

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

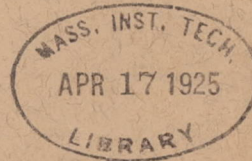
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**NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS**

REPORT No. 203



ACCELERATIONS IN FLIGHT

c. 3

By J. H. DOOLITTLE



WASHINGTON
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1925

AERONAUTICAL SYMBOLS.

1. FUNDAMENTAL AND DERIVED UNITS.

	Symbol.	Metric.		English.	
		Unit.	Symbol.	Unit.	Symbol.
Length....	<i>l</i>	meter.....	m.	foot (or mile).....	ft. (or mi.).
Time.....	<i>t</i>	second.....	sec.	second (or hour).....	sec. (or hr.).
Force.....	<i>F</i>	weight of one kilogram.....	kg.	weight of one pound.....	lb.
Power....	<i>P</i>	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, ml^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_s

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. $(i_s - i_w) = \beta$

Angle of attack, α

Angle of downwash, ϵ

REPORT No. 203

ACCELERATIONS IN FLIGHT

By J. H. DOOLITTLE
Massachusetts Institute of Technology

FOREWORD

The original of this report was presented, at the Massachusetts Institute of Technology, in partial fulfillment of the requirement for the degree of master of science.

I am indebted to Lieut. C. N. Monteith, of McCook Field, for correcting the work and putting it in a more presentable form for publication.

Certain conjectures which were not compatible with the results of research, conducted at McCook Field, were omitted, but the conclusions drawn remain substantially unchanged.

REPORT No. 203

ACCELERATIONS IN FLIGHT

By J. H. DOOLITTLE

INTRODUCTION

This work on accelerometry was done at McCook Field in March, 1924, for the purpose of continuing the work done by other investigators and obtaining the accelerations which occur when a modern high-speed pursuit airplane is subjected to the more common maneuvers. The results are presented in this form for publication as a technical report of the National Advisory Committee for Aeronautics.

The airplane used was the Fokker *PW-7*. (See figs. A, B, and C.) The airplane mounts the Curtiss *D-12* engine, and all control surfaces are balanced as shown in Figure B. This airplane has the following characteristics:



FIG. A.—Fokker PW pursuit airplane

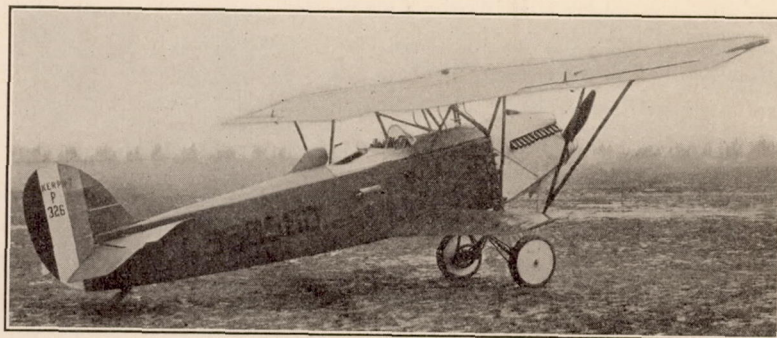


FIG. B.—Fokker PW-7 pursuit airplane

Total weight, as flown.....	(Approx.) 3,200 pounds.
Engine power.....	420 at 2,100 R. P. M.
High speed at ground.....	156 M. P. H.
The wings are internally braced.	

The accelerometer used is similar to the one designed by Mr. F. H. Norton for the National Advisory Committee for Aeronautics, and was built by the Emerson Instrument Co. The National Advisory Committee for Aeronautics accelerometer designed by Mr. Norton is described in Technical Report No. 100.

The instrument was calibrated by attaching it to the flywheel of a steam engine capable of maintaining constant speed for a given throttle setting. The details of the calibration are given in the body of the report.

The accelerometer was placed at the *c. g.* of the airplane and was so oriented that the accelerations recorded were those perpendicular to the plane of the wings.

The accelerations were taken for the following maneuvers:

- Loops at various air speeds.
- Single and multiple barrel rolls.
- Power spirals.
- Tail spins, power on and off.
- Half loop and half roll, and "Immelman turn."
- Inverted flight.
- Pulling out of a dive at various air speeds.
- Flying the airplane level and straight with a considerable angle of bank.
- Flying in "bumpy air."

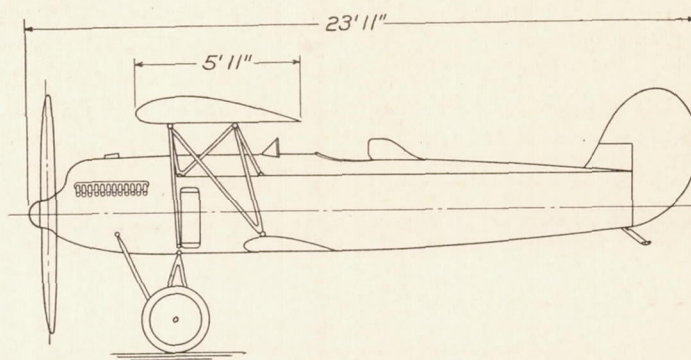


FIG. C.—Fokker PW-7 pursuit airplane

SUMMARY OF THE RESULTS

The accelerations in suddenly pulling out of a dive are greater than those due to any maneuver started at the same speed.

The accelerations obtained in suddenly pulling out of a dive with a modern high-speed pursuit airplane equipped with well-balanced elevators are shown to be within 3 or 4 per cent of the theoretically possible accelerations. How close this agreement would be in the case of a similar airplane equipped with unbalanced elevators would be determined by additional experiments.

Accelerations due to flying the airplane in average "rough air" do not exceed 2.5 *g.*

The maximum acceleration which a pilot can withstand depends upon the length of time the acceleration is continued. It is shown that the pilot experiences no difficulty under the instantaneous accelerations as high as 7.8 *g.*, but that under accelerations in excess of 4.5 *g.*, continued for several seconds, the pilot quickly loses his faculties. While this is disconcerting to the pilot, it is not necessarily dangerous for one in good physical condition unless continued for a period of 10 to 12 seconds.

REFERENCES

- British R. & M. Nos. 376 and 469.
- N. A. C. A. Reports Nos. 99 and 100.
- N. A. C. A. Technical Note No. 3.
- Bureau of Aeronautics, U. S. N., Technical Note No. 39.

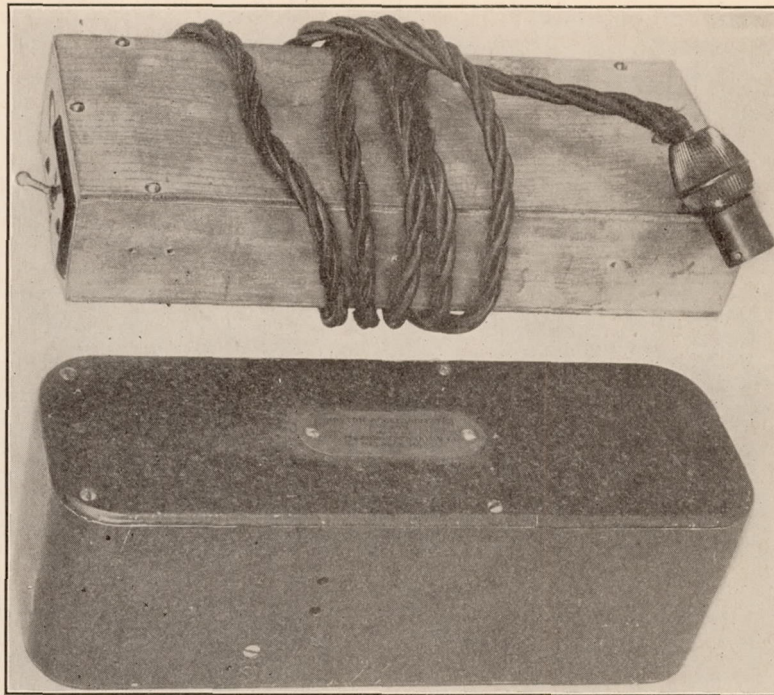
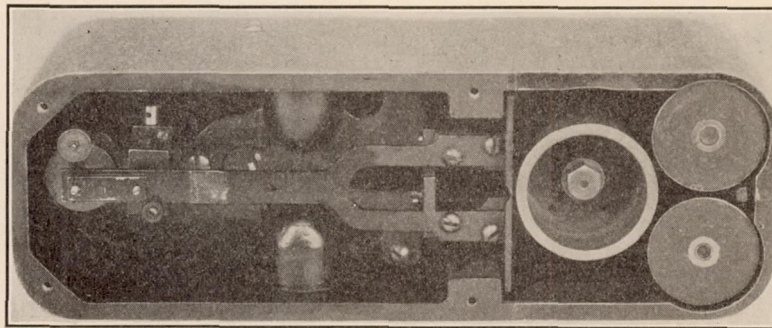
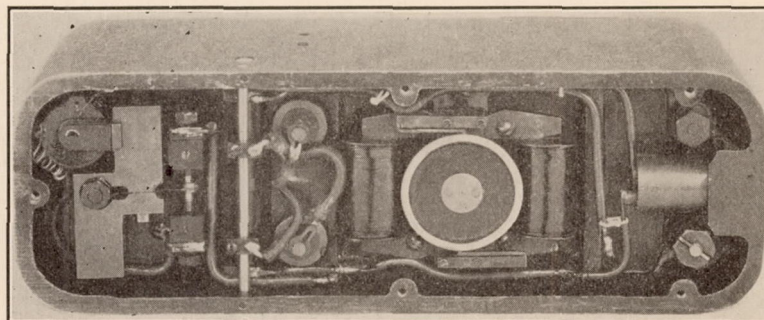


FIG. D.—Norton accelerometer No. 100



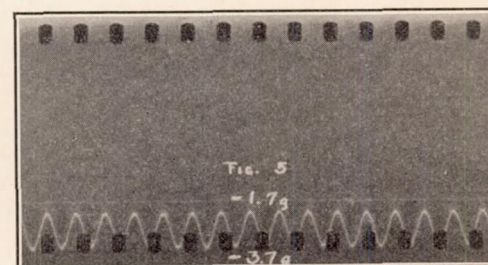
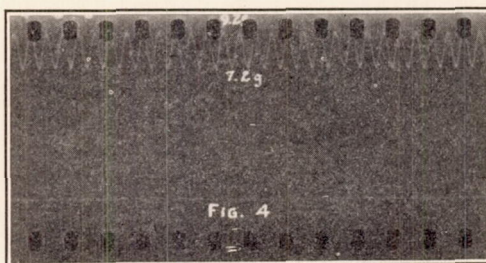
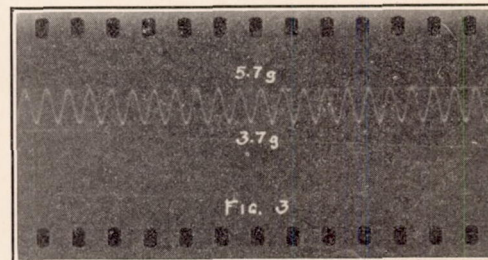
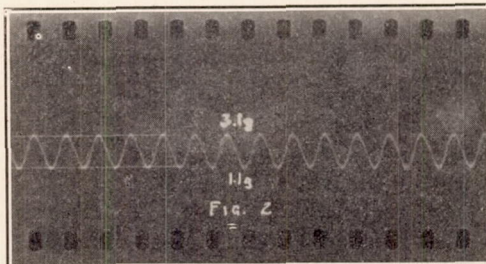
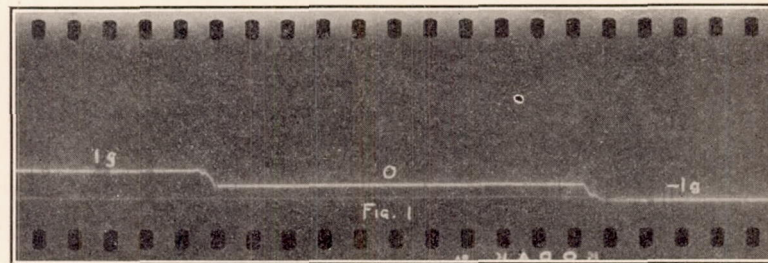
View with top removed. Norton accelerometer No. 100



View with bottom removed. Norton accelerometer No. 100

CALIBRATION OF THE INSTRUMENT

The accelerometer was calibrated by securing it to the flywheel of a steam engine, which gave substantially constant speed for a given throttle setting. Since the wheel revolved in a vertical plane, the instrument traced out a sine curve of amplitude $2g$. Three runs were made with the instrument in the position to give positive accelerations, and one with the instrument inverted, to give negative accelerations. Eight points on the calibration curve were obtained from those runs. Three additional points were obtained by removing the instrument from the wheel and holding it erect, on its side, and inverted, corresponding to $1g$, $0g$, and $-1g$. (See figs. 1 to 5.)



The expression $F = \frac{WV^2}{gR}$ was used in calculating the accelerations. The ratio F/W is referred to as A ; hence $A = \frac{V^2}{gR}$ where

$$V = 2\pi RN.$$

R = The distance of the accelerometer spring from the center of the shaft of the wheel in feet.

g = Acceleration due to gravity, or 32.2 ft./sec./sec.

The following table gives the values obtained:

ACCELEROMETER ERECT

<i>R</i>	R. P. M.	r.p.s. = <i>N</i>	<i>A</i>	<i>A</i> (top of wheel)	<i>A</i> (bottom of wheel)
2.84	46.5	0.775	2.09	1.1	3.1
2.84	70.0	1.167	4.74	3.7	5.7
2.84	92.0	1.533	8.19	7.2	9.2

ACCELEROMETER INVERTED

2.99	51.0	0.85	-2.65	-1.7	-3.7
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¹The accuracy of the measurements did not warrant giving the results any closer than the nearest 0.1.

It should be noted that the reference line in the records of the instrument is not at 0, but corresponds to $-0.75 g$.

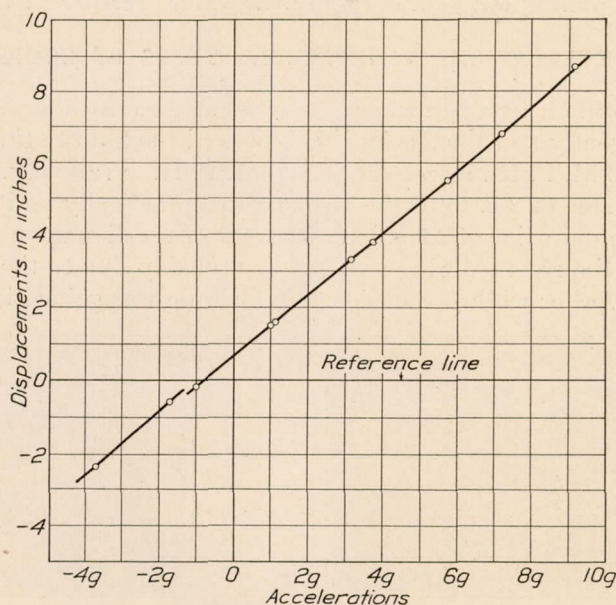


FIG. E.—Calibration curve for Norton accelerometer No. 100.

The calibration curve was found to be a practically straight line. (See fig. E.) The discontinuity in the curve is due to the fact that the hairspring which takes the play out of the mirror is unable to perform its function under negative accelerations.

MOUNTING OF THE INSTRUMENT

Considerable difficulty was encountered in designing a suitable mounting for the instrument, but it was found that excellent results could be obtained by supporting it on rubber sponges. The instrument was carried in a box which allowed a clearance of about three-quarters of an inch on all sides. Four sponges were placed under the instrument, with two on top. This mounting absorbed all vibration except when the airplane was held in a power spin and a tight spiral with power. In the case of the spin, the amplitude appears to be dependent upon the engine speed, while the period is probably dependent upon the airplane itself. The principal cause of the vibration in this maneuver appears to have been propeller flutter. In the case of the power spiral, the fact that the acceleration is fairly large and of considerable duration caused the sponges to be compressed, thus decreasing their elasticity and allowing the effect of the vibration on the records to be much more marked.

CALIBRATION OF THE AIR-SPEED INDICATOR

The air-speed indicator on the airplane was calibrated by flying-speed courses at the ground. The following table gives the results of this calibration:

Indicated air speed	True air speed (at the ground)
<i>M. P. H.</i>	<i>M. P. H.</i>
50	57.0
60	68.3
70	78.0
80	85.6
90	95.3
100	105.0
110	114.5
120	124.0
130	133.6
140	143.3
150	153.0
160	162.5

The air speeds mentioned in the following discussion, with the exception of the results giving accelerations in pulling out of a dive, are the values read from the air-speed indicator.

ACCELERATIONS IN DIFFERENT TYPES OF LOOPS²

Figure 6 is the record for a loop in which the speed at the start was 160 M. P. H. The stick was pulled back very gently and the airplane was allowed to climb to the top of the loop. The speed at the top was 60 M. P. H., increasing to 120 M. P. H. in recovery. The acceleration was almost constant at a value of 2 *g*. until the airplane was practically on its back, then fell off to 0.5 *g*., rising to a maximum value of 2.7 *g*. in pulling out of the dive upon completion of the loop. (The irregular part of the record during recovery is probably due to the fact that the airplane passed through the propeller wash.) Considerable altitude was gained in making this loop.

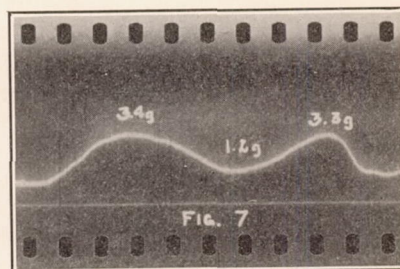
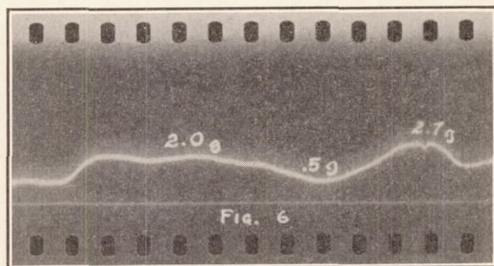


Figure 7 is the record for a loop, started at a speed of 160 M. P. H., in which the stick was pulled back more rapidly than in the first one and the first quarter of the loop was of much shorter radius. The speed decreased to 60 M. P. H. at the top, increasing to 120 M. P. H. in pulling out. The maximum acceleration in starting into the loop was 3.4 *g*. This decreased to 1.2 *g*. at the top and increased to a maximum of 3.3 *g*. in pulling out of the dive. Had the airplane been held on its back a little longer at the top (which the pilot could have done by pushing forward on the stick) it would have been a practically circular loop, with no gain or loss of altitude.

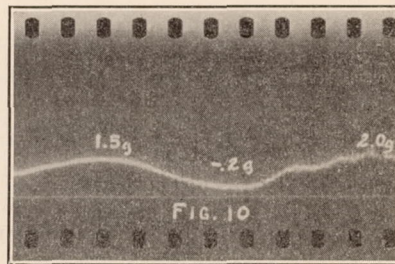
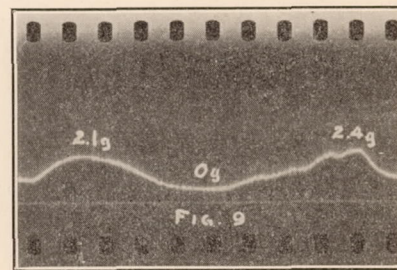
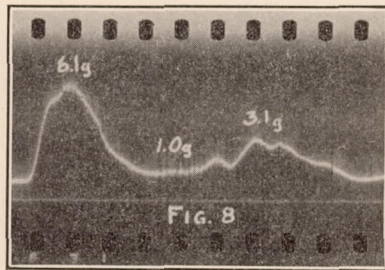
Figure 8 is the record for a loop, started at 160 M. P. H. in which the stick was pulled back quickly, the airplane being allowed to fly itself over. The speed decreased to 50 M. P. H. at the top, increasing to 110 M. P. H. in recovering. The acceleration reached a value of 6.1 *g*. very quickly, then fell to a value of 1 *g*. at the top. The record shows that the recovery was very

² All the following tests were carried out during the pilot's first flight in the airplane, and represent loads that might be imposed by an inexperienced pilot rather than those normally imposed by one with considerable experience in flying the airplane. The pilots of the First Pursuit Group, United States Army Air Service, contend that a modern pursuit airplane should be capable of withstanding quick recovery from long dives. The accelerations obtained in recovery from dives at different air speed serve as an indication of the load factors for which the modern pursuit airplane must be designed.

poorly made in this case, the acceleration increasing by jumps to a maximum of 3.1 *g*. Altitude was lost in making this loop.

Figure 9 is the record for a loop started at 120 M. P. H. The speed fell to 30 M. P. H. at the top and rose to 105 M. P. H. in pulling out. The maximum acceleration at the start was 2.1 *g*; this fell to zero at the top, and rose to a maximum of 2.4 *g* in pulling out.

Figure 10 is the record for the slowest loop that the pilot was able to make. It was started at 100 M. P. H. The speed fell to 30 M. P. H. at the top, and rose to 70 M. P. H. in pulling out. The stick was pulled back gently but steadily in order to impose as small a load as possible, but, at the same time, to get the airplane on its back with as little loss of speed as possible. The maximum acceleration in starting was 1.5 *g*. This decreased to -0.2 *g* at the top, and increased to a maximum of 2 *g* in pulling out. Even though the speed of the airplane at the top of the loop was below the minimum required for level flight, there was no tendency for it to fall off on one wing, and it was possible to complete a smooth loop.



The results of the different loops show that the loads which occur in this maneuver depend upon how abruptly the pilot pulls back on the control stick when starting a loop at any given speed. In the recovering from the upside down position at the top of the loop, the pilot tends to allow the airplane to dive farther than is necessary and then pulls out too abruptly. In case the airplane stalls in the upside down position, the tendency to do this is even greater, because the pilot is anxious to regain flying speed. Then, after regaining flying speed, he recovers as quickly as possible in order to avoid unnecessary loss of altitude. This, of course, imposes greater loads than are actually necessary. The pilot attempted to guard against this condition, but it shows to some extent in the records.

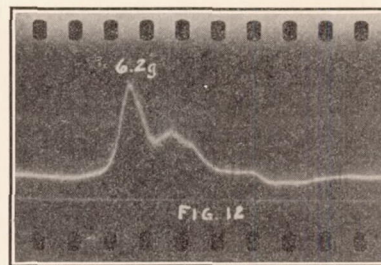
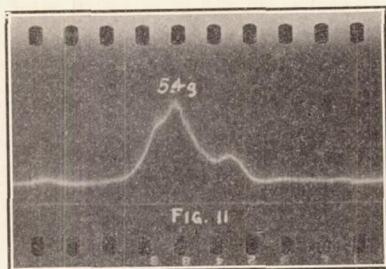
The time required to complete a loop with this airplane was from 12 to 18 seconds, depending upon the speed at which the loop was started and the diameter of the loop.

ACCELERATIONS IN SINGLE AND MULTIPLE BARREL ROLLS

The exact manner of executing a barrel roll differs with each pilot and each type of airplane, but in any case the airplane must be brought rapidly to a large angle of attack while traveling at a comparatively high speed. The method used in these tests was as follows: The stick was pulled back and to the right, thus imparting a rolling moment at the same time that the angle of attack was rapidly increasing. Right rudder was then applied, and almost immediately thereafter the ailerons were crossed. (While the ailerons are not necessary for the execution

of single and double barrel rolls, the maneuver is started with greater ease and rapidity by using the ailerons. The use of the ailerons in triple and quadruple rolls is almost essential.)

The cumulative effect is to cause autorotation about an axis coinciding approximately with the original direction of the airplane. The longitudinal axis of the airplane is at a considerable angle to this axis of rotation. The angular velocity of the roll depends upon the speed at which the roll is started. The effect of this is found in practice by the tendency of a high-speed airplane to continue rolling if thrown violently into the first roll. It is easier to come out of each succeeding roll on account of the decrease in forward velocity, which makes for a decrease in the angular velocity of roll. The forward velocity finally decreases to a point where the airplane no longer continues to roll unless the airplane is allowed to dive more and more steeply to maintain the proper speed. In this case the roll finally becomes a spin. In the case of a relatively low-speed airplane this point is reached after the first roll, and in very low-powered airplanes it is generally necessary to dive the airplane with power on to give the speed required for the completion of one roll.



The aerodynamics of the roll and the spin are essentially the same, and this similarity is substantiated, in the records for multiple rolls, by the rapid falling off of the peak loads after the initial maximum and the tendency toward a constant load. In the following records the momentary stoppages of the recording film make it impossible to determine accurately the time required to complete any of the rolls. It appears, however, that a single roll requires about 5 seconds, a triple roll about 9 seconds, and a quadruple roll about 12 seconds, for completion.

Figure 11 is the record for a single roll executed gently, starting at a speed of 150 M. P. H. The stick was pulled back slowly, as indicated by the slope of the curve. The airplane did not whip over as it should, so the stick was pushed forward very slightly and then jerked back. (The point of pushing forward on the control stick shows as a flat spot about three-quarters of the way up on the curve.) The airplane then whipped over and came out of the roll with a forward speed of 100 M. P. H. The maximum acceleration was 5.4 *g*.

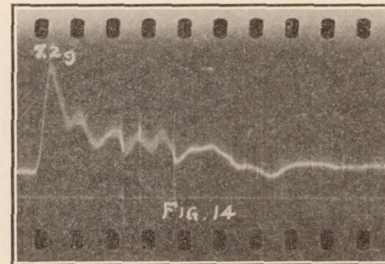
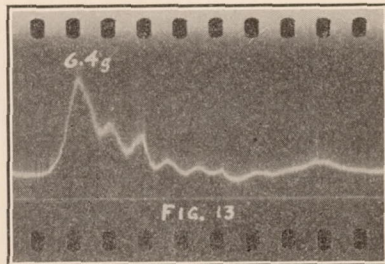
Figure 12 is the record for a single roll executed somewhat more violently, starting at a speed of 150 M. P. H. The stick was jerked back sharply, and the acceleration increased rapidly to a maximum of 6.2 *g*. The speed at the end of the maneuver was 100 M. P. H. The record shows that, after the roll was completed, the stick was pushed forward in order to bring the airplane into a level position.

A double roll was made, but the instrument did not start. The maneuver was started at 150 M. P. H. and the speed on coming out was 100 M. P. H. The airplane was nose down slightly after completion of the two rolls.

Figure 13 is the record for a triple roll, started at 150 M. P. H. and finish at 100 M. P. H. The airplane was nose down about 10° after the completion of the third roll. The stick was pulled back to bring the airplane level again. This is indicated by the small hump in the curve at the right of the record. Each roll gives two points of maximum acceleration, the first one in each case being greater than the second. The initial acceleration of 6.4 *g*, is the only one which is dangerously large.

Figure 14 is the record for a quadruple roll, started at 160 M. P. H. The stick was pulled back sharply and the acceleration increased very quickly to a value of 7.2 *g*. That the speed did

not fall off as might be expected is indicated by the fact that the second, third, and fourth rolls all gave practically the same acceleration. After the third roll, the airplane nosed down and commenced to pick up speed. The record indicates the point at which the airplane was pulled up and the fourth roll made. The angular velocity had decreased to such an extent that the fourth roll was made with difficulty. The record indicates that the time required for the completion of the first roll is the longest, due to the time lost in imparting to the airplane the initial angular velocity. The fourth roll is next in part of time required, and this due to the necessity



of pulling the airplane over, principally with the ailerons. The fine vertical lines in the figure indicate momentary stoppages of the film-actuating mechanism, and as a result the record is slightly crowded together at these points.

All rolls were made to the right, and the engine was left at full throttle. This airplane does not roll easily at lower speeds.

ACCELERATIONS IN POWER SPIRALS

Figure 15 is the record of accelerations in a power spiral. With the engine running at full throttle the airplane was banked up to approximately 70° . At first the pilot attempted to hold both speed and altitude constant, but the radius of the turn was so large that the acceleration was very small. The airplane was then pulled into a tighter turn, and the acceleration increased to a maximum of $3.3g$. During the time that the airplane was held in a turn of approximately constant radius, both the speed and the acceleration decreased. The speed dropped from 120 to 70 M. P. H. and the accelerations from $3.3g$ to $1.9g$.

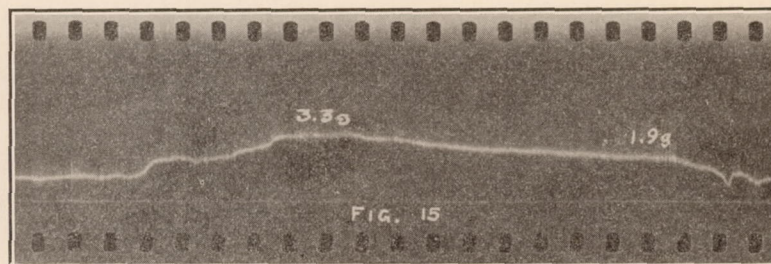
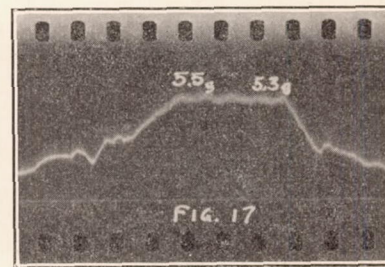
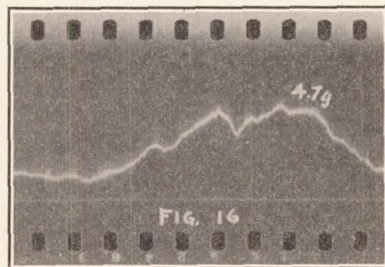


Figure 16 is the record of a power spiral of short radius. In starting this maneuver the nose was allowed to drop until a speed of 140 M. P. H. was reached. The airplane was banked to approximately 70° . It required some time for the pilot to establish steady conditions, but a constant acceleration of $4.7g$ was finally obtained. After the steady condition was reached, the pilot gradually began to lose his sight, and for a short time everything went black except for an occasional "shooting star" similar to those seen when one is struck on the jaw. The pilot appeared to retain all faculties except sight, and no difficulty was experienced in righting the airplane. Sight returned almost immediately when the acceleration was decreased to normal by restoring the airplane to a condition of steady level flight.

This maneuver was repeated to give a check on these results. The airplane was again put into a power spiral, banked to approximately 75° , at a constant airspeed of 140 M. P. H. This

speed was maintained at that value by loss of altitude. The airplane was pulled in as sharply as possible in this case, and while the loss of sight did not appear to occur more quickly the interval between normal sight and complete loss of it was apparently shorter. The airplane was quickly righted after complete loss of sight. The acceleration in this case, as shown in Figure 17, varied from 5.5 *g.* to 5.3 *g.*, being more nearly constant than in the preceding case, where less care was exercised in holding the speed, angle of bank, and stick force constant.

The effect of this maneuver on the pilot is not particularly uncomfortable. The sensation is that of having a tight band around the forehead and a feeling that the eyeballs are about a half an inch too low in their sockets.



ACCELERATIONS IN MISCELLANEOUS MANEUVERS

Figure 18 is the record for a roll off the top of a loop. The maneuver was started as an ordinary loop, except that one wing was allowed to drop slightly. At the top of the loop the wings of the airplane were almost vertical. From this position it was leveled out by means of the rudder and ailerons, and the airplane proceeded in the direction opposite to that in which the maneuver was started and at an altitude greater by the diameter of the half loop. The speed at the start was 150 M. P. H. and 50 m/h at the top of the loop. The maximum acceleration was 3.2 *g.*, falling to 0 about the time that the airplane regained its level position.

Figure 19 is the record for a maneuver that is usually called the true Immelman turn. This maneuver is made by completing the first half of a true loop. From the upside down position at the top of the loop the airplane is halfrolled to the upright level position, and flight is continued in the direction opposite to that in which the maneuver was started. In this case, the speed at the start was 150 M. P. H., decreasing to 40 M. P. H. just as the airplane came back to its position of level flight. The maximum acceleration was 4.4 *g.* The acceleration decreased to 1 *g.* at the top of the loop, increased slightly as the airplane rolled over, then decreased to 0.5 *g.* as the airplane settled just before picking up its normal flying speed.

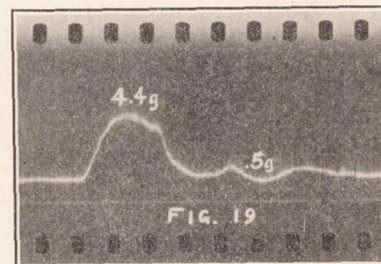
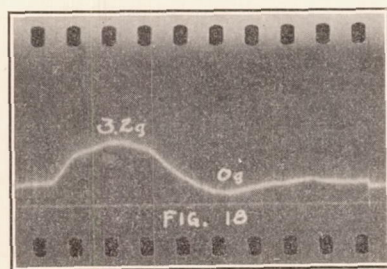
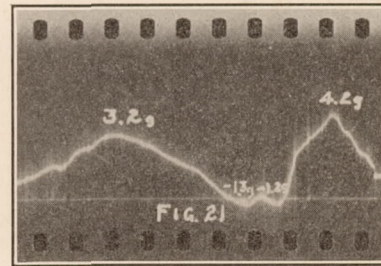
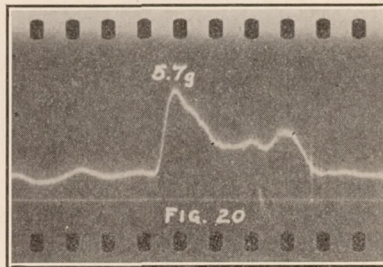


Figure 20 is the record for a vertical bank, started at 150 M. P. H. and finished at 90 M. P. H. In executing this maneuver the airplane was first rolled over to a position with the wings vertical and then pulled around as quickly as possible without loss of altitude. The maximum acceleration was 5.7 *g.* The latter part of the record is irregular and indicates that the recovery was very poorly executed.

The first peak in Figure 21 is the acceleration due to starting a loop. At the top of the loop the stick was held forward in order to keep the airplane on its back. In this position the

stick was pushed forward twice, and the maximum negative accelerations recorded were $-1.3 g$ and $-1.2 g$. The second positive peak is that due to recovery from the dive and getting the airplane in normal position again. The curious part of inverted flying is that the accelerations seem to be much larger than they really are and that they appear to be of much greater duration.

Figure 22 is the record for a spin with the engine throttled. The airplane was stalled, and it turned through approximately 180° before it fell off into the spin. The first vertical line on the record was made after one and a half turns had been completed, the next after five more turns, and the last one after five more turns. The maximum acceleration was $2.6 g$, after which it became practically constant at a value of $2.1 g$. The record indicates that the oscillations



which are sometimes found in accelerometer records of spins³ are, in this plane, damped out after the second turn. This may be due in part to the manner of going into the spin. The airplane came out of the spin very easily and quickly. The record indicates a time interval of something less than one second per turn in the spin.

Figure 23 is the record for a spin with full power. The spin was started by pulling the airplane up until the nose was almost vertical. It was then allowed to fall off into a right-hand spin. The average acceleration was $2.3 g$. The record indicates that there was considerable vibration during this maneuver, and it appears to have been due to propeller flutter. The vibration did not appear in the wings. The number of turns made was not noted, but the spin seemed to be faster than the one without power. The pilot attempted to stop the spin without throttling the engine, but the airplane did not respond readily. At this time the airplane was too close to the ground to continue attempts at recovery, so the engine was throttled and the airplane recovered at once. It is believed that this airplane could be brought out of a spin without throttling the engine, but that loss of altitude in so doing would be considerable.

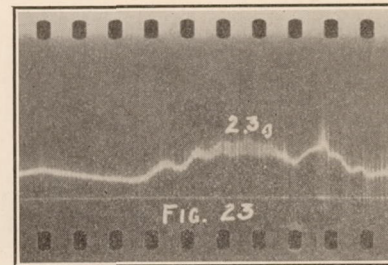
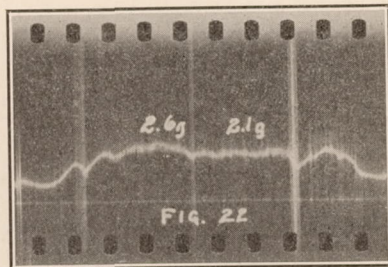


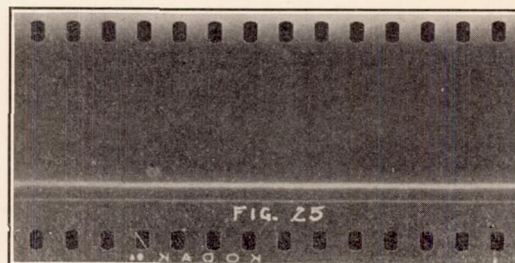
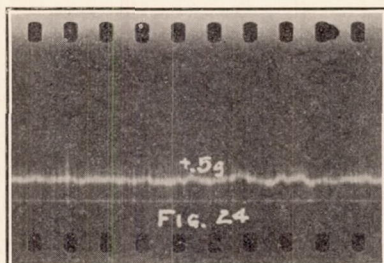
Figure 24 is the record taken while flying the airplane in a practically straight level course while banked up to approximately 60° . A steady acceleration of $0.5 g$ was recorded. This indicated that the effective lift given by the wings is $0.5 \times \cos 60^\circ = 0.25$, or approximately one-quarter the total weight of the airplane. The remainder of the lift is being given by the side-fin area of the airplane, which includes the fuselage, fin, rudder, chassis, etc.

ACCELERATIONS DUE TO FLYING IN ROUGH AIR

There are several conditions which go to make up the condition described by pilots as "rough air." The disturbance may be due to convection currents, to the eddying of the wind

³ See fig. 24, National Advisory Committee for Aeronautics Technical Report No. 99, "Accelerations in Flight," 1920.

over uneven terrain, one or both of which the pilot may encounter at altitudes as great as 6,000 feet above the surface of the ground, or to the eddying of the air in the plane between two layers of air traveling in different directions. This type of disturbance may be met at any altitude. The effect on the airplane of flying into such disturbances depends upon how the airplane meets the disturbance. If the airplane flies directly into an up current, there is a sudden increase



in lift and the pilot experiences a bump that throws him into his seat more firmly. With a down current the reverse is the case. If, however, the airplane encounters a rising or descending current with one wing only, the effect is to roll the airplane out of its level position.

In order to obtain some records of the accelerations resulting from flying in rough air, an accelerometer was mounted in a *DH-4B* airplane. This airplane was flown on cross-country trips for a total of about 35 hours. No very severe bumps were encountered, and the records may be taken to indicate normal flying conditions.

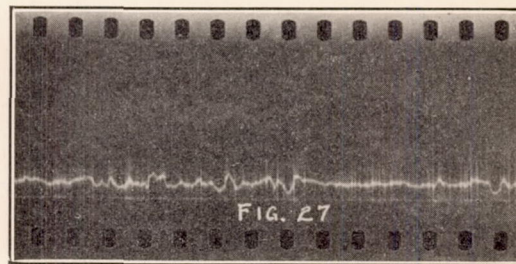
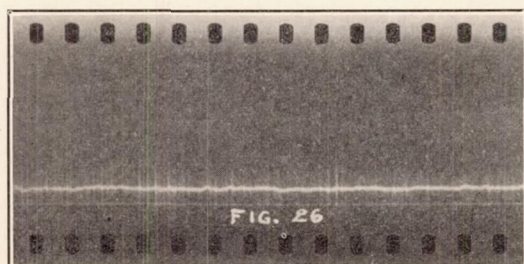
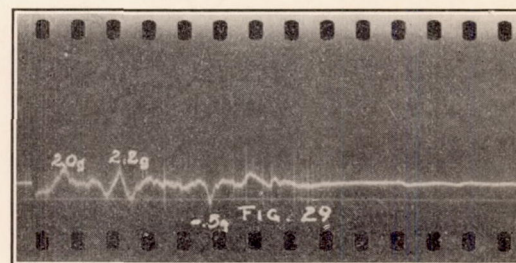
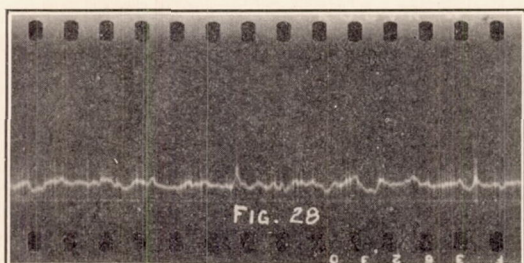


Figure 25 is a record taken while flying over the level country near Winchester, Md., at an altitude of 2,000 feet. The record shows an absence of any disturbances.⁴

Figure 26 is a record taken over the same area on another day, showing practically no disturbances.

Figures 27 and 28 are records taken in flight over the mountains between Washington and Moundsville. The ridges were crossed at low altitudes, and the weather conditions may be



considered as average for this location. The accelerations obtained vary from small negative values to almost 2 *g*.

Figure 29 is a record taken while flying at 1,500 feet over the level country between Wilmington and Philadelphia. The accelerations obtained vary from 2.2 *g*. to -0.5 *g*., and the

⁴ These records were made in December, 1923. The instrument had a different setting and the calibration curve given in fig. E does not apply.

changes occur suddenly. It is probable that these accelerations are the result of the airplane's flying into convection currents.

No very severe atmospheric conditions, such as thunderstorms, were encountered on these flights, and it is not possible to predict the accelerations that might be encountered under such conditions. In general, accelerations set up as the result of bad atmospheric conditions seem to the pilot to be much more severe than they really are. In maneuvers the pilot knows about what to expect and he is prepared for it, but when he is thrown up against the safety belt or down into the seat unexpectedly, he has the impression that conditions are worse than accelerometer measurements would indicate.

ACCELERATIONS IN PULLING SUDDENLY OUT OF A DIVE

The maximum theoretical acceleration that can be given to an airplane can be calculated as follows: The minimum speed at which the airplane can fly is

$$V_{\text{minimum}}^2 = \frac{\text{Lift} = \text{Weight}}{K_y \text{ maximum} \times \text{Area of wings}}$$

If the airplane is flying at a speed higher than the minimum, the angle of attack will be such that the value of K_y will satisfy the general lift equation. If, while flying at any value of V larger than the minimum, the angle of attack is instantly changed to that giving maximum K_y , the speed can not instantly change to V_{minimum} and the result is that the lift on the wings is no longer equal to the weight but is of a considerably larger value. The ratio of this larger lift to the weight of the airplane is the acceleration in terms of g and is

$$\frac{F}{W} = \frac{V^2}{(V_{\text{minimum}})^2}$$

The maximum speed at which the airplane can travel is its limiting speed in a vertical dive, where the weight is equal to the drag of the airplane. Then the maximum theoretical acceleration which can be given to any airplane is

$$\frac{F}{W} = \frac{(V_{\text{maximum}})^2}{(V_{\text{minimum}})^2}$$

For the *JN-4* (Curtiss) this is about 14. For high-speed racing airplanes it may be as much as 25, and for the airplane used in making the above tests, assuming a minimum speed of 57 M. P. H. and a maximum of 250 M. P. H., it is approximately 19. In other words, if the airplane is diving at limiting speed and the elevators are instantly pulled up to balance at the angle of attack of maximum lift, the wings must be able to support a load equal to 19 times the weight of the airplane if they are to bring the airplane out of the dive.

If the airplane can not be brought to the angle of attack of maximum lift instantly, the acceleration will not be as great as the theoretical one. In order to get a comparison between the theoretical and the actual accelerations when pulling out of a dive at various air speeds, this airplane was, as suddenly as possible, pulled out of a dive at airspeeds of 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, and 160 M. P. H. (indicated). These air speeds were reduced to true speeds for the purpose of comparison, as shown in the following table:

Air speed	Acceleration (experimental)	Acceleration (calculated)
<i>M. P. H.</i>		
66.3	1.3	1.35
76.0	1.6	1.78
85.6	2.1	3.25
95.3	2.7	2.79
105.0	3.3	3.40
114.5	3.9	4.04
124.0	4.6	4.74
133.6	5.3	5.50
143.3	6.1	6.32
153.0	6.4 (low)	7.22
162.5	7.8	8.15

Figures 30 to 40 are the records from the accelerometer.

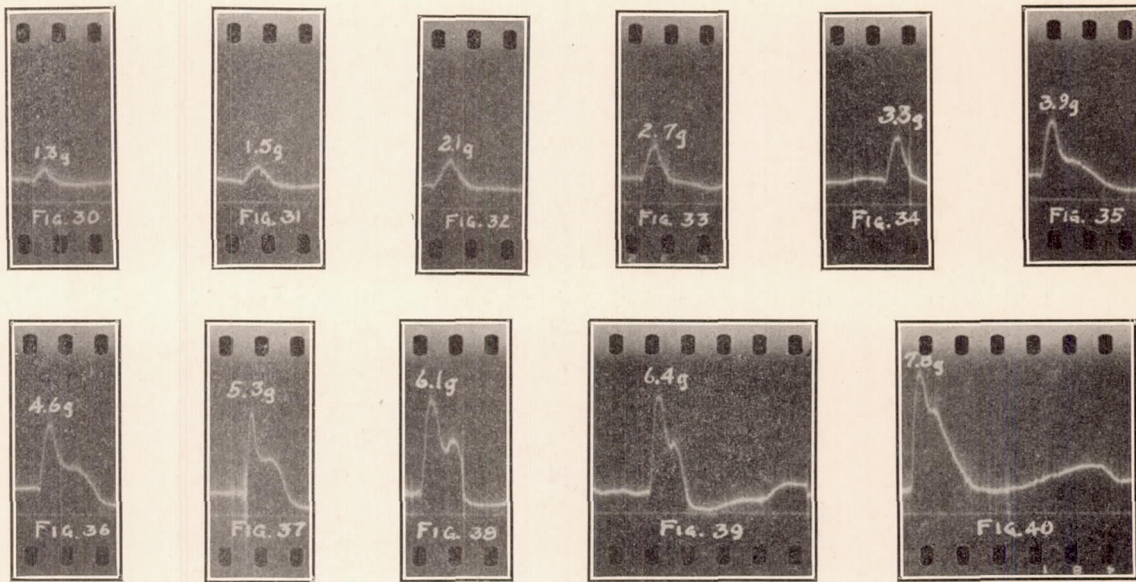


Figure 41 gives the curves plotted from the data in the above table. All points derived from the experimental data, with the exception of the point at 153 M. P. H., lie on a smooth curve which lies below the theoretical curve by approximately 3.5 per cent. The calculations were based on a minimum speed of 57 M. P. H. It is difficult to determine this accurately. If the minimum speed were 56 M. P. H., the calculated values would exceed the experimental values by approximately 7 per cent, and if the minimum speed were 58 M. P. H., the calculated and experimental values would be approximately the same.

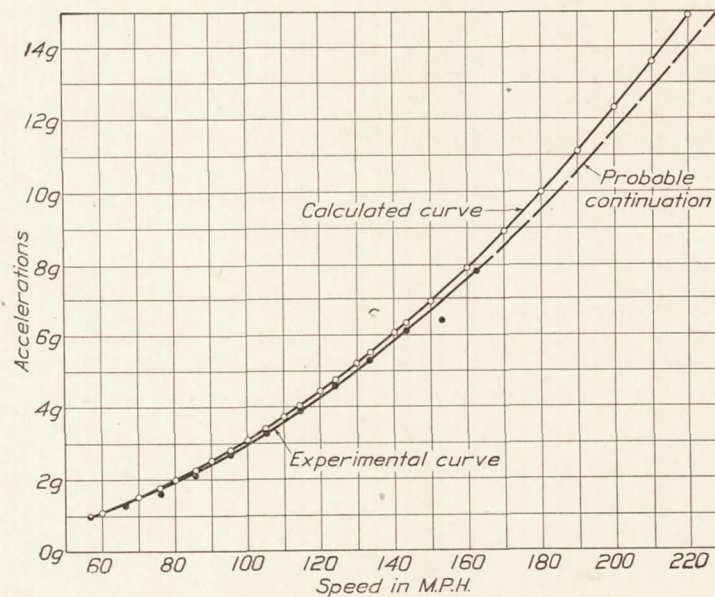


FIG. 41.—Curves showing theoretical and actual wing loads on PW-7 (Fokker) pursuit airplane

After landing, inspection of the wings of the airplane showed that the veneer covering of the upper wing, on the under surface, had split from the trailing edge to the rear spar, and from the trailing edge to a point back of the rear spar on top, as shown in Figure 42. In this particular type of construction there is no drag bracing between the spars; the veneer covering replaces it.

At the high angles of attack, at which all severe loads occur, there is a considerable antidrag load on the wing. The drag stresses are assumed to be taken by a box beam, the two spars acting as the flanges and the veneer covering as the webs. Actually the entire wing acts as a beam, and the trailing edge is not sufficiently strong to act as a part of the flange, particularly in the cutout at the center section where the failure occurred. This failure is not dangerous, as the rear spar would have to break before it could go any farther. The failure demonstrates clearly that the wing has deflected up and forward under the load.



FIG. 42.

CONCLUSIONS

It appears from the above tests that the worst stresses are imposed on an airplane in the sudden recovery from dives at high speeds, although the acceleration obtained in making a barrel roll at the same speed is only 5 or 10 per cent smaller. The actual load which can be imposed depends chiefly upon:

- (a) The ratio of the square of the speed of the dive to the square of the minimum speed.
- (b) The degree of longitudinal stability inherent in the airplane.
- (c) The damping due to pitch.
- (d) The time required to move the elevator in changing the angle of attack from a small to a large value. This is really a function of how much force the pilot is required to exert in moving the control stick.

In all airplanes other than the pursuit type the first three items are of such magnitude that it is certain that extremely high loads can not be imposed. The control forces will be great enough to prevent anything approaching instantaneous change of angle of attack unless the elevators are exactly balanced. Even in this case the other three conditions would probably operate to prevent it.

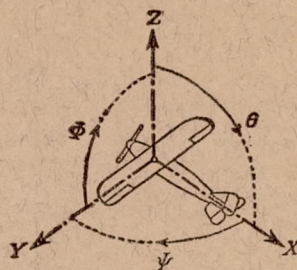
In the case of the pursuit airplane the speed range is great, and stabilizing and damping forces are reduced to a minimum consistent with easy handling in combat. The ability of the pilot to impose large dynamic loads therefore depends largely upon the ease with which he can move the elevators when traveling at speeds in excess of the maximum horizontal speed. If the elevators are perfectly balanced, there seems to be no reason why he can not impose loads very close to the theoretical values, and in the above tests, made with an airplane having elevators almost perfectly balanced, the actual loads obtained were but 3.5 per cent less than the theoretical. This airplane was designed to support a dynamic load of 8.5. Actually it would probably support about 10, judging by a static test of an airplane exactly like this one except that the wings were fabric covered. It would follow that if the airplane were suddenly pulled out of a dive at a speed in excess of 185 M. P. H. (and which would frequently occur in actual combat with this airplane) the wings would fail. It was this consideration which caused the engineering division of the Air Service to require a factor of 12 at high angles of attack for pursuit airplanes and to recommend against the use of balanced controls on that type.

EFFECT OF LARGE ACCELERATIONS ON THE PILOT

From the results of these tests it is apparent that serious physical disorders do not result from extremely high accelerations of very short duration, but that accelerations of the order of 4.5 *g.*, continued for any length of time, result in a complete loss of faculties. This loss of faculties is due to the fact that the blood is driven from the head, thus depriving the brain tissues of the necessary oxygen. To the pilot it seemed that sight was the only faculty that was lost. The flight surgeons at McCook Field are of the opinion that sight is the last faculty to be lost under these conditions, even though the pilot may be under the impression that he retains all the others. This opinion is based on the observation of men undergoing rebreather test. The acceleration which an individual can withstand for any length of time depends upon his blood pressure, the person with the higher blood pressure being able to withstand the higher acceleration. Upon the condition of the heart depends the ability of the individual to recover quickly from the effect of prolonged acceleration. If the heart is in good condition, there is no danger in undergoing such a strain unless the acceleration is continued for a period in excess of 10 or 12 minutes, after which death will result. The same is true of the rebreather test; unconsciousness will result from the deprivation of oxygen and death will result if this is continued for the same length of time.

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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.		Designa- tion.	Sym- bol.	Positive direc- tion.	Designa- tion.	Sym- bol.	Linear (compo- nent 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

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

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 $\Phi = \tan^{-1} \left(\frac{V}{2\pi r n} \right)$

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.