HYDRAULICS IN FLIGHT-DECK MACHINERY

BY

CAPTAIN D. J. I. GARSTIN, R.N.

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INTRODUCTION

It is now more than fifty years since the first attempts were made to operate aircraft from warships. Two lines of development emerged: one was to launch a float-equipped aircraft which could alight on the water at the end of its sortie and be recovered on board by crane; the other, with which this paper will be chiefly concerned, was to operate land-based aircraft, equipped with wheels, on and off a landing deck on top of a ship.

The former development was aimed primarily at spotting for gunfire or other warlike activities of the parent ship, and came to an end in about 1944 with the increasing vulnerability of the aircraft, the development of radar, and the need to cram considerably more new equipment into ships, which necessitated the removal of items that had proved, in practice, to be of marginal value. By contrast the development of the aircraft carrier has proceeded apace, and now the aircraft that fly from it are in every way comparable to their contemporaries that are restricted to operation from shore airfields. As far as ships other than aircraft carriers are concerned, the wheel has recently come full circle, because nearly all are now carrying helicopters which have the versatility to justify their accommodation on board that the seaplane or flying boat so conspicuously lacked.
Both lines of development depended on machinery built into the ships—for launching only in the case of aircraft flown from battleships and cruisers, and for aircraft recovery and a variety of other services in the aircraft carrier. Most of this machinery is in some way hydraulic and, though a highly specialized technique, is a good example of the versatility of hydraulic power using elementary principles and of the effect of successive refinements.

The major items of flight-deck machinery are the catapult for launching the aircraft and the arresting gear for recovery. In addition there are: aircraft-handling equipment, particularly for loading the aircraft on to the catapult; crash barriers for last-ditch recovery of aircraft that cannot be recovered normally into the arresting gear; lifts of exceptionally large size to transfer aircraft from the flight deck to the hangar beneath, and vice versa; operating gear to lower obstructions out of the way when flying, such as wireless masts and the like; hangar doors, and a variety of chocks let into the deck and designed to be raised to prevent aircraft being inadvertently manoeuvred over the side. As a recent development, hydraulically operated deflection plates of large size have been installed on flight decks to catch and deflect upwards the blast from jet engines.

PERFORMANCE AND SAFETY

Performance

The performance of catapults and arresting gear has had to keep pace with the requirements of the aircraft; these are always increasing in size and weight and their take-off and landing approach speeds have also increased over the years, despite a number of high-lift devices that have been applied progressively to aircraft.

The trend over the years is shown in Figs. 1 and 2. The difference in shape of the curves of speed and weight between catapults and arresting gear is explained by the trend, in high-performance aircraft, for an increasing proportion of the take-off weight to be in the form of fuel, which is, of course, consumed before the aircraft lands.
Safety of Operation

Any machinery that is used to launch and recover aircraft—worth, perhaps, £1,000,000 each—from ships, must have standards of reliability far in excess of those normally required in engineering, so that ‘fail safe’ has been the normal practice for many years. Any defect, even quite trivial in itself (for instance a fractured pressure-gauge pipe), can result in the loss of an aircraft and its crew. There is no doubt that this requirement has resulted in development being rather slow and in a reluctance to indulge in sophisticated engineering, particularly in the control field. It is greatly to the credit of this predominantly hydraulic machinery that these standards have been met.

Closely allied to the safety due to freedom from defects is that of consistency of performance. During both the launching and recovery processes, aircraft are being loaded to their limits, with factors of safety sometimes less than 2 between working and failure stresses, as would never be tolerated in other forms of engineering. When to this is added the fact that flying a modern high-speed aircraft on to or off the flight deck of an aircraft carrier is just about the most difficult thing that it is possible to ask a pilot to do, the need for consistency is clear. Consistency is normally obtained by making the control gear as simple as possible and it has been necessary to reject many otherwise promising developments for this reason. Not many years ago, it was held that a performance excursion outside the laid down tolerances once in 4000 operations was enough to make a catapult control system unacceptable.

While not wishing to over-emphasize the factors of reliability and consistency, they do form the foundations on which all flight-deck machinery engineering is based and always have to be satisfied first, before anything else is considered.

Storage of Energy

In flight-deck machinery, large amounts of energy are required in short bursts, with relatively long pauses between operations, which requires an energy storage system, to economize on power units. The air-loaded hydraulic accumulator offers a means of achieving this statically, cheaply, and effectively,
provided that the quantity of energy required at one operation is not excessive. This is a virtue of hydraulics which cannot be approached by any other storage system.

Viscosity

In an application where high consistency is required, variation in viscosity of the hydraulic fluid is a major embarrassment. In flight-deck machinery it is fortunately possible to use water-based hydraulic fluid, where the viscosity change is much less than when using oil.

Explosion Risk

Water is the only really safe, commonly available, hydraulic fluid. Any hydrocarbon fluid can be dangerous, either by ignition of the finely atomized spray that emerges from a microscopic leak, or by 'dieselling', which is caused by permitting fluid to flow rapidly into a closed end containing air. Both these dangers increase with the size of the system and with the pressure. The danger from an atomized spray is also independent of the type of hydraulic system and is very difficult to guard against, particularly in a system as extensive as that of a catapult. Dieselling can occur in any type of system under pressure, but is particularly likely in a system that is normally kept under pressure by means of an air-loaded accumulator. In a system where pressure is supplied directly by a pump, parts of the system are normally opened only when the whole is unpressurized, though carelessness can cause dieselling even there.

The Diesel explosion, as its name implies, is caused by compressing air rapidly, so as to raise its temperature sufficiently to initiate combustion in the oil. The most common and the most likely way that this occurs is by opening too rapidly the valve to a pressure gauge that has been replaced after servicing. A large pressure wave is generated, which can cause failure of some part of the pressure system, leading to sudden release of the potential energy stored in the accumulator and disintegration of the system. Should there be appreciable quantities of air in the fluid, the disintegration is even more violent, owing to rapid reaction of the fluid with the air mixed with it.

Extensive damage and fatalities have been caused in catapult hydraulic systems due to both of these phenomena—though not in British built ships, where water has always been used as the hydraulic fluid—the Diesel explosion being the more devastating both in extent and effect.

CATAPULTS

A catapult is a device that accelerates an aircraft from stationary to its flying speed in a very small distance compared with the free take-off run, by the application of a horizontal force of several times the aircraft's weight. The advantages of doing this are so obvious that it is not surprising that interest in catapults goes back a long time. What is, perhaps, rather more surprising is that a catapult capable of launching an aircraft and fitted into a ship—though admittedly only a house-boat—was constructed by Samuel Pierpont Langley (then Secretary of the Smithsonian Institute in Washington) in 1902, and a manned, powered aircraft, piloted by Charles M. Manley, was launched at 12.20 p.m. on 7th October 1903, thereby anticipating the Wright brothers by some two months. Alas, although the launch was successful, the flight was not, so the Wright brothers' record stands. They also used a catapult to launch their flying machines, though not for their original flights of Kitty Hawk; there is a record of their having used one at Detroit in 1904 and photographs have recently been published by Gibbs-Smith (1) showing the preparations for and the execution of a catapult launch in France in 1908.

Cruiser and Battleship Catapults

The first twenty years or so of catapult development was almost entirely devoted to the launching of spotter aircraft from normal warships. The United States Navy was first in the field and a successful catapult was developed between 1911 and 1915, when it went to sea in the U.S.S. North Carolina. With this, aircraft could be launched from the ship while steaming at its normal speed and without the ship having to be manoeuvred out of line especially to provide the optimum wind—two essential factors that made the use of spotter aircraft in battle feasible.

By the outbreak of World War II, catapults were widely fitted to battleships, battle cruisers, and cruisers, the aircraft on the catapults being prominent features of the warship photographs of many nations in Jane's Fighting Ships of the period.

Successful catapults to launch spotter aircraft nearly all used cordite as the source of power for launching the aircraft, though manoeuvring was hydraulic. The most difficult problem was to retard the moving parts of the catapult itself within the short distance available, to retain them and the trolley on which the aircraft was mounted on board the ship at the end of launch. Many ingenious variations on the principle of the choke were used, and by 1939 development had reached a stage where the catapult moving parts, weighing 5 tons, could be brought to rest from about 70 knots in a distance of 12 ft.

Catapults in Aircraft Carriers

The 'flat top' aircraft carrier was developed primarily with the idea that normal, wheeled aircraft should be able to take off entirely under their own power and land again by free run. With the relative size and speed of ship and aircraft, this was practicable in the early days of aircraft carrier operation, and even up to the Korean War of 1950, most propeller-driven aircraft could take off without assistance from the flight decks of both British and American aircraft carriers.

Catapults were fitted in the U.S.S. Langley in 1920; the first British ships to be so fitted were H.M.S. Courageous and H.M.S. Glorious in 1934, since which time all British aircraft carriers, except some converted merchantmen during World War II, have had catapults, usually two, but at least one. In the early days, the use of catapults was limited to adverse conditions—for instance, when the wind was very light and the flight deck crowded, so that there was not sufficient take-off run available for the early aircraft of a detail. On occasions, catapults were used to launch aircraft in harbour.

With the introduction of jet-propelled aircraft, this situation changed radically overnight to one where no aircraft could become airborne in operational conditions without external assistance. Fortunately for the cause of the aircraft carrier as part of a modern weapons system, this situation arose at the same time as the development of the slotted cylinder catapult, which was the break-through that was needed to keep the aircraft carrier viable.

In order not to obstruct the flight deck, catapults fitted in aircraft carriers are invariably located below decks, with only a track containing a shuttle, to which is attached the towing hook for the aircraft, actually at flight-deck level, with the hook protruding a few inches above.

The catapult in the aircraft carrier must be capable of launching a wide variety of types of aircraft, requiring different end-speeds and being of different weight, in random order at short intervals of time. It is also necessary to launch up to thirty aircraft from a single catapult at one session, though this is not common. It was soon found that the use of cordite as the launching source of energy was not practicable because of variations in rate of burning—and therefore of catapult performance—as the temperature of the explosion
CATAPULT STROKE

FIG. %-TYPICAL CATAPULT PERFORMANCE CHARACTERISTICS

chamber increased, even with water cooling, during a series of launches in quick succession.

Both the Royal and the United States Navies developed hydraulically-operated catapults, using air as the energy storage medium. This type served both navies very well and, before being superseded by the slotted cylinder catapult in the early 1950s, had been developed to the stage where the catapult could launch an aircraft weighing approximately 15 000 lb at 95 knots in a length of 96 ft, with a maximum acceleration of 4.7 g. This entailed an energy release of some 7 500 000 ft lb in 2 seconds. At the end of the launching stroke, the moving parts, which were substantial, including ropes of considerable length, were stopped in a distance of 23 ft. This required pressures in the retardation cylinder of 10 000 lb/sq in., which was high for the middle 1940s.

Before discussing the hydraulic aspects of slotted cylinder catapults, the requirements of the control system are briefly described. All catapults at present work on an energy cycle where the working fluid is stored. The catapult is a single-stroke reciprocating engine, so that the natural expansion curve of the working fluid as the launch takes place follows the normal law, $pv^a = C$. This is not what is required. To launch an aircraft, the pressure on the catapult piston must build up rapidly and smoothly, in a controlled manner to a set maximum, which must then be maintained until the end of the launch. This entails throttling the flow of working fluid to the piston during the early part of the launch and, in all actual catapults, there is a slight droop in the pressure characteristic towards the end of the launch. This is shown in Fig. 3. Precise control is needed both to ensure that the maximum permitted piston force is not exceeded, although it must be reached, and to approach as nearly as possible to the required characteristic. The normal measure of catapult efficiency is the ratio of maximum to mean acceleration imposed on the aircraft; the mean acceleration controls the speed with which the aircraft leaves the catapult, while the maximum is the greatest load applied to it. The nearer the ratio of these accelerations approaches unity, the more efficient the catapult. Some loss of efficiency is inherent in the requirement to build up the load on the aircraft progressively, but skilful development of the control system and matching it to the aircraft to
be launched can reduce the other losses to a minimum. Ratios of the order of 1.2 or less are common, over a wide range of energy release rates. In principle, variation in energy release, to take account of the weight and launching speed of different aircraft, can be obtained either by varying the programme of the control system, or by adjusting the initial pressure of the working fluid in its storage chamber. Both have been used and both are satisfactory, the choice normally being one of rapidity and convenience of operation. Hydro-pneumatic catapults latterly worked on a constant pressure cycle, with the launching valve programme being varied, whereas steam catapults have a constant launching valve programme and control is by adjusting the initial steam pressure.

**Slotted Cylinder Catapults**

The slotted cylinder catapult and its development has been described often and will not be repeated here. However, what is not generally realized is the amount of hydraulics that go into it. Though the actual launch of the aircraft is done by steam, almost everything else is hydraulic. Not unnaturally, most of the published documents concentrate quite rightly on the novel and extremely successful application of the slotted cylinder principle, which is of absorbing technical interest. Here it will not be referred to at all, attention being concentrated on the hydraulic aspect.

**Retardation**

As has been described above, the best that could be done in previous catapult designs was to retard from 70 knots in 12 ft or from 95 knots in 23 ft. The aim in the slotted cylinder catapult was to retard parts weighing 4500 lb from 200 knots in 5 ft. This required a break-through in retardation gear design. In principle, it was not too difficult to decide what should be done; a horizontal open-ended cylinder filled with water was needed, with a choke ring, into which would enter a profiled ram, attached directly to the piston assembly. The principal difficulty was to keep it full of water, when sited horizontally, with one end
open, which was solved by a simple and ingenious device. If water is flowed into a cylinder in such a manner as to encourage the formation of a vortex, a helical pattern will become stable, with an air core down the centre. If radial vanes are attached to the dead-end plug, this will destroy the rotation of the water as it reaches it and water will flow into the centre to fill the air core, which is a function of the rotational flow pattern. The end result is that the cylinder fills completely with water and can be used as the retardation reservoir. The initial penetration of the retardation ram into the cylinder interrupts the water supply, which is of low pressure and outside the choke ring. The flow pattern is shown diagrammatically in Fig. 4, which also shows the water flow during retardation. As the water emerges from the annulus between ram and choke ring, it impinges on a bucket, formed in the front end of the piston. Some momentum exchange occurs as the water flows round this bucket, but its real purpose is to disperse the flow so that the energy is rapidly and completely destroyed.

This retardation system has been progressively developed to stop catapult parts weighing 9350 lb from a speed of 275 knots (465 ft/s) in a distance of 7 ft. To do this the maximum retardation is 1080 g, the maximum retardation cylinder pressure 52 000 lb/sq in. and the maximum force on the ship's structure about 3000 tons. Some 32 000 000 ft lb of kinetic energy is destroyed in 0.03 s, representing a rate of doing work of 3 000 000 hp. This is the maximum condition, the loads in normal operation being about one-third of the maxima.

Right from the start, this retardation system has worked perfectly. It is a monument to the results that can be obtained by really hard thought, allied to a determination to keep the engineering simple. Although much less spectacular than the slotted cylinder development, the retardation gear is engineering of equal merit.

Launching Valve Operation

The launching valve that admits steam from the storage accumulators to the cylinders is called a 'Roto-Valve', which is nothing more or less than a sophisticated plug cock. In order to fulfil its function, it has first to be lifted, to break the taper seal that makes it steam-tight, and then rotated, in accordance with the set programme, to admit steam to the cylinders.

The control system is well suited to hydraulic operation; this enables sequence operation of the lifting and rotating jacks to be arranged with all the necessary interlocks to ensure correct operation. Further, the exhaust valve, which permits steam to escape to atmosphere at the end of launch, is operated hydraulically and interlocked into the same system, as also is the pressure-breaking valve, which is kept open at all times except during a launch, to ensure that any unwanted steam that finds its way into the cylinders leaks away without causing damage. Despite its multiple functions, the system is really quite simple and is shown in Fig. 5.

Manoeuvring

At the end of a launch, the piston assembly must be drawn back rapidly in preparation for the next shot; there are also many occasions during operation and maintenance when manoeuvring, at rather slower speed, is required. These functions are simply attained by the use of a single hydraulic jigger-and-rope assembly, speed variation being obtained by means of restrictions in the fluid flow. This jigger works at 4000 lb/sq in. and it is an interesting measure of the rate of development that it has about the same energy capacity as a complete catapult fitted to one of the older aircraft carriers.

Hydraulic System

Although 4000 lb/sq in. does not seem anything very spectacular these days, it was quite a large step in the late 1940s, particularly in relation to the size of
PRESSURE SUPPLY FROM LiV ACCUMULATOR TWO-WAY FIG.

SLOTTED CYLINDER CATAPULTS—DIAGRAM OF CONTROL VALVE OPERATING SYSTEM

the system, which contains approximately 300 gal of fluid in a typical installation and which is fitted with a seven-throw pump of 80 gal/min output. In view of the known danger of using oil in this system, a proprietary water-based hydraulic fluid of American origin is used and this has proved entirely satisfactory, having adequate lubricating properties to enable it to be used as the hydraulic pump lubricant.

The pump and the system are reinforced by an air-loaded accumulator, arranged vertically, so as to minimize wear and this, too, has given no trouble.

Leaks generally and seal failures are not uncommon, requiring considerable maintenance, but are not excessive, taking into account the extent and complexity of the system and its very large number of joints and seals.

Catapult Ancillary Equipment

It is necessary, in order to launch an aircraft by means of a catapult, to position it laterally in relation to the catapult track with precision greater than the taxiing accuracy of the average pilot. The frequency of abortive attempts to load the aircraft and the delays in launching caused thereby seriously reduced the usefulness of the catapult as a method of helping aircraft to become airborne. A device known as a roller mat positioner was therefore developed to do this job mechanically. The positioner consists of two frameworks, set either side of the catapult track, in the loading area, in which are mounted rollers, with their axes parallel to each other and to the track. The tops of the rollers are flush with the deck and their surfaces are fluted, to improve grip on the tyres. These rollers can be rotated so as to produce translation of any object placed upon
FIG. 6—ARRANGEMENT OF ROLLER MAT POSITIONER FOR CATAPULT
them towards the catapult track. In addition, they can be clutched into or out of or released from the driving mechanism. If the pitch between driven rollers on either side of the track centre line is selected to be the same as the track of the aircraft main wheels, then an aircraft coming up off centre will be deflected sideways by the driven rollers on the side to which it is off centre, the other main wheel moving freely on the free rollers, until it is accurately positioned. At the same time, the wheels come to rest against chocks, to make sure that the aircraft is aligned with the catapult. This device, which is shown in Fig. 6, is hydraulically driven and the clutches are hydraulically operated. A motor-driven pump is sited conveniently below decks, with the hydraulic motor in the frame box containing the rollers and which is fitted in a shallow trough in the deck, some 12 in. deep.

This may seem an example where the use of hydrostatic drive is hardly justified; after all, rotary motion is required and direct electric-motor drive might seem a better solution. When looked at as a problem in engineering installation, however, hydraulic drive is much superior. The zone immediately below the site on deck where the positioner mats must go is extremely congested, so that it is quite impossible to fit there a large 20 hp electric motor. No motor running at the required speed, which is slow, could possibly be made small enough to fit in the box frame on deck, so that direct drive would involve some unpleasant drive shaft geometry problems; in addition repair work that may be required on catapult steam-side components involves lifting the positioner mats and this is made markedly easier where only a few pipes, in addition to the holding down bolts, have to be disconnected.

Therefore, this positioner is an excellent example of the virtues of hydrostatic drive both in flexibility of installation and in driving a low-speed high-torque motor from a high-speed low-torque pump; in this particular use, efficiency of power transmission is of almost no account, whilst flexibility of installation is all-important.

ARRESTING GEAR

Historical

The history of the attempt to slow down an aircraft after landing, in a shorter distance than either a free run or the machine’s own brakes can achieve, does not go back quite so far as launch assistance. On 18th January, 1911, an American aviator, Eugene Burton Ely, landed on and took off from a platform 120 feet long constructed on the armoured cruiser U.S.S. Pennsylvania; this was an arrested landing, but sandbags were employed as the arresting medium, which hardly counts as a hydraulic operation. However, the fundamental feature of all subsequent arresting gears—a wire stretched transversely across the deck and engaged by a hook dangling from the aircraft—was used.

The United States Navy developed the transverse wire type of arresting gear during the 1920s and an independent development took place in Britain in the early 1930s, the first ship to be fitted being H.M.S. Courageous in 1933. Since then, all aircraft carriers have been fitted with arresting gear, which has been progressively developed to keep pace with the requirements for recovering aircraft. Unlike the catapult, which was a convenience rather than a necessity until about 1950, the arresting gear has been used as an essential feature of aircraft carrier operation since the middle 1930s. Even in those days, its landing run was too great to permit a military aircraft of reasonable capability in the air to land on deck without externally applied retardation. The landing interval between successive aircraft also required a deck park of recovered aircraft, protected from the landing area by a crash barrier. This reduced even further the landing run available on the deck and increased reliance on arresting gear.
Transverse Wire Arresting Gear Operation

The arrangement of the arresting gear is shown in Fig. 7. A wire is stretched across the landing path of the aircraft and is engaged by a hook attached to the aircraft. The aircraft pulls the bight of the wire after it, which in turn draws off more wire from the jigger, thereby compressing it. The fluid displaced by movement of the jigger piston is passed through an orifice, in accordance with a previously decided programme, thus destroying energy.

The performance of a transverse wire arresting gear is a combination of impact, inertia, and hydraulic effects. The impact effect comes first; both in theory and in practice it is complex and will not be discussed here, except to remark that it can, in some circumstances, dominate the whole arresting process. As the impact effects decay, they are succeeded by those of inertia of the moving parts. Owing to the geometry of the transverse wire, these come into action relatively slowly, but they are substantial, owing to the considerable weight of the moving parts that must be accelerated as the wire is drawn out. Lastly, the hydraulic effect takes over and this provides the majority of the energy destruction. The aircraft feels rope tension, so that the aim is to keep this as constant as possible; should this be attained, then the geometry of the transverse wire would permit a maximum to mean deceleration ratio of about 1.2.

In practice, because of the combination of the three effects of impact, inertia, and hydraulic resistance, 1.4 is the best that can be done, with a characteristic as shown in Fig. 8.
The reeve ratio of the jigger is as high as possible, in order to provide as much pull-out of wire on deck, with the minimum size of pressure cylinder below. Diameters of cylinder are of the order of 15 in. and the working pressure at this diameter is about 10,000 lb/sq in. The design of the crossheads on which the rope pulleys are mounted is critical, as also are the strength and stability of the piston rod as a strut. In fact, in later designs there is no piston rod as such, the ram being the same diameter along its full length.

The orifice area, through which the working fluid is squeezed to destroy energy, needs to be varied throughout the stroke of the ram to give the required retardation performance. This can be done either by an internal choke ring and cut-off rod arrangement, or an external relief valve. A third method is to fit a simple relief valve, where the resistance to movement during an arrest is carried out at constant pressure and altering the relieving pressure provides for a wide range of energy absorption. This arrangement has been used in practice, but has proved unsatisfactory, because there is considerable variation in the aircraft approach speed and an exceptionally fast aircraft bottoms the gear; this puts a heavy shock load on gear and aircraft and probably damages both. A gear that relies on an orifice programme proportional to the stroke does not do this, because the pressure drop across the orifice is a function of the speed of movement of the ram, so that it adjusts itself to stop a fast-landing aircraft.

The early types of gear, which went out of production in the late 1940s, used a profiled cut-off rod, with a choke ring of constant size attached to the piston. By displacing some of the fluid into an accumulator during the arresting process, enough energy could be stored to reset the gear after use without the need for external power and this feature of regeneration has been preserved in all subsequent arresting gears in the interests of reliability and simplicity. To provide for the widest range of aircraft kinetic energy destruction, the programmed orifice between the choke ring and the cut-off rod was supplemented by another orifice in parallel, that was fixed for any one set of conditions, but which could be varied in size to extend the range of energy absorption of the gear.

Current Gears

When designing the arresting gears now in service, which have an energy absorbing capability much greater than that of the earlier gears, it was clear that, not only would they have to be much larger, but also that they would have to operate at substantially higher pressure if they were to be kept to an overall size
that could be installed in an aircraft carrier. The range of energy required was such that the choke ring and cut-off rod, plus a by-pass valve that had served so well previously, could not be used. In addition, the pressure, about 10,000 lb/sq in., at which the gear was going to operate, gave rise to some doubt about the stability of the cut-off rod as a tube subjected to external pressure.

It was therefore decided to use an external relief valve and to pass the whole of the fluid into an accumulator. The use of a pressure-sensitive relief valve having been discredited, the basic requirement was that the relief valve should conform to a programme related to ram movement and that it should be capable of adjustment over a wide range of energy absorption without external by-passes. This problem was solved by the use of what has been called a spline valve, which gave a gear arrangement shown in Fig. 7 and whose principle of operation is shown in Fig. 9.

The control valve consists of a piston moving axially in a cylinder, through a choke ring in which it is a close fit. As can be seen from Fig. 9 the flow of fluid from the arresting gear main cylinder passes through diametrically opposed slots in the choke ring and then through an orifice formed by the choke ring and axial grooves cut in the periphery of the piston. The grooves are vee-shaped and their depth is varied over the length of the piston; thus, if the piston is moved axially along the cylinder during the course of operation of the arresting gear, an orifice programme proportional to the movement of the gear main ram can be obtained. Additionally, if several sets of axial grooves are cut in the periphery of the piston, by indexing the latter to a different radial position, grooves with varying characteristics can be brought into use as part of the variable orifice. The piston is driven axially by an auxiliary piston and cylinder attached to the main piston crosshead, with areas arranged so that the movement of the control piston, or spline valve, is smaller than that of the crosshead. Thus, by the use of hydraulics to the best advantage, a device of great elegance has been developed that fulfils the functions of two valves in previous designs and which is variable at will over a wide range of performance. It is relatively simple to manufacture and has the advantage that very high pressures are confined to comparatively small components, mostly of plain cylindrical shape, that can be made sufficiently strong quite simply.

The spline valve has proved entirely successful and is a first-class example of the adaptability of hydraulics to meet special requirements and, further, of an adaptability that can be realized at reasonable cost.
The Future Arresting Gear

The present type of arresting gear is approaching the limit of its development, not hydraulically, but from every other point of view, particularly in connection with the inertia of the moving parts. For some years, work has been proceeding at the Royal Aircraft Establishment on arresting gears employing long tubes, in which move pistons, connected by flexible wire-rope piston rods directly, over pulleys, to the transverse span that makes contact with the aircraft hook (2). These have been developed principally for airfields, where the pull-out distance through which an aircraft can be permitted to move during the arresting process is very much greater than in a ship, with correspondingly reduced deceleration. The tubes, which have orifices in their walls all along their length and are filled with water, can conveniently be disposed either side of a runway. During an arrest, water is forced out of the holes into the atmosphere by the passage of the piston, and the energy of the aircraft is thereby destroyed. A photograph of the water spray arising from an arrest is shown in FIG. 10.

A version of this type of gear, but enclosed so as to prevent water from spraying around and equipped for rapid resetting, is at present under development, with a view to its use in aircraft carriers. If successful it will be a breakthrough in arresting gear technology comparable to that of the slotted cylinder catapult. It works very well in the airfield version where, despite its somewhat unusual application, the rope forming the piston rod has so far given no trouble.

This type of gear has great potential and in principle it is possible to use it to stop the largest aircraft yet envisaged, with an installation that is itself relatively insignificant in cost. Its potential as a safety device for the runways of large commercial airports gives hope that it may be used at some future date to reduce the danger of aborted take-off.

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AIRCRAFT LIFTS

All aircraft carriers are arranged with the hangar immediately below the flight deck and aircraft are transferred from one to the other by means of a lift. By normal standards, these lifts are very large, having platforms of up to 60 ft × 40 ft, weighing upwards of 50 tons and capable of carrying a weight of about 20 tons, through a distance of about 20 ft. The lift is specified to be capable of striking aircraft down from flight deck to hangar without power being available and of returning, unloaded, to the flight deck position. This can be attained by over-balancing the platform itself.

Some lifts are worked mechanically, but a fair number are hydraulic. The main advantage of hydraulic operation is flexibility in siting the operating machinery, a matter of some importance, because the lift machinery is both bulky and heavy and, for a mechanical drive, must be positioned where everyone would much prefer not to have it. However, in this case, the price to be paid for this flexibility is both size and complication.

CONCLUSION

The descriptions of the various items of flight-deck machinery in this Paper have necessarily been somewhat cursory, to fit within the confines of a single paper. Each section could easily be expanded to form a paper on its own.

The main factor that emerges is the capability of simple hydraulic machinery to perform functions of a very specialized nature, in which the supply and precise control of large amounts of power are involved, and to do this without excessive development cost.

The practical difficulties have nearly always loomed much larger than the theoretical. The actual machinery components are large and the scale effect thus introduced has presented many manufacturing problems, including such basic factors as the size of forgings that could be produced with the physical strength that was required. Over the years, development has been progressive, so that improved techniques have been used as they became available, to improve both performance and reliability simultaneously.

Only a handful of engineers work on flight-deck machinery and it would be quite impossible for development to have gone at the speed it has, if the general advance of the technology of hydraulic machinery had not also been rapid during the last twenty years. It is certain that without hydraulic flight-deck machinery the aircraft carrier as we know it today could not exist.

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FIG. 10 is reproduced by permission of the Director, Royal Aircraft Establishment.

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