2

CATAPULTS

An aircraft requires a certain initial speed before it is enabled to lift itself and its load. This speed is normally obtained by " Taxi-ing " along the surface of the land or water for a considerable distance, the engine not being sufficiently powerful to accelerate the aircraft very rapidly. A catapult is a device for accelerating the aircraft by means of an externally applied force so that it can attain the required take-off velocity in a restricted length of travel.

For launching aircraft from ships, a catapult installation consists essentially of a trolley or cradle on which the aircraft can be mounted and through which the launching force can be applied. This cradle must be capable of being propelled along a track, suitably mounted, so that the aircraft can be launched in any given direction.

The factors governing the design of a catapult are :—

(*a*) The weight of the aircraft to be launched.
(*b*) The maximum permissible acceleration.
(*c*) The launching speed required.
(*d*) The available space for installation.

Up to the present time the maximum weight of aircraft catered for by catapults in H.M. Ships is 8,000 lb.

The permissible acceleration is limited by the strength of the aircraft rather than by the physical capabilities of the pilot and crew. Acceleration of between 3 and 4 *g* (*i.e.*, three and four times the acceleration of a freely falling body) can be provided for in the design of modern aircraft.

The required launching speed will vary with the type of aircraft catapulted, but in general it has been found that an air speed of about 50 knots is sufficient in temperate climates.

The speed required, taken in conjunction with the permissible acceleration, naturally determines the length of catapult necessary.

The latter dimension is limited by the available space which can be provided for installation, and the extent to which the length when stowed can be increased when the catapult is in operation.

It is the purpose of this article to describe the manner in which each of these factors has been provided for in the various designs now on service in the fleet.

Before the war, the United States Navy Department were experimenting with power operated catapults, and the first successful launch was made in 1912.

During the war several catapults, which were modifications of the original type, were installed in U.S. warships. These catapults were operated by compressed air and consisted essentially of a trolley, mounted on a runway which was permanently connected to the deck by trestles.

The runway was about 50 ft. long and the trolley was connected by a system of wire ropes and pulleys to a ram moving in a cylinder which was built into the structure. The movement of the ram was multiplied up to the trolley in some definite ratio. In the first designs the trolley went overboard with the aircraft and was afterwards retrieved—if possible! In later models buffers or brakes were fitted to absorb the energy of the system after the launch and to bring the trolley to rest at the end of the runway.

After the armistice, experiments continued with air operated catapults, and in 1921 the use of powder as a means of providing the required motive power was investigated.

By 1924 a powder operated catapult had been designed and constructed by the United States Bureau of Naval Ordnance, and this was installed in a battleship. The general features of the design were similar to those of the air operated type, there being a cylinder and ram with wire rope multiplication to the trolley.

The charge was ignited and allowed to expand into an expansion chamber communicating with the ram cylinder. This provided some degree of control over the rate of burning and consequent pressure rise.

In England the question was receiving attention as early as 1911, when a patent for a gravity operated catapult was taken out, but was not proceeded with.

In July, 1916, a provisional specification for a compressed air or powder operated catapult was received in the Munitions Inventions Department, and it was subsequently decided to issue a specification for the purpose of inviting tenders for the construction of a catapult.

Two catapults were completed and tested, both of which were air operated, and their design was in general accordance with those built in the United States.

These catapults were constructed by Messrs. Armstrong Whitworth & Co., and Messrs. Waygood & Otis, Ltd., respectively.

In 1922 two designs for catapults were prepared by order of the Air Ministry.

Mr. R. F. Carey, who had been associated with the design of the earlier catapult built by Messrs. Waygood Otis, Ltd., undertook the design of one, and the other design was prepared by the Royal Aircraft Establishment, Farnborough, under the supervision of Mr. P. Salmon.

The first Carey catapult was constructed at H.M. Dockyard, Chatham, and in 1925 was installed in H.M.S. *Vindictive* on the top of the aircraft hangar.

A repeat Carey catapult was ordered in 1926 for installation in H.M.S. *Resolution*. This also was built at Chatham, and embodied certain modifications found necessary after experience in *Vindictive*.

The catapult gave satisfactory performance on service, and was eventually removed from *Resolution* in 1930.

Carey Catapult.—This catapult was designed to launch aircraft up to 7,000 lb. weight at 45 miles per hour, with a mean acceleration of 2 g.

The mechanism follows the lines of the original American catapults, in that the motion of a compressed air operated ram working in a cylinder, is transmitted by means of wire ropes and pulleys at a 3 : 1 multiplication to the launching trolley.

The structure which carries the operating mechanism is about 50 ft. long, and the upper girders of the structure form the runway for the trolley.

The retardation of the trolley and mechanism is effected by hydraulic pressure. At the end of the acceleration stroke liquid in front of the ram piston which has been allowed to escape freely during acceleration, is locked in the front part of the cylinder. This liquid is allowed to escape during the retardation stroke through a graduated port formed in a projection on the piston, and the hydraulic pressure so generated absorbs the energy of the system.

In order that the retardation of the ram may be communicated to the trolley a second rope known as the retarding rope is rove in exactly the same manner and in the same ratio as the accelerating rope, only it is connected to the after end of the trolley, and is in tension during the retardation stroke.

The liquid, which is a 50/50 mixture of glycerine and distilled water, is displaced during the acceleration stroke into a receiver cylinder attached to the side of the catapult.

After a launch has been carried out, air can be admitted to this receiver cylinder, and the liquid forced back into the power cylinder, causing the system to return to its original position.

R.A.E. Catapult.—The R.A.E design was entirely different from any catapult then in existence. It was designed to launch aircraft up to 7,000 lb. weight at 45 m.p.h., with a mean acceleration of 2 g., the acceleration run being 34 ft.

The catapult consists of a girder structure in which is mounted a cylinder containing a number of tubes arranged to slide within each other after the manner of a telescope. The cylinder is attached to the structure in such a way that the tubes, of which there may be three or four, can slide out of each other in a forward direction. The innermost tube is attached at its forward end to the launching trolley, which runs on wheels guided by rails on the top of the structure.

Each tube is made smaller than the one in which it telescopes, and an annular space formed between them by a piston fitted at the rear end of the smaller tube and a bush at the front end of the larger. The resulting space is filled with fluid, and the annular area is made equal to the bore of the smaller tube. Ports are formed in the circumference of the inner tubes at the rear ends.

The propelling force is compressed air, which acts on the piston of the first ram.

The motion of this ram is then transmitted to the other rams by means of the fluid, and the resulting motion of the final ram is that of the first multiplied by the number of rams.

To bring the trolley to rest after the aircraft has been launched the rams are designed to act as buffers for the last portion of their stroke. Small ports at the rear end of the rams are gradually shut off as they pass through the neck bush and the fluid is locked in the annular space, thus bringing the mechanism to rest smoothly.

To return the rams and trolley after launching use is made during the launching stroke of the kinetic energy of the fluid issuing from the final ram, to charge up a cylinder of compressed air attached to this ram.

When the residual pressure in the firing cylinder is released the trolley automatically returns, and its rate of return can be controlled by the release valve on the firing cylinder.

Cordite Operated Catapults.—Early experiments were carried out at the Royal Aircraft Establishment in 1926, using cordite as propelling medium for the first multiple ram type catapult, which had already worked satisfactorily with compressed air.

It was immediately evident that satisfactory performance with cordite could not be obtained unless special forms of cordite were used.

In the production of these special cordite charges, Woolwich Arsenal were associated with Farnborough, and in 1927 a repeat of the original multiple ram type catapult and constructed by Messrs. MacTaggart & Co., Loanhead, was delivered at Woolwich for cordite experimental work. During a period of 18 months attempts were made to produce a satisfactory charge which would give regular results on service, but the degree of success was not encouraging, being inferior to that already achieved by Farnborough.

Subsequently another multiple ram type catapult capable of launching aircraft up to 8,000 lb. in weight at 55 m.p.h. was installed at Woolwich, and a further attempt made to obtain satisfactory results with cordite charges.

Trials with this catapult were completed in 1929, and the results were considered to be sufficiently promising to warrant carrying out sea trials. The charge which was eventually produced for use on service followed closely the original design of the R.A.E., Farnborough.

A cordite operated catapult of the multiple ram type was subsequently installed in H.M.S. *York* in 1930. A second catapult of the same type, but operated by air was installed in H.M.S. *Frobisher* in 1928. The catapult was never satisfactory, and was eventually removed and placed in store.

During the time that trials were being carried out with "Carey" and "R.A.E." type catapults, both ashore and on service afloat, a statement of requirements for the performance of naval catapults was circulated to several firms with a view to obtaining original suggestions for future construction.

No design was submitted which would meet all the requirements, but an order was placed with Messrs. Vickers, Ltd., for a multiple Ram type catapult. A launching speed of 55 m.p.h. was specified, and the catapult was of the fixed type, being 80 ft. 9 in. long and weighing about 15 tons. This catapult is now installed at the R.A.F. Base, Leuchars, and is used for training purposes.

Meanwhile the question was receiving attention in the professional departments of the Admiralty, and three proposals were put forward, two by members of the Admiralty staff and one by the R.A.E., Farnborough.

The three types were known as the "Slider" type, the "Extending Structure" type and the "Hinged Structure" type, and each was designed for a launching speed of 55 m.p.h. with a length when stowed not exceeding 46 ft.

The "hinged structure" type was a repeat to a larger scale, of the original multiple ram type. Its advantage lay in the ability to fold the structure when the rams were in the closed position. The forward half of the structure swung round on hinges and lay alongside the rear half which was mounted on a training rack.

This catapult is 82 ft. long when extended, and can be folded to 44 ft. for stowing.

The launching travel is 50 ft.

The catapult was originally installed at Woolwich for cordite charge experimental work.

Subsequently it was fitted on the quarter deck of H.M.S. *Hood*.

It was finally removed in 1932 and placed in store.

The Extending Structure Catapult.—This catapult is designed to launch aircraft weighing 8,000 lb. at 57 m.p.h. or 7,000 lb. at 60 m.p.h., the launching run being 50 ft. 6 in. When closed for stowing the catapult is 46 ft. long, and this length is increased to 75 ft. 9 in. when in operation.

This alteration in length is effected by constructing the catapult in three parts.

These consist of a main structure mounted on four rollers and rotatable about a centre pivot, and two subsidiary frames each half the length of the main structure, which slide inside it on gunmetal slippers.

The extending portions can be rigidly locked to the main structure in either the stowed or extended position.

The mechanism of the catapult consists of a cylinder and ram as in the "Carey" type.

The ram is connected through a system of ropes and pulleys to the trolley which runs on a track formed on the top of the main and extending structure. The rope system is so arranged that no alteration in rope tension occurs during the extending or closing of the structure.

The arrangement of ropes will be best understood by reference to Fig. (I).

The crosshead on the ram carries eight sheaves mounted on roller bearings, four on each side. The two outer sheaves on each side carry the accelerating rope while the retarding rope passes round the inner ones.

The ends of the ropes are attached to the trolley base at four points, provision being made for adjustment of the rope length at each point of attachment.

The acceleration rope, *i.e.*, the one to the left of the figure, is shown for the port side of the catapult only. It passes round the equalising sheave to the starboard side where the arrangement is similar.

Part of the retardation rope has been omitted from the diagram for the sake of clarity, but the arrangements are the same for both ropes.

The equalising sheaves are provided to ensure that the trolley receives an even pull.

To hold the trolley and mechanism in the firing position against the drag of the airscrew a spring loaded release hook is provided.

This is carried on a screwed shaft which can be manoeuvred over a limited range backwards and forwards, and permits movement of the trolley between the stowed and firing positions either by hand or by electric power. In the stowed position the C.G. of the aircraft is approximately over the centre of the catapult.

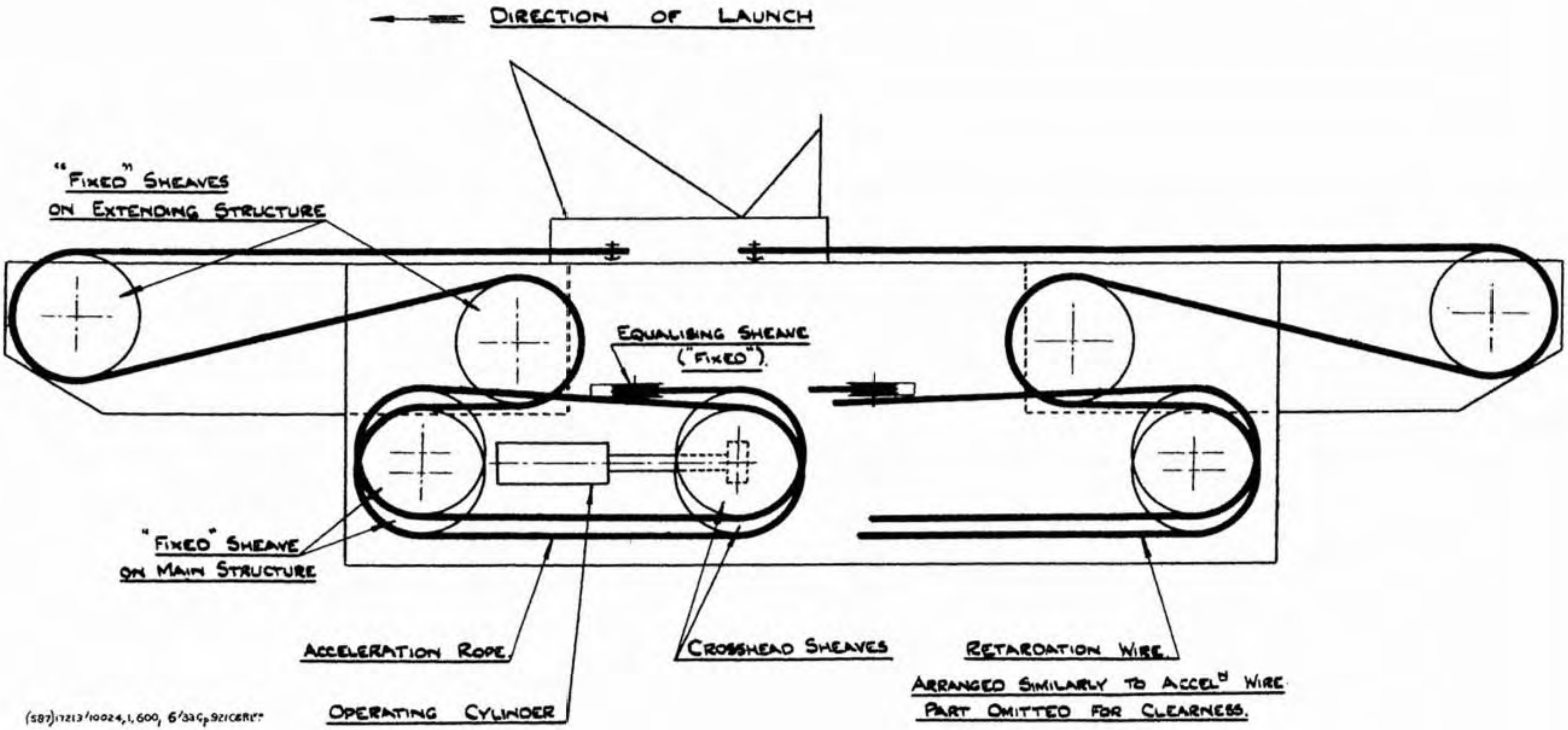
The operation of the catapult can be followed by reference to the diagrammatic arrangement in Fig. II. With the trolley in the firing position the piston (4) is at the right-hand end of the cylinder (1). Forward of the piston the cylinder is filled with the mixture referred to previously up to a given height in the gauge glass (19) on the receiver cylinder (5), by means of the hand pump (18).

Air is then admitted to the receiver at about 15 lb./in.^{2} pressure to force the liquid up through the vent cocks (11) and (12) and expel any air into the sight box (20), the method adopted being as follows:—The air manœuvring valve is put to " run aft position " (A), the two-way valve (8) is set to " manœuvre," and the air supply to the catapult is opened sufficiently to allow the small amount of air required to pass by way of these valves (7) and (8) to the receiver cylinder. When a full flow of liquid from the vent cocks is obtained the vent cocks are shut, the air supply shut off, the two-way valve set to " launch " and the air manœuvring valve put to the mid-position. With the two-way valve at " launch " the receiver cylinder is open to atmosphere through the separator (22) and exhaust box (23).

EXTENDING STRUCTURE TYPE

(4 TO 1) ROPE MULTIPLICATION

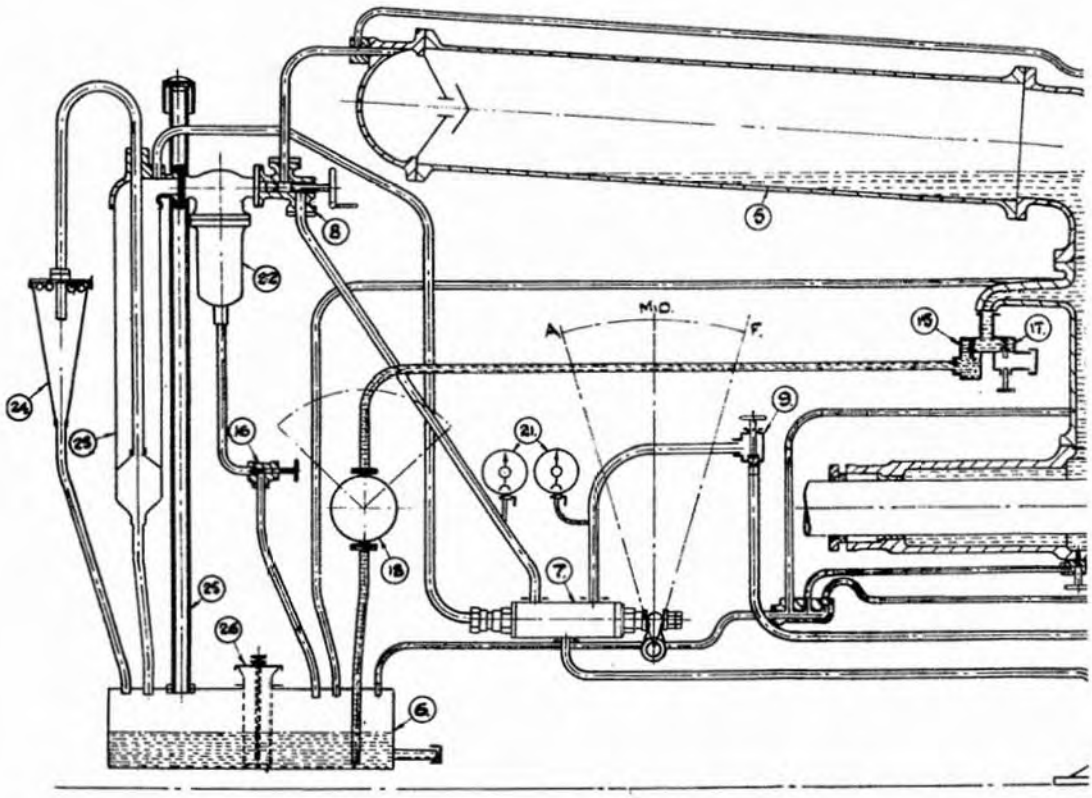
FIG I



(587)17213/10024, 1,600, 6/33 Gp.921 C&R Ltd.

AIR MANOEUVRING GEAR
DIAGRAMMATIC ARRANGEMENT
NOT TO SCALE

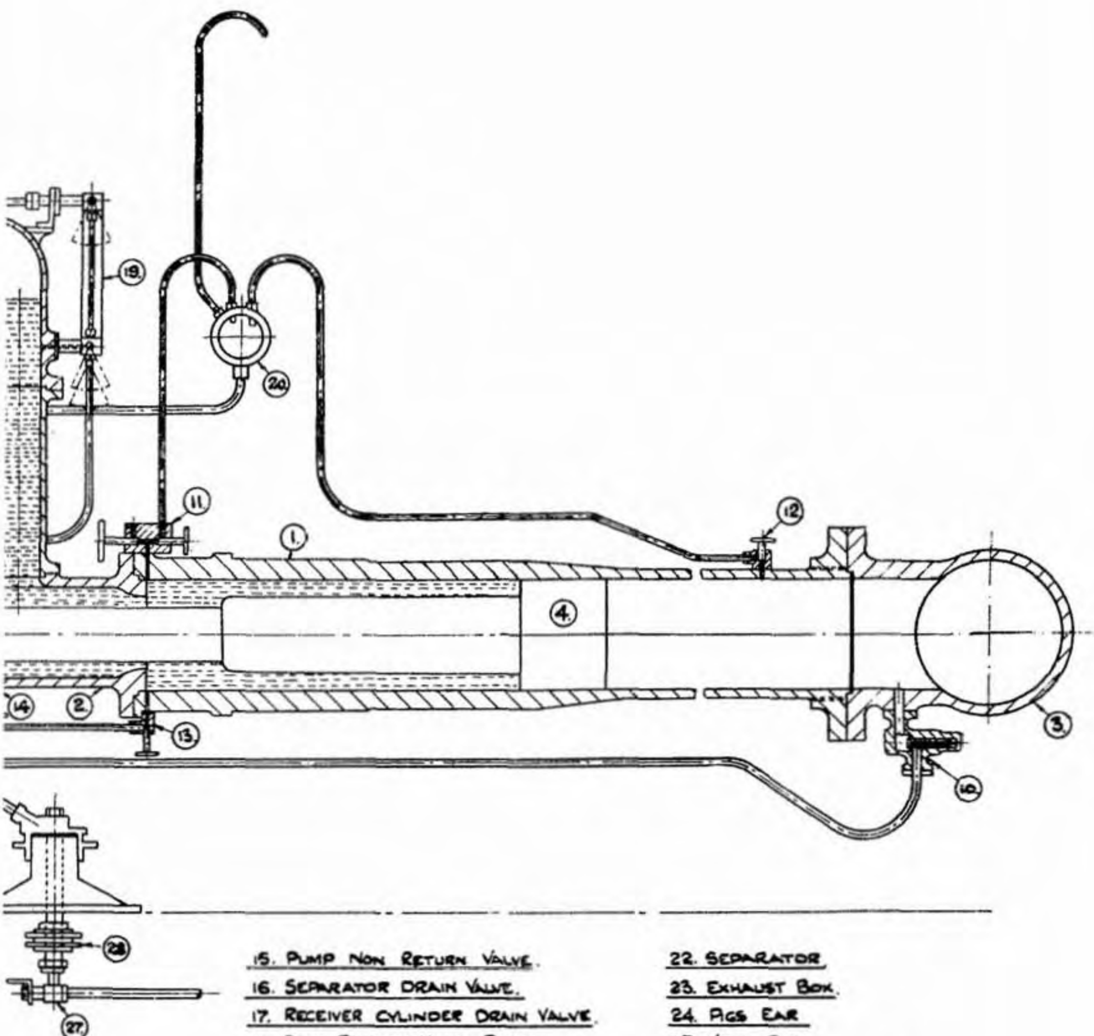
EXTENDING STRUCTURE



1. POWER CYLINDER.
2. CYLINDER EXTENSION.
3. EXPLOSION UNIT.
4. PISTON.
5. RECEIVER CYLINDER.
6. SUMP TANK.
7. MANOEUVRING VALVE.
8. TWO WAY VALVE.
9. STOP VALVE.
10. AIR NON RETURN VALVE.
11. AFTER CYL^S AIR COCK.
12. FORWARD CYL^S AIR COCK.
13. CYL^S DRAIN COCK.
14. CYL^S EXTENSION DRAIN COCK.

TYPE.

FIG II



15. PUMP NON RETURN VALVE.
16. SEPARATOR DRAIN VALVE.
17. RECEIVER CYLINDER DRAIN VALVE.
18. SEMI-ROTARY HAND PUMP.
19. GAUGE GLASS.
20. SIGHT BOX.
21. PRESSURE GAUGES

22. SEPARATOR
23. EXHAUST BOX.
24. PIGS EAR
25. VENT PIPE
26 SUMP FILLER & DIP ROD
27. AIR SUPPLY PIPE SWIVEL
28. COLLECTOR RINGS

As the piston moves forward the displaced liquid passes from the cylinder into the cylinder extension and away to the receiver. During the acceleration stroke this flow is unrestricted, but when the conical portion of the piston enters the cylinder extension the available area for passage of liquid is considerably reduced and retardation commences. As the larger section of the cone passes into the opening so the area is still further reduced and the back pressure thus set up gradually brings the piston to rest.

To return the trolley after a launch the manœuvring valve and two-way valve are put to the same positions as for venting. The release valve on the explosion unit is opened and air is admitted to the receiver cylinder.

With this type of catapult the trolley can be traversed along the whole length of track by air. This air shot, as it is called, serves to show that everything is in working order.

The preparation for an " air shot " is the same as for a launch except that it is necessary to reduce the release hook setting. The breech is blanked by a dummy cartridge and air is admitted to the explosion unit by putting the manœuvring valve to the " run forward " position (F) and opening the stop valve (9). Air then passes to the explosion unit through the non-return valve (10). When sufficient pressure has accumulated behind the piston to overcome the release hook, the trolley will move forward along the track. The return of the trolley is carried out as before.

With this catapult the extensions can be run in and out and the trolley manœuvred either by hand or by electric motor, but hand training gear only is fitted.

A faster extending type catapult is now being produced. The stowage length has been increased in view of the extra length required to attain the higher speed, and the ratio of speed of trolley to speed of ram is 6 : 1.

The Slider Type Catapult.—These are divided into two types, the heavy type for the larger sizes of aircraft and the light type for medium weight aircraft, but the principle is the same in each type.

The trolley travels along a slider which itself travels along the structure, the total travel of the trolley thus being the sum of its travel relative to the slider and that of the slider relative to the structure.

The Light Slider Type (*see* Fig. III).—The forward end of the ram carries a crosshead with four pulleys attached. Around these pulleys pass the ropes which accelerate and retard the slider, the ends of the ropes being anchored to the structure. The speed of the slider is thus twice the speed of the ram. At each end of the slider are two more pulleys which guide the ropes governing the motion of the trolley, these ropes are also anchored to the structure and pass round equalising sheaves on the trolley. The speed of the trolley is twice that of the slider, *i.e.*, four times that of the ram.

The slider is of circular section and carries two guides on each side, the lower one sliding in the guide on the structure, and the other providing the track on which the trolley slides.

The release hook is carried on two screwed shafts by means of which it can be manœuvred over a limited stroke to engage with the release pin on the ram crosshead. This gear can be operated either by electric motor or by hand.

The retardation and return of the trolley are carried out by the same method as is used in the extending type.

This catapult can be trained either by hand or by electric motor.

The Heavy Slider Type (*see* Fig. IV).—In this case the slider is attached directly to the ram and a 3 : 1 multiplication is introduced between slider and trolley. The slider is a built-up girder of roughly square section, and carries a channel on each side which forms a path for a number of rollers fixed to the upper members of the structure. An angle projecting from the upper surface of the slider forms a track for the wheels of the trolley which are arranged in pairs to bear on the under side of the track.

Incorporated in the slider is a tank which acts as the receiver for the liquid displaced by the piston during a launch. This tank is always open to atmosphere as the manœuvring is done entirely by hand, a rack being secured to each side of the bottom of the slider into which pinions can be engaged by means of a clutch. The training gear is also hand operated.

The retardation arrangement is different to that employed in the light slider.

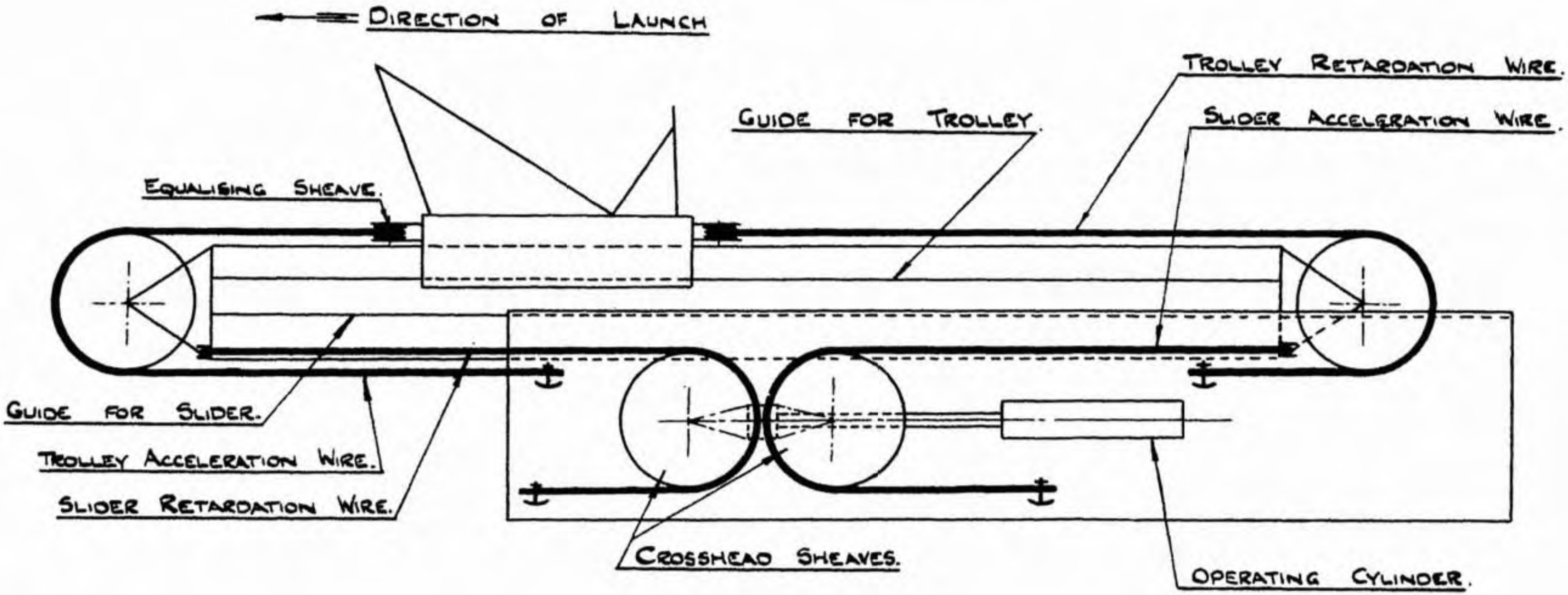
Secured to the ram at the piston end are two tapered keys (*see* Fig. IVA). Ports into the inside of the ram are situated just ahead of the forward end of the keys. At the forward end of the cylinder is a bush with two keyways through which the keys on the ram pass. An extension of the cylinder is carried forward from the cylinder. As the piston moves forward the displaced liquid passes through the ports into the inside of the ram which is in direct communication with the tank in the slider. At the end of acceleration the ports in the ram are cut off from direct communication with the cylinder by the bush at the forward end, and the only passage for the liquid is through the keyways in the bush into the cylinder extension, and thence through the ports into the interior of the ram. At the same time the keys are advancing into the keyways and still further restricting the flow as they advance. By this means the opening is gradually closed and the ram is brought to rest.

In the new designs the keys and keyways have been dispensed with and the ram which passes through a plain bush is undercut

LIGHT SLIDER TYPE

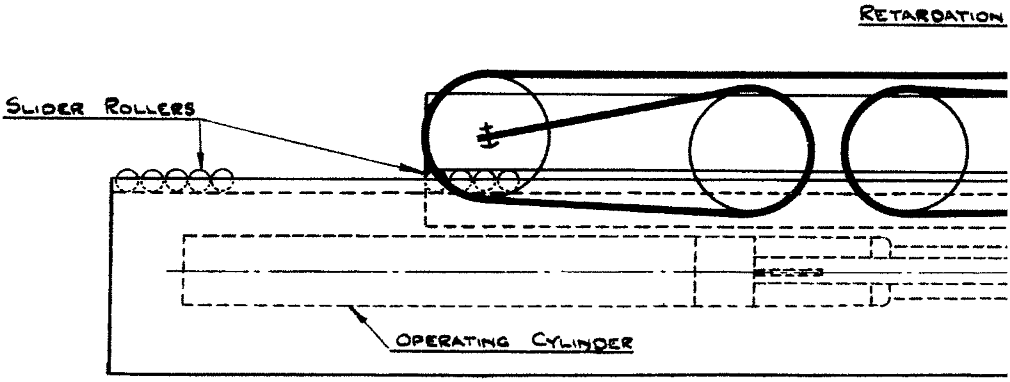
FIG III

(4 TO 1) ROPE MULTIPLICATION



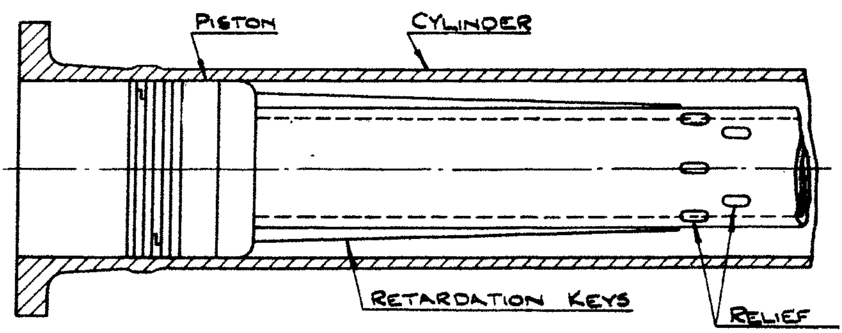
HEAVY SLIDER

(3 TO 1) ROPE



HEAVY SLIDER

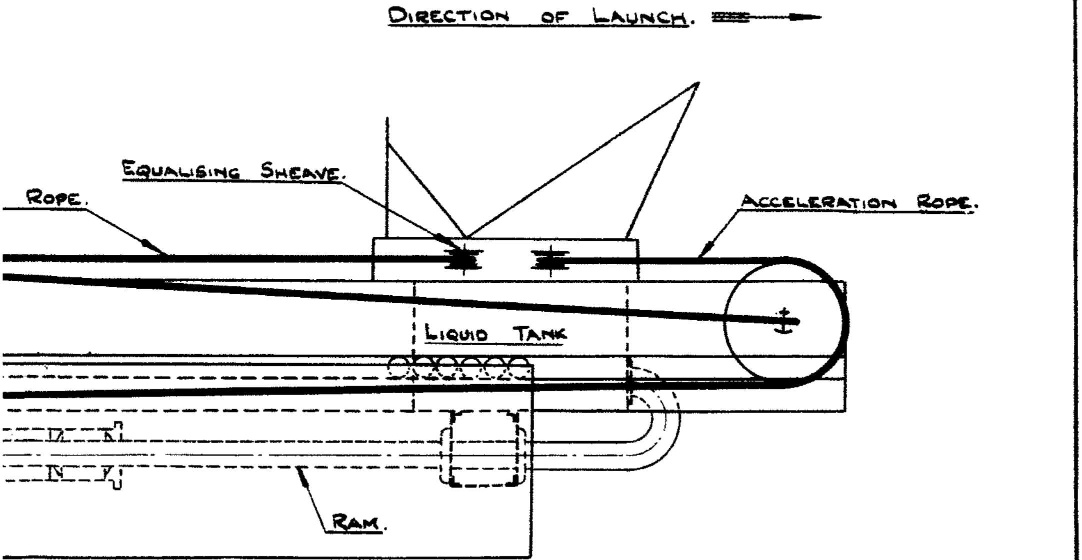
RETARDATION



TYPE.

MULTIPLICATION

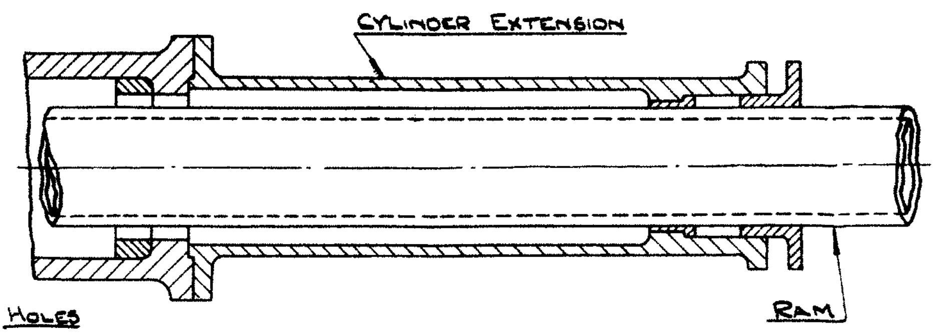
FIG IV



TYPE

DEVICE.

FIG. IV a.



to the correct shape to give the required area for flow during the last 3 ft. of its travel.

The release hook is similar to that employed in the light slider type except that it is fixed to the structure.

When this catapult was first put on trials a very heavy knock occurred a fraction of a second after the trolley came to rest. This was overcome by fitting a snifting valve which would allow air to be drawn into the cylinder extension as it was considered that the knock was probably the result of the creation of a vacuum due to the acceleration of the liquid in the interior of the ram when the ram itself was being retarded.

Trolley Superstructure.—It has been stated in the foregoing description that the accelerating forces are transmitted to the aircraft by means of a form of cradle in which the aircraft rests, and that this cradle is attached to a trolley which is propelled along a track by the power mechanism.

In foreign countries the general practice is to apply the accelerating force through the float and under-carriage.

While this arrangement enables the aircraft to be mounted on the cradle more readily it necessitates a strong and heavy undercarriage, and also confines the use of the cradle to seaplanes.

In this country it has been the practice to apply the accelerating and supporting forces through the fuselage of the aircraft, so that the line of action of the former force passes as close to the centre of gravity of the machine as possible.

The type of cradle which is now in general use was developed primarily by the R.A.E., Farnborough. It consists of two portions, the trolley or base frame, and the superstructure. *See* Fig. V.

The trolley is a rectangular frame which is mounted on four flanged wheels or slippers.

The superstructure is of universal design for all catapults, and is based on the original R.A.E. production. It consists of four legs supported by struts, and arranged to hold the aircraft at four points, two just abaft the root section of the lower plane on either side of the fuselage, and two at the after end of the fuselage on either side.

The front points transmit the accelerating force, and the rear ones take the vertical reactions due to the C.G. and C.P. of the aircraft being forward and above the front points.

Hooks at the top of the legs engage with the catapulting spools on the aircraft, these latter and the hook jaws are made of spherical contour to enable the inclination of the front and rear legs to be adjusted to suit various types of aircraft.

The front legs can be adjusted laterally for varying width between front spools, as can the rear legs, the latter also being capable of fore and aft adjustment.

As the aircraft leaves the superstructure the front legs fall forward to ensure that the fuselage and tail plane assembly will pass over them. To enable this to take place the main inclined struts are made telescopic, and as the structure falls forward the rate of collapse is controlled by an oleo arrangement within the telescopic strut, the superstructure being brought to rest without shock.

When the superstructure is erected, the front legs are prevented from collapsing by pivoted release links (3) which fit over pins (4) on the main struts. These release links are withdrawn during the acceleration of the trolley by the trip gear mechanism (5) the wheels of which run up on ramp rails secured to the catapult structure.

This mechanism also withdraws the front detents (6), which are pushed up in front of each of the front spools, to prevent the aircraft moving forward under the action of the airscrew before the launch takes place.

Trials.—The first catapult of a particular type goes to Woolwich for determination of the correct cordite charges.

Running-in trials to remove initial stiffness are first carried out and the charges which will just break and just not break the release hook are determined to ensure that the release hooks of future catapults of the same class shall be given the same setting, which is essential if regular results are to be obtained.

When the running-in trials have been completed the trials to determine the correct charges to give consistent results when :—

(*a*) Firing trolley alone at full speed.

(*b*) Firing dead loads of known weight at full speed, are carried out.

Occasionally temperature trials are carried out to find the effect of variation of temperature of cordite on speed of launch.

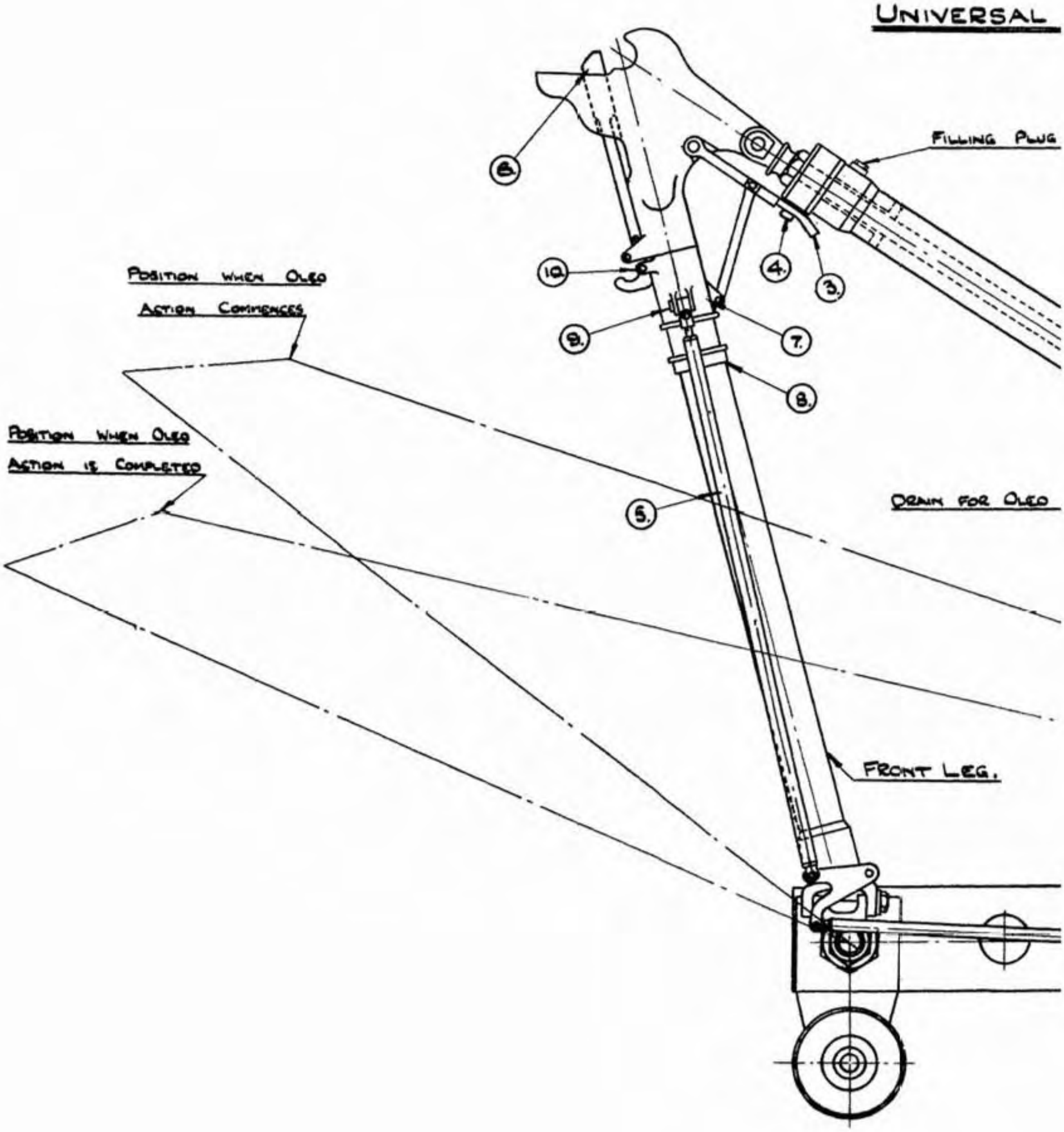
Next regularity trials involving six light and six heavy launches with test weights are carried out. If consistent results are obtained on these trials the catapult and charge are considered satisfactory.

One of each class of catapults is also mounted in the *Ark Royal* for sea trials. These consist of launching at least one dummy aircraft followed by launches of a "live" aircraft.

Other catapults of the same class do the running-in and regularity trials only.

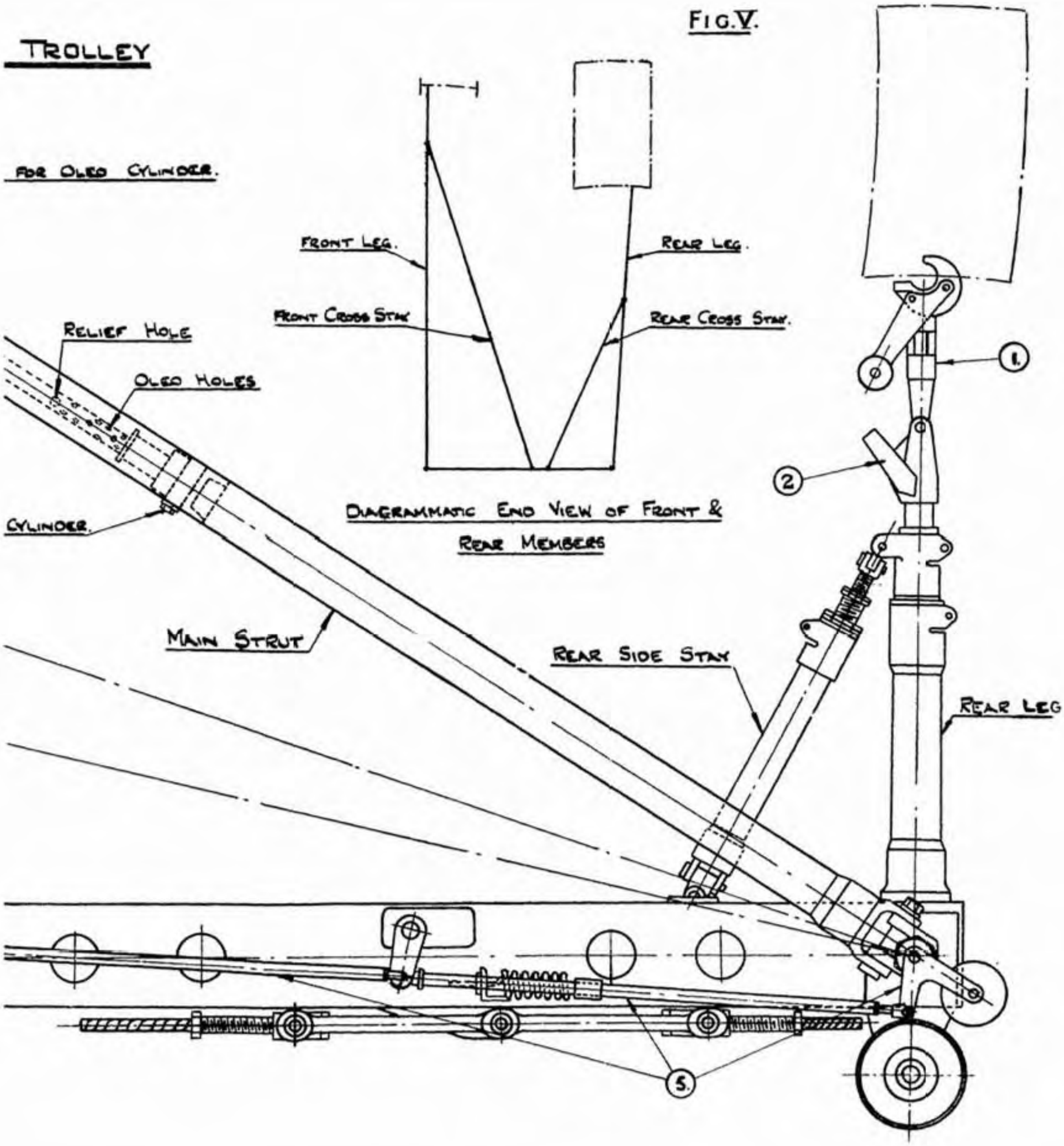
Future Design.—The extending structure and slider types of catapult have proved most satisfactory in service and as has been mentioned above, new types of these are in process of design or construction.

Designs of slider and extending types of catapult suitable for fitting on the top of a turret are at present being developed. The extending type will have only one extension instead of the usual two.



UNIVERSAL
FILLING PLUG
POSITION WHEN OLEO ACTION COMMENCES
POSITION WHEN OLEO ACTION IS COMPLETED
DRAIN FOR OLEO
FRONT LEG.
6.
10.
4.
3.
9.
7.
8.
5.

FIG. V.


TROLLEY
FOR OLEO CYLINDER.
FRONT LEG.
REAR LEG.
FRONT CROSS STAY
REAR CROSS STAY.
RELIEF HOLE
OLEO HOLES
CYLINDER.
DIAGRAMMATIC END VIEW OF FRONT & REAR MEMBERS
MAIN STRUT
REAR SIDE STAY
REAR LEG
1.
2
5.