FLIGHT DECK MACHINERY

by

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PART II—ARRESTING GEAR

The following notes are divided into two sections, viz. :

1. Fleet Carrier Arresting Gears, up to and including H.M.S. *Implacable*.
2. British Light Fleet and Escort Carrier Arresting Gears.

In order fully to appreciate certain features of the gear, and certain changes which have been made recently, a short résumé of the history of the development of the gear is given, with an explanation of the fundamental principles upon which the different designs are based.

FLEET CARRIER ARRESTING GEARS

Early Winch Gear

The original hydraulic Mark III arresting gear was designed about 1931 and the first gear made to this design was installed in H.M.S. *Courageous* and tried out at Malta in January, 1933. Prior to that *Courageous* had been fitted with a Mark I gear, which consisted essentially of a transverse deck span led to a winch at each end, the resistance being provided by hydraulically operated friction brakes on the winches. The gear was unsatisfactory for two reasons. Firstly, it was impossible to obtain identical resistances on both winches, with the result that the wire had a tendency to be pulled out more from one winch than the other, with consequent slewing of the aircraft on the deck. This was sometimes so violent that the undercarriage tyres were burst.

The aircraft in service at that time were *Ospreys*, *Nimrods* and, later, III Fs. These were all fitted with tail skids, which suffered from the second characteristic of this type of gear, namely, as the resistance to the wire being pulled out, and hence the tension in the wire, was constant, the aircraft was subjected to an increasing retarding force due to the " sine effect " of the angle of the rope. The arresting hook on the aircraft was some distance below the thrust line, and the C.G. and the arresting hook naturally sought to lie in the plane of the bight of the wire : consequently as the aircraft approached zero velocity, the tension in the wire remaining constant, the aircraft was held with its tail high up. The aircraft came to rest in this attitude and at that instant was still subject to the maximum wire tension by reason of the elastic stretch in the wire. This stored-up energy in the wire jerked the aircraft backwards, and in so doing dissipated the force which was sustaining the aircraft in a tail-up attitude : so the tail " slammed " on the deck, and broken tail-skids resulted.

A study of this performance led to the formulation of the design requirements for arresting gear, which are :—

(i) A smooth build-up of retarding force when the aircraft picks up the wire (this is inherent in the " sine effect " of the transverse wire system, but is affected by the " inertia tension " in the wire due to the acceleration of the mass of the wire and sheave system).

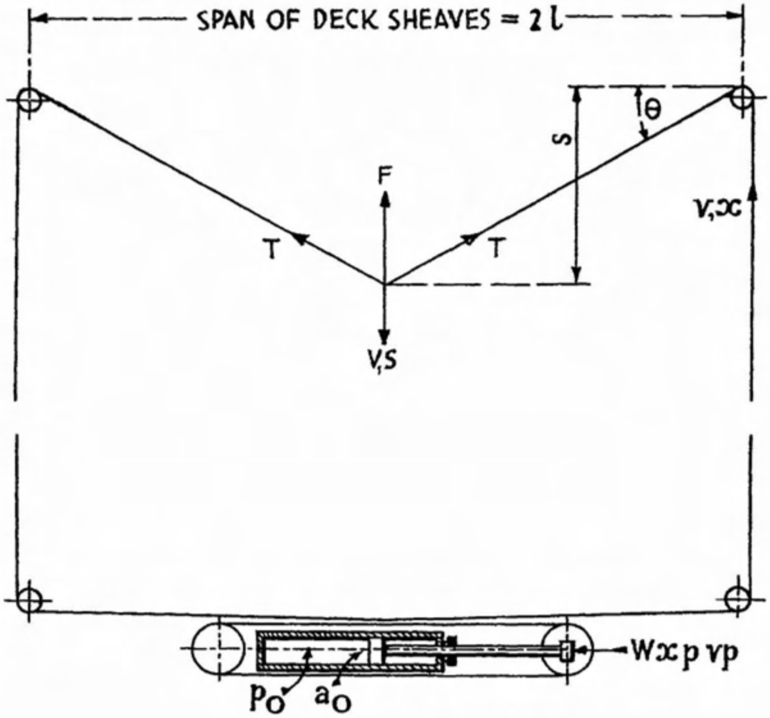

FIG. 1.

(ii) The maintenance of the maximum retarding force which can be applied to the aircraft for as long as possible, subject to (iii) ; and

(iii) The steady diminution of the wire tension as the velocity of the aircraft approaches zero, in order to allow the tail of the aircraft to settle on to the deck.

A Mark II design of winch gear was produced, involving two winch drums connected by a differential on which the brake was applied ; consideration was given to controlling the brake application either by velocity or by " stroke." No gear to this design was produced.

Development of Hydraulic System

It was clear that the desired performance could be obtained with certainty by a simple hydraulic system and hence the Mark III design was prepared, and as already stated the first gear to this design was installed in *Courageous* for trials. The fundamental principle of the Mark III gear is that the retarding force applied to the aircraft is a function of the velocity of the aircraft : how this is achieved will be made clear by the following explanation of the gear, and by reference to Figs. 1 and 2.

When the aircraft " enters " the wire, the velocity of the wire v becomes V sin θ. Mark III gears are rove 12/1 and therefore the velocity of the piston is v/12. As the piston is pushed into the cylinder, the fluid in front of it has no exit other than through the annular orifice between the piston choke-ring and the cut-off rod. This creates a fluid pressure which resists the motion of the

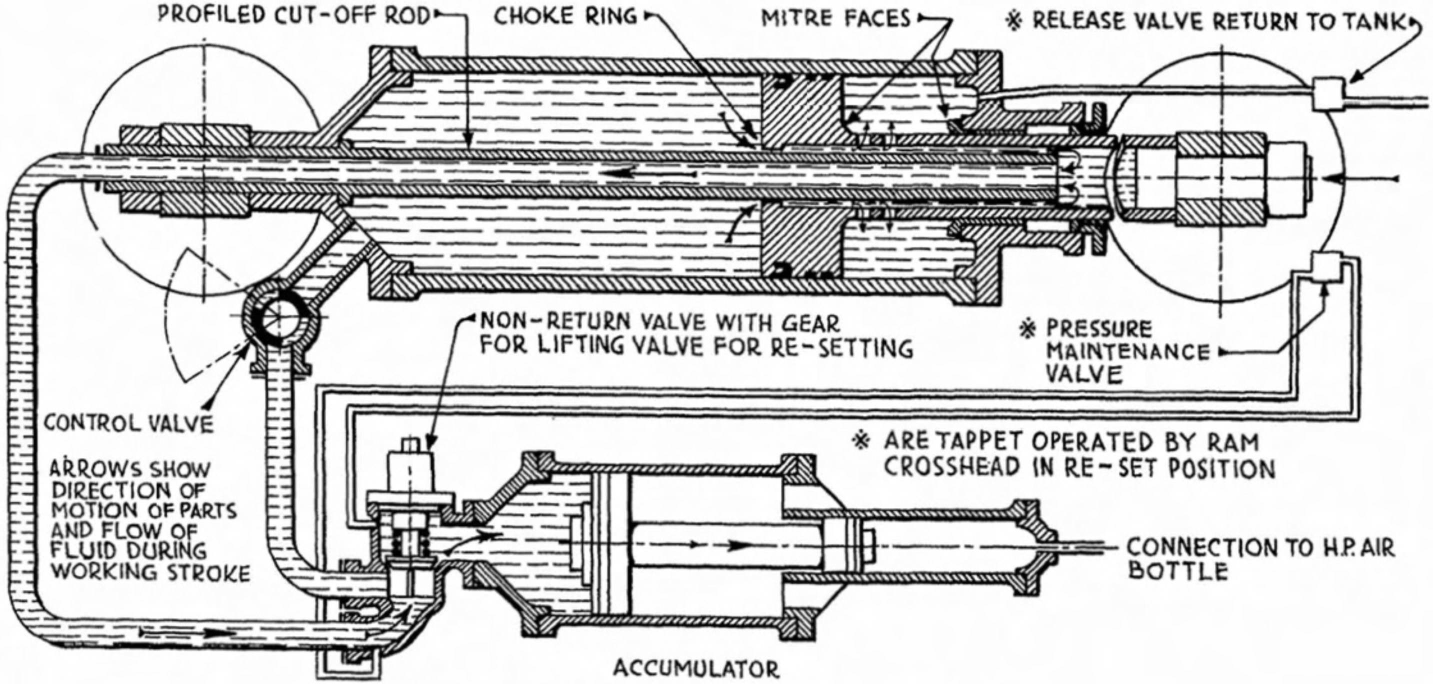

FIG. 2.—MARK III ARRESTING GEAR—DIAGRAMMATIC ARRANGEMENT

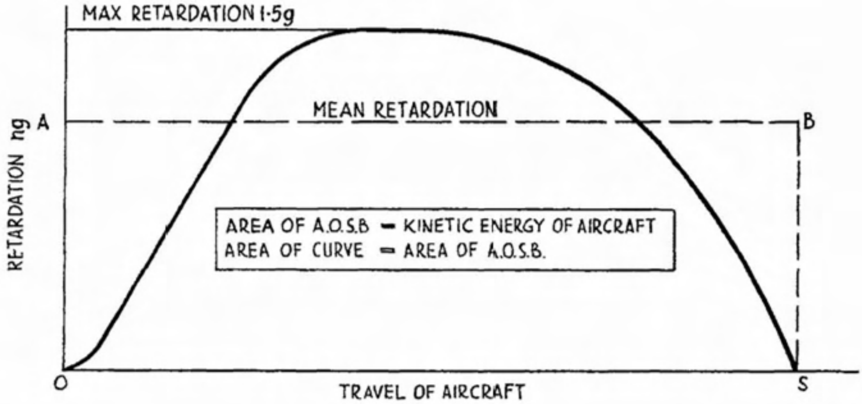

Fig. 3

piston, and therefore creates a tension in the wire : the kinetic energy of the aircraft is converted into pressure energy in the fluid, which in turn becomes velocity energy in the orifice and this is dissipated in heat. The area of the annular orifice between the choke-ring and the cut-off rod is not constant—the cut-off rod is " profiled." To arrive at the correct profile the case is taken of the heaviest aircraft entering the wire at the maximum speed : an " ideal " curve of retardation (ng) to a base of travel of aircraft (s) is constructed (Fig. 3) which satisfies the following conditions :—

(i) The build-up of retardation is gradual—on a deck span of 100 feet between deck sheaves, the maximum retardation cannot be reached in less than 60 feet without getting an unacceptably high tension in the wire, since the retarding force is a function of the wire tension and the sine of the angle of the wire.

(ii) The maximum retardation permitted in aircraft of British design up to the present is 1.5 g.

(iii) The reduction of retardation towards the end of the aircraft's travel must be gradual in order to avoid tail-slam.

(iv) When converted to retarding force by multiplying the retardation by the weight of the aircraft, the area of the diagram, representing work done, must be equal to the kinetic energy of the aircraft at the speed of entry.

From the basic retardation curve the following curves are derived successively:

(i) Aircraft velocity (V)/aircraft travel (s).

(ii) Wire velocity (v)/stroke of wire (x).

(iii) Piston velocity (v_p)/stroke of piston (x_p).

(iv) Force on aircraft (F)/aircraft travel (s).

(v) Wire tension (T)/stroke of wire (x).

(vi) Piston load (W)/stroke of piston (x_p).

(vii) Pressure causing flow through orifice (p_o)/stroke of piston (x_p), and hence orifice area (a_o)/piston stroke (x_p), from which the diameters of the cut-off rod can be calculated.

Absorption of Aircraft Energy

Not all the energy of the aircraft, however, is absorbed in the orifice. As the piston is pushed into the cylinder, fluid is displaced from the cylinder into the accumulator against the load of the air piston, and this comparatively small proportion of the aircraft's energy is saved up from each landing and is used for pushing out the piston and resetting the wire for the next landing. It will be obvious that since the retardation is re-active, an aircraft of maximum weight entering at less than the speed for which the gear is designed will produce on itself a retardation less than the maximum—theoretically. Neglecting disturbing factors such as friction, and the small portion of the energy absorbed by the accumulator, an aircraft of maximum weight will always go the full stroke, irrespective of its speed of entry.

Resetting the wire

The case of an aircraft of less than the weight for which the gear is designed is somewhat different—if it enters at maximum speed, it would produce the same tension in the wire as the aircraft of maximum weight, since the wire tension is a function of velocity only. This tension would impose a force on the aircraft which would produce, with a light aircraft, a retardation in excess of the permitted maximum of 1.5 g. To get the correct characteristic for a light aircraft, it would be necessary to design and fit a cut-off rod specifically for that aircraft, but as this is obviously impossible where the same gear has to deal with different aircraft, a compromise is adopted and the " control valve " is fitted for the purpose of providing additional escape area.

Aircraft Weight Adjustment

Since the a_o/x_p curve for the lighter aircraft is "higher" than that for the maximum weight aircraft, but similar in shape, and meets the maximum weight curve at the end of the stroke, the area to be added to the maximum weight curve is not constant. The addition of mechanical gear to operate the control valve to provide the correct variable additional area is possible, but is not justified on account of the mechanical complication involved, so that the compromise of adding a fixed additional area by means of the control valve is adopted, and a scale on the control valve operating gear is provided, graduated in weight of aircraft.

While the aircraft is pulling out wire, and the piston is being forced into the main cylinder, the displaced fluid is forced into the accumulator cylinder through a non-return valve In order to reset the gear this valve is by-passed by the resetting valve, or in later gears (H.M.S. *Indomitable* onwards) the non-return valve is lifted, and the fluid is expelled from the accumulator back into the main cylinder, driving out the piston rod, pulling in the wire and resetting it.

Main cylinder design

The arrangement of the wire and its supports on the flight deck has had a considerable influence on the design of the main cylinder unit. In order that the hook on the aircraft can pick up the deck span, the latter has to be supported about 4 in. above the deck. (It is not unusual for a hook to pick up a wire lying flat on the deck, but it cannot be depended upon to do so). In earlier ships, up to but not including H.M.S. *Illustrious*, the wire was supported above the deck in " stanchions," which were hinged to fold down forwards, and provided with a fork end to hold the wire. When raised the stanchions lay forwards at an angle of about 60 degrees. So that they could be pushed down if an aircraft wheel should hit them, they were raised by springs and were pulled down against the springs by hydraulic cylinders. In spite of this spring arrangement they formed considerable obstructions and were therefore positioned out near the edges of the flight deck. The camber of the deck and a practical limitation of the height of the stanchion (21 in.) made it necessary to maintain a high tension in the wire in the reset position in order to keep the bottom of the catenary of the wire span between the stanchions four inches above the top of the camber of the deck, at the middle line.

High initial tension

The use of a high accumulator pressure acting on the piston, adequate to maintain the necessary tension in the wire when reset, was precluded by the design condition which required that the tension in the wire at the end of the aircraft's travel should be reduced to a minimum to avoid tail slam. An arrangement was therefore adopted whereby in the re-set condition only, the necessary crosshead load was obtained by making the accumulator pressure act on the whole area of the piston (Fig. 2). This was achieved by providing mitre faces on the piston and the inner end of the piston rod neck-ring bush, so that the piston formed a valve when it came to the end of the stroke and isolated the piston annulus from the interior of the piston rod and the rest of the system. By a release valve, tappet operated by the crosshead, the isolated annular space was opened to the tank and pressure in this space dropped to atmospheric. The accumulator pressure in the main cylinder then acted on the cylinder side of the piston, being maintained in spite of leakage by the pressure maintenance valve, also tappet operated by the crosshead.

The high initial tension so obtained was sufficient to keep the wire at the correct height above the deck, but did not affect the aircraft adversely, since only a small additional tension had to be applied by the aircraft to break the mitre faces apart, and thereafter pressures and forces become normal.

Troublesome features

This arrangement worked quite well, but introduced one or two troublesome features into the operation of the gear, for instance a certain amount of fluid was lost from the cylinder annulus through the release valve each time the gear was reset, as the valve being tappet operated was bound to open before the extreme end of the stroke. This loss meant that the accumulator had to be kept pumped up, for which purpose an air operated ram pump was provided. If the accumulator was allowed to empty, hydraulic pressure was lost and the wire could not be reset. Also, if the rope tensioning gear, formed by a travelling sheave in a bight of the wire moved by travelling nuts on screwed shafts rotated through rod gearing by hand from the control position, were set up too tightly the piston mitre faces might just be prevented from seating, with both the release valve and the maintenance valve open, so that the accumulator discharged to the tank, and pressure was lost in the system. On the whole, the arrangement was satisfactory and achieved the desired result, but it required skilful manipulation.

Introduction of retractable undercarriages

When aircraft with retractable undercarriages were introduced (e.g. *Skua*) trouble arose because the undercarriage wheels being retractable were smaller than hitherto. The *Skua* had 24-in. diameter wheels, and if a landing were made widely off centre, with a wheel near the stanchion, it was quite possible for the wheel to go under the arresting wire, with disastrous results. In *Illustrious* a different form of support for the rope was introduced ; the object being to keep the wire a minimum height of 4 inches off the deck without it anywhere being more than 9 inches off the deck. This was achieved by substituting for the stanchions, which had been fitted in all ships up to and including H.M.S. *Ark Royal* (1938), a " deck spring " on the middle line of the deck—simply a piece of round spring steel bar, bent into a bow, and secured to the deck at one end. The spring lifted the wire, but did not offer any resistance to a wheel running over it. The deck being of armour the spring could not be recessed, but to lower the wire the spring was pulled down flat on the deck by means of a wire passing through a hole in the deck, operated by a small air cylinder under the deck.

The deck span was divided into two, which were sufficiently short to enable the wire to be held 4 inches above the deck without the height anywhere exceeding about 8 inches. The fact that the deck-springs were right in the centre of the landing area was, however, a disadvantage, as they were constantly being hit by aircraft hooks. As a result of experience in *Illustrious* two deck springs per wire were fitted in *Formidable* and later ships, up to and including *Implacable*, whereby the span was divided into three catenaries and adequate height could be maintained without using the full available tension.

Simultaneously, with the middle line rope support, hydraulic rope tensioning gear was introduced in *Illustrious :* this did away with the hand operation and consisted of a sheave in a bight of wire carried on the ram of a hydraulic ram-cylinder unit, the pressure being taken from the accumulator and controlled by stop valves (one opening to pressure and one to exhaust) at the control position. The ram was designed so that the tension in the wire when the tensioning gear was opened to the full accumulator pressure was just not sufficient to " break " the mitre faces in the main unit. This gear made manipulation of the gear rather simpler : if a unit would not reset properly it was only necessary to release tension, reset, and tension up again.

Adoption of double reeving

Prior to *Illustrious*, arrester units only operated one wire, i.e. one cross-deck span, per unit, but in *Illustrious*, originally intended to be similarly equipped, one of the units was double-rove as an experiment. To follow the method of reeving, the unit must be visualised as symmetrical about a centre line, with six sheaves on each side of each crosshead, referred to as " forward " and " after " sheaves, since the unit is fitted athwartships. In the first experimental double reeving, the wire went from the forward starboard deck sheave, round all the sheaves, on one side of the unit, up to the deck at the port after deck sheave, across to the starboard after deck sheave, down and round the sheaves on the other side of the unit, and emerged on the port forward deck sheave, the circuit being completed by the forward deck span. The deck spans, which must be renewable and therefore separate from the main reeving, are coupled to the latter by " centre-span couplings." When an aircraft landed off centre, it tended to pull out more wire from the deck sheave on the side nearer which it landed ; this created a tendency for the wire to " fleet " round the reeving, and resulted in the idle centre span (i.e. the one of the pair which was not picked up) moving athwartships until the centre-span coupling came up against the deck sheave brackets which acted as a stop. When this happened, the tension in the half of the reeving pulling the coupling against the stop became greater than in the other half. This uneven tension was greatly accentuated on the unit, since each side of the unit was rove 12/1 and a heavy twisting couple was imposed on both the cylinder and ram crossheads. This occurred to such an extent in the original unit in *Illustrious* that the ram plug and cylinder cover joints were started and the unit had to be replaced. At the same time, a modified system of double reeving was adopted, in which the wire passed round alternate sheaves on the unit, each " side " of the reeving embracing three pairs of sheaves on each side of the unit. By this means balanced loads are obtained on the crossheads, and twisting forces eliminated.

This balanced system of double reeving has been adopted as standard for all units, and all ships from (and including) *Illustrious* onwards are fitted with double rove units, each unit operating two cross-deck spans.

Apart from the obvious advantage of being able to operate two wires from each unit, the double rove system has a valuable attribute in that when an aircraft lands off-centre and fleets the wire until the idle span coupling stops it, as explained above, the tension in the leg of wire to the side nearer which the aircraft lands is greater than in the other leg ; the resultant of these two tensions, therefore, passes to the inboard side of the C.G. of the aircraft, so that a yawning couple is created tending to pull the tail outboard—hence when an aircraft lands off-centre in a double-rove wire it tends either to go up the deck parallel to the middle line, or to turn in towards the middle line. There was no such righting couple in a single rove unit, because since there was no limit to the fleet of the wire, the tension in the two legs was always the same ; hence the resultant of the tensions in the two legs lay outside the C.G. of the aircraft, tending to pull the tail inboard. This was demonstrated on a number of occasions, when aircraft landing off-centre yawed violently outboard and went over the side near which they landed.

Modifications required for light aircraft

The arresting gears of the *Illustrious* Class and *Indomitable* were designed to arrest aircraft of 11,000 lbs. weight entering Nos. 1, 2, 3 and 4 units (counting from aft) at 60 knots, and Nos. 5 and 6 at 55 knots : the control valves were designed to accommodate aircraft down to 5,500 lbs. In H.M.S. *Unicorn* the gears were the same in all respects, except that the cut-off rods were re-designed to suit aircraft of 20,000 lbs. weight entering at 60 knots, lower factors of safety being accepted in components of the units under these conditions. The gears for *Indefatigable* and *Implacable* were designed for the same performance as *Unicorn*.

When the first deck landing trials were carried out in *Unicorn* it was found that Seafires, the lightest aircraft handled, were being subjected to retardations obviously in excess of 1.5 g., as shown by damage to the fuselage : accelerometers were installed in the aircraft and showed that at the start of arrestment a retardation of over 2 g. was being applied. This appeared as a sharp peak just after the aircraft picked up the wire ; after a study of a number of diagrams it was rightly concluded that the tension which the aircraft has to create in the wire to part the mitre faces in the unit, in conjunction with the light weight of the aircraft, was imposing this unacceptably high retardation.

It was decided to take advantage of the fact that, with two rope supports in the width of the deck, the length of the catenaries of wire between supports was so much less than the original case for which the mitre faces had been provided, and that the wire could therefore be substained at the requisite height above the deck with a reduced initial tension when the wire was reset, to operate the gear without letting the mitre faces close. This was simply done by blanking the release valve, and shortening the main wire. In addition, the accumulator pressure was slightly increased ; this was found to be quite possible without causing tail slam, and not only maintained a higher initial tension, but also gave a quicker reset, which was an added advantage. Further trials showed a decided improvement in the shape of the retardation curve. That this change was not so drastic as might appear at first sight will be appreciated from the remarks on the gear designed for H.M.S. *Empire Audacity*.

This change has now been made in all the Fleet Carriers, and in addition the ports in the ram which allow flow into the cylinder annulus have been increased in size and additional ports cut through the piston behind the choke-ring.

Developments in control arrangements

The control arrangements have undergone some interesting changes. Before *Ark Royal* there were two control positions one controlling odd-numbered units in the starboard nets and the other controlling the even-numbered units in the port nets. The reason for this was so that a hit on one side of the ship would not put all the gears out of action. In *Ark Royal* the control positions were all put on the port side, but were widely separated fore and aft. *Illustrious* had two panels for her units, and they were put together in the port nets, mainly to obtain centralised control, and to reduce the number of operating personnel. The panel had a formidable battery of gauges, sight-boxes, indicators, levers and handwheels. During her working up a close study was made of the operation of the *Illustrious* gear, and led to some sweeping changes.

The principal change was a psychological one—it was obvious that the operator could not give his whole attention to what was going on on the deck, and at the same time give the attention to the gauges and indicators necessary to prevent failure of the gear due to loss of pressure or accumulator level, or rope tension. Complete concentration on events on deck is essential when a large number of aircraft is landing at 30-second intervals, and no distractions can be tolerated.

In *Formidable* and *Victorious*, with flight deck beams 6 feet deep, the control panels were built inside the hangar, on the port side, and the watch-keeper stands on a platform between the beams. The panel contains all the instruments and controls required for the complete operation of the gear. Abreast this position, in the port side nets, a small panel is provided, fitted only with one hand-lever and one pedal : these are connected by wires or servo-control with the controls on the main panel. The hand-lever raises and lowers all the rope supports, while the pedal operates all the resetting valves. The operator in the nets has therefore nothing to take his attention from the deck. He is in communication with the watch-keeper on the main panel by voice-pipe, and the latter is able to concentrate on the instruments—he has over-riding control, and can instantly take over the operation in the event of the control worker outside becoming a casualty, operating the gear on orders given over the arresting gear loudspeaker telephone system. The Commander (Flying) on the bridge has an order-transmitter by means of which he indicates to the watch-keeper on the main panel the type of aircraft being received, in order that the correct control valve setting may be put on.

In making this arrangement there were other considerations—mainly, that none of the hydraulic pipes of the system go outside the hangar armour, and therefore the whole system except the ropes and sheaves is under protection ; in addition, being protected from the weather reduces maintenance. In ships subsequent to *Illustrious* Class the flight deck beams are very much shallower, and there is no room to put the main panels actually inside the hangar, so the main panel is housed, together with the accumulator and air-bottles, in a compartment on the upper gallery deck, armoured on its ends and outboard side. With the gear simplified as it now is by the elimination of the mitre faces, as described above, there are only two defects likely to occur during normal operation, apart from normal mechanical faults common to all hydraulic equipment (such as leaking glands) ; these are :—

(i) *Failure to maintain initial tension*

(*a*) If two wires operated by one unit cannot be tensioned, and the ram is at end of its stroke, then the main wires of that unit must be shortened by cutting and re-socketing end couplings.

(*b*) If no wire can be tensioned, a failure of hydraulic pressure is indicated. This may be due to no accumulator air pressure, or to a leak having developed which has caused the accumulator to lose all its fluid.

A case occurred in *Implacable*, when all her aircraft were in the air, of failure to tension owing to loss of fluid from the accumulator resulting from the collapse of the fluid piston leather : no aircraft could land-on, and all had to be landed ashore. The packing of the fluid piston of the accumulator consists of a single U-leather : the design is still the same as in the original Mark III gear in *Courageous*, and could with advantage be modified in accordance with our latest experience in catapult main pistons, in which three rings of U-section of moulded synthetic rubber bonded with flax and brass wire are inter-spaced with grease rings. This arrangement lubricates the rings, and where the cylinder walls are intermittently wet and exposed to the air, leaves a film on the cylinder walls preventing corrosion, a fruitful source of packing wear. As a result of the *Implacable* incident, modification has been made in her, and is being made in all other Fleet Carriers. This consists of the addition of a second accumulator system, the second accumulator being of the simplified type as introduced in *Empire Audacity* and used in British-built Escort and *Colossus* Class.

(ii) *Tendency to reset prematurely*

When an aircraft comes to rest there is a good deal of elastic stretch in the wire : if the pilot holds the aircraft on the brakes the wire remains tight and cannot be got out of the arresting hook. The pilot must release his brakes as soon as he comes to rest, and allow the aircraft to run back sufficiently (about 6 ft.) to allow the tension to go out of the wire, which generally falls out off the hook when slack.

Occasionally a most infuriating trouble arises—the wire creeps back and does not go slack when the pilot lets the brakes off. The only thing to do is to allow the aircraft to be pulled back slowly until the wire is reset, and then push the aircraft aft until the hook is clear of the wire. As this probably involves the aircraft being pulled aft for about 150 ft. at a walking pace, it is particularly upsetting for all aircraft waiting to land-on, and upsets the rhythm of landing, parking and striking down.

The cause of this trouble is :—

(i) That the non-return valve between the main cylinder and the accumulator has not seated properly. Formerly this was a simple spring-loaded non-return valve, and a separate resetting valve, bye-passing the non-return valve, was used, but latterly pneumatically-operated lifting gear was fitted to the non-return valves, and gives a more rapid rate of resetting—the cure is to ensure that the non-return valve is perfectly free to seat itself and that the seat and valve face are in good condition.

(ii) That the tappet-operated pressure-maintenance valve is not shutting properly. This was at one time a frequent source of trouble, and stop valves were fitted in the maintenance valve supply pipes at the control panel ; if creep stopped when this valve was shut it was the one at fault, but if it did not stop then the non-return valve was defective.

BRITISH LIGHT FLEET AND ESCORT CARRIER ARRESTING GEARS

The first British Escort Carrier was *Empire Audacity*, converted from a captured German passenger-cargo ship. It was originally intended that she should be succeeded by a considerable number of similar conversions, so a new

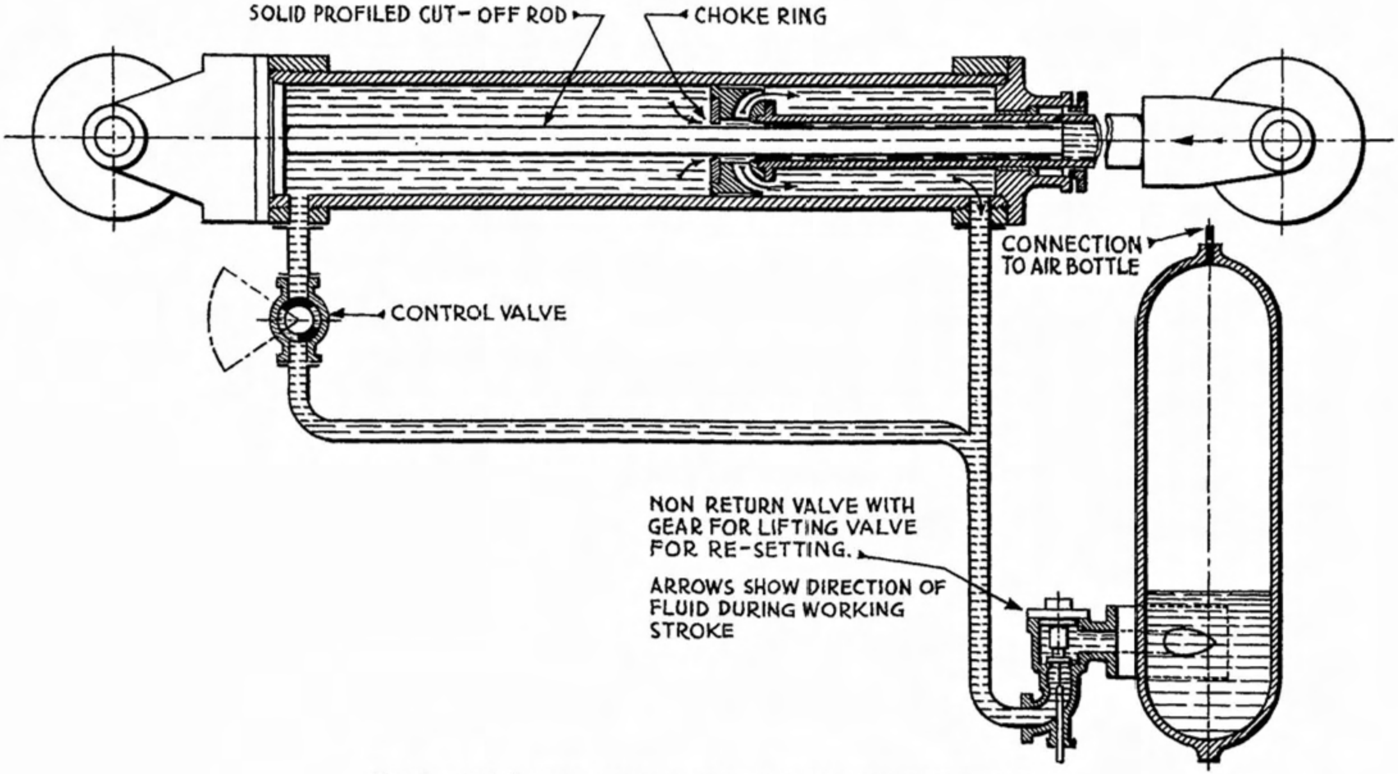

FIG. 4.—*Audacity* TYPE ARRESTING GEAR—DIAGRAMMATIC ARRANGEMENT

design of arresting gear was produced in 1940, based on previous experience, but of a very much simpler type, the basic design requirements being adhered to, but particular attention being paid to simplicity and speed of production, ease of operation and maintenance.

The main unit comprised no forgings—both the cylinder and ram were solid drawn steel tubes, and the crossheads, cylinder feet, etc. were of welded steel construction. The T-shaped crossheads were departed from, all the sheaves being together on a steel pin carried between the two arms of the crossheads. The unit was double rove on the alternate sheave system. No mitre faces were employed, the stroke of the piston being such that when reset the piston was about 6 in. from the end of the cylinder, whereby rope tensioning gears were rendered unnecessary, since the piston " followed up " the rope stretch. The accumulator consisted simply of an air-bottle, housed vertically, the fluid expelled from the unit entering tangentially near the bottom of the bottle, and the normal level being about one-quarter full. Compressed air was introduced above the fluid and no piston employed; since glycerine and water was the working fluid no aeration occurred, but the submerged tangential entry helped to prevent it, as entering fluid caused a vortex without breaking the surface.

The piston was designed as a bronze casting, with large ports from the wake of the choke ring loading to the annulus side. As there was no condition where a static pressure difference could arise between the two sides of the piston, no U-leathers were employed, light bronze piston rings being fitted. The normal type of control valve was employed, and resetting was effected by a servo-cylinder lifting the accumulator non-return valve. A simple diagram of the arrangement of this gear is given in Figure 4.

Right from the start, this gear was noticeably smoother than the Fleet Carrier Type. Pilots who had had experience of *Illustrious* Class gears confirmed this. The gear was very easy to operate and maintain, and generally fully justified the development from previous design. As a result of experience in *Empire Audacity* the simplified type of gear was adopted for *Pretoria Castle*, *Vindex*, *Campania*, and *Nairana*, with slight refinements, and it is also being installed in the 1942 Light Fleet Carriers.

The gear is subject to the same troubles as that in the Fleet Carriers, except that as only the simple air-bottle type of accumulator is used there is very little danger of leakage from the system. The only sources of leakage are valve spindle glands and the main ram gland from which leakage is visible and easily stopped.