NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 1966

EXPERIMENTAL INVESTIGATION OF FLUTTER OF A PROPELLER WITH CLARK Y SECTION OPERATING AT ZERO FORWARD VELOCITY AT POSITIVE AND NEGATIVE BLADE-ANGLE SETTINGS

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SUMMARY

An investigation was made of the flutter of a small one-blade wooden propeller with a Clark Y section. The flutter speed and flutter frequency were obtained with the propeller at zero forward velocity at blade-angle settings, measured at 0.8 radius, from about 25° to -25° and at pressures from 0.321 to 1.0 atmosphere.

The highest flutter speeds were found in the vicinity of the angle of zero aerodynamic moment and the flutter speed increased considerably in this region with decreasing pressure. Over the remainder of the pitch range the flutter speeds were much lower and varied little with pressure. The maximum experimental flutter speed was 63 percent of the approximate theoretical classical flutter speed, which fact indicates that even under ideal conditions an appreciable factor of safety must be observed by designers. The flutter frequency was found to approach the natural torsional frequency of the propeller at both large positive and negative angles of attack.

INTRODUCTION

Propellers and wind-tunnel fans have been known to fail. In many cases these failures were believed to have been caused by stall flutter of the blades while operating at high positive and negative angles of attack. An investigation was therefore made to determine the flutter characteristics of a propeller with a Clark Y section at both positive and negative angles of attack. The tests were made in air at pressures from 0.321 to 1.0 atmosphere, and over a blade-angle range, measured at 0.8 radius, from 25° to -25°.

SYMBOLS

$\theta_{0.8R}$ blade-angle setting at 0.8 radius, degrees

c chord of propeller section, feet

b semichord, feet

t thickness of propeller section, feet

R radius to tip of blade, feet

r radius to propeller section, feet

κ ratio of mass of a cylinder of air of diameter equal to airfoil chord to mass of airfoil

α angle of attack, degrees

c_l section lift coefficient

x distance of center of gravity measured from leading edge, fractions of chord

a coordinate of torsional stiffness axis in terms of semichord as measured from midchord position

r_α nondimensional radius of gyration of airfoil section in terms of semichord referred to a

ω_α torsional frequency, radians per second

M Mach number

V velocity at 0.8 radius, feet per second

V_f flutter speed, feet per second

APPARATUS AND TEST METHODS

The Langley supersonic sphere used for these tests consists of a steel tank enclosing a 500-horsepower electric motor which rotates the model assemblies. Provisions are made to pump out the air in the sphere until the pressures for the desired testing conditions are reached.

Flutter characteristics were obtained on a small one-blade wooden propeller (fig. 1) of laminated Sitka spruce construction and with a Clark Y airfoil section. The model dimensions and pitch distribution are shown in figure 2. Strain gages mounted on the model indicated flutter, and these gages together with the tachometer were wired to a recording oscillograph which recorded the flutter speed and flutter frequency. Flutter runs were made at zero forward velocity at pressures of 0.321, 0.470, 0.686, and 1.0 atmosphere, and at $\theta_{0.8R}$ from 25° to -25°. Flutter was not observed, however, during all tests. In some cases, the flutter speed was higher than the safe operating speed range of the propeller, and in others the amplitude of the flutter was very small.

During each flutter run, the rotational speed was increased gradually until large-amplitude flutter was observed. No attempt was made to increase the rotational speed above the point at which flutter was observed because it was quite violent in most cases.

RESULTS AND DISCUSSION

The theoretical variation of lift coefficient c_l with blade angle setting $\theta_{0.8R}$, with only the inflow angle taken into account (reference 1), is shown in figure 3. The experimental results are presented in figures 4 to 7 as functions of the blade-angle setting $\theta_{0.8R}$. The angle $\theta_{0.8R}$ is the pitch setting when the twisting of the blade, such as observed in the tests of reference 2, is neglected.

The experimental flutter coefficients $V_f/b\omega_\alpha$ are shown in figure 4 as a function of $\theta_{0.8R}$. These data indicate that at the angle of zero aerodynamic moment the flutter speed shows a marked increase, which occurs as c_l approaches about 0.50. The same tendency was shown by the data of reference 2. The type of flutter encountered under these conditions is believed to be very similar to the classical flutter of wings. At large positive and negative blade-angle settings the flutter speeds are much lower than the classical flutter speeds, and little variation of flutter speed with pressure change occurs at these angles. This flutter is associated with stall and is commonly called stall flutter. Its character is different from the classical case in that the flutter is almost entirely torsional. Conservatively, it appears that a propeller of the type used in this investigation with $V/b\omega_\alpha$ less than 1.0 should not encounter stall flutter in air under any of the conditions of pitch setting and of pressure included in these tests.

The ratios of tip speeds at flutter to the theoretical classical flutter speeds, as calculated by the approximate two-dimensional flutter formula with no account taken of centrifugal forces (see table I), for the different pressures used in these tests are presented in figure 5. This method of calculating the theoretical flutter speed was used for comparisons because no adequate propeller flutter theory is available. Since the maximum experimental flutter speed was 63 percent of the theoretical flutter speed, an appreciable factor of safety must be employed by the designer even under ideal conditions. The minimum flutter-speed ratio at positive angles of attack was 0.28, whereas at negative angles the minimum flutter-speed ratio was 0.18. The flutter-speed ratio decreases as $1/\kappa$ is increased, particularly at large positive and negative angles of attack.

Although no significance is attached at this time to the tip Mach numbers at flutter, they are shown in figure 6.

The flutter-frequency values in figure 7 tend to show an inverse relation to the flutter speed and have the lowest values near the angle of zero aerodynamic moment. The flutter frequency at both large positive and negative values of $\theta_{0.8R}$ approaches the natural torsional frequency of the propeller.

CONCLUDING REMARKS

The experimental flutter speed in these tests was always below the theoretical classical flutter speed. Even under ideal conditions, the designer must apply an appreciable factor of safety to insure against flutter if calculations are made by using the approximate flutter formula. The data indicate that a propeller of the type tested in this investigation having the nondimensional flutter-speed coefficient less than one, and operating under the same conditions of pitch setting and of pressure included in these tests, should not encounter stall flutter. The ratio of experimental to theoretical classical flutter speeds decreases as the air density within the sphere is decreased, particularly at large positive and negative angles of attack. The flutter speeds at negative angles of attack are lower than those for the corresponding positive angles of attack.

The flutter frequency approaches the natural torsional frequency of the propeller at both large positive and negative angles of attack.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., August 30, 1949

REFERENCES

1. Glauert, H.: The Elements of Aerofoil and Airscrew Theory. Cambridge Univ. Press, reprint of 1937, pp. 208-221.

2. Theodorsen, Theodore, and Regier, Arthur A.: Effect of the Lift Coefficient on Propeller Flutter. NACA ACR L5F30, 1945.

TABLE I

CALCULATION OF THEORETICAL CLASSICAL FLUTTER SPEEDS AT 0.8 RADIUS

[By method of reference 2]

Pressure (atmospheres)	κ	Flutter speed at 0.8 radius (ft/sec)
1.000	1/45	838
.686	1/66	1015
.470	1/96	1227
.321	1/140	1490

Sample calculation for atmospheric conditions:

$$x = 0.44$$

$$r_\alpha{}^2 = 0.24$$

$$\kappa = \frac{1}{45}$$

$$c = 0.182 \text{ foot}$$

$$R = 2.58 \text{ feet}$$

$$\omega_\alpha = (390)(2\pi)$$

$$b = \frac{c}{2} = 0.091 \text{ foot}$$

$$V_f \approx b\omega_\alpha \sqrt{\frac{r_\alpha{}^2}{\kappa} \frac{1/4}{x - \frac{1}{4}}}$$

$$\approx (0.091)(2\pi)(390) \sqrt{\frac{(0.24)(45)(0.25)}{0.44 - 0.25}}$$

$$\approx 838 \text{ feet per second}$$

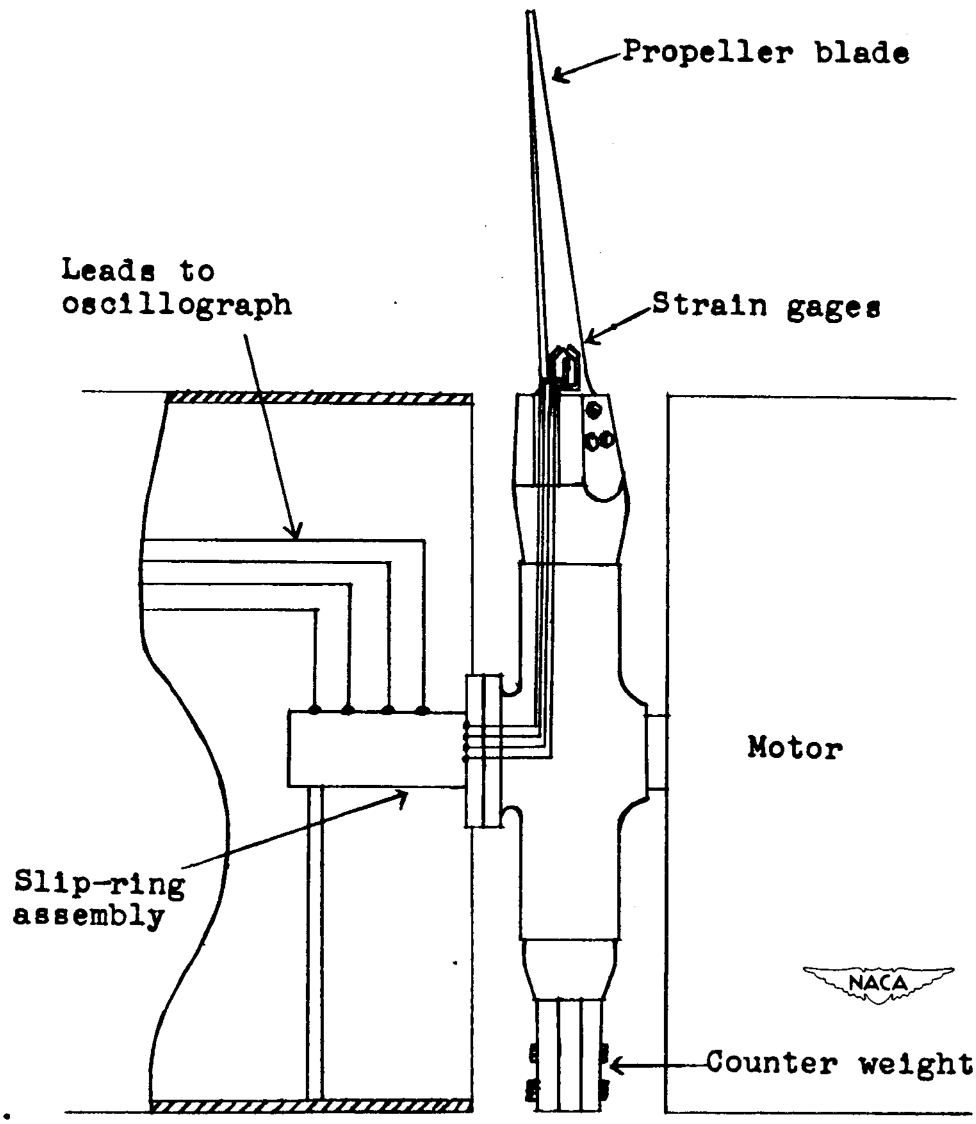

Figure 1.- Schematic diagram of propeller assembly.

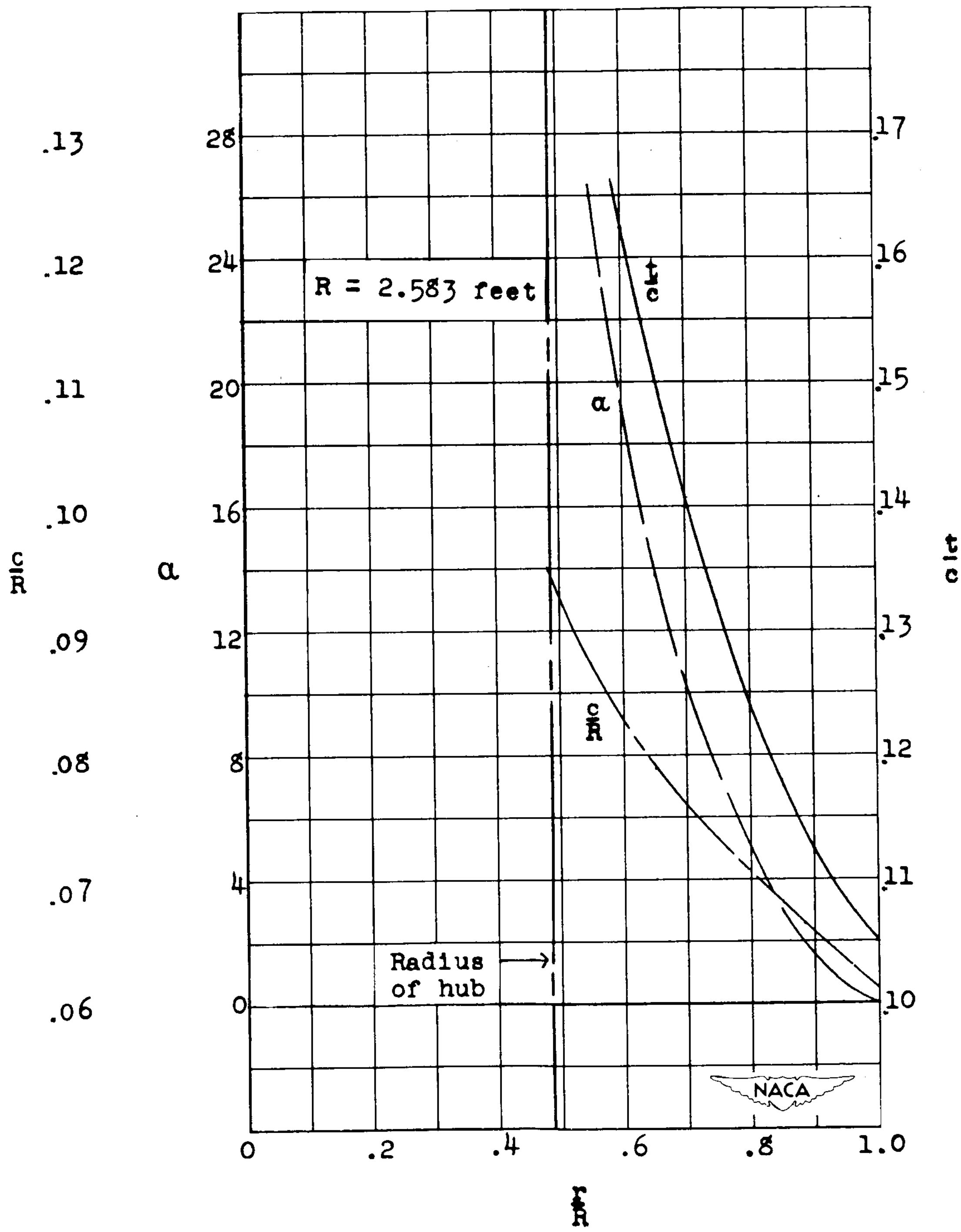

Figure 2.- Propeller blade parameters.

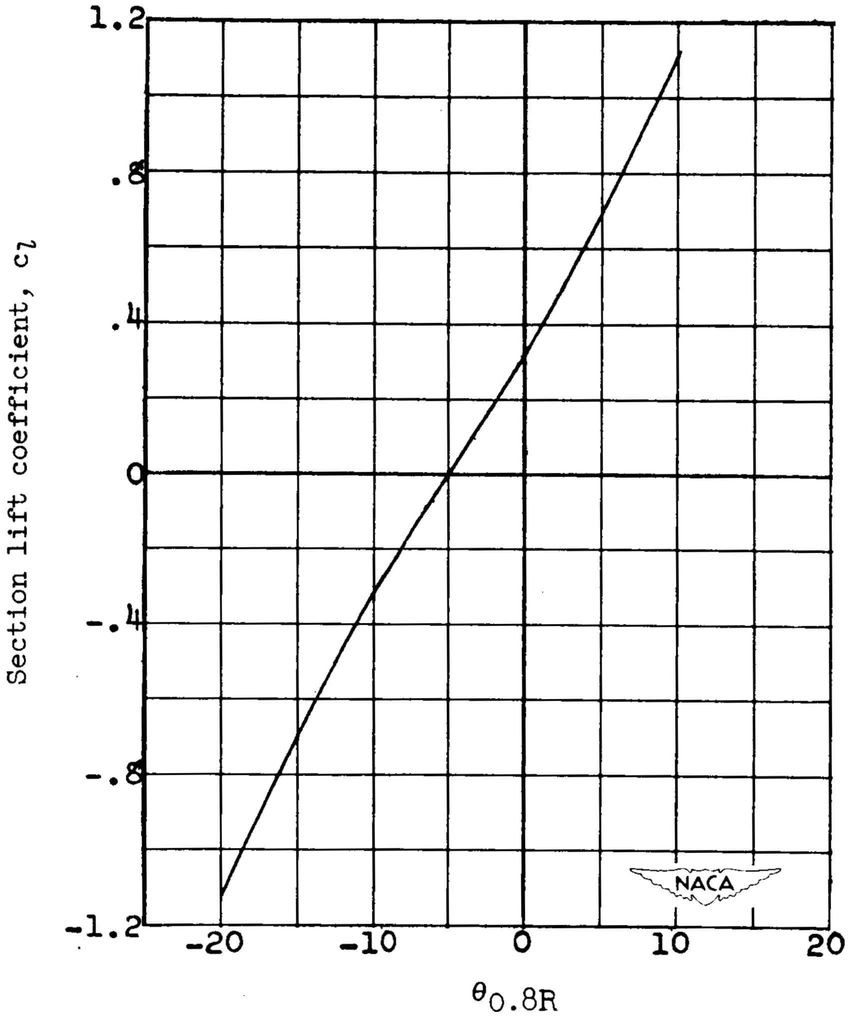

Figure 3.- Theoretical variation of c_l with blade-angle setting at 0.8 radius at zero forward velocity.

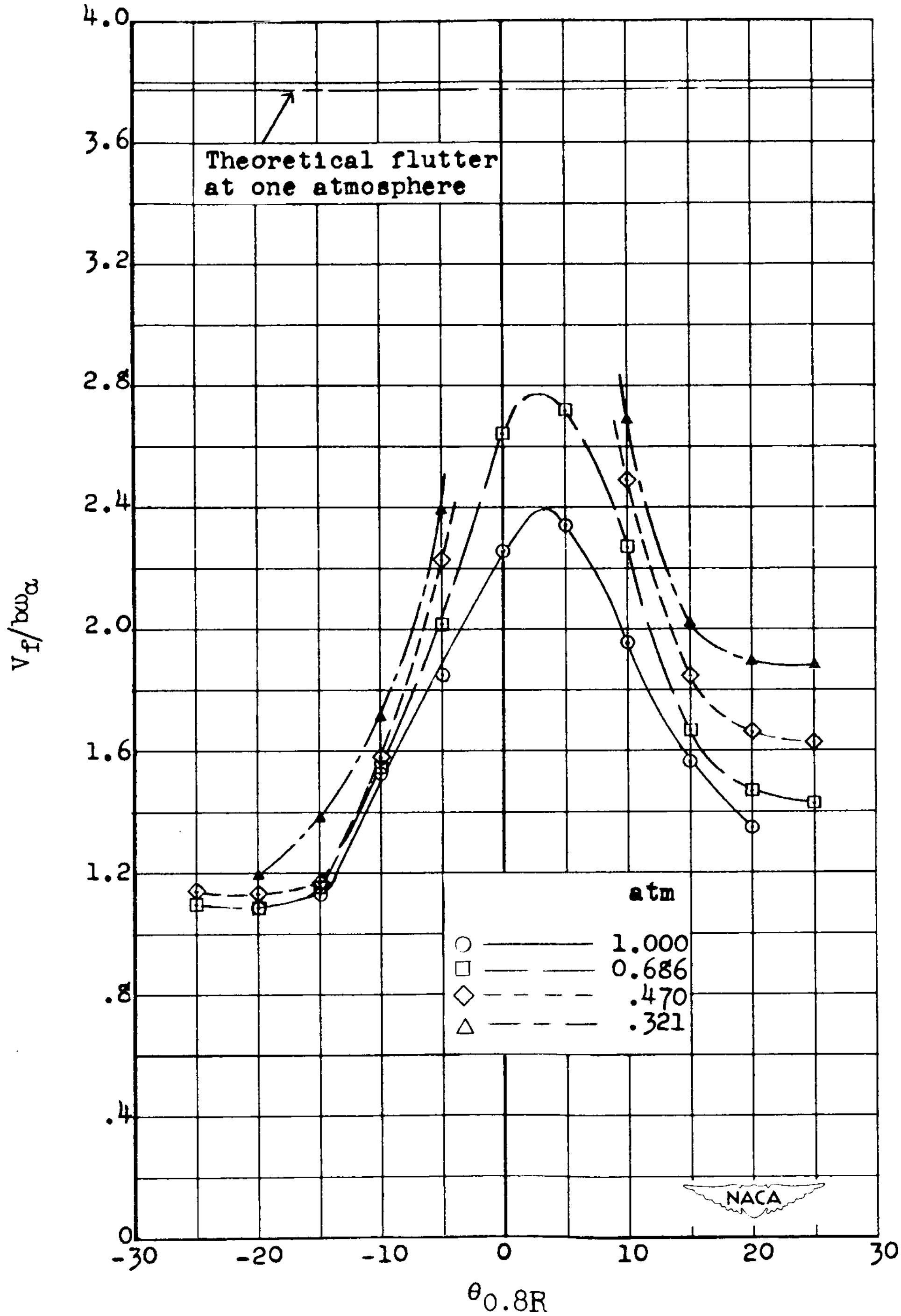

Figure 4.- Variation of reduced frequency $V_f/b\omega_\alpha$ with $\theta_{0.8R}$.

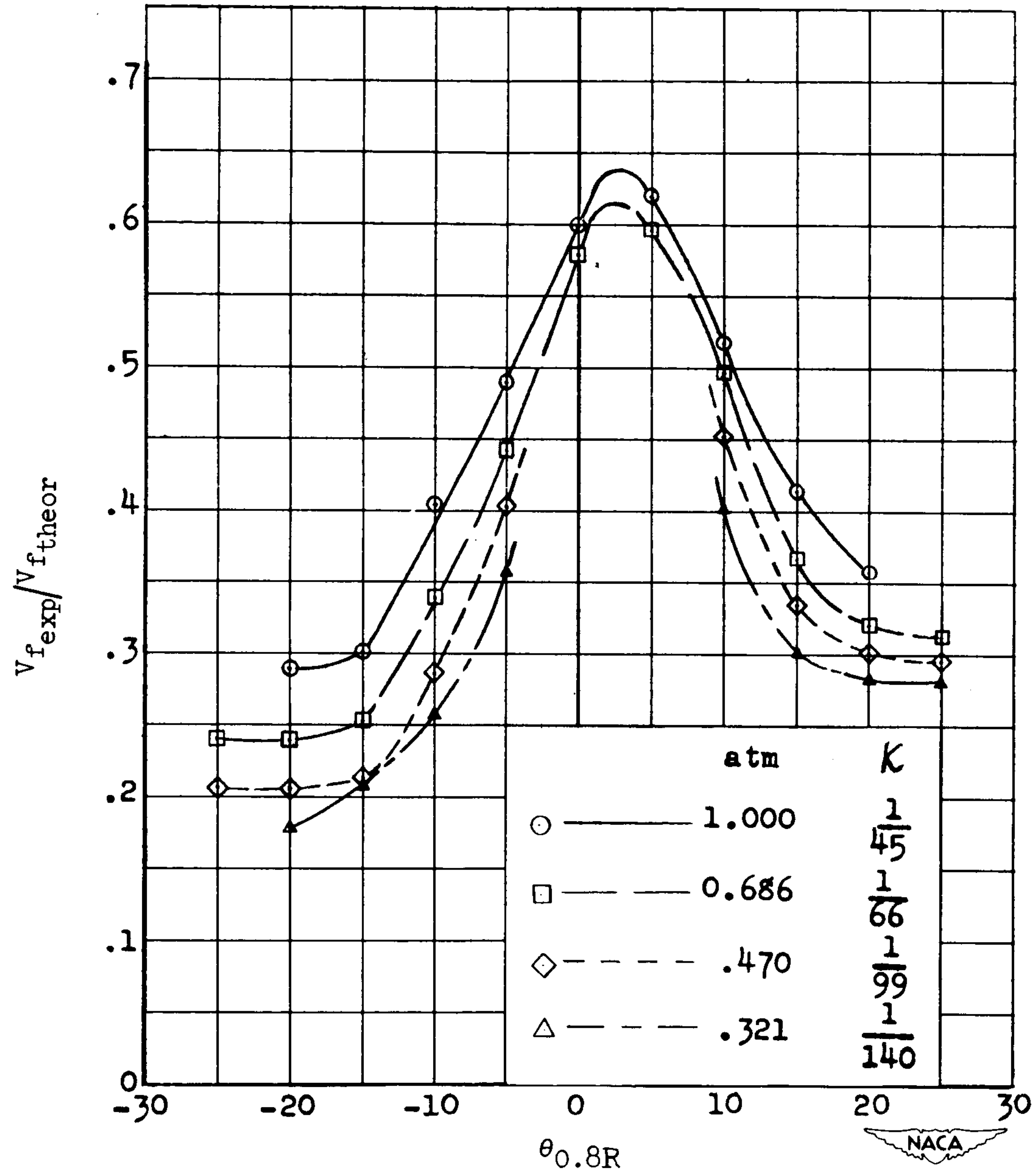

Figure 5.- Ratio of tip speed at flutter to the theoretical classical flutter speed as affected by the variation of $\theta_{0.8R}$.

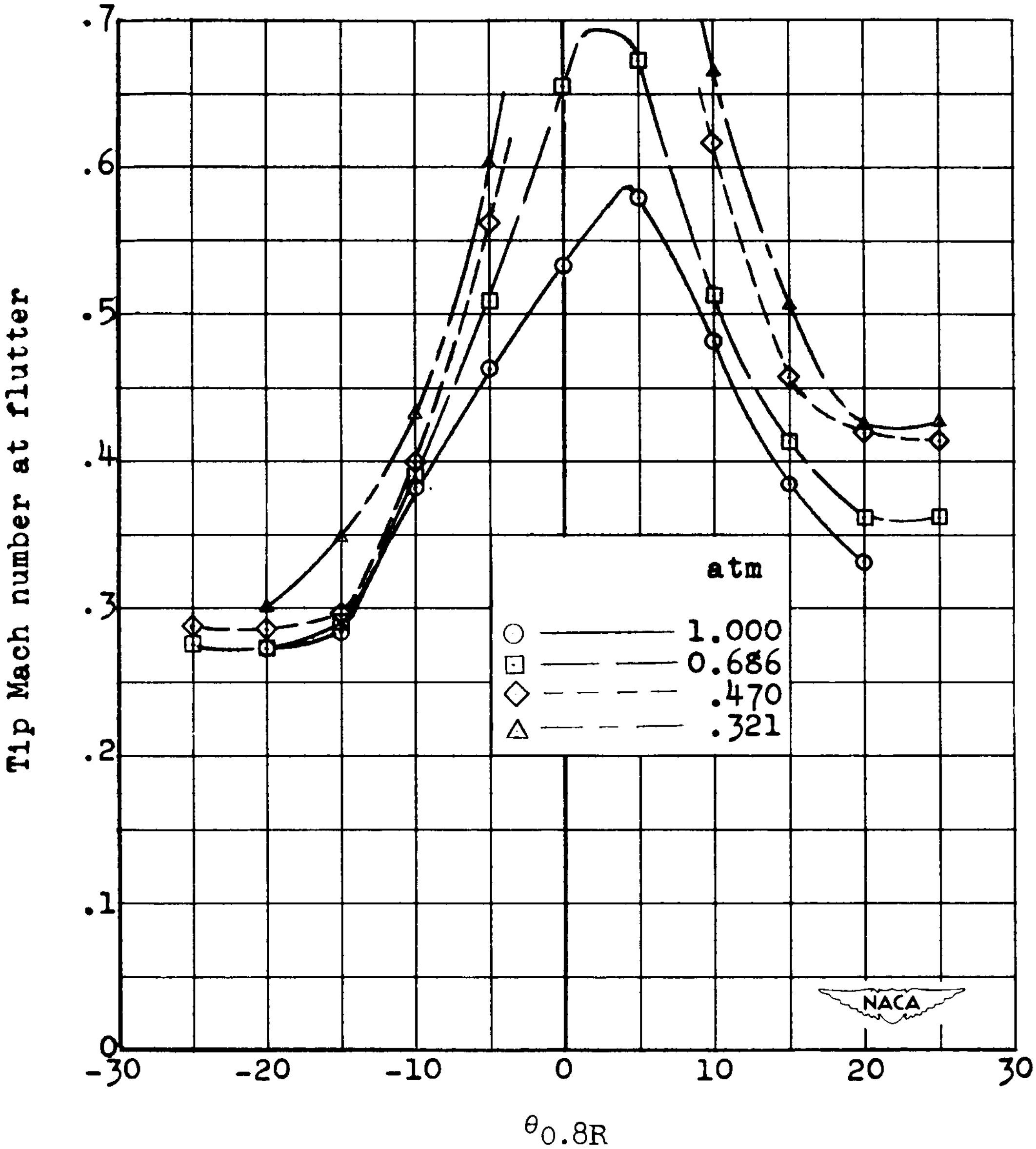

Figure 6.- The variation of tip Mach number at flutter with $\theta_{0.8R}$.

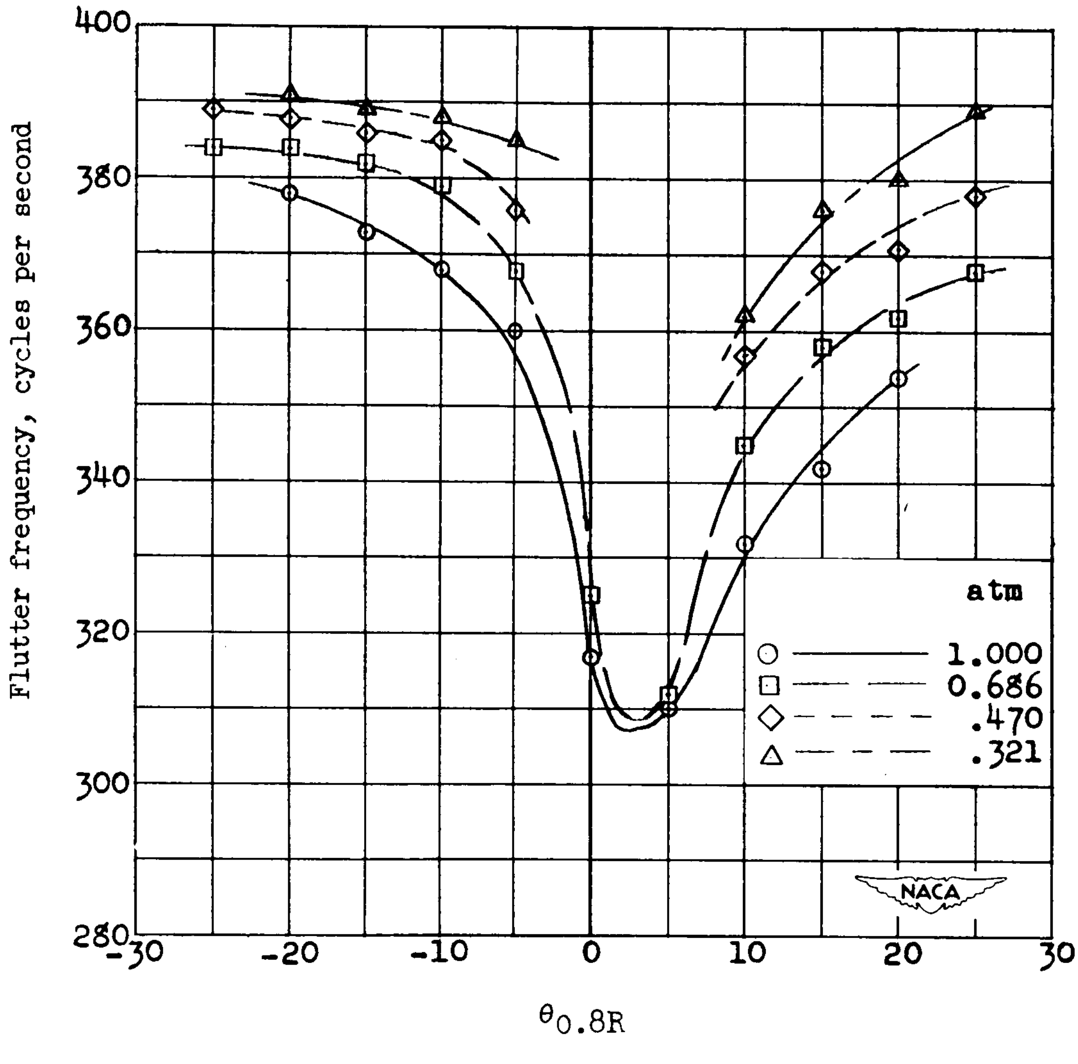

Figure 7.- Flutter frequency as a function of $\theta_{0.8R}$.