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Aeroplane Undercarriages.

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THIS paper has not been written with the object of describing in detail the many existing types of aeroplane undercarriage, but those which have been selected for description very fairly represent the most important types; neither is it intended to deal at any length with the method employed in carrying out any specific design.

The chief object is to bring attention to bear on the actual conditions that must be fulfilled, and if we can arrive at some fairly definite conclusion as to what is required in this direction, we shall have a firmer basis to work from in designing the undercarriage in particular, and to a limited extent, the aeroplane as a whole.

ALIGHTING.

In the first place it will be as well to consider the principles of alighting.

One of the most important rules in connection with this is to bring the machine head to wind before actually touching the ground, as the speed relative to the earth is thereby decreased, and the machine quickly comes to rest. Landing in a side wind puts heavy lateral strains on the undercarriage, and in a following wind the speed may be dangerously high. In the case of a machine fitted with brakes and some efficient form of front skid, the danger of alighting with the wind is considerably reduced, and although the rule of landing against the wind should be observed whenever possible, there may be times when this cannot be managed, as in the case of a forced descent when flying low.

When flying across country, a height of at least 1,000 ft. should be maintained in order to give sufficient time to choose a suitable landing ground in case of engine failure. When descending

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with the power cut off, it is always advisable to plane down at an angle rather steeper than the best gliding angle of the machine, as the controls are then more sensitive owing to the higher speed,

while in gusty winds there may be a certain loss of stability if the speed is not kept reasonably high. When a few feet from the ground, the machine is gradually levelled up until the angle of

incidence of the planes has almost reached the maximum for lift,

FIG. 2.

and if this manoeuvre is properly timed, the machine will be slow-

ing up and gradually dropping until the wheels make contact with the ground, without perceptible shock. In the case of a forced landing in a place where the ground is very soft, or where the

DIAGRAM SHOWING LANDING OF TYPICAL MONOPLANE.

ANGLE OF PLANES TO FLIGHT PATH = α		" AXIS OF MACHINE TO FLIGHT PATH = β		" " HORIZONTAL = γ		H.	
A.	B.	C.	D.	E.	F.	G.	H.
$\alpha = 14^\circ$	$\alpha = 13^\circ$	$\alpha = 12^\circ$	$\alpha = 11^\circ$	$\alpha = 10^\circ$	$\alpha = 9^\circ$	$\alpha = 8^\circ$	
$\beta = 10^\circ$	$\beta = 9^\circ$	$\beta = 8^\circ$	$\beta = 7^\circ$	$\beta = 6^\circ$	$\beta = 5^\circ$	$\beta = 4^\circ$	
$\gamma = 10^\circ$	$\gamma = 8^\circ$	$\gamma = 6^\circ$	$\gamma = 4^\circ$	$\gamma = 2^\circ$	$\gamma = -1^\circ$	$\gamma = -4^\circ$	
							MACHINE GLIDING: 1 IN 5.3.
							$\alpha = 7^\circ$ $\beta = 3^\circ$ $\gamma = -8^\circ$

Index letters are references to positions shown in diagram below.

A—MACHINE LANDS.
FLIGHT PATH HORIZONTAL.
WHEELS AND SKID TOUCH SIMULTANEOUSLY.

FIG. 3.

wheels are liable to meet with serious forward resistance, it is advisable to level up and take "way" off the machine, and thus diminish the horizontal velocity, so that the actual landing will be as nearly vertical as possible. The critical alighting angle

is shown on the lift and drift chart of the plane (Fig. 2) which, in this case, refers to a two-seated Blériot monoplane. This and some of the other charts have been prepared for me by Mr. Watts, of the Army Aircraft Factory. It will be noticed that when an angle of about 15° has been reached, the lift begins rapidly to fall off, while the drift increases, and it is therefore useless to tilt the machine to any greater angle. On reference to the Resistance and Power Chart (Fig. 1), it will be noticed that this angle gives a speed of approximately 38 miles per hour, which, in this case, is the lowest possible speed in still air (Figs. 1, 2 and 3 relate to the same monoplane).

A number of serious aeroplane accidents have been caused directly or indirectly through the inefficiency of the undercarriage. Since the advent of the practical flying machine, insufficient attention has been given to this member, although improvement has been made, in many cases, by more substantial construction.

The speed of machines has greatly increased, and will undoubtedly continue to do so, which fact alone calls for a more suitable type of landing gear than those provided in the early machines. It must not be overlooked, however, that these modern fast machines are readily and easily controlled, and this naturally assists the duty of the undercarriage.

It might be supposed that alighting at a speed of 60 miles per hour would be attended by considerable difficulty, but this is not so providing the ground has a reasonably good surface, and it is only in the case of a forced landing on unsuitable ground that trouble is likely to occur.

In modern machines, high speed is obtained more by the reduction of head resistance than by the use of high powers, and by reducing the area of supporting surfaces, which means that the machine possesses a greater speed range. It is doubtful, in the author's opinion, whether special devices will be provided for enabling the surface to be varied in extent, as this would entail extra weight and complication.

If the power plant of an aeroplane were infallible as regards reliability, there would be little necessity for providing a more suitable undercarriage than that in use at the present time, as the pilot would always choose convenient and safe ground for alighting. Even now, engine breakdowns are more the exception than the rule compared with the state of affairs a comparatively short time ago, but as there will always be the possibility

of forced landings, the machine must be provided with the best possible form of undercarriage.

It will now be as well to consider the conditions that should be fulfilled by the ideal undercarriage:—

- (a) Its first duty is to allow the machine to attain its flying speed while on the ground. There must be the least possible resistance while rolling in order that the machine may accelerate to the required speed as quickly as possible.
- (b) It must be arranged to give a high degree of stability in a fore and aft direction, as well as laterally, while travelling at high speed over uneven ground.
- (c) It must be efficiently sprung to eliminate rolling shocks.
- (d) The machine must be capable of being steered on the ground without the aid of the propeller blast.
- (e) Some efficient form of brake must be provided.
- (f) It must be designed with a view to easy repairs.

(Most of the above conditions apply to rolling and taking off from the ground; the following are connected with alighting):—

- (g) It must be provided with a suitable device for absorbing the shocks of landing.
- (h) It must be capable of withstanding the considerable side strains attendant upon landing in a broadside wind.
- (i) It must be provided with some form of leading skid or wheel, which is normally clear of the ground, but which is sufficient in all cases to prevent the machine turning over.

While considering these features, there are other important points that must not be overlooked. While an aeroplane is actually flying, the undercarriage is merely an encumbrance in the form of weight and head resistance, and although it is obviously desirable to cut weight to a minimum wherever possible, this is not the place where a great reduction should be made, as it is practically impossible to estimate correctly the strains to which the various members are subjected, and therefore a liberal factor of safety must be allowed.

Improvement lies more in the direction of simplifying the design, thus reducing head resistance and weight, at the same

time fulfilling the conditions of the ideal undercarriage as far as possible.

There are, of course, limits to the kind of ground on which an aeroplane can alight safely, and the most efficient landing gear is the one which gives the greatest range in this direction.

It is no easy matter to decide what constitutes unsuitable ground for landing. If it was desired that a machine should alight safely in a cornfield, on the side of a steep hill, or amongst ditches and marsh ground, the undercarriage would assume impossible dimensions as regards weight and size. It is reasonable, however, to assume that the ground will be of uneven surface, such as ploughed land, sand, or long grass on a medium incline.

The landing gear is seldom subjected to abnormal strains in landing, provided, of course, that the pilot is fairly experienced, but in rolling over bad ground after landing or before getting off, it may have to withstand far greater shocks, especially when rolling with a following wind, in which case the normal flying speed of the machine will be exceeded.

Probably, one of the worst conditions for alighting is a very soft ground, such as ploughed land, or loose sand; in such a case the machine tends to turn over when the wheels sink, and this may be suitably guarded against by providing a wheel or skid some distance in front of the main rolling wheels, thus fulfilling the conditions in clause (i).

The design of an undercarriage is, to a large extent, governed by the type of machine to which it is fitted. The popular type of single tractor machine offers certain difficulties to the fitting of a reliable gear, chiefly owing to the position of the tractor, which prevents a substantial skid arrangement being provided in front, while other types of machine may present difficulties in a different direction.

However, the generally accepted arrangement for practically any type of machine is to place the main wheels approximately under the centre of gravity and to provide a rear support, which generally takes the form of a skid, in front of the main wheels. When resting on the ground most of the weight is taken by the main wheels, and a comparatively small loading given to the rear skid.

The height of the undercarriage is determined by the propeller, which must be allowed suitable clearance from the ground under

all conditions. It is advisable, therefore, to place the propeller as high as possible in order to keep the centre of gravity in the vertical line low down, but there are other principles of design which govern the position of the propeller within certain limits. In order to leave the ground, or to alight, at a speed below that normally attained when flying, it is necessary to increase the angle of incidence, and this must be allowed for by so arranging the rear skid that the machine lies at an angle of about 18° ; the front skid or wheel will then be well clear of the ground, and will only come into action when the machine pitches forward. The weight supported by the rear skid depends upon whether a lifting or non-lifting tail plane is used, but in any case, the skid must be so loaded as to leave the ground in a short distance, as otherwise it will prevent rapid acceleration when starting. Also, a heavy load on the rear skid means that the main wheels are some distance in front of the centre of gravity, and this tends to tilt the machine back when landing, thus causing it to rise again owing to its suddenly increased angle, and in this manner the machine may rebound several times before coming to rest. With a directional tail, or one giving slight lift, the construction of the framework between this member and the main planes can be very light, as the bending moment is small; but, if it has to withstand the shocks transmitted by a heavily loaded skid, weight must be added to give it sufficient strength. It is therefore apparent that the main rolling wheels should be nearly under the centre of gravity.

TYPES OF UNDERCARRIAGE.

Wright Biplane.—The gliders used by the Wright brothers were provided with skids, and this form of undercarriage was retained in their first power-driven aeroplane. For starting, the machine was given its initial impetus by means of a falling weight, which operated a small trolley through the medium of a rope and pulley gear. The machine was mounted on this trolley, which it left when the flying speed had been reached, and landed on the skids, which were not provided with any form of shock-absorbing device.

The Wright aeroplane is chiefly interesting from the fact that it was the first practical machine in which a rigid framework was provided beneath the planes in place of the flexibly mounted undercarriages adopted by the French constructors at about the

FIG. 4.—Farman Biplane.

same period, the outcome of these two systems being the combination of skids and wheels in later types of machines.

The chief advantage of this system is that it provides a rigid structure to which the main lifting wires may be fixed, these wires also being effective in taking any side strains imposed on the undercarriage itself.

Farman Biplane.—Farman was the first to combine wheels with skids (Fig. 4), and this type of undercarriage has found favour with a large number of constructors. Ash is chiefly used, and the machine is supported from the skids by four or more struts, which are wired up rigidly to the main planes. The skids are 9 feet apart, and each carries a pair of rolling wheels, which are attached by rubber bands. A short radius rod allows the wheels a certain amount of lateral motion. The maximum vertical travel of the wheels is about 8 in., but it is seldom that the skids come in contact with the ground. It is certainly not advisable that they should do so, as the shocks transmitted to the whole machine would be excessive. The rear skid carries a weight of about 200 lb., but owing to the propeller slip stream passing over the lifting tail planes, the skid leaves the ground in a few yards. A machine which has a weight-carrying tail plane has the advantage of not tending to pitch forward when landing on soft ground, owing to the weight being well back in relation to the position of the wheels, but owing to its disadvantages from an aerodynamic point of view, the weight-carrying tail is giving place to the purely directional tail. In the latter case there is practically no lift given to the rear part of the machine by the propeller slip, and therefore the wheels must be placed farther back in order to diminish the weight on the rear skid, which makes for a greater tendency to pitch forward when landing. It was probably for this reason that the Blériot monoplane, entered for the French Military Trials, was fitted with a weight-carrying tail, although this type had previously been abandoned in favour of a directional tail. The motor fixed to this machine was a 140 h.p. Gnome, and with this weight well forward, there would naturally be trouble in the landing test, which included alighting on ploughed land.

In its original form of eight struts and four wheels, the head resistance in the Farman type was excessive, but in the latest models the number of struts has been halved.

Blériot Monoplane.—The two main rolling wheels have a track

FIG. 5.—Bleriot Monoplane.

FIG. 6.

of about 6 feet, and are allowed a vertical travel of 12 in., the suspension being by rubber cable (Figs. 5 and 6). The wheels are arranged to swivel through about 45° , and are held in the normal position by light rubber cables (Fig. 7). The tail of the machine is supported by a skid of bent cane, which

FIG. 7.

carries a comparatively light load. The absence of any kind of front skid makes this type of undercarriage unsuitable for use on very uneven ground, as there is nothing to prevent the machine turning over should the wheels be suddenly retarded by an obstruction, or by sinking into soft ground.

Whether swivelling wheels as adopted by Blériot are desirable,

is a very debatable point. When flying in a side wind, the machine naturally has lateral motion relatively to the ground and, unless it can be brought head to wind when landing, the undercarriage and wheels are subjected to severe side strains. Swivelling wheels obviate this trouble, but are attended by certain disadvantages which probably outweigh their useful feature. These are—extra weight, head resistance, and complication, and also a difficulty in steering on the ground because, if it is anything but level, the machine always tends to run down hill. The more useful practice of making wheels with wide hubs sufficiently strong

FIG. 8.

to withstand side strains and to do away with swivelling devices enables the machine to be steered on the ground with certainty, and makes for a cleaner and lighter design. It is interesting to note that in the latest type of Blériot the undercarriage has been greatly simplified by the adoption of non-swivelling wheels. These are shown in Fig. 8. The head resistance and weight are both rather high in the early types.

Breguet Biplane.—The Breguet undercarriage is a distinct departure from the ordinary type. In this machine the designer has successfully provided a real shock-absorbing device in place of the usual rubbers or springs (Fig. 9). The rolling wheels are

only 15 in. diameter, with $3\frac{1}{2}$ in. tyres, and are therefore well

FIG. 9.—Breguet Biplane.

adapted to withstand side strains, at the same time they are com-

paratively light. No skid is fitted to the rear part of the machine,

FIG. 10.—Nieuport Monoplane.

but the rudder is designed to perform this function should it

come in contact with the ground. The weight is normally taken by the two rolling wheels, which are placed under the centre of gravity, and the propeller thrust is sufficient to pull the machine on to the single front wheel, which is steerable, and is coupled up to the hand wheel that operates the rear rudder. By this device the machine can easily be manoeuvred on the ground. This undercarriage has a very short wheel base, and, as might be expected, this does not make for easy rolling on uneven ground. Reference will be made to the Breguet shock absorber later on.

Nieuport Monoplane.—As the keynote of this machine is high aerodynamic efficiency, the design of the undercarriage has naturally been governed by the same principle, therefore head resistance has been reduced to a minimum. This is accomplished by the use of oval steel struts rigidly fixed to a central steel tube skid, while the wheels are mounted at the end of a transverse laminated spring, which is attached to the skid in a position well forward of the centre of gravity (Fig. 10). The result is a very rigid construction, while tie wires are almost entirely dispensed with, and the various parts likely to be damaged can easily be replaced. The wheels are fairly small in diameter, and have a comparatively narrow track, and this sometimes causes the machine to cant over laterally until the wing tip comes into contact with the ground. The ends of the wings, however, are constructed to withstand these strains, and therefore materially assist the duty of the undercarriage, without adding extra head resistance or weight. The after end of the central skid takes the place of the more usual tail skid, but carries a large proportion of the total weight. A short base of support is generally to be discouraged, as it does not make for good fore and aft stability on uneven ground, but in this case some advantage is gained by the braking effect given by the heavily loaded skid when pulling up after landing. When starting away, the propeller thrust is sufficient to take most of the weight off the skid, so that the speed is not seriously damped. As regards simplicity and cleanness of design, the Nieuport gear is probably ahead of any other, and from this point of view will no doubt have influence on future designs. The use of the wings themselves as lateral skids may also lead to development in further simplifying the main undercarriage.

The efficiency of its primary function as a landing gear has

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often been doubted, but from practical results it would seem to be better than usually supposed. I have to thank Lieut. Bar-

FIG. 11.—Cody Biplane.

ington-Kennett, of the Air Battalion, R.E., for some of the notes on this machine.

Cody Biplane.—The undercarriage of this machine is chiefly constructed of wood, and has a central skid between the main rolling wheels; on the front end of this skid are fixed two smaller wheels (Fig. 11). The rear skid is a comparatively short distance behind the main wheels, thus giving the machine a short base of support, but, owing to the high centre of thrust, the rear skid carries little or no weight after the first few yards. The main wheels have a track of about 3 ft., and support the machine through two spiral springs, which give a maximum travel of about 10 in. The propeller is placed comparatively high up, and advantage is taken of the fact of the bottom plane being correspondingly low by keeping the wheel track narrow, and providing small wheels at the end of the lower main planes. These are normally clear of the ground, but come into action if the machine is canted over sideways.

BRAKES.

After alighting it is desirable, and sometimes essential, to bring a machine to rest in a short distance. For instance, a good landing may be made in a confined space, but considerable damage may be done by the machine running into some obstruction, as generally the only braking effect is provided by the rear skid, and this is often almost negligible, especially in the case of a machine with a non-lifting tail. Various forms of brakes have been suggested, and these often take the form of a dragging skid, which is let down from a certain part of the machine into contact with the ground. It is difficult to realise that any such device can be efficient when taking the various conditions into consideration. In the first place, the skid and its gear must be of very substantial construction, as, unless it be capable of supporting practically the whole weight of the machine, the braking effect would be comparatively small, and, in any case, the extra weight and resistance would be considerable. Also, it must be suitably sprung, or the shocks transmitted to the machine while running on bad ground will be excessive. Air brakes have also been advocated, and generally take the form of small planes, which are held flat against the sides of the main body of the machine, and are swung out to present a normal surface to the direction of motion in order to slow the machine down. Any form of air brake is of little use owing, in the first place, to its inefficiency at slow

speeds (when most needed), and secondly, it may actually help the machine along if used in a following wind.

Probably, the most suitable brake is one acting directly on the main wheels, and may be of the tyre, rim, or band type; if it is found necessary to use some form of non-skid tyre, the tyre brake will obviously be unsuitable, but in either case the extra weight and resistance need be very small. In addition to the advantage of bringing the machine quickly to rest, the brake may be used for holding it when starting and running the engine, and also to prevent running back after landing on an incline.

WHEELS.

There is a tendency to make wheels and tyres very light, with the result that they frequently buckle in the event of a rough landing. Plain bearings are preferable to ball bearings, as they generally enable a lighter hub and axle to be used, and facilitate quick replacements. The hub should be wide to resist side strains, and ordinary motor cycle tyres give considerably less trouble than the light aeroplane tyres which are often used. For reasons of decreased resistance, wheels with dished steel sides are preferable to spoked wheels, and if properly constructed might show an advantage in the strength to weight ratio.

STEERING GEAR.

The provision of an efficient device for steering the machine on the ground is, if possible, more important than the fitting of brakes. If the starting or alighting ground is very confined, there must be a considerable risk when rolling with a machine which has inferior steering arrangements, but in the case of one provided with suitable brakes and steering gear, the chance of accidents on the ground is very considerably reduced. The Farman type machine is rather by accident than design provided with a fairly good steering gear, without the addition of any parts over those used for steering when in the air. The rudder is placed at the rear of the machine, and is directly in the propeller slip stream, so that even when stationary the rudder is in the equivalent of about a 40 mile an hour wind, and it is therefore possible to steer the machine while the propeller is running fast, but if a

landing is made with the engine stopped, this control is lost, and likewise in the event of a side wind, the machine has a tendency to swing round head to wind, even if the rudder is put hard over.

In the case of the Blériot type machine, the conditions for ground steering are worse, because, owing to the propeller being in front, the rudder is not affected to the same degree as in the Farman type.

A steering device, which is always certain in action, can be obtained by pivoting the rear skid and working it from the same wheel or foot bar that operates the rear rudder; in this case the machine can be steered on the ground independently of any side winds, and it does not rely on the propeller slip stream. This system has been tried out on the latest experimental machine constructed at the Army Aircraft Factory, and has proved to be efficient.

STEEL CONSTRUCTION.

Metal is, of course, more reliable than any kind of timber as regards quality, and is not affected by extremes of temperature, while a metal construction lends itself to the system of rigidly joining the struts to the skids, and generally to the elimination of the comparatively large number of tie wires usually adopted when the undercarriage is constructed chiefly of wood. In the case of an accident there is less danger owing to the buckling of the steelwork, whereas trouble may be caused by the splintering of wooden struts.

Wood is an excellent substitute for steel, being light, cheap, very easily worked, and what is of great importance, it is readily obtained and fitted in the case of breakdowns.

Ash is almost universally adopted as the most suitable timber for undercarriage construction, being fairly light, with a high degree of elasticity, while it is sufficiently hard to take bolts and fixings. It is especially suitable for all types of skids, which are subjected to bending and torsional strains, and is, in fact, used throughout the undercarriage by many constructors.

RUBBER SPRINGS.

Rubber is largely used for shock absorbers in place of steel springs owing to its lightness and adaptability to various systems of suspension. Fig. 12 is a chart showing the extension of ordinary rubber bands against fabric covered rubber cable; it will be noticed that the latter gives a proportionately higher loading as the travel increases, which fact is an advantage in most cases, especially in connection with the lateral stability of a machine

I. Rubber Stranded Shock Absorber, 91 strands, 0.75 mm.² area, covered with webbing.
II. Rubber Band, 7 in. original length.

FIG. 12.

when rolling, as the higher resistance of the cable meets the increased loading before the machine is canted over to the extent that would be possible if plain rubber bands were used. Rubber cable has better lasting qualities owing to the protection afforded by the fabric covering, and has a higher ultimate stress due to the additional resistance of the fabric.

SUSPENSION.

Returning to the matter of suspension, a shock-absorbing device is not alone sufficient to meet the requirements of landing and rolling on uneven ground. In the first place (as mentioned in clause c, p. 294), it is necessary to provide some kind of "undamped" spring between the main body of the machine and the wheels, in order that the latter may ride over the inequalities of the ground when rolling without transmitting these movements to the whole machine. For instance, supposing an aeroplane to be rolling at a speed of 30 miles per hour, and the wheels come into contact with a small mound 6 in. high, with a slope of 45° , then the direction of motion of the machine should remain practically unchanged, while the vertical velocity of the wheels will be 44 ft. per sec., but if the springs are in any way damped, very heavy strains will be transmitted to the whole structure.

In landing, the requirements are different (clause g, p. 294). If the machine is gliding, it will be descending with uniform velocity, as the planes are carrying the weight, whereas if it drops a certain distance without load being taken by the planes, then it will be the same as a falling weight, having acceleration. This latter condition may be brought about by taking "way" off the machine by tilting it back till the planes cease to lift, or by a following gust of wind, which may considerably diminish the horizontal speed relatively to the air, and therefore cause the machine to lose a portion of its lift.

Both these conditions of alighting require some device to *absorb* the shock when striking the ground, and ordinary springs or rubbers are not capable of doing this, as the momentum is not destroyed in overcoming resistance, but is stored in the spring, and is given out again by the machine rebounding. It is necessary to absorb work, and one of the most efficient methods of doing this is by means of an oil dash-pot as provided on the Breguet machine. A shock absorber of this type is shown in Fig. 13. It is composed of two telescopic tubes, the lower one, which may be called the cylinder, being attached to the axle of the rolling wheels, and the upper tube or piston, to the main frame of the machine. When fully extended, the cylinder is full of oil, a cup leather being provided to prevent leakage between the surfaces; when the wheels meet the ground, the oil is displaced into

the upper tube through a spring-loaded valve, which is set to open at a pre-determined pressure.

While resting on the ground, the weight is taken by the helical spring, which does duty while rolling, at the same time the valve is held open by a third spring, and therefore there is practically, no damping effect from the oil, which can pass freely through the

FIG. 13.—Breguet Type Shock Absorber.

ports. The oil passes from the upper tube to the lower one through the central back pressure valve, while a small air-hole in the top of the piston tube allows for the displacement of the oil.

The chart, Fig. 14, shows the sort of diagram given by a shock absorber of this type, while the other curves show the results obtained by using ordinary undamped springs.

CONCLUSIONS.

Having considered the various conditions to be fulfilled, we may now review the various undercarriages at present in use, with the object of seeing how far they meet the case. It must be remembered that we are dealing with conditions that apply to the unsuitable kind of ground before mentioned, and not to the comparatively level surface that is usually chosen for alighting.

In the first place, the majority of aeroplanes are wanting in some form of front support, sufficiently far forward of the centre

DIAGRAMMATIC COMPARISON OF OLEO-PNEUMATIC AND COIL SPRING SHOCK ABSORBERS.

FIG. 14.

of gravity to make it impossible for the machine to turn over when the wheels are suddenly retarded. The next most important point is the want of a real shock absorbing device in place of the usual springs or rubber bands, while the provision of efficient brakes and steering gear is equally essential. There are, of course, individual cases where some of these conditions are fulfilled, as, for instance, on the Breguet, which is provided with a mechanical steering device and efficient shock absorbers, but, in the majority of cases, these features are wanting. However, these, with other improvements, must eventually be provided to give the aeroplane its greatest possible range of utility.

THE DISCUSSION.

Mr. DE HAVILLAND: There is very little I have to say before the discussion. Mr. Legros has asked me to explain the meaning of lift and drift, as he thinks there may be some of you not quite certain of it. It comes in Fig. 2 in the paper. There is a certain resistance set up in driving a plane through the air which is called drift, and there is a lift in an upward direction. The curve of the plane has a certain effect on the lift and drift. In the diagram, Fig. 2, on page 291, you will see the ratio of lift to drift. (The lift is on the right-hand side.) At 6 degrees, the lift co-efficient is 0.04 and the drift co-efficient is given as 0.004. In this case the ratio of lift to drift is about 10 to 1. In Fig. 1, page 290, the curves of resistance and power are only approximate. They cannot be taken as absolutely correct, because there are certain things which make it very difficult to obtain absolute accuracy, and they are given simply to show that at certain degrees and certain angles of the planes, the speed falls to a certain figure. You will see in Fig. 2 that between 15 degrees and 20 degrees the lift begins to fall off very quickly, and the drift increases. That means to say that it is no use jacking the plane up to any steeper angle because the lift is lost. Between 14 degrees and 16 degrees it gives a speed of about 38 miles per hour, whereas the h.p. available shows that a speed of about 60 miles per hour can be attained on this particular machine. This cannot be taken as exactly correct, but the figures do show the approximate speed range in the machine.

Mr. MERVYN O'GORMAN: My first sentiments on the subject of aeroplaning were wrapped up in surprise that one could ever drive what seemed like a motor car in such a manner as to bump satisfactorily against anything at all; for to alight is to bump against mother earth, at forty miles an hour. But I have since been frequently "alighted" by many fliers, by the author amongst others, who has shown by the cinematograph how he himself does it, and what the mechanism of it consisted in. There is, however, one more marvellous thing than an aeroplane touching lightly on returning to earth at forty miles an hour, and that is the way in which a rook or sparrow, flying at 30 miles an hour,

instead of running along for some 75 or 100 yards before his momentum is used up, manages to dispel the stored energy at once on reaching a twig without breaking it. That is a marvellous thing, worthy of emulation by us, and it leads me to a point upon which I think it is possible to differ from the author. He derives from the lift and drift curve of a wing section that there is no advantage in slowing the speed by setting the planes in a cabré attitude beyond 14 degrees. My point is that, though lift falls off after 14 degrees in this case, there is still much advantage to be gained by increasing more and more the air resistance by turning the wings into an attitude which is more nearly normal to the direction of flight. Suppose the aeroplane to be practically in contact with the ground, I think that if we could then turn the wings round quickly enough in precisely the same manner as the rook or the sparrow, so that they are almost facing at right angles to the direction of motion, we might be able to obtain almost the same quick deceleration, and if the flyer had practised this it could be done without a fall by timing the movement exactly. The flyer would have his aeroplane's tail touching the ground, and he should, as the birds do, alight up wind, and then would quickly put his wings in the extreme cabré position. If he had a strong retardation like this from the air he would run no risk of capsizing if he should decide to put the wheel brakes on strongly in addition. We must remember that it is not absolutely necessary for the flyer to be supported by his wings at this last moment. The important thing to obtain is the least velocity of contact with the irregularities on the ground. On a large smooth ground little is to be gained, but on a lumpy ground I am sure that by this means he would be able to bring himself to rest very much more gently, and spare the landing chassis the really rough treatment which it often has to suffer. The author's views differ from that, I know, as we have talked about it, and I am quite sure that we shall all be interested to hear him uphold his point of view. He speaks, on page 293, of the machine having a variable speed range for the purpose of alighting slowly, and is doubtful whether it will ever be possible to alter the sail area of the wings for the purpose of supporting the weight at a slower speed. It is possible that he is right, but I am very sanguine about the future, and am inclined to expect much in the way of mechanical ingenuity when we are freed from the more important cares of stability and negotiating unsteady winds. No one who

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has not actually seen it done would believe in the production of that little Swiss singing bird that comes out of a gold box the size of a watch, sings a charming tune, wags its head, opens its bill, warbles its throat, flaps its wings, and bows before finally disappearing. If this could be made in gold and steel, then the application of folding wings to aeroplanes is a trifle compared to what mechanical ingenuity can do and has done. For the present, there is another way by which the effective sail area of an aeroplane might be increased or restricted without actually varying the visible area of the wings, and that is by altering the fore and aft slope of the wings. There are other ways that may commend themselves more to the author, and perhaps he will give us some alternative suggestions as to how to obtain slow and fast flying. He has exhibited the Royal Aircraft Factory's chart which showed how to obtain a range of speed which, after all, is not unimportant. Some of the machines he has shown will be able to fly at anything from 40 to 60 and 90 ft. per second, that is, 40 to 60 miles an hour, which is a 25 per cent speed range, and is quite substantial. He may have in his head figures of the speed range of the Aircraft Factory's BE2 aeroplane, and it might interest some members to know what that is. The problem of getting a good landing chassis has got this resemblance to the problem of a gun recoil mechanism, that a lot of energy has to be used up and got rid of through a certain very limited range of movement, and although he refers to the Breguet aeroplane and its buffer gear, he has not told you, because he is unwilling to boast, that he has himself been working, and I think has done good work, in evolving a form of landing chassis on the gun recoil principle which externally resembles Breguet's. In such gear the wheels must be allowed to be sprung, so that they rise and fall rapidly over the irregularities of the ground, while at the same time there must be an energy absorption device which absorbs the shock uniformly throughout a given length of travel. It will be of service to us before long I hope, as, of course, what we want to do is to be able to get the machine to go on rough ground, particularly for military purposes. A great difficulty which has to be overcome is that of getting rid of the cross-bar at the bottom of the landing gear. This bar exists on many aeroplanes, and when the skids come to the ground it will catch in and be irregularly retarded by every kind of growing thing from scrub to wheat and even down to not very long grass. That bar, which will be below

the axle when the skids reach the ground, if at the level of the skids may be caught and the aeroplane upset. It will have been seen in the cinematograph pictures that that particular bar has been got rid of on aeroplane BE2, not only at the skid level, but there is no cross-bar whatever in the lower part of the structure. The skids are kept apart, and the only bar that there is—and that could even be got rid of, but with difficulty—is the axle. The axle is, at least, at the height of the radius of the wheels from the ground, and therefore with a certain length of grass it is possible to alight. With the alighting chassis I complain of, using the cross-bar, the grass sometimes coils round it, and stops the lower part of the aeroplane while the upper part continues, and produces the effect known in France as “*piquer du nez*,” the machine dives on to its nose. This is a warning which it is certainly very important to keep in mind in the design of landing gears. I agree with what the author says in the paper, that it is absolutely essential that the chassis should be well up to its duty. If a fracture occurs before the flyer leaves the ground, then his career as an airman may be quite appreciably prejudiced when he alights. Above all, the design must be good in the face of the most severe weight cutting. Weight cutting means that every conceivable item must be designed with a full appreciation of the stresses it will bear, and there must be a given amount of metal to bear them, plus the smallest factor of safety that the designer dare use, and it is very difficult to estimate how far the factor of safety may be reduced, especially with effects such as those due to landing which are unknowable to any calculations.

MR. A. E. BERRIMAN: From the point of view of discussion, this paper suffers somewhat from an over-abundance of information. It is difficult to know where to begin, and it seems dangerous to isolate any one particular point for special comment. From the engineer's standpoint, however—and it is presumably the purely engineering side of the subject rather than its aerodynamic aspect that interests Members of the Institution of Automobile Engineers—the subject-matter for discussion appears to be very ably condensed in the series of clauses (a) to (i), wherein are enunciated the conditions to be fulfilled by an ideal undercarriage.

The first of these may be translated as involving the necessity for wheels, and, if the ground is very bad, the desirability of

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using wheels that are large. It is the purpose of the engineer to make the best use he can of the materials at his disposal, rather than to devote his time to the elaboration of new solutions to relatively less important detail, and it may be argued, therefore, that clause (a) is satisfied by a fair size of pneumatic-shod wire wheel.

The second clause presumably refers to the unstable equilibrium of an aeroplane moving over the ground just prior to flight. At this moment it is balanced on a single pair of wheels, the tail being lifted off the ground by the action of the elevator. If the wheels strike an obstacle there is a tendency for the machine to pitch forward on its nose, which may be attended with serious consequences to the pilot and certain damage to the propeller if that happens to be the foremost member of the machine. The engineer's problem is, therefore, to design some sort of guard that will come into action in such an emergency and yet not materially encumber the machine in other ways. The most satisfactory solution at present has been the skid, which is normally maintained by the wheels several inches above the ground. It is a question how far the skid should project and what should be its curvature. Very long skids are not in themselves necessarily more of a safeguard than shorter skids thoroughly well designed. Further information as to the requirements of the case are desirable. The same subject is brought up in clause (i), which specifically defines the necessity for some member in the undercarriage for preventing the machine from turning over under *any* circumstances. In those aeroplanes which have an elevator in front, there is an incentive to continue the skids to the axis of the elevator support, which seems to form the basis of a satisfactory design. In the case of monoplanes that have tractor screws in front, the elevator being in the tail, a long skid is not so easily arranged.

There is also the question of one central skid versus two skids. In the former case the transverse base of attachment to the axle is virtually a mere point, which increases the bending strain on the axle itself and also reduces the lateral stiffness of the machine against side strains on the ground. On the other hand there is, of course, a saving in weight, as in the notable example of the Nieuport, where the axle itself is a spring. The necessity of being able to withstand side strains on the ground is specified in clause (h), and it is a point for discussion whether the wing

extremities when suitably provided with fenders in the form of wheels or skids can be justifiably used as emergency supports, having regard to the nature of the wing structure.

The desirability of a brake, urged in clause (e), would appear to point to the advantage of disappearing wheels, so arranged that the machine can land on its skids direct, but, in clause (g) is emphasised the necessity of absorbing the landing shock, to which the above solution is antagonistic. The question of absorbing the landing shock, as distinct from rolling shocks, is a matter of very great interest and importance. Before the engineer can very well tackle the problem of design under this head, however, it seems necessary that he should be put in possession of the limits to which the shock is to be absorbed. There is a degree of bad landing beyond which no absorber can save the machine from disaster; the question arises, where is the economic limit? It seems to me that it must vary with the type and purpose of the machine. A heavy passenger carrier used for pleasure or commercial purposes would justify a much more elaborate arrangement than would presumably be considered necessary on a light, high speed army scout.

Having regard to the fact that something must break in the long run, there is the consideration that it might be most economical and equally satisfactory to design the shock absorber in the form of a weak member that should regularly give way in a bad landing. I remember seeing Capt. Dickson purposely drop with his Farman biplane into the alighting ring during the Bournemouth competitions, and nothing was damaged except the undercarriage struts, which could easily be replaced. It depends on how often the landing is likely to be bad, because it might not be considered worth while to carry, on service aeroplanes—which, for the moment, are those most in the eye of the designer—any apparatus that would add weight and expense. Looking further forward into future developments, there can, of course, be no question as to the importance of evolving a satisfactory shock absorbing device.

In connection with the question of the collapse of landing chassis under the conditions stated above, it is also worth considering the principle of designing the undercarriage in two tiers, so to speak; that is to say, so to arrange the various members that the collapse of the lower stratum still leaves the machine with a firm support and its propeller high and dry above the ground.

Mr. S. F. CODY: I certainly feel honoured on being called upon to speak before a gathering of mechanical engineers. I am not a mechanical engineer, and profess no training in that way at all. I am an aeronaut and a designer of aeroplanes—at that I have worked for some twenty-eight years. Leaving my experience aside, however, the subject to-night is the landing chassis. I do not suppose I can say a lot to interest you. I have never made but one landing chassis—it was successful as far as I used it—and I have stuck to it. I am quite prepared to roll my big aeroplane over a ditch of any depth, six feet wide, at any speed over 10 miles per hour. I am prepared to run it into a log one foot thick laid on level ground without any lift on the planes, by showing a load of over 1,200 lb. on the springs that carry the machine, right up until it strikes the log. I have tried this, and the only result in the way of damage was that the pneumatic inner tubes punctured. The machine lifted into the air very high at first, and then, of course, took a normal flight from that position. I may say that the combination which the Army Aircraft Factory have turned out in their latest design of machine is quite successful, because it goes about on Laffan's Plain, which was very much condemned by everybody in early aviation, and it goes round successfully. I do not think I have seen it crippled at any time, and that is saying a lot on behalf of the machine. I used to get crippled frequently when I first went out, but my "cripples" were generally pneumatic tyre punctures, and at that time I had no spares. I worked for Government then, but I wish they had been a little more liberal in my time; had they been I would, perhaps, have better works on Laffan's Plain now. Even if they would open their hearts to-day it would please me infinitely, and I might be able to produce something a little more successful than I have already done, although I shall go on trying to the end, doing my best. The question of avoiding the long grass that Mr. O'Gorman spoke of is going to be rather a difficulty unless we build higher wheels, because I do not know of any landing chassis that clears the ground any more than mine does, or any more than do either the de Havilland or the Nieuport machines. The Farman, I think, shows rather a cumbersome arrangement near the ground, but I am very much in love with the Nieuport system of landing chassis. It is one of the simplest and neatest I have ever seen.

Dr. H. S. HELE-SHAW: I feel that a great deal of credit is

due to the pioneers like Mr. Cody for their work in connection with that most important and essential feature of the flying machine—the undercarriage. Mr. Cody stated he had only made one type. He may dispute the fact or deny the soft impeachment that he is an engineer. He may mean that he did not receive an early training as an engineer, but we cannot follow Mr. Cody in his wonderful tenacity of purpose together with the meagre, and I might say, almost discreditable want of support that he has received, without feeling that he is a born engineer. I remember an early Wright machine, when Wilbur Wright began to make his first attempts, on what was merely a skid which was drawn along by a falling weight without a wheel at all. Then we had the Farman, which put on the wheels, together with the skid originally used by Wright, and I must say that I think it was a backward step. Blériot discarded the skid, and only used the wheel. If you look at the picture of the Blériot machine, I think you will agree with the author, whose actual words are very striking. No engineer can look at page 299, and see that front wheel without a skid, and not feel that what the author says is absolutely true, namely, “The absence of any kind of front skid makes this type of undercarriage unsuitable for use on very uneven ground, as there is nothing to prevent the machine turning over should the wheels be suddenly retarded by an obstruction, or by sinking into soft ground.” I think the author means “diving.”

MR. DE HAVILLAND: Yes.

DR. HELE-SHAW: You mean not by turning over as we generally understand it, but running along and pitching on its nose, and from that picture one can see instinctively that Mr. Cody is the man who has evolved the right thing. If one looks at the Cody machine, it will be seen that it realises the necessity of combining the wheel with the skid, and I think every engineer in this room feels that that is a sound and proper method. It gives the benefit of the wheels on the hard ground and the benefit of the skid on the soft ground, and it seems to me that that is a proper engineering combination. It is a very important subject, and I daresay, great as the loss of life has been, it would have been enormously greater if it had not been for the undercarriage. I do not know if Mr. Cody, Mr. O’Gorman, and others who watched these early flights can tell us how many of what have been trivial accidents might have been fatal accidents if it had not been for the efficiency of the undercarriage, and, incidentally, the use of

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that marvellous contrivance, the pneumatic tyre. I wish that we had been able to combine in this paper another type of under-carriage, namely, the under-boat, which enables an aeroplane to rise off the water. I think that is going to be a very important thing in the future, if the aeroplane is to be adopted in the Navy, because without it the aviator will often not be able to return to his ship.

I should like to say in conclusion that I think the contrivance which interests me most is that described on the last page. I have been doing a great deal of work with Mr. Martineau on the use of oil, and I am very pleased to see another application of oil in the Oleo pneumatic gear. I hope the author will tell us something more about this, because undoubtedly the curves shown in Fig. 14, page 313, are very remarkable. Nos. I. and II., I notice, are coil springs in compression, respectively 5 in. and 10 in. No. III. shows that with the Oleo pneumatic gear the curve is almost a level line. That is about the best illustration I have ever seen of the true shock absorber. The extra springs on the back of a motor car are for the purpose of absorbing shock, but I have never before seen a diagram so strikingly illustrative of the real need of the shock absorber as this diagram of the Oleo pneumatic gear. I suppose I am right in saying that the horizontal line indicates that practically there is none of the severe change of effect, and that it is a perfectly uniform resistance from beginning to end of the shock in this form of gear?

Mr. DE HAVILLAND: Yes, that is so.

Dr. HELE-SHAW: I hope the author, in his reply to this discussion, will tell us a little more about this shock absorber, it will be very interesting. We cannot help feeling, when we think about it, that this undercarriage is only a concession to a very imperfect stage of our progress in the science. Birds have not got any runners. One has only to watch a gull from Blackfriars bridge. When the gulls want to bring themselves up, they quickly alight on the parapet without any shock absorber, or skid, or pneumatic tyre. One cannot help feeling that the time will come when mechanical flight will have reached a period when these concessions to imperfection have disappeared, and that we are now only at an intermediate stage. When you see the largest and heaviest birds alight gracefully and gently on the ground, you know perfectly well that what is possible mechanically in that case must be ultimately possible to engineering

science. We have not yet got to the end of the subject, and there is plenty of room for development in this most modern branch of engineering.

THE PRESIDENT: The shock absorber shown in Fig. 13 of the paper appears to work on the same principle as the hydraulic buffer stops fitted at many terminal stations in England for the purpose of absorbing very large shocks. This principle has been found efficacious in arresting trains when the velocity of impact has not been too great. I will now call on Mr. de Havilland to reply to the discussion.

MR. G. DE HAVILLAND, replying on the discussion, said: Mr. O'Gorman suggested that the wings might be tilted up to more than 15 degrees in order to slow up in landing. This might be possible, but it would probably mean a lot of extra work, and a gradual tilting of the plane to a very big angle. It is also sometimes hardly correct to do that, because, in the case of landing with a following wind, the machine would be driven on, and would land faster. It seems to me that if the machine were to be fitted with very efficient brakes of some sort, as it can be, it would be doing the same thing in rather an easier way, but it is very difficult to say until experiments have been made with a machine with wings that can be so tilted. Mr. O'Gorman also spoke about the surfaces being varied. Of course, it is very difficult to say anything about that yet, but in the case of a very fast machine, where head resistance is cut very low, it is difficult to understand how it can be done without increasing the head resistance, not to mention other complications. The chart shows that the machine has a fairly large range of landing speed. The speed range of the aeroplane which Mr. O'Gorman mentioned, the Army Aircraft machine, is about 40 to 65 miles per hour, and landing at 40 miles an hour is comparatively easy, and against a slight wind the speed is further reduced. Mr. O'Gorman also mentioned a very important point which I omitted to mention in the paper, namely, the cross-bar between the skids. In the case of the ground being very uneven, and the wheels being sprung up, the tie rod is liable to meet a mound in the ground, and be swept off or drag the skids together, or wreck the machine in that way. A better way is to wire the ends of the axles to a ring in the middle and thence to the body of the machine so that there is a good clear space between the skids for any obstruction.

Mr. Berriman raised the point of the size of wheels. Big

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wheels are certainly an advantage on very bad ground, but they have generally the disadvantage of being very weak sideways, which is rather an important point. Small wheels are stronger sideways, and there is generally very little trouble in getting way on a machine unless the ground is very marshy or bad, when I think large wheels would be an advantage. Of course, there is a compromise between the two, and a 26 or 28 in. wheel is generally found to be about right. Mr. Berriman also mentioned clause (b) in reference to stability on the ground. That is really referring to the base of support of the machine. I consider that a long base of support is a great advantage for the same reason that a motor car with a long wheel base rides more easily than one with a very short wheel base. Over very bad ground, the machine with a short wheel base, like the Nieuport, plunges a lot, and if it happened to land on exceptionally bad ground there might be trouble from that cause, whereas a long base of support gives the machine a much better chance. With regard to clause (b), that the machine must be efficiently sprung to eliminate rolling shocks, this is really quite distinct from clause (g), which relates to absorbing the shock of landing. In rolling, the only spring required is one such as a motor car is provided with to ride over the bumps; but in landing, as is pointed out on the last page, the actual shock should be absorbed, and not given out again as is done by a spring, so that really these two clauses are quite separate. Mr. Berriman also suggested that the skid would be an efficient brake. This is very doubtful, because as the skid is generally unsprung, and is rigidly attached to the machine, the shocks are very excessive when it touches hard ground, and in fact it is inadvisable that the skid should ever touch the ground if the brake is attached to the wheel, which is the part that is sprung. In the Farman machine, the skids seldom touch the ground unless the wheel or axle collapses, and really they never act as a brake unless they sink into very soft ground, when the skid comes into contact with the ground. Mr. Berriman also mentioned side wind landings, and thought possibly the Nieuport was rather bad in this way. Lieutenant Barrington Kenneth told me there was considerable trouble with the spring axle, and it is liable to break at the axle box, where it comes through. That is the weak point of the machine. If it is running at all sideways there is a large bending moment on the spring, and the box is sometimes liable to break. In a side

wind landing with an ordinary long axle, providing the wheels are made with reasonably wide hubs, that form of gear is better than the Farman, because, in a very bad side landing, the wheels are liable to turn right under the skids, but with wheels on a long axle that is impossible.

Mr. Cody mentioned that he had made only one type of under-carriage. Of course, I have seen a lot of his machine, and I believe it is a very good type. The single skid is very stiff, and might be better than the Nieuport because there are two springs, so that he has side supports instead of a single support in the middle.

Dr. Hele-Shaw asked me to explain the Breguet shock absorber. I think it can be seen fairly clearly in Fig. 13. When fully extended it is as shown in the left-hand view. The top spring is quite free; the oil is in the bottom part, and when the machine lands the oil is displaced into the top tube through the ports at the side. It practically amounts to a spring-loaded valve; it is a safety valve, and the oil is squeezed through it. As a matter of fact, the area of the ports is predetermined, but it is very difficult to get any results in the form of curves; the principle is that the valve is opened by the pressure of oil against the spring, and the oil is squeezed through for the whole length of the travel under constant pressure until the valve actually comes down on the lower spring. This spring is arranged to hold the valve open so that when the machine is rolling on the ground the springing is undamped.

Dr. HELE-SHAW: For the benefit of those who are not familiar with this, may I ask whether the closed position is the normal condition and the extended position arrived at when the shock absorber has operated, or, in other words, if the two eyes at the top are for tension rods or compression rods?

Mr. DE HAVILLAND: These buffers are fixed one on each side of the underneath part of the body of the machine, the bottom ends being fixed to the axle. When the machine is in the air these buffers are right out as shown in the dotted lines in Fig. 9 and as on the left-hand side of Fig. 13. On landing, or when the machine is resting on the ground with the springs taking the weight, the wheels are driven up as shown in the full lines in Fig. 9, and the buffer closes right up as shown on the right-hand side of Fig. 13.

Continuing, Mr. de Havilland said: Dr. Hele-Shaw also referred to the curves in Fig. 14. The curve of the Oleo pneumatic

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buffer is, of course, more or less approximate owing to the damping effect of the oil, which is always there; there is practically no rebound even in a fairly hard landing. The shock absorber from which this curve was obtained had a travel of 16 in. as against 10 in. and 5 in. for the springs, but the load does not rise much over 2,000 lb., whereas in that with the 5 in. spring the load goes up to over 10,000 lb. That spring curve is probably not quite correct, as most likely the curve would go far down below the zero line, and the machine would rebound several times. These curves were made for a vertical velocity of landing of 9 ft. per second, which corresponds to a gliding angle of about 1 in 11, and that means a very bad landing; generally, even with a coil spring, the curve would not be anything like so high as that given, but it shows that with a properly designed Oleo pneumatic buffer a very harsh landing can be made without any damage being done to the machine.

Mr. Legros has mentioned the railway hydraulic buffer stop as being something like this shock absorber. The principle on which both depend is that of the dashpot, the only difference being that for an aeroplane some provision must be made for ordinary undamped springing while rolling. If there were no springing provided in the buffer so as to enable it to take up rapid oscillations, very big shocks would be transmitted to the machine, and therefore at the end of the travel the valve is held open so that the oil passes through quite freely when it is rolling.