PART 1 : SECTION 6

CHAPTER 2

FUEL SYSTEMS AND THEIR MANAGEMENT

Introduction

1. This chapter deals with those parts of the fuel system peculiar to the airframe as opposed to engine fuel systems which are dealt with, for piston engines in Section 2, Chapter 3, and for turbo-jet engines in Section 3, Chapter 6. Early practice was to arrange the fuel system so that each tank fed direct to an engine through a tank selector cock and an engine master cock, but present practice is to feed an engine from one tank (or from a collector box) only and to feed fuel from the other tanks automatically into this one tank. The following paragraphs explain the purpose and function of the various components used in both piston and gas-turbine engine fuel systems.

Requirements of a Fuel System

2. Fuel systems are designed to :—

(*a*) Function in all attitudes, and at all temperatures and altitudes likely to be encountered in normal operation.

(*b*) Ensure that all the fuel is available to any engine or combination of engines, whether or not the other engines are running.

(*c*) Ensure that it is possible to fill all tanks quickly and completely.

(*d*) Make the vulnerability of the aircraft as low as possible.

3. **Autobalance.** The large quantities of fuel carried in some aircraft necessitate an automatic balancing system (autobalance) to control the fuel levels in the various tanks and keep the C.G. within its limits.

Fuel Tanks

4. Aircraft fuel tanks are of two general types ; those permanently installed, and auxiliary tanks which may be fitted internally or externally as required. Most permanent tanks were, until recently, generally metal or semi-rigid tanks mounted in the wings or fuselage and were protected against crash damage or fire by self-sealing coverings consisting of layers of rubber on the outside of the tank. Fuel from a punctured tank, on reaching the central layer, caused the rubber to swell until the hole was closed, and so stopped or reduced the leakage. However, because of the weight and thickness of rubber required to provide effective protection, self-sealing covers are not used on many later types of service aircraft.

5. **Integral Tanks.** When box-spar or D-spar construction is used in the wings these spars can be made fuel-tight and used as integral tanks.

6. **Bag Type Tanks.** Light-weight crash-proof bag tanks are in common use. These consist of a thin rubber bag housed in a smooth-sided compartment in the wings or fuselage. This type of tank depends for its crash resistance on the resilience of the bag, which behaves like the bladder of a football when subjected to external loads.

7. **Auxiliary Tanks.** These may be fitted to most types of aircraft and include fixed tanks, usually carried internally, and drop-tanks which may be dropped after use. It is unusual to provide any form of crash or self-sealing protection for auxiliary tanks, and their construction depends largely on their estimated expectation of life. Those carried in bomb-bays are usually of a light alloy, but tanks carried externally may be made of mild steel, plywood, reinforced paper or plastic, as they are intended to be jettisoned before combat. Usually the drop-tanks transfer fuel to one of the permanent tanks rather than direct to an engine. The fuel in this permanent tank should be used for the first stage of a flight so as to empty the drop-tanks as soon as possible. Drop-tanks may be released manually, electrically, or by means of explosive bolts.

Venting

8. An air vent is fitted to the top of each tank so that air can enter as fuel is used ; the vent is also used to regulate the pressure within the tank when pressurization is used to prevent fuel boiling and/or for transfer purposes. Pressurized tanks are fitted with a pressure relief valve incorporating a small spring-loaded suction relief valve. This admits air into the tank if the pressurizing system fails, thus preventing the formation of a vacuum and the possible collapse of the tank with use of fuel, or on descent.

9. Some aircraft do not use pressurization to counter fuel boiling or for fuel transfer purposes. In this case tanks are usually vented on the under surface of the wing or behind the rear spar, preferably in a region of constant static or, if possible, positive pressure. In one particular system a selector valve is used so that when the ventral tank is not in use it is vented to atmosphere, while the remaining tanks are pressurized ; when the ventral tank is in use it is pressurized, and the remaining tanks are vented to atmosphere.

Fuel Contents Gauges

10. Fuel contents gauges are, with few exceptions, electrically operated and can be calibrated to indicate either in terms of gallons remaining or in pounds (lb.) remaining. For various reasons, *e.g.* the shape of the tanks, contents gauges may not give accurate indications of small quantities of fuel. Gauges are calibrated to give a correct indication when the aircraft is in the flying attitude, and on some older systems a second scale for use in the tail-down attitude is provided.

11. Contents gauges give the pilot a continuous reading of the fuel state. The principle of operation of the most common system is based on the dielectric values of air and fuel. Each tank unit consists of two concentric tubes which serve as a variable condenser ; the capacitance varies as the fuel level rises and falls and this measurement is transmitted to the gauge. A variant consists of small condensers on flexible straps, fitted into pockets in the tank, which operate the gauges through amplifier units. Changes in aircraft attitude have little effect on the indications given by these two systems, which do not incorporate a float and have no moving parts. In addition to calibration errors, small errors can arise from the fact that the gauges are not compensated for changes in fuel temperature.

12. Early forms of electrical fuel gauges are calibrated to a formula which, when using fuels other than the standard calibrating fuel, can lead to the gauge over-reading by as much as 18%.

13. Later gauges are calibrated to an improved formula which reduces the extent of all previous errors by about 50%. These gauges can be identified by the fact that they indicate their contents in mass instead of gallon units. The earlier gauges are not to be re-calibrated and therefore are always subject to their original errors.

14. It is emphasized that all gauges operate on the same principle, but the smaller errors of the mass unit gauges are the result of an improved calibration formula which allows for a variable factor (density) which was not previously taken into consideration.

15. A system which makes use of a float, mechanically coupled through gearing to an electrical transmitter, is still in use in some aircraft.

Errors of Fuel Contents Gauges

16. Individual electrical fuel gauges are subject to *instrument and installation* errors to a varying degree ; these errors are virtually constant on any one gauge. However, the *calibration error* may vary widely ; the cause and extent of calibration error are discussed in the following paragraphs. Fuel gauges are calibrated to read accurately only when a certain specified fuel is used. The use of another fuel may lead to errors in which the gauge can over-read by as much as 18%. Since the extent of the error, due to inconsistencies in the electrical conducting property of the fuel, varies with the chemical composition and density of the fuel and also depends on the calibration formula used, a simplified explanation of the source of the errors is given.

17. For the electrical measurement of fuel contents, two characteristics of the fuel are made use of. These are the *permittivity* (the specific inductance capacity) and the *density*, which are defined as follows :—

(*a*) *Permittivity* (*K*). This is the ratio of the capacity of a given condenser, using a given conducting medium (dielectric), to the capacity of the same condenser using air or a vacuum as the dielectric.

(*b*) *Density* (*D*). This is the mass of the fuel per unit volume at the prevailing temperature. Temperature affects the density ; if two similar fuels are compared at different temperatures, then for a constant mass (quantity of matter) the cooler fuel has a smaller volume and hence it has a greater mass per unit volume, *i.e.* the density is higher.

18. Although no definite relationship exists between the permittivity and density of a fuel, it can be assumed that an increase in D usually results in an increase in K. The rate of increase of K with D varies according to the fuel specification, *i.e.* the rates of increase for AVTUR, AVTAG and AVGAS are not the same.

Volumetric Contents Gauges

19. All volumetric fuel gauges assume a constant value of K and make no allowance for variations in density ; the gauges are calibrated from the expression K−1. While the principal fuels for gas-turbine and piston-engine aircraft were AVTUR and AVGAS respectively, the errors arising from this method of calibration were small, since the values of K and D for each fuel are virtually constant. With AVTAG fuels, however, the gauges of gas-turbine aircraft may have appreciable errors because of the wider permittivity range resulting from the varying density of this fuel. The occasional use of AVGAS which is mixed with the AVTUR or AVTAG in the tanks causes further changes in the permittivity.

20. The higher the permittivity of a fuel the greater will be the tendency for the gauge to over-read. A gauge which is calibrated for a permittivity of 2·1 has a calibration index of :

$$K-1$$
$$\text{or } 2{\cdot}1-1=1{\cdot}1$$

If a fuel having a permittivity of 2·3 (D=·85) is measured by the same gauge, the calibration error is about :

$$\left(\frac{2{\cdot}3-1}{2{\cdot}1-1}\times 100\right)-100\,\%$$
$$=\left(\frac{1{\cdot}3}{1{\cdot}1}\times 100\right)-100\,\%$$
$$=\quad 18\,\%$$

The gauge would therefore over-read by 18%.

Mass Unit Gauges

21. Mass unit gauges indicate the quantity of fuel remaining in terms of pounds (lb.) and have smaller errors than the volumetric type since they are calibrated to allow for density as well as permittivity. This type of gauge is calibrated to the expression K−1/D and since K, as stated earlier, usually increases with D, the resultant error is reduced.

22. Mass unit gauges are calibrated for the following fuel values :—

(*a*) Gas-Turbine Engines K=2·1 D=·779

(*b*) Piston Engines K=1·95 D=·701

These are mean values for the respective fuel groups. Taking the same figures as used in the example of para. 20 for a volumetric gauge calibrated from the early formula, it can be seen that the order of the error is considerably smaller. If the gauge is calibrated using the index $\frac{K-1}{D}$ and a fuel of 2·1 permittivity, then :

$$\frac{K-1}{D}=\frac{2{\cdot}1-1}{{\cdot}779}-1{\cdot}412$$

If a fuel of 2·3 permittivity and a density of ·85 is measured by the same gauge, the error becomes roughly :

$$\frac{\frac{2{\cdot}3-1}{{\cdot}85}}{1{\cdot}412}\times 100-100\%=108-100\%=+8\%$$

The gauge therefore over-reads by 8%.

23. It can be seen that by altering the method used for calibrating the gauge the error, for the same fuel in each case, is reduced from +18% to +8%.

Summary of Errors in Fuel Gauges

24. When using different fuel specifications, the average errors introduced into the gauge readings are as follows. Positive errors indicate an over-reading gauge and negative errors indicate under-reading.

FUEL	VOLUME MEASURED		MASS MEASURED	
	PISTON	TURBINE	PISTON	TURBINE
AVTUR/ AVTAG	—	− 7% to + 7%	—	− 5% to + 3%
AVCAT (Naval gas-turbine a/c)	—	0 to + 12%	—	0 to + 6%
AVGAS ...	− 6% to + 6%	0 to − 17%	0 to + 6%	0 to − 6%

Recommendations when Using Fuel Gauge Indications

25. Since it is not possible to give a simple method of assessing fuel gauge errors without an accurate knowledge of both the permittivity and density of the fuel *in the aircraft tanks*, it is recommended that all flight planning should take place on the assumption that the gauges, irrespective of type, will tend to over-read in *gas-turbine aircraft* using fuel in the AVTUR/ AVTAG range and under-read on the few occasions when AVGAS is used. In *piston-engined aircraft* it should be assumed that they will tend to over-read. In conclusion it is pointed out that although the mass unit gauge does not give an accurate reading, the errors are *about half those of the volumetric contents gauges.*

Flowmeters

26. Flowmeters are used to measure the total amount of fuel delivered to the engine. Basically they consist of a transmitter (some form of electronic device in later types) and an indicator. The transmitter measures the quantity of fuel passing through a chamber or passage, and transmits an electrical signal to the indicator via, in later types, the electronic device.

27. The indicator shows the rate of flow in lb. per minute, and the total weight of fuel consumed in lb. Early indicators show gallons consumed. The indicator should be reset to zero before flight.

28. Flowmeters in service aircraft may be divided into two main types : those sensitive to fuel specific gravity (gravimetric types), and those sensitive to fuel volume (volumetric types). The gravimetric instrument gives a true indication (within limits) of the actual weight of fuel passed, whereas the volumetric type, although indicating in terms of weight, is only accurate when used with fuel of the specific gravity for which it is calibrated ; usually a mean S.G. 0·78 is assumed. When used with fuel of S.G. 0·75 or 0·81 (extremes of the AVTAG/AVTUR range) it has an indication error of about $\pm$ 5% of true.

29. The gravimetric flowmeter will eventually replace the volumetric type in all aircraft. As an interim measure a manual setting device for fuel specific gravity changes can be used with volumetric flowmeters.

30. Flowmeters incorporate an automatic bypass to ensure that, if the instrument fails, the supply of fuel to the engine is not affected. In early types the bypass operates only in an electrical failure, and therefore, to guard against mechanical failure of the flowmeter at a vital moment, the bypass is controlled electrically by a switch. The switch should be off during take-off to bypass the flowmeter. Booster pumps of the tanks in use should normally be switched on to ensure accuracy of the flowmeters.

Fuel Cocks

31. There are six main types of fuel cocks :—

(*a*) *Engine Master Cocks.* These are used to isolate each engine from the main fuel supply and are found on both piston- and gas-turbine engines. When used on gas-turbine engines the cock carries out the same function as the L.P. cocks (sub-para. (*e*)).

(*b*) *Cross-Feed Cocks.* This cock is most commonly used on piston-engined aircraft The cock which controls the fuel transfer between the separate tanks for the inner- and outer-engine fuel systems in the port wing is known as the *port cross-feed cock.* Similarly the cock which controls the fuel between the inner- and outer-engine fuel systems in the starboard wing is known as the *starboard cross-feed cock.* The cock controlling the transfer of fuel from one wing to the other is known as the *centre cross-feed cock.* Use of a cross-feed cock therefore enables any one, or a group of engines, to be fed from any one or a group of tanks.

(*c*) *Tank Cocks or Selector Cocks.* These enable any one of two or more tanks to be selected and are common to both jet- and piston-engined aircraft.

(*d*) *Balance Cocks.* Used to balance the levels of fuel in different tanks, these may be encountered in jet- and piston-engined aircraft.

(*e*) *Low-Pressure Cocks.* In gas-turbine fuel systems the pilot-controlled cocks installed between the fuel tanks and the H.P. pumps are known as low-pressure (L.P.) cocks or engine master cocks. The L.P. cocks in some installations are interconnected with a refuelling cock.

(*f*) *High-Pressure Cocks.* There is a high-pressure (H.P.) cock on every gas turbine, which controls the supply of high-pressure fuel from the high-pressure pumps to the engine. On some American aircraft, movement of the throttle rearwards through a gated position is used instead of a separate H.P. cock.

32. Fuel cocks are either manually or electrically operated. Manually controlled cocks are generally operated by means of tele-flex controls, or by some form of cable and mechanical linkage. Fuel systems used in later aircraft are complex and the fuel cocks are often located some distance from the cockpit ; to eliminate long mechanical linkages the cocks are electrically controlled. In some aircraft, when the electrically controlled L.P. cocks are switched on, a micro-switch operates at the same time and automatically switches on the appropriate booster pump.

Booster Pumps, Transfer Pumps, and Transfer Systems

33. Fuel booster pumps may be electrically or air operated and are standard on most aircraft.

In some older aircraft they are fitted externally in the pipe leading from a tank or group of tanks, but in modern aircraft they are always of the immersed type fitted within a tank at its outlet.

34. A bypass permits fuel to flow from the tank, by gravity or by suction from the engine-driven pump, when the booster pump is not running.

35. The purpose of booster pumps is to keep the pressure in the fuel lines above atmospheric pressure, thus preventing vapour (or air) locks from forming, and to ensure a steady fuel supply to the engine-driven pumps during take-off, landing, at high power settings, and at high altitudes. Unless otherwise recommended in Pilots' Notes they can be left on at all times in flight.

36. Booster pumps cannot be relied on to maintain sufficient pressure for the correct functioning of piston-engine carburettors or injectors, or gas-turbine engines, after failure of the main engine-driven pump. (In early piston engines fitted with a float-type carburettor the booster pump could supply fuel at sufficient pressure to keep the engine running at low power.)

37. Booster pumps should not normally be left on when the engine is stopped unless recommended in Pilots' Notes. On piston engines if the fuel cut-off is not closed, use of the booster pumps in some systems may cause flooding of the supercharger casing. In gas turbines if the L.P. or H.P. cocks are not closed immediately after a faulty start, the burner chambers may be flooded and in both types of engine there is a risk of fire during a subsequent start. As booster pumps are fuel-cooled they should not be left running for long periods when the fuel tanks are empty.

38. **Transfer Pumps.** Booster pumps can be used as transfer pumps to pump fuel from one tank to another or to a collector box which feeds the engine direct. A test ammeter socket is fitted in each booster or transfer pump circuit to check the pump.

39. The immersed pumps used in some fuel auto-balance systems are of a variable speed type and are usually automatically controlled, except for take-off when they are set by the pilot to give maximum output.

Water and Fuel Drains

40. Water drains are provided in the tank sumps. Drains are also provided around tank fillers so that spilt fuel or water can drain to atmosphere.

Filters

41. To prevent any solid matter in the fuel from reaching and obstructing the carburettor jets of piston engines, filters are fitted close to the carburettor inlet at each engine and in addition a coarse strainer is fitted at each tank outlet. In gas-turbine engines high-pressure and low-pressure filters are installed in their respective pipelines.

Fuel Flow under Negative *g* Conditions

42. On gas-turbine aircraft that are cleared for aerobatics the fuel system permits up to 15 seconds' inverted flight at high power without risk of fuel starvation. This period should never be exceeded in any condition of inverted flight, as in addition to the risk of flame extinction the lubrication system is adversely affected. In certain instances, fuel systems suitable for prolonged inverted flight are fitted to piston engines.

43. Under negative *g* conditions, on some gas-turbine aircraft the collector box of the fuel system is designed to maintain the fuel flow for a limited time. When negative *g* is imposed, gravity-operated clack valves close the tank vents and seal off a reservoir of several gallons, sufficient for about 15 seconds' inverted flight. It should be noted that when the total fuel contents are low, the negative *g* traps may not be full, thus reducing the period of negative *g* under power.
Fig. 1 shows the operation of a typical system used on Meteor aircraft.

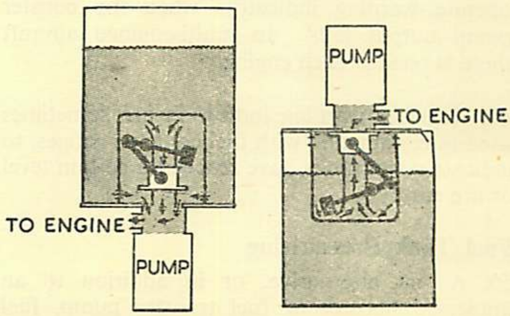

Fig. 1.
Typical Arrangement for Fuel Flow under Negative *g* Conditions.

44. Where collector boxes are not used, the inverted flight installation is sometimes fitted in individual tanks. When this is done, each tank booster pump is fitted in a negative *g* fuel trap containing several gallons of fuel.

45. **Recuperators.** On some systems a *recuperator* is used to ensure a fuel flow under negative *g* conditions. A recuperator is an integral part of the main tank and contains air at a slightly lower pressure than the booster pump pressure. In normal flight, fuel is forced by the booster pump into the recuperator so that several gallons are stored by the booster pump pressure opposing the lower air pressure. When the aircraft is inverted the booster pumps are no longer immersed, so that the air pressure in the recuperator forces the trapped fuel into the fuel lines. On resuming a normal attitude the booster pump pressure again restores the level of fuel in the recuperator and seals it off ready for the next period of negative *g*. Provision is made for topping up the supply of compressed air in the recuperator.

46. A further method of ensuring a fuel flow during inverted flight is to fit two immersed fuel pumps in the main tank, one for normal flight and the other for inverted flight.

47. It can be seen from the few examples briefly described above that there are many methods of obtaining a fuel flow under negative *g*. Pilots' Notes describe the system used on each type of aircraft in which inverted flight is allowed.

Fuel Pressure Warning and Fuel Transfer Indicators

48. Fuel pressure warning devices are fitted in the low-pressure portion of gas-turbine fuel systems, usually at the low-pressure filter, and operate warning indicators when the booster pump output falls. In multi-engined aircraft there is one for each engine.

49. Transfer warning indicators are sometimes used in conjunction with fuel contents gauges, to indicate when tanks have reached a certain level or are empty .

Fuel Tank Pressurizing

50. As an alternative, or in addition to an immersed booster or fuel transfer pump, fuel tanks (particularly drop-tanks) are frequently pressurized to force the fuel to the engines or to the main tank. Pressure from the exhaust side of a vacuum pump, or from the compressor of gas turbines, is fed into the top of the tank through the venting system which is fitted with a pressure relief valve. In some systems auxiliary tanks replenish the main tanks and are pressurized at all times, fuel being transferred automatically under the control of a float valve in each main tank whenever the contents of the main tank fall below a certain level.

51. In addition to the use of pressurization for fuel transfer purposes it has the following additional advantage. The boiling point of fuel is considerably lower than that of water, and, like all liquids, depends on the external pressure to which it is subjected and on its R.V.P. (see Chapter 5 of this section). If an aircraft is climbed rapidly to altitude, especially after standing in the sun for some hours, the fuel may boil violently causing a considerable loss through the tank vents and a build-up in internal tank pressure (AVGAS starts boiling at an air pressure of 7 lb./sq. in. and AVTUR at 0·25 lb./sq. in.). Under similar conditions the suction of the fuel pumps causes boiling of fuel in parts of the fuel system, causing a vapour lock which may cause complete or partial stoppage of the fuel flow. These difficulties can be overcome by :—

(*a*) Pressurizing the fuel tanks.

(*b*) Pre-cooling the fuel.

(*c*) Fitting fuel booster pumps in the bottom of the tanks to push fuel through the pipes, instead of sucking it through.

Aircraft with high cruising ceilings and fuel flows may need fuel pre-cooling and will have pressurized fuel systems. In very long-range high-altitude aircraft it is possible that towards the end of a long flight the fuel may need warming to restore its fluidity and speed of flow through the filters. This may be done by making use of thermostatically controlled filter units.

Use of Booster Pumps at High Altitudes

52. When an aircraft is climbed, an inherent feature of all fuels is the liberation of air from the fuel in the form of bubbles. Under extreme conditions the rapid release of air causes very turbulent conditions within the fuel tank, and apart from loss of fuel up the vent pipe the tank may be overstressed. All booster pumps are fitted with a de-aerator and, to prevent frothing of the fuel, booster pumps should be switched on in all tanks while climbing.

Fuel Auto-Balance Systems

53. In some aircraft the fuel levels in the various tanks are automatically balanced so that the

contents of the front and centre tank groups are kept in balance with those of the rear and wing tank groups to keep the C.G. within limits. In one system, balancing is done by a relay, working with the fuel contents amplifiers, which varies the booster pump r.p.m. and output. If the balancing system fails, balancing can be done by a switch which provides an alternative electrical supply to the booster pump speed relays. This switch has three positions and can be used to manually control the tank levels in conjunction with an indicator which shows whether the aircraft is nose or tail heavy.

54. In another system, delivery from each tank group is controlled by booster pumps assisted by air pressure, at a rate determined by the particular system. This system is, in effect, controlled by the fuel gauges. If one tank empties faster than at the designed rate, the booster pump output of that tank is reduced until the fuel levels are again approximately correct. If the system fails, the individual tank L.P. cocks can be used to control the fuel levels.

55. A further method takes the correct amount of fuel from each tank by means of a fuel flow proportioning device. This consists of a metering unit, similar to a spring-loaded vane type pump. Each fuel tank has its own metering unit, and all the metering units are carried side by side in what is termed a proportioner pack. There is a separate inlet from each tank to its metering unit, and a common outlet from the proportioner pack to the engine. The rate of flow from each metering unit is proportional to its tank capacity. Each unit is independent, but the vane assemblies are coupled together and are rotated by fuel passing through the unit. Since each unit delivers a fuel flow proportional to the capacity of its tank, and as the rotational speed is common, each metering device delivers the correct amount of fuel to the common delivery and maintains the tank levels so as not to displace the C.G. Where multi-tank systems are used in large aircraft, two or more packs may be necessary. More than one engine may be fed from the outlet of each proportioner pack. In certain installations, additional assemblies, in the form of electrical actuators and fuel valves, have been fitted to the basic mechanism to cater for pressure refuelling and defuelling requirements. An additional advantage of this auto-balance system is that, if a tank booster pump fails, the fuel in that tank is still drawn off proportionately by its metering unit.

Fuel Jettisoning

56. Fuel jettisoning equipment is installed in some aircraft to permit the safe and quick disposal of fuel from selected tanks to reduce the all-up weight if a landing is necessary at an early stage of the flight. Jettisoning fuel improves the chances of maintaining height after engine failure, reduces the landing speed, and the empty tanks provide a measure of buoyancy after ditching.

57. The equipment consists of tank jettison valves inter-connected to air vent valves, and if necessary a jettison pipe lowering mechanism. The large diameter jettison valves are fitted in the base of selected fuel tanks and are designed to open and close rapidly. The valves may be actuated mechanically, hydraulically, pneumatically, or electrically, from the main aircraft services, or from separate systems provided for this purpose.

58. The jettison valves, which are usually spring-loaded to the closed position, are positioned so that when jettisoning is completed slightly more than 1% of the total volume of fuel carried is left in the tank to prevent the formation of an explosive mixture.

59. Jettison pipes may be rigidly mounted or of the telescopic and hinged type and are inclined at an angle of 45° to 60° to the flight path.

60. **Operation.** When the fuel jettison control is operated the jettison pipes lower and then jettison valves and air vent valves open in the selected tanks to permit the fuel to flow out under gravity or assisted by air pressure. The rate of discharge depends on the head of fuel. Initially, when the tank is full, the rate is high but decreases as the fuel level falls. Fuel jettisoning can be stopped at any stage of the operation without affecting the fuel system.

61. **Fire Risk.** All jettison valves should be closed before landing. Apart from the normal electrostatic charge absorbed when flying through hail, rain, or charged dust, additional electrostatic charges of a similar nature may be induced by fuel jettisoning. This charge is normally discharged on touch-down, and therefore it is essential that no fine spray or vapour envelops the aircraft on touch-down.

Use of Nitrogen

62. In some aircraft the air space above the fuel in each tank is filled with nitrogen to prevent explosions resulting from enemy action. A supply of nitrogen at high pressure is piped to reducing valves from which it is delivered to the fuel vent system at low pressure. Nitrogen flows into the tanks as fuel is consumed, taking the place of air which would form an explosive mixture. When this system is fitted, the nitrogen main supply master cock should be turned fully on before starting the engine. When the nitrogen is used to pressurize the fuel tanks an alternative air system is provided. This air system is brought into use automatically when the nitrogen system is not in use, or when the nitrogen pressure in the tanks falls below a certain figure.

Pressure Refuelling and Defuelling

63. Pressure refuelling is a method of filling aircraft fuel tanks from an external pumping unit which delivers fuel under pressure to one or more connections on the aircraft, from which the fuel flows via a refuelling system to the fuel tanks.

64. Pressure defuelling is a method of emptying the tanks, through a defuelling system, to one or more connections on the aircraft and then via a pipeline to an external pumping unit, which imposes a suction at the connection. On some aircraft the same connection can be used for both refuelling and defuelling.

65. Pressure refuelling and defuelling is now a requirement on all types of aircraft, except for training, certain light communication, and other aircraft on which concessions to the requirement have been granted. All pressure refuelling systems are capable of withstanding the refuelling pressure of 50 lb./sq. in.

66. These requirements are met in most instances by the provision of :—

(*a*) Pressure refuelling couplings readily accessible from the ground.

(*b*) Automatically operated shut-off valves in each tank, which stop the flow when the tank is full.

(*c*) Fuel delivery galleries capable of passing the required volume of fuel and withstanding the refuelling pressure.

67. **Defuelling.** In some aircraft the complete system, or selected tanks in the system, can be defuelled through the pressure fuelling couplings. By setting the appropriate fuel cocks, tanks may be defuelled :—

(*a*) By gravity. (The flow will fall as the head of fuel decreases.)

(*b*) By suction from the tanker.

(*c*) Under certain conditions by means of the booster pumps.

These methods may be used singly or together, depending on the system, and in some instances can defuel at rates up to 75 gallons per minute.

Flight Refuelling—Probe and Drogue System

68. Flight refuelling can be arranged for virtually all types of aircraft, with no limitations other than a maximum height of 35,000 feet and a maximum I.A.S. of 300 knots. The basic system consists of one or more refuelling probes on the receiver aircraft and a cone-shaped drogue on the end of the hose trailing from the tanker aircraft. The probes on the receiver aircraft may be on the nose, attached to the wings, or on individual auxiliary tanks. At night, the interior of the cone-shaped drogue is illuminated to make it visible to the pilot of the receiving aircraft.

69. The probe and drogue system is quick, extremely simple, and allows a high rate of fuel transfer. The pilot guides the probe into the drogue. The fuel valve in the probe nozzle opens when contact is made and closes when contact is broken. When contact is made with the coupling in the drogue, the probe nozzle is automatically gripped by spring-loaded toggles which are sufficiently powerful to make a fuel-tight joint, but permit an automatic breakaway when the separating force reaches a set figure. The hose drum unit in the tanker aircraft is so arranged that, when the probe enters the drogue and overcomes part of the drogue drag, the hose drum starts to wind in the hose. This give-and-take action continues throughout the refuelling operation, allowing the refuelling aircraft a certain latitude of movement and maintaining a tight hose from start to finish.

70. After the hose from the tanker aircraft is fully trailed and the tanker is ready for the operation, an amber light on the tanker glows to tell the receiver pilot that he can start refuelling. The receiving aircraft should close in with a final overtaking speed of about five knots, the probe should be aligned with the drogue and contact made. After engagement, speed should be reduced to formate with the tanker, during which time up to 20 feet of hose may have been

wound in. The main fuel cock in the transfer system is opened automatically when about five feet of hose have been rewound, and the amber light is replaced by a green light which indicates that fuel is under pressure. If the hydraulically operated Mk. 7 probe nozzle is used, the receiver pilot then opens the nozzle to start the transfer of the fuel. Rates of flow are generally between 200 and 500 gallons per minute, depending on the type of aircraft being refuelled.

71. Refuelling may be stopped at any time in any of the following ways :—

(*a*) By the formating aircraft falling back and extending the hose to the position at which the tanker main cock is closed, with or without actual breakaway.

(*b*) By means of automatic shut-off valves when all tanks are full, as indicated by lights in the cockpit of the receiving aircraft.

(*c*) By automatic shut-off in the tanker after a set quantity of fuel has passed through the meter.

(*d*) By release of the fuel valve button in the receiving aircraft.

When transfer is complete the refuelled aircraft should decrease speed slightly, when the hose will extend to its full length, automatically closing the main cock, and changing the lights from green to amber. When the critical tension is reached, the drogue toggles release the nozzle and separation will be complete.

GENERAL RECOMMENDATIONS FOR THE MANAGEMENT OF FUEL SYSTEMS

Piston-Engined Aircraft

72. Pilots' Notes detail the exact management of the fuel system. In systems in which an engine is supplied from a single main tank there is little to do except check that the main cock is on, that the booster pump is on when required, and to keep a watch on the contents gauges and the flowmeter, if fitted. Replenishment of the main tank from auxiliary or drop-tanks is either automatic or effected by turning on air pressure or switching on the transfer pumps as required. In the latter case, care is necessary to ensure that the main tank is not over-filled unless float valves, which automatically prevent this, are fitted.

73. In other systems, where a number of tanks may be used to supply an engine direct, avoid changing over to a fresh tank while at high power, in combat conditions, at low altitude, or when about to land. The change-over should preferably be made before the tank in use empties, or, if maximum range or endurance are required, immediately the fuel pressure warning indicator flickers, *i.e.* a tank should not be run dry. The fresh tank should first be selected together with its booster pump, then the fuel cock and booster pump of the empty tank should be turned off. This is important, particularly with pressurized tanks, to prevent an engine cutting owing to air or fuel vapour locks. If a piston engine cuts when a tank empties, the throttle should be closed to prevent overspeeding when the engine picks up on the fuel in the new tank. After the change-over has been made, the engine should be idled until it is running smoothly and then opened up slowly. With some injectors, if difficulty is experienced in getting the engine to pick up, the cut-off should be put in the off position for a few seconds to build up pressure.

74. The contents of auxiliary, and particularly drop-tanks, should be used as early in the flight as possible. This avoids loss of fuel if conditions later necessitate drop-tanks being released, and also improves manœuvrability and trim where such tanks are remote from the C.G. of the aircraft.

Use of Centre Cross-Feed Cocks

75. Centre cross-feed cocks should only be opened in the following circumstances :—

(*a*) After engine failure, to enable the fuel which would normally be available to the failed engine to be used by the remaining live engines.

(*b*) To enable fuel from the tanks in one wing to be used to supply all engines, if all fuel is lost from the other wing tanks.

76. The following example which assumes that a port engine of a four-engined aircraft has failed, and the starboard engines are to be supplied with fuel from the port wing tanks only, illustrates the correct use of the centre cross-feed cock :—

(*a*) Turn off the engine master fuel cock of the failed port engine.

(*b*) Select the required port tanks.

(*c*) Open the centre cross-feed cock.

(*d*) Turn off the fuel cocks on all other tanks. When the fuel level in the selected port tanks has fallen to a minimum (and preferably before the engines cut through fuel starvation) the action to be taken depends on whether or not fuel is completely exhausted from the port wing. If there is still fuel available in the port wing, proceed as follows :—

(*e*) Turn on the fuel cocks of the tanks to be used next.

(*f*) Turn off the fuel cocks of the tanks in use. If, however, fuel is exhausted from the port wing proceed as follows :—

(*g*) Turn on the fuel cocks of the tanks in the starboard wing.

(*h*) Turn off the fuel cocks of the port tanks.

77. Using the same example, to enable the fuel from the tanks in the port wing to be used to supply all engines following complete exhaustion or loss of fuel from the other wing, proceed as follows :—

(*a*) Select the required tanks in the port wing.

(*b*) Open the centre cross-feed cock.

(*c*) Turn off the fuel cocks of all other tanks. When the level in the tanks in use has fallen to a minimum, and preferably before the engine cuts through lack of fuel :—

(*d*) Turn on the fuel cocks of the tanks to be used next.

(*e*) Turn off the fuel cocks of the tanks in use.

78. If for any reason, when all engines are running, one set of wing tanks is emptied before the other, open the centre cross-feed cock at the first signs of fuel starvation, or earlier, and turn off the cocks of the empty tanks. In systems not using booster pumps the fuel cocks of the tanks which are running dry should be turned off *before* the centre cross-feed cock is opened to prevent the possibility of air being drawn through the empty tanks to the live engines and thus causing engine failure due to air locks.

Gas-Turbine Aircraft

79. Many gas-turbine aircraft have completely automatic systems, although automatic fuel balance control with a standby manual control system is also used. The L.P. cocks are not used in flight except in certain emergencies. Details of operating the system are given in Pilots' Notes for the type. Details of the management of fuel systems not in the above two categories are also given in Pilots' Notes for the type.

80. When ventral, and/or a combination of pylon and wing-tip tanks are carried, the transfer of fuel to the main tank is automatically made by air pressure, the transfer starting when the level in the main tank has fallen by a set amount. The transfer is controlled by shut-off valves in the tanks being supplied. Sometimes indicators are provided to show when the transfer ceases, but if indicators are not provided reference to the gauge of the tank to which the transfer is being made gives an indication—the gauge showing a steady fall after transfer ceases. If no indicators are fitted and if the main tank level continues to fall after levelling off and reducing power after the climb, it can be assumed that the transfer system is not functioning. This is because the main tank fuel level may fall during the climb, even when transfer is in progress, because while the engine is at high power it is taking fuel from the main tank at a greater rate than the transfer system can transfer the fuel from the other tanks.