NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 149

PRESSURE DISTRIBUTION OVER THE RUDDER AND FIN OF AN AIRPLANE IN FLIGHT

By F. H. NORTON and W. G. BROWN

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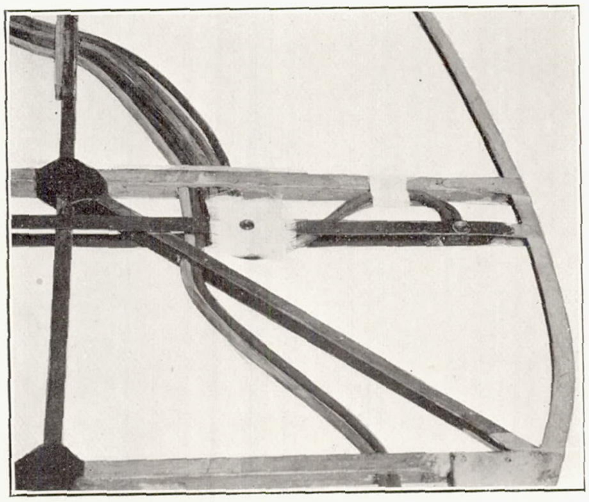

FIG. 1.—A SECTION OF RUDDER BEFORE COVERING.

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Langley Memorial Aeronautical Laboratory.

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	HP
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.

Span, b; chord length, c.

Aspect ratio = b/c

Length of body (from c. g. to elevator hinge), f.

Coefficient of viscosity, μ

3. AERODYNAMICAL SYMBOLS.

True air speed, V

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 setting of horizontal tail surface, i_t

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

e. g., for a model aerofoil 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 tail setting, $(i_t - i_w) = \beta$

Angle of attack, α

Angle of downwash, ϵ

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SUMMARY.

This investigation was carried out by the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory for the *purpose* of determining the loads which occur on the vertical tail surfaces in flight. The *method* consisted in measuring the pressures simultaneously at 28 points on the rudder and fin by means of a recording multiple manometer. The *results* show that the maximum load encountered in stunting was 7 pounds per square foot on the rudder and fin, and it is probable that this might rise to 10 pounds per square foot in a violent barrel roll; but in steady flight the average loads do not exceed 0.6 pound per square foot. The maximum load on the rudder and fin may occur at the same instant as the maximum load on the horizontal tail surfaces and the maximum normal acceleration. The torsional moment about the axis of the fuselage due to the rudder and fin may rise as high as 250 foot-pounds. The results obtained from this investigation have a direct application to the design of the rudder, fin, and fuselage.

INTRODUCTION.

At present there are apparently no data available on the loads that may be experienced by the rudder and fin in flight. The design of these parts has been based partly on wind-tunnel tests and partly on actual experience, but what the actual magnitude and distribution of load is during various maneuvers has not been even approximately known. It has been the usual practice in airplane design to require the rudder and fin to withstand 15 to 25 pounds per square foot, or somewhat less than for the horizontal tail surfaces, although many actual structures have twice this strength.

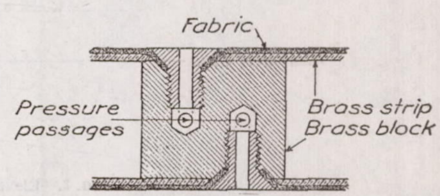


Fig. 2.—Section showing method of applying pressure holes in rudder.

In order to obtain exact information as to the character of rudder and fin loads, a standard rudder and fin on a JN4h was fitted up for measuring the pressure distribution. The airplane was then flown under several conditions of steady flight and through such maneuvers as were thought to impose the greatest stresses, while continuous records were being made of the various pressures, the control position, the air speed, and the normal acceleration.

METHODS AND APPARATUS.

The apparatus used in this investigation consisted of a multiple manometer for recording simultaneously 30 pressures, a control position recorder for the three controls, a recording air speed meter, and a recording accelerometer. These instruments are the same as were used to obtain the results in Report No. 148, where a full description of them is given. As the rudder and fin were quite thin, it was necessary to employ a somewhat different method of constructing the pressure holes than had been used previously. This method[1] is clearly shown in Figures 1 and 2, and proved to be highly satisfactory as it gave a smooth sharp hole on the surface with no possibility of leaks. The form of the rudder and fin with the location of the holes is shown in Figure 3.

[1] Flossendruckmessungen, Technische Berichte, Oct. 15, 1915.

The methods of testing were exactly the same as those described in Report No. 148 and consisted in flying the machine through the various maneuvers while simultaneous records were being taken on all of the instruments. Zero points were taken at the beginning and end of each record and the air-speed meter was calibrated on each flight. All of these flights were made at such an altitude that the air density was 0.9 of standard, but neither the air speed nor the pressures are corrected for density.

The scope of the tests consists of the following runs:

1. Several steady flights at various air and motor speeds. The loads experienced in uniform flight were so small, however, that the results are not given here.
2. A steeply banked left turn at 75 miles an hour.
3. A barrel roll to the right. Unfortunately this roll was commenced at too low an air speed, as can be seen from the records, so that the rudder load is probably considerably smaller than normal with a roll on this type of airplane.
4. A tail spin of two and one-half turns to the right.

The pressures which are worked up in the same way as for Report No. 148 are first plotted along sections parallel with the X axis of the airplane. The areas of these curves are then

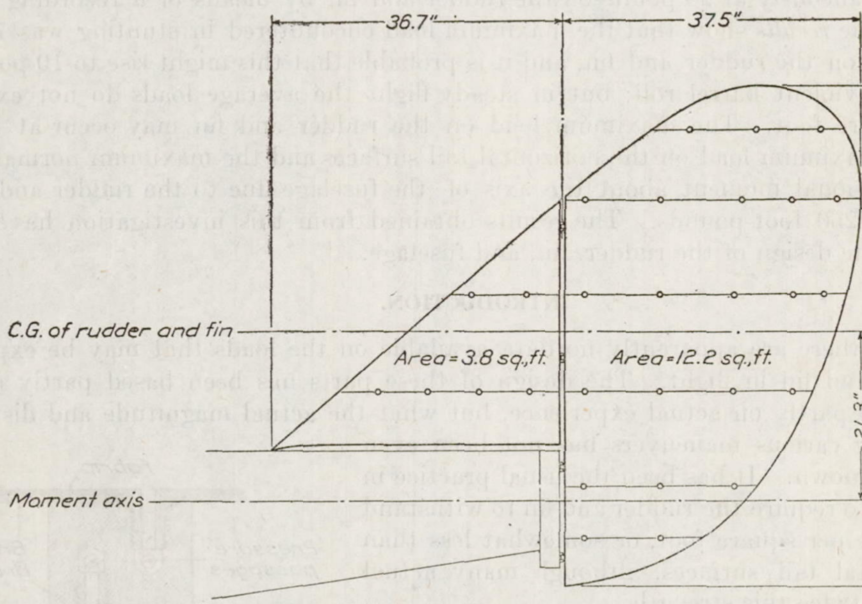


FIG. 3.—Elevation of fin and rudder showing location of ho es.

plotted along a vertical base line, the area under this resulting curve giving the total load on the rudder and fin. This method was adopted as it was thought that the vertical position of the center of pressure was of more importance than the horizontal position, although the latter can be found from the curves included if any one wishes to carry through the integration. As the area of the fin was small it was not separated from the rudder in any of these cases.

The discussion of precision given in Report No. 148 applies equally to this investigation, although as the spacing of the pressure holes was closer in this test the errors due to misdrawing the curves will be considerably smaller. Altogether the load on the rudder and fin should be precise to 0.3 pound per square foot.

RESULTS OF TESTS.

LEFT TURN.

In Figure 4 there are shown the pressures over the entire surface of the rudder and fin for various intervals of time during the turn. The main features of interest are the high peaks of pressure at the leading edge of the fin and somewhat back of the rudder hinge. The maximum local load indicated is approximately 21 pounds per square foot.

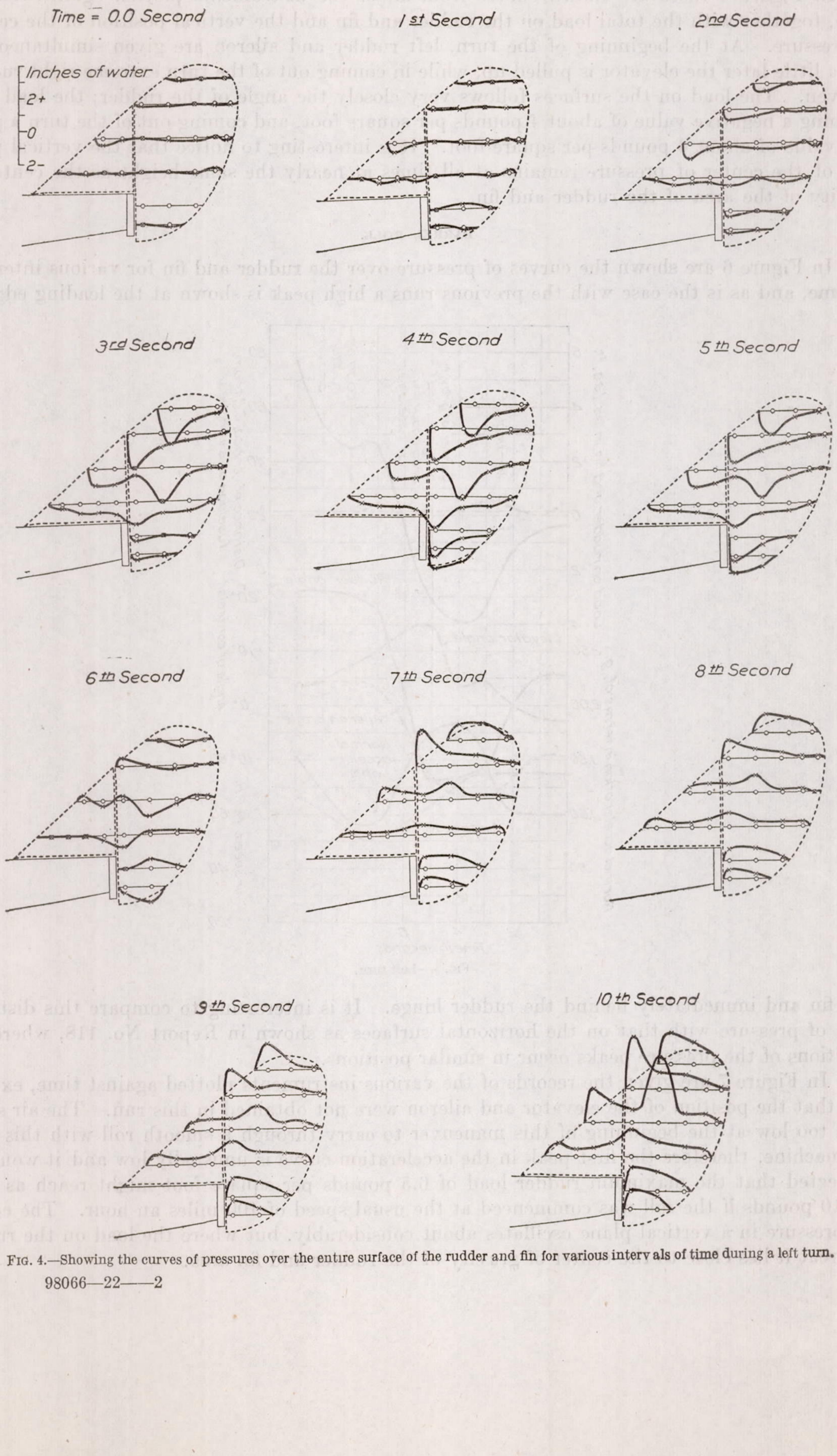


FIG. 4.—Showing the curves of pressures over the entire surface of the rudder and fin for various intervals of time during a left turn.

In Figure 5 there are shown curves from all of the instruments plotted against a time scale, together with the total load on the rudder and fin and the vertical position of the center of pressure. At the beginning of the turn, left rudder and aileron are given simultaneously and a little later the elevator is pulled up, while in coming out of the turn extreme right rudder is given. The load on the surfaces follows very closely the angle of the rudder; the load first reaching a negative value of about 4 pounds per square foot, and coming out of the turn a positive value of about 6 pounds per square foot. It is interesting to notice that the vertical position of the center of pressure remains at all times at nearly the same height as the center of gravity of the area of the rudder and fin.

BARREL ROLL.

In Figure 6 are shown the curves of pressure over the rudder and fin for various intervals of time, and as is the case with the previous runs a high peak is shown at the leading edge of

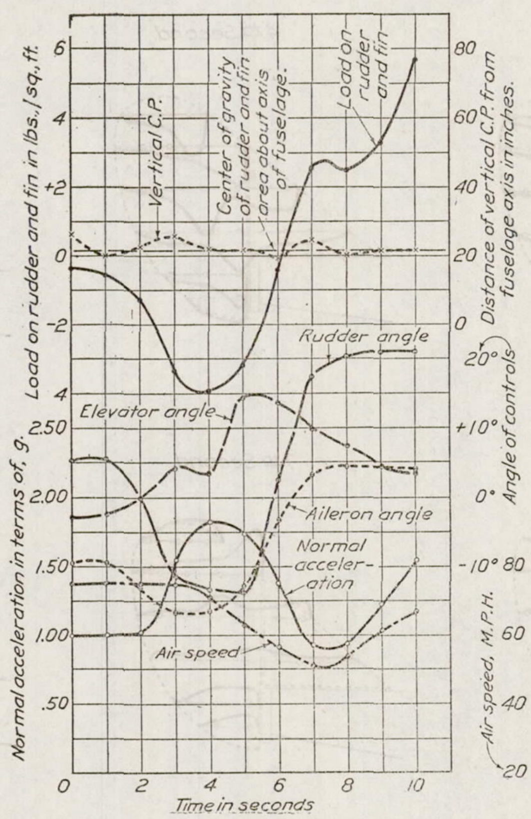


FIG. 5.—Left turn.

the fin and immediately behind the rudder hinge. It is interesting to compare this distribution of pressure with that on the horizontal surfaces as shown in Report No. 118, where the positions of the pressure peaks occur in similar positions.

In Figure 7 are given the records of the various instruments plotted against time, excepting that the position of the elevator and aileron were not obtained in this run. The air speed was too low at the beginning of this maneuver to carry through a smooth roll with this type of machine, therefore the first peak in the acceleration curve is unusually low and it would be expected that the maximum rudder load of 6.5 pounds per square foot might reach as high as 10 pounds if the roll was commenced at the usual speed of 100 miles an hour. The center of pressure in a vertical plane oscillates about considerably, but where the load on the rudder is great it lies close to the center of gravity of the rudder and fin area.

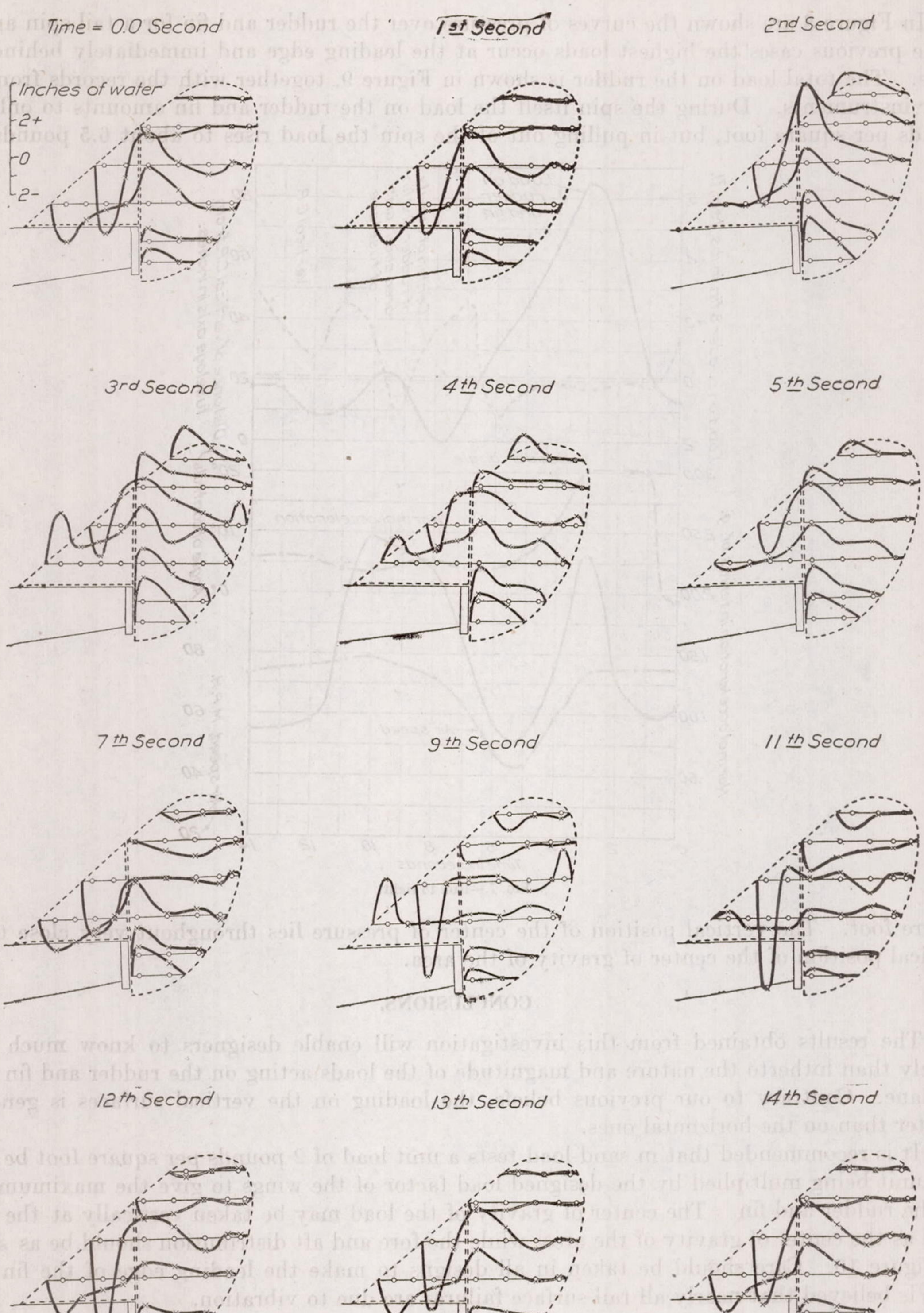


FIG. 6.—Showing the curves of pressures over the entire surface of the rudder and fin for various intervals of time during a barrel roll.

TAIL SPIN.

In Figure 8 are shown the curves of pressure over the rudder and fin for a tail spin and as in the previous cases the highest loads occur at the leading edge and immediately behind the hinge. The total load on the rudder is shown in Figure 9, together with the records from the other instruments. During the spin itself the load on the rudder and fin amounts to only 3.5 pounds per square foot, but in pulling out of the spin the load rises to about 6.5 pounds per

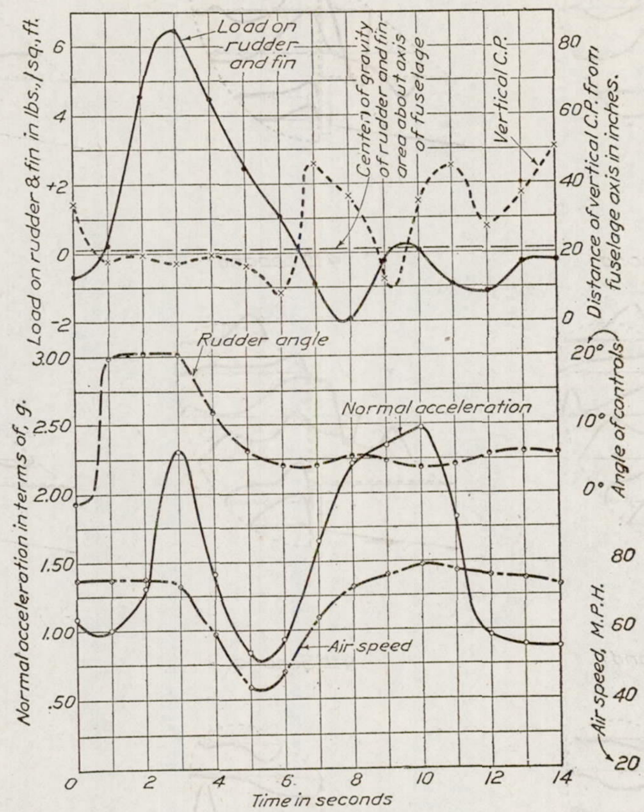


FIG. 7.—Roll to right.

square foot. The vertical position of the center of pressure lies throughout very close to the vertical position of the center of gravity of the area.

CONCLUSIONS.

The results obtained from this investigation will enable designers to know much more closely than hitherto the nature and magnitude of the loads acting on the rudder and fin of an airplane. Contrary to our previous beliefs, the loading on the vertical surfaces is generally greater than on the horizontal ones.

It is recommended that in sand-load tests a unit load of 2 pounds per square foot be used, this unit being multiplied by the designed load factor of the wings to give the maximum load on the rudder and fin. The center of gravity of the load may be taken vertically at the same level as the center of gravity of the area, while the fore and aft distribution should be as shown in Figure 10. Care should be taken in all designs to make the leading edge of the fin stiff, as it is believed that nearly all tail surface failures are due to vibration.

The operation of all of the instruments in this test were satisfactory and, except for a few detailed changes for increased convenience, no alterations are considered necessary. The method of applying pressure holes is satisfactory and will be used in future tests. When further work of this nature is carried out it is believed that it will be desirable to make similar tests on rudders and fins of different shapes and on airplanes of much higher speed.

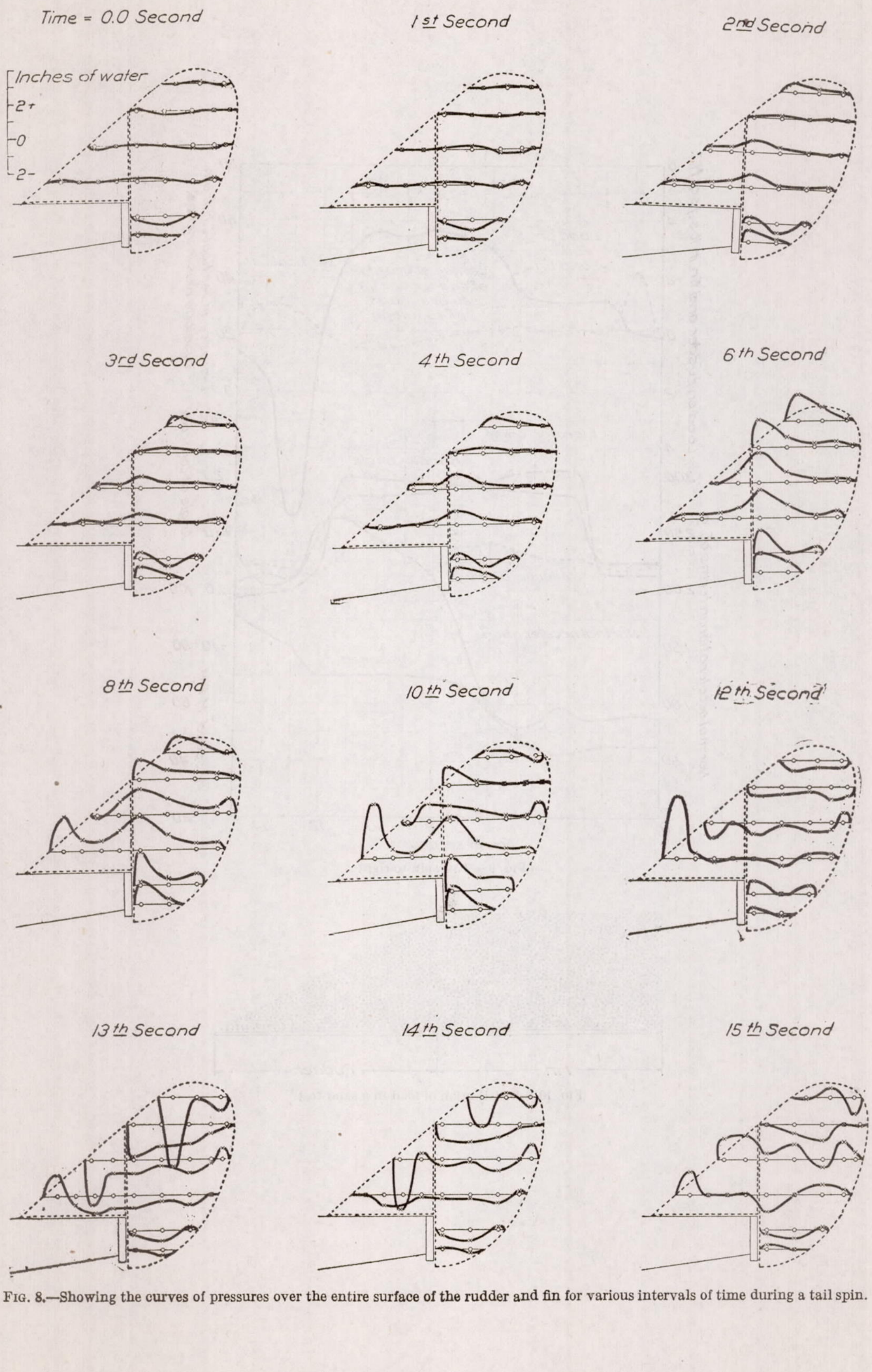


FIG. 8.—Showing the curves of pressures over the entire surface of the rudder and fin for various intervals of time during a tail spin.

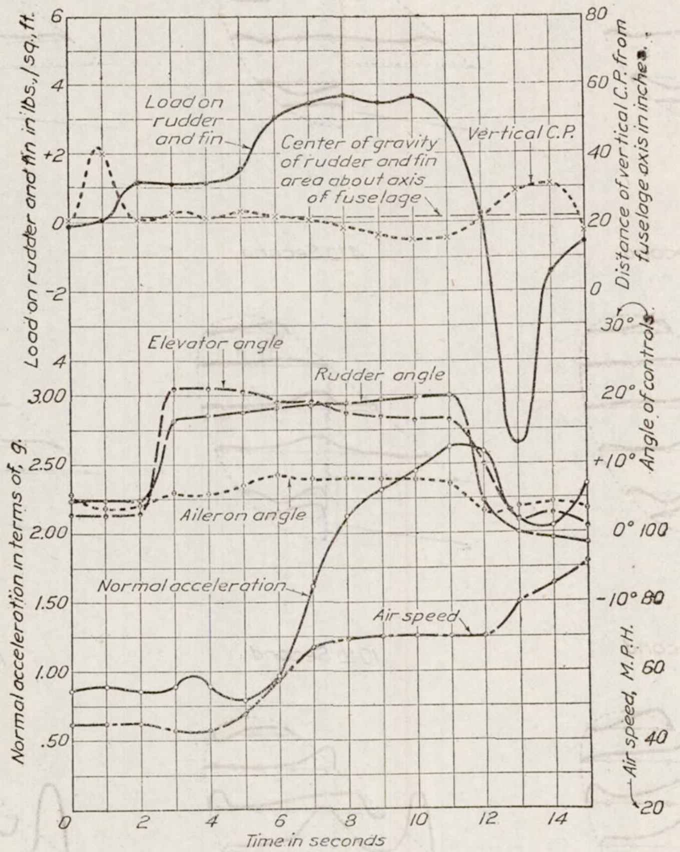


FIG. 9.—Tail spin to right.

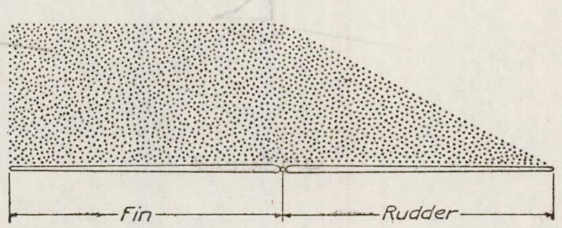
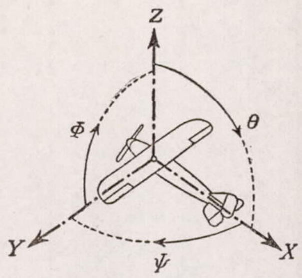


FIG. 10.—Distribution of load in a sand test.



Positive directions of axes and angles (forces and moments) as 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 ⟶ Z	roll......	Φ	u	p
Lateral.........	Y	Y	pitching...	M	Z ⟶ X	pitch....	θ	v	q
Normal.........	Z	Z	yawing.....	N	X ⟶ Y	yaw.....	Ψ	w	r

Absolute coefficients of moment

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

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) Geometric pitch, p_g

Pitch ratio, p/D

Inflow velocity, V′

Slip-stream 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 $\Phi = \frac{V}{\pi\,D\,n}$

5. NUMERICAL RELATIONS.

1 HP = 76 kg. m/sec. = 550 lb. ft/sec.

1 kg. m/sec. = 0.01315 HP

1 mi/hr. = 0.4470 m/sec.

1 m/sec. = 2.237 mi/hr.

1 lb. = 0.4536 kg.

1 kg. = 2.204 lb.

1 mi. = 1609 m. = 5280 ft.

1 m. = 3.281 ft.

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