NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 523

THE INFLUENCE OF WING SETTING ON THE WING LOAD AND ROTOR SPEED OF A PCA-2 AUTOGIRO AS DETERMINED IN FLIGHT

By JOHN B. WHEATLEY

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s² or 32.1740 ft./sec.²

m, Mass $=\frac{W}{g}$

I, Moment of inertia $=mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu.ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o}=\frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s. the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of *c.p.* from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_o, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Flight tests were made on a PCA-2 autogiro with wing settings of 2.2°, 0.9°, and −0.5°. The wing load and rotor speed were measured in steady glides. The results obtained show that a wide variation in rotor speed as a function of air speed can be obtained by a suitable adjustment of the wing setting; that by decreasing the wing setting the upper safe flying speed, determined by the decrease in rotor speed, is greatly increased; and that the interference of the wing on the rotor thrust and lift coefficients is negligible. The prediction of autogiro wing loads is assisted by the data given in this paper.

INTRODUCTION

During the flight tests on a PCA-2 autogiro (references 1 and 2) it was found that at an air speed of about 140 miles per hour the rotor speed decreased to a value (100 r. p. m.) that approached the lowest safe operating condition. A restrictive limit upon the safe diving speed of the machine was thus imposed and flight at high air speeds was made somewhat hazardous. An examination of the previously obtained information concerning the division of load between rotor and wing (reference 2) disclosed that the rotor was carrying only 60 percent of the weight at high speed, the remainder being carried by the fixed wing. This condition was thought to be the major cause of the decrease in rotor speed.

Although the trend of the design of modern small autogiros is toward the elimination of the fixed wing, in larger sizes it will probably remain to support the landing gear and possibly to increase the efficiency. The wing load is not easily predicted because there are no quantitative data on either rotor downwash or rotor-wing interference. The effects of successive changes in wing setting on the wing load and rotor speed were therefore determined. The wing setting was made adjustable on the ground by alterations in the wing-root fittings, and pressure-distribution measurements of the fixed wing loads at different wing settings were obtained in flight tests. The information obtained in these tests should be of material use in the prediction of the wing load and rotor speed of a given design. This paper presents the results of the tests conducted by the National Advisory Committee for Aeronautics at Langley Field, Va., in 1933 and 1934.

APPARATUS AND METHODS

The autogiro used in these tests was a standard Pitcairn PCA-2 (references 1 and 2) except that alterations were made in the wing-root fittings so that the angle of wing setting i_w, measured with reference to a plane perpendicular to the rotor axis, was adjustable on the ground. The fittings were modified in such a manner that wing settings of 2.2°, 0.9°, and −0.5° could be obtained.

The required measurements in flight were obtained by the standard N. A. C. A. photographic-recording instruments. The wing normal force on one wing panel was determined by pressure-distribution measurements; the other panel loads were not measured because in reference 2 it had been found that the two wing panel loads were very nearly equal. Dynamic pressure was measured by an air-speed recorder connected to a swiveling pitot-static head mounted on a boom projecting ahead of the fixed wing; recorded values were corrected by calibrating the installation against a trailing pitot-static head suspended beneath the machine. Attitude angle was recorded by a pendulum-type inclinometer, changes in static pressure by a recording statoscope, and rotor speed by visual observations of an electric tachometer driven by the rotor. The air density for each run was determined by a visual observation of the pressure altitude on an indicating altimeter and by observing ground temperature and assuming a temperature gradient of −3° F. per thousand feet of pressure altitude.

The flight tests consisted of a series of steady glides with the propeller stopped in a vertical position and with the successive wing settings of 2.2°, 0.9°, and −0.5°. During these tests the rotor speed and wing pressure distribution were measured; the rotor speed was obtained from a time history of rotor revolutions. As the data obtained on rotor speeds were inconsistent with existing data (reference 2) on a wing setting of 3.6°, it was decided to obtain rotor speeds from visual

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observations of an electric tachometer connected to the rotor and to use the rotor speeds so obtained in the test data instead of using the values obtained from the rotor counter. Auxiliary tests were made at wing settings of 2.2°, 0.9°, and −0.5° in which the air-speed head was calibrated against a trailing pitot-static head.

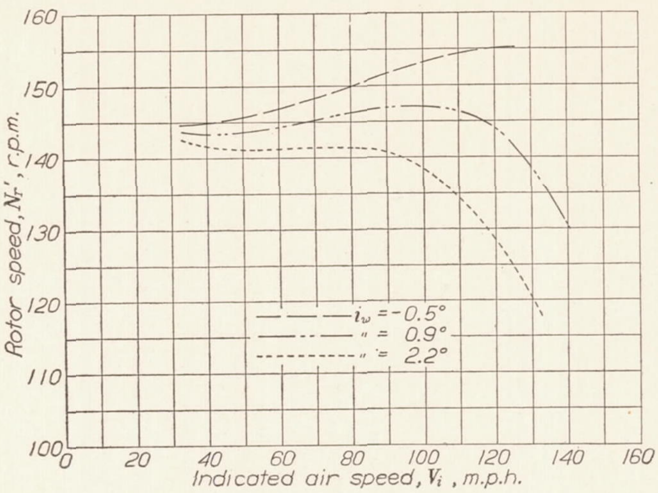

FIGURE 1.—Effect of wing setting on the rotor speed of a PCA-2 autogiro as a function of air speed.

RESULTS

Rotor speeds were corrected to a density of 0.00210 slug per cubic foot by the relation that the rotor speed varies inversely with the square root of the relative density. Figures 1 and 2 show the rotor speeds, obtained from the electric tachometer, plotted against indicated air speed and tip-speed ratio, respectively.

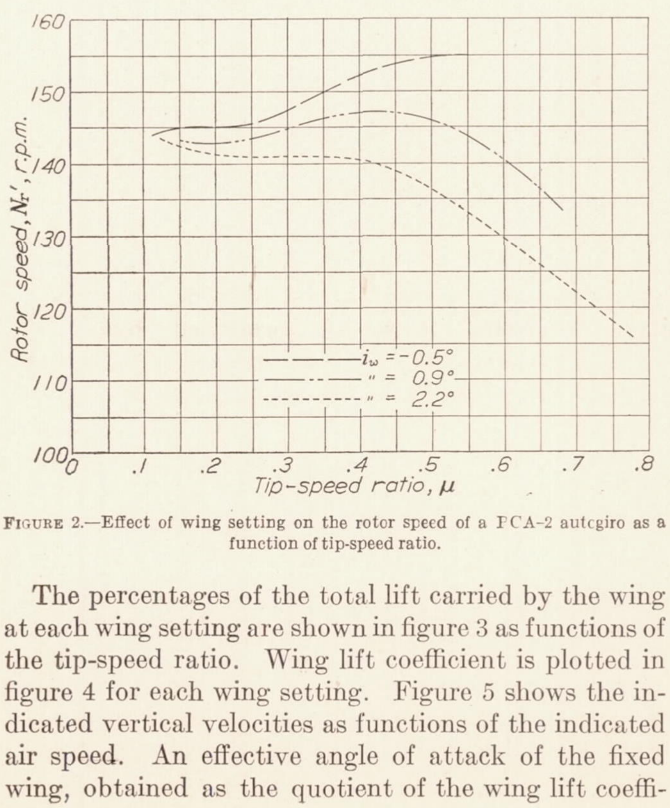

FIGURE 2.—Effect of wing setting on the rotor speed of a PCA-2 autogiro as a function of tip-speed ratio.

The percentages of the total lift carried by the wing at each wing setting are shown in figure 3 as functions of the tip-speed ratio. Wing lift coefficient is plotted in figure 4 for each wing setting. Figure 5 shows the indicated vertical velocities as functions of the indicated air speed. An effective angle of attack of the fixed wing, obtained as the quotient of the wing lift coefficient and the calculated wing lift-curve slope, is plotted in figure 6. The calculated lift-curve slope a_w was assumed to be the slope of a wing of the same aspect ratio and section, arbitrarily reduced by 5 percent to allow for wing-fuselage interference. The downwash at the wing, which was assumed to be the difference between the angle of the wing to the undisturbed air stream and this effective angle of attack, is shown in figure 7. The rotor lift and thrust coefficients are shown in figures 8 and 9, respectively, as functions of the tip-speed ratio. The rotor forces were calculated on the assumption that the load on the rotor was the total weight less the amount carried by the wing.

PRECISION

Accidental errors, as reflected in the dispersion of the experimental points, have no serious influence on the faired curves. The probable experimental error in the faired curves is estimated to be:

N_r'	±1 r. p. m.
V_i	±1 percent.
μ	±2 percent.
Wing loads	±3 percent.
C_{L_w} (below maximum C_{L_w})	±3 percent.
V_{V_i}	±5 percent.
C_T	±3 percent.
C_{L_r}	±3 percent.

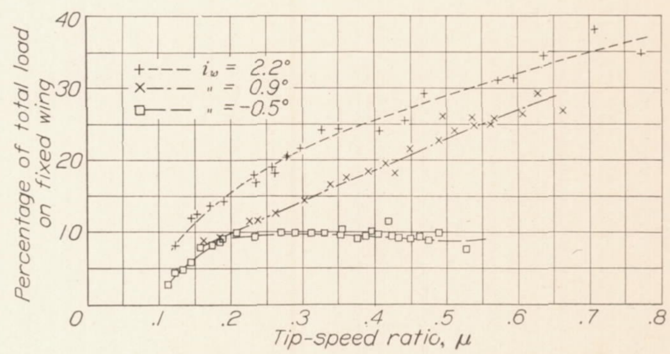

FIGURE 3.—Change of wing load of a PCA-2 autogiro with wing setting.

DISCUSSION

The data obtained in these tests were intended to supplement the information on wing loads contained in reference 2. A comparison of the data showed, however, that the wing load at a wing setting of 3.6° (reference 2) was actually smaller at some tip-speed ratios than the load obtained at a wing setting of 2.2°. This discrepancy can be partly explained by the differences in the test procedure and in the condition of the wing root. The tests in reference 2 were made with an idling propeller and with the wing root in its original condition; whereas the tests here reported were made with a stopped propeller, and with the wing root altered to permit the change in wing setting by the addition of a small fairing that slid up and down the side of the fuselage. The discrepancy in the wing-load results could have been caused by these two tests differences, since the form of the wing root and the air-flow conditions at that point are critical factors insofar as the wing lift coefficient is concerned.

The influence of wing setting upon rotor speed is clearly illustrated in figures 1 and 2. A change in the

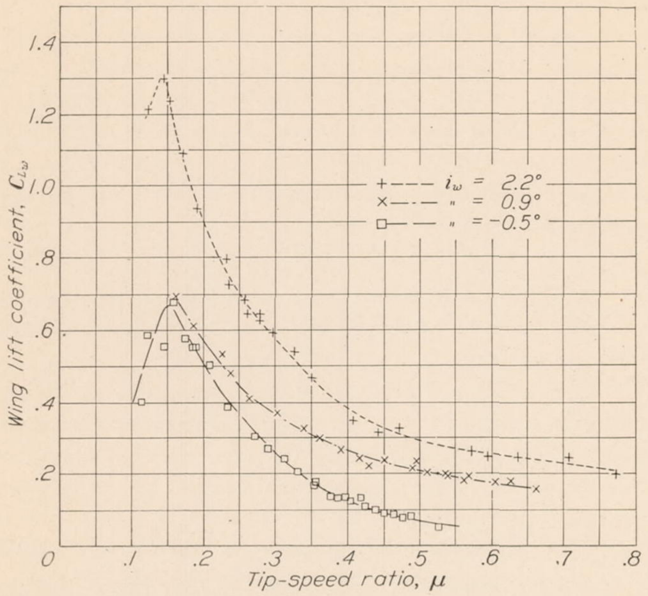

FIGURE 4.—Influence of wing setting on the wing lift coefficient of a PCA–2 autogiro.

wing setting from 2.2° to −0.5° resulted in a change in the rotor speed at 130 miles per hour from 120 r. p. m. to 155 r. p. m.; by extrapolation of the curves shown in figure 1 it can be seen that at −0.5° wing setting the rotor speed will be greater than 100 r. p. m. at 180 miles

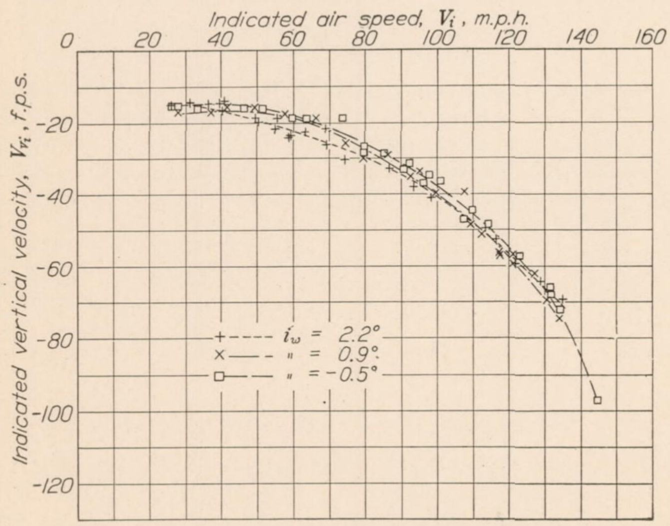

FIGURE 5.—Vertical velocity of a PCA–2 autogiro in a steady glide as affected by wing setting.

per hour. The value of 100 r. p. m. is assumed from experience to be the lowest safe operating speed.

A comparison of figure 3 with figure 2 establishes the correlation between wing load and rotor speed; successive decrements of the wing load are shown to correspond to successive and approximately proportional increments in the rotor speed.

The wing lift coefficient C_{L_w} shown in figure 4 varies in the expected manner with wing setting. The low values of maximum C_{L_w} for i_w=0.9° and −0.5° are

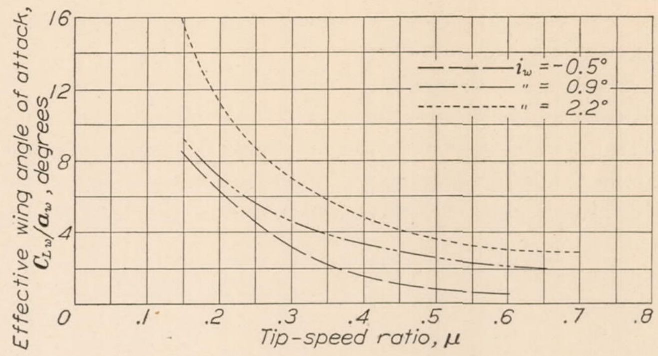

FIGURE 6.—Effective wing angles of attack of a PCA–2 autogiro.

thought unimportant. The angle of attack changes rapidly in the range where the maximum C_{L_w} occurs, and the number of points obtained in this range was

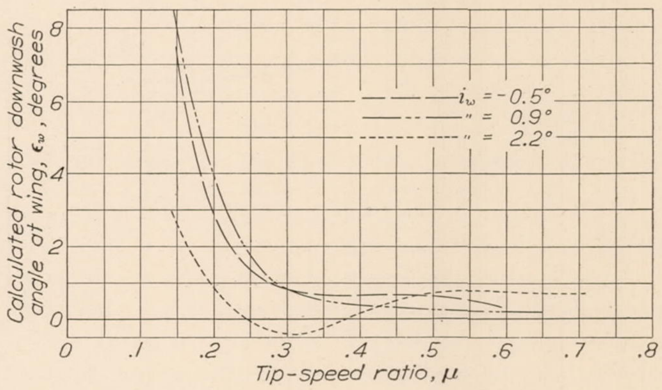

FIGURE 7.—Rotor downwash angles at wing of a PCA–2 autogiro.

probably insufficient definitely to determine the maximum lift in each condition.

Figure 5 discloses that the measurements of vertical velocity by the recording statoscope are, unfortunately,

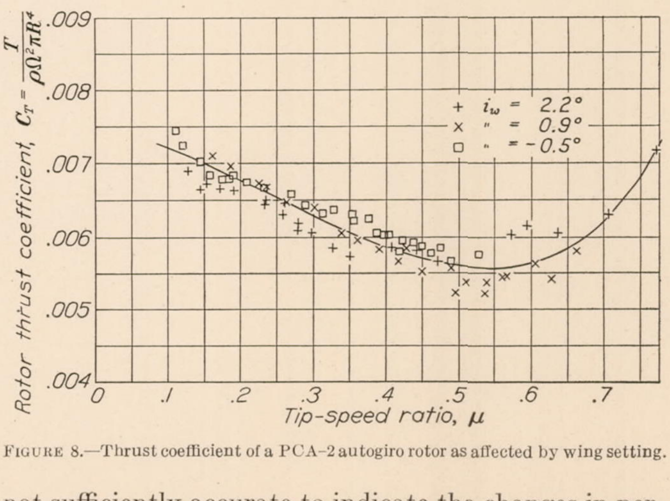

FIGURE 8.—Thrust coefficient of a PCA–2 autogiro rotor as affected by wing setting.

not sufficiently accurate to indicate the changes in performance caused by changing the wing setting. The wing would be expected to carry its load more efficiently than the rotor; consequently the performance of the autogiro should be affected adversely by shifting load from the wing to the rotor. This effect is, however, apparently smaller than the dispersion of the points on the vertical velocity curves and therefore cannot be evaluated.

The angles of attack of the wing shown in figure 6 are not entirely consistent with the changes in wing setting. The discrepancies are, however, small enough to be considered part of the experimental error, so that the results of the figure support the hypothesis that the change in the wing angle of attack is equal to the change in wing setting.

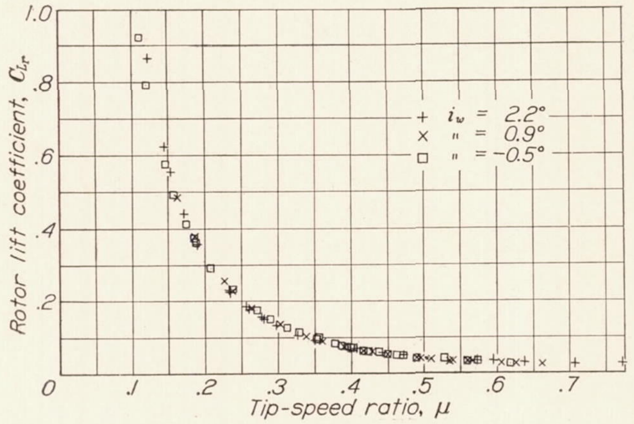

FIGURE 9.—Lift coefficient of a PCA-2 autogiro rotor as affected by wing setting.

In order that the results of these tests should be of general use, the rotor downwash angles have been calculated and are shown in figure 7. Identical curves should have been obtained for the three wing settings since the rotor lift coefficient at a given tip-speed ratio appears not to have been affected by the fixed wing. Results for the wing setting of 2.2°, however, are not in accord with those for the other two settings and are inconsistent in that they show a decreasing downwash angle with decreasing μ (increasing rotor lift coefficient) over a portion of the range covered. The correct curve is probably a weighted mean of the three curves shown.

Figures 8 and 9 are considered of interest because they establish the fact that the wing has, over a wide range, a negligible interference effect on the rotor within the limits of experimental error. It also appears that the scale of the rotor, considered proportional to the product of its tip speed and predominating chord, is large enough so that an increase in the scale of 35 percent (a change in N_r' from 118 r. p. m. to 155 r. p. m.) has no appreciable influence on its lift and thrust coefficients.

CONCLUSIONS

1. A wide variation of rotor speed as a function of air speed may be obtained by suitable adjustments of the wing setting.
2. It is possible by a suitable adjustment of the wing setting to increase the air speed at which the rotor speed of the PCA-2 autogiro becomes dangerously low (less than 100 r. p. m.) from 140 miles per hour to about 180 miles per hour.
3. The interference of the wing on the autogiro rotor is negligible insofar as the thrust and lift coefficients are concerned.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
LANGLEY FIELD, VA., *December 28, 1934.*

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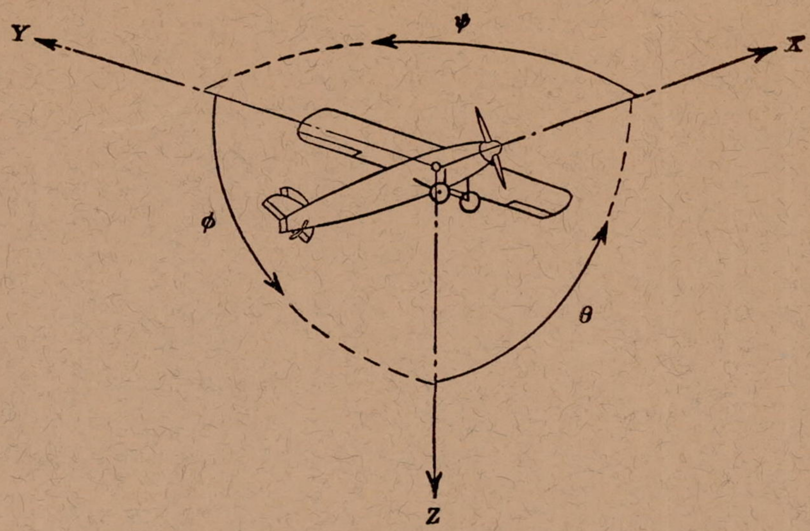

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Sym-bol		Designation	Sym-bol	Positive direction	Designa-tion	Sym-bol	Linear (compo-nent along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l = \frac{L}{qbS}$ (rolling) $C_m = \frac{M}{qcS}$ (pitching) $C_n = \frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

- D, Diameter
- p, Geometric pitch
- p/D, Pitch ratio
- V', Inflow velocity
- V_s, Slipstream velocity
- T, Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$
- Q, Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$
- P, Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$
- C_s, Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$
- η, Efficiency
- n, Revolutions per second, r.p.s.
- Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.
1 metric horsepower = 1.0132 hp.
1 m.p.h. = 0.4470 m.p.s.
1 m.p.s. = 2.2369 m.p.h

1 lb. = 0.4536 kg.
1 kg = 2.2046 lb.
1 mi. = 1,609.35 m = 5,280 ft.
1 m = 3.2808 ft.