NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 418

PRELIMINARY INVESTIGATION OF MODIFICATIONS TO CONVENTIONAL AIRPLANES TO GIVE NONSTALLING AND SHORT-LANDING CHARACTERISTICS

By FRED E. WEICK

1932

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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.

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By FRED E. WEICK
Langley Memorial Aeronautical Laboratory

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By Fred F. Weick

SUMMARY

This report describes flight and landing tests made on a group of conventional airplanes at the laboratory of the National Advisory Committee for Aeronautics. The upward deflection of the elevators was limited to the point where the airplanes could not be made to spin without the aid of power. With the elevator travel thus limited, the airplane in every case had good lateral stability and good aileron effectiveness up to the highest angles of attack which could be obtained in a glide, although this was not true in any case without the limited control. All ordinary flight maneuvers could be performed with the elevator displacement limited, but usually there was not sufficient control to get the tail down for a normal 3-point landing.

In order to investigate the feasibility of making landings by gliding straight to the ground with the full but limited amount of tail-depressing longitudinal control in use, glides were made and the vertical velocities measured. These were found to range from 12 to 24 feet per second for the various airplanes tested; and since the lateral stability and control in the glides with the control sticks full back to the limited positions were satisfactory, it seemed that landings could be satisfactorily made in this manner if reasonably long-stroke shock-absorbing landing gears were provided. In addition, a comparison was made between the computed distance required to glide in this manner over an average obstruction and alight upon the ground and the distance required for the shortest conventional-type landing. For this purpose both medium and short conventional landings were measured with all the airplanes tested, and the comparisons indicated that much shorter landings could be made by gliding straight in with the stick full back to the limited position.

As this type of landing seemed to have several advantages, one of the airplanes (the Verville "AT") was fitted with long-travel shock-absorber struts and actual landing tests were made in which the distances, as well as the accelerations upon contact with the ground, were measured. The glide landings with the control stick full back to the limited position were satisfactory, the landing runs as well as the air distances being substantially shorter than the shortest present-day conventional landings. Other landings made by gliding straight in at higher air speeds, and landings in which the flight paths were somewhat leveled off just before contact were also satisfactorily performed. The various landing tests showed that with the airplane as modified a safe landing is made in smooth air almost regardless of the manner in which the airplane is brought to the ground, as long as the air speed is held to within about 15 miles per hour of the minimum, the wings are held level laterally, and the controls are not used violently. In gusty air other factors are encountered which complicate the problem, and this condition is being studied further.

After it had been determined that satisfactory landings could be made, more detailed flight tests were made on this airplane with the elevator deflection limited. These showed that the control limitation did not appreciably affect the ability to perform acrobatic or ordinary maneuvers in flight, and that the airplane could be satisfactorily maneuvered in turns during glides with the stick full back to the limited position.

INTRODUCTION

The problem of improving the safety of flying continues to be of paramount importance. Accident reports indicate that most accidents are still connected with forced or bad landings or with the tendency of airplanes to spin under the very conditions in which they should be most readily controlled; i. e., at the slow air speeds and high angles of attack likely to be encountered in a forced landing. The statistics given in one of these accident reports (reference 1) show that of the reported accidents in the Army, Navy, and commercial activities up to 1929 slightly more than two-thirds were connected with spins, stalls, or landings. One-half of all the accidents are listed as caused either by the deficiency of the pilot in regard to technique or judgement or to carelessness. It is therefore evident that at the present time airplanes are too difficult to land and to control, particularly in critical situations, such as forced landings. It is also evident that the safety of flying would be greatly increased if airplanes (1) had satisfactory stability, (2) required less skill to land, and (3) required a smaller space for landing.

That present-day conventional airplanes have unsatisfactory lateral control and stability at their slowest speeds and at their highest angles of attack is well known. In general, however, the bad conditions exist only at angles of attack near or above that of the stall (the peak of the lift curve). This difficulty has been overcome in some cases by the use of special devices, such as slots or auxiliary airfoils, that increase the angle of attack at which the wing, or at least the tip of the wing, stalls. If this angle happens to be above that which can be maintained with the amount of longitudinal control available, the lateral stability and controllability should be at least fairly satisfactory throughout the entire possible speed range. In this connection a study of the problem of spinning led to the conclusion that any airplane can be spun, regardless of the devices, such as slots, with which it may be equipped, if it has sufficient longitudinal control to maintain a high enough angle of attack to actually stall the entire wing.

All these points considered, the fact seems apparent that if an airplane is to be laterally stable and controllable throughout its entire range, it must meet the fundamental requirement of having the longitudinal control insufficient to maintain an angle of attack at which the entire wing is stalled.

The results of a number of stalled glide tests with ordinary conventional airplanes (reference 2) gave an indication that most of the airplanes tested had only a small amount of longitudinal control beyond that required to just stall them. It seemed that with several of the airplanes only a small limitation in the uptravel of the elevators would be required to keep them from spinning without the aid of power, and that they would probably still have sufficient control for all ordinary flight maneuvers. In this connection an earlier test is of interest. In this test the uptravel of the elevators had been limited on a *VE–7* airplane to the point where it could not be spun without the aid of power. This test showed that all ordinary maneuvers in flight could be accomplished satisfactorily with the limited control except that there was not sufficient control to get the tail down for a normal 3-point landing.

Although it is likely that the provision of this limitation in the longitudinal control would ordinarily in itself be a definite improvement in safety without seriously affecting the landing characteristics, a further study of the landing situation was made. From this study it seemed that an airplane having its longitudinal controls limited to the point where it could not be actually stalled in a glide would be reasonably stable and controllable with the full amount of tail-depressing longitudinal control in use, and that such an airplane could be safely landed by gliding in to the landing surface with the control column full back if it were equipped with a landing gear which would satisfactorily absorb the shock. This kind of landing can not be safely made in present-day conventional airplanes without limiting their longitudinal control, regardless of the shock-absorbing capacity of the landing gear, because of the poor lateral stability and controllability at high angles of attack and the possibility of losing control or falling into a spin. It also seemed likely that an otherwise conventional airplane could be landed in this manner with less skill and in a shorter distance, as well as without the particularly good eyesight (depth perception) required for the present-type landings with their leveling-off step.

In order to study further the feasibility of this combination of longitudinal control and landing, two sets of simple flight tests were run and are reported here. Both sets were made on the same conventional airplanes. In one set landings were made in the conventional manner as a basis for comparison. The horizontal distance required to get from a height of 50 feet to the ground was measured, and also the distance required to come to a stop. With every airplane medium 3-point landings were made first and then the shortest landings which, in the estimation of the pilots, could be safely made. In the other set of tests, the uptravel of the elevators was limited until the airplane could not be made to spin, first without and then with the aid of power. Then the vertical velocity and the effectiveness of the aileron control were noted in glides with the control stick full back to the limited positions. The horizontal distance required to get from an altitude of 50 feet to the ground by gliding in with the control stick back at the limited position was then estimated and compared with that required for the shortest ordinary-type landing made with the same airplane.

Inasmuch as the above simple tests indicated that all the airplanes could be flown satisfactorily throughout the entire speed range with the controls limited to the point where a spin could not be performed without the aid of power and that with the glide-type landings the landing distance could be materially reduced, a more complete trial with actual landings was thought desirable. One of the airplanes, the Verville *AT*, was fitted with a long-travel shock-absorbing gear and was repeatedly landed by gliding in from an altitude to the landing surface with the control stick held back to the limited position. Other landings were made by gliding to the surface at successively higher air speeds, and also by gliding in at these higher air speeds to a height of a few feet and then pulling the control stick back to the limited position to flatten out the glide and reduce the landing shock. In addition, more complete tests were made on the effect of the limited control on the various flight characteristics of the airplane.

It is desired to acknowledge the assistance in this work of the committee's test pilots, William H. McAvoy and Melvin N. Gough, particularly in suggesting some of the latter tests on the flight characteristics with the controls limited.

CONVENTIONAL LANDING TESTS

A list of the airplanes tested, together with their main specifications, is given in the following table:

Airplane	Engine	Approximate gross weight in test	Wing area (square feet)	Wing loading (pounds per square foot)	Type
Doyle O-2	LeBlond	1,320	160	8.2	Open monoplane.
Fleet XN2Y-1	Warner	1,580	194	8.2	Open biplane.
Consolidated PT-1	Wright E-2	2,500	283	8.9	Do.
Verville AT	Continental	2,300	242	9.5	Do.
Boeing PW-9	Curtiss D-12	2,800	241	11.6	Do.
Curtiss Falcon A-3	Curtiss D-12	4,300	351	12.3	Do.
Fairchild FC2W-2	P. & W. Wasp	4,371	336	13.0	Cabin monoplane.
Fairchild FC2W-2	P. & W. Wasp	5,330	336	15.9	Do.

Almost every field in which a landing is likely to be made is surrounded by obstacles such as trees, buildings, or electric wires, which make it necessary for the airplane to have an altitude of about 50 feet or more at the edge of the field. The comparison of the distances required for landing should, to be of real value, therefore take into account the horizontal distance required from a point where the airplane is over an obstruction to a point where it touches the ground, as well as the length of the ground run after touching. In these tests the horizontal distance required for the airplanes to get from an altitude of 50 feet to the ground was measured, as well as the length of the ground run. These distances were obtained for normal 3-point landings and also for the shortest landings which the pilots considered it safe to make, considering the stability and controllability of the airplane while landing and the ability of the landing gear to absorb the shock without failure. These short landings were made by gliding in as near the stall as possible but still with sufficient speed to level off just before touching the ground, so as not to damage the landing gear. In the case of the Fairchild, fast 2-point landings were also made for comparative purposes. All landings were made on a reasonably smooth, level, and firm field covered with grass.

In making the tests it was desired that the pilot not actually be forced to fly over an obstacle, which would not only introduce errors in that the exact altitude while crossing the obstacle would be difficult to measure, but would require a part of the pilot's attention to direct the airplane to just the right position and not leave him free to make the best and shortest possible landing. The landings were therefore made in a large field (Langley Field) and a simple method was used to mark the spot at which the airplane had an altitude of 50 feet when coming in to land. This marking was done by suspending a small paper bag filled with a white powder (whiting) so that it hung 50 feet below the airplane; as the airplane came down to that altitude the bag struck the ground and broke, leaving a white mark. The bag was supported by a fine fishline cord and loaded with lead shot, so that at the speeds of the approaching glides it trailed back at an angle of about 20°, this angle being considered, of course, in determining the length of the cord. This length was such that the bag hung 50 feet below the bottoms of the wheels. Another bag of powder was suspended at the level of the bottoms of the extended wheels, this one marking the spot where the airplane touched the ground.

Most of the airplanes tested were not equipped with brakes; and since reasonably reliable data on the effect of brakes on the landing run were available (reference 3, and unpublished tests with Fairchild), all these landings were made without the use of brakes. Computed ground runs are also given for all the airplanes

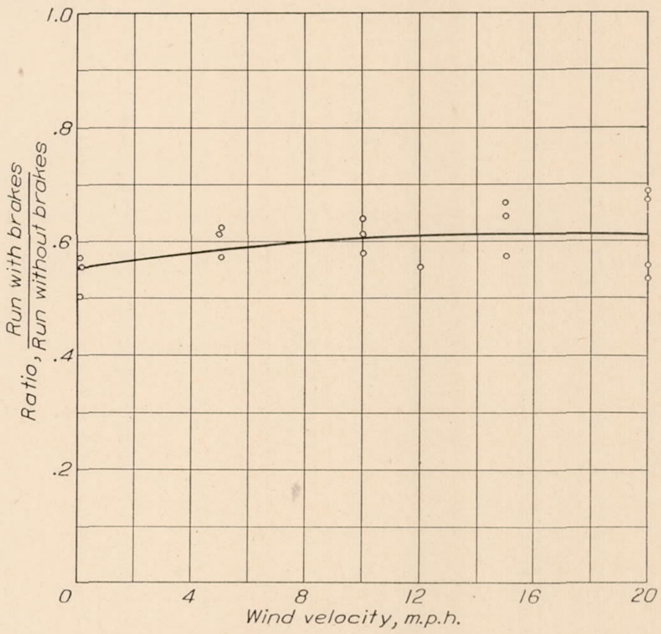

FIGURE 1.—Effect of brakes on the landing run

landing with the brakes on, the computations being based on the above tests made with and without the use of brakes. (An exception was made in the case of the Verville, which was tested both with and without brakes, because of the fact that it was used in the final glide landing tests.)

The wind velocity was measured near the point of landing with a vane-type anemometer and the results of the landing tests were corrected to the condition of no wind. This correction was made with the aid of relations obtained from the above brake tests, which are plotted in Figures 1 and 2. First, the landing run with brakes is found for the same wind from the average line in Figure 1. Then the run with brakes but with no wind is found from Figure 2. Finally, the run with no wind and without brakes is computed by increasing the run with brakes by 82 per cent, this being the average value from the above tests. Although all these corrections must be considered approximate, they apply to performances which are very difficult to repeat exactly, and they therefore serve their purpose satisfactorily.

In addition to the wind correction to the ground run, the horizontal distance required to get from an altitude of 50 feet to the ground was also corrected for wind velocity, assuming that the wind velocity was the same up to an altitude of 50 feet as at an altitude of 6 feet, where it was measured. On account of the velocity gradient which is ordinarily present, the actual wind velocity was no doubt somewhat higher at 50 feet, and the correction for the wind was therefore somewhat smaller than it should have been; but since all these tests were run during low wind velocity (3 to 7 miles per hour), the error in the correction does not seriously affect the results.

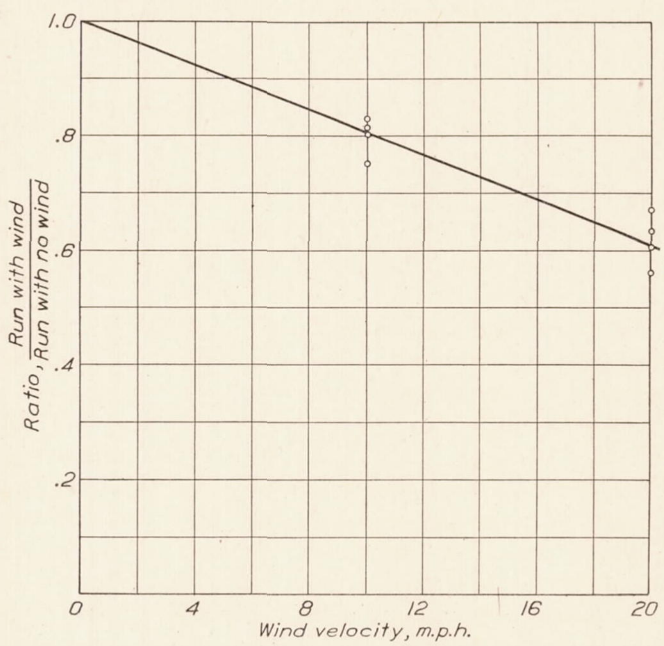

FIGURE 2.—Effect of wind on the landing run, brakes being used to full extent

The results of the conventional landing tests are given in detail in Table I. The horizontal distance required to get from an altitude of 50 feet to the ground and also the total distance required to get from an altitude of 50 feet to a stop, corrected to the condition with full use of brakes and no wind, are listed in the following table for the shortest landings made with each airplane.

Wing loading (pounds per square foot)	Airplane	Horizontal distance required (feet), full brakes: 50-foot altitude, to ground	Horizontal distance required (feet), full brakes: 50-foot altitude, to stop
8.2	Doyle O-2	386	700
8.2	Fleet XN2Y-1	505	811
8.9	Consolidated PT-1	400	686
9.5	Verville AT	434	880
11.6	Boeing PW-9	533	1,043
12.3	Curtiss Falcon A-3	777	1,202
13.0	Fairchild FC2W-2	752	1,212
15.9	Fairchild FC2W-2	628	1,225

The distance required to get from a height of 50 feet to the ground is from one-half to two-thirds of the total distance, the average value being 57 per cent. Several of these landings were accompanied by severe shocks and bounces; and although it can not be definitely stated that they were the shortest landings possible without breaking the airplanes, they certainly represent the shortest which could be made with reasonable safety to the airplane in an emergency. Those with the Doyle, the Consolidated *PT-1*, the Boeing *PW-9*, and the last one with the Fairchild loaded to 15.9 pounds per square foot, were particularly extreme. Considerable skill was apparently required in all cases.

The distances required for landing from an altitude of 50 feet and coming to a stop are with one exception in the order of the wing loadings, the heavier loadings requiring the greater distances. The Consolidated *PT-1*, which makes particularly short landings, is a training plane with exceptionally high drag. Because of this high drag it has a steeper gliding angle than the other airplanes of about the same wing loadings, which accounts for the short distance obtained with it.

From Table I it is apparent that the lengths of the ground runs were not greatly different for fast, medium, or slow landings with the same airplane, and that the difference between long and short landings was almost entirely in the air.

It may be concluded from these tests that for conventional airplanes the shortest distance required to land and come to a stop from an altitude of 50 feet in a reasonably safe manner is roughly proportional to the wing loading, and ranges from about 700 to 1,200 feet for wing loadings from about 8 to 16 pounds per square foot. Also, these short landings require considerable skill on the part of the pilot. The ordinary 3-point landings require from 20 to 60 per cent greater distance than the shortest landings.

SPIN AND GLIDE TESTS WITH LONGITUDINAL CONTROL LIMITED

These tests, in which measurements were made in full flight only, were for the purpose of (1) finding the necessary amount of limitation of the elevator travel of a number of conventional airplanes in order to prevent them from spinning; (2) finding the approximate effectiveness of the ailerons in a glide with the stick back to the limited position; and (3) providing approximate data for calculating the minimum horizontal distance required to glide from a height of 50 feet to the ground.

The same airplanes as were given the previous landing tests were used. In each case, with the stabilizer set at its maximum tail-depressing position, the up-travel of the elevators was limited step by step until the airplane could not be forced to spin—first with the engine throttled and then with the aid of power. (Since with most present conventional airplanes a higher angle of attack can be reached with the power on than without it, a greater elevator limitation is required to prevent the possibility of spinning with the aid of power than without it.) Then, with the elevator limited to the point where the airplane could not be spun without power, glides were made with the control stick at the limiting position and the rate of descent (or the vertical component of the velocity) was measured by means of a sensitive altimeter and a stop watch. Also, in these glides, the effectiveness of the aileron control was noted and compared with that of ordinary cruising flight, the comparison being purely a qualitative one representing the judgment of the pilot.

In regard to the tendencies of the airplanes to fall into spins, a few of them could be put into a steady glide with the control stick fully back and then turned satisfactorily, with no apparent tendency to drop a wing or fall into a spin. There is the likelihood, however, that in an unfortunate situation near the ground one of these airplanes might be put into such a position that it would start into a spin because of a quick maneuver or possibly gusty air. For this reason, the criterion used here as a standard for an airplane which is safe from the possibility of falling into a spin is that it can not be spun either from ordinary stalls or by means of any other manuevers, such as a stalled wing-over, which might get the airplane into a spin with the aid of dynamic forces.

The amounts of limitation required to prevent the airplanes from being spun are shown in the following table. The elevator angles are measured from the stabilizer chord with the stabilizer in the maximum tail-heavy position, and they depend to some extent on its range of adjustment.

Airplane	Maximum upward deflection of elevators		
	Original condition, unlimited	Spin not possible without power, and lateral stability and control satisfactory in glide with stick full back	Spin not possible even with power
	°	°	°
Doyle O-2	29	12	−6
Fleet XN2Y-1	27	12	2
Consolidated PT-1	35	23	−2
Verville AT	[1] 47	27	9
Boeing PW-9	20	−2	−8
Curtiss Falcon A-3	·37	30	1
Fairchild FC2W-2	25	[2] 16	----------

[1] This value was obtained with a special elevator lever, and is about 15° higher than the maximum deflection on the original airplane.
[2] On account of the nature and size of the Fairchild FC2W-2 no prolonged attempts were made to spin it and no attempts were made with power. With this elevator angle the lateral control and stability in a glide were satisfactory.

In order to make it impossible to spin the airplanes without the use of power, and also to obtain satisfactory lateral stability and control in a glide with the control stick full back, it was necessary to reduce the maximum uptravel of the elevators by from 4° to 22° on the various airplanes. In every case the airplane apparently still had sufficient control with this limited elevator movement to perform satisfactorily all ordinary nonacrobatic maneuvers in full flight.

A particularly interesting point is that in every case the aileron control in a glide with the control stick full back to the limited position was surprisingly good. In fact, in the opinion of the pilots the ailerons were very nearly as effective under these conditions as they were at ordinary cruising speeds.

The preceding table also shows that in order to prevent the possibility of spinning with the aid of power, a further reduction of the maximum uptravel of the elevators by amounts ranging between 6° and 29° was necessary. This additional reduction is due to the fact that present conventional airplanes are so balanced that, for a given elevator setting, much higher angles of attack are attained with power on than with power off. The particular airplanes tested did not have sufficient tail-depressing control for ordinary flight when the elevators were limited to the point where no spin could be obtained with the aid of power.

If it is of sufficient importance for an airplane to be incapable of spinning under any conditions, with or without power, this condition can be satisfactorily brought about without special devices by designing the airplane in such a manner that for a given control setting it balances at approximately the same angle of attack with the power either on or off. The elevator limitation which would prevent spinning without power would then also prevent it with power, and there would still be sufficient longitudinal control for all ordinary flight maneuvers, with the exception of a short 3-point landing of the present normal type.

The vertical velocity measured in a glide with the control stick back at the limited position which prevented a spin without the aid of power is given for each airplane in the first column of the following table. The air speeds along the flight paths, which were very nearly the same as the minimum gliding speeds, are given in the second column, these being computed values except in the cases of the Fairchild and the Verville. These two airplanes were tested with trailing Pitot bombs in connection with other investigations. In the other cases it is thought that values computed from the probable lift coefficients as obtained from the average results of many full-scale tests on other airplanes are more accurate than those given by ordinary air-speed indicators and are satisfactory for the purpose of estimating the landing distance. The distance required to glide in the above manner with the full limited amount of longitudinal control in use from a height of 50 feet to the ground is given for each airplane in the third column for comparison with the corresponding distance for the shortest conventional landing in the fourth.

Airplane	Vertical velocity in feet per second	Air speed in feet per second	Computed horizontal distance, 50-foot altitude to ground (feet)	Measured horizontal distance, 50-foot altitude to ground, shortest conventional landing (feet)
Doyle O-2	12	73	300	386
Fleet XN2Y-1	15	78	255	505
Consolidated PT-1	19	78	198	400
Verville AT	24	87	174	434
Boeing PW-9	13	90	343	533
Curtiss Falcon A-3	16	90	280	777
Fairchild FC2W-2	14	91	330	752 and 628

This table shows that the computed distances required to glide from a height of 50 feet to the ground with the full limited control in use are much shorter than the distances required for the shortest conventional-type landings. Thus it seems likely that if the landing shock is absorbed satisfactorily, landings can be made with practically all conventional-type airplanes by merely gliding in to the ground with the full limited tail-depressing control in use, not only without danger of losing control or of starting to fall into a spin but also in a considerably smaller space. In fact, in many cases it seems that the horizontal distance required to get from a height of 50 feet to the ground can be cut in half.

The vertical velocities in the glides with the full limited amount of longitudinal control in use ranged from 12 to 24 feet per second. It may be that 24 feet per second is somewhat higher than is desirable, in which case it could be cut down to a suitable value by merely limiting the elevator travel a little more. Although little information is available in regard to the highest vertical velocities which can be used satisfactorily, it is known that at least one airplane, the McDonnell entry to the Guggenheim safe-airplane contest, has been repeatedly landed at vertical velocities up to about 20 feet per second without difficulty. It can therefore be assumed that with careful design the landing-gear problem will not give rise to any particular difficulty other than the provision of long-travel shock absorbers.

FIGURE 3.—The Verville *AT* airplane

In this connection, each of the airplanes tested had an attitude in the "landing glide" with which a satisfactory landing could be made. The fuselage attitudes were such that the tail was slightly below the nose, but in no case was the tail skid as low as the wheels.

In addition to shortening the gliding distance, it seems probable that the ground run should be considerably shorter with the glide-type landing. This is due to the fact that the rather high acceleration which accompanies the shock caused by the high vertical velocity can be expected to press the wheels onto the ground more firmly than in conventional landings, and therefore aid the braking effect.

COMPLETE TRIAL OF LIMITED CONTROL AND GLIDE LANDING COMBINATION

Inasmuch as the foregoing preliminary flight tests indicated that the combination of limited control and glide landing might have practical value in connection with most present-day airplanes, it was thought desirable to make actual landing tests on an airplane having its elevator travel limited and also having a suitable landing gear. The Verville *AT* was used for this purpose because, of the airplanes available, it presented the least difficulty to the provision of a reasonably long-travel shock absorber in the landing gear. After being fitted with long-travel shock-absorbing struts, this airplane was landed by gliding to the ground with the control stick held back at the limited position. The accelerations upon striking the ground were measured in these landings, as well as the distance required to get from a height of 50 feet to the ground, and the length of the ground run.

Additional landing tests were then made to find the effect (1) of gliding in to the ground without leveling off, at various air speeds somewhat higher than that obtained with the stick full back; and (2) of gliding in at these air speeds to a short distance above the ground and then leveling off before making contact. This latter method merged into the present normal manner of landing when the air speeds in the glides were 10 to 15 miles per hour above the minimum air speed.

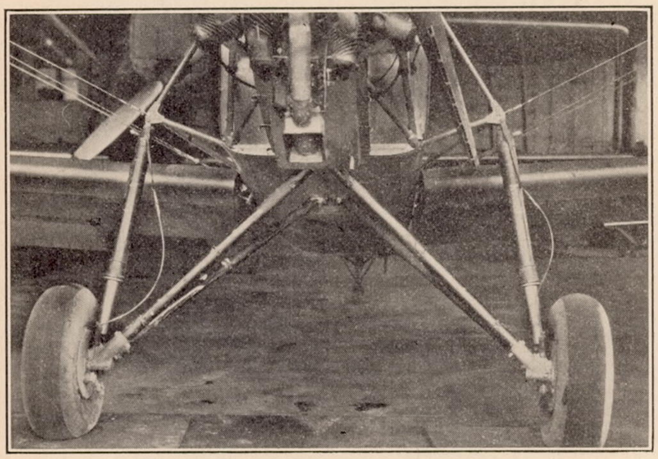

FIGURE 4.—Landing gear with long-stroke shock-absorber struts

After the practicability of landing in an extended steady glide with the control stick full back to its limited position had been established, more complete flight tests were made on this airplane to find the approximate effect of the control limitation on the general flight characteristics. These tests included the ability to make turns in glides with the control stick held full back to the limited position, the effect on the flight path of pulling up suddenly from glides at various air speeds, and the ability to perform acrobatics.

Modification of the Verville "AT" airplane.—The airplane with its original landing gear is shown in Figure 3. It is a conventional 2-place open-cockpit biplane with low-pressure tires (15 pounds per square inch) and oleo struts. By merely replacing these struts with a pair of long-travel "Aerol" oleo-pneumatic struts which belonged to another airplane and happened to be available, the shock-absorbing ability was increased to the point where it was thought satisfactory for test purposes. The landing gear did

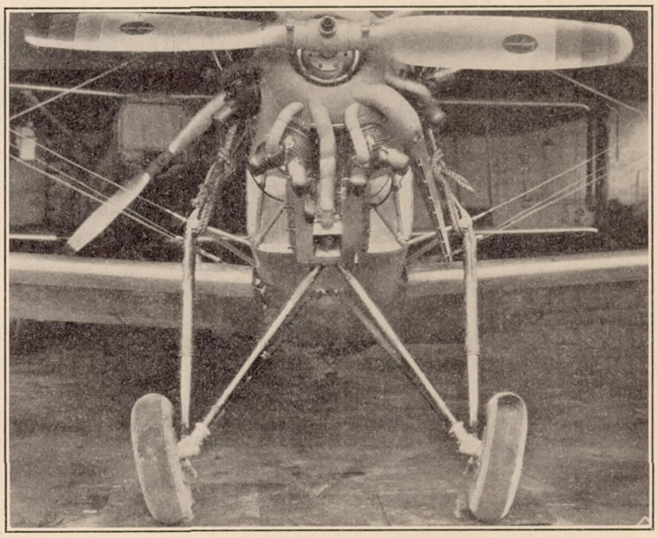

FIGURE 5.—Modified landing gear with struts fully extended

not, however, lend itself satisfactorily to as long a stroke as was desired, because of the large change in the angle of the wheels with respect to the ground. For this reason a stroke of only 13 inches was used although the struts had a maximum deflection of 18 inches available.

The landing gear with the special struts is shown in Figure 4. The slack cables shown with the struts were for the purpose of limiting the stroke to 13 inches when the wheels were off the ground. The struts operate by compressing air on the down stroke and snubbing the return by means of oil. With the airplane resting on the ground the air pressure in the struts was adjusted so that they were extended about 8 of the possible 13 inches. Figure 5 shows the landing gear fully extended and in Figure 6 it is fully compressed. In the latter case the tires are deflated to represent the condition in which they are pressed to the rim in a hard landing. The great variation in the angles of the wheels with respect to the ground is apparent. This would not, of course, be tolerated in a landing gear designed for the stroke used.

The airplane was originally equipped with a small tail wheel with an oleo strut having a stroke of 3 inches. This strut was replaced by an oleo-pneumatic strut having a stroke of 8 inches, the static air pressure being adjusted to give an extension of about 5 inches with the airplane resting on the ground.

Modification of the landing gear to make it capable of withstanding much greater vertical velocities than usual might naturally be expected to entail an appreciable increase in weight. If the greater amount of energy is absorbed by proportionately increased shock-absorption properties, however, the loads on the various parts will remain the same, and any weight increases will be due directly to the shock-absorbing gear. In this connection it is interesting that modifying the Verville landing gear by replacing the three shock-absorbing struts increased the weight by a total of just under 8 pounds.

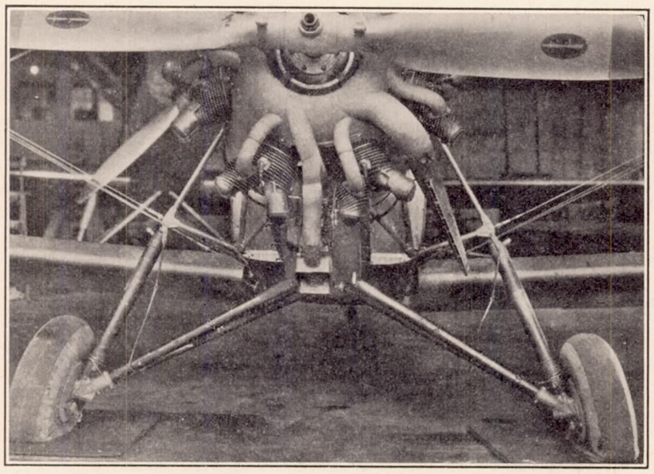

FIGURE 6.—Modified landing gear with struts fully compressed and tires deflated

From the spin and glide tests it will be recalled that the Verville *AT* had a vertical velocity of 24 feet per second in a glide with the stick full back to the limiting position with which the airplane could not be spun without the aid of power. This, it seemed, was too high a rate of descent for the shock to be satisfactorily absorbed with a landing-gear stroke of only 13 inches. It was thought that for the landing gear as modified the vertical velocity should not be greater than about 16 feet per second. In order to find the limiting elevator position for this vertical velocity, a series of glides were made with the elevator deflection fixed at various angles. The results of these glide tests are given in Figure 7, which shows also the indicated air speeds. A vertical velocity of 16 feet per second was obtained with an elevator deflection of something over 10°, and the following tests were all made with the upward deflection of the elevators limited to 10°.

It is interesting that the minimum value of the air speed is obtained with this elevator angle, any further deflection being accompanied by a slightly higher air speed. The minimum air speed in a glide, as measured by means of a trailing-bomb Pitot, was found to be 59 miles per hour. This is a rather high value for an airplane with a wing loading of 9.5 pounds per square foot, but is somewhat advantageous in this investigation in that it makes the test conditions for the glide-type landing more severe.

In the glide with the stick held back to the limited position, the fuselage is inclined at an angle of 6° at which attitude the tail wheel is about 2 feet above the level of the main wheels. In these glides the airplane sometimes took up a slight longitudinal oscillation when the stick was held fixed either in the full-back position or in any position back of neutral. The oscillations did not always occur, but could easily be induced by abrupt use of the controls. They could always be stopped by a slight use of the control, and unless forced by abrupt control movement they were probably not large enough at any time to prevent a safe landing. This tendency should, however, be eliminated in airplanes intended to land in this manner.

Glide landings with stick full back in limited position.—For these landings the airplane, at an altitude of 200 or 300 feet, was put into a steady glide with the stabilizer full tail heavy and the stick back to the limited position. Although the stick was held approximately full back, it was moved forward very slightly when necessary to prevent a longitudinal oscillation

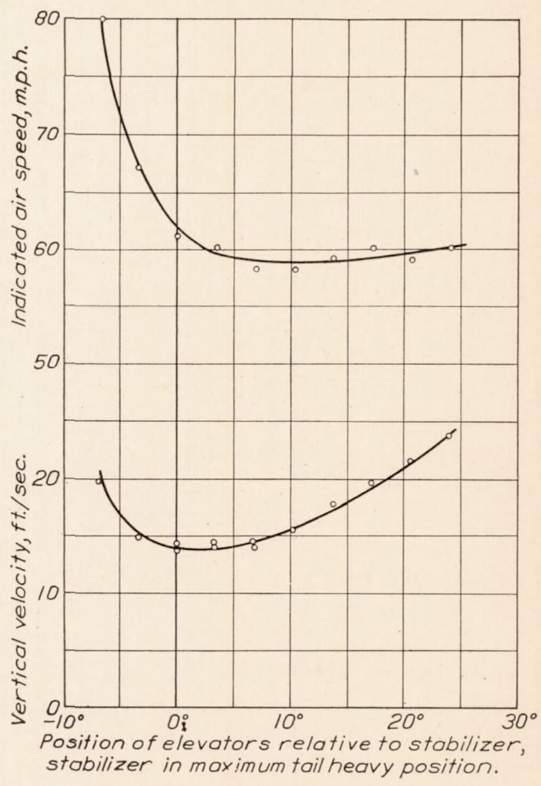

FIGURE 7.—Vertical velocities and air speeds in glides with various elevator deflections. Verville *AT* airplane

from developing. The airplane was then merely held on a straight course in this glide until it came in contact with the ground. The horizontal distance required to get from a height of 50 feet to the ground and the length of the ground run were measured in the same manner as for the ordinary landings previously described. In addition, the maximum acccelerations at the center of gravity and at the tail wheel were measured in each landing to give an indication of the loads set up by the impact.

The results of three of these landing tests, one of which was made in a 12 miles per hour wind but is included for comparison, are given in the following table.

Wind velocity (miles per hour)	7	7	12
Distance, 50-foot altitude to ground (feet)	199	200	180
Time, 50-foot altitude to ground (seconds)	2.6	2.5	2.6
Average vertical velocity from 50 feet to ground (feet per seconds)	19	20	19
Corrected distance, 50-foot altitude to ground, no wind (feet)	224	226	226
Brakes used	(1)	(2)	(2)
Ground run (feet)	487	327	270
Corrected ground run, no wind (feet)	513	380	352
Total distance, wind as measured (feet)	686	527	450
Total distance, no wind (feet)	737	606	578
Maximum acceleration at *c. g.*, (g)	5.5	4.6	(3)
Maximum acceleration at tail, (g)	3.5	5.5	(3)

[1] No.
[2] Partly. The brakes were not applied over the first half of the ground run because the tendency to nose over seemed too great.
[3] No record.

The horizontal distance required to get from a height of 50 feet to the ground, when corrected to the condition of no wind, was only about 225 feet for each of the three landings. This is just about half of the distance required for the shortest landing with the unmodified airplane, which was 434 feet. (Table 1.) The ground runs are also much shorter with the glide-type landings, but the percentage reduction is not quite so great. Without brakes the ground run was 513 feet as compared with 860 feet for the shortest landing with the unmodified airplane.

The average vertical velocity from a height of 50 feet to the ground, it will be noticed, was in the neighborhood of 19 feet per second as obtained from the measured time intervals. Although this is not an accurate method of finding the velocity, it is an indication that the rate of descent at the time of landing was somewhat higher than the average value of 16 feet per second found in the steady glides with the stick back at the limited position. This fact can probably be explained by the fact that the wind velocity was no doubt appreciably less near the ground than at altitudes greater than 50 feet, and consequently as the airplane approached the ground its air speed became less than the minimum required for a steady glide and its rate of descent became somewhat greater.

The glide landings with brakes are not representative of proper braking conditions, for the pilots did not feel it safe to apply the brakes until about half the ground run had been completed. This is particularly disadvantageous with this type of landing, for it would be expected that the greatest braking effect would be obtained during the first few yards of contact where, on account of the vertical acceleration, the force pressing the wheels onto the ground is much greater than just the weight of the airplane. As shown by the maximum accelerations recorded in the preceding table, this pressure against the ground rose to an instantaneous value of four or five times the weight of the airplane in the test landings. In addition to the tendency to nose over which caused the landing runs in these tests to be longer than those which could have been obtained with a properly located landing gear, the landings were accompanied by a bounce in which the wheels were off the ground by as much as a foot or a foot and a half for a distance as great as 80 feet. Over this distance the brakes could obviously have had no effect. The bounce is thought to be due to the unchecked rebound of the large low-pressure tires, and could probably be reduced, if not entirely eliminated, either by the use of high-pressure tires or with the proper coordination of tires and shock-absorber struts.

Even with these unfavorable braking conditions, the corrected ground runs in the two measured glide landings with partial use of the brakes were only 352 feet and 380 feet as compared with the braked run of 445 feet in the shortest landing with the unmodified airplane.

The accelerations of about $5g$ which were measured in these landings are probably somewhat higher than desirable from a structural standpoint, although the landings were not so uncomfortable as an ordinary bad bump in an automobile. These accelerations can be reduced to a smaller value by providing the shock-absorbing gear with a longer or more effective stroke.

In these landings the front shock-absorber struts deflected about 10½ inches out of a possible 13 inches, as shown by grease marks on the telescoping tubes, and the tail strut deflected about 7 inches out of a possible 8 inches.

A comparison of Figures 5 and 6 reveals the fact that the tread increases a large amount as the struts are compressed, this change being about 3 feet. Since tracks on the ground after one of the landings showed that this change of tread took place with a forward movement of only about 4 feet, it is apparent that the tires must have been subjected to very large side loads, and that the particular landing gear used is unsatisfactory for this type of landing. A few feet farther along marks in the landing surface made by the brake levers indicated that the tires were completely depressed. Apparently the tires were not damaged in any way. In fact, the landings were made repeatedly with no failures of any kind, and with a properly designed landing gear there seems no reason why such landings could not be made a regular procedure under smooth air conditions if desired.

Other forms of landings.—The above glide-type landing with the control stick held full back to the limited position throughout the entire maneuver represents one extreme of the range of landings which it is possible to make with an airplane so modified. Although it is the shortest form of landing, it is accompanied by a rather high acceleration which could easily be eliminated in the general run of landings, where sufficient space is available, by flattening out somewhat in the usual manner. The glide landing with the stick full back would then be used mainly as an emergency measure, and fortunately would be not only the shortest landing but would be properly made by the natural reaction of the pilot; i. e., by pulling the stick all the way back. This is in contrast to the present conditions in which many experienced pilots have serious accidents apparently because this natural tendency overcomes their training and they pull the stick too far back.

In order to investigate the gentler landings which would probably be made under ordinary conditions, tests were made in which the airplane was glided in at a series of different air speeds somewhat above the minimum and then at a few feet above the ground was leveled off as much as possible by moving the stick back. The accelerations, which were measured in each case as a measure of the severity of the landing, are listed here:

Speed in glide, miles per hour above minimum	Maximum acceleration at *c. g.*	Maximum acceleration at tail
3	3.0	4.7
6	2.7	3.5
9	1.6	1.1
12	2.2	2.2
15	1.8	1.4

For the cases in which the approaching glide was 9 miles per hour or more above the minimum gliding speed, the accelerations were within the range of those obtained in ordinary conventional landings with present-day airplanes. The landings in these tests, however, were appreciably shorter and had higher rates of descent than average conventional landings, the low accelerations and smooth landings being due to the long-travel shock-absorbing gear.

Several conventional-type landings were also made with the elevator travel limited, and these were quite satisfactory as ordinary 2-point landings—with the tail wheel between 1 and 2 feet above the ground as the main wheels touched.

In connection with the glide-type landings it was thought desirable to find the effect of gliding straight in to the landing surface at speeds somewhat higher than the minimum. As shown by Figure 7, the vertical velocities are below 20 feet per second in glides up to about 80 miles per hour, so that it should be possible to make landings by gliding straight in without leveling off at speeds well above the minimum, and to absorb the shock satisfactorily. With sufficient excess speed, however, the airplane would leave the ground again, possibly in a dangerous manner. The tests showed that glide landings could be satisfactorily made in this manner up to a speed about 10 miles per hour above the minimum. The landings in this range were always accompanied by a bounce, sometimes as high as 2 feet, but the accelerations were not high, ranging from $1.9g$ to $4.3g$. In a landing with the gliding speed 15 miles per hour above the minimum, however, the bounce seemed dangerously high and uncontrolled, although no damage was done to the airplane.

Summarizing, these series of preliminary landing tests indicate that an airplane having this combination of limited control and long-travel landing gear can not only be landed in a shorter distance and with somewhat less skill than a conventional airplane but that ordinarily it can be landed as gently and in a much shorter distance; furthermore, a safe if not always graceful landing is made almost regardless of the manner in which the airplane is brought to the ground as long as the air speed is within about 15 miles per hour of the minimum, the airplane is held level laterally, and the controls are not used violently. (Smooth air conditions are assumed.) If the glide landings are to be made with the minimum of skill, the airplane should have good longitudinal as well as lateral stability in a glide, with the stick fixed back at the limited position. It should glide in a smooth path without an appreciable tendency to oscillate or hunt.

More detailed tests on the flying characteristics of the Verville "AT" with limited elevator travel.—Since the landings were satisfactory with the upward elevator deflection limited to 10° and the provision of a long-travel shock-absorbing gear, it was thought desirable to investigate in somewhat greater detail the flying characteristics with the limited control. The first preliminary tests had shown only that in a glide with the stick full back to the limited position the lateral stability was satisfactory and the aileron control was just about as effective as in ordinary cruising flight. These later tests comprised three main groups: A series of glides at different air speeds to find the effect on the flight path of suddenly pulling the control stick full back in a glide and holding it there; a series of turns of different degrees of sharpness in glides with the stick held full back, to find the vertical velocity in the turns and the altitude required for recovery to a straight glide suitable for landing; and, finally, tests to show the effect of the limited control on acrobatic maneuvers.

Abrupt pull-up tests in glides.—These are extreme examples of the effect of one kind of violent handling of the controls in landing. They are of interest mainly in showing what kind of landing could be expected if the stick were pulled back suddenly at any altitude in the approaching glide and then held full back. Each test was started from a steady glide during which, at a signal from the observer, the stick was suddenly pulled full back and held there. The maneuver was performed twice at each of several different air speeds. The first time the manuever was performed, the vertical velocity in the steady glide and then throughout the pull-up was obtained by getting the time interval for each 50 feet of descent by means of a sensitive altimeter and a bank of six stop watches, all of which could be started at once. (See reference 2.) The second time, the air-speed variation was noted.

In each case after the stick was pulled back the airplane lost some of its rate of descent and the flight path was leveled off to some degree, the amount depending on the speed in the original glide. When this speed was 15 miles per hour greater than the minimum gliding speed, the flight path was flattened out to the point where it was approximately level at one portion. At the end of this flattening-out process the speed of the airplane in each case went below the minimum steady gliding speed, the amount depending on the speed in the original glide, and in regaining its minimum flying speed the vertical velocity and the air speed both increased to values above those for a steady glide. Thus an oscillating motion took place, which, although it became less with each oscillation, was still appreciable after the third, even in the mild cases. In this connection it will be recalled that this airplane sometimes oscillated mildly even in as steady a glide as could be maintained with the elevator held fixed in this position. This degree of dynamic stability is not uncommon in present-day conventional airplanes, and it is thought that the oscillations following a sudden pull-up are probably common to all of them.

The main results of these tests are given in the following table:

Speed in glide (miles per hour)	59	62	64	66	68	70	74	101
Speed in glide (miles per hour above minimum)	0	3	5	7	9	11	15	42
Vertical velocity in glide (feet per second)	14–18	14	14	15	15	15	16	------
Minimum air speed in pull-up (miles per hour)	-------	58	58	58	58	57	53	40
Minimum vertical velocity in pull-up (feet per second)	-------	10	8	7	5	3	0	------
Altitude loss from start of pull-up to minimum vertical velocity (feet)	-------	30	30	30	30	30	30	------
Maximum air speed following pull-up (miles per hour)	-------	59	60	60	60	61	64	75?
Maximum vertical velocity following pull-up (feet per second)	-------	18	24	40	45	35	60	84
Altitude loss from start of pull-up to maximum vertical velocity (feet)	-------	100	120	125	120	80	80	0

The first column gives the conditions in a steady glide with the control stick held back at the limited position. The air speed varied within a range of about 1 mile per hour and the vertical velocity varied from 14 to 18 feet per second, or ± 2 from the mean value. This variation was probably due partly to the tendency to oscillate and partly to the condition of the air which was a little gusty, for the variations were not entirely regular. The last column is for the other extreme, for it was made from a glide of 101 miles per hour, and the nose went up until the fuselage was vertical at an altitude about 80 feet above the pull-up. The first oscillations in this case were very severe and the air-speed values could not be accurately determined, but a maximum vertical velocity of about 84 feet per second was reached as the airplane passed the level at which the pull-up had been started.

In the pull-ups made from glides between 3 and 15 miles per hour faster than the minimum, it is interesting to note that in each case the minimum rate of descent occurred at about 30 feet below the level at which the stick was pulled back. This is an indication that still gentler landings could have been made in the flattened-out landings reported in the preceding section if the leveling-off process had been started at 30 or 40 feet instead of about 10 feet above the ground. In applying these results to possible landings, however, it should be kept in mind that the tests were made at an altitude of about 2,000 feet, and that they do not include the effect of the reduction of the wind velocity near the ground due to surface friction.

An appreciable reduction in the vertical velocity was obtained by pulling the stick back even in the glides which were only slightly faster than the minimum. In the cases where the original glide was not over 5 miles per hour above the minimum, a landing could probably have been made at any point before or after the pull-up without damaging the airplane if the stick were pulled back and held there. With the faster glides, however, the airplane falls off more rapidly after the pull-up, and at altitudes 50 or 60 feet below the point where the stick was pulled back the vertical velocities begin to get dangerously high. These high vertical velocities can, of course, be avoided by the use of the elevator control after the pull-up, but they are included here to show what might be expected in the worst case where the stick is suddenly pulled full back and held there. Even this could apparently be done without damage if the original glides were not more than 15 miles per hour faster than the minimum and the sudden pull-up were made at a height of 50 feet or less above the field. If the pull-up were made at a height greater than 50 feet, however, the airplane would hit the ground in a dangerous manner.

The flight paths of the Verville *AT* throughout two of these pull-ups are given in Figure 8 as worked up from the data measured. They are of a more or less approximate nature, but are thought to represent the conditions sufficiently well to show how the two cases compare. In the one which started with a steady glide 5 miles per hour faster than the minimum gliding speed, the best point to make a landing would be at about 30 feet below the pull-up, where the vertical velocity would be about 8 feet per second, or half that in the steepest landings made in a steady glide with the stick full back. The worst point at which to touch the ground would be at about 120 feet below the pull-up, where the vertical velocity would be about 24 feet per second. This is probably about the maximum which could be withstood by the present long-travel landing gear, and inasmuch as the fuselage was about level at that point, it probably represents about the extreme condition in which a landing without damage could be made. In the other pull-up shown in Figure 8, which was made from a glide at 15 miles per hour above the minimum speed in a steady glide, the flight path became horizontal at about 30 feet below the pull-up. At the worst point, however, the airplane was nosed down 20° in what amounted to a dive at 35° below the horizontal, and its vertical velocity was about 60 feet per second. Striking the ground in that condition would undoubtedly result in a very serious crash. As stated before, however, this condition can easily be avoided by the proper use of the elevator control and is only included here as an example showing the limits outside of which the controls can not be used improperly with safety, even with the combination of limited longitudinal control and long-stroke shock absorbers.

Turns of various sharpness with stick held full back to limited position.—These tests were made to investigate the possibilities of making turns satisfactorily in glides with the stick full back to the limited position. This information is of interest from the standpoint of maneuvering into a difficult forced landing, or of quickly deflecting the course, just before landing, in order to avoid an unforeseen difficulty. Steady turns of various degrees of sharpness, ranging from very mild to as sharp as possible, were made and the air speed, rate of descent, time for one complete turn, angle of bank, and longitudinal attitude were measured. Then at a signal from the observer the airplane was taken out of the turn and put into a straight glide as rapidly as possible, the stick being held full back to the limited position throughout. The variation of the vertical velocity in the recovery from the turn was obtained by means of the sensitive altimeter and bank of stop watches used in the previous tests on pull-ups. The lateral and longitudinal attitudes in the steady turns were found by sighting over pivoted straightedges and adjusting them to be parallel to the horizon.

The radius of each turn has been found from the relation,

$$R = \frac{t\sqrt{V^2 - v^2}}{2\pi}$$

where

R—radius in feet.

t—time for one turn (360°) in seconds.

V—velocity along flight path in feet per second.

v—vertical component of velocity in feet per second.

The main results for the various turns are tabulated in the following table.

Radius of turn (feet)	1, 340	910	510	310	240	230
Angle of bank (degrees)	6	10	18	34	48	63
Longitudinal attitude (degrees)	+6	+6	+7	+7	−5?	−5?
Altitude lost per 360° turn (feet)	1, 440	1, 270	.740	490	480	465
Air speed (miles per hour)	60	60	60	67	72	95
Vertical velocity (feet per second)	15	19	20	24	32	43
Approximate altitude required to straighten path (feet)	20	30	40	60	80	110
Vertical velocity as path becomes straight (feet per seconds)	19	19	18	24	23	22
Maximum vertical velocity in the following oscillation (feet per second)	19	25	18	25	25	45

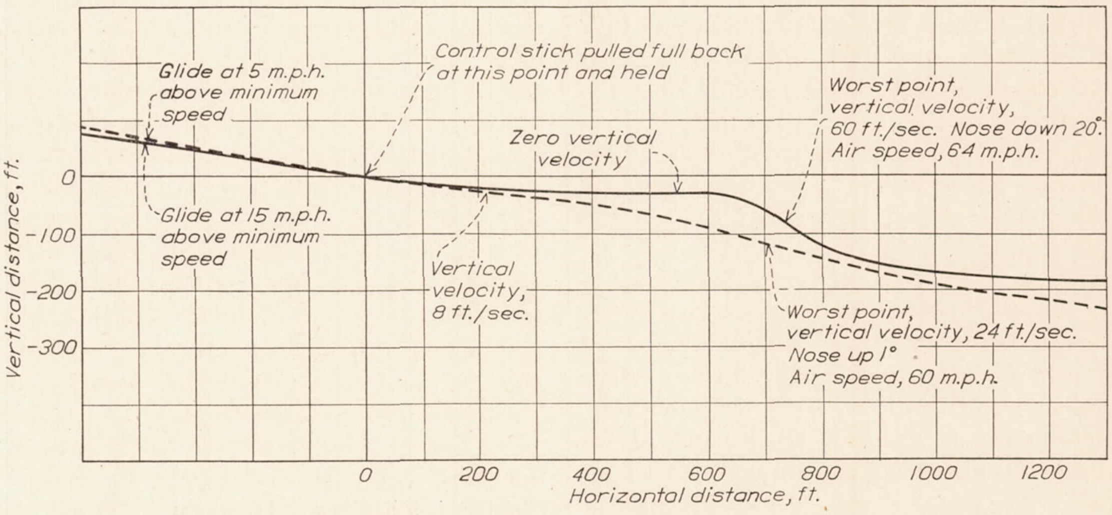

FIGURE 8.—Flight paths following sudden pull-ups from glides at 5 and 15 miles per hour above minimum gliding speed

The radii, it will be noticed, varied from a quarter mile to a minimum of about 230 feet, and the corresponding angles of bank from about 6° to 63°. The longitudinal attitude was about the same in all the turns having angles of bank up to 34° as in a straight glide with the stick full back; i. e., the nose was up about 6° or 7°. With the steeper banks the straightedge could not be sighted against the horizon, but the attitude appeared to be about 5° nose down in each case.

The altitude lost during each complete 360° turn diminished as the turns became sharper, although the rate of descent increased. The minimum height required for one complete turn was found to be 465 feet.

For the turns with angles of bank of 18° or less the air speed, vertical velocity, and longitudinal attitude were about the same as in the straight glide with the stick full back in the same fore-and-aft position.

In each recovery to a straight path, the quick change started an oscillation in pitch similar to those following the pull-ups. In all the cases except that of the sharpest turn the airplane could probably have been landed without damage at any time during the oscillations. Following the sharpest turn, however, the oscillations were much more severe and the maximum value of the vertical velocity rose to the excessively high magnitude of 45 feet per second.

In addition to the above series, two other turns were measured. In both of these the airplane was first put into a straight glide with the stick back at the limited position, and then at a signal from the observer the direction of flight was changed approximately 90° as quickly as possible and the path straightened out again. The purpose of these was to show the ability to maneuver rapidly as if avoiding an obstacle while in a glide with the stick full back. The first turn was performed satisfactorily except that the familiar longitudinal oscillation was set up with a maximum vertical velocity of about 36 feet per second. The normal amount of bank was used in this turn. In the second trial the amount of bank was slightly lower and was reduced more gradually before straightening out. In this case there was no appreciable oscillation and the maximum vertical velocity was 28 feet per second. The altitude required to make the complete 90° turn and recover was approximately 200 feet.

The tests showed that the airplane can be satisfactorily maneuvered in turns with the elevator fixed at its maximum limited upward position, but that, unless the control movements are made gently, undesirable oscillations will occur in the recovery. These oscillations can be immediately stopped by use of the elevators, but would be dangerous under certain conditions near the ground if the stick were held hard back following a violent maneuver.

Oscillations such as these, which are the result of rather poor dynamic longitudinal stability (insufficient damping) at high angles of attack, are apparently common to many present-day aircraft. Although this condition is not troublesome in the operation of these airplanes as they are now controlled, the condition is undesirable and should be eliminated in connection with airplanes having a limited amount of elevator deflection if they are expected to be flown in glides with the stick full back.

Effect of the elevator limitation on acrobatic maneuvers.—In order to find whether acrobatic maneuvers would be hindered or made impossible by the limited elevator deflection, tests were made of loops, rolls, and minimum-radius turns.

Loops were made quite satisfactorily with the limited control and did not require the full amount of the limited control available.

The minimum-radius turns with power were also made satisfactorily, the full amount of control available not being necessary except with the engine throttled below 1,200 revolutions per minute.

Satisfactory rolls could not be obtained on this airplane even with the full original elevator deflection available. The maneuver was apparently the same with the limited elevator deflection.

Effect of gusty air conditions.—A short time after the foregoing tests had been completed, the temporary shock-absorber struts installed on the Verville *AT* airplane were replaced by a new pair of shock-absorbing struts having a usable stroke of 12 inches. (The reduction of 1 inch from the original 13-inch stroke was necessary on account of new end fittings.) With this equipment additional glide landings were made. Finally, three were made with the elevator-limiting device removed on a day in which the wind happened to be particularly gusty. It had an average velocity of from 12 to 15 miles per hour as found by means of an anemometer at a height of 5 feet, but the speed at any instant apparently varied widely, probably from about 5 to 25 miles per hour. Two satisfactory glide landings were made under those conditions, but in the third approach to the ground the glide path was exceptionally steep and the vertical velocity was obviously high, although the fuselage and wings apparently had their normal attitudes. In this landing one side of the landing gear failed, and the airplane slid along on one wing tip and the opposite wheel for a distance of about 90 feet to a stop.

The two bags of white powder were fortunately being used in this landing, and their markings showed that the horizontal distance required to get from a height of 50 feet to the ground was only 100 feet. Allowing for a 40-foot wind correction, this gives an average flight path angle with respect to the air of just under 20°, and assuming that the airplane was traveling along the flight path at its minimum speed of 59 miles per hour, the average vertical velocity from a height of 50 feet to the ground may be calculated as just under 30 feet per second. This is about 10 feet per second, or 50 per cent higher than that measured in previous landings.

A glide landing of this type with a normal attitude and a high vertical velocity can be accounted for in two ways. It could be caused either by pulling the control stick somewhat back of the position corresponding to a vertical velocity of 16 feet per second in a steady glide or by the gusty air conditions. The explanation of the pilot is as follows:

> During the approach from approximately 600 feet the airplane passed into a gust which caused it to accelerate rapidly to a high vertical velocity. This gust condition started at 75 to 100 feet from the ground and apparently continued up to the point of landing. Fortunately, this gust was of such a nature

that no appreciable local forces were evident tending to disturb the attitude of the airplane, and the first indication of the effect of the gust was a sensation of the airplane dropping away.

This statement from an experienced test pilot makes it seem probable that the high vertical velocity was caused entirely by the gusty air conditions and that it would have been attained whether or not the longitudinal control had been limited.

The investigation is being continued along two lines. The Verville *AT* airplane is being fitted with a landing gear having a substantially longer travel, and the fuselage is being strengthened to enable the airplane to withstand landings at higher vertical velocities. Further glide landings will then be made under various air conditions. A study is also being made of the variation of the wind velocity and direction under gusty air conditions.

CONCLUSIONS

1. This preliminary investigation indicates that most present-day conventional airplanes, if modified by (1) limiting the uptravel of the elevators to the point where they could not be made to spin without the aid of power; and (2) providing them with long-stroke shock-absorbing landing gears which would satisfactorily absorb the shock of landing in a steady glide with the control stick held full back, would make possible:

    a. Glides with satisfactory lateral stability and control throughout the entire range of angles of attack possible to maintain.

    b. Landings without power under normal conditions without the possibility of falling into a spin.

    c. Landing over average obstructions and coming to a stop in one-half to two-thirds of the distance required for the shortest present-day conventional landings.

2. The above-mentioned control limitation on the Verville *AT* airplane had no appreciable effect on the ability to perform acrobatic or ordinary maneuvers in flight.

3. Investigations should be carried on having the aim of decreasing the tendency to bounce in landings with high vertical velocity, of improving the dynamic longitudinal stability at high angles of attack, and of determining the effect of gusty air conditions on glide landings.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
LANGLEY FIELD, VA., *January 25, 1932.*

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TABLE I

RESULTS OF CONVENTIONAL LANDING TESTS

Airplanes		Doyle O-2		Fleet XN2Y-1		Consolidated PT-1		Verville AT		Boeing PW-9		Curtiss Falcon A-3		Fairchild FC2W-2		Fairchild FC2W-2	
Wing loading (pounds per square foot)		8.2		8.2		8.9		9.5		11.6		12.3		13.0		15.9	
Type of landing		Medium	Slow [1]	Medium	Slow	Medium	Slow [2]	Medium	Slow	Medium	Slow [3]	Medium	Slow	Fast	Slow	Fast	Slow [4]
Wind speed (miles per hour)		6	5	7	7	6	6	5	5	7	7	6	7	5	6	3	5
Distance, 50-foot altitude to ground (feet)		760	354	670	440	542	360	483	400	936	475	900	710	1,070	700	1,500	580
Time, 50-foot altitude to ground (seconds)		9.3	4.3	9.4	6.3	6.4	4.8	5.6	4.5	------	5.4	9.1	6.4	10.0	5.9	13.0	6.0
Corrected distance, 50-foot altitude to ground, no wind (feet)		841	386	768	505	597	400	527	434	1,036	533	980	777	1,149	752	1,559	628
Ground run (feet)		455	482	440	440	410	430	840	730	690	730	625	625	950	740	910	1,000
Probable ground run with brakes (feet)		266	282	264	264	242	254	480	[5] 400	415	438	375	375	520	407	500	550
Corrected ground run with brakes, no wind (feet)		300	314	306	306	272	286	534	445	480	510	425	425	567	460	527	597
Corrected ground run without brakes, no wind (feet)		545	570	556	556	495	520	970	860	875	930	775	775	1,026	825	954	1,076
With wind as measured	Total distance without brakes (feet)	1,215	836	1,110	880	952	790	1,323	1,130	1,626	1,205	1,535	1,335	2,020	1,440	2,410	1,580
	Total distance with brakes (feet)	1,026	636	934	704	784	614	936	800	1,351	913	1,275	1,085	1,590	1,107	2,000	1,130
Corrected to no wind	Total distance without brakes (feet)	1,386	956	1,324	1,061	1,092	920	1,497	1,294	1,911	1,463	1,755	1,555	2,175	1,577	2,513	1,704
	Total distance with brakes (feet)	1,141	[2] 700	1,074	811	869	[3] 686	1,061	880	1,516	[4] 1,043	1,405	1,202	1,716	1,212	2,086	1,225

[1] Bad bounce. [2] Pancake with bad bounce. [3] Very slow, needed burst of power. [4] Very hard landing. [5] Actual test with brakes.

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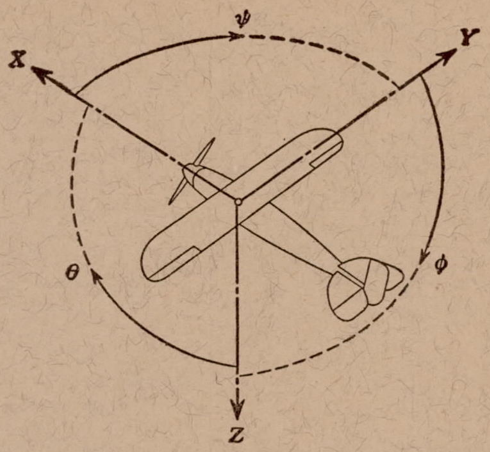

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	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.