

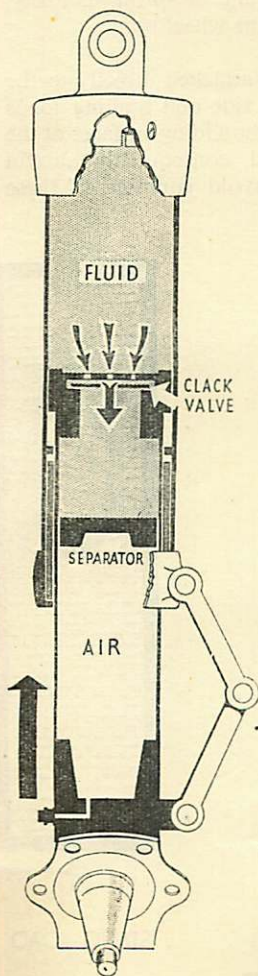
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PART 1 : SECTION 5 CHAPTER 3 UNDERCARRIAGES

Introduction

1. The undercarriage, although an essential component of all landplanes, embarrasses aircraft designers owing to its weight and bulk. It is required to :—

- Support the aircraft while on the ground.
- Absorb the shocks of all landings and provide for reasonably smooth taxiing.
- Withstand the side loads of crosswind take-offs and landings.
- Give minimum rolling friction for take-off, and minimum drag in the air.
- Give a large braking effect for landing.



2. An aircraft is usually supported on the ground by three undercarriage units : two main wheels and a nose or tail wheel unit, all of which may be retractable.

3. Various methods are used to absorb taxiing and landing shocks. On some light aircraft the undercarriage units are fitted with rubber springs, but most service aircraft are equipped with either undercarriage shock-absorbers of the oleo-pneumatic type similar in operation to that in the simplified diagram in Fig. 1, or of the oil-compression type similar in operation to that shown in simplified form in Fig. 2.

Fig. 1. Undercarriage Shock Absorber Oleo-Pneumatic Leg

Oleo-Pneumatic Shock Absorbers

4. The operation of oleo-pneumatic shock absorbers is as follows :—

(a) *Extended.* As the aircraft becomes airborne the load on the shock absorber strut is reduced to zero, and consequently there is no force opposing the air pressure in the air chamber. Therefore the separator piston is forced upward, causing the pressure to be transmitted through the liquid to the upper cylinder head, resulting in the plunger tube being forced downwards until the piston reaches the stops.

(b) *Static.* When the aircraft is on the ground, its weight compresses the strut. The separator piston is therefore forced down by the liquid passing through the holes in the piston to the plunger tube until the air pressure is sufficient to balance the load on the strut.

(c) *Compression.* When the aircraft lands, the plunger tube and the piston are forced up. The liquid above the piston is forced through the holes in it, causing the flutter valve to open, thus allowing the liquid to pass through the holes in the valve to the plunger tube. The separator piston is therefore forced downwards, compressing the air below it. This action absorbs the landing shock.

(d) *Extension.* After the initial landing shock the air pressure, being greater than that required to support the load, drives the separator piston upwards. Thus the liquid in the plunger tube is forced upward and the flutter valve closes, leaving a single hole in the piston through which the liquid can pass to the upper cylinder. This upward transfer of the liquid tends to force the upper cylinder head away from the piston, so the strut extends. The restricted transfer of the liquid through the piston slows the speed of extension and damps the rebound.

Oil-Compression Shock Absorbers

5. The operation of oil-compression shock absorbers is as follows :—

(a) *No Load.* Under no-load conditions the undercarriage leg is fully extended and the non-return valve in the piston is closed.

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(b) *Landing Load.* Landing loads force the sliding cylinder upwards over the piston. Entry of the piston rod in the cylinder reduces the internal volume and the fluid is therefore compressed. Simultaneously fluid below the piston is transferred to the piston-rod side, lifting the valve and passing through the surrounding ports in the piston. Under these conditions the upper piston ring is moved to the top of its groove and the outer fluid ports in the piston are therefore closed off.

(c) *Recoil.* When the load is absorbed the energy stored in the compressed fluid tends to force the piston and cylinder apart at high speed. This movement, however, necessitates the return of the fluid to the underside of the piston. As the valve is now seated, the return passage for the fluid is limited to the remaining ports in the piston. The outer ports are open in this case, since the piston ring is forced to the bottom of its groove. By restricting the flow in this way the speed of recoil is controlled.

(d) *Static Load.* Under static load the undercarriage leg telescopes until the piston enters the sliding cylinder sufficiently to create a pressure which sustains the load.

6. The operation of the nose-wheel and tail-wheel shock-absorber units is similar to that described above, but their construction differs slightly. Besides being considerably smaller, the strut is usually designed to allow the wheel to castor freely while the aircraft is on the ground and to trail in a true fore-and-aft position when it is relieved of all loads. In some assemblies this action is obtained by a helical sleeve fitted to the upper cylinder and a helical surface formed on the plunger tube. While the aircraft is on the ground the strut is sufficiently compressed to keep the helical surfaces disengaged, permitting the plunger tube to rotate in the upper cylinder. When the wheel is relieved of its load, however, the compressed air in the strut forces the plunger tube down, causing the helical surface to engage, aligning the wheel correctly. To prevent oscillation of the wheel (shimmy) from developing at certain speeds on the ground, a mechanical wheel-locking device, or hydraulic or spring dampers, may be incorporated in the wheel unit.

7. When the wheels are attached directly to the shock-absorber unit, the side and braking loads are transmitted through the sliding surfaces of the absorber cylinders, and consequently careful design is necessary to avoid jamming of these

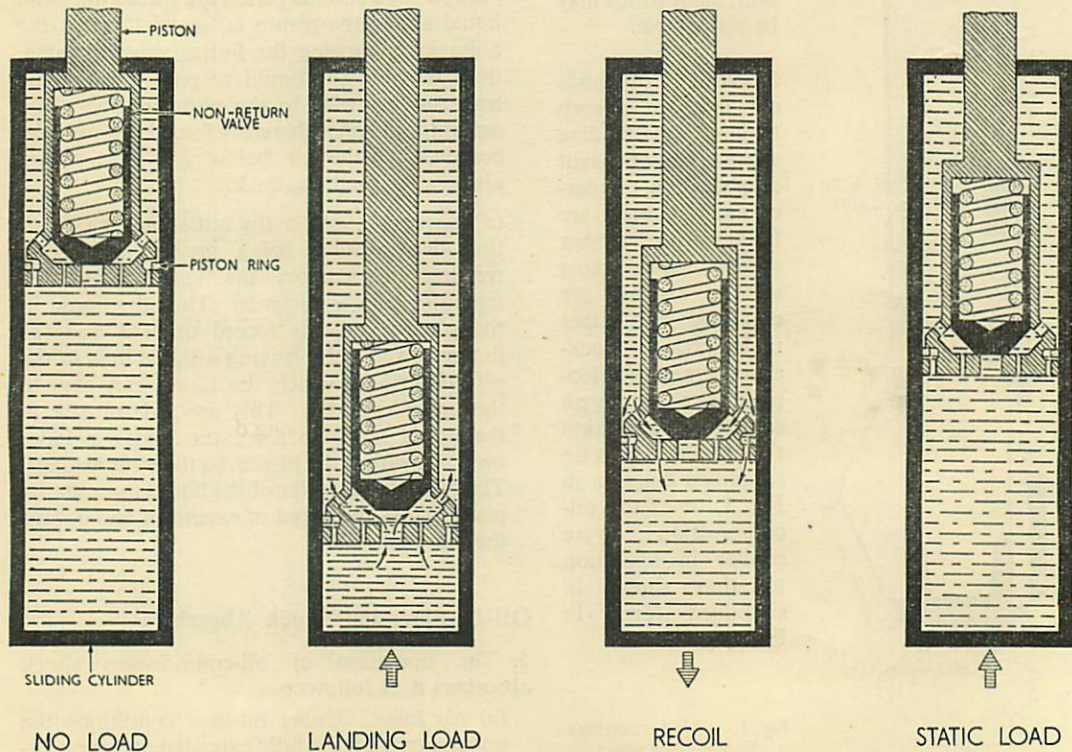


Fig. 2. Undercarriage Shock Absorber Oil-Compression Leg

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moving parts. The introduction of the articulated (levered) undercarriage (Fig. 3) has relieved the shock-absorber unit of all but end loads. The undercarriage can be relieved almost completely of the side loads by the use of castoring wheels.

8. Minimum rolling friction for take-off is obtained by using a wheeled undercarriage. Other methods have been tried but have proved to be less satisfactory. It is usually best to use a fixed, well-faired undercarriage for speeds up to 130 knots, or more if the fairings can be used to house air intakes, armament, etc. Above this speed a retractable undercarriage is usual.

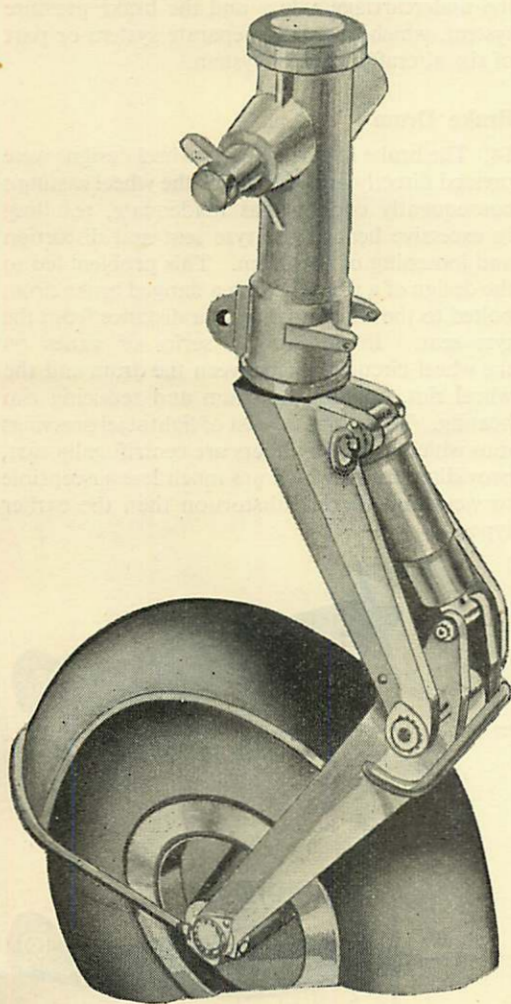


Fig. 3. Levered Type Undercarriage Unit

Problems Associated with the Undercarriage

9. Two of the main problems associated with the undercarriage are an aircraft's stability on the ground and its wheel loading. The former depends on the position of the main wheels relative to the aircraft's centre of gravity (C.G.). If the main wheels of an undercarriage are too close to the C.G., heavy braking will cause the aircraft to nose over (Fig. 4), but if the wheels are well ahead of the C.G. the brakes can be more powerful and the engines can be run up without special measures to hold the tail down, because the tendency to nose over is reduced. However, bringing the wheels well forward of the C.G. increases the tendency for the aircraft to ground loop (*i.e.* to swing of its own accord into a tightening turn) because of the greater variation in the ratio of moment arms between the C.G. and each wheel as the swing develops. Thus a much greater effort is required from the differential braking to stop the swinging movement. The wider wheel track shown in Fig. 5(G) increases the length of each moment arm equally, tending to equalize their ratio, with the result that less differential braking force is required to check the swing. The use of a lockable or steerable tail wheel as in Fig. 5(H) produces a large righting moment which opposes the swinging tendency. Castoring main wheels (Fig. 5(I)) turn freely in the direction of motion, within their castoring limits, thus reducing considerably their respective swinging moments; therefore on aircraft fitted with castoring main wheels there is no tendency to swing if the brakes are used with a slight differential action.

10. The nose-wheel undercarriage overcomes both the nosing-over and the ground-looping tendencies described above. The nose wheel prevents the aircraft from nosing over (Fig. 4) and the location of the C.G. well forward of the main wheels gives the aircraft directional stability (Fig. 5(J)). However, the nose-wheel undercarriage has the following disadvantages :-

- (a) More damage is done if the nose wheel collapses than if a tail wheel fails.
- (b) The heavier structure of a nose wheel involves greater weight.

11. **Wheel Loading.** Wheel loading (lb./unit area) is defined as the static load, at take-off weight, on each wheel. Wheel loading has to be considered in conjunction with runway strength. If the wheel loading is too high the runway structure will be damaged and the tyre will sink into it. Consequently a designer must keep these

loads within the limitations of existing runways. All runways are given a load classification number (L.C.N.), that of an average bomber airfield runway being 30, which means that the runways will withstand the following loads *per undercarriage unit* fitted with a single wheel :—

- (a) 45,000 lb. with a tyre pressure of 50 lb./sq. in.
- (b) 33,000 lb. with a tyre pressure of 75 lb./sq. in.
- (c) 27,000 lb. with a tyre pressure of 100 lb./sq. in.
- (d) 20,000 lb. with a tyre pressure of 150 lb./sq. in.

From these figures it can be appreciated that for heavy aircraft using existing runways the designer has to use multi-wheel arrangements. These result in a lighter undercarriage, smaller wheels, and easier stowage in the thin wings of high-speed aircraft. The wing stowage problem can also be met by using a tandem undercarriage (Fig. 6) in conjunction with outriggers carrying small wheels.

BRAKES

12. The comparatively high weights and speeds at which many aircraft touch down puts a severe burden on the wheel brakes, which have to convert the aircraft's energy of motion into heat, and then dissipate the heat to prevent damage to the tyres. There are two main types of brakes, the drum brake and the disc brake. Both types may be operated pneumatically, hydraulically, or mechanically. The drum brake, described in paras. 13 and 14, is extensively used but is being replaced by the disc type described in para. 16. The details of all brake units used in the R.A.F. will be found in A.P.2337. If overworked, both

disc and drum brakes suffer badly from decreased effectiveness (fading) due to the disc or drum becoming overheated or glazed owing to friction. To overcome this another form of brake is used in which a steel or copper disc which is attached to the wheel rotates between one or more pairs of braking pads. When the brakes are applied the pads squeeze the disc with such force that they may become very hot towards the end of a landing run.

Drum-Type Brake Assembly

13. For ease of explanation, the drum-type brake assembly is considered in three sections: the brake drum, which is connected directly to the wheel; the brake unit, which is secured to the undercarriage axle; and the brake pressure system, which may be a separate system or part of the aircraft's control system.

Brake Drum

14. The brake drums on early wheel designs were pressed directly into the rim of the wheel casting; consequently cooling was inadequate, resulting in excessive heat at the tyre seat and distortion and loosening of the drum. This problem led to the design of a wheel having a flanged brake drum bolted to the wheel casting at a distance from the tyre seat. In addition, a series of vanes on the wheel circulate air between the drum and the wheel rim, cooling the drum and reducing rim heating. The drums consist of light steel pressings into which iron alloy liners are centrifugally cast, providing drums which are much less susceptible to wear and thermal distortion than the earlier types.

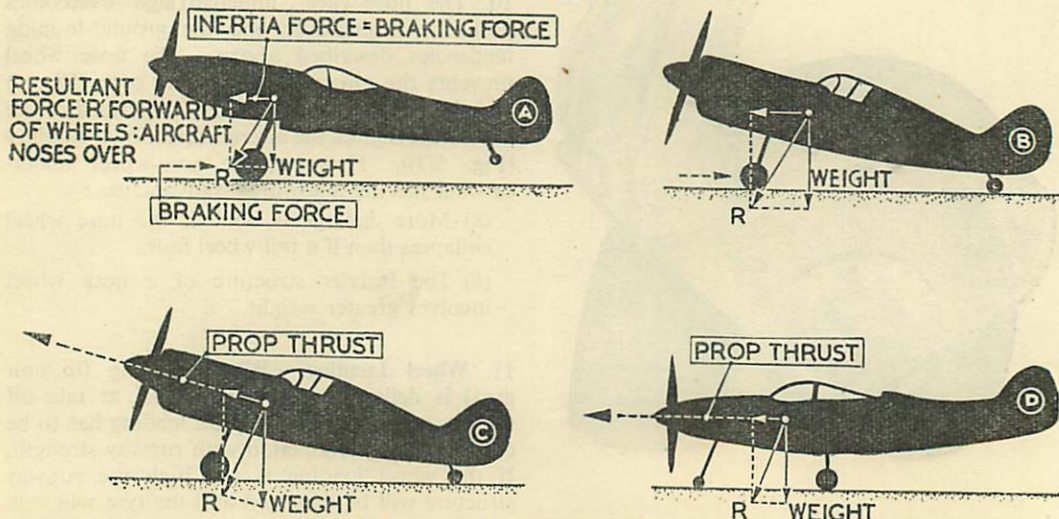


Fig. 4. Undercarriage Stability in the Pitching Plane

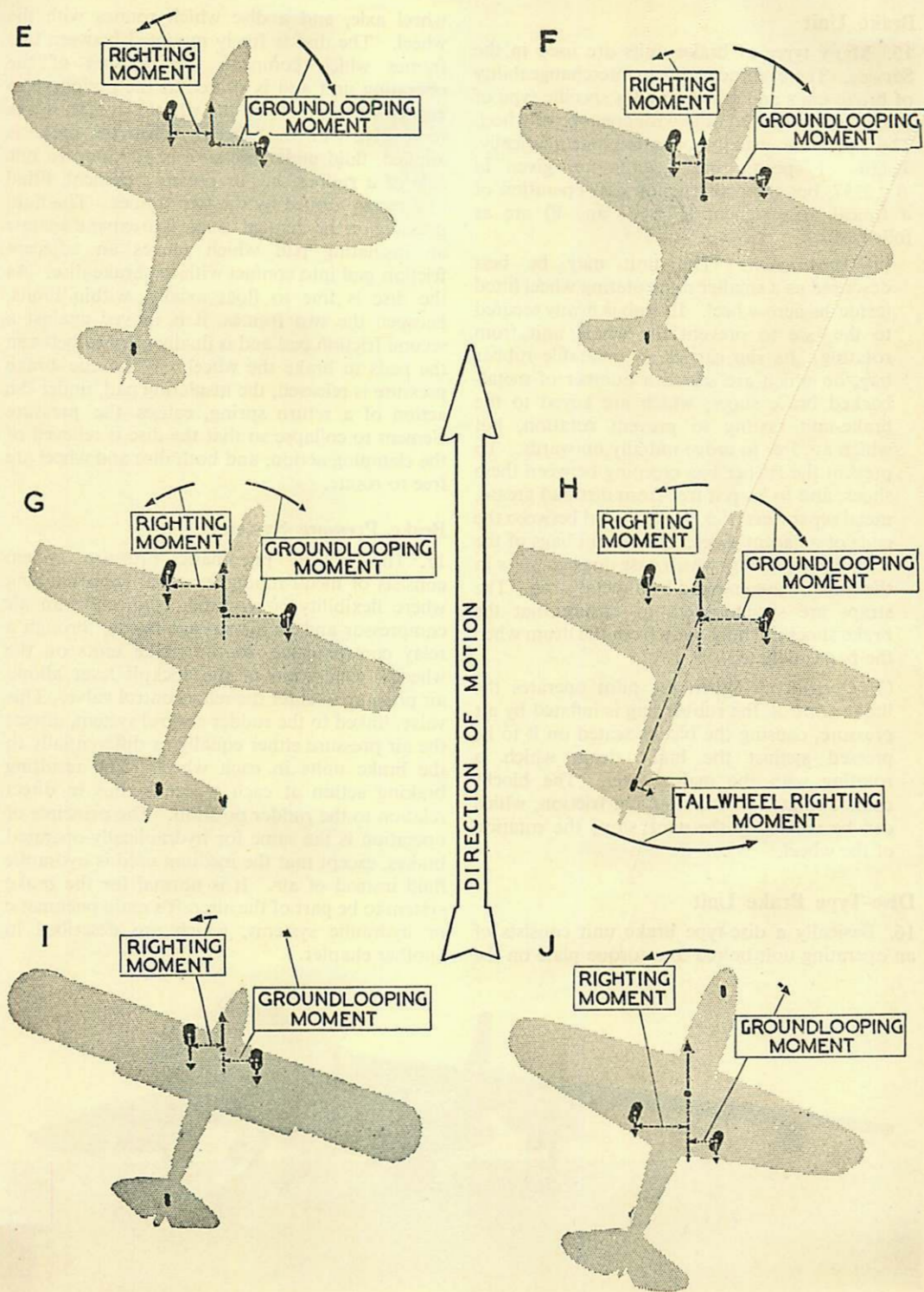


Fig. 5. Undercarriage Stability in the Yawing Plane

Brake Unit

15. Many types of brake units are used in the Service. There is practically no interchangeability of brake units and wheels, and a specific type of unit is generally used only with one type of wheel. The units are usually operated pneumatically. Details of specific brake units are given in A.P. 2337, but the construction and operation of a typical arrangement (Figs. 7 and 8) are as follows :—

(a) *Construction.* The unit may be best described as a smaller non-rotating wheel fitted inside the aero-wheel. Its hub is firmly secured to the axle to prevent the whole unit from rotating. Its rim carries an inflatable rubber bag, on which are seated a number of metal-backed brake shoes, which are keyed to the brake-unit casting to prevent rotation, but which are free to move radially outwards. To prevent the rubber bag creeping between these shoes, and to keep it free from dirt and grease, metal separators (Fig. 9) are placed between the ends of adjacent shoes. The metal bags of the shoes have two lugs which pass through slots in the rim and are engaged by a metal strap. The straps are springloaded to ensure that the brake shoes are held away from the drum when the bag is deflated.

(b) *Operation.* When the pilot operates the brake control, the rubber bag is inflated by air pressure, causing the blocks seated on it to be pressed against the brake drum which is rotating with the main wheel. The blocks cannot rotate, so the resulting friction, which can be varied by the pilot, stops the rotation of the wheel.

Disc-Type Brake Unit

16. Basically a disc-type brake unit consists of an operating unit bolted to a torque plate on the

wheel axle, and a disc which rotates with the wheel. The disc is freely mounted between two frames which comprise the housing of the operating unit and is slotted at the periphery to engage with spigots on the wheel; it is thus free to revolve with the wheel. When the brake is applied, fluid under pressure is admitted to one side of a rubber sac, or pressure element, fitted in a recess formed by the two frames. The fluid pressure on the element causes it to expand against an insulating pad which moves an adjacent friction pad into contact with the brake disc. As the disc is free to float axially, within limits, between the two frames, it is moved against a second friction pad and is finally gripped between the pads to brake the wheel. When the brake pressure is released, the insulating pad, under the action of a return spring, causes the pressure element to collapse so that the disc is relieved of the clamping action, and both disc and wheel are free to rotate.

Brake Pressure System

17. The typical pneumatic pressure system consists of metal tubing, or thick rubber tubing where flexibility is required, connecting an air compressor and an air storage bottle, through a relay control valve, to the brake units on the wheels. Operation of the cockpit lever allows air pressure to enter the relay control valve. This valve, linked to the rudder control system, directs the air pressure either equally or differentially to the brake units in each wheel. The resulting braking action at each wheel is thus in direct relation to the rudder position. The principle of operation is the same for hydraulically-operated brakes, except that the medium used is hydraulic fluid instead of air. It is normal for the brake system to be part of the aircraft's main pneumatic or hydraulic systems, which are described in another chapter.



Fig. 6. Tandem Undercarriage

Maxaret Anti-Skid Unit

18. The Maxaret anti-skid unit permits a pilot to apply brake on landing or taxiing, without fear of locking his wheels. This is particularly important in the case of bogie undercarriage units, where the braking force is applied to all wheels simultaneously in the same bogie unit. Owing to aircraft inertia, method of shock absorption, and the bogie action when traversing uneven surfaces, loadings vary greatly between the wheels on the

same unit and there is risk of independent skidding, and tyre-scrubbing by individual wheels. Also the indications of a single-wheel skid are not easily detected in the cockpit in heavy aircraft with nose-wheel undercarriages. The compact and entirely self-contained control unit is fitted in circuit with the manual control and is suitable for mounting either on the torque-plate, or on the undercarriage leg where the torque-plate is integral.

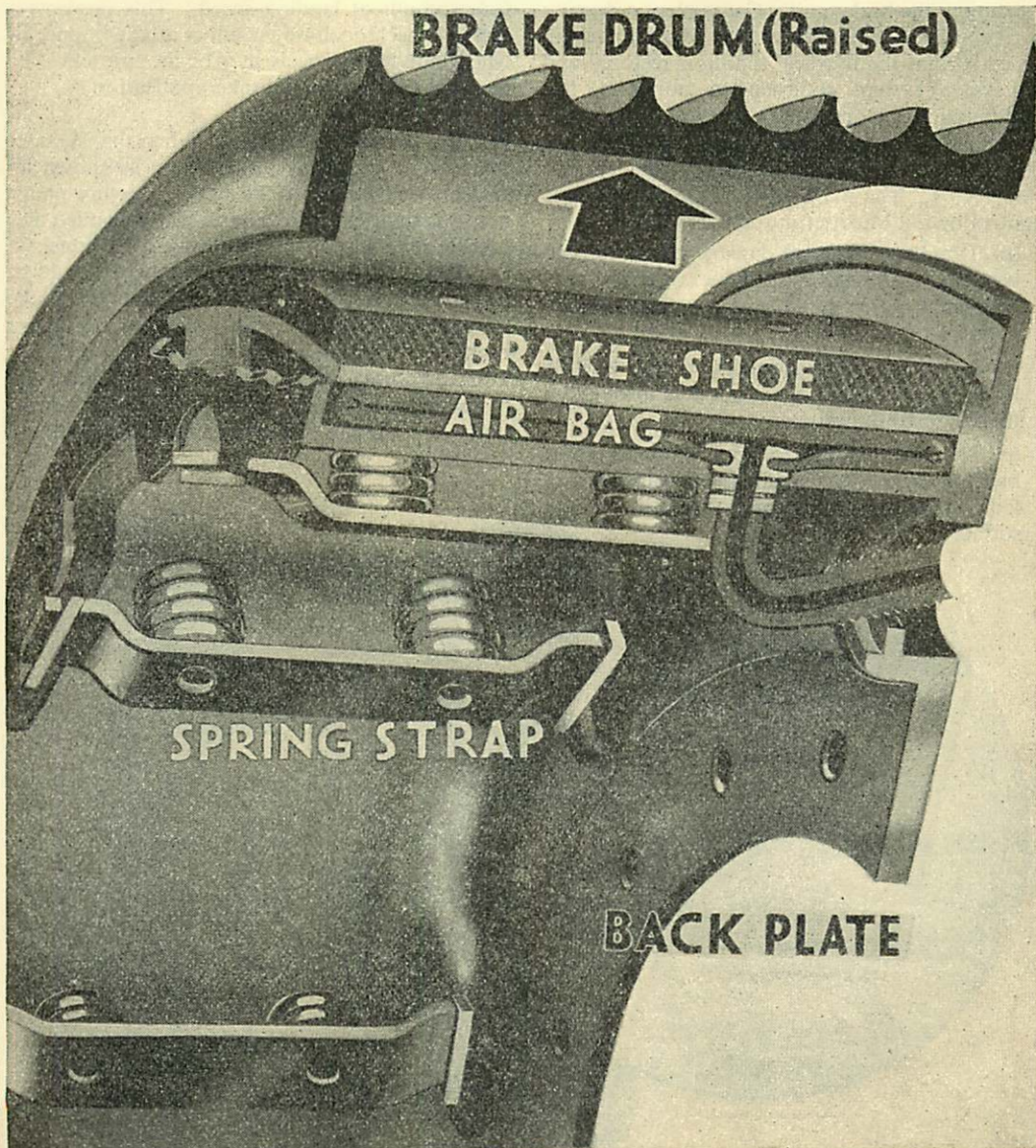


Fig. 7. Section of a Brake Assembly

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19. **Control Unit.** The control consists primarily of a valve arrangement regulated by a flywheel housed in a rubber-tired shell which is rotated by direct contact with a track on the landing wheel. The valve arrangement is connected to the hydraulic line from the brake lever to the associated brake unit, and is sensitive to angular deceleration consistent with an approaching skid of the wheel. When this condition occurs sufficient energy is released by the flywheel to operate the valve system and release the pressure existing in the brake unit. Consequent reduction in the brake torque allows the wheel to regain speed so that the flywheel setting is restored and the valve system returned to normal. The re-admission of pressure to the brake unit immediately restores the brake torque to the degree selected by the pilot until the tendency to skid recurs. The main advantages of automatic control by the Maxaret unit are as follows :—

(a) Tyre wear and tyre damage are minimized because skidding and wheel locking are prevented. Thus tyre life and performance are greatly improved.

(b) Maximum brake torque, and consequently maximum retardation, are possible throughout the entire landing run.

(c) The pilot is free to apply any degree of braking effort he requires, without fear of locking the wheels irrespective of the runway surface.

The Maxaret unit will operate only after the wheels have been spun up. *Therefore the brakes must not be applied before touching down.* On later types the brakes can be fully applied before touching down.

20. **Brakes Release During Wheel-Bounce.** Should a wheel lock dead (as occurs when leaving the landing surface while the brake is applied) the flywheel action moves the valve mechanism to "brake-off" for a period up to a maximum of four seconds at landing speed. This prevents a locked-wheel touch-down, either after a bounce or when individual wheels in a bogie unit leave the landing surface during brake application.

21. **Use in Normal Landing.** When the Maxaret units are in continuous operation, as shown by violent oscillations of the brake pressure gauge needles, then the brakes are being applied too fiercely for the prevailing runway conditions ; if no Maxaret units were fitted the wheels would be locked. Nothing is gained by applying full brake pressure under such conditions, and maximum braking effort is obtained by applying sufficient brake pressure to cause only occasional operation of the Maxaret units, *i.e.* only moderate oscillations of the brake pressure gauge needles should be visible.

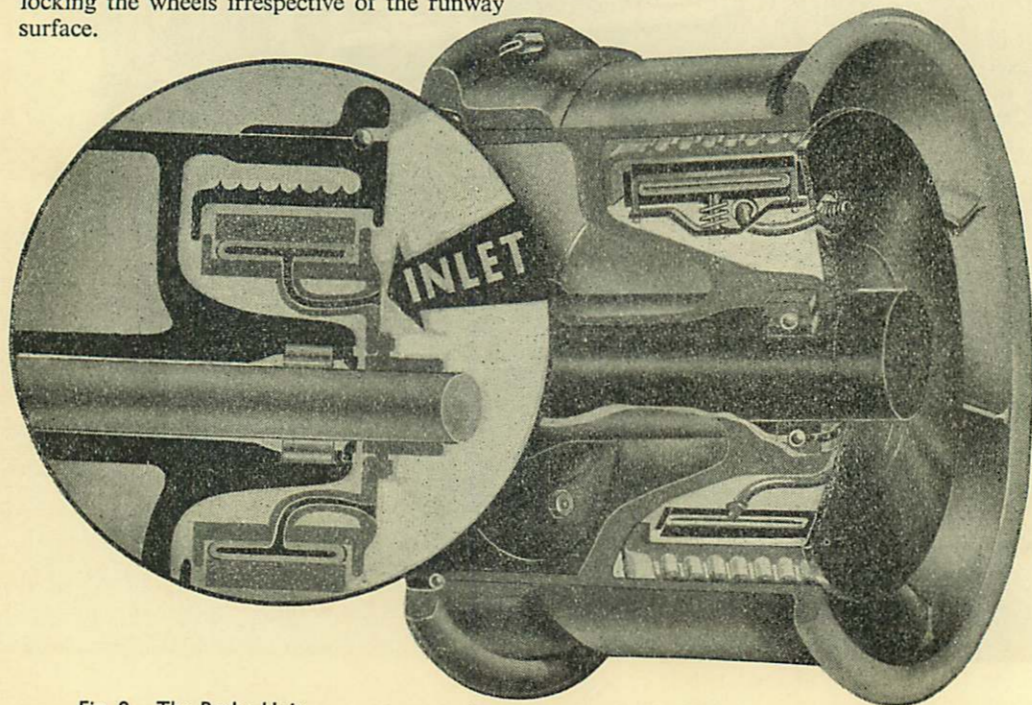


Fig. 8. The Brake Unit

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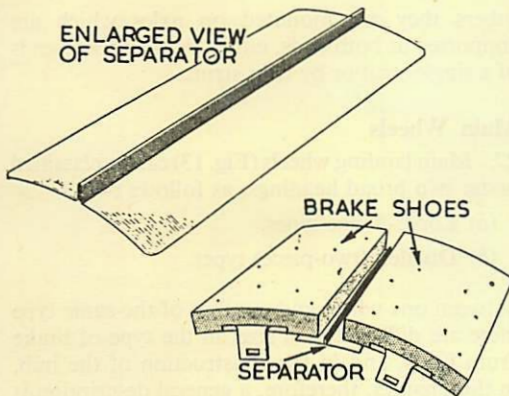


Fig. 9. Brake Shoe Separator

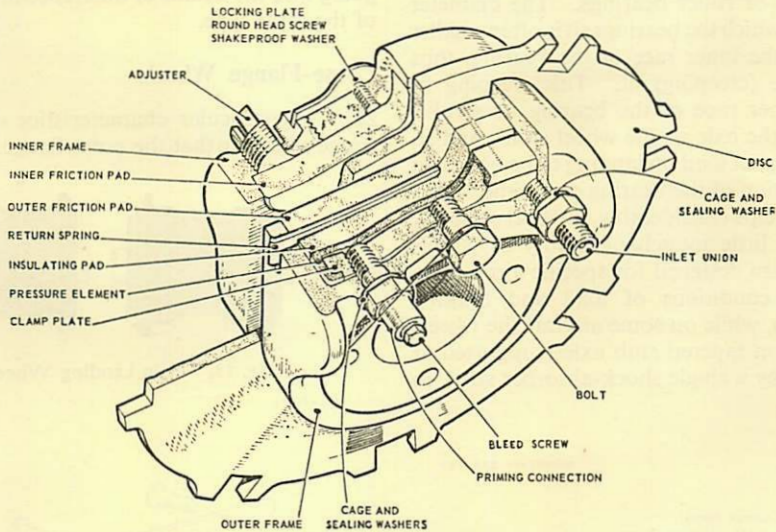


Fig. 10. Disc-Type Brake Unit

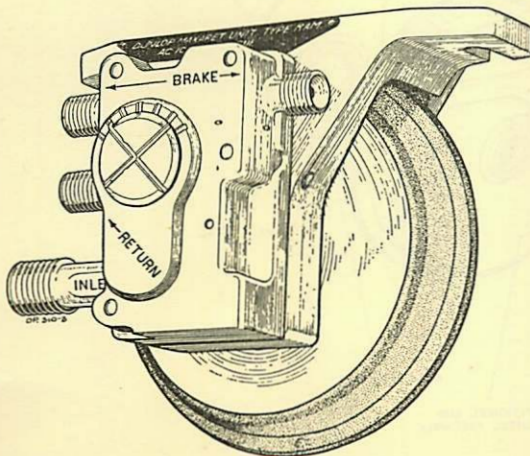


Fig. 11. Maxaret Anti-Skid Unit

22. **Use in Emergency (Hydraulic Failure).** When landing after a hydraulic failure, each operation of the Maxaret units and each operation of the pilot's brake controls exhausts some of the emergency accumulator fluid. The emergency fluid should be conserved by using only moderate braking pressures immediately after touch-down. Braking can then be increased progressively to a degree which does not cause excessive operation of the Maxaret units.

23. In all types of landing, a continuous and not intermittent application of the brakes is desirable.

24. **Overheating.** The much increased braking efficiency obtained by the fitting of Maxaret units results in greater heating of the brake units. Misuse of the brakes can cause a fire at the brakes. After a landing which has involved heavy braking, ten minutes should elapse before the next landing, so that the brakes can cool. If the intervening period of taxiing has also required prolonged use of the brakes, twenty minutes should elapse before the next landing. During brake tests and when bedding-in new brake pads, the same precautions should be observed.

25. **Use on Slippery Runways.** If the runway is wet or icy or for some other reason has a low coefficient of friction, only slight braking may

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cause the Maxaret units to operate, *i.e.* a low brake pressure may tend to lock the wheels. In these circumstances, if a hydraulic system failure has occurred, the brakes should be used with care because excessive operation of the Maxaret units rapidly exhausts the emergency braking supply of hydraulic fluid.

WHEELS

26. Wheels are usually constructed from castings. The metal used in these castings is usually magnesium alloy, although a few wheels have been made from aluminium alloy castings and forgings. The complete wheel may be any one of a series of variations of a simple wheel, which consists of an outer rim, which seats the tyre, and a hub which rotates about an axle either on ball or roller bearings. The diameter of the axle on which the bearings sit is often smaller than that of the inner race of the bearing, thus giving a loose (creeping) fit. This creeping fit allows the inner race of the bearing to revolve slowly round the axle as the wheel spins, and so permits the impact load on landing to be borne on a different section of the bearing each time. This loose fit also helps considerably in wheel removal. There is very little interchangeability of wheels because they are designed for specific aircraft, to meet certain conditions of load and braking stresses. Also, while on some aircraft the wheels are mounted on tapered stub axles supported at one end only by a single shock-absorber strut, in

others they are mounted on axles which are supported at both ends, either by the forked ends of a single strut or by twin struts.

Main Wheels

27. Main landing wheels (Fig. 13) can be classified under two broad headings, as follows :—

- (a) Loose-flange types.
- (b) Divided (two-piece) types.

Between one wheel and another of the same type there are differences in size, in the type of brake drum fitted, and in the construction of the hub. In this chapter, therefore, a general description is given of a typical wheel of each type, without going into the details of difference in other wheels of the same type.

Loose-Flange Wheels

28. The particular characteristics of the loose-flange wheel are that the outer flange is detachable

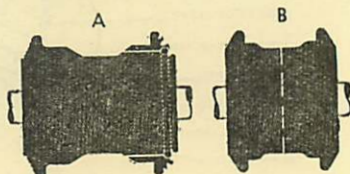


Fig. 13. Main Landing Wheels

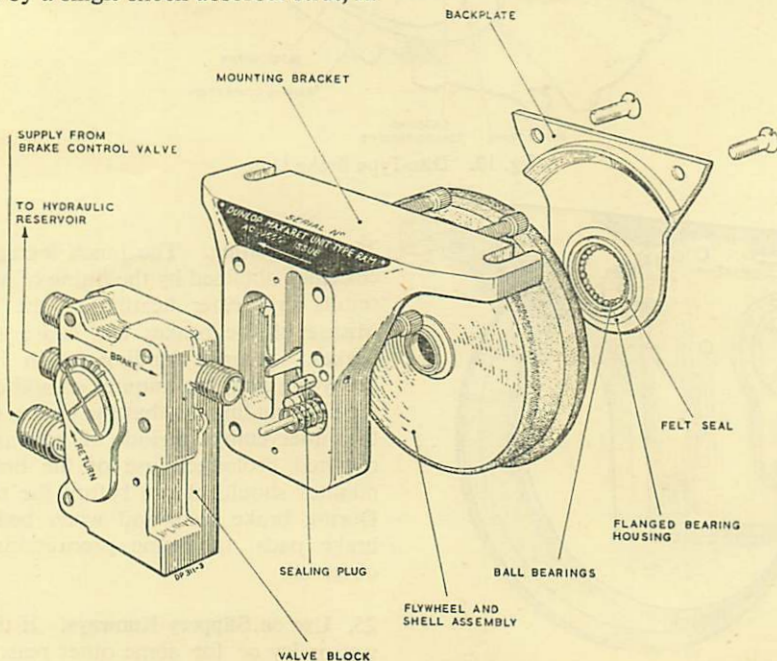


Fig. 12. Maxaret Anti-Skid Unit—Main Components

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to facilitate tyre removal, and is located on a cylindrical portion of the wheel rim. A split lock-ring of steel engages with the grooves cut in the wheel and in the flange, and a locating collar is fixed to the ring at a short distance from its end. This collar mates with a notch cut in the wheel and an aligned notch in the detachable flange, and serves to prevent flange rotation about the wheel while transmitting torque forces from tyre to rim during braking. Both flanges of the wheel are knurled to lessen tyre creep. The side pressure of the inflated tyre locks the components and prevents the flange from coming off.

Divided Wheels

29. In the divided wheel a two-piece, heat-treated casting forms the body of the wheel. Each part has a tyre-seating surface and an integral tyre-retaining flange which is hollow and open to the atmosphere to dissipate the heat generated during braking. The outer side of each part carries a steel brake drum. This may be either pressed into the wheel casting or bolted to the wheel casting as an additional component. The halves of the wheel are joined together with stainless steel bolts. (*Paras 30 - 35 appear on next leaf.*)

Disc Wheels

28. Disc wheels are used with amphibian aircraft, and are constructed entirely of non-ferrous metals and stainless steel to withstand corrosion from sea water. A disc wheel is cast in one piece. Special oil seals and watertight discs are fitted into the hub on each side of the wheel to keep the inner bearing free from water. Brake linings are treated with a special compound which excludes water, yet does not decrease friction unduly during braking.

Tail and Nose Wheels

29. Most tail and nose wheels are small versions of the main wheels described in the preceding paragraphs. However, whereas the main landing wheels are surface-finished with paint, electron tail and nose wheels are given a metallized finish of aluminium to provide the necessary continuity with the electrically-conducting tyres which are usually fitted to discharge the aircraft static electricity on landing.

TYRES

30. The chief functions of the aircraft tyre are to support and cushion the aircraft while at rest, or when moving on the ground. When the aircraft is airborne, however, the tyres and wheels become dead weight. The problem of the designer is, therefore, to reduce the size and weight of these components to a minimum, yet still retain an adequate safety factor. Aircraft tyres are subjected to wear during landing, when the tyre and wheel unit, initially stationary, is suddenly scraped over the ground at touch-down speed. The wheels are spun rapidly up to the running speed of the aircraft, but in this process there is considerable inertia between the tyre and the ground surface, which results in the tyre being abraded, especially when tarmac or concrete runways are used. However, the wear which occurs at touch down is negligible when compared to the wear which occurs in braked conditions, this being the biggest cause of tyre wear. The greatest stresses in the tyre (as against wear) occur during taxiing, particularly if prolonged and if the brakes are used extensively.

31. An aircraft tyre consists of a rubber tube and an outer cover; the former retaining the air, and the latter providing the strength to contain the air pressure exerted by the tube, and to ensure protection of the tube against the wear and tear of service.

Inner Tubes

32. The tube is an air container, and to function properly it must fit inside the cover without creasing or undue stretching. The rubber compound from which it is made has the following characteristics: low weight, flexibility, low porosity, durability, and resistance to heat. Nearly all sizes of tubes are produced by a moulding process and each tube consists virtually of one piece of vulcanized rubber with no perceptible weakness at the joint or variation in thickness. Specially reinforced tubes are provided to withstand the excessive heat generated by wheels that have the brake drums built into their rims. Where the tube touches the metal rim it is reinforced by an additional thickness of rubber containing heat-resisting ingredients.

Outer Covers

33. The construction of an outer cover is as follows:—

(a) *Carcass.* The carcass embodies plies or webs made of cords of cotton, rayon, or nylon spaced apart by thin threads, the whole being impregnated with rubber which prevents the cords of adjacent plies from rubbing and cutting one another as the tyre flexes in use.

(b) *Breakers.* Two very narrow plies, known as the breakers, are usually placed between the casing and the tread. They are encased in thicker layers of rubber, and they absorb and distribute load shocks, protecting the carcass from concussion damage.

(c) *Bead.* The portion of the tyre cover in contact with the wheel rim is known as the bead, and is formed by interlocking the plies in the tyre around high tensile-strength wire coils which encircle the rim. The beads are sufficiently rigid to prevent their slipping over the rim flange as the tyre flexes, and to minimize chafing between the bead and rim flange, or between the casing fabric and wire coils. The wire coils are made rigid by bonding all the wires together in rubber, the wire being specially treated to ensure a strong bond between the metal and rubber.

(d) *Tread.* The tread is the protective outer layer of abrasion-resisting rubber and can be smooth or moulded in a pattern. Outer covers are constructed with patterned treads as these are more effective on wet, smooth runways of tarmac and concrete, and they prevent extended scoring or cutting of the tread when the aircraft is taxiing on loose surfaces.

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Tyre Creep

34. All tyres, when first fitted to their wheels, tend to move slightly as they settle down on their rims. This initial movement varies according to load, inflation pressure, braking, and shimmy, and may be more than one inch on some of the larger main landing wheels. After the settling down period, there is a tendency for this movement to continue gradually, and if permitted beyond a certain limit the valve will be torn from the tube.

35. To detect this movement a white creep mark

is painted on the side walls of a newly fitted outer cover and continued on to the wheel rim. (Some covers have moulded arrows on their walls, the space between them being painted white.) The width of this mark is related to the amount of creep allowed, *if any*; for example, on some installations when the mark on the outer cover becomes out of step with the mark on the wheel by the width of the mark, the complete tyre must be removed for attention. For outer covers of 24-inch outside diameter and below, the width of the creep mark is 1 inch, and for those above 24-inch outside diameter the width is $1\frac{1}{2}$ inches.

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