FIG. 1.—AIRCRAFT RANGED ON FLIGHT DECK

FLIGHT DECK MACHINERY

by

COMMANDER (E) C. C. MITCHELL, O.B.E., R.N.V.R.,

Engineer-in-Chief's Department

PART I—ACCELERATORS

Accelerators are fitted in all aircraft carriers of the Fleet and Light Fleet Classes. They are fitted at the forward end of the flight-deck, usually on the port side, and their function is to launch aircraft in circumstances in which they could not fly off: for instance, if the ship is steaming on such a course that the wind relative to the flight-deck is blowing across the deck, the aircraft cannot fly off—to enable them to do so it would be necessary for the ship to alter course until the relative wind is straight down the deck—but they can be launched by the accelerator in a "cross" wind, so that there is no need to alter course. When there is a large range of aircraft to be flown off, the deck space may be so taken up that the aircraft at the front of the range have not sufficient length of deck in front of them in which to gain flying speed under their own power, and so the accelerator is used to launch aircraft until the deck is cleared sufficiently for the remainder to fly off.

FIG. 2.—A BARRACUDA READY TO LAUNCH

Figure I shows aircraft ranged ready for launching, and Figure II shows one loaded on to the accelerator trolley, and the next one in the ready position. Again, heavily loaded aircraft in a low relative wind may not be able to get off under their own power even if they took the whole length of the deck, and so must be launched by the accelerator.

Catapults were at one time fitted in ships without flight-decks, i.e., battle ships and cruisers. The difference between a " catapult " and an " accelerator " is that in a catapult a superstructure fitted on the launching trolley carries the aircraft bodily by its "catapulting spools," which are illustrated in Figure III, and the aircraft's undercarriage plays no part—it was usual to launch either aircraft on floats or amphibians, since they had to land in the sea and be hoisted on board. In the accelerator, the aircraft's weight is carried by its own wheels, as shown in Figures II and IV, and it is propelled along the deck by the accelerating force which is transmitted to it through its front spools.

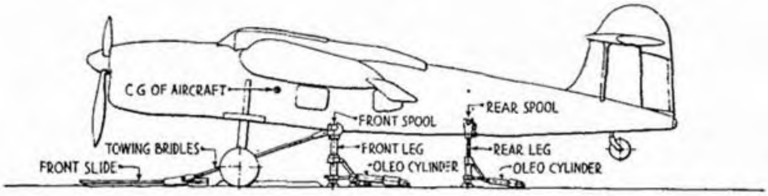

FIG. 3.—OUTLINE OF AIRCRAFT SHOWING CATAPULT SPOOLS

In catapults it was usual to apply the accelerating force to the trolley through the medium of a multiplying rope and sheave system from a cylinder and piston unit, in which the motive fluid was cordite gas generated by a charge fired in a breech attached to the cylinder. While an accelerator system is mechanically similar, the requirement that an accelerator must be able to launch an unlimited number of aircraft with a very short interval of time between launches makes the use of cordite impracticable, on account of the great heat developed by the burning of the charge, and the difficulties of loading the cordite charges into the breech. So in accelerators a hydro-pneumatic system is employed.

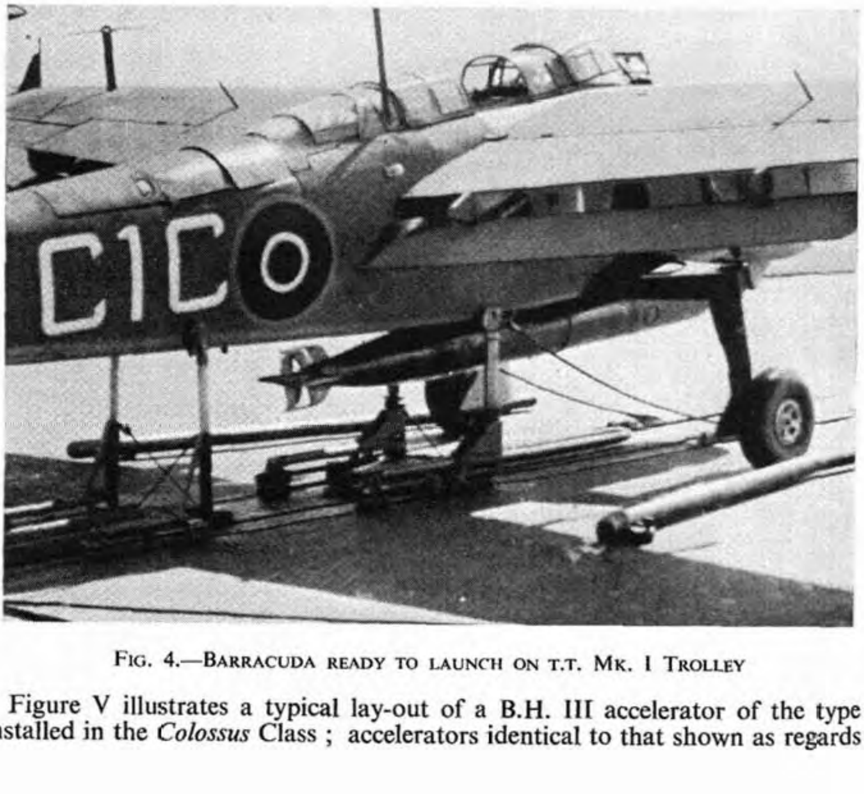

FIG. 4.—BARRACUDA READY TO LAUNCH ON T.T. MK. I TROLLEY

Figure V illustrates a typical lay-out of a B.H. III accelerator of the type installed in the *Colossus* Class ; accelerators identical to that shown as regards

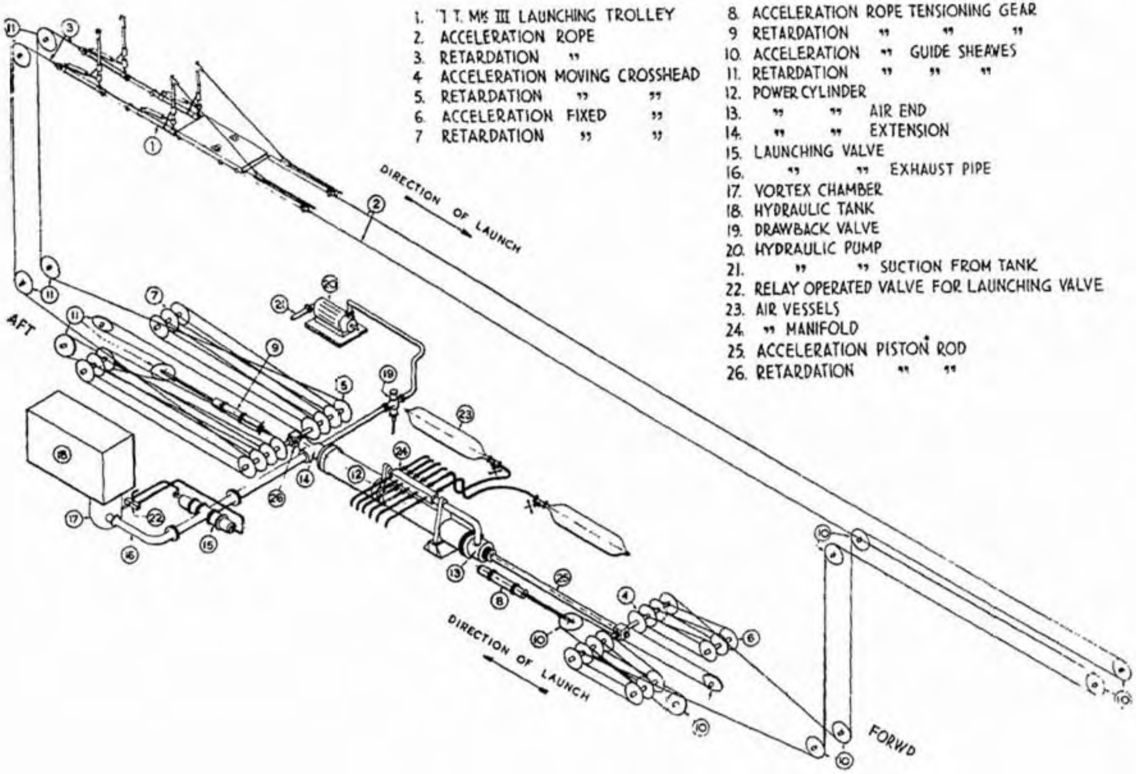
1. T.T. MK III LAUNCHING TROLLEY
2. ACCELERATION ROPE
3. RETARDATION "
4 ACCELERATION MOVING CROSSHEAD
5. RETARDATION " "
6. ACCELERATION FIXED "
7 RETARDATION " "
8. ACCELERATION ROPE TENSIONING GEAR
9 RETARDATION " " "
10. ACCELERATION " GUIDE SHEAVES
11. RETARDATION " " "
12. POWER CYLINDER
13. " " AIR END
14. " " EXTENSION
15. LAUNCHING VALVE
16. " " EXHAUST PIPE
17. VORTEX CHAMBER
18. HYDRAULIC TANK
19. DRAWBACK VALVE
20. HYDRAULIC PUMP
21. " " SUCTION FROM TANK
22. RELAY OPERATED VALVE FOR LAUNCHING VALVE
23. AIR VESSELS
24. " MANIFOLD
25. ACCELERATION PISTON ROD
26. RETARDATION " "
DIRECTION OF LAUNCH
AFT
DIRECTION OF LAUNCH
FORWD
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

FIG. 5

their major components, but differing in minor ancillaries, are installed in all Fleet Carriers from *Illustrious* to *Implacable*.

Air and hydraulic system

Figure VI is a schematic diagram of the air and hydraulic system. The power cylinder (12) contains a piston (A), to which piston rods of equal length (25) and (26) are attached ; these pass through glands on the air end (13) and the cylinder extension (14), respectively. The air end (13) is connected by a large pipe to the air manifold (24), to which twelve air vessels (23) are connected ; stop valves are fitted on each air vessel, and at each pipe where it connects to the manifold. At the " retarding " end of the power cylinder, i.e., the opposite end from the air end, a heavy bronze choke ring (C) is screwed into the cylinder, which is made thicker at the retarding end ; and the cylinder extension (14) is bolted on to the cylinder flange. The main piston (A) has an extension on the forward side, of larger diameter than the piston rod (26), called the retardation profile (B), which has a slight taper, the larger end being towards the piston (A) and of such diameter that it has a clearance of 0.005 inches in the bore of the choke ring (C).

Two large pipes are fitted to the cylinder extension (14) : one of these connects to the launching valve (15), which in turn is connected by the launching valve exhaust pipe (16) to the vortex chamber (17) of the hydraulic tank (18), which is open to atmosphere, and is housed on the deck above the machinery compartment. The other pipe from the cylinder extension is connected to the draw-back valve (19), and the latter is connected to the discharge side of a turbine-driven centrifugal pump (20). Water is supplied to this pump from the hydraulic tank (18) by the suction pipe (21).

The outer ends of the acceleration and retardation piston rods (25) and (26) carry the acceleration and retardation moving crossheads (4) and (5), and corresponding fixed crossheads (6) and (7) are secured to the ship's structure at the ends of the machinery compartment. The moving crossheads (4) and (5) carry four sheaves on each side, so that an 8/1 multiplication of the piston's stroke and velocity is obtained at the trolley. The accelerating rope (2) is attached to one side of the trolley (1), whence it is lead round the guide sheaves (10), the sheaves on the moving crosshead (4) and the fixed crosshead (6), then round the sheave mounted on the piston rod of the accelerating rope tensioning gear (8), round the sheaves on the other side of the crossheads and back, where it is attached to the other side of the trolley (1).

The retardation rope (3) is rove in a similar manner.

In both ropes the bight of the rope passes round the compensating sheaves on the rope-tensioning gears (8) and (9) ; by this means the tensions in the two sides of the accelerating reeving are equalised, and similarly in the retarding reeving. The pistons of the rope tensioning gears are hydraulically loaded, so that the initial rope tension in the system can be adjusted as necessary, and stretch in the ropes taken up. By manipulating the rope tensioning gears the trolley can be " trimmed " so that it is always in the same position in the track when the piston is at the end of the stroke.

When the gear is in the " firing position," with the trolley at the after end of the track, the piston (A) is held hard against the stop provided inside the air cover (13). With the air vessel stop valves opened, the piston is subject to the full air pressure, but the hydraulic pump is so designed that its discharge pressure exceeds the maximum air pressure by a considerable margin. Thus with the launching valve (15) shut, the water in the cylinder annulus is maintained at the full pump pressure, the connection between the pump discharge and the power cylinder being made through a tappet operated pressure maintenance valve, which by-passes the drawback valve (19).

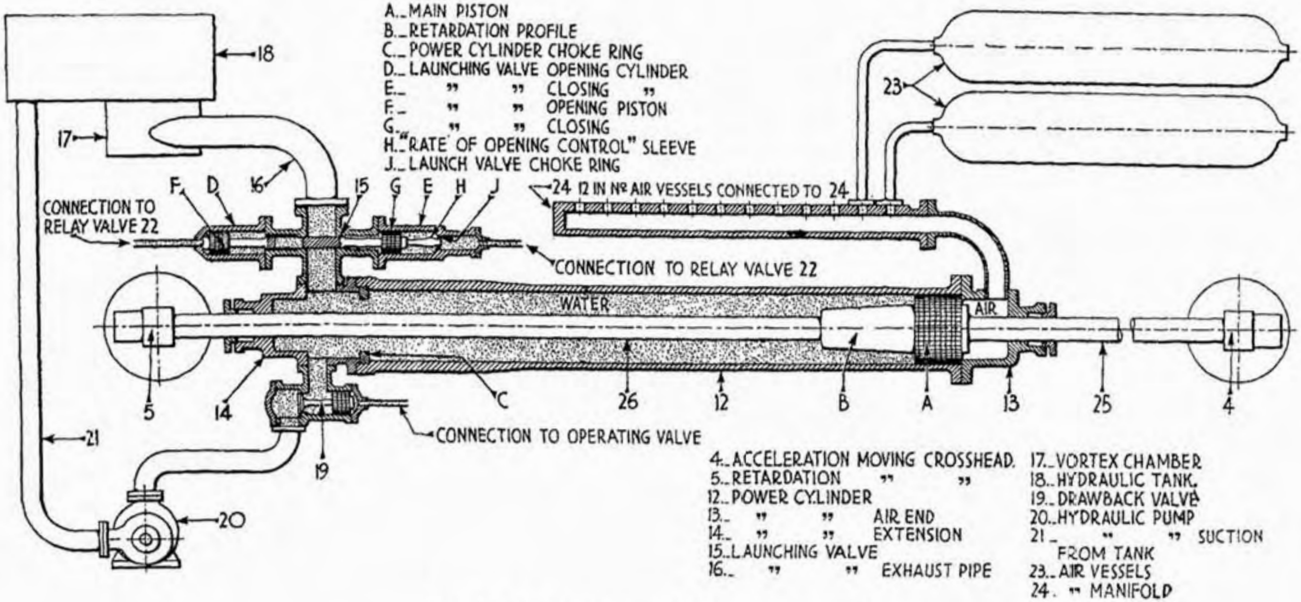

FIG. 6.—DIAGRAM OF ACCELERATOR MACHINERY
(THIS SHOULD BE STUDIED IN CONJUNCTION WITH FIG. 5)

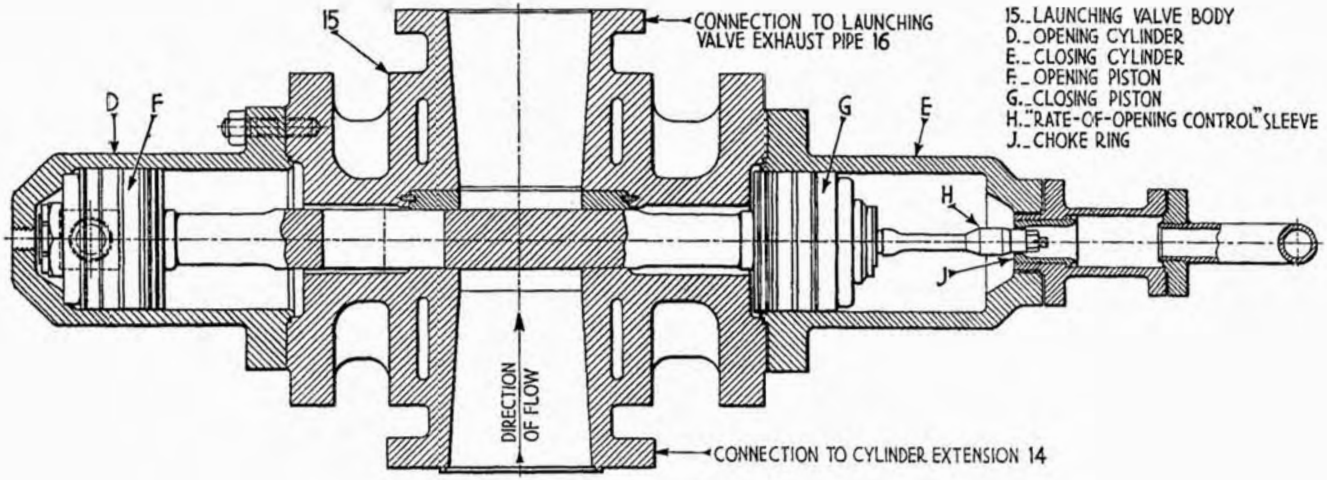

FIG. 7.—ARRANGEMENT OF LAUNCHING VALVE.

But even if the piston is not hard back against the stop, the water on the retarding side of the main piston (A) is locked in the cylinder annulus by the launching valve (15) and the piston and trolley are locked.

Launching arrangements

To launch, the control worker in the control position at the edge of the flight-deck operates the launching lever ; this causes a pilot valve to operate the relay valve (22), which admits pressure to the opening cylinder (D) of the launching valve (15), and allows the closing cylinder (E) to exhaust to the tank (18) and the launching valve opens.

Figure VII is an enlarged and somewhat simplified arrangement drawing of the launching valve.

As soon as the launching valve begins to open it allows water to be discharged from the power cylinder annulus, causing a drop in the pressure. The difference in pressure between the air on one side of the piston (A) and the water pressure on the other creates a load on the piston, which pushes it along the cylinder; the trolley is drawn forward by the accelerating rope, while the retarding rope is " paid off " by its crossheads at the same rate.

When the launching valve is full open the water has a free escape from the cylinder, and the water pressure in the cylinder annulus due to its expulsion is negligible, so that the force exerted by the whole air pressure acting on the piston becomes available to accelerate the ropes and sheaves, the trolley and the aircraft.

The accelerating stroke continues until the retardation profile (B) enters the choke ring (C) ; as soon as it does so the escape of the water from the annulus between (B) and the cylinder is checked, and it is forced through the small annular orifice between (B) and the choke ring (C). This orifice is designed so that the expulsion of the water through it at a rate corresponding to the velocity of the piston creates a high pressure in the water in the annulus. This pressure exerts a force on the piston which not only balances the force due to the air pressure, but also resists the continued movement of the piston. The inertia of the trolley, the ropes and the sheaves, acting through the retardation piston rod (26), pulls the piston along against the resistance of the water pressure, and in so doing their kinetic energy is absorbed and they are brought to rest.

As soon as the trolley comes to rest at the end of the stroke the control worker closes the launching valve (15) and by a remote control opens the drawback valve (19). Water under pressure from the pump enters the cylinder via the cylinder extension (14) and drives the piston back to the air end of the cylinder, recompressing the air into the air vessels, and drawing the trolley back to the after end of the track ready for the next aircraft. Then the drawback valve is closed, and the gear is in the locked condition already described.

The cycle can be summarised thus :—

1. The air drives the piston forwards, accelerating the mass of the piston, piston rods, sheaves, ropes, trolley and aircraft.
2. The water absorbs the energy of the piston, piston rods, sheaves, ropes and trolley.
3. The pump forces the piston back and recompresses the air.

The air is, therefore, used as a spring, and is not expended ; the pump gives to the air the energy which it imparts to the moving parts and the aircraft, and as the pump is driven by a turbine, the accelerator is in effect steam operated —it can go on operating for an unlimited number of cycles, at as high a rate as the size of the pumps will permit.

Design requirements

In designing an accelerator particular attention must be paid to the way in which the aircraft is accelerated ; the magnitude of the acceleration which can be applied is important, and must be limited to such a value as will not incapacitate the air crew nor overstress the aircraft, but the rate of change or build up of acceleration at the start is not less important. An aircraft is an elastic structure, and a violent surge of acceleration would cause a reflex action in the airframe and undercarriage which might cause serious damage. The rules which govern the acceleration are :—

1. The maximum acceleration must not exceed 1.25 times the mean acceleration.
2. The acceleration must build up smoothly from the start to the maximum in a trolley travel of about 10 feet, or in not less than 0.4 seconds.
3. The acceleration must, where aircraft are launched through their catapulting spools, diminish steadily from the maximum to the end of acceleration.

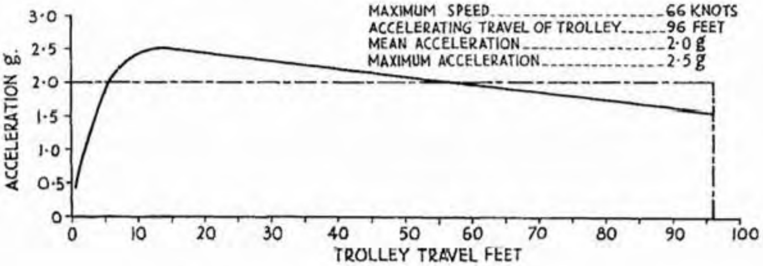

FIG. 8.—GRAPH OF DESIGN REQUIREMENTS

In an air operated accelerator such as that described, the third requirement is met automatically by the expansion of the air, as the rate of pressure drop during the stroke is related to the swept volume of the piston and the capacity of the air vessels. This also governs the first requirement to a considerable extent, but not entirely ; the accelerating ropes form a very elastic link between the piston and the trolley, and a jerky movement of the main piston would cause such an oscillation in this elastic system that high peak accelerations would be imparted to the aircraft.

A somewhat similar rule is followed for the retardation, the peak retardation being limited to 1.25 times the mean : in this case it is for the sake of the ropes, which would be overstressed if oscillations of retardation were propagated in the rope system.

The " ideal " curves of acceleration and velocity which form the basis of the design are illustrated in Figure VIII.

The smooth build up of acceleration, the second requirement, is achieved by controlling the rate at which the launching valve opens. As already explained, at the start of the launch the pressure of the air is partly balanced by the back pressure in the water due to its expulsion through the launching valve, the surplus of air pressure being available for applying the accelerating force to the piston. A smooth and controlled rate of opening of the launching valve

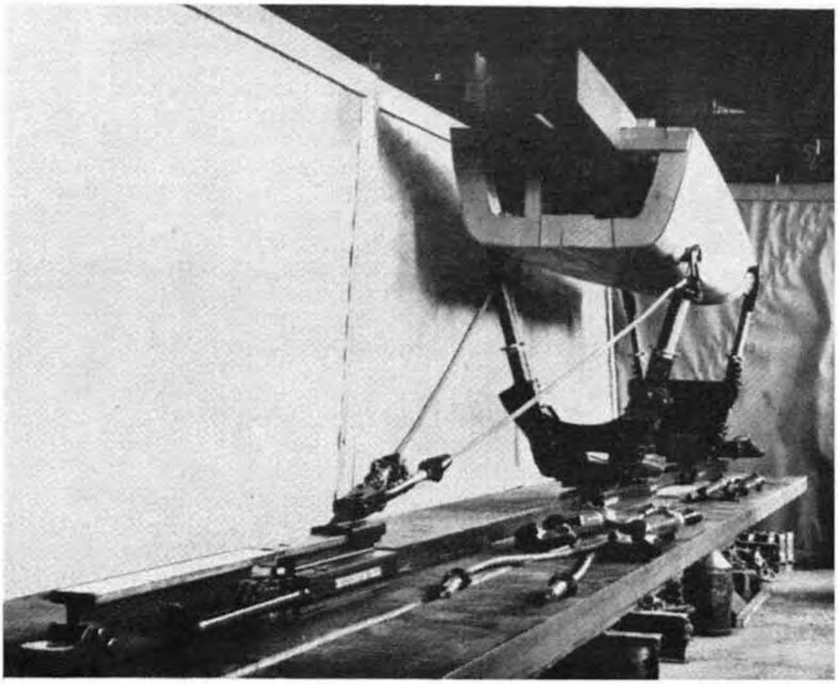

FIG. 9.—S.T. MK. II TROLLEY. VIEW FROM FRONT

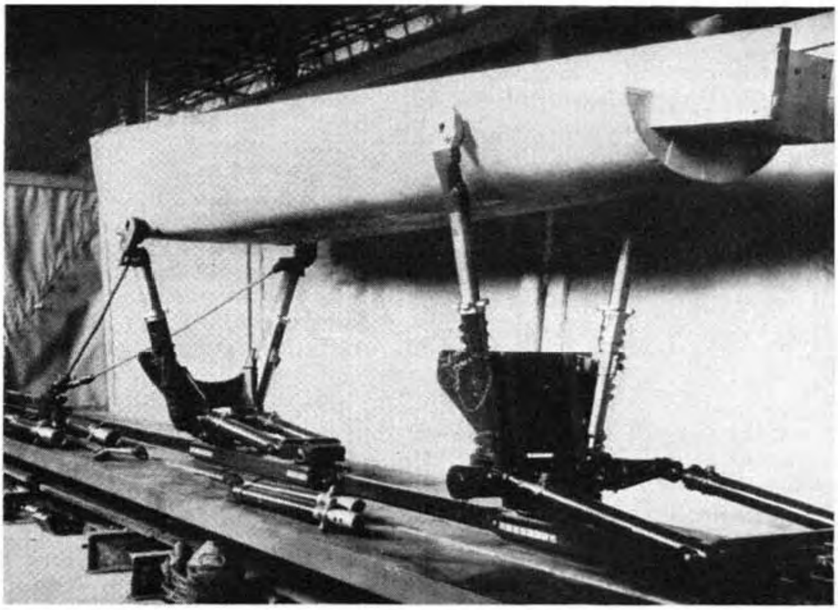

FIG. 10.—S.T. MK. II TROLLEY. VIEW OF REAR

therefore results in a steady build up of accelerating force on the piston, and consequently on the aircraft, and is achieved by the arrangement shown in Figure VII.

A spindle attached to the closing piston (G) of the launching valve carries a " rate-of-opening control " sleeve (H), which in conjunction with a choke-ring (J) formed in the closing cylinder (E), provides an annular orifice through which the water in the cylinder can escape during the opening stroke. The sleeve is profiled so that when pressure is admitted to the opening cylinder and acts on the piston (F), there is an adequate escape for the water in the opening cylinder and the valve begins to move quickly ; but this quick movement only carries the valve through the " lap " stroke, and towards the end of the lap the orifice diminishes so that the valve slows down, and commences to open very slowly. This slow rate of opening is maintained until the area through the launching valve is calculated to be such that the trolley has reached its maximum acceleration ; then the orifice is increased, and the valve allowed to complete its travel to full open, at a higher speed. By this means the rate of opening of the launching valve is rigidly controlled ; it is not dependent on the human factor in operation, and can only be modified by dismantling the valve and machining a new profile on the sleeve ; it has no moving or wearing parts, and is therefore consistent and reliable in operation.

Record of actual launch

Figure XI is a completely synchronised record of an actual launch, in which the movements of the launching valve, main piston and trolley and the pressures in the power cylinder were recorded on a common time base.

Interesting points to note in this record are that zero time is the movement of the control worker's launching lever ; the displacement and the speed of opening of the launching valve can be followed, and the drop in water pressure in the power cylinder. This was a launch of a medium weight aircraft at a slow speed, 57.5 knots, so the air pressure required was only 1,000 lb./sq. in., approximately—the drop in the water pressure from the static pressure of 1,900 lb./sq. in., can be followed, and as soon as there is a balance of air pressure over water pressure the piston and trolley commence to move, and acceleration begins. The acceleration builds up as the launching valve opens. The first movement of the trolley is at 0.8 secs., and the maximum acceleration is reached at 1.3 secs., so the time for build up from start to maximum acceleration of 0.5 secs. meets the second requirement for acceleration, and is satisfactory. As this is a slow launch, the trolley only moves about 5 feet during this time. From the start the velocity of the trolley builds up smoothly, until retardation begins ; the velocity of the piston multiplied by 8 is superimposed on the plot of the trolley velocity, so that the motion of the two can be compared. A slight oscillation of the piston can be seen at the start of retardation, but this is damped out by the rope system, and the motion of the trolley is perfectly smooth. It is noticeable that once the maximum acceleration is reached it conforms exactly to the air pressure curve. The acceleration is free from peaks or surges, and the maximum acceleration is 1.9g. ; the mean acceleration for this speed is 1.52g., so that the ratio of maximum to mean acceleration is 1.25 and the first requirement is met. Similarly the peak retardation is 10g., and the mean for this speed is 7g. ; the ratio of maximum to mean is 1.42, but this is acceptable in a slow launch, where the conditions differ from those for which the retardation profile was designed. At the full speed of the accelerator, 66 knots, the mean and maximum accelerations are 2.0g. and 2.5g., while the mean and maximum retardations are 9.2g., and 11.5 g. ; at any retardation less than 11.5g., the maximum designed retardation, the ropes in the system are within their designed stress.

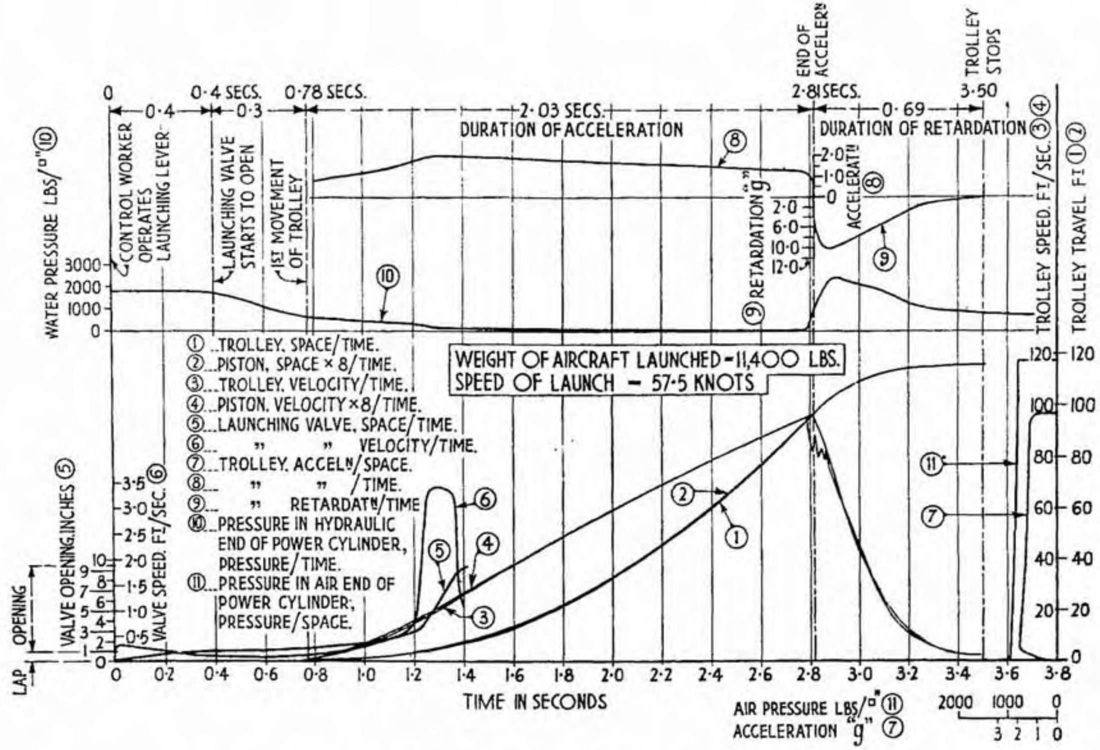

FIG. 11. RECORD OF LAUNCH OF AIRCRAFT FROM B.H.III ACCELERATOR

Acknowledgement is made of the assistance given by the Low Pressure Ballistics Section of C.S.A.R., Woolwich, who used their equipment to obtain these records, and plotted the curves shown on Figure IX.

When the accelerator is not in use, it is usual to stow the trolley at the forward end of the track, as described later. With the trolley in this position the main piston (A) is at the retarding end of the power cylinder (12), so the cylinder is full of air. A great deal of trouble was experienced in the earlier B.H.III's as a result of this, because as the piston moved to the end of the cylinder it left the surface of the bore wet, and naturally standing full of air for even a short time gave rise to corrosion of the bore of the cylinder. Then when the piston was moved back along the bore of the cylinder roughened by rust, the U leathers, which were used at that time, were badly abraded, and the U leathers wore out in a very short time. It can be readily appreciated that the renewal of these packings was a formidable task, as it involved casting off the ropes, taking off the air cover (13), and uncoupling the acceleration piston rod (25) from the main piston (A).

Introduction of piston lubrication system

The main piston was re-designed, and a lubrication system introduced as shown in Figure XII. Heavy U section rings, specially designed for this duty, were made of moulded synthetic rubber bonded with fabric and brass wire. Six of these rings are fitted, three facing each way ; between each U-ring there is a gunmetal junk ring, and between the two groups of three, a separator or cage ring, which registers with holes bored radially through the wall of the piston. Opposite the space formed between each cage ring and U-ring, a hole is bored radially into the interior of the piston, into which a steel pipe is welded. These pipes pass right through the bore of the retardation piston rod (26), and are collected together at a panel mounted on the retardation crosshead (5) where a stop valve and grease connection is fitted on each pipe. By pumping grease into the connections on the panel, the spaces between the U-rings and junk rings are charged with grease. Whichever way the piston moves, the grease ring at the end of the piston leaves a film of grease on the cylinder wall, and protects it against corrosion. Moreover, whichever way the piston moves, each U-ring follows a grease ring, so that every U-ring is moving over a lubricated surface. The function of the cage ring is to trap leakage ; if either air or water leaks past its group of packings it passes into the interior of the piston, and out through the bore of the piston rod or the holes in the lubrication manifold housing. Such leakage is readily apparent, so it is easy to keep a check on the packing. It is particularly important in the piston that air should not leak into the water end, as this would upset the retardation, and that water should not leak into the air end. The cage ring effectively prevents this.

The arrangement described is now fitted in all B.H.III accelerators and has been successful ; by protecting the cylinder walls and lubricating the rings, the wear in these has been reduced to such an extent that there is no need to open up the cylinder except at the routine annual inspection, and the rings may not require renewal even then.

Development of twin track trolley

Reference to the catapulting spools on the aircraft has been made earlier in this article. It was a requirement in the design of all naval aircraft which have been in service until recently, that catapulting spools were to be fitted. When the first B.H.III type of accelerator was being designed for installation in the *Illustrious* Class, an attempt was made to dispense with a trolley and to launch it by towing it along the deck by means of wire bridles attached to the front catapulting spools. Experiments were carried out at the Royal Air-

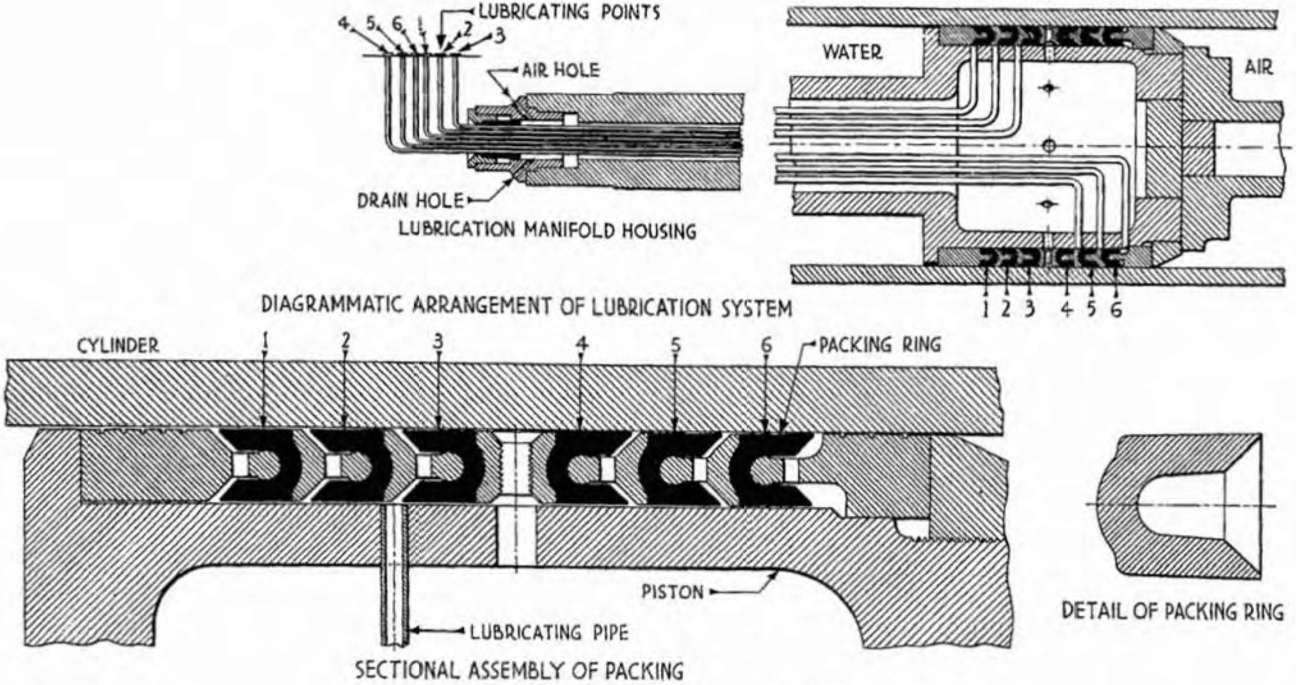

Fig. 12.—Accelerators B.H.III. Main Piston Lubrication System

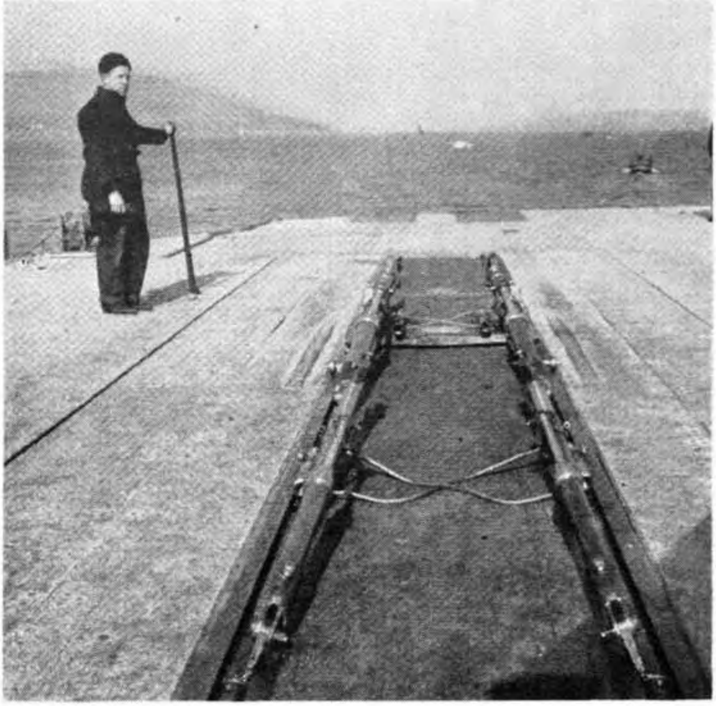

FIG. 13.—T.T. MK. III TROLLEY. LEGS COLLAPSED AT END OF TRACK

FIG. 14. T.T. MK. III TROLLEY. STOWAGE COVERS OPENED

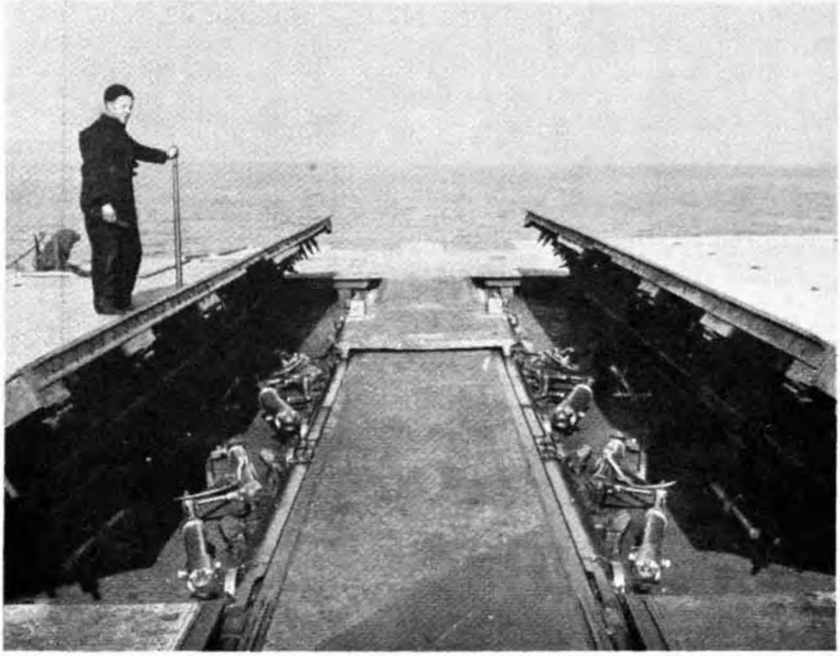

FIG. 15.—T.T. MK. III TROLLEY. TROLLEY FOLDED DOWN INTO STOWAGE SPACE

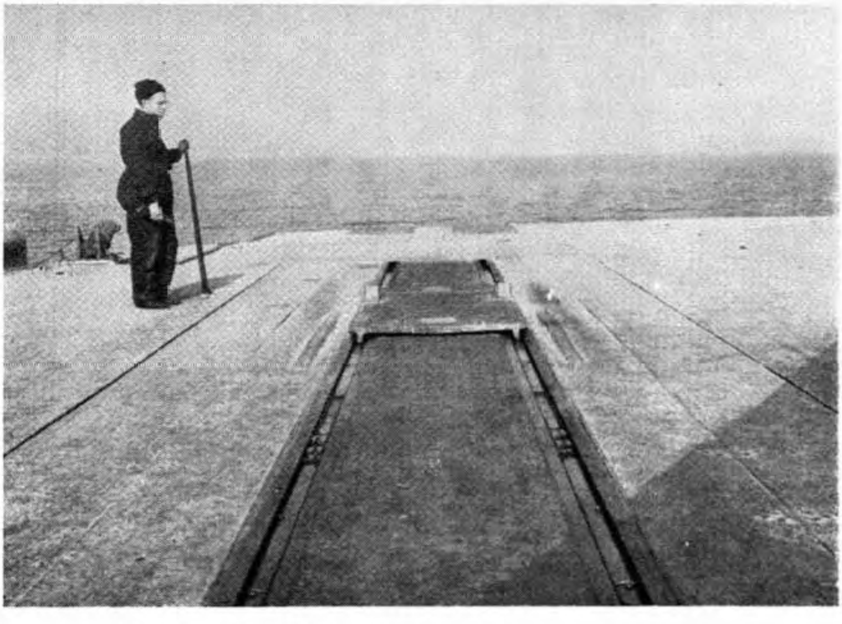

FIG. 16.—T.T. MK. III TROLLEY. TROLLEY STOWED AND COVER CLOSED

craft Establishment, Farnborough, and it was found that due to the relative positions of the front spools and centre of gravity of the aircraft, the application of the bridle pull at the front spools caused excessive loads on the tail and airframe. To reduce these, legs were introduced to support the airframe at the rear spools, which were designed to take the downward loads incidental to catapulting. It was then found that the bridles damaged themselves during retardation, and it was thought that they might foul the tail wheel, so legs were introduced to support the front hooks and to restrain the bridles during retardation. The Single Track Trolley, as fitted in *Illustrious* Class, *Indomitable* and *Unicorn*, was the outcome of this development. This trolley is illustrated in Figures IX and X, where the catapulting spools are shown fitted to a wooden mock-up of part of the airframe.

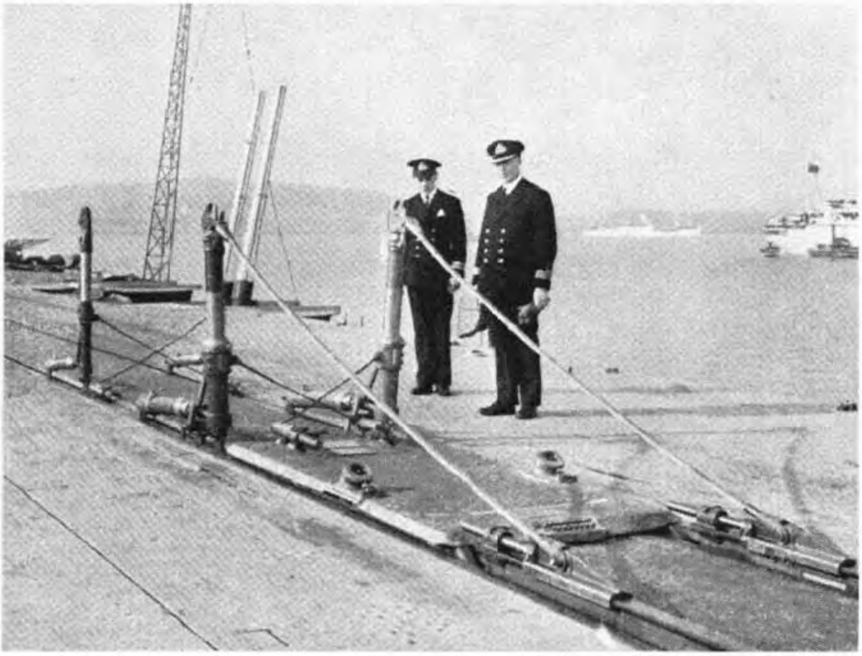

FIG. 17.—T.T. MK. III TROLLEY. LEGS ERECTED

Experience with the single track trolley was unsatisfactory ; it was unstable and liable to damage, and was heavy to remove and refit when not in use.

When *Implacable* and *Indefatigable* were being built, it was decided to make a different approach to the problem ; to accept the fact that a trolley was necessary, and to design a trolley which would be stable, but would still allow some inaccuracy in positioning the aircraft for loading ; and to make a trolley which could be easily stowed when not in use. A twin-track was adopted. The prototype twin track trolley, T.T. Mk. I, is shown launching a Barracuda in Figure IV.

The final design of the T.T. Mk. III trolley, as installed in *Implacable*, *Indefatigable* and *Colossus* Class, is illustrated in Figures XIII to XVII. These show the method of folding the trolley down into the stowage spaces, which are closed by power operated hinged covers.

It was realised some years ago that aircraft could be launched by towing them along the deck with wire bridles, provided that the towing hooks were so positioned on the aircraft relative to the centre of gravity that excessive pitching moments and loads on the airframe were avoided. But as long as it was a requirement that aircraft must be fitted with spools for catapulting, it was not possible to strengthen the aircraft and fit towing hooks for " tail-down " launching in addition, as the extra dead weight on the aircraft was unacceptable. The catapulting requirement has now been given up, and all new aircraft now coming into service are fitted with towing hooks. There is, therefore, no need for a trolley, and it is replaced by a small towing hook, running in a single track sunk flush in the deck. When the aircraft is loaded on to the accelerator a wire bridle with an eye at each end is hooked on to the towing hooks on the aircraft and the bight passed over the accelerator towing hook. Prior to the start of acceleration the aircraft must be held back against the thrust of its airscrew ; this is done by a " hold-back ," which hooks on to a suitable fitting at the tail of the aircraft, and into a power operated rack fitted flush in the deck. When the bridle and hold-back are hooked on, the rack is moved aft, and the bridle tensioned to a pre-determined load. The hold-back is fitted with a breaking ring, designed to withstand the airscrew pull, but to break when subject to a load equal to the weight of the aircraft. So as soon as the build-up of the accelerating force transmitted by the gear to the towing hook builds up to 1g., the hold-back ring breaks, the hook opens, and allows the aircraft to move forward under the pull of the bridle.

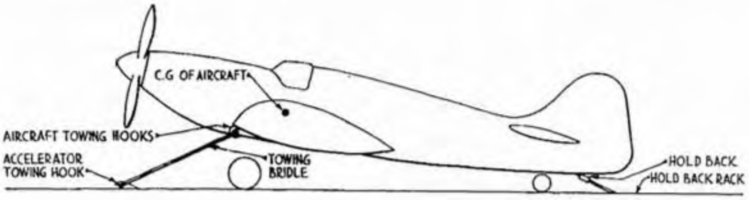

FIG. 18.—DIAGRAM OF " TAIL-DOWN " LAUNCHING

This method of launching is called " tail-down " launching and is illustrated diagrammatically in Figure XVIII.

Arrangements for " tail-down " launching only are being adopted in *Majestic* Class and later ships.