HANDLING AVIATION FUELS IN AIRCRAFT CARRIERS

('THE NEW LOOK')

BY

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The advent of jet aircraft into the Fleet Air Arm introduced a new fuel which had to be handled in aircraft carriers. With this fuel came a number of handling problems which were, at the same time, complementary to problems arising from the aircraft's needs for a more rapid rate of refuelling.

Aviation fuel systems in carriers tended to :—

(*a*) Become complicated in detail due to :—

(i) Safety requirements
(ii) Lessons learnt from experience
(iii) Changes in Staff requirements

(*b*) Present a large maintenance problem.

A programme of improvements to these systems has been undertaken, and it is the purpose of this article to explain the trend of thought in the development of aviation fuel systems in carriers.

WORLD WAR II

The systems fitted in the carriers of World War II were divided into two categories : air blown systems and water-displaced drum stowages.

Air Blown Systems

Petrol was carried in a number of cylindrical drum tanks surrounded by water (FIG. 1). Air, at 50 lb/sq. in. displaced the petrol from these drums through risers to a ring main in the hangar. From this ring main leads were taken to both hangar and flight deck fuelling points.

The ring main was a dual purpose system used for both fuelling and defuelling. An air driven reciprocating pump was fitted in each control room, taking a suction from the mains and discharging to the drum tanks for defuelling aircraft and draining the systems.

The disadvantages of this system were :—

(i) Fuel was likely to be contaminated since it was fed through a bottom suction
(ii) The amount of fuel carried was limited
(iii) Fuelling and defuelling could not be carried out simultaneously
(iv) Avgas vapour was present under pressure
(v) The fuelling system was contaminated when fuel was embarked into the ship as there was no separate filling line fitted.

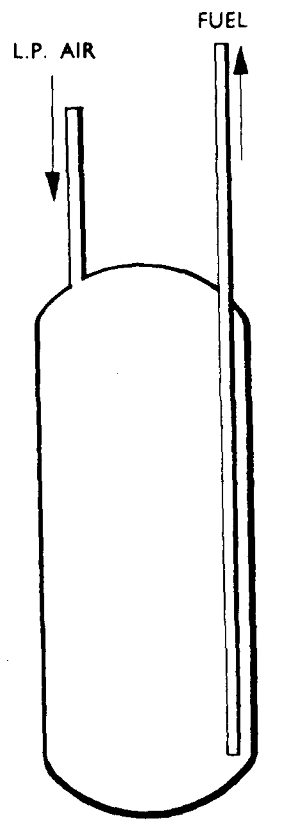

FIG. 1—THE AIR-BLOWN SYSTEM

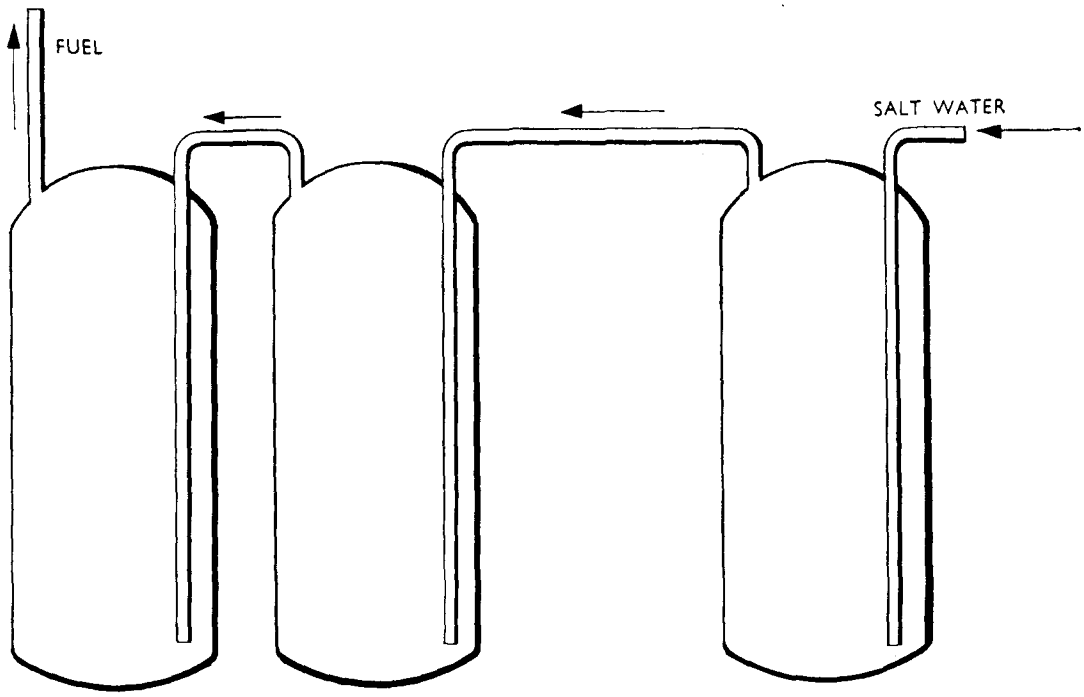

FIG. 2—WATER-DISPLACED DRUM STOWAGES

Water Displaced Drum Stowages

In this system the drum tanks in any one stowage were connected in series, and water was pumped into the tanks by air driven pumps, the fuel being displaced from tank to tank by the water (FIG. 2).

While this system eliminated the risk of contamination due to bottom suctions and the hazard of having Avgas vapour under pressure, the other disadvantages of the air blown systems remained.

In both systems the only filtering media were coarse gauze strainers and chamois leathers.

POST WAR CARRIERS

Design Requirements

Protected Stowages

The increasing demand to carry larger quantities of Avgas in carriers resulted in the adoption of the American water-displaced or ' protected ' stowage.

This type of stowage consists of a small ' draw-off ' tank fitted inside a ' main ' tank which is surrounded by a ' saddle ' tank. The whole is surrounded by a cofferdam (FIG. 3).

Sea water is admitted to the saddle tank, and the fuel is displaced by a siphoning pipe to the main tank. From the main tank the fuel is led, via a second siphoning pipe, to a draw-off tank and thence to the fuelling pumps.

Increased fuelling rates are given by using either turbo or motor driven fuelling pumps. Dual ring mains fitted in the hangars provide simultaneous fuelling and defuelling, the latter being carried out by a combined drain and air pump which maintains a high vacuum in the defuelling mains.

Consideration was given to ' inerting ' the cofferdam for reasons of safety. It is the American practice to do this and also to jacket the pipe systems with an inerted space. It was decided not to adopt this procedure, and the cofferdams were fitted with continuous ventilation.

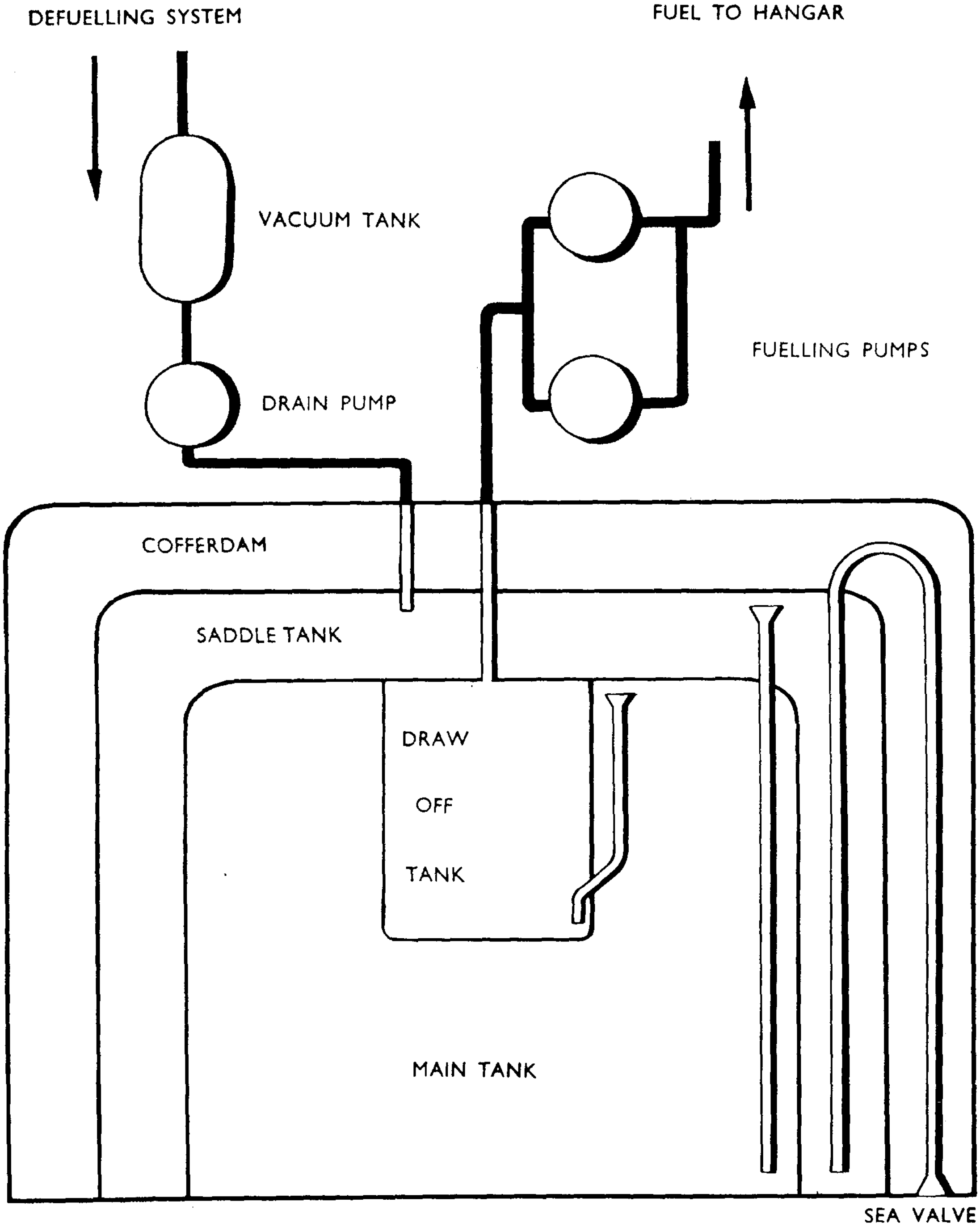

FIG. 3—PROTECTED STOWAGE

Filtration

The degree of filtration required for the new aircraft was much higher than with previous systems. A maximum dirt particle size of $2\frac{1}{2}$ microns (1 micron = 1 millionth of a metre) was stated to be the largest acceptable particle size, and at the same time there was a need to ensure that the fuel contained no free water whatsoever.

Sintered bronze filters were adopted and fitted to all fuelling points, each filter being fitted with a float operated shut-off valve for use in the event of water passing in any quantity into the system.

Pressure Refuelling

With aircraft carrying ever increasing quantities of fuel there came a need to refuel the aircraft under pressure. An international standard was agreed upon which requires fuel to be delivered to the aircraft coupling at a pressure of 50 lb/sq. in. plus or minus 5 lb/sq. in. at all rates of flow up to the maximum for which the aircraft is designed. There is also a requirement for surge pressures to be limited :—

(i) By the aircraft's fuelling system being designed to limit surge pressures to 75 lb/sq. in.

(ii) If (i) is not possible, by the refuelling system control valve limiting surge pressures to 120 lb/sq. in.

To meet these requirements a pressure control valve of the restrictor type was designed and which included a sensing device in the form of a venturi to allow for pressure drops occurring in the valves, hose reels and hoses so that a steady pressure of 50 lb/sq. in. could be maintained at the hose outlet.

Hoses and Hose Reels

Larger fuelling rates at higher pressures required larger hoses. To facilitate stowage of the hoses, hose reels were designed in which the fuel passed through the hub of the reel to the hose. The requirement, with Avgas, for the ability to rapidly defuel the aircraft, required a hose of rigid structure. There was also a requirement for the hose to be flexible at a temperature of minus 26 degrees C.

The Arrival of Jet Fuels

The introduction of jet aircraft called for a new fuel. A fuel of high flash point which could be safely carried in ordinary hull type tanks was required.

There was considerable discussion given to the jet fuel to be used in the Navy. Avtur, generally in use with shore based aircraft, had a flash point considered too low for safe storage in unprotected tanks (110 degrees F.). Consideration was given to blending fuel as has been the American practice, Avgas and a wide cut fuel being passed through a machine designed to give the correct proportions of the two fuels at any selected ratio. It was finally decided that naval aircraft should operate on Avcat alone. (Flash point 140 degrees F.). The quantity required to be carried in the ship was limited. A simple pumping system was provided to supply a few fuelling positions in the hangars and on the flight deck.

A change in policy required an increased quantity of Avcat (and a corresponding reduction of Avgas) and for Avcat to have the same degree of dirt filtration and freedom from water as Avgas ; Avcat also was required to be supplied for pressure refuelling.

Accordingly some protected stowages were turned over to Avcat, the ring mains in the hangars were isolated and the Avgas pumping arrangements used for Avcat. The original Avcat pumping systems were altered to become an Avcat transfer system, transferring fuel from the hull tanks to the protected stowages.

Problems Arising in the Use of Avcat

It became evident that whereas water will readily separate from Avgas, it will not separate easily from Avcat. As an indication of the difficulty in separating water from Avcat under gravity settling, the following figures show

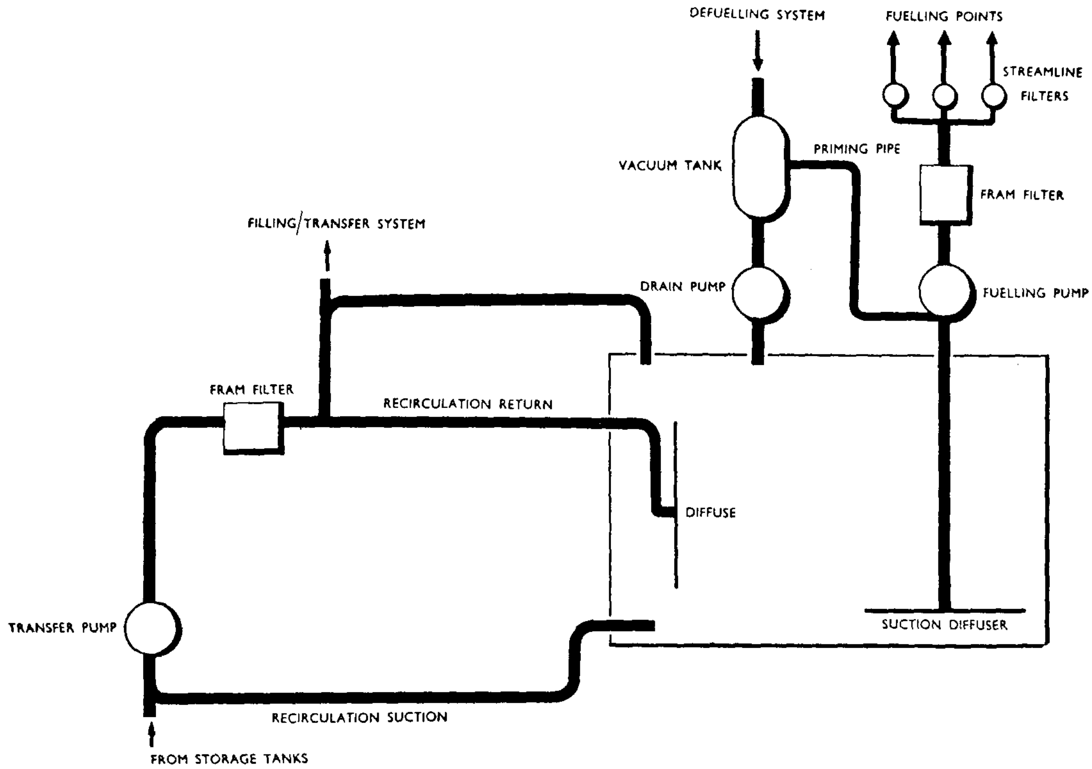

FIG. 4—AVCAT SERVICE TANK

the time required for a water droplet of a given size to settle through 1 foot depth of fuel :—

30	micron droplet	—	1 hour
20	,, ,,	—	4 hours
10	,, ,,	—	2 days
2	,, ,,	—	8 days

It became apparent that the ability of Avcat to hold water in suspension for long periods accelerated the rusting of steel, and that the tanctectol protective paint used in the stowage was attacked by the fuel.

The fuel reaching the sintered bronze filter packs therefore contained water droplets, grease (from valves), rust and tanctectol. The filters choked rapidly. The effect of the filters choking was not only to reduce the fuelling rate, but the high pressure drop across the filtering media enabled water to be forced through. The filter packs proved very difficult to clean (in fact after each cleaning process only 60 per cent of the efficiency achieved at the last cleaning process could be attained) and a very large maintenance burden was placed upon the ships staffs.

As a stop-gap, small capacity Stream-line filters were supplied to ships, and the resulting reduction in fuelling rates had to be accepted. It was found that the packs in these Stream-line filters had to be changed very frequently, but the fuel delivered to the aircraft was acceptable.

Attack on Avcat Problems

The lines of attack in order of priority were adopted as follows :—

(*a*) To eliminate water displacement of Avcat

(*b*) To coat all Avcat tanks with a suitable high duty preservative (*c*) To press for supplies of fuel from tankers to be in as clean a state as possible

(*d*) To employ means of separating water from the fuel and to provide dirt filters.

Elimination of Water Displacement

While this was a reasonably straight forward proposition, the pumps fitted in the ships had been designed to operate with fuel supplied to them under the head of sea water. It was therefore necessary to design rapid priming arrangements. This was done by using orifice plates fitted in connections led to the air pump of the combined drain and air pump. Once the fuelling pumps were initially primed, arrangements were made for continuous priming to be supplied by means of the vacuum in the defuelling system, the air pump suctions being changed to this system after priming the fuelling pumps.

There was also a requirement to ensure that a pressure could not be exerted upon the stowages by over filling or by mal-operation. Suitable safety devices are used, depending upon individual ship installations, employing either a large bore overboard discharge or float operated shut-off valves.

There was a general opinion that the fuel in the stowage probably lay in three layers : a water bottom, a middle layer of water/fuel mixture and clean fuel. It was arranged, therefore, that fuelling pump suctions should be taken through a diffuser fitted 2 ft 6 in. from tank bottoms. This opinion has been substantiated by experience, and the height of suction selected has proved satisfactory.

It was considered necessary to be able to re-circulate the contents of the service tanks (ex-' protected ' stowages), to

(*a*) Clean the suspected fuel/water layer

(*b*) Clean the fuel if it was necessary to embark fuel directly into service tanks from a tanker

(*c*) Clean the fuel if filters fitted to transfer systems failed.

Use was made of the existing transfer system to re-circulate the service tanks, suction being taken from the tank bottoms, passed through filters and returned through a diffuser at a high level in the tank to prevent disturbance of the contaminated fuel at the lower levels (FIG. 4).

Sullage arrangements were also provided for the removal of free water.

Coating of Tanks

The Director of Naval Construction carried out an investigation into suitable high duty preservatives, and various ones have been employed including epikote and prodorfilm. The application of these coatings has presented many problems. The tanks have to be shot blasted to ensure cleanliness, removal of all rust, etc. ; a process made difficult by the shape and size of many of the ships tanks. Application of the coatings has to follow a certain procedure which is made more difficult by the toxic nature of the paints.

Supplies of Fuel from Tankers

The Director of Stores has arranged for the tanks of R.F.A.s to be coated with high duty coatings and is investigating the fitting of suitable filters and water separators.

Dirt Filtration and Water Separation

The removal of dirt from fuel is a mechanical process and provided that the filtering medium has sufficient strength to withstand pressure drops across it, a sufficient number of capillaries to prevent a high pressure drop occurring at high flow rates, pores of the right size and a complicated route within the capillaries, dirt particles will be stopped.

Water Separation

It is well to understand the ways in which water may get into the fuel. The chief ways are :—

(1) In the fuel supplied by the tanker

(2) Across the interface where water is present in tanks

(3) By mal-operation of the systems (i.e. flushing arrangements)

(4) By condensation from the atmosphere in tanks, pipes, etc.

Water may be present in the following forms :—

(i) In fairly large globules

(ii) As fine globules

(iii) As an emulsion.

Although not a method of water removal, every effort must be made in the first instance to prevent water from entering the fuel.

Thereafter the following methods of removing water are available (centrifuges not being practical owing to size) :—

(*a*) By Settling and Sullage—This is only effective for large globules and requires time.

(*b*) By Gauze Filters—These will remove globules of water—the size depending upon the mesh used, and until such time as the gauze becomes water ' wetted '.

(*c*) By Coalescing—In this method the fuel is constrained to pass through passages where the globules of water are forced together to make larger globules which are removed by settling or filtration.

(*d*) By passing the fuel through a screen impregnated with a water repellant, e.g. silicone (i.e. the screen is hydrophobic). This method is normally employed in conjunction with a coalescer.

(*e*) By Absorption—In this method specially prepared papers absorb the water as the fuel is passed through.

(*f*) By Porous Bronze Plates—These plates can remove water by the same mechanism as gauze filters. It is thought, however, that under certain conditions these plates may act as coalescers.

(*g*) ' Edgewise ' or between papers (' transmission ') by the same mechanism as gauze filters although down to a smaller globule size.

(*h*) By a combination of the above.

Mechanism by which Water may be Removed from Fuels

The exact mechanism by which fuel and water may be separated is not known, but it has been established that for a given method of removal the maximum pressure drop across the medium before water will be passed is a function of the difference between the surface tensions of the fuel and water.

For a water removing medium to function correctly it is therefore imperative that this maximum pressure drop, which varies for each particular fuel, is not exceeded. This problem may be made more difficult by the addition of such things as corrosion inhibitors or greases (as from lubricated valves) which have a saponifying effect resulting in a reduction of the difference in the surface tensions between water and fuel.

Choice of Filters

A very wide survey was made of filtering and coalescing methods and media available in Europe, the U.S.A. and Canada, before a choice was made of the filters which seemed most suitable for naval purposes. In deciding upon the filters to be used, the methods to be adopted within the ships for handling the fuel were first resolved.

It was agreed that fuel transferred from storage tanks to service tanks should pass through bulk filters/water separators, and that the contents of the service tanks should be re-circulated through similar filters/water separators. It was also agreed that all fuel passing to the ring mains should pass through bulk filters/water separators and that at each fuelling point there should be a final filter capable of removing any last traces of water.

It was therefore decided to employ the following :—

(*a*) *Fram Filter*. This filter has a coalescing stage and a rejection stage. Between the stages water is collected in a sump. If bulk water is presented to this filter or the critical pressure drop is exceeded water will pass but on the resumption of normal conditions, the filter regains its effectiveness. It is a dirt filter as well as a water separator.

(*b*) *Stream-line Filter*. This is the most effective filter available. It removes water by two methods :—

  (i) Edgewise on paper discs ; and

  (ii) By absorption in paper discs.

  It is the second method which makes the filter so effective as the absorption can wring out the last traces of water.

  This filter is essentially a dirt filter which will remove traces of water. It is not a water separator.

If a filter of the Stream-line type were used for bulk separation of water from fuel, when fully saturated with water, it would effectively shut off the entire system it is feeding. It was therefore decided to employ a Fram unit for this duty, knowing that under certain conditions water may be passed, but the system can still be used, the Stream-line filter giving full protection, and only shutting off a single fuelling point if saturated with water.

It becomes important, therefore, to record the pressure drops occurring across the filters so that their efficiency and future life may be estimated. A differential pressure gauge has therefore been developed for this purpose suitable for the high working pressures involved and able to stand full pressures on each leg separately.

The line of action in this problem may be summarized as :—

Fram Filters for transfer, re-circulation and supply of fuel to the ring mains

Stream-line Filters (of sufficient capacity) at the fuelling point.

To avoid contamination by condensation, pipe systems are left full on completion of fuelling operations.

The policy adopted by the Engineer-in-Chief towards this problem is that water and dirt are as much enemies to the pilot as guided weapons and that the cost of improvements are small when compared with the loss of an aircrew or aircraft.

FUELLING EQUIPMENT PROBLEMS IN AV FUEL SYSTEMS

While dealing with the fuel handling problems, it became evident that other problems affecting fuelling equipment were arising. These were :—

(*a*) The pressure control valves were erratic in operation and the design was such that a failure in any part caused the valve to remain open.

(*b*) The spring-loaded relief valves fitted downstream of the control valves were subject to variations in the conditions of the defuelling system to which they exhausted (atmospheric pressure to a vacuum of 20 inches). Also it seemed that a spring-loaded valve protected the system in which it was fitted but did not effectively safeguard the aircraft at the end of the system.

(*c*) Hoses suffered from damage due to aircraft and flight deck transport running over them. They also suffered from plasticizer extraction; the plasticizer being necessary to afford flexibility in the hose under very low temperature conditions. They were also heavy to handle.

(*d*) The hose reels provided a heavy maintenance load and were very difficult to service. The fuel-tight gland made them difficult to operate.

(*e*) The depth gauges hitherto employed in water-displaced stowages were unsatisfactory, and it was most difficult to record the amount of fuel in these stowages.

(*f*) There was a possible danger from the methods employed for embarkation and transfer of fuel (e.g. 'overshot' filling) and of static electricity causing an explosion.

(*g*) There was a very different opinion between each carrier on the disposition of fuelling points in the ships. The advent of the angled flight deck drastically altered earlier trends of thought.

Action taken to Overcome Equipment Problems

In attacking these problems the first requirement was to gain a little time in hand so that equipment could be properly tested before being introduced into the Fleet. Secondly, it was necessary that any such tests should be realistic.

(*a*) There are two types of pressure control valves which can meet the requirements of pressure refuelling :—

(i) By-pass

(ii) Restrictor.

With the by-pass type of control valve, excess fuel is returned to pump suction. With an airfield refuelling tanker this is comparatively simple, and this type of valve affords good control characteristics. However, in a carrier system, where a large number of fuelling points are fitted, it is not feasible to do this without an overflow return system (the defuelling system could not be used as it would not then be available for defuelling).

The restrictor type valve affords the best solution for Carrier use. Accordingly a number from those commercially available were purchased and trials arranged ashore on an actual aircraft refuelling rig ; further trials at sea being conducted so that endurance to service conditions could be evaluated. Experience with the original design of valve showed that the gum content of the fuel

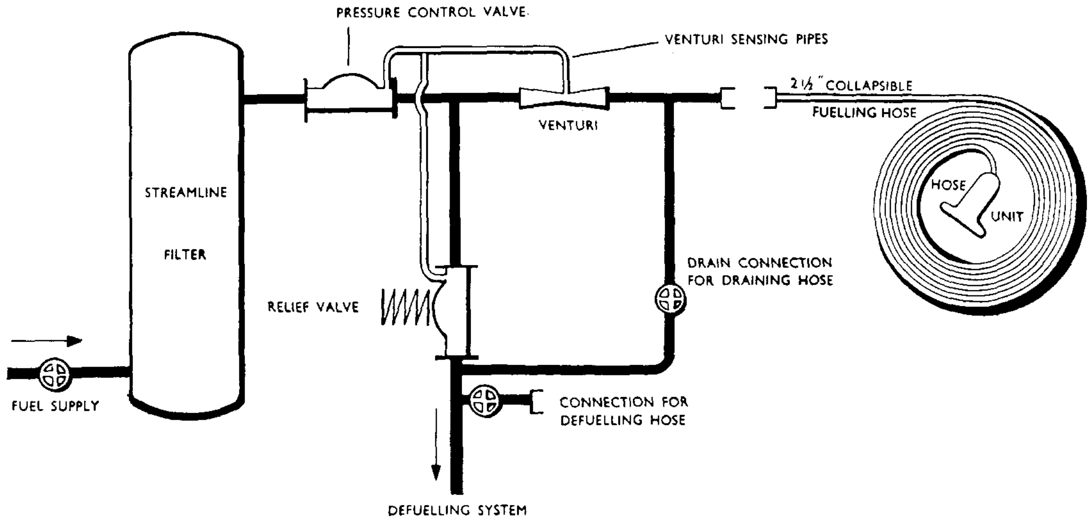

FIG. 5—FUELLING STATION LAYOUT

could affect the working of a valve designed with close clearances. The requirements that were called for, in addition to control characteristics, included freedom from erratic control caused by the gum content, the ability of the valve to fail ' safe ' (i.e. shut) should any part of the valve fail, and for surge pressures to be limited. With regards to the latter quality, E.-in-C. called for a design which would limit surge pressure to 75 lb/sq. in. A venturi is fitted to each valve to compensate for pressure drops occurring down stream of the controller.

Trials, both ashore and at sea, have allowed a reasonable assessment to be made of the valve most suited to naval requirements, and action has been taken accordingly to replace existing valves with the new type.

(*b*) The relief valve presented an interesting problem. It was necessary, owing to the varying conditions in the defuelling system, to employ a balanced valve. It was therefore decided to employ a valve which essentially is a by-pass controller. This valve is sensed from the same venturi that controls the control valve so that very good safeguards for the aircraft are provided. In the event of a failure of the control valve, excess pressure will be relieved to the defuelling system and it is possible to continue fuelling using the relief valve as a by-pass controller. Although this may appear as a contradiction of earlier remarks on by-pass controllers, it is reasonable to assume that controller failures will be isolated instances.

(*c*) With the change in balance of fuels, it was agreed that the requirement to be able to defuel jet aircraft at a rapid rate was not required. The defuelling of jet aircraft becomes mainly a maintenance requirement. It was therefore possible to consider using a collapsible hose for fuelling. A few selected fuelling points were chosen for defuelling purposes and separate $1\frac{1}{2}$ in. diameter hoses will be provided for this purpose. The new hose is lighter to handle (particularly in a high wind on a flight deck), is not liable to damage from flight deck transport, etc., and affords simpler stowage. There was now no need for the hose reel to be part of the pipe system ; this allows a simpler system involving smaller pressure drops.

In addition, a relaxation in the requirements for cold weather operation allows a reduction in plasticizer required in the hose construction reducing the troubles of plasticizer extraction.

(*d*) The new collapsible hose allowed a completely new conception of a hose reel to be adopted. The new reel was divorced from the pipe system. With a collapsible hose it could be much smaller and lighter. A design was therefore produced which allowed the hose to be reeled on from the hose outlet end ; the reel also provided stowage for the hose end units required to couple hose to aircraft for pressure refuelling. (When a collapsible hose is used, it is necessary to unreel its complete length.)

(*e*) Further consideration of the problem of measuring the contents of a tank under varying head of sea water allowed a simple differential gauge to be evolved which will be fitted externally to the tanks to afford easy maintenance.

(*f*) A considerable survey has been made into the dangers of static electricity, and no final decision has yet been reached upon this subject, so far as Avcat is concerned.

(*g*) An Av fuel working party was set up to select positions in ships at which fuelling points should be fitted. A standard policy has now been adopted which is related to the requirements of the new aircraft coming into service. In general there is a reduction in the number of points fitted, and the positions are chosen in relation to the operation of the angled deck.

GENERAL

Av Fuel News Letters

In order to keep ships' officers, staffs and Admiralty departments aware of developments and trends of thought and to explain to ships why action was being taken to alter their systems at short notice (there not being time to inform them officially), an Av fuel News Letter has been originated. It is stressed in these letters that the experience and ideas of those at sea are required to assist H.Q. staff in selecting the best equipment, and to make alterations where necessary. This two-way interchange of information has proved successful.

Filtration Standards

The standard of filtration of fuel now adopted is slightly less stringent than that required originally but agrees with international agreements. The fuel must be free of all traces of free water, and the filters are required to remove 95 per cent of solid contaminations with a size distribution of 1–5 microns, the effluent containing not more than 1 milligram per litre of solid particles.

Detection of Water

The detection of very small quantities of free water can only be done by a laboratory process, but a ready-use detector is being introduced into service which will detect, at its lowest point of sensitivity, 20–25 parts per million of water. This is a degree of contamination not visible to the naked eye. Research into continuous reading detectors of an even more sensitive nature is being carried out.

Simplification of Systems

To simplify operation, maintenance and to reduce risks due to mal-operation, the systems (particularly Avgas systems) are being simplified as opportunities occur. At the same time the new filtration and water separation methods are being applied to the Avgas systems, although the troubles are not so acute. In the main, the Avgas systems are being designed for eventual incorporation into the Avcat systems.

Admiralty Standard leak-proof valves have been superseded by lubricated plug cocks, and new greases introduced which will not adversely affect the separation of water from the fuel.

CONCLUSION

A difficult period has been experienced. Initially, equipment was provided to face new and untried problems and at a time when it was thought that pressure refuelling of aircraft was imminent. Many lessons have been learnt, and incorporated in new design equipment. The future is looked forward to with confidence, and we feel able, with assurance, to advise our allies of our progress in this field. A great deal of co-operation has been received from many authorities and firms, not least from the Oil Companies.

It is the earnest hope of the E.-in-C.'s Department that one of the pilots' enemies has been beaten.