NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 167

THE MEASUREMENT OF THE DAMPING IN ROLL ON A JN4h IN FLIGHT

By F. H. NORTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

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	sec.	second (or hour)	sec. (or hr.).
Force	F	weight of one kilogram	kg.	weight of one pound	lb.
Power	P	kg.m/sec	....	horsepower	IP
Speed	....	m/sec	m. p. s.	mi/hr	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W=mg$.

Standard acceleration of gravity, $g=9.806\text{m/sec.}^2=32.172\text{ft/sec.}^2$

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

Density (mass per unit volume), ρ

Standard density of dry air, 0.1247 (kg.-m.-sec.) at 15.6°C. and 760 mm. = 0.00237 (lb.-ft.-sec.)

Specific weight of "standard" air, 1.223 kg/m.^{3} = 0.07635 lb/ft.^{3}

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

Area, S; wing area, S_w, etc.

Gap, G

Span, b; chord length, c.

Aspect ratio $=b/c$

Distance from $c.\ g.$ to elevator hinge, f.

Coefficient of viscosity, μ.

3. AERODYNAMICAL SYMBOLS.

True airspeed, V

Dynamic (or impact) pressure, $q=\frac{1}{2}\rho V^2$

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

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

Cross-wind force, C; absolute coefficient $C_c=\frac{C}{qS}$.

Resultant force, R

(Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

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

Angle of stabilizer setting with reference to thrust line i_t

Dihedral angle, γ

Reynolds Number $=\rho\frac{Vl}{\mu}$, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi/hr., normal pressure, 0°C: 255,000 and at 15.6°C, 230,000;

or for a model of 10 cm. chord, 40 m/sec., corresponding numbers are 299,000 and 270,000.

Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length), C_p.

Angle of stabilizer setting with reference to lower wing. $(i_t-i_w)=\beta$

Angle of attack, α

Angle of downwash, ϵ

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REPORT No. 167.

THE MEASUREMENT OF THE DAMPING IN ROLL ON A JN4h IN FLIGHT.

By F. H. Norton, Chief Physicist.

SUMMARY.

This investigation was carried out by the National Advisory Committee for Aeronautics for the purpose of measuring the value of L_p in flight. The method consisted in flying with heavy weights on each wing tip, suddenly releasing one of them, and allowing the airplane to roll up to 90° with controls held in neutral while a record was being taken of the air speed, and angular velocity about the X axis. The results are of interest as they show that the damping found in the wind tunnel by the method of small oscillations is in general 40 per cent higher than the damping in flight. At 50 m. p. h. the flight curve of L_p has a high peak, which is not indicated in the model results. It is also shown that at this speed the lateral maneuverability is low.

INTRODUCTION.

The stability derivatives of airplanes have been mainly determined in the wind tunnel by the method of small oscillations. As there is some doubt as to the validity of the derivatives measured in this way several of these have also been determined in flight. In N. A. C. A. Report No. 112 the values of Y_v, L_v and N_v have been obtained in free flight and their agreement with the wind tunnel results is not as good as could be wished. As accurate values of the damping coefficients in flight are of use in many problems it was thought desirable to make careful measurements of L_p.

METHODS AND APPARATUS.

This test was carried out on a JN4h airplane in every way standard[1] except for the addition of wing tip weights. The method consisted in loading a box on each wing tip[2] with 150 pounds of sand and when in steady flight suddenly releasing the sand in one box, while with neutral controls the airplane was allowed to roll up to a vertical bank. At this point the rudder was kicked over and the other box emptied. The sand in the boxes was carefully dried each time and from observations on the ground it was estimated that a box was emptied in less than 0.5 seconds.

The instruments used were the N. A. C. A. recording air speed meter[3] and angular velocity recorder.[4] The latter instrument consists of an electrically driven gyroscope whose precessional force, due to a given angular velocity, is recorded on a moving film. The air speed was recorded merely as a check on the pilot's flying and to be sure that the speed did not fall off before a steady angular velocity was reached.

Tests were made at speeds from 40 m. p. h. to 90 m. p. h. at an altitude for which the density was 0.9 of standard. The speed of the motor was in all cases 1,350 r. p. m. The weight of sand in each box was 150 pounds and its distance from the center of the airplane was 14.7 feet.

As the tests were all flown at a density which was 0.9 of standard, the indicated air speed should be divided by 0.95 to give the true air speed. The angular velocity as read in the air corresponds to this corrected velocity and the lower density, and must be multiplied by 0.90 to give the approximate angular velocity under standard conditions. The velocities given on the

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[1] N. A. C. A. Report No. 70.
[2] N. A. C. A. Report No. 112.
[3] N. A. C. A. Technical Note No. 64.
[4] N. A. C. A. Report No. 155.

curves in this report, however, are not corrected in the above manner for it would be necessary to correct the angular velocity in a rather complicated way to account for the change in angle of attack with the change in density. It was considered better, therefore, to give the values as they were read for they will be most usually applied to flying conditions at that density. If it is desired to make a comparison with the wind tunnel tests the approximate corrections given above can be applied to these values.

PRECISION.

The air speed meter was carefully calibrated over a speed course just after the test; so that the readings should be precise, except at the stalling speeds, to ± 2 miles per hour. The angular velocity recorder was calibrated frequently on a revolving table, which should give a precision in this quantity of 0.01 radians per second. The sand was weighed out in every case to within 1 per cent of the indicated value.

All of the tests were made in smooth air and the flying was so carefully executed that numbers of check runs on different days agreed with the previous values within 0.01 radians per second.

The constant angular velocity was reached in about 1.0 seconds, corresponding to an angle of bank of about 6°. No side slip was detected at this angle so there is every reason to believe that the angular velocity when first reaching its constant value is the true rolling velocity due to the given moments.

A slight error may have crept into the results by the sand boxes themselves influencing the damping coefficients, but as they were on the under side of the lower wing, and approximately 80 per cent of the damping is due to the upper wing, their effect can have been very slight—at the most not over 5 per cent.

Rolling has been considered in wind tunnel tests to occur about an axis through the center of gravity, but it may be readily seen that this does not necessarily hold true in flight. If we consider the airplane flying with both sand boxes loaded in steady flight, we will have an angle of attack which will be in equilibrium with the loaded plane. When one load of sand, however, is released the angle of attack will be greater than necessary to support itself, causing this wing to rise. The action will then be the same as if a force of 150 pounds was suddenly applied upwards to that wing tip. After a short time, however, the angle of attack will have decreased to its equilibrium value for the lighter load, in which case the light wing will be lifting enough to provide one half of the moment due to the remaining sand; the heavy wing will of course be lifting the same amount, so the total result will be an equivalent moment on each wing of half the moment given by the sand. These conditions will therefore force the airplane to rotate about its center of gravity. Due to the fact that one sand box is loaded, the center of gravity will be displaced from the plane of symmetry by about 0.8 of a foot, but this in turn will make the light wing provide more damping than the heavy one, so that the center of rotation will lie somewhere between the plane of symmetry and the center of gravity, probably nearer the former. There can be no doubt that the airplane revolves approximately about an axis through the plane of symmetry, and what error there is can not make the value of L_p too small.

RESULTS.

The form of the records of angular velocity for air speeds of over 50 m.p.h. is shown in figure 1. There is a steady rise in angular velocity for about one second corresponding to an angle of bank of about 6° and then a constant value is maintained until the controls are moved. This constant value is the one used in plotting the curves. The records taken at speeds below 50 m.p.h. have a form as shown in Figure 2 indicating that a steady value has not been obtained in the length of time available. Autorotation undoubtedly occurs at these low speeds.

The curve of angular velocity in roll for the JN4h due to a constant rolling moment of 2,210 feet pounds is shown in Figure 3. As the air speed decreases from 85 m.p.h. the angular velocity increases, as we should expect. At 65 m.p.h., however, the angular velocity starts to decrease reaching a minimum at 53 m.p.h.; and then increases very rapidly at speeds below this.

The curve is not drawn through the last two points as they do not represent the true angular velocity because of autorotation.

From a theoretical standpoint, assuming a straight lift curve, we should expect the angular velocity to follow the dotted curve in Figure 3; so the dip in the curve at 53 m. p. h. was quite unexpected. A number of check runs, however, conclusively established this peculiarity. Searching for some explanation of this it was noted that some of the angular velocity curves of a set of aerofoils with ailerons recently tested in the N. A. C. A. wind tunnel showed the same effect, although not so markedly; that is, there was a peak at about 7° and a dip just before autorotation began.[5]

To study this phenomenon more closely, an aerofoil was mounted on its X axis in ball bearings in the center of the wind tunnel. The aerofoil was then set at various angles of attack, a constant rolling moment was applied to it by means of a cord and weight, and its rate of rotation noted. Although the precision of the test was not high, there was little doubt that the rotational speed was practically constant with changes in angle of attack up to angles near the burble point, where of course it increased.

As it was believed that there could not be any serious error in the flight methods it was concluded that there must be a distinct difference between the model and flight conditions at medium angles of attack. To test this out the JN4h without sand boxes was rolled by the sudden application of full aileron and the time to reach 36° bank taken. The results obtained averaged from several runs—are shown in Figure 4 and clearly confirm the results shown in Figure 3. That is, the rolling velocity is constant for speeds down to 65 m. p. h., decreases to a minimum at 55 m. p. h., and then increases again. Lower air speeds were not attempted as the ailerons become ineffective near the burble point.

The damping coefficient in roll is found from the angular velocity and the rolling moment by the following formula:

$$L_p = \frac{M}{72p}$$

where p is the angular velocity and 72 is the mass of the airplane in slugs.

The values worked out in this way are plotted in Figure 5, and give the curves of the same general shape as for the angular velocity. As before, the curves have not been drawn through the two points at the low speed as the angular velocity did not reach a constant value. For the sake of comparison a curve of L_p as measured by the method of small oscillations on a JN2 model is plotted in the same Figure after being transferred to the same air density as the full scale airplane. It will be seen that this curve is a straight line except at the low speeds where it rises abruptly. Above 65 m. p. h. the two curves are similar except that the model values are approximately 40 per cent higher than the full scale ones. Although the two airplanes, the JN2 and JN4h, are not the same, the latter should have only a slightly larger damping coefficient due to its greater span. At speeds below 65 m. p. h. the curves are quite dissimilar due to the dip on the full scale curve.

It does not seem to be possible at present to explain this interesting phenomenon, but it seems clear that the tunnel does not give results comparable with full scale, and the reason for this lack of similarity deserves further study. At speeds above 65 m. p. h., however, the two kinds of tests agree more nearly and the flight values of L_p can certainly be taken with confidence as they check up well in computations of lateral maneuverability.

CONCLUSIONS.

As the damping in flight on the JN4h is considerably larger at 50 m. p. h. than it is at speeds above 65 m. p. h. it is evident that lateral maneuvers could not be carried out as rapidly around that speed, a fact which is shown by actual measurements. This report shows from the results obtained that the conventional methods used in determining stability derivatives in the wind tunnel are questionable. More work should be carried out, preferably on several airplanes, to determine the reason for this discrepancy between the value of L_p in the tunnel and in flight.

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[5] N. A. C. A. Report No. 169.

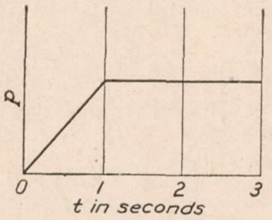


FIG. 1.—Form of records of angular velocity for air speeds over 50 M. P. H.

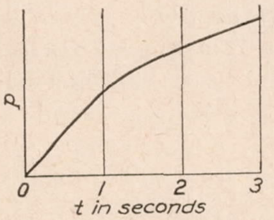


FIG. 2.—Form of records of angular velocity for air speeds below 50 M. P. H.

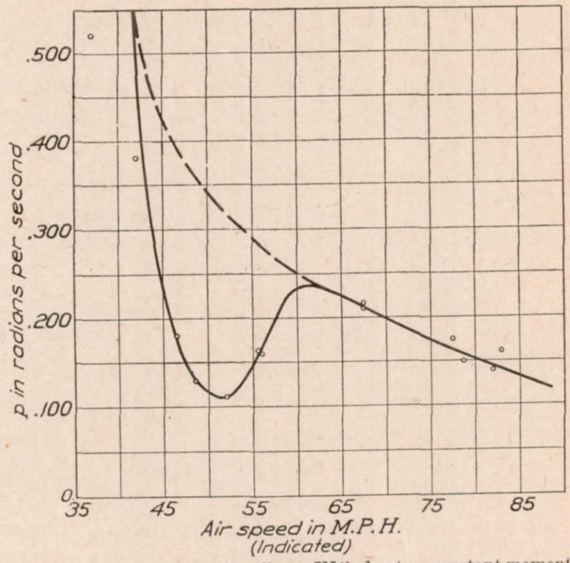


FIG. 3.—Angular velocity in roll of a JN4h due to a constant moment of 2210 ft. lbs.

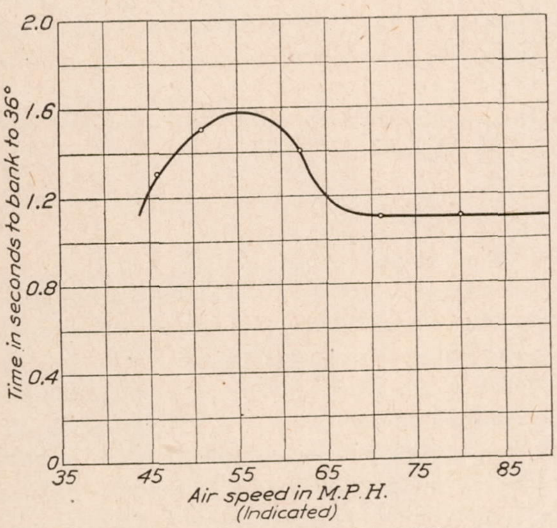


FIG. 4.—Lateral maneuverability of JN4h.

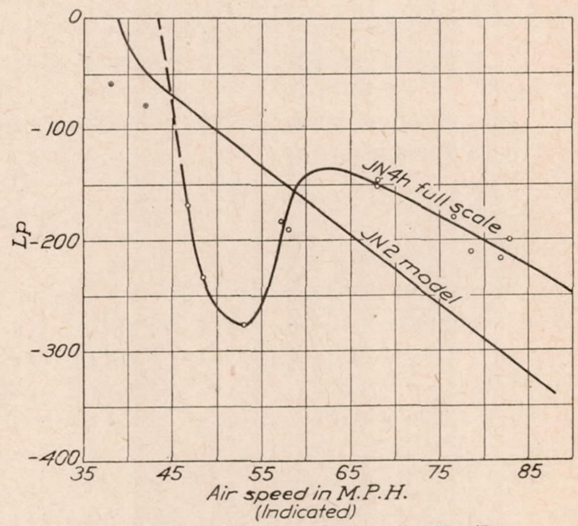
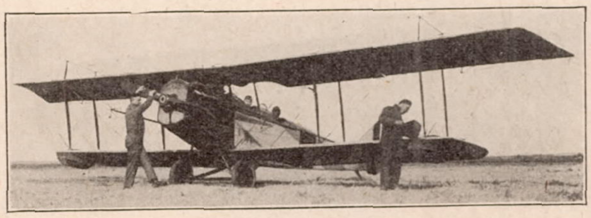
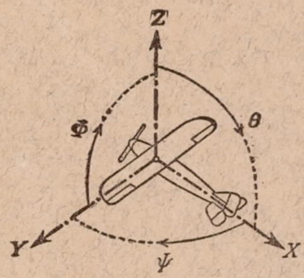


FIG. 5.—Values of damping coefficient in roll. (Lp.)



The JN4 airplane ready to take off with full sand boxes.



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

$$C_l = \frac{L}{q\,b\,S} \quad C_m = \frac{M}{q\,c\,S} \quad C_n = \frac{N}{q\,f\,S}$$

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

4. PROPELLER SYMBOLS.

Diameter, D
Pitch (a) Aerodynamic pitch, p_a
(b) Effective pitch, p_e
(c) Mean geometric pitch, p_g
(d) Virtual pitch, p_v
(e) Standard pitch, p_s
Pitch ratio, p/D
Inflow velocity, V'
Slipstream velocity, V_s

Thrust, T
Torque, Q
Power, P
(If "coefficients" are introduced all units used must be consistent.)
Efficiency $\eta = T\,V/P$
Revolutions per sec., n; per min., N
Effective helix angle $\Phi = \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS.

1 HP = 76.04 kg. m/sec. = 550 lb. ft/sec.
1 kg. m/sec. = 0.01315 HP
1 mi/hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi/hr.

1 lb. = 0.45359 kg.
1 kg. = 2.20462 lb.
1 mi. = 1609.35 m. = 5280 ft.
1 m. = 3.28083 ft.