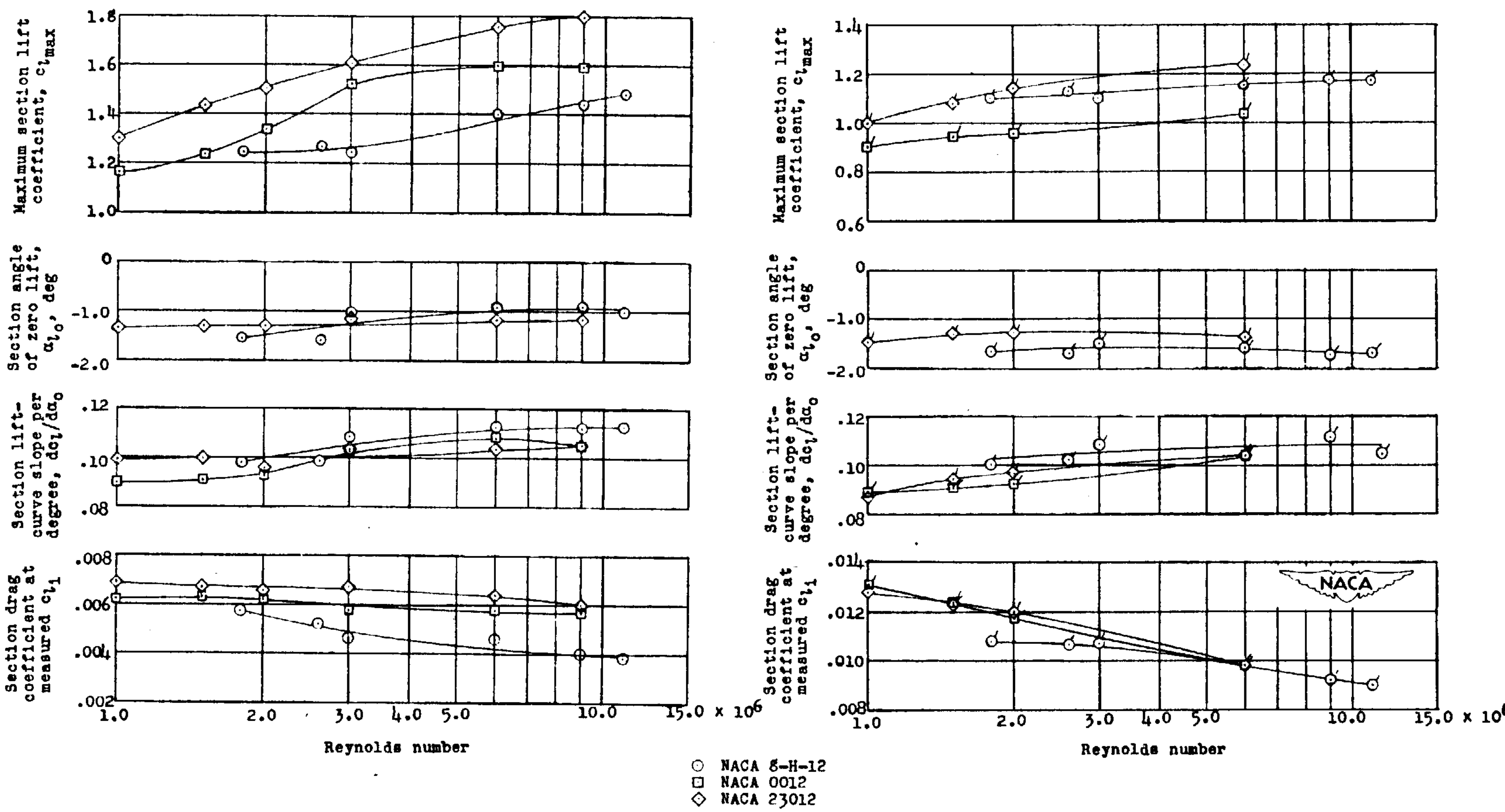
(a) Section lift and pitching-moment characteristics.

Figure 1.- Aerodynamic characteristics of the NACA 8-H-12 airfoil section, 24-inch chord.



(b) Section pitching-moment characteristics about the aerodynamic center and section drag characteristics.

Figure 1.- Concluded.



(a) Airfoils with smooth surfaces.

(b) Airfoils with standard leading-edge roughness.

Figure 2.- Variation with Reynolds number of section maximum lift coefficient, angle of zero lift, lift-curve slope, and drag coefficient at design lift coefficient for the NACA 8-H-12 airfoil section, in comparison with the NACA 0012 and NACA 23012 sections.

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