NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 457

MANEUVERABILITY INVESTIGATION OF AN "O3U-1" OBSERVATION AIRPLANE

By F. L. THOMPSON and H. W. KIRSCHBAUM

1933

For sale by the Superintendent of Documents, Washington, D.C. - - - - - - - - - - - - - - Price 5 cents

AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp.
Speed		{km/h	k. p. h.	mi./hr.	m. p. h.
		{m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s^2 $= 32.1740$ ft./sec.^{2}

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

ρ, Density (mass per unit volume).

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

Specific weight of "standard" air, 1.2255 kg/m^3 $= 0.07651$ lb./ft.^{3}.

mk^2, Moment of inertia (indicate axis of the radius of gyration k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord.

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

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) 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 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;

or for a model of 10 cm chord 40 m/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.

REPORT No. 457

MANEUVERABILITY INVESTIGATION OF AN "O3U-1" OBSERVATION AIRPLANE

By F. L. THOMPSON and H. W. KIRSCHBAUM
Langley Memorial Aeronautical Laboratory

171586—33.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

(An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. Its membership was increased to 15 by act approved March 2, 1929 (Public, No. 908, 70th Congress). It consists of members who are appointed by the President, all of whom serve as such without compensation.)

REPORT No. 457

MANEUVERABILITY INVESTIGATION OF AN "O3U-1" OBSERVATION AIRPLANE

By F. L. Thompson and H. W. Kirschbaum

SUMMARY

This report presents the results obtained in maneuverability tests conducted by the National Advisory Committee for Aeronautics with an "O3U-1" observation airplane. This investigation is the third in a series of similar investigations requested by the Bureau of Aeronautics, Navy Department, for the purpose of comparing the maneuverability of different airplane types and to provide quantitative data for use in establishing a criterion or method for rating the maneuverability of any airplane. The two former investigations were conducted with the fighter types designated "F6C-3" and "F6C-4" and have been reported previously.

Measurements of the air speed, the angular velocity, the linear acceleration, and the positions of the controls were made during abrupt single-control maneuvers with three stop positions for each control, during steady horizontal turns for the determination of minimum radius, and during 180° turns by various methods. Flight-path coordinates in two dimensions were determined for the 180° turns by means of a special camera obscura designed for the previous investigation of the "F6C-4" airplane. All maneuvers were performed at an altitude of approximately 3,000 feet.

The results of the abrupt single-control maneuvers are presented by curves showing the variation of the measured quantities with respect to air speed and control movement. The results of the 180° turns are shown by time histories of the measured quantities for one maneuver of each type and by a table giving principal flight-path dimensions, altitude change, speed change, time required for completion, and maximum values of recorded quantities for all turns. The minimum radius of turn for steady horizontal flight at an altitude of 3,000 feet was found to be 322 feet at 74 miles per hour as compared with 155 feet at 76 miles per hour and 135 feet at 62 miles per hour for the "F6C-3" and "F6C-4" airplanes, respectively.

INTRODUCTION

A series of three investigations of the maneuverability of military airplanes has been conducted by the National Advisory Committee for Aeronautics at the request of the Bureau of Aeronautics, Navy Department. The results of the first two of these investigations pertain to the single-seat fighter airplanes, *F6C-3* and *F6C-4*, and are given in references 1 and 2. The results of the third investigation, which was conducted on an *O3U-1* observation airplane, are presented herein. These investigations have been made for the purpose of obtaining data that will facilitate the rating of military airplanes according to their maneuvering qualities.

The general procedure followed in this investigation was similar to that used in the two previous ones. Maneuvers were chosen so as to show as well as possible the separate and combined effectiveness of various elements that influence the ability of the airplane to maneuver. The maneuvers chosen can be divided into three principal groups: Abrupt single-control maneuvers, 180° turns by various methods, and steady horizontal turns for the determination of minimum radius of turn. Recording instruments within the airplane were used to determine air speed, linear acceleration, angular velocity, and position of controls. Angular accelerations were deduced from angular-velocity records. A camera obscura on the ground was used to record flight paths during 180° turns. Various items pertaining to the performance of the airplane were determined in a series of preliminary tests.

The tests with this airplane complete the contemplated series of investigations. The data obtained from the complete series of tests are now being studied for the purpose of developing a satisfactory criterion or method of rating airplanes according to their ability to maneuver. This study has not been completed and will be reported at a later date.

APPARATUS AND METHODS

APPARATUS

In this investigation tests were made on an *O3U-1* airplane (fig. 1) equipped with a 450-hp. air-cooled engine. The principal specifications pertaining to the dimensions and arrangement of this airplane are shown in the appendix. The gross weight for the tests was 4,055 pounds and the center of gravity was located 16.54 inches back of the leading edge of the lower wing. This weight and center-of-gravity location correspond to the conditions specified for the normal full load. The ailerons on this airplane have a differential movement as shown in figure 2.

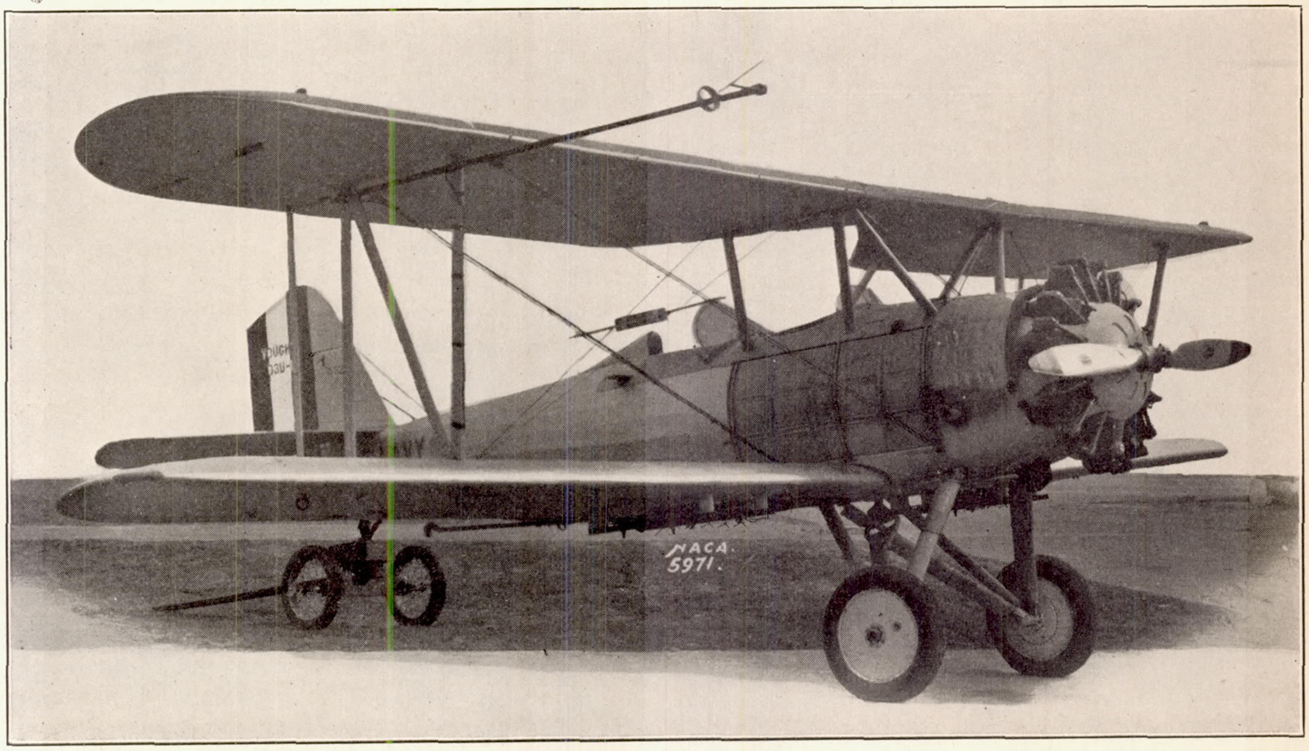


FIGURE 1.—The *O3U-1* airplane.

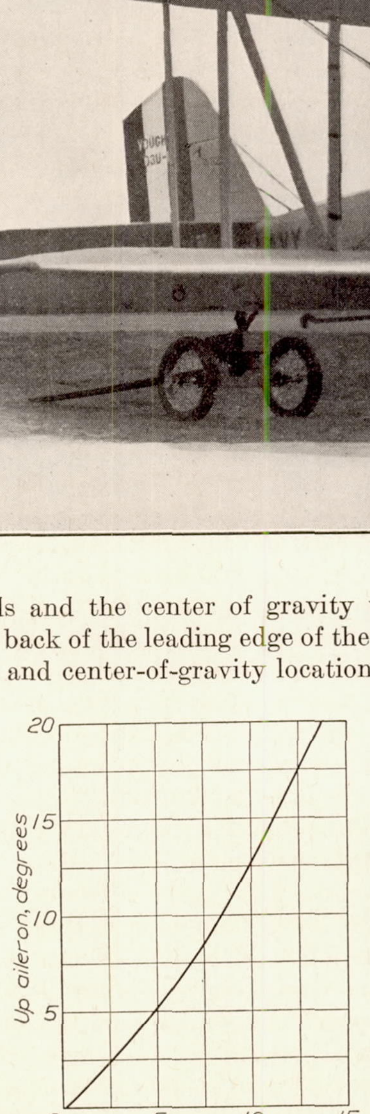


FIGURE 2.—Differential aileron action on *O3U-1* airplane.

The recording instruments in the airplane consisted of a control-position recorder (reference 3), three angular-velocity recorders (reference 4), a 3-component accelerometer (reference 5), an inclinometer, and a performance recorder containing an air-speed unit (reference 6) and an aneroid unit. All these instruments give continuous photographic records. An electrically driven timer was used in conjunction with these instruments to synchronize the records.

The accelerometer was located in the rear cockpit as near to the center of gravity as possible. The control-position recorder was connected to the three controls in the front cockpit. The air-speed recorder was connected to the swiveling pitot-static head mounted on a boom extending forward 1.1 chord lengths from the upper wing (fig. 1) to eliminate the errors caused by interference. A liquid-in-glass thermometer was mounted on the interplane wires to permit observation of air temperatures during flight.

As previously mentioned, a camera obscura was used to record flight paths during 180° turns. This apparatus and its accessories are described and illustrated in reference 2.

A system of one-way radiotelephone communication from the ground to the airplane was used in conjunction with the camera obscura to coordinate flight and ground operations. The microphone was located near the camera for use by a ground observer. An aircraft radio receiver designated "Type BC-SA-167" by the

Signal Corps, United States Army, was installed in the airplane.

METHOD

Preliminary tests.—Preliminary tests were made with the airplane in the full-scale wind tunnel and in flight. The data obtained in these tests served several purposes but particularly permitted the calculation of the minimum radius of turn. In the wind-tunnel tests the propeller-thrust curve was determined with the airplane at 0° angle of attack. In the flight tests several level runs and full-throttle climbs were made from which numerous data were obtained. A calibration of the swiveling air-speed head was determined by obtaining simultaneous records of the air speed indicated by this head and that indicated by another head suspended 60 feet below the airplane. The angle of attack for the level runs was obtained from records of the attitude of the airplane. The air temperature and engine speed were noted and the barometric pressure of the air recorded so that the true air speed and thrust horsepower could be computed. The level runs were made at an air density corresponding approximately to a standard altitude of 3,000 feet ($\rho/\rho_0=0.915$) and the climb data were obtained at about the same density. An additional item obtained during the preliminary tests was the stabilizer position required for balance with zero stick force at each speed, hence at each angle of attack.

From the wind-tunnel and flight data, lift and drag characteristics for the power-on condition and curves of horsepower required and horsepower available at a standard altitude of 3,000 feet were computed. When making these computations it was assumed that the thrust was directed along the thrust axis and that the thrust coefficients were not influenced by the angle of attack. The computations involved in determining the desired quantities are as follows:

For level flight

$$C_L=\frac{2(W-T\sin\alpha_T)}{\rho SV^2} \qquad (1)$$

and

$$C_D=\frac{2T\cos\alpha_T}{\rho SV^2} \qquad (2)$$

where W is the weight of the airplane

$T=C_T\rho n^2D^4$ is the effective thrust

α_T is the angle of attack of the thrust line, and the other symbols have their usual significance. For a given flight condition the thrust coefficient C_T was found from the observed V/nD and the thrust curve obtained from the wind tunnel.

Although all the preliminary flights were made at approximately the same air density, there was sufficient variation in the test conditions to influence appreciably the calculated values of horsepower required and horsepower available. Consequently, the procedure followed in finding the horsepower curves for the altitude of 3,000 feet entailed corrections necessary to reduce observed results to the common altitude. The forms of expressions used in finding horsepower were:

$$\text{hp}_{\cdot\text{reqd}}=\frac{\text{drag}\times V}{550\cos\alpha_T}\text{ (level flight)} \qquad (3)$$

and

$$\text{hp}_{\cdot\text{avail}}=\frac{TV}{550}\text{ (full-throttle climbs)} \qquad (4)$$

The flight data for the level runs give the lift and drag coefficients and angle of attack for a given velocity at the air density of the flight. The lift coefficient required for flight at the same velocity and at the desired standard density was found from the relation

$$C_L'=C_L\frac{\rho}{\rho'} \quad \text{(the prime refers to the value at the required standard altitude)} \qquad (5)$$

and the corresponding angle of attack was found from the lift-coefficient curve. The drag coefficient corresponding to this required angle of attack was then found and the horsepower required calculated by means of the expression

$$\text{hp}_{\cdot\text{reqd}}=\frac{C_D'\rho' V^3S}{1{,}100\cos\alpha_T'} \qquad (6)$$

The corrections to thrust horsepower available were made in accordance with the average variations with altitude given by Diehl in reference 7.

Principal tests.—The flight program of the principal tests included single-control maneuvers requiring the abrupt use of elevator, ailerons, and rudder; 180° turns in vertical and horizontal planes; some special slow rolls; and steady horizontal turns for the determination of minimum radius of turn. The tests were performed in an air density corresponding approximately to that at a standard altitude of 3,000 feet and, in general, were started from steady level flight at various speeds with the stabilizer adjusted for zero stick force. As the procedure during the tests was essentially the same as that described in references 1 and 2, it will be described very briefly herein.

The single-control maneuvers, except those involving the ailerons, were made at various indicated air speeds up to the maximum level-flight indicated air speed of 124 miles per hour. A limit of 97 miles per hour was placed on the speed for abrupt aileron maneuvers to prevent undue stress of the airplane. The single control involved in each test was moved as quickly as possible and great care was taken to prevent the movement of any other control during the initial stage of the subsequent motion. Tests were made with the normal full movement and with two intermediate stop positions for each control, corresponding roughly to one half and three fourths of the full movement. The control movements were as follows: Elevator up 30.3°, 22.6°, and 18.0°; left aileron down 13.0°, 10.4°, and 6.4°; rudder right 27.0°, 19.5°, and

13.9°. A test for each condition was performed by each of two pilots.

The various types of 180° turns are classified as wing-over, horizontal turn, half aileron roll—half loop, half kick roll—half loop, and Immelman turn. The maneuvers were performed in the field of the camera obscura so that the flight paths could be recorded. When it was possible to do so, the maneuvers were started from various speeds up to the maximum indicated air speed of 124 miles per hour. For the Immelman turn the starting speed was raised to 132 miles per hour by diving slightly at the start. Several special slow rolls were made in which the pilot attempted to produce rotation solely about the X axis. After many attempts the desired motion was approximately attained. The steady horizontal turns used to determine the minimum radius of turn were started with full throttle and gradually tightened up until the desired air speed was attained without changing the throttle. Records were taken after steady conditions were attained at this air speed. This procedure was repeated for several speeds in the lower part of the normal speed range. In each case the stabilizer was set for high-speed level-flight balance.

Values of control position, angular velocity, and linear accelerations were obtained directly from the instrument records. Angular accelerations were derived from the recorded angular velocity by graphical differentiation. True air speed was derived from the air-speed records, barometric-pressure records, and observed temperature. Flight paths for the 180° turns were determined from the camera-obscura records in accordance with the method described in reference 2.

PRECISION

Lag in the angular-velocity recorders influenced the records obtained by these instruments considerably in the abrupt single-control maneuvers. Lag tests were made with these instruments and the results were used in applying corrections to the flight data. The validity of the corrections is not entirely assured, however, so that the angular accelerations obtained from the flight records are not regarded as satisfactorily precise except as regards their use in indicating similarity or difference in the manner in which the controls were applied by the two pilots in the abrupt single-control maneuvers. The precision of the various measurements is estimated to lie within the following limits:

Linear accelerations,	±0.05 g
Air speed,	±2 percent
Control position,	±1°
Angular velocities,	±2 percent for fairly steady motion
Angular velocities,	±7 percent for maximum values in abrupt maneuvers
Flight-path dimensions,	±4 per cent

RESULTS

PRELIMINARY TESTS

The results of the preliminary tests are shown in figures 3 to 7, inclusive. The variations of stabilizer position with indicated air speed (fig. 3) can be used in determining the stabilizer setting during each maneuver performed in the principal tests by reference to the indicated air speed at which the maneuver was performed. In a similar manner the curves in figure 4 indicate the initial angle of attack and propeller speed in each maneuver. The effective thrust coefficients shown in figure 5 were used in a manner previously described for the calculation of forces during steady turns and in determining the lift, drag, and horsepower curves shown in figures 6 and 7. Attention is called to the fact that the lift and drag characteristics pertain to the power-on condition rather than the power-off condition as would be obtained in glide tests. The lines of constant angle of attack on the horsepower curves are utilized in calculations described later regarding the minimum radius of turn.

SINGLE-CONTROL MANEUVERS

Elevator maneuvers.—The data obtained in abrupt pull-ups are shown in figures 8, 9, and 10 where maximum normal acceleration, maximum pitching velocity, and maximum pitching acceleration are plotted against initial indicated air speed. Noteworthy features of the results for full elevator movement are that the values for normal accelerations are not proportional to the second power of the velocity, that the curves of maximum pitching velocity flatten at high speed, and that the flattening is different for the two pilots. These peculiarities are attributed chiefly to the large force required to operate the elevators. A study of the records obtained in these pull-ups shows that the time required to operate the elevators increased with speed and was such as to permit a considerable decrease in air speed during the period required to operate the elevators. The decrease in air speed permitted the maximum normal accelerations to attain smaller values than would have occurred if the change in angle of attack could have been accomplished rapidly. In this connection it should be mentioned that in the tests reported in references 1 and 2 the normal accelerations were found to vary as the second power of the initial air speed. The difference in the curves of maximum pitching velocity attained by the two pilots is attributed to the fact that Pilot A did not actually attain the nominal full elevator movement at high speeds and utilized rather more time during the latter stage of the elevator movement than did Pilot B. Differences in piloting are also reflected in the difference between the curves of maximum pitching accelerations for the same nominal control movement.

The average effect of elevator movement on maximum pitching velocity and acceleration is shown in figure 11 for three indicated air speeds. These curves

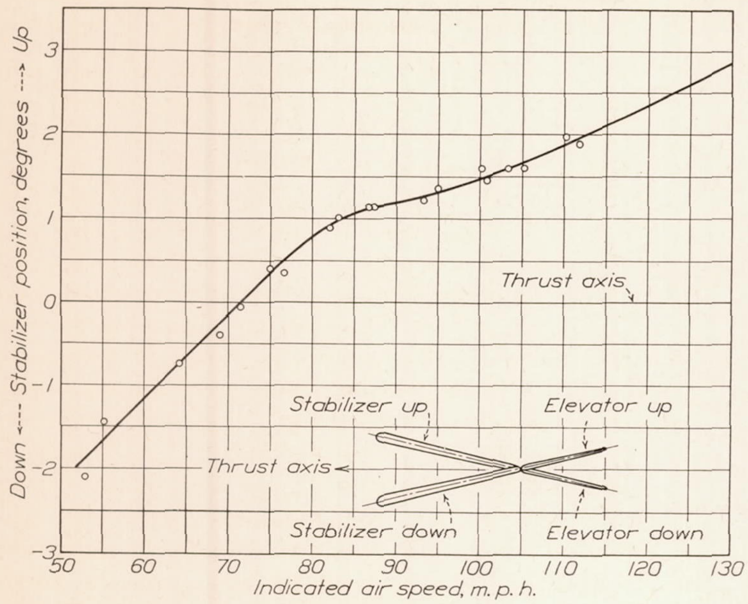


FIGURE 3.—Stabilizer setting for zero stick force in steady level flight (*O3U-1* airplane).

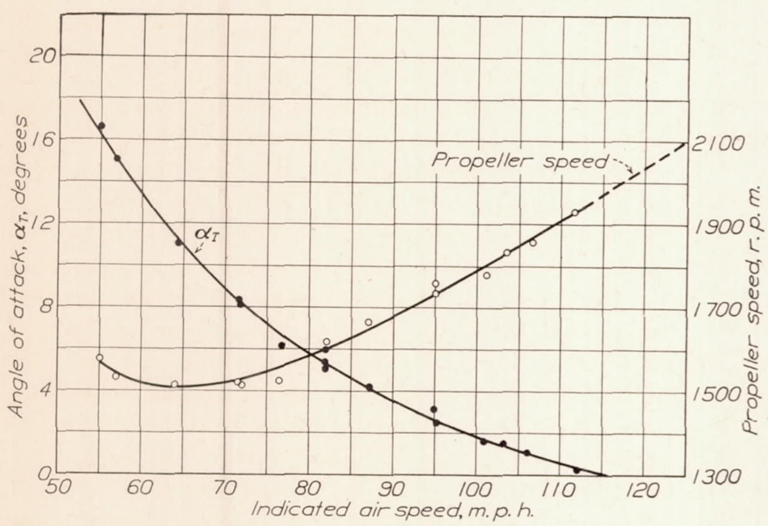


FIGURE 4.—Variation of angle of attack and propeller speed with indicated air speed for steady level flight at altitude of 3,000 feet (*O3U-1* airplane).

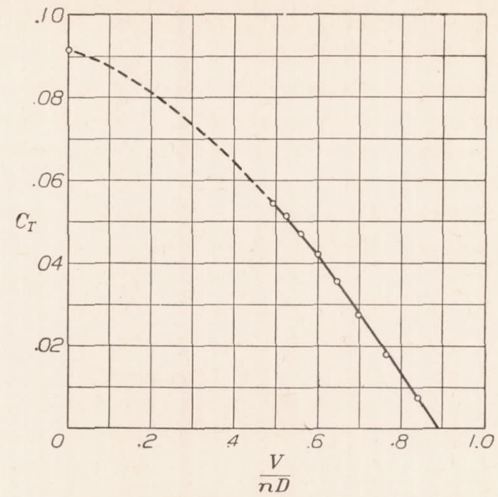


FIGURE 5.—Effective thrust coefficients for *O3U-1* airplane at zero angle of attack.

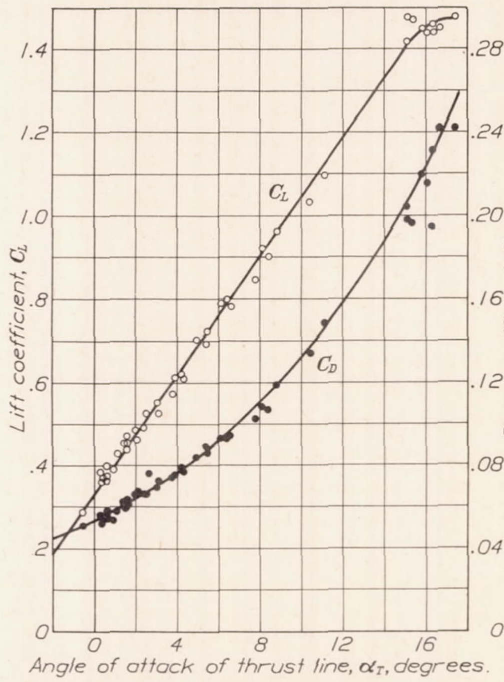


FIGURE 6.—Lift and drag coefficients calculated from level-flight data (*O3U-1* airplane).

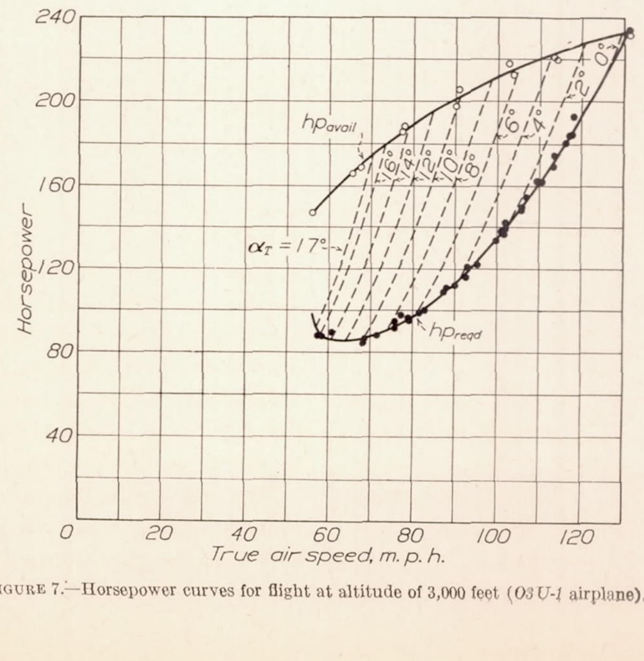


FIGURE 7.—Horsepower curves for flight at altitude of 3,000 feet (*O3U-1* airplane).

were obtained from the average curves of the preceding figures. The slopes of these curves show that increasing the elevator movement would increase the elevator effectiveness during the initial stage of the rotation, but that the final rate of rotation would not be appreciably increased.

Aileron maneuvers.—The data obtained in the tests involving abrupt aileron movements are shown in rapidity than did Pilot B. As this difference exists in spite of repeated attempts by Pilot B to obtain values equaling those obtained by Pilot A, the values obtained by Pilot A should probably be regarded as exceptional. Thus, as in the case of the elevator maneuvers, the force required to operate the controls apparently had some influence on the maneuver. In this case, however, the maximum angular velocities

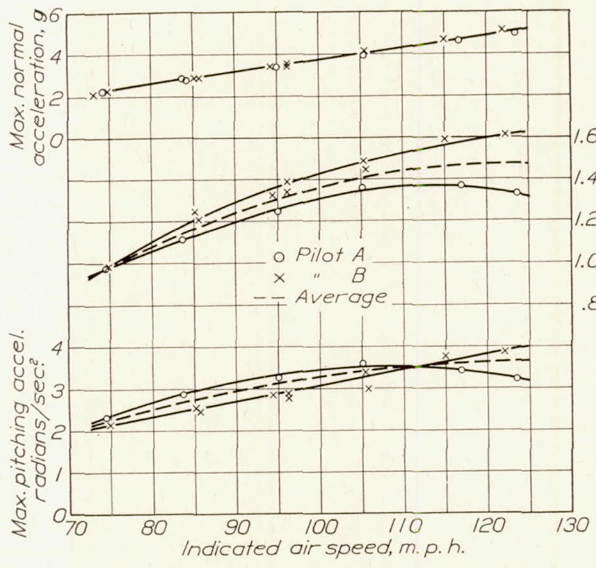


FIGURE 8.—Maximum values of normal acceleration, pitching velocity, and pitching acceleration for abrupt pull-ups with 30.3° (full) elevator movement (*O3U-1* airplane).

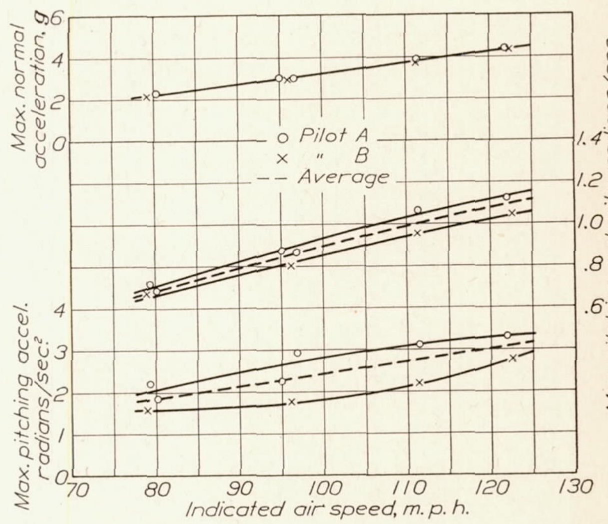


FIGURE 10.—Maximum values of normal acceleration, pitching velocity, and pitching acceleration for abrupt pull-ups with 18.0° elevator movement (*O3U-1* airplane).

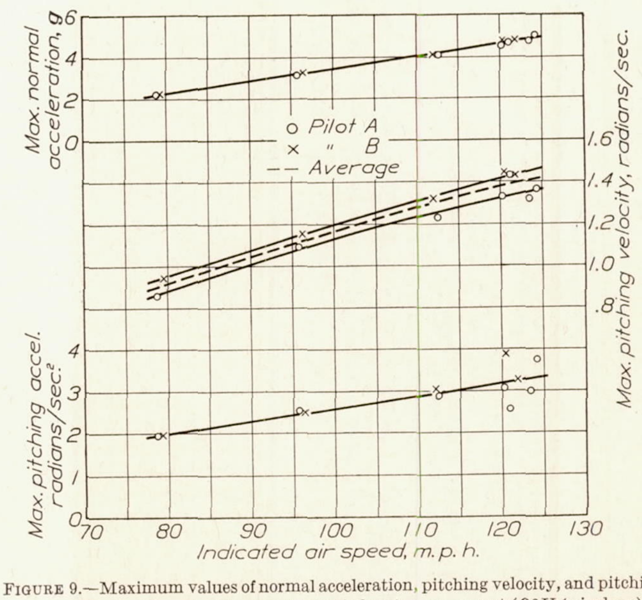


FIGURE 9.—Maximum values of normal acceleration, pitching velocity, and pitching acceleration for abrupt pull-ups with 22.6° elevator movement (*O3U-1* airplane).

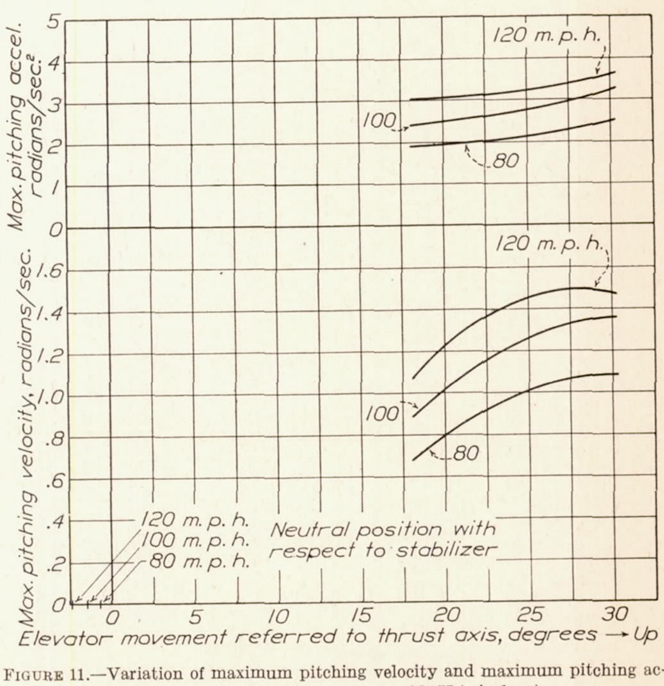


FIGURE 11.—Variation of maximum pitching velocity and maximum pitching acceleration with elevator movement (*O3U-1* airplane).

figures 12, 13, and 14 where maximum rolling velocity and acceleration are plotted against indicated air speed. The difference between the maximum rolling accelerations attained by the two pilots with full aileron movement indicates that Pilot A exerted a greater stick force and thereby moved the ailerons with greater show no consistent differences. As the period during which the high acceleration acts is very short the large stick force in this case apparently has no appreciable influence on the pilot's ability to roll the airplane. The large force required may be important, however, in complicated maneuvers where the pilot is unable to concentrate his energy on the operation of the ailerons.

The curves in figure 15 show maximum rolling velocity and acceleration against aileron movement. The values of acceleration for full movement were taken from the results obtained by Pilot B, as those obtained by Pilot A are considered to be exceptional. The positive slope of all the curves in this figure indicates that the effectiveness of the aileron will be increased by increasing the movement.

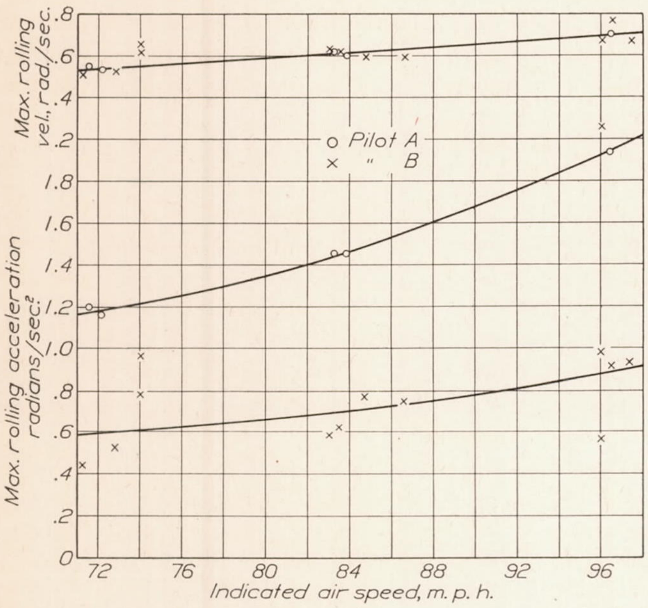


FIGURE 12.—Maximum values of rolling velocity and acceleration for abrupt aileron movement, left aileron down 13.0°, full movement (*O3U-1* airplane).

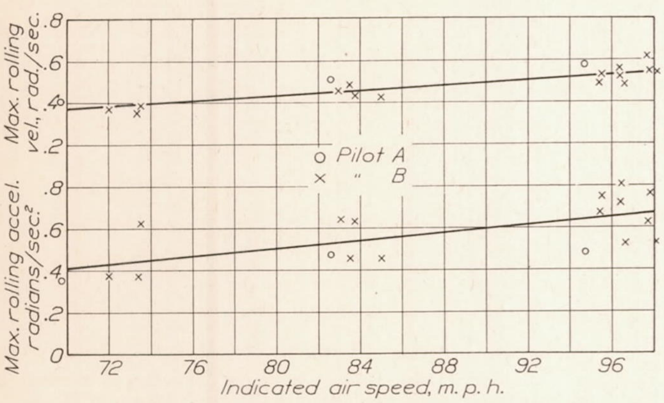


FIGURE 13.—Maximum values of rolling velocity and acceleration for abrupt aileron movement, left aileron down 10.4° (*O3U-1* airplane).

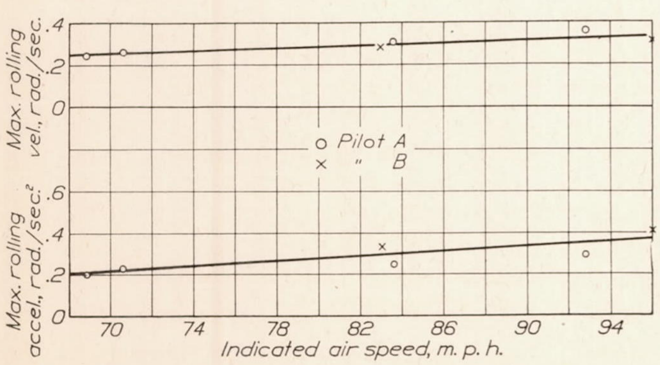


FIGURE 14.—Maximum values of rolling velocity and acceleration for abrupt aileron movement, left aileron down 6.4° (*O3U-1* airplane).

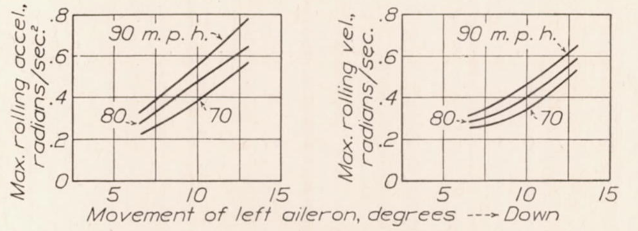


FIGURE 15.—Variation of maximum rolling velocity and maximum rolling acceleration with aileron movement (*O3U-1* airplane).

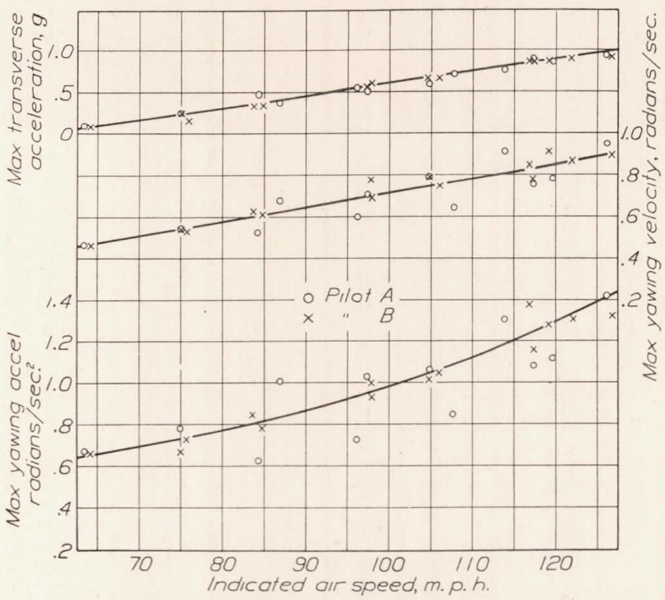


FIGURE 16.—Maximum values of transverse acceleration, yawing velocity, and yawing acceleration for abrupt rudder movement, right 27.0°, full movement (*O3U-1* airplane).

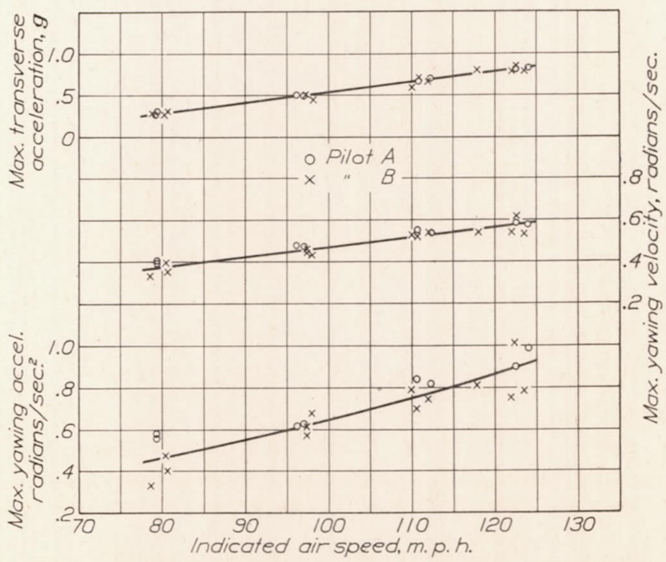


FIGURE 17.—Maximum values of transverse acceleration, yawing velocity, and yawing acceleration for abrupt rudder movement, right 19.5° (*O3U-1* airplane).

Rudder maneuvers.—Maximum values of transverse acceleration, yawing velocity, and yawing acceleration obtained in the maneuvers involving the abrupt use of the rudder are shown in figures 16, 17, and 18. In contrast to the results obtained with the two other controls, there is no evidence of a consistent difference due to difference in piloting. The curves of figure 19

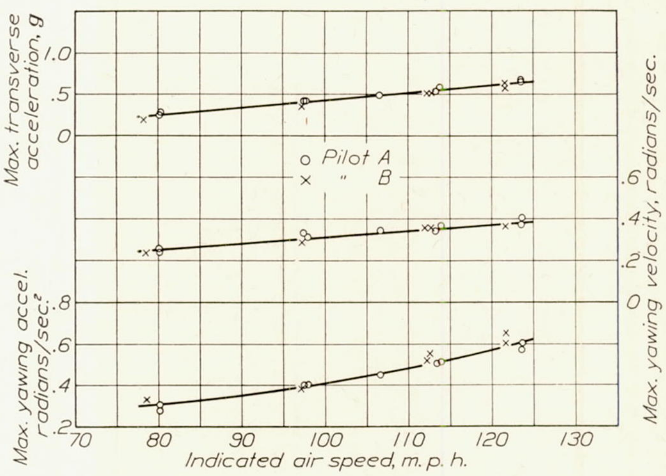


FIGURE 18.—Maximum values of transverse acceleration, yawing velocity, and yawing acceleration for abrupt rudder movement, right 13.9° (*O3 U-1* airplane).

showing the variation of maximum yawing velocity and acceleration with control movement indicate a practically constant increase of rudder effectiveness with increased movement.

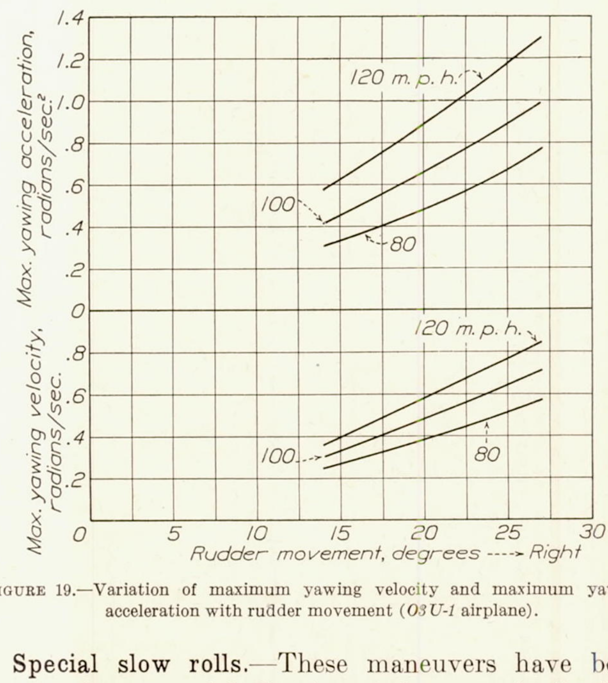


FIGURE 19.—Variation of maximum yawing velocity and maximum yawing acceleration with rudder movement (*O3 U-1* airplane).

Special slow rolls.—These maneuvers have been regarded as a good indication of the control effectiveness. It was concluded, however, that the performance of these maneuvers is so closely related to the pilot's skill that the results are of small value where quantitative data are required. The results obtained in one of these maneuvers are shown in figure 20. These results illustrate the most nearly successful attempt to produce rotation solely about the X axis.

Turns of 180°.—The results for the 180° turns are shown principally in table I. Time histories of data obtained in each type of turn are given in figures 21 to 25, inclusive. The data shown in these figures are representative of each type of maneuver. Table I gives a complete summary of significant quantities determined in these maneuvers. The flight-path dimensions given in this table apply to the projection of the flight path in either a vertical or horizontal plane. The wing-over is regarded as a horizontal-plane maneuver in which there is no resultant change of altitude. Data from the horizontal-plane maneuvers in which the airplane did not return to approximately the initial altitude were excluded. The Immelman turn, the half kick roll—half loop, and the half aileron roll—half loop are regarded as vertical-plane maneuvers although the actual motion was not strictly limited to a vertical plane. The maneuvers were regarded as complete when the starting point had been passed after reversing the direction of flight. In several cases the flight-path records were terminated slightly before completion of maneuvers. The extrapolation of the flight paths to determine the time required for completion in those cases results in no appreciable error.

The relative merits of the various maneuvers can be judged by a comparison of the data given in table I. Owing to the violence of the half kick roll—half loop, this maneuver was not performed at speeds greater than 102 miles per hour, but for the range of speed in which it was performed it required the least time for completion, the time being about 10 seconds. The time required to complete the horizontal turns decreased rapidly with increased speed until at 123 miles per hour, the time required was only 8.3 seconds. The wing-over turns required the greatest time for completion, the time being about 21 seconds at all speeds. The least horizontal displacement required for turning was about 500 feet and occurred in the half kick roll—half loop at 84 miles per hour and the horizontal turn at 123 miles per hour. The greatest horizontal displacement required was 1,390 feet and occurred in the half aileron roll—half loop at 117 miles per hour. As previously noted, the Immelman turn was performed with a slight initial dive to gain speed for the performance of the maneuver. The speeds that have been tabulated for the above cases are indicated air speeds and are about 4 percent less than the true air speeds.

Steady horizontal turns.—The results of the tests to determine the minimum radius of steady horizontal turn are shown in figure 26. Experimental points obtained from the same tests by two methods of calculation are given. The most direct method involved

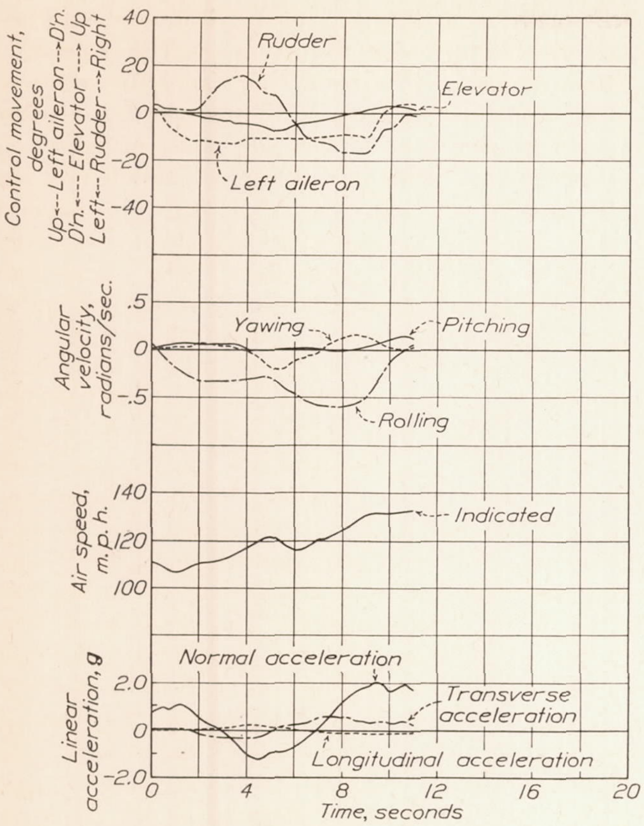


FIGURE 20.—Slow roll, attempting roll about *X* axis only (*O3U-1* airplane).

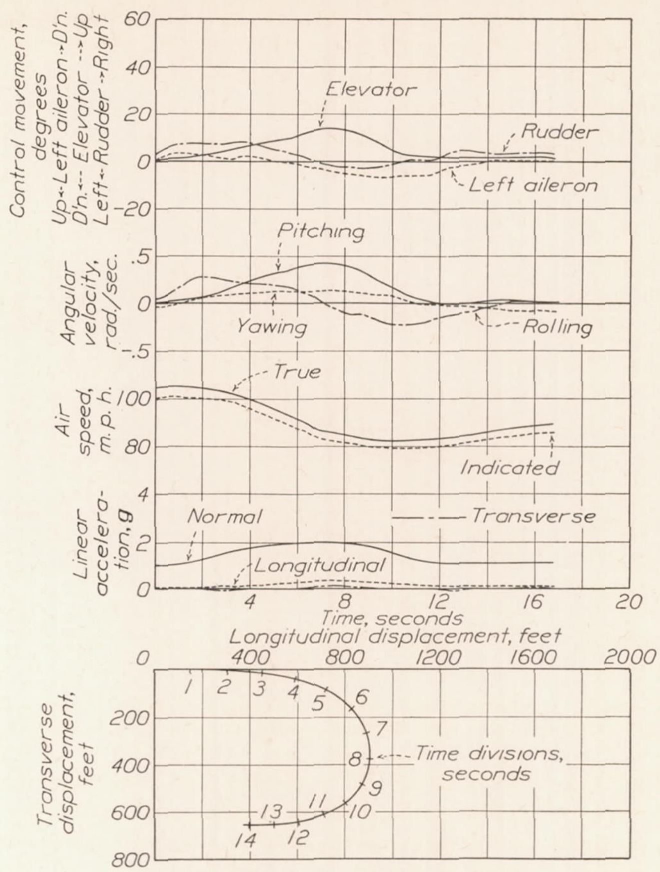


FIGURE 22.—Horizontal turn (*O3U-1* airplane).

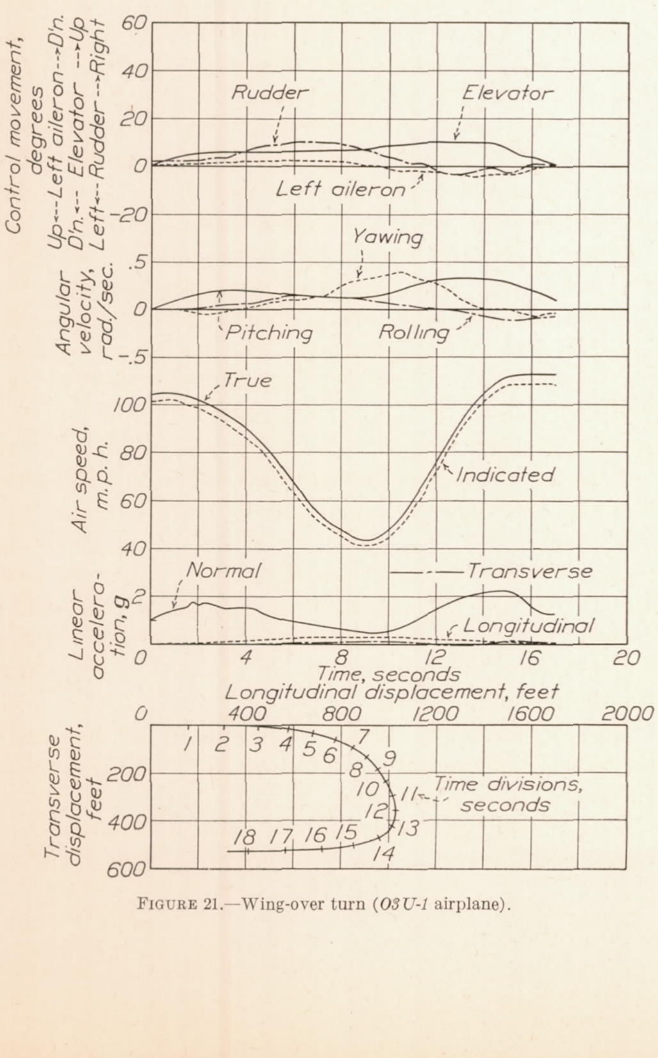


FIGURE 21.—Wing-over turn (*O3U-1* airplane).

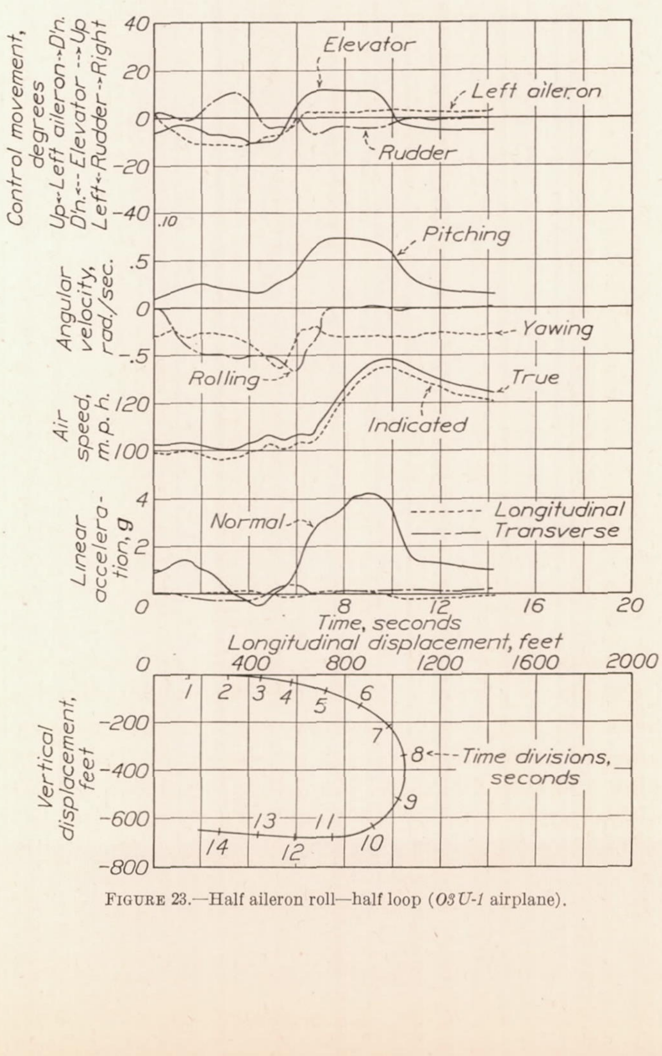


FIGURE 23.—Half aileron roll—half loop (*O3U-1* airplane).

only the recorded air speed and acceleration, from which the radii were calculated by means of the equation

$$r=\frac{V^2}{(a_R^{\,2}-g^2)^{1/2}} \tag{7}$$

where r is the radius of turn

a_R, the resultant accelerometer reading

V, the true air speed.

The results obtained by this method were erratic, possibly because the airplane was traveling in its own wake.

For the second method the data required from the steady turns were air speed and corresponding engine speed. The thrust was calculated by means of these flight data and the thrust curve of figure 5. The angle

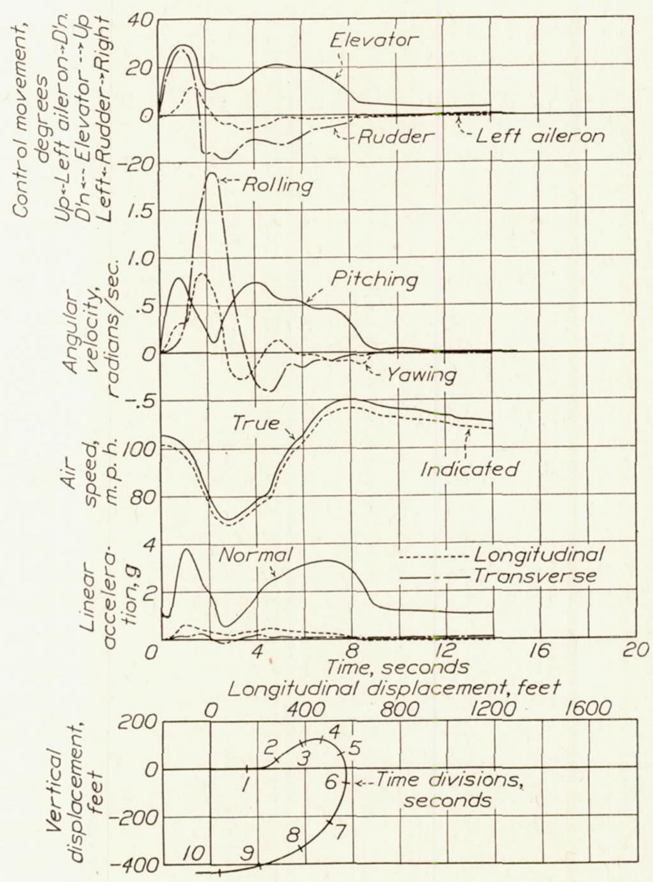


FIGURE 24.—Half kick roll—half loop (*O3U-1* airplane).

of attack and corresponding lift coefficient were then found by utilizing first and second approximate solutions of equation (2) and the curves of figure 6. The resultant acceleration was calculated by means of the expression

$$a_R=\frac{g(C_L\rho SV^2+2T\sin\alpha_T)}{2W} \tag{8}$$

and r was found from equation (7). The values obtained by this method lie close to a smooth curve that represents fairly well an average of the points obtained by the previous method. This curve shows the minimum radius of turn to be 322 feet at 74 miles per hour.

The usual method of calculating minimum radius of turn where flight data are not available is to use curves of horsepower available and required. (See reference 8, p. 217.) This method utilizes the expression

$$r=\frac{V^2}{g\tan\theta} \tag{9}$$

where θ is the angle of bank, given by the expression

$$\theta=\cos^{-1}\left(\frac{Vl}{V}\right)^2 \tag{10}$$

and V_l/V is the ratio of the speed in level flight to the speed in a steady turn at the same angle of attack.

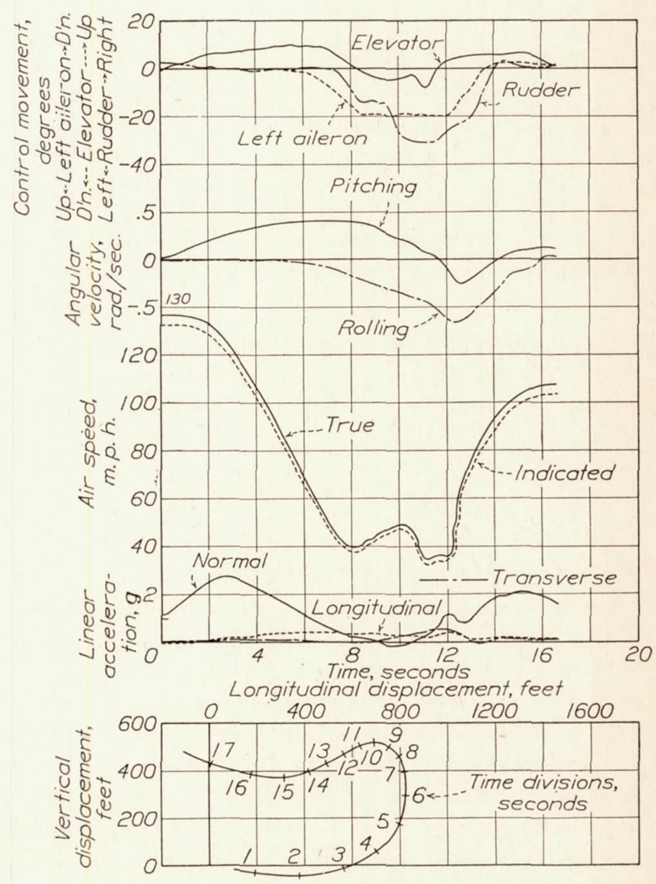


FIGURE 25.—Immelman turn (*O3U-1* airplane).

Radii calculated by this method using the horsepower curves of figure 7 are shown by the broken curve in figure 26. The corresponding values of V and V_l are found from the curves of horsepower required and horsepower available by having these curves intersected by other curves representing the variation of horsepower required with speed at constant angles of attack, that is, at constant drag coefficients. Such curves for various angles of attack are shown by dotted lines in figure 7. The results obtained by this method give a minimum radius of 295 feet, which is about 8 percent less than the probably more nearly correct value shown by the previous curve and which lies within the region covered by the scattered points obtained by the most direct method. Consideration of the change of horsepower required and horsepower available with altitude indicates that the minimum radius at sea level would be about 18 percent less than the value at 3,000 feet.

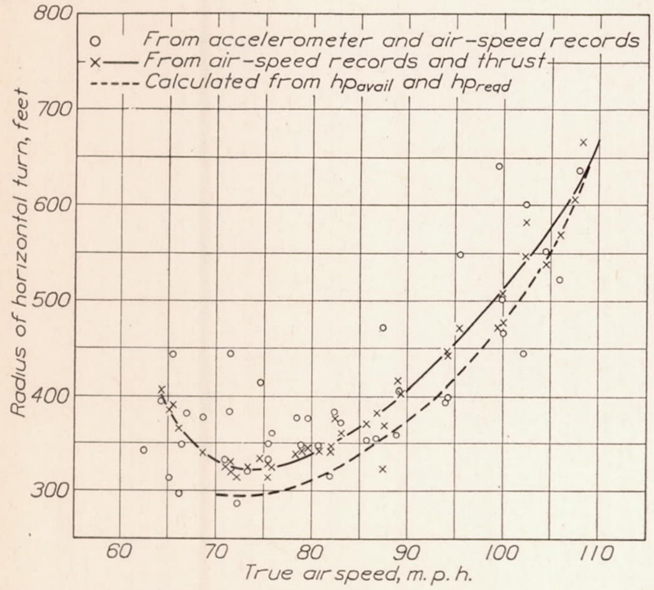


FIGURE 26.—Radius of steady horizontal turn with full throttle at altitude of 3,000 feet (*O3U-1* airplane).

SUMMARY OF RESULTS

With full elevator movement (up 30.3°) maximum angular velocities in pitch as obtained by either pilot varied from 0.98 radian per second at 75 miles per hour to 1.61 radians per second at 122 miles per hour. These values agree closely with the data obtained with the *F6C-4* airplane. Considerable time was required to move the elevator at high speed, apparently because of the large force required, so that there was a considerable decrease in speed before the angle of attack for maximum lift was attained. No appreciable increase in pitching velocities would have been attained by increasing the allowable elevator movement above 30.3°.

With the full aileron movement (left aileron down 13.0°, right aileron up 18.5°) the maximum rolling velocities varied from 0.53 radian per second at 71 miles per hour to 0.70 radian per second at 97 miles per hour. At the same indicated air speeds with the *F6C-4* airplane the maximum rolling velocities attained were 0.61 and 0.75 radian per second, respectively, but at 140 miles per hour the *F6C-4* airplane attained a rolling velocity of 0.90 radian per second. Although the large force required to operate the ailerons apparently affected the maximum rolling accelerations as attained by the two pilots, maximum angular velocities were not affected. An increase in the allowable aileron movement above 13.0° would have increased the maximum rolling velocity attainable.

With full rudder movement (right 27.0°) maximum yawing velocities varied from 0.46 radian per second at 64 miles per hour to 0.90 radian per second at 127 miles per hour. At corresponding speeds with the *F6C-4* airplane the values obtained were about 0.10 radian per second greater than those obtained with the *O3U-1* airplane. No effect of the force required to operate the rudder was indicated in either the angular acceleration or angular velocity attained. The variation of angular velocity with control movement indicated that greater angular velocity would have been attained with an increase in the allowable rudder movement.

In the 180° turns the half kick roll—half loop in general required the least time (about 10 seconds) for completion. The violence of this maneuver excluded it from test at speeds greater than about 100 miles per hour. At full speed the horizontal turns required the least time for completion (about 8 seconds). Wing-over turns required the greatest time for completion (about 21 seconds at all speeds). An Immelman turn was performed in which the altitude gained was 430 feet and the time required for completion was 17 seconds. In this particular maneuver, however, sufficient momentum was acquired by diving slightly at the start. Similar maneuvers were made with the *F6C-4* airplane at generally higher speeds and in generally less time than was required for the *O3U-1* airplane. An exception is noted in the case of the horizontal turns, however, in which the *F6C-4*, with an initial speed of 128 miles per hour, required about 9 seconds and a horizontal displacement of 565 feet, and the *O3U-1*, with an initial speed of 123 miles per hour, required about 8 seconds and a horizontal displacement of 490 feet. The one maneuver of this class that provides the most definite indication of superior maneuverability of the *F6C-4* airplane over the *O3U-1* airplane is the Immelman turn. With the *F6C-4* airplane this maneuver was performed without diving at the start, required 11 seconds for completion, and resulted in a gain of 550 feet of altitude.

The minimum radius of turn at an altitude of 3,000 feet was found to be 322 feet at a true air speed of 74 miles per hour. The minimum radius calculated from horsepower curves was 8 percent less than that value. The estimated minimum radius at sea level is 265 feet. The minimum radii for the *F6C-3* and *F6C-4* airplanes were 155 feet at 76 miles per hour and 135 feet at 62 miles per hour, respectively, for an altitude of about 2,500 feet, which is sufficiently close to 3,000 feet to make the test results comparable.

The tests with the *O3U-1* airplane complete the contemplated series of investigations. Consideration is now being given to the problem of developing a suitable criterion or method for rating airplanes according to their ability to maneuver. The results of this study will be reported at a later date. An important factor to be considered is that the method of rating should be based on items that are independent of the personal characteristics of a particular pilot, and that, as far as is possible, can be determined readily. Maximum speed, control effectiveness as shown by the results of abrupt single-control maneuvers, and minimum radius of steady horizontal turn are regarded as items of particular importance. The fact that the excess energy required for maneuvering is largely acquired through loss of speed suggests the possibility that the maximum kinetic energy that an airplane can surrender without varying the speed beyond the range of normal level-flight speeds may prove to be a particularly useful and convenient item.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *January 19, 1933.*

APPENDIX

SPECIFICATIONS OF "O3U-1" AIRPLANE [a]

Type	Tractor biplane, landplane.
Engine	Pratt and Whitney, R-1340-C.
Horsepower	450 at 2,100 r.p.m.
Full load	4,057 lb.
Weight per square foot	12.5 lb.
Weight per horsepower	9.02 lb.
Maximum speed	138 m.p.h.[b]
Service ceiling	16,300 ft.
Wing area including ailerons	325.6 sq. ft.
Aileron area	32.6 sq. ft.
Stabilizer area	23.6 sq. ft.
Elevator area	18.5 sq. ft.
Fin area	4.4 sq. ft.
Rudder area	14.1 sq. ft.
Airfoil section	Upper N-22, lower G-398.
Wing span	36 ft.
Length	26 ft. ¾ in.
Height	10 ft. 8 in.
Gap	5 ft. 5 in.
Chord	Upper 5 ft. 5 in., lower 4 ft. 9 in.
Angle of incidence	0°.
Stagger	17.5 in.
Dihedral	Upper 2°, lower 1.75°.
Sweepback	4.75°.
Distance back from leading edge lower wing to *c.g.*	16.27 in.

[a] From Table of Characteristics, Weights, and Performance of U.S. Navy Observation and Training Planes. Bureau of Aeronautics, Navy Department, January 1931.

[b] Maximum speed as flown during tests, 132 m.p.h.

REFERENCES

1. Dearborn, C. H., and Kirschbaum, H. W.: Maneuverability Investigation of the F6C-3 Airplane with Special Flight Instruments. T.R. No. 369, N.A.C.A., 1930.
2. Dearborn, C. H., and Kirschbaum, H. W.: Maneuverability Investigation of an F6C-4 Fighting Airplane. T.R. No. 386, N.A.C.A., 1931.
3. Ronan, K. M.: An Instrument for Recording the Position of Airplane Control Surfaces. T.N. No. 154, N.A.C.A., 1923.
4. Reid, H. J. E.: A Study of Airplane Maneuvers with Special Reference to Angular Velocities. T.R. No. 155, N.A.C.A., 1922.
5. Reid, H. J. E.: The N.A.C.A. Three-Component Accelerometer. T.N. No. 112, N.A.C.A., 1922.
6. Norton, F. H.: N.A.C.A. Recording Air Speed Meter. T.N. No. 64, N.A.C.A., 1921.
7. Diehl, Walter S.: The Reduction of Observed Airplane Performance to Standard Conditions. T.R. No. 297, N.A.C.A., 1928.
8. Diehl, Walter S.: Engineering Aerodynamics. Ronald Aeronautic Library. The Ronald Press Co., New York, 1928.

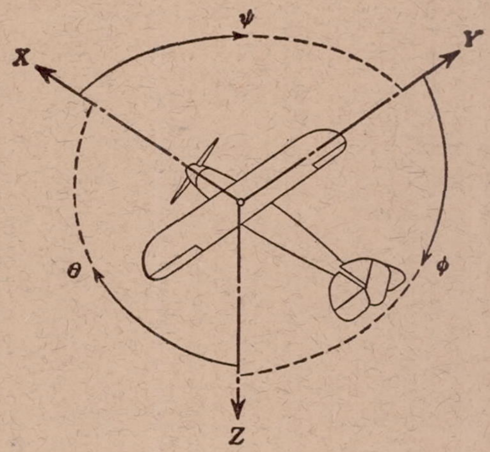
TABLE I

SUMMARY OF SIGNIFICANT QUANTITIES MEASURED IN VARIOUS MANEUVERS WITH THE "O3U-I" AIRPLANE

Maneuver	Indicated air speed, m.p.h.		Altitude, feet		Longitudinal displacement, feet	Time to complete maneuver, seconds	Maximum normal acceleration, *g*	Maximum angular velocities, radians/second			Maximum control movement, degrees		
	Start	End	Maximum variation (+) gain, (−) loss	Resultant (+) gain, (−) loss				*X* axis	*Y* axis	*Z* axis	Elevator [1]	Aileron [2]	Rudder [3]
Wing-over turn	84	94	--------	--------	980	21.0	2.20	0.17	0.34	0.36	12	−6	7, −5
	100	108	--------	--------	1,025	20.8	2.25	.15	.32	.38	9	2, −4	10, −4
	116	111	--------	--------	970	20.5	2.10	.41	.25	−.22	7	2, −6	6, −4
Horizontal turn	84	79	--------	--------	820	19.5	1.55	.24	.29	.18	10	4, −7	9
	100	87	--------	--------	900	17.5	2.00	.27	.41	.12	13	2, −7	8, −3
	115	93	--------	--------	670	11.6	2.60	.42	.57	.16	16	5, −11	11, −3
	123	99	--------	--------	490	8.3	3.00	.44	.58	.22	16	7, −6	13, −4
Half aileron roll—half loop	84	109	−630	−600	750	15.0	3.64	−.73	.69	−.73	−12, 11	−14, 5	3, −10
	99	119	−680	−675	1,050	16.0	4.20	−.66	.72	−.64	−11, 11	−12, 2	10, −7
	117	--------	−660	−470	1,390	18.0	4.25	−.56	.66	−.29	−15, 4	−8, 4	8
	122	141	−560	−340	1,290	16.7	4.10	−.62	.63	--------	−7, 14	−15	8, −7
Half kick roll—half loop	84	108	−665	−575	495	10.2	3.10	1.50	.66	.88	31.5	7, −4	31, −16
	102	112	−560	−440	570	10.2	3.80	1.88	.77	.82	28.5	11, −6	27, −19
Immelman turn	132	104	550	430	830	17.0	2.70	−.66	.39	--------	9, −8	−20	−31

[1] Elevator up, +. [2] Left aileron down, +. [3] Rudder right, +.

U. S. GOVERNMENT PRINTING OFFICE: 1933



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	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component 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

$$C_l=\frac{L}{qbS} \qquad C_m=\frac{M}{qcS} \qquad C_n=\frac{N}{qbS}$$

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 lb./ft./sec.
1 kg/m/s = 0.01315 hp.
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.
1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.