CHAPTER 1

AIRCRAFT FUEL SYSTEMS

Objectives

1. In compiling the material for this Chapter due consideration has been given to the relevant Skill and Knowledge Specifications (SAKS) for the trade of Aircraft Technician (Propulsion). Therefore, this Chapter covers the SAKS requirements in the following subject areas:

- Open orifice fuel systems.
- Pressure refuelled fuel systems.

Introduction

2. Sections 1 and 2 of this book contain information concerning the fuel systems of piston and gas turbine engines, but details were not included to explain how the fuel supply was carried in the aircraft or to indicate what problems are encountered.

3. Logically, an aircraft must be able to carry sufficient fuel to enable the engines to work over long periods. In this instance, a liquid fuel is carried and the fuel is converted into propulsive force by the aero-engine. The aircraft side of a fuel system, which we shall now consider, consists of storage tanks, vent system, piping, filters, flow controls, valves and contents gauges.

The Purpose of a Fuel System

4. The fuel system of an aircraft must be able to carry sufficient fuel to enable the aircraft to fulfil its operational role, and a small safety reserve of fuel must remain after the aircraft has completed its task and landed. Another important feature of the fuel system is its ability to provide the aero engine with an adequate supply of fuel under all the conditions met in flight when an aircraft is operated to the limit of its design capabilities.

Types of Aircraft Fuel Systems

5. There are two basic types of fuel systems used in military aircraft.

- The open orifice fuel system.
- The pressurized fuel system.

Each of these fuel systems follows a logical pattern where a component is fitted only because of a specific need and the number of parts is thus kept to the minimum consistent with the proper function of the fuel system.

The Open Orifice Fuel System

6. The open orifice fuel system (sometimes called 'open vent or overwing') is the original fuel system fitted to early aircraft and it is filled from a trigger-operated nozzle similar in principle to the nozzle used to fill the fuel tank of a motor vehicle. Hinged panels in the top surface of the aircraft wing provide access to the tank filler caps and this is why these systems are sometimes called 'overwing refuelled' systems. Such systems are now restricted to aircraft in the following categories:

- Elementary training aircraft (such as the Bulldog).

- Small advanced training aircraft (less than 10 000lb all up weight (AUW)).
- Light communications aircraft.
- AOP aircraft (less than 10 000lb AUW).

Note. Provision may be made for emergency open orifice refuelling of more advanced operational aircraft. Details of such systems are included in the aircraft Air Publications (*see* preparation for flight for type information).

7. There are two basic open orifice fuel systems:
   - The gravity feed fuel system (now rarely used).
   - The pump fed fuel system.

8. **Gravity feed fuel system.** Early piston engined aircraft used a gravity feed fuel system similar in principle to the fuel system of a motor cycle (Fig 6.1.1).

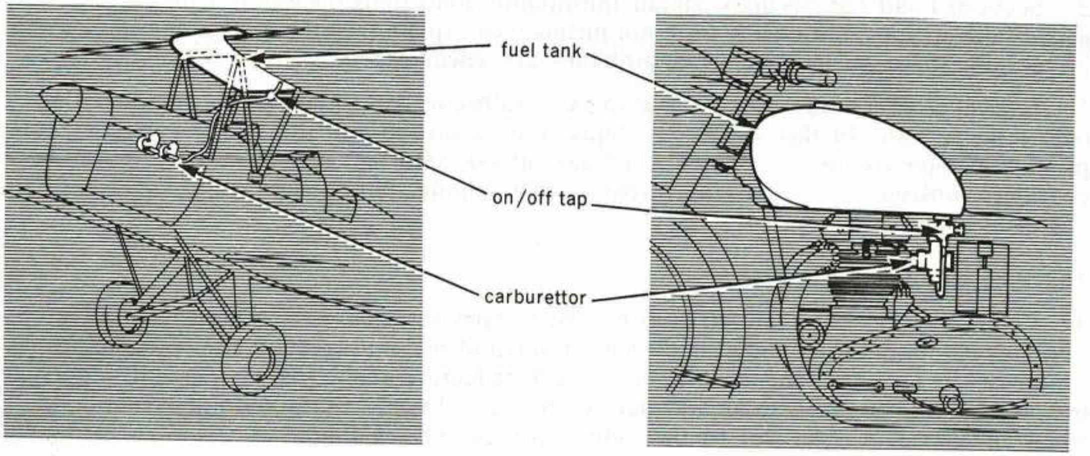

Fig 6.1.1. A gravity feed fuel system

9. In a gravity feed fuel system the fuel tank is situated above the level of the engine so that the weight of the fuel causes the fuel to flow to the engine. In such a system, an ON/OFF tap must be fitted near the fuel outlet from the tank and a gauze filter is fitted near the fuel inlet to the carburettor. The fuel tap (more often called a fuel cock) is a fitting which is essential to prevent excessive spillage of fuel during system servicing, when system components are removed, and in case of a fractured fuel pipe. The fuel filter is intended to prevent particles of foreign matter from reaching the jets in the carburettor. However, the amount of protection which the filter can give is limited by the gravity feed requirement — *ie* the filter must allow a free flow of fuel at low pressure differentials.

The shape, size, and position of a gravity feed fuel tank will normally limit the amount of fuel which can be carried. Therefore, to increase the operational range of an aircraft, additional fuel tanks may need to be fitted in the aircraft wings and fuselage. The wing and fuselage tanks are often below the level of the carburettor and gravity feed is no longer possible.

10. **Pump feed fuel systems.** In a multi-tank open orifice fuel system, where the tanks are well below the level of the engine, low pressure fuel pumps are used to feed the fuel to the engine where an engine driven pump (EDP) increases the fuel pressure to the correct value for supplying the engine. In the simple two tank system shown in Fig 6.1.2, each tank has a low pressure fuel pump which is operated by electricity. In the supply line from each tank is a non-return valve (NRV) that is fitted to prevent fuel from one tank feeding into the other and, although in twin engined aircraft, each tank normally feeds the engine on the same side of the aircraft, a 'cross feed' line is fitted between the two fuel supply lines to make all the fuel available for either engine.

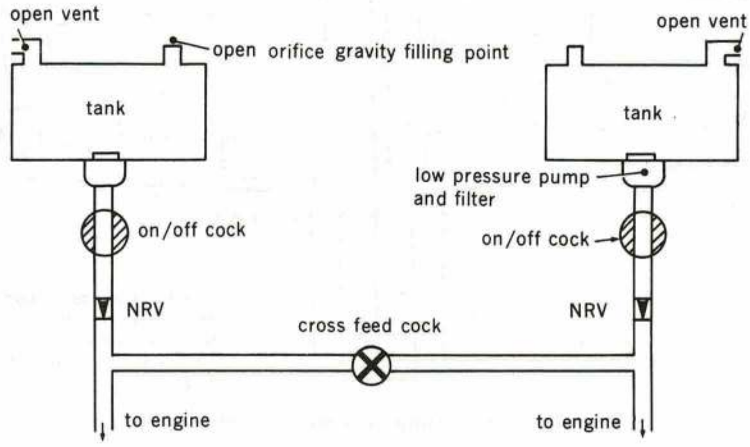

Fig 6.1.2. Pump feed fuel system

11. Multi-tank fuel systems can use a low pressure fuel booster pump for each tank, or the tanks can feed into a collector tank and a booster pump can be used to pump the fuel from the collector tank to the engine(s) (Fig 6.1.3). Any number of fuel tanks can be used so that all

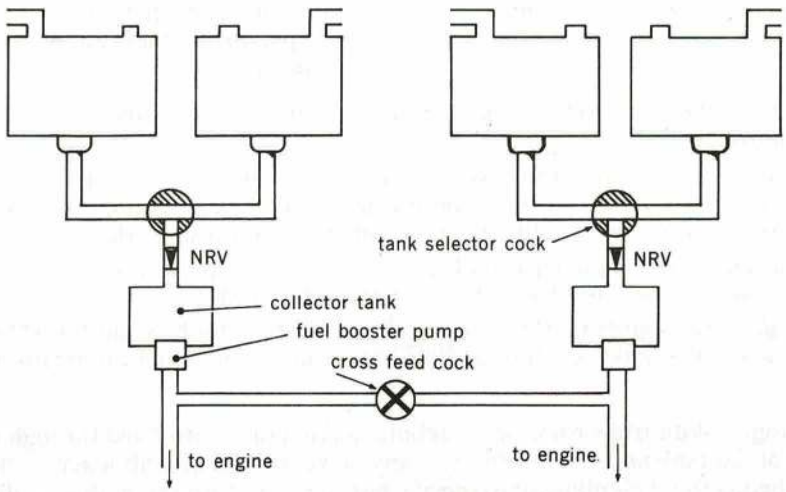

Fig 6.1.3 Use of a collector tank

suitable space is used to advantage and, when several fuel tanks are used on each side of the aircraft, the tanks are usually fitted in groups with each group serving its own collector tank. Such fuel systems require cross feed and fuel transfer facilities so that all the fuel is available for use by any combination of engines. The fuel tanks should be numbered in the sequence shown in Fig 6.1.4.

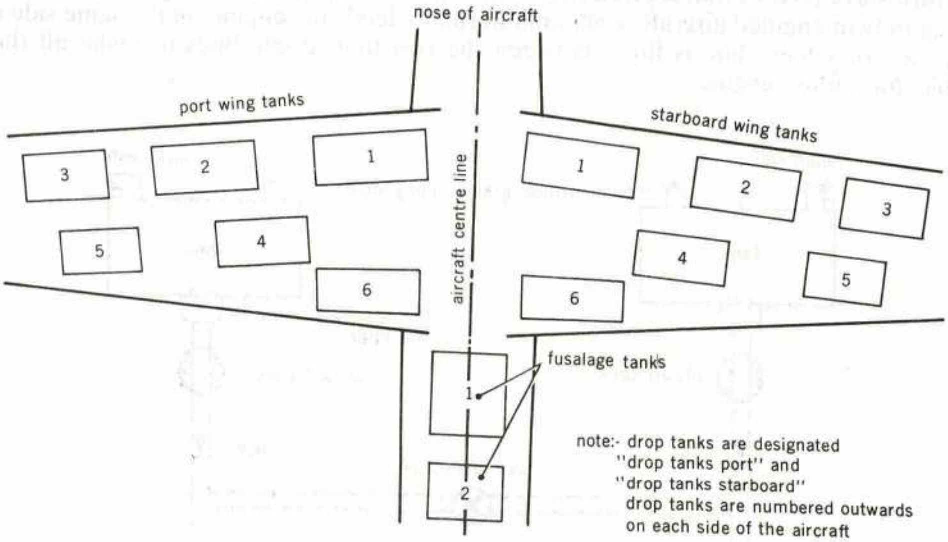

Fig 6.1.4. Numbering sequence for fuel tanks

12. **Open venting.** Sometimes aircraft fuel systems are vented direct to atmosphere with nothing to prevent fuel from passing through the vents: such fuel systems are referred to as 'open vent' systems. Thus, we find that any of the following terms apply to a single type of fuel system:

- Open orifice fuel system
- Overwing refuelled system

} Terms indicating that the tanks are filled by use of a trigger nozzle hose

- Open vented fuel system. — This will be an open orifice system (but not all open orifice fuel systems are open vented).

13. In practice, the basic open orifice system is not entirely satisfactory because of the following features:

- **Open vents.** There are times in flight when the force of gravity will act upon an aircraft in the direction opposite from normal. This is called a negative 'g' condition — *ie* the aircraft is inverted. In negative 'g' conditions, fuel will be lost through the open vents.
- **Fuel starvation.** Unless the basic fuel system is modified, the aero-engine will be starved of fuel in negative 'g' conditions and it will hesitate or stop.
- **Fuel boiling.** When an aircraft climbs rapidly to a high altitude, conditions may arise which cause the fuel in the tanks to vaporize (boil) and considerable fuel can be lost through open vents.
- **Replenishing.** With trigger nozzle refuelling the fuel tanks are filled through a filler orifice in the top of the tank and, therefore, it is only on very small aircraft where refuelling can be accomplished without climbing onto the aircraft. For small aircraft with a small fuel capacity of 20 to 40 imperial gallons the time factor may be reasonable but, for large aircraft carrying

between 3000 and 4000 imperial gallons, the time spent in refuelling is considered to be unacceptable and this is why open orifice fuel systems are limited to the aircraft listed in para 6.

14. The foregoing information indicates that there are a number of logical steps which can be taken to improve the basic open orifice fuel system to make it more suited for aircraft use. Although open orifice fuel systems remain in use they have, in many instances, been improved to:

- Prevent fuel from spilling overboard during negative 'g' conditions.
- Ensure a fuel feed to the engine for brief periods of negative 'g'
- Prevent fuel loss through fuel boiling at altitude.

15. To prevent loss of fuel through open vents, a vent valve can be fitted which allows free inwards or outwards air venting without allowing any fuel to spill to atmosphere. To ensure a supply of fuel for the engine in negative 'g' conditions, an anti-'g' trap or a fuel accumulator is fitted and either of these devices give a limited fuel supply to the engine sufficient to keep it running for a few seconds under negative 'g' conditions. To prevent the fuel from boiling at altitudes, valves are fitted to maintain the pressure in the fuel tanks above ambient atmospheric pressure at altitude.

Bulldog T Mk 1 Fuel System

16. Not all modern 'open orifice' fuel systems are proofed against the effects of negative 'g', and the fuel system fitted to the Bulldog trainer aircraft is a basic fuel system without refinements (Fig 6.1.5).

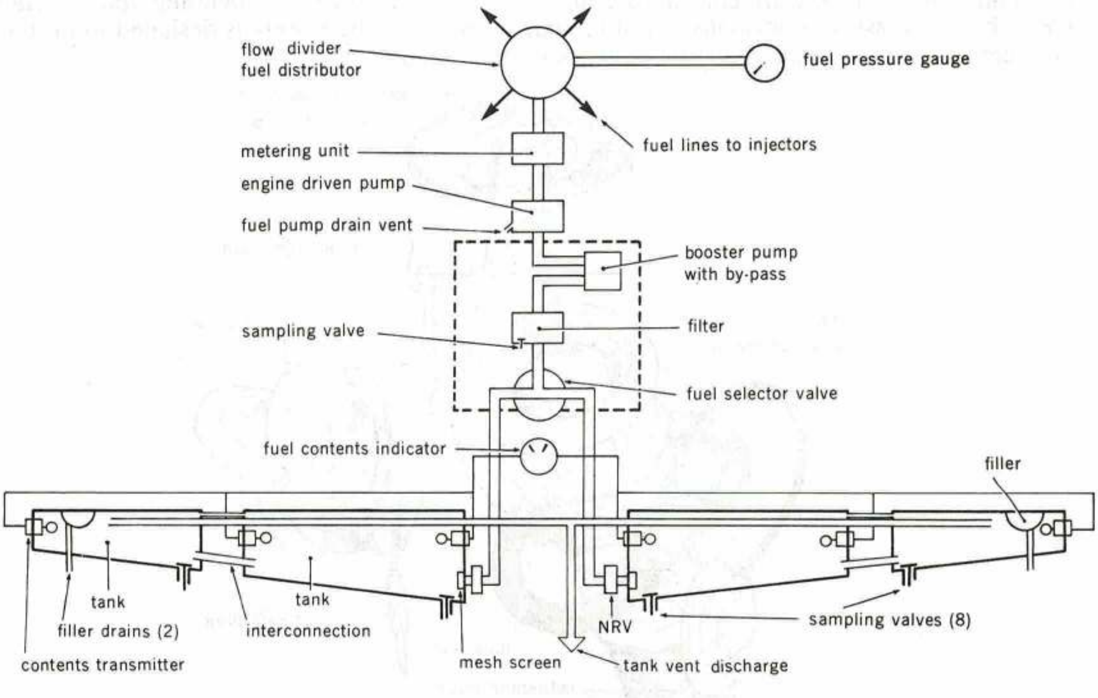

Fig 6.1.5 Bulldog T.Mk1 fuel system

17. The Bulldog fuel system has four fuel tanks — two in each mainplane. Each pair of tanks is interconnected so that there are only two filling points, one in each mainplane. Each pair of tanks holds 16½ imperial gallons of fuel to give the aircraft a total fuel capacity of 33 gallons (with 32 gallons of usable fuel). The system is fuelled through a filler orifice in each outer tank and fuel automatically fills the inner tanks through the interconnections between outer and inner tank. The feed to the engine is from the inner tanks and through non-return valves (NRV). After passing through the NRV the fuel enters a combined ON/OFF and tank selector cock before passing through a fuel filter and entering the inlet side of the fuel booster pump. Fuel from the booster pump is fed, at low pressure, to the inlet side of the engine driven fuel pump (EDP) which supplies the fuel injection system of the engine. The fuel tanks are vented to atmosphere through a common open line vent and each tank is fitted with a float operated contents transmitter which is connected to a fuel contents gauge in the cockpit to indicate the amount of fuel remaining in the fuel system.

PRESSURE REFUELLED SYSTEMS

18. **Definition.** The term pressure refuelled system is used to differentiate between the open orifice, gravity filled, fuel system which is open vented and an all enclosed fuel system which is normally filled through a special connector (Fig 6.1.6) by fuel under pressure (although provision may be made for emergency gravity filling). In these systems, pressure air is fed to some of the fuel tanks above the fuel when the engine is running. Fuel systems which are designed for pressure refuelling (at a pump pressure 3.4 bar (50 psi)) are sometimes called pressurized fuel systems because air pressure is used for fuel transfer and fuel feed purposes. The air pressure above the fuel prevents the fuel from boiling at altitude and the number of fuel booster pumps can be reduced because the pressure air is also used for transferring fuel to the last tank(s) in the system where fuel booster pumps are fitted. This does not mean that the fuel tanks and fuel lines are constantly subjected to high pressures. Depending upon aircraft type, the air pressure is normally about 0.4 bar (6 psi), and the system is designed to protect the fuel tanks from excessive pressure above this value

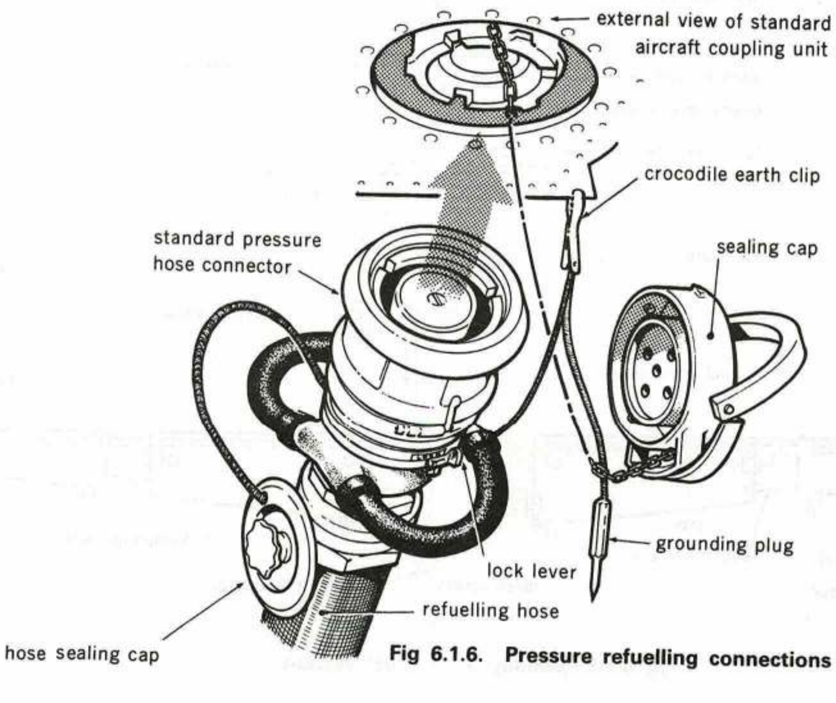

Fig 6.1.6. Pressure refuelling connections

19. **Design considerations.** With regard to such basic necessities as fuel capacity, fuel feed to the engines, normal tank venting and cross feeding, the pressure refuelled system must meet requirements similar to those of the open orifice fuel system. In addition, the pressure refuelled system will:

- Provide one or two refuelling points which are easily reached by a person standing on the ground.
- Prevent damage to the fuel system when the delivery line pressure is 3.4 bar (50 psi).
- Enable the aircraft tanks to be filled within a design target time.

20. **Filling with correct grade fuel.** Pressure refuelling systems are used for turbine-engined aircraft only. The aircraft tanks are replenished through a special connector and all refuellers with pressure hoses to match the aircraft connector should contain aviation turbine fuel. However, not all turbine-engined aircraft are pressure refuelled and some early turbine-engined aircraft (*ie* Canberra and Jet Provost) remain in service with open orifice fuel systems. Therefore, the type of refuelling hose must not be taken as a proof of the type of fuel in the bowser. A pressure refueller will contain aviation turbine fuel (AVTUR), but the trigger nozzle refueller may be filled with aviation gasoline (AVG AS) or turbine fuel. The only sure way of using the right fuel is to match the aircraft fuel markings with the markings on the bowser. Open line refuelling points on flying training aircraft are marked as shown in Fig 6.1.7.

21. **Reasons for pressurizing a fuel system.** Gas turbine-engined aircraft have their fuel system pressurized for the following reasons:

- To provide a means of transferring fuel between tank groups without using pumps.
- To transfer fuel from the fuel tanks in sequence into a single collector tank.
- To maintain a pressure above the fuel in the tanks and thus prevent the formation of fuel vapour as the tanks empty.
- To prevent the fuel from boiling because of the rapid drop in atmospheric pressure and temperature experienced in a high rate climb to altitude.
- Maintain the shape of flexible tanks as the fuel is used up.

22. **Fuel tankage general.** The fuel tanks may be either of flexible or rigid construction and both types of tank may be used in the same aircraft fuel system. Some aircraft designs include integral fuel tanks as a part of the aircraft structure and, in addition to

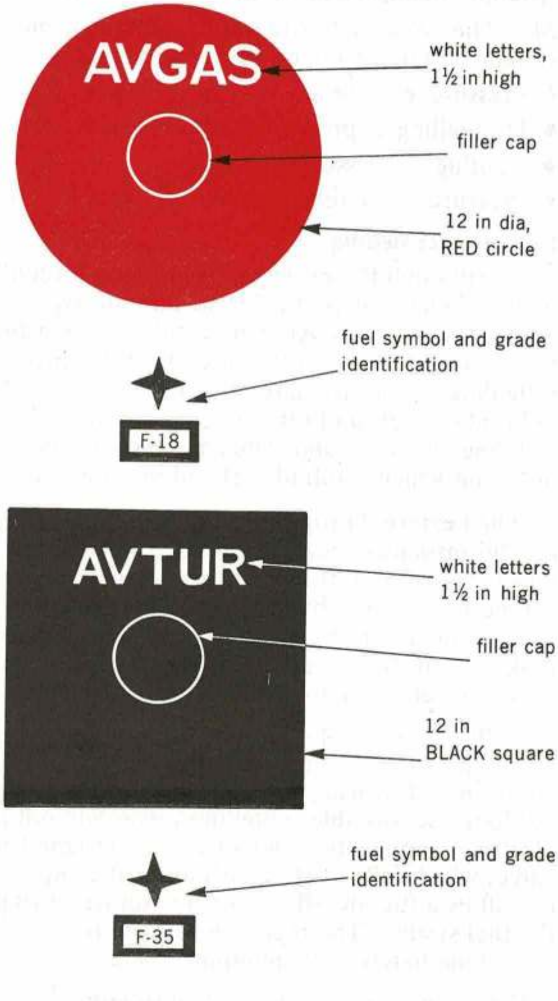

Fig 6.1.7 Examples of filler point markings

the internal tanks, externally carried fuel tanks may be fitted to many aircraft. External tanks are usually fitted at the wing tips, on pylons under the wings, or as a snug fit underneath the fuselage.

23. **Fuel flow.** Transfer of fuel from the external tanks is achieved by using pressure air taken from the compressor of the aero-engine. The pressure air is passed through a reducing valve and then fed into the external tanks above the fuel so that the pressure acts upon the fuel to push it inwards towards the internal part of the fuel system. Usually, fuel is fed to the engines from a centre fuselage tank that is constantly topped up — first from the external tanks and then from the internal wing tanks until the last of the fuel is contained in a centre fuselage tank. The actual fuel feed to the engine-driven fuel pump is by a fuel booster pump that is fitted in a collector tank which contains a negative 'g' trap. The negative 'g' trap ensures that fuel is supplied to the engine during brief negative 'g' conditions. Gauge probes are fitted in all tanks to monitor the weight of fuel remaining and flow meters are fitted to measure the rate at which the fuel is being consumed.

Ground Management of the Fuel System

24. The following paragraphs contain a more detailed explanation of a pressurized fuel system described under the headings of:

- Pressure refuelling.
- De-fuelling a pressurized fuel system.
- Venting a pressurized system.
- Pressurizing a fuel system.

Pressure Refuelling

25. Although the principle of pressure refuelling is the same for all aircraft, there are many details which are particular to aircraft type and, therefore, it is important to consult the appropriate aircraft Air Publication to learn the details of a *specific* fuel system. Generally, fuel is introduced into the aircraft tanks through the aircraft refuel/defuel coupling unit and refuelling valves. The aircraft coupling unit is a NATO approved connector which matches the international ground refuelling hose and is positioned within easy reach of an operator who is standing on the ground. The coupling must be easy to reach because the operator has to lift the hose unit which is full of fuel and the combined weight of both hose and fuel is considerable.

When external drop-tanks are fitted, they may fill with the main fuel system or they may, in certain instances, need to be filled through an open orifice gravity filler (one filler for each tank). Many aircraft, which are normally pressure refuelled, are designed so that the system can be replenished by gravity feed if pressure refuelling equipment is not available. Gravity filling is necessary to cover all possible operational situations although, on some aircraft, the tanks cannot be completely filled by gravity and, therefore, the range of the aircraft may be adversely affected by gravity refuelling.

26. Pressure refuelling is not just a matter of connecting the refuelling hose and proceeding to pump. The flow of fuel into the aircraft fuel system is through refuelling valves which are controlled electrically by float-operated switches or by manually-operated selector switches. Although serviceable refuelling valves will not permit a fuel flow unless they are receiving an electrical supply, the fuel system is designed to withstand the effects of a faulty refuelling valve, which fails to close, without suffering damage. In such circumstances, the vent system can allow a fuel overflow which is sufficient to prevent a great rise in the internal pressure of the fuel system. The fuel over-flowing from the vent exit is readily seen by the operator who will immediately stop pumping fuel.

For pressure refuelling the fuel system circuits should be live but, *no other electrical services should be in use.*

27. **Refuelling control panel.** Because pressure refuelling requires an electrical supply, controlling switches are needed to energize or isolate the refuelling circuits. On some early aircraft, the manually-operated switches, timing devices, and indicator lamps were fitted as individual items anywhere in the vicinity of the aircraft coupling unit but, in later designs, these items have been fitted on a conveniently placed panel so that they are grouped together close to the aircraft refuelling coupling (Fig 6.1.8).

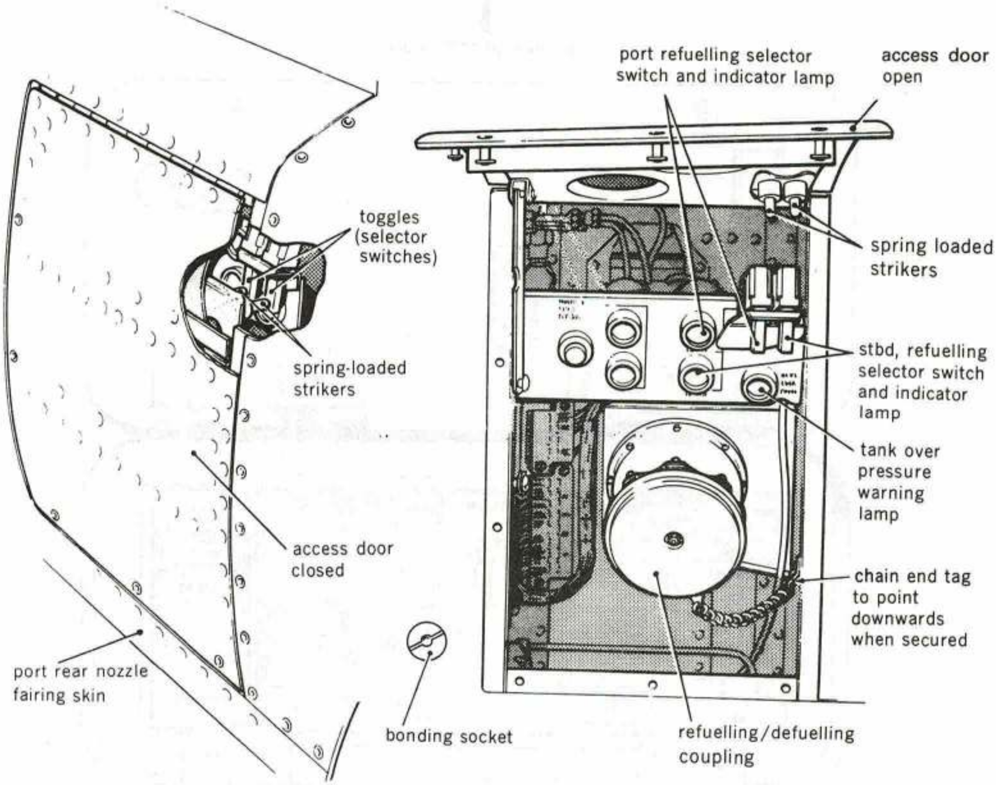

Fig 6.1.8 Refuel/defuel control panel

28. **Refuelling.** In final preparation for refuelling, the tanker is earthed and then bonded to the aircraft. The low pressure fuel cock is set to OFF, the refuelling hose is connected to the aircraft pressure coupling unit, and the selector switches are set to the ground refuel position. Moving the selector switches energizes the refuelling circuits so that the aircraft will accept fuel and pumping may begin. The 'tank full' indicator lights are controlled jointly by float switches and the refuelling selector switches. In the majority of fuel systems, the lights are on when the selector switches are on and the tanks are not full; the lights then go *out* as the float switches operate when the tanks are full. Unfortunately, this is not always true and, in some instances, the indicator light comes *on* when the tanks are full (check the aircraft AP). However, test buttons are fitted so that the lamps can be tested to ensure that they are serviceable and will light at the appropriate time. Regardless of lamp operation, the refuelling valves should automatically shut off the fuel flow as the tanks become full and the lights are an external indication of which tanks are full or otherwise.

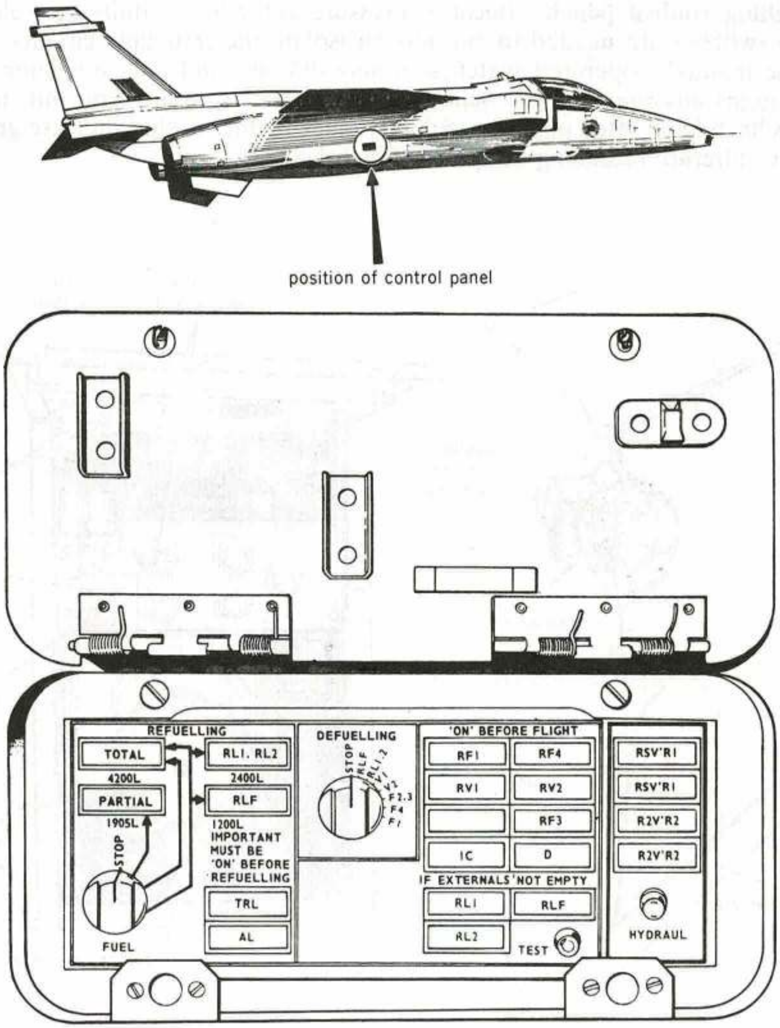

Fig 6.1.9 Refuelling panel with partial load selectors

29. **Partial fuel load.** Some aircraft fuel systems include partial load selectors which are mounted on the refuelling control panel (Fig 6.1.9). Where special selectors are not fitted, the partial fuel load must be obtained by use of the manual selector switches.

Defuelling a Pressurized Fuel System

30. In general, the defuelling connections are the same as those made for refuelling. However, the electrical services may not be needed; this will depend upon the type of refuel/defuel valves fitted and the need to use fuel booster pumps for defuelling (*see* aircraft Air Publication). In many cases, pressure air is used to assist the fuel flow and to retain the shape of fuel tanks, during defuelling, in much the same way as pressure air is used when the engine is running. The pressure air for defuelling is provided by a low pressure air compressor which is connected to an external air supply point on the aircraft.

Note: Not all aircraft fuel systems will drain completely through the pressure refuel/defuel coupling and, in such circumstances, other methods must be used to complete the task — *eg* the use of fuel booster pumps or removal of drain plugs.

31. Details of a particular fuel system and instructions for its management are found in the relevant aircraft Air Publication but, in general, to drain a pressure fuel system requires the following work to be done:

- Set the low pressure fuel cock to off.
- Bond the defuelling equipment to the aircraft and connect the hose to the refuel/defuel coupling.
- If required, connect an air supply to the external air supply point.
- Connect an external electrical supply (if required).
- Select 'defuel' as detailed in the aircraft Air Publication.
- Set the defuelling equipment to defuel.
- Start the air compressor if an external air supply is needed.
- Start the pumping equipment and defuel until one of the following objectives is achieved:
  - The new fuel load is achieved.
  - The required tanks are empty.
  - The fuel system is drained completely.

32. **Use of fuel booster pumps.** In some instances, the fuel booster pumps may be needed before the tanks can be completely emptied. In other instances, one side of a fuel system may drain leaving fuel in the other side; again the use of the appropriate fuel booster pumps will provide the answer. ON NO ACCOUNT RUN THE FUEL FLOW PROPORTIONER.

33. After defuelling is completed, remove all external equipment and restore both aircraft and fuel system to normal. Where a manually-operated defuel cock is fitted, it is very important that it is reset to the normal position. Some aircraft require the use of a special key to operate the manual defuel cock and, as a precaution, the key cannot be removed from the aircraft whilst the cock is in the defuel position. Thus, the cock must be reset to the normal position to enable the key to be withdrawn.

Venting the Pressure Fuel System

34. The pressure refuelled fuel system is vented for the following reasons:

- To balance the pressure within the fuel system with ambient atmospheric pressure.
- To cater for thermal expansion or contraction of the fuel and air inside the fuel system.
- To prevent fuel from spilling to atmosphere during normal operation of the aircraft.
- To provide a ready means of feeding an inert gas into the fuel tanks when this is necessary.
- To spill fuel clear of the aircraft structure if a refuelling valve fails to close during refuelling.
- To protect the fuel system from excessive internal pressure.

35. The pressure filled fuel system which uses air pressure for fuel transfer is in many respects a sealed system, and yet to prevent the generation of excessive pressures, the system must have vents which are capable of controlling the pressure (Fig 6.1.10). Rapid changes in outside air temperature will cause thermal expansion or contraction of the fuel and air inside the fuel system. If the pressure inside the fuel system rises, it is necessary to allow excess pressure to vent outwards or, if the internal pressure drops, air must be allowed to enter and restore the pressure; this is called outward and inward venting. It may be catered for by a single double-acting vent valve or two valves may be used. Fuel systems are subjected also to rapid

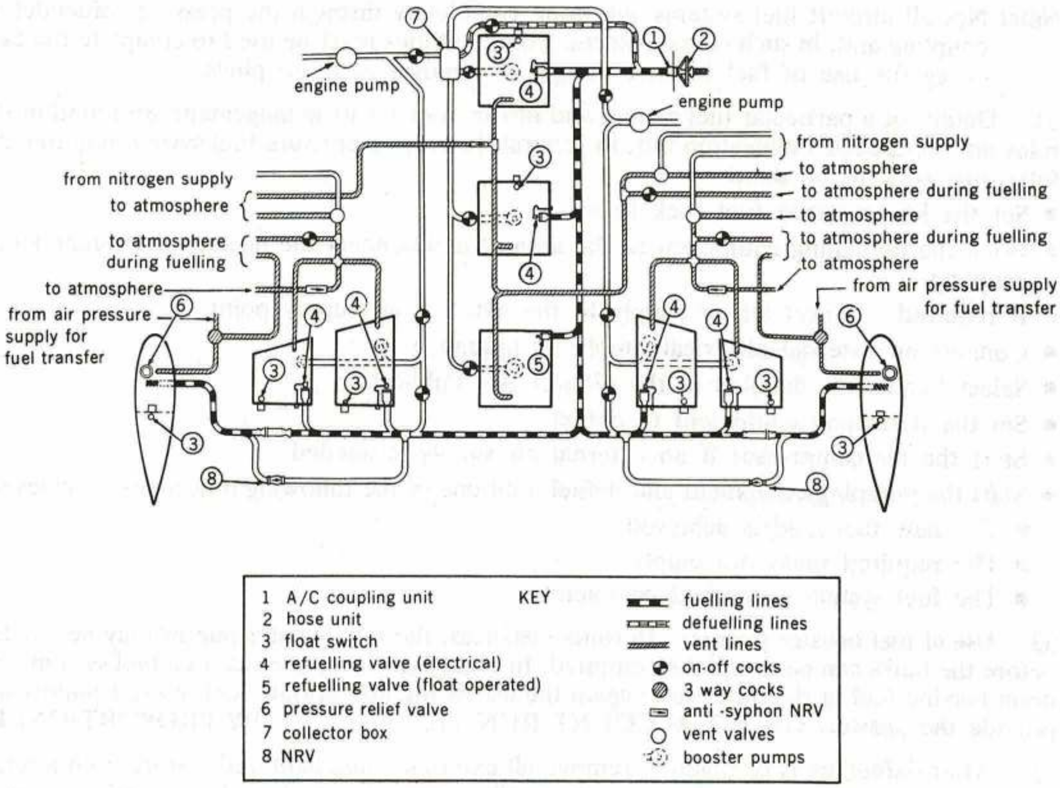

Fig 6.1.10 A typical pressurized fuel system

changes in atmospheric pressure as the aircraft climbs and dives. In such circumstances, the correct ratio between inside and outside pressure is maintained by a differential pressure valve.

36. When considering how to vent a fuel system, it is necessary to take into account the rate at which the system fills because displaced air must leave the system as quickly as the fuel enters. A further consideration is the possible failure of a refuelling valve and subsequent feeding of fuel into a tank which is already full. The feed line pressure can reach 50 psi and the fuel tanks can withstand only pressures in the region of 10 psi/15 psi. Therefore, a vent valve and vent pipe must be able to provide a fuel flow equal to the rate at which fuel is entering the fuel tank.

To reduce the fuel flow, some later refuelling valves have a built-in restrictor which comes into action if the valve fails to shut. The restrictor is activated by the back pressure from the tank and it reduces the fuel flow, through the failed valve, so that the pressure remains insufficient to damage the fuel tank.

Pressurizing a Fuel System

37. The main reasons for feeding pressure air into aircraft fuel tanks are given in para 21. The air for pressurization is obtained from the compressor of the aero engine and passed through a pressure reducing valve before entering the fuel system pressure lines and galleries (Fig 6.1.1). In some instances vent lines may be used, but separate pressure lines are preferred because, if vent lines are used for pressure air purposes, their efficiency for venting is automatically reduced.

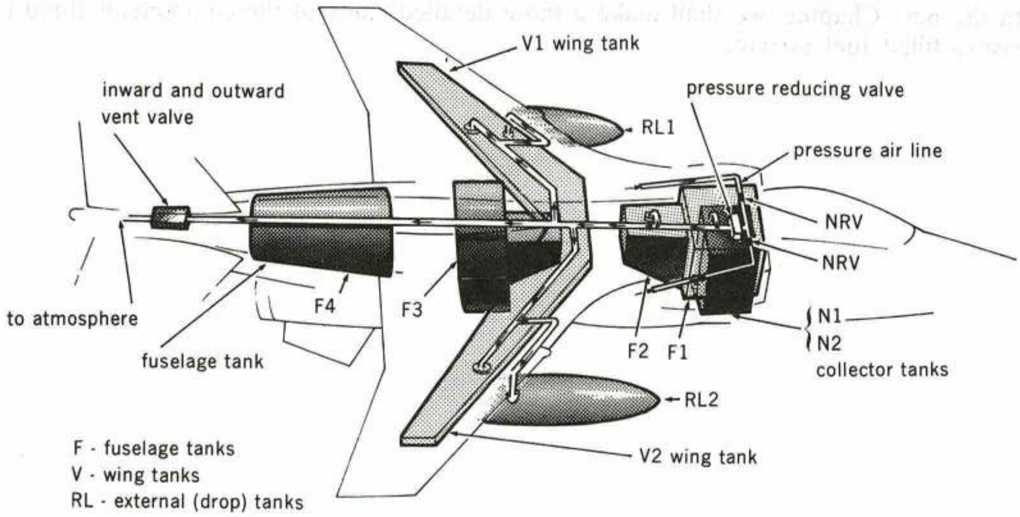

Fig 6.1.11. Fuel system pressure air lines

38. The pressure air layout will be peculiar to aircraft type and details are obtained from the aircraft Air Publication series. In general, the pressure air is reduced to about 6 psi (0.4 bar) before it is piped into the air space of the fuel tanks which do not have fuel pumps, and the pressure of the air is sufficient to feed the fuel into either collector tanks or fuselage tanks where fuel booster pumps are fitted to feed the fuel to the engine-driven fuel pumps. *Fuel is never fed to the engine pumps by air pressure.* Normally, the transfer of fuel is controlled by the action of float-operated switches and fuel transfer valves. The pressure air is fed to the external tanks and wing tanks furthest from the aircraft centre line. When the low pressure fuel pumps have lowered the level of fuel in a collector or fuselage tank, a float switch operates to start the transfer of fuel from the external tanks into the partially empty tank. Indicators in the cockpit are energized to show that fuel transfer is taking place and low level float switches close the fuel line from the tank when the tank is empty. The action of the low level float switch prevents pressure air from entering the fuel lines and moves the indicator in the cockpit to the tank empty position. Normally, the external tanks empty first and then the wing tanks, followed by the fuselage tanks.

CONCLUSION

39. In this Chapter we have considered fundamental information relating to aircraft fuel systems including the following:

- Pressure and gravity refuelling.

- Defuelling methods.
- Fuel system vents.
- The use of low pressure fuel pumps combined with pressure air for fuel transfer purposes.

40. When you have studied this Chapter, you should be able to understand the problems involved in supplying fuel to an aero-engine in flight and how these problems are solved.

In the next Chapter, we shall make a more detailed study of the components fitted in a pressure filled fuel system.