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AIRFRAME AND SYSTEMS
CHAPTER 8: FUEL SYSTEMS

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INTRODUCTION

Aircraft engines use either a gasoline based fuel (piston engines) or a kerosene based fuel (gas turbine engines). It is imperative for aircraft safety that the correct type of fuel be used for each application.

FUEL TANK CONSTRUCTION

Fuel tanks are generally constructed using one of three construction methods. These are;

- Rigid,
- Flexible, and
- Integral.

RIGID FUEL TANKS

Rigid tanks are usually constructed out of aluminium alloy. They are generally of welded construction and may include internal baffles.

These tanks generally require some form of restraint and padding to prevent them moving during manoeuvring and prevent damage should they move within their compartment.

They are usually used as fuselage tanks in light aircraft, or may be mounted under the wing in some military installations such as the C130 Hercules.

Some large aircraft such as the KC10 airborne refueller use rigid metal tanks inside the fuselage to hold the extra fuel required for their role. Refer to Figure 8-1.

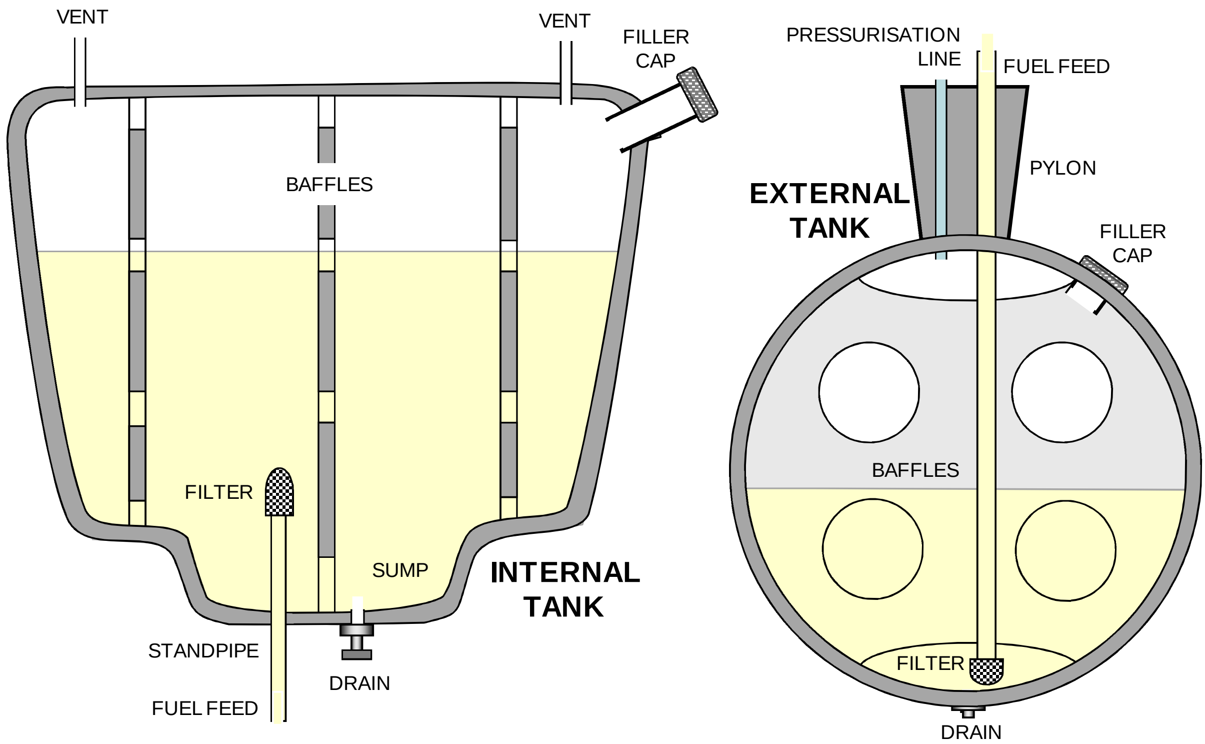

Figure 8-1 Rigid Tanks

FLEXIBLE FUEL TANKS

There are two variations of flexible rubber fuel tanks. They are;

- thin (2 to 3 mm) bladder (bag) tanks, and
- thick (300 mm) bladder tanks.

Thin flexible tanks are constructed out of thin fabric reinforced with neoprene rubber or plastic sheeting, which is impervious to fuel. The major advantage of a flexible or this type is that it can be made to fit any available space and can be made to fit almost any shape. They are attached to the aircraft structure by cords or welded lugs.

Thick flexible tanks maintain their own shape due to the thickness of the rubber which is normally of at least three layers. The centre layer is often made from a special compound that will react and swell when exposed to fuel. This provides a self sealing capability if punctured by munitions. Military helicopters and battlefield support aircraft use these tanks. It is common for these tanks to contain foam linings to suppress leakage and lower the risk of fire in the event of an accident.

Many light aircraft use thick flexible fuel tanks in the wings to lower the chance of fuel leakage.

One of the problems associated with flexible rubber tanks is drying out when not in use. For this reason the tanks should always contain some fuel, usually classified as unusable fuel, or be wiped out with an oily rag if they are to be left unused for a prolonged period.

Many small business jets use flexible tanks as centre-line tanks to improve range. Refer to Figure 8-2.

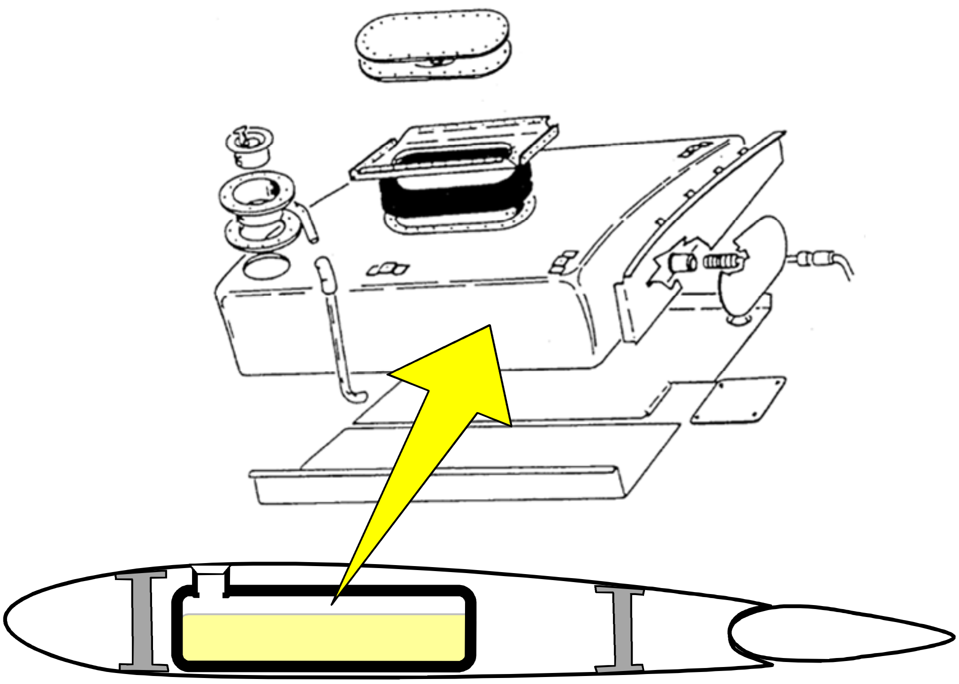

Figure 8-2 Bladder Tank

INTEGRAL FUEL TANKS

Integral tanks are the most common type of fuel tanks.

An integral tank is part of the wing structure, usually being formed by the front and rear wing beams and the upper and lower surface of the wings. This requires special sealing and is usually accomplished by a sealing compound applied between all surfaces and fasteners, and a clear, fuel proof lacquer which is sprayed over the interior of the tank.

The main advantage of the integral wing tank is that the fuel actually adds strength to the wing by helping to relieve wing up-bending. Refer to Figure 8-3. Many light aircraft use the centre section between the wings as an integral tank.

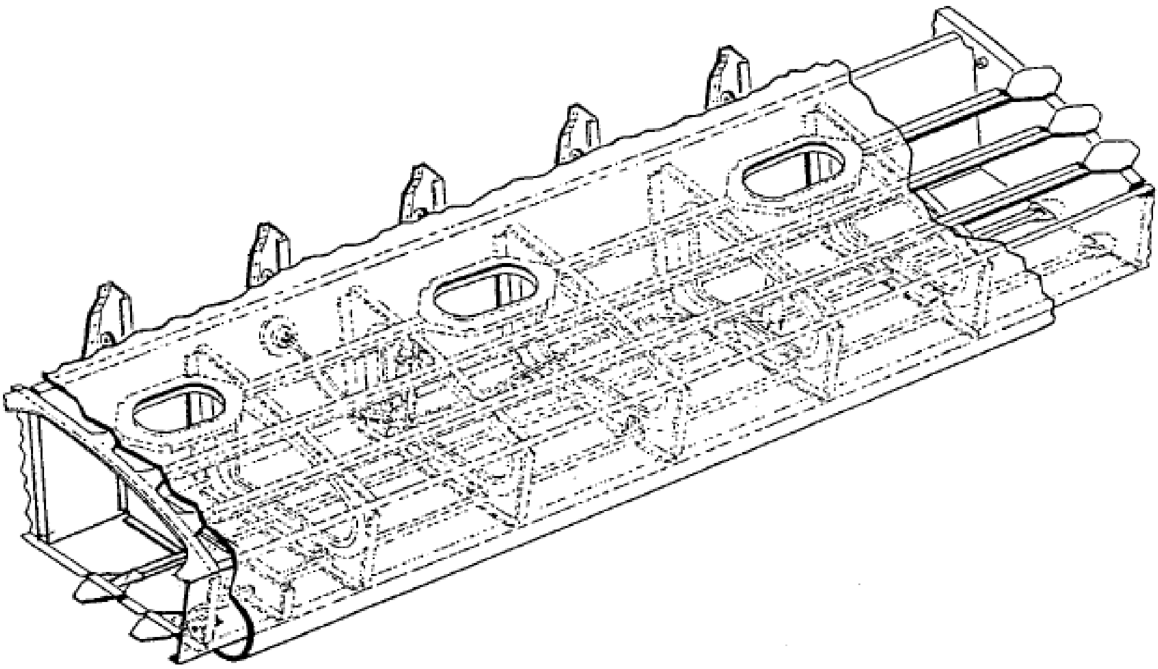

Figure 8-3 Integral Tank

ALL FUEL TANKS

Large fuel tanks contain baffles which slow the movement of fuel during aircraft manoeuvring. The baffles form internal compartments within the tank, which help slow the movement of large volumes of fuel.

If these large volumes of fuel were allowed to move unrestricted within the tank space, it would cause serious problems if air were to be trapped by cascading fuel into an unvented corner of the tank. This in turn could lead to serious structural problems.

Another function of the baffles is to control the flow of fuel within the tank by allowing fuel to pass slower toward the wingtip than to the fuselage. This is especially necessary in unbalanced, high bank angle manoeuvres during which large shifts in fuel weight could cause serious control problems, as well as structural problems particularly at the wing tip. Refer to Figure 8-1.

FUEL TANK LOCATION

In single engine high winged aircraft, a single, gravity feed type fuel tank is often satisfactory. A filter and shut-off valve located between the tank and engine are the only essential components required. In low wing mono-planes a similar type of tank layout is satisfactory, except they will require a fuel boost pump to supply the fuel from the fuel tank to the engine. The tanks are usually mounted on the longitudinal centre-line, so that they are as close as possible to the centre of gravity.

Multi-engined aircraft normally have the fuel tanks located in the wings behind the engines. The tanks will normally be arranged so that each engine is supplied from the one tank.

As a general rule tanks are always numbered from left to right. Rear-engined aircraft usually have tanks located in the wing structure and underfloor fuselage, and rely on pumps to supply the engines. Refer to Figure 8-4.

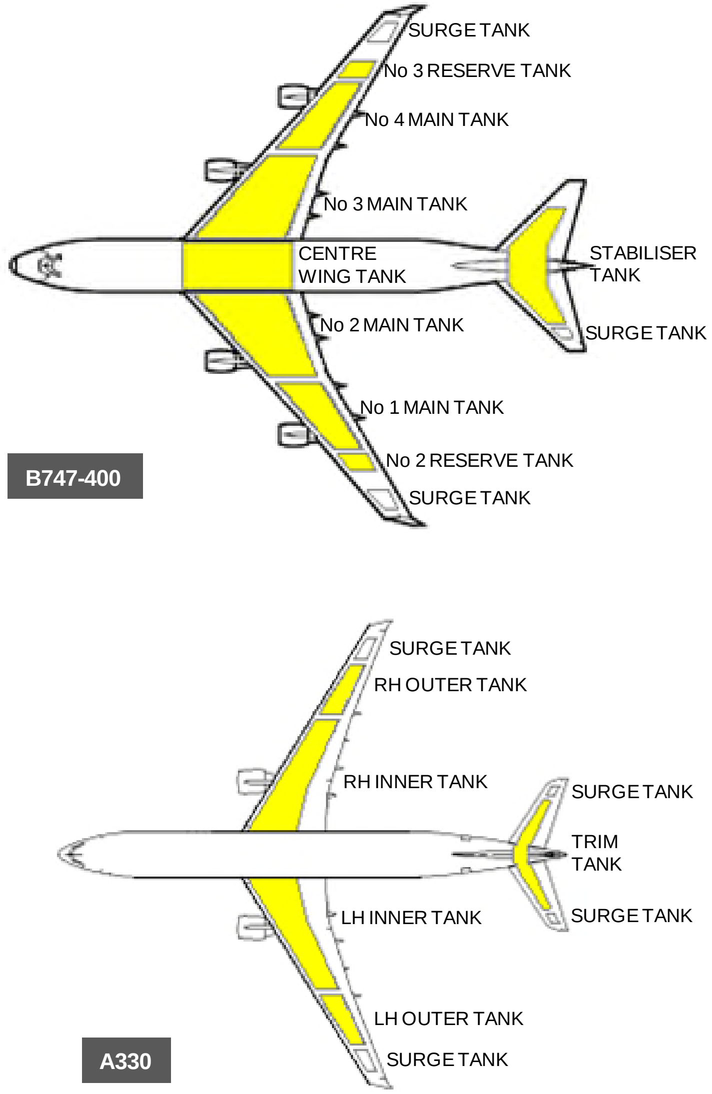

Figure 8-4 Fuel Systems – Tank Locations

All fuel systems are susceptible to the accumulation of water, due to condensation on the inside of the tank walls. It is extremely important that this water be removed prior to flight. To enable the water to be drained and to allow samples of the fuel in the tank to be taken, sump drains are normally fitted.

In large aircraft systems these are normally located in the lowest potion of the aircraft wing tanks, while in other aircraft they may be located at the lowest point of the feed lines. Water has a specific gravity of one and is heavier than both gasoline and kerosene type fuel, so will sink to the bottom of either the tank or associated piping. Sump drains are fitted in the low part of each tank and some fuel supply lines which enable any residual water to be drawn off.

SUMP DRAINS

It is a requirement that the drains be positioned so that they discharge clear of all parts of the aircraft. The drains must also be located or protected to prevent fuel spillage in the event of a landing with the landing gear retracted. Tank sump drains are also referred to as condensate or water drains. Refer to Figure 8-5.

Figure 8-5 Condensate Drain Valve

FUEL TANK VENTING

Fuel tank venting is vital to the safe operation of the aircraft fuel system. Without tank ventilation it is possible for a flexible tank to collapse, or an integral tank to bulge and rupture, splitting the wing structure. This is more evident when considering the refuelling rates on some of the larger jet aircraft, some being as high as 700 gallons per minute at 60 psi. All the air displaced by the fuel entering the tank must be vented overboard or the internal pressure in the tank will cause serious damage.

As the aircraft climbs and descends the internal pressures in the tank must be allowed to equalise or structural problems will also occur. When the aircraft is fully refuelled and the ambient temperature increases the fuel will expand and overfill the tank causing serious structural problems if the pressure is not relieved.

To overcome these problems a vent system is required which will allow only air to enter and leave the aircraft, but allow fuel to be removed and replaced from individual tanks.

Most systems will contain positive and negative vent valves which will allow air pressure inside the tank to equalise with ambient pressure, and also allow fuel out to a holding tank, known as a surge tank, to relieve excess fuel pressure. This fuel is returned to the tank by either gravity feed or by a venturi type ejector pump. No matter what components individual systems may have it is important that the inlet/outlet scoop for the vent air is clear and unobstructed. Refer to Figures 8-6 and 8-7.

In summary a fuel venting system on any large commercial aircraft should achieve the following.

- allow air out of each tank as it is being refuelled,
- allow air into each tank as the fuel is being consumed,
- accept into a small holding (surge) tank any excess fuel from each tank, caused by over-fuelling, thermal expansion or sloshing and return that fuel back to a tank to be consumed later,
- automatically stop the refuelling process if the holding (surge) tank becomes full, and
- provide a small positive pressure (ram air) to each tank during flight

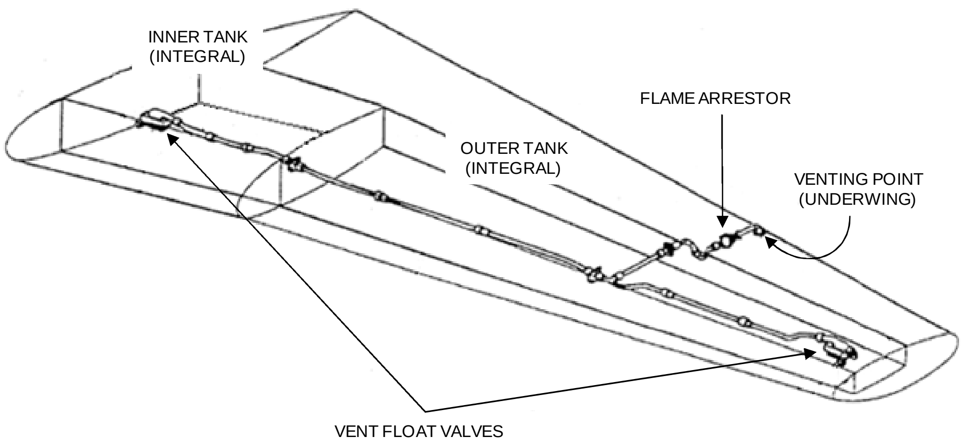

Figure 8-6 Fuel Tank Venting System

Figure 8-7 Fuel Tank Vent

FUEL TYPES

AVIATION GASOLINE (AVGAS)

Aviation gasoline is available in two grades. They are;

- **AVGAS 100 LL** (Low Lead) - BLUE - Complies with DERD 2485
- **AVGAS 100** (100/130) - GREEN

Both of these fuels have an octane rating of 100/130. The octane rating refers to the anti-knock qualities of the fuel, 100 being applicable when a lean mixture is used and 130 when a rich mixture is used. AVGAS 100 also contains tetra-ethyl-lead (TEL) and is therefore considered environmentally unfriendly. AVGAS 100 LL has an octane rating which is suitable for both rich and lean settings.

Automobile Gasoline (MOGAS)

The octane rating of automobile gasoline (MOGAS) is between 87 and 95, and thus creates a problem with the anti-knock capabilities leading to pre-ignition and detonation and is therefore not ideal for use in aircraft piston engines. It is also much more volatile than AVGAS and is therefore prone to vapour lock in fuel lines and pumps, especially at high temperatures and high altitudes. MOGAS also contains some alcohol which will cause deterioration of seals and gaskets, leading to major flight safety problems.

Many of the major engine manufacturers have refused to certify their engines with MOGAS, meaning using it will void the manufacturer's warranty. The CAA has issued a Airworthiness Notice (98) permitting its use in certain light aircraft, but limitations regarding fuel specification, storage, source and operating procedures apply. Special precautions to avoid vapour lock are stipulated namely;

- the temperature of the fuel in the tanks must be less than +20°C,
- the aircraft must be flown below 6,000 feet, and
- because of the higher volatility of MOGAS, carburettor hot air systems must be serviceable and used, since the risk of icing is greater than with AVGAS.

AVIATION TURBINE FUEL (AVTUR)

Turbine fuels are liquid hydrocarbons similar in chemical composition to kerosene, and are not octane rated. They have a low freezing point and a high boiling point, necessary for operations at the altitudes ranges that gas turbine engines are most efficient at and the range of high and low ground temperatures the aircraft may operate in. AVTUR is not colour coded and is naturally colourless or straw coloured.

The most commonly used types of gas turbine fuels are;

- **JET A** American military equivalent is JP-8. Primarily available for use within the USA. It contains no gasoline, has a Specific Gravity (SG.) of .807 at +15°C and has a maximum specified freezing level of -40°C or -40°F.
- **JET A-1** The equivalent is JP-5. The most commonly used fuel in commercial aviation. It has a lower freezing point than JET A, a specific gravity of .807 at +15° C and has a minimum specified operating temperature of -47°C or -58°F. Jet A-1 contains a fungus suppressant and a Fuel System Icing Inhibitor (FSII).
- **JET B (AVTAG)** The equivalent is JP-4. A blend of 70% kerosene and 30% gasoline, known as wide cut fuel. It has a very low freezing point, but also has a low flash point which presents a considerably greater fire hazard than JET A-1. It also has a lower SG. than JET A-1 which can cause a reduction in available range, and engine fuel control adjustments are required prior to operation.

Pilots should be aware of the limitations and disadvantages created by the use of alternate fuels. Flight altitude restrictions may apply due to the higher fuel freezing temperature, and high volatile fuels will cause cavitation and vapour lock at high altitudes and high operating temperatures. In certain countries government approval may be required before the use of wide cut gasoline is permitted.

FUEL DENSITY AND TEMPERATURE

FUEL DENSITY

Heat energy value per unit of fuel should be as high as possible, allowing greater flight range from a minimum weight of fuel. The calorific value of a fuel is an expression of the heat or energy content per unit weight of fuel that is released during combustion. For range the calorific value of fuel should be as high as possible, enabling more energy to be obtained from a given volume of fuel. As the heat value per kilogram is practically the same for all fuels, a comparison can be obtained by comparing SG of fuels. SG is a measure of the density of a fuel and varies with a change in temperature.

FUEL TEMPERATURE

Temperature variations affect the SG of the fuel and this can have a major affect on the quantities being ordered from refuellers. For instance a .005 change in SG on 175,000 litres of fuel could result in a weight change of approximately 800 kg. For this reason it is normal practice to use three decimal places when working out the SG prior to refuelling.

FUEL IDENTIFICATION

Aircraft fuelling points, refuelling vehicles, pipes and ground installations are marked with distinctive colour coding to distinguish between gasoline and kerosene supplies. The labelling and colour coding is illustrated in Figure 8-8.

Hoses are marked by a band of the applicable colour at least one foot long at each end of the hose. The bands must completely encircle the hose and have the grade of fuel stencilled in contrasting colour in one inch lettering.

Refuelling pits and fixed piping must have similar markings to the hoses. As well each inlet and outlet must also have a ceramic or metal tag or disk with the product name and colour code clearly printed on them. All refuel vehicles are to display the correct colour coding of the fuel they are carrying and also a sign 4" x 6" permanently bolted to the rear compartment of the fuel service equipment bay.

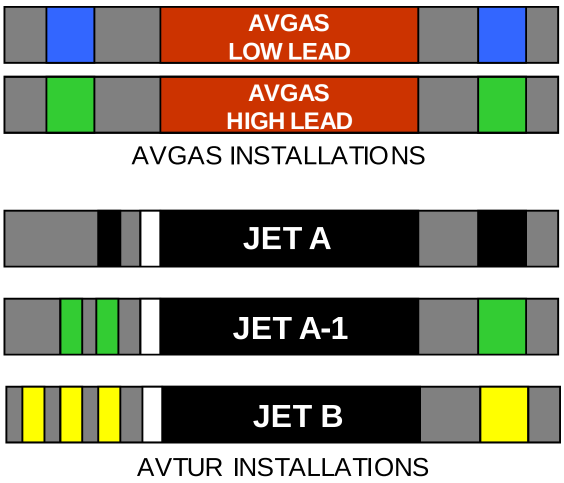

Figure 8-8 Identification of Fuel Installations

FUEL CHARACTERISTICS

AVGAS

Aviation gasoline is a volatile hydrocarbon compound that has a wide range of boiling points and vapour pressures. This is necessary to allow for the various requirements such as starting, acceleration and power. If the fuel vaporises too easily, fuel lines may become filled with vapour causing decreased fuel flow, and eventually vapour lock which will cause the engine to stop. If the fuel does not vaporise readily then the engine will be hard to start, show poor acceleration and low power characteristics.

Octane rating refers to the anti-knock qualities of the fuel, 100 being applicable when a lean mixture is used and 130 when a rich mixture is used. AVGAS 100 also contains tetra-ethyl-lead (TEL) and is therefore considered environmentally unfriendly. Tetra-ethyl lead is added as an additional anti-knock compound, however if too much TEL is added increased corrosion and spark plug fouling can result.

AVGAS 100 LL has an octane rating which is suitable for both rich and lean settings. The octane rating number has no relationship to the fire hazard associated with the fuel, and indicates only the performance inside the aircraft engine.

The flashpoint of a fuel is the point at which it produces vapour which it will readily ignite with a small spark or flame. The higher the flashpoint the harder it is to ignite the vapour. Higher flashpoint fuels have obvious advantages for storage, handling and in the event of an aircraft accident. However they also have disadvantages, such as hard starting.

AVTUR

Turbine fuels are derived from the distillate family, and are basically kerosene or kerosene/gasoline mixtures. They are hydrocarbons and contain a little more carbon and sulphur than gasoline.

JET A is a heavy kerosene with a high flashpoint and lower freezing point than normal kerosene. It has a very low vapour pressure meaning little or no loss from boil-off or evaporation at high altitudes.

JET A-1 has very similar qualities except that it contains a substance known as Fuel System Icing Inhibitor (FSII) which aids in the prevention of the formation of ice in the fuel.

AVTAG

JET B is a blend of aviation gasoline and kerosene (usually about 70/30). It has a very low freezing point, a low vapour point and also has a very low flash point, making it more hazardous to use. The specific gravity of JET B is lower than both JET A and JET A-1, which will usually require adjustments of the fuel control system and also greater consideration of available range because of the different thermal energy of the fuel.

KEROSENE FUELS

All jet fuels are able to absorb water more easily than gasoline type fuels. As the SG of kerosene type fuels is much closer to water than gasoline, any water introduced in the fuel by either condensation or refuelling operations will take longer to "settle out" of the fuel. This creates a problem when flying at altitude as the water will form ice crystals in the fuel, which may cause blockage of aircraft filters.

Kerosene fuels also form waxes if subjected to extremely cold temperatures, which also create a hazard by blocking fuel filters and restricting flow in fuel system lines.

WAXING

Waxing is the depositing of heavy hydrocarbons from the fuel at low temperatures. The deposits take the form of paraffin wax crystals which can clog the fuel filter and interfere with the operation of the fuel control unit. The effects of waxing can be minimized by;

- **a.** the refinery keeping the levels of heavy hydrocarbons low, and
- **b.** the inclusion of a fuel heater in the engine fuel system.

FUEL QUALITY CONTROL

FUEL DELIVERY

Dirt, water, paint or any inappropriate additives are considered contaminants and can cause system blockage or lower the effective octane rating of the fuel. Fuel suppliers and airport fuel contractors are required by law to maintain and supply clean fuel, free of water, to aircraft.

Typically at large airports fuel is delivered from an underground system with accessible connection points at each aircraft parking position. Small fuel pumping trucks connect to the underground system, filter and pump the fuel into the aircraft. Refer to Figure 8-9.

It is extremely rare to receive contaminated fuel from this type of source. Refuellers however, are required to sample the fuel from the pump truck at each refuel.

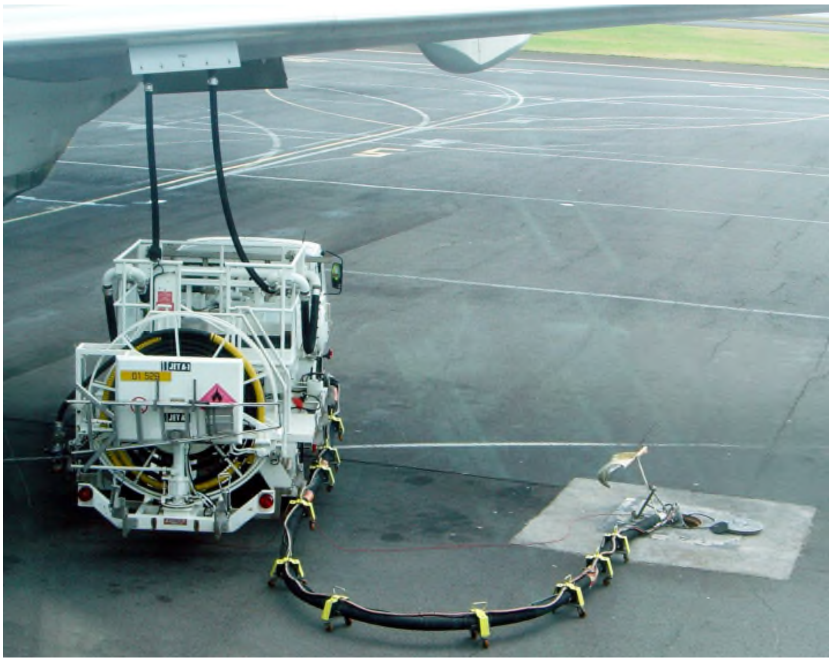

Figure 8-9 Refuelling from an Underground Supply

AIRCRAFT TANKS

Water contamination of fuel in aircraft tanks can be reduced by refuelling an aircraft as soon as possible after landing. Aircraft descending from the cold temperatures encountered at high altitude to hot airfields will experience condensation on the inside of fuel tanks, the lower the fuel level the greater the amount of condensation. Keeping the tanks full will reduce the amount of air in the tanks and reduce the amount of water. The water that does form in the tanks runs down the walls and collects in the sump located at the bottom of each tank.

Aviation authorities have a mandatory requirement that a fuel check be carried out <u>before the first flight of the day</u>, and <u>after each re-fuel</u>.

There are three levels of water contamination:

Dissolved Water is water in solution that cannot be detected by any methods normally available. The quantity of water depends on the temperature of the fuel, the higher the temperature the more water the fuel can retain. The accepted level of dissolved water in solution is .006% by weight at 70°F and at this level it is not harmful to engine operation.

Suspended Water is water that can vary from a cloud of heavy droplets which are easily seen, to a transparent haze of minute droplets which are only detectable by using chemical testing equipment. In this form water presents no problem to engine operation, however as the fuel cools in flight the water turns to ice and can block the engine fuel filters. This situation is catered for by heating the fuel to keep the water in suspension.

Free Water is consolidated globules or a sheet of water on the bottom of the tank, either from accumulation of suspended water or from condensation from the sides of the tank. Free water if ingested in sufficient quantities can cause severe engine problems including flame-out.

FUEL CONTAMINATION CHECK

The contamination check should consist of taking a sample of the correct fuel in a clean container from the fuel source, and another from the aircraft drain point(s). Normally solid contaminants will sink and fuel will sit on top of any water. The following should serve as a guide to the visual assessment of aircraft fuels:

- Colour - AVGAS is dyed blue or green while AVTUR is undyed and can vary in appearance from colourless to straw yellow.
- Solid matter (rust, sand, dust, scale) may be suspended in the fuel or settle on the bottom of the sampling vessel.
- Free water (undissolved water) will appear as droplets on the sides of the sampling vessel, or as bulk water in the bottom.
- Suspended water will cause the fuel to appear hazed or cloudy.

Overall the fuel sample should appear clear and bright. Clear refers to the absence of sediment or emulsion and bright refers to the sparkling appearance of the fuel which should be free from cloudiness or haze.

CHEMICAL TEST

Water detecting paste may be used for checking for fine droplets of suspended water contamination. Fine droplets of suspended water may be present even though the fuel sample appears to be clear. The paste is applied to the end of a spatula and is allowed to sit on the base of the container for about ten seconds. Fresh paste must be used for each test.

More commonly used today is the hydro test kit which uses small disposable test capsules containing chemically treated wafers. A fuel sample is drawn through the capsule by a syringe. If water is present the wafer within the capsule will change to purple. A new capsule must be used for each test and new capsules must be kept dry so as not to absorb ambient moisture. Refer to Figure 8-10.

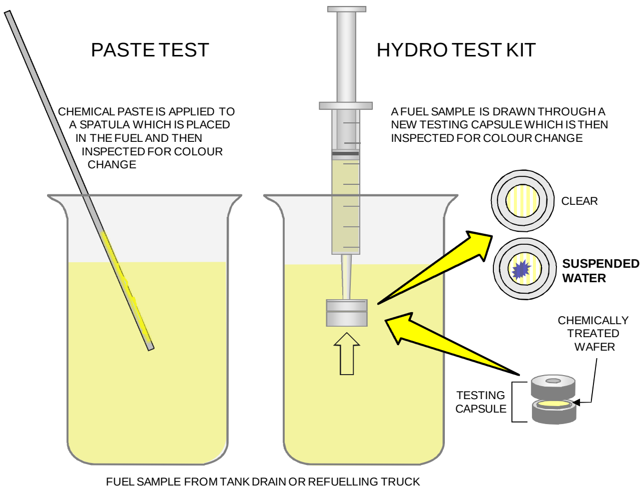

Figure 8-10 Chemical Testing for Suspended Water

If water is found fuel must continue to be sampled until such time as the sample is clear.

REFUELLING

There are two methods of refuelling being the simple hand held refuelling hose and trigger operated nozzle commonly referred to as “over wing” refuelling and the more complicated single point pressure refuelling system fitted to modern large aircraft.

No matter what system is used the pilot must be aware of all limitations regarding his aircraft.

SIMPLE OVER WING REFUELLING

The manual refuel points are located at the high point of each tank. Normally these openings are located on top of the wing, but may also be found on the side of the fuselage for centre section tanks.

They are typically fitted with a locking cap with a double action to prevent inadvertent opening during flight. The caps will normally be fitted with an arrow indicating the direction the cap should be fitted in, with the latch away from the airflow.

The recommended type and grade of fuel should be stencilled next to the filler cap, and an earth point for connecting the fuel nozzle earthing lead should be located in close proximity.

The caps are positioned in such a way to allow a set airspace inside the tank to allow for expansion and fuel movement and to prevent the tank from being overfilled. Refer to Figure 8-11.

When refuelling manually care must be taken not to overbalance the aircraft laterally, particularly if the aircraft has a narrow wheel base. In small multi-tank aircraft the correct filling sequence must be followed, or CofG limits may be compromised, which could lead to the aircraft settling on its tail.

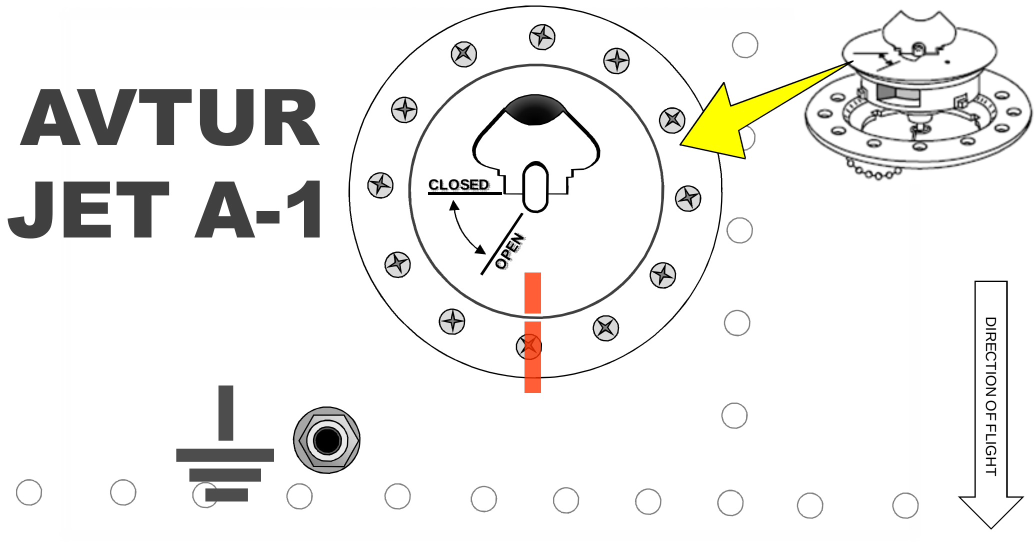

Figure 8-11 Tank Filler Cap

BONDING OR EARTHING PROCEDURE

It is imperative that the correct earthing procedure be followed during fuelling operations to prevent the possibility of static electricity from causing a fire.

The correct procedure in sequence is:

1. the aircraft is bonded to an approved earthing point,

2. the tanker is bonded to an approved earthing point,

3. the tanker is bonded to the aircraft, and

4. the refuel nozzle is bonded to the aircraft PRIOR to the connection being made.

This earthing procedure applies to ALL methods of refuelling and of course de-fuelling. Refer to Figure 8-12.

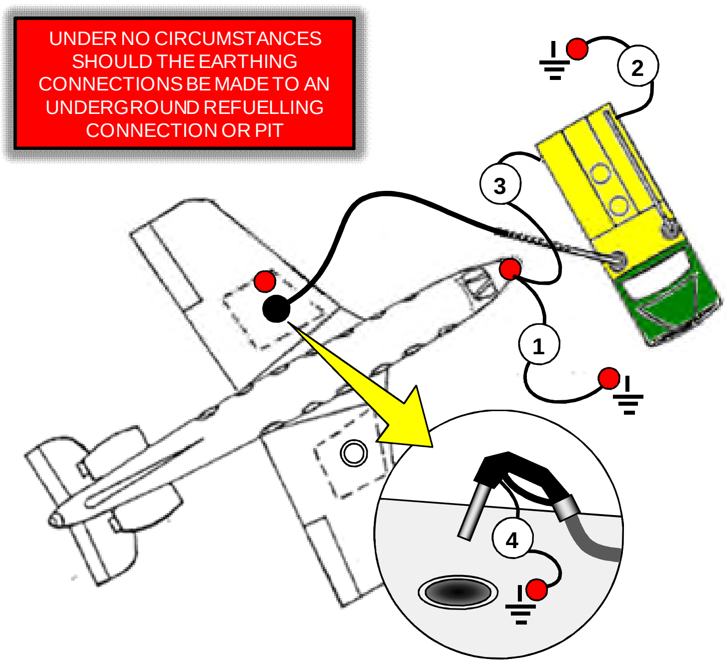

Figure 8-12 Refuel Bonding

SINGLE POINT PRESSURE REFUELLING

Single point refuelling is a method used to control the refuelling or de-fuelling of all the tanks of a large aircraft from one point. The system usually consists of two fuelling adaptors located at one point on the aircraft, usually on the underside of the wing, called single point refuelling adaptors, and a Single Point Refuel system control panel.

The refuelling adaptors are connected to the tanks by a refuel manifold. The manifold is connected to the tanks by refuel control valves, which are controlled by the switches on the single point refuel control panel.

The system is capable of refuelling all the aircraft tanks to the desired levels from one point, usually by one person. Large aircraft may have multiple refuelling hose connection points to reduce refuelling time but refuelling control is always conducted at the single point refuel control panel. Refer to Figure 8-13.

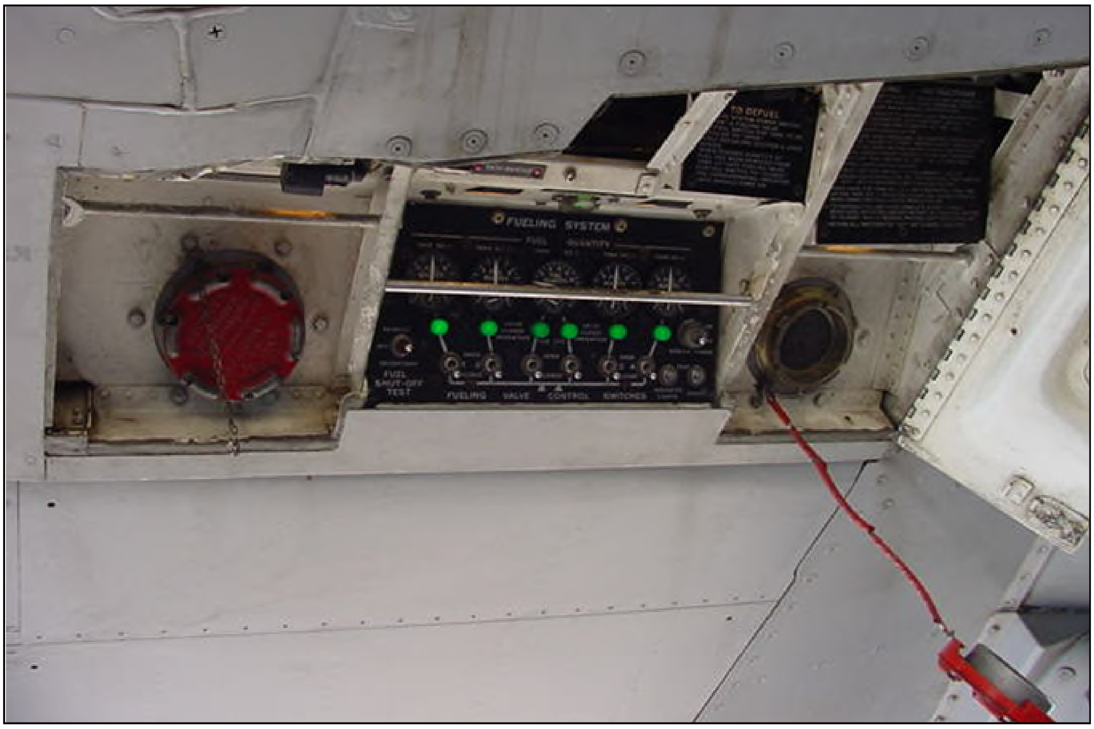

Figure 8-13 Single Point Refuel Panel (Typical)

The control panel displays individual tank quantity on gauges or digital readouts and provides control switches for each tank. This allows the operator to open or close the refuelling input to each tank.

The fuel input to each of the tanks is controlled through tank refuel valves located in the top of each tank. Tank refuel valves are electrically controlled but use the "hydraulic" pressure of the incoming fuel to operate the valve to open or closed. Refer to Figure 8-14.

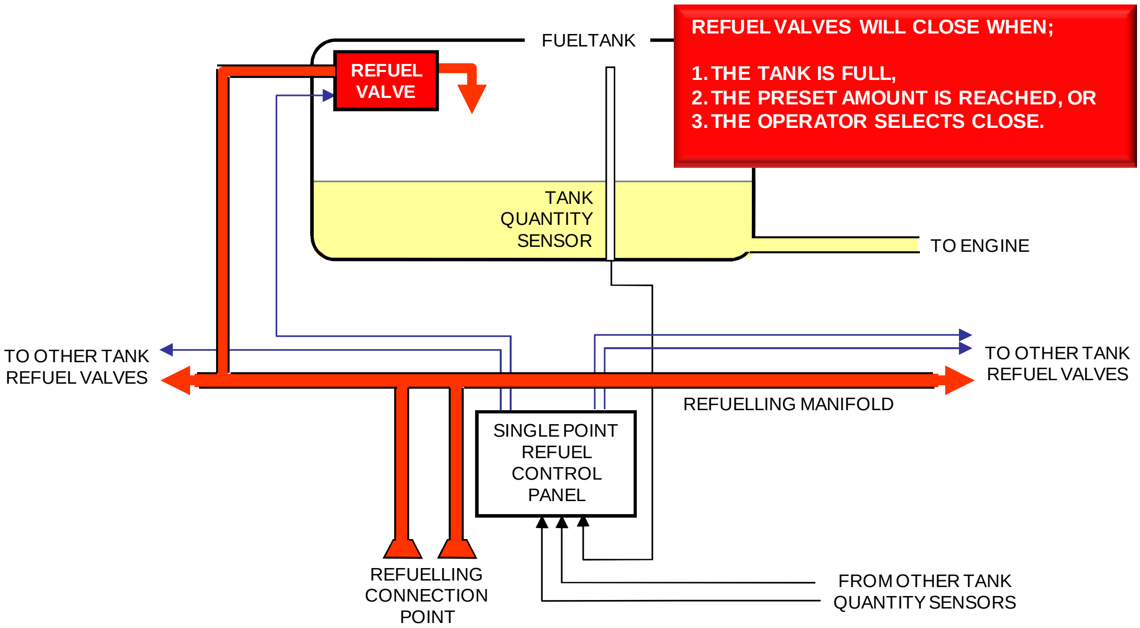

Figure 8-14 Refuel Valve

REFUELLING OPERATION

Aircraft pressure refuelling systems have maximum flow rates and maximum fuel pressure limits which must adhered to during refuelling or severe structural damage to tanks and plumbing will occur. Typical flow rates are 300 Gallons per Minute (GPM) through each hose connection at a refuel pressure of 60 PSI.

Additionally, in large multi-tank aircraft the correct filling sequence must be followed, to maintain the minimum amount of stress at the wing root to fuselage joint. Wing tanks should always be filled first before any fuel is added to fuselage or horizontal stabilizer tanks.

Each aircraft will have a specific procedure to follow but in general, single point pressure refuelling is conducted as follows.

The pump truck or tanker hoses are connected to the aircraft refuelling adaptors following the correct bonding procedure previously detailed and fuel pressure is applied.

Typically the refuel panel has a power ON control switch which provides power to the refuel valves and quantity indicators located on the panel.

After the operator has received the total fuel load required he will open the refuel valves for the wing tanks which begin to fill. Refuel valves are normally tested (closed) at this point to ensure they will operate correctly when the tank is full.

The wing tanks are the primary supply tanks to the engines so when the total fuel required load is small the operator will close the individual refuel valves as each tank reaches the required quantity. With large fuel loads which require filling of the fuselage tanks this should not be started until the wing tanks are full.

At completion of the refuel the operator will shutdown the refuel panel, disconnect the hoses and provide the crew with the amount of “uplift” fuel delivered.

Modern refuel systems may be preset to the required quantities and refuel valves will close automatically. Refer to Figure 8-15.

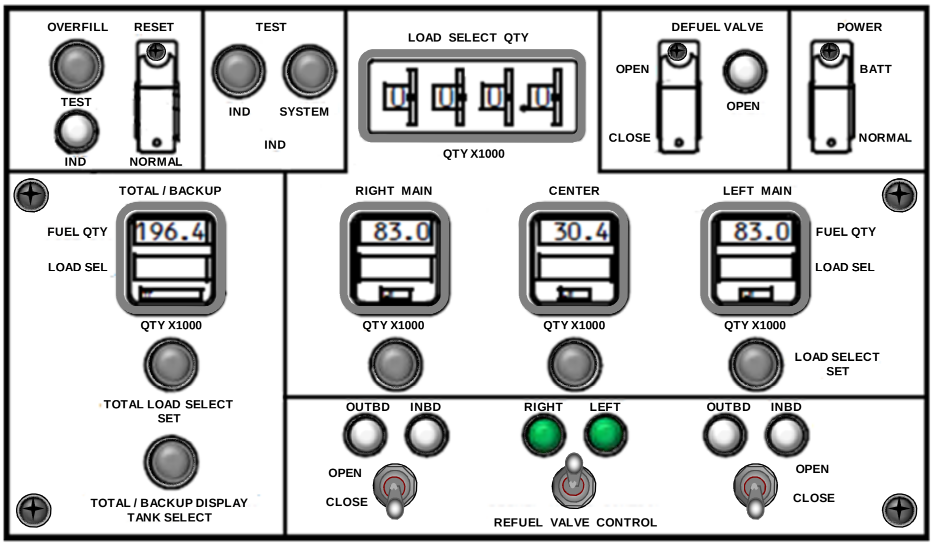

Figure 8-15 Modern Refuel Panel (B-777)

Refuelling aircraft can be potentially dangerous and many precautions have to be observed when refuelling is conducted, particularly with passengers on board or boarding.

GENERAL PRECAUTIONS TO BE OBSERVED WHEN REFUELLING

1. ensure that refuelling vehicles are parked so that;

a) they will not hit the aircraft if they roll, or

b) not cause damage as the aircraft settles due to the increased weight.

2. other vehicles and equipment must not be parked under the wings or aircraft. As the aircraft settles under the weight of fuel severe damage may occur.

3. aircraft engines must not be operated.

4. APUs may be operated, but must be started before the fuelling connections are made.

5. external electrical supplies must not be connected or disconnected.

6. maintenance work which could cause ignition must be suspended.

7. oxygen systems should not be recharged.

8. HF, VHF radios and any RF emitters should not be used. Strobe lights should be off.

9. smoking or other sources of ignition are not permitted in the fuelling zone. The fuelling zone extends not less than six metres radially from the filling and venting points.

10. if thunderstorm activity (lightning) is present or anticipated fuelling should be suspended.

FUELLING ZONES

During refuelling potentially explosive fuel/air vapour is displaced from the aircraft tanks via the venting points. To minimise the danger Fuelling Zones are declared. These are a minimum of 6 metres radius from both the refuel points and the venting points. Refer to Figure 6-16.

- Within the zones the following is prohibited;
- Naked lights,
- Use of radios,
- Mobile phones or pagers,
- Photographic flash bulbs or electronic flash equipment,
- Wearing steel studded footwear,
- The carrying of matches or lighters,
- The movement of ground equipment fitted with metal wheels or steel studded tyres, and
- The use of any electrical equipment other than those which are certified safe with spark protection.

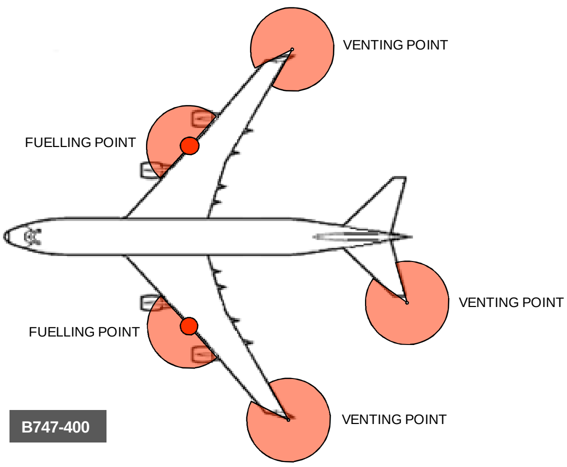

Figure 8-16 Fuelling Zones

REFUELLING WITH PASSENGERS ONBOARD OR BOARDING

Refuelling with passengers on board is allowed in most countries provided;

- the fuel is not AVGAS, and
- munitions or dangerous cargo are not being carried.

Passengers may remain on board or begin boarding provided that;

- there are two exits open and manned by fully trained and type qualified crew members, and
- a crew member must be present in the cockpit and have interphone connection with the refueller or maintenance engineer.

CONDENSATE (WATER) DRAINS

Fuel is to be checked before the first flight of the day and also after each refuel, allowing a reasonable settling time for water to come out of suspension.

To conduct this check fuel samples are drawn from each tank at the condensate (sump) drain.

DE-FUELLING

Any fuel taken out of aircraft tanks must be treated as contaminated fuel. It should not be used in aircraft tanks again until full quality control checks have been carried out. De-fuelling should be into an empty storage container or truck, which should be quarantined from all other fuel. The fuel remains the property of the aircraft operator and disposal is their responsibility.

ZERO FUEL WEIGHT

Zero Fuel Weight (ZFW) is defined as the weight of the aircraft not including fuel. All aircraft will have a Maximum Allowable Zero Fuel Weight (MZFW) stated in the Aircraft's Operating Manual.

Fuel contained in the wing tanks exerts a downward force on the wings which relieves stress loads in the wing roots caused by the upward lifting forces.

As fuel is burned off in flight, the stress relieving downward force is reduced and the wing root stress increases.

The "Zero Fuel" case is the worst possible situation that could conceivably occur in flight and the maximum allowable zero fuel weight limit covers this extreme possibility, ensuring the aircraft remains controllable and structurally intact if all fuel is consumed.

At any time fuel carried in the fuselage or tail becomes unusable due to failure of valves or boost pumps it is considered to be a load and the weight must be added to the ZFW.

If this added weight brings the ZFW above the maximum limit the aircraft should not be flown to the normal positive and negative 'g' limits when approaching low fuel states.

FUEL SUPPLY

Fuel supply systems vary from the simple gravity supply system found on a high wing light aircraft to a multi pump system found on a large commercial aircraft. The most important requirement of the system is that it meets the demands placed on it by the operation of the aircraft.

A basic fuel system is shown in Figure 8-17. The tanks contain a vent system for air pressure equalising, a filler cap for adding fuel, a drain for drawing fuel samples from the bottom of the tank and a supply line to the engine. In this instance a selector valve is fitted to allow fuel to be fed to the engine from either tank allowing fuel balance to be maintained. A fuel filter is fitted in the supply line with a drain valve attached.

Many high wing light aircraft rely on gravity feed to supply the engines. This system is effective for a small aircraft which does not require large amounts of fuel.

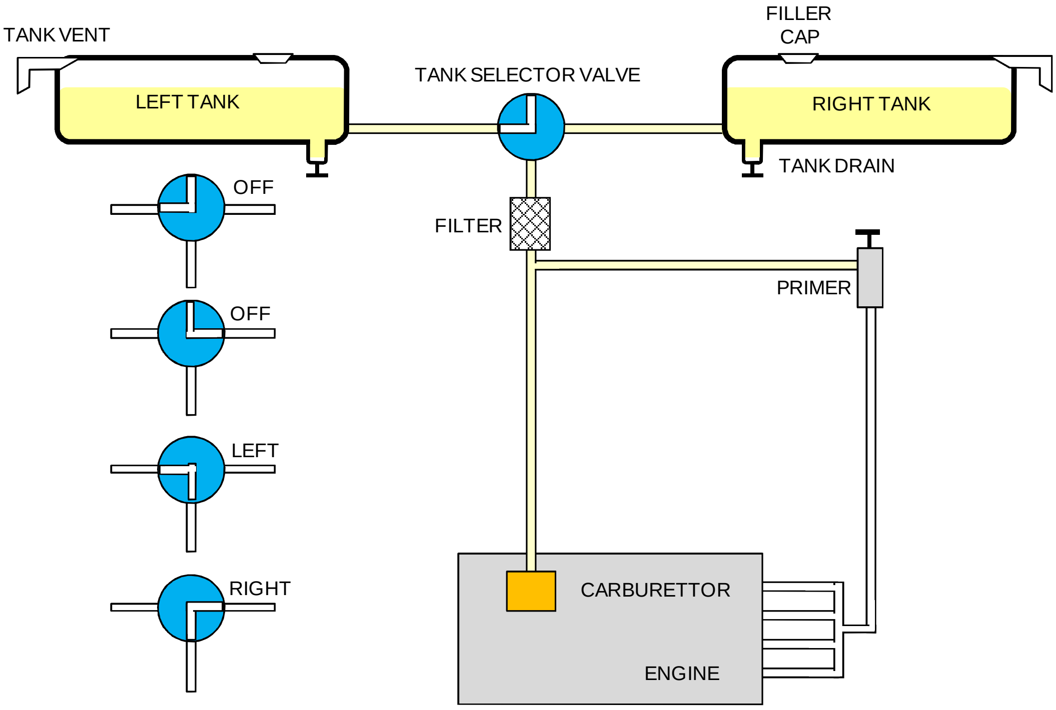

Figure 8-17 Light Aircraft Gravity Feed Fuel System (Typical)

However a low wing, single engine aeroplane cannot rely on gravity feed to supply the engine. A fuel pump, known as a "Boost Pump", is fitted to ensure positive engine feed throughout all phases of flight, particularly take-off and landing, and flight at altitude.

This pump may be an electric driven pump, either AC or DC, and may be located external to the tank in the engine feed line or if internally located it is usually in the low point of the tank raised off the bottom to reduce the possibility of water being drawn into the supply line. Refer to Figure 8-18.

This means that the fuel that is located in the bottom of this compartment is unusable, and is normally a nominated amount published in the manufacturer's operating manual.

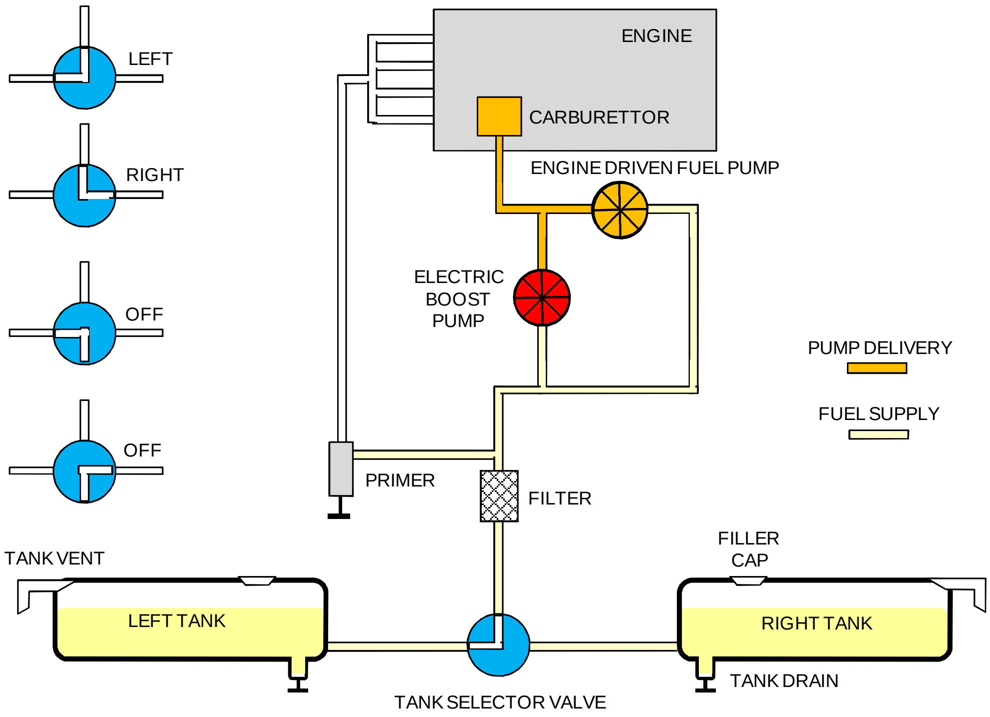

Figure 8-18 Light Aircraft Low Wing Fuel System (Typical)

This system requires some modifications to satisfy the needs of a large jet transport aircraft. The engines must be supplied with fuel at all phases of flight, including the high nose up/nose down attitudes found during climb and descent. Due to a combination of the large area of the tanks and the high angles of attack during descent and approach it is likely that a single boost pump would become starved of fuel.

Consider the B747-200 as an example large aircraft fuel system. Refer to Figure 8-19.

FUEL TANKS

This configuration is typical of large aircraft systems with four **MAIN TANKS** located behind the engines numbered 1, 2, 3 and 4, from left to right, a **CENTRE WING TANK** (CWT) and a pair of **RESERVE TANKS** outboard of the 1 and 4 main tanks. Outboard of the Reserve Tanks are **SURGE TANKS** for the fuel vent system.

FUEL PUMPS

Each of the Main Tanks has two **BOOST PUMPS** to supply the engines while the Centre Wing Tank has two **OVERRIDE/JETTISON PUMPS** which can supply either the engines or jettison fuel. Two **JETTISON PUMPS** are fitted in tanks 2 and 3.

To overcome the problem of high angles of attack and low fuel states during descent, dual Boost Pumps are fitted in each main tank, one in the front section and one in the rear section of the tank. Pumps are positioned inside a separate compartment within the tank, known as a collector tank or box. This ensures that the boost pump is provided with a positive supply of fuel to allow for unusual attitudes of the aircraft.

The pumps are normally fitted above the bottom of the tank to prevent the ingress of any water from the bottom of the tank to the engine feed line. The pumps will normally join a common manifold but be separated by individual non-return valves to prevent a pump from by-passing back to the tank in the event of the other pump failing.

To allow for the unlikely failure of both pumps a suction outlet is also provided, which will allow the Low Pressure engine driven fuel pump to draw fuel for engine operation. If this was to happen aircraft altitude may have to be reduced to prevent cavitation of the engine driven fuel pumps.

The Boost Pumps are usually both AC powered, usually from different electrical busses, and any one will be sufficient to supply the engines needs under all operating conditions. Each engine is supplied with fuel from the tank located directly behind the engine (MAIN TANK) through a tank to engine feed line.

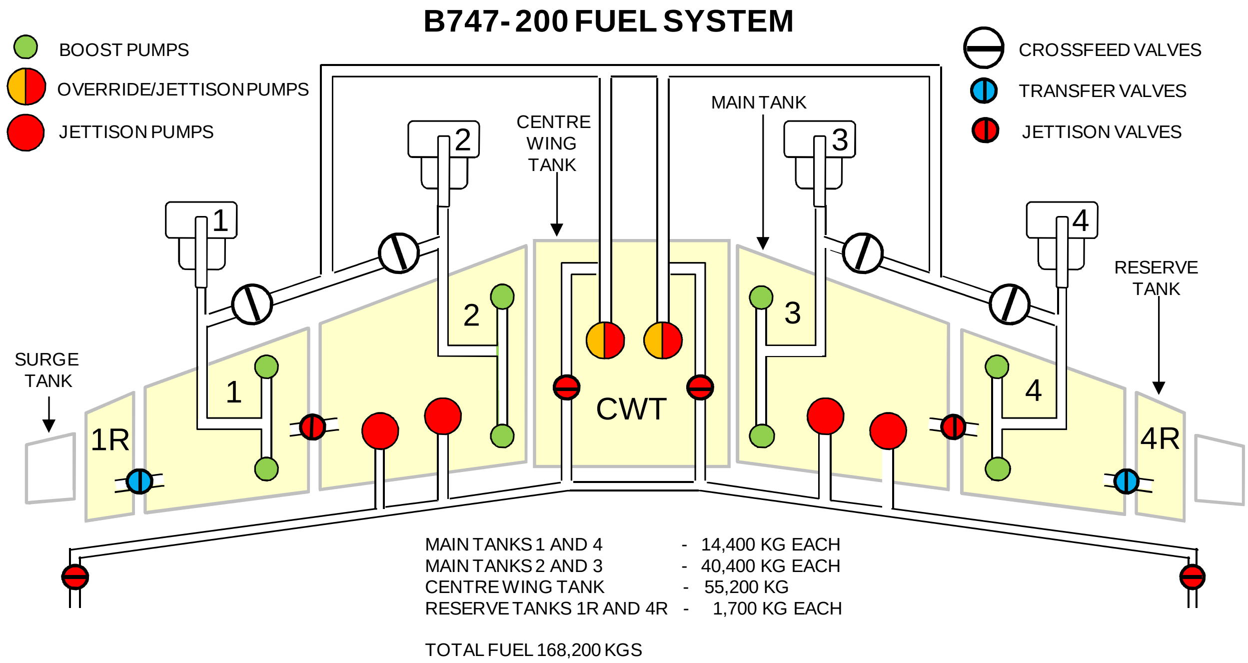

Figure 8-19 Large Aircraft Fuel System

The output of each tank Boost Pump is sensed by a pressure switch which illuminates a **LOW PRESSURE** caution message in the flight station. The output lines of all Main Tank, Centre Wing Tank, Override/Jettison and Jettison pumps have one-way check valves installed to prevent fuel from being pumped into the tank when pumps are inoperative.

The fuel system illustrated has a reserve tank outboard of the outboard main tanks, which can be used for extended range operations. When used the fuel is gravity fed into the outboard main tanks through a Reserve Transfer Valve.

Not shown in the diagram is the last item in the fuel supply line which is a Fuel Shut-off Valve. This valve provides a means of shutting the fuel supply off to the engine.

This valve may be referred to by various names (depending on the aircraft manufacturer) such as Engine LP Cock, Engine LP Shut-off Valve, Engine Spar Valve and Engine Firewall Shut-off Valve.

It is controlled by the engine shut-down switch in the cockpit and by the Emergency Shutdown Handle or Button.

With this valve closed no fuel can go to the engine, but fuel from the tank may be used through the crossfeed system to supply other engines.

CROSSFEED SYSTEM

The crossfeed system consists of plumbing which runs between the outboard engines to which all engine feed lines are connected through **CROSSFEED VALVES**. The centre wing tank is connected to the **CROSSFEED MANIFOLD**.

When fuel is required to be fed to the engines from the CWT, the CWT Override/Jettison Pumps are turned on. The Crossfeed Valve for the engines to be supplied must be opened to allow the CWT fuel to enter the tank to engine lines.

CWT Override/Jettison Pump pressure is of sufficiently higher pressure above the normal tank Boost Pump pressure to feed the engines without turning the tank Boost Pumps off. The check valves in the tank to engine lines prevent CWT fuel or fuel from other main tanks from entering individual tanks.

When malfunctioning engines are shutdown in flight a lateral imbalance of fuel will begin to occur and the crossfeed system can be used to maintain equal fuel weight in opposing tanks.

<u>The crossfeed system allows any main tank to feed any engine, and the CWT to feed any engine.</u>

TRANSFER SYSTEM

Note that crossfeed system does not allow the transfer of fuel between CWT and Main Tanks, or between different Main Tanks. In the system illustrated transfer of fuel from tank to tank is used when reserve fuel is transferred to the associated main tank normally towards the end of the flight.

In aircraft fitted with stabiliser fuel tanks a transfer system is provided to transfer fuel to the CWT at the appropriate time during the flight.

<u>A transfer system cannot feed an engine directly. It will only transfer fuel from one tank to another.</u>

FUEL SYSTEM OPERATION

The series of Figures 8-20 thru to 8-25 summarise the different normal feed, crossfeed and transfer operations that take place during a flight.

For engine start, fuel is fed directly from each engine's associated Main Tank. This configuration ensures best fuel supply for start. Refer to Figure 8-20.

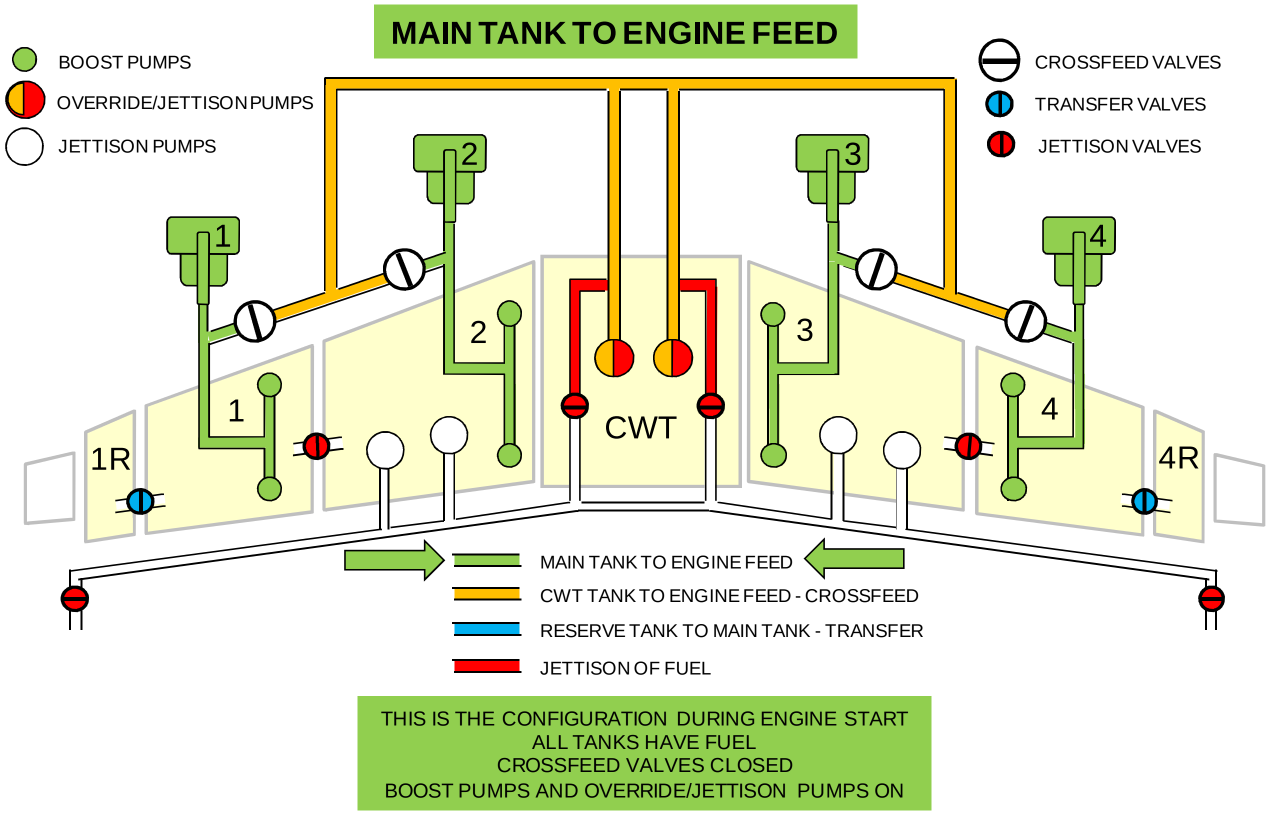

Figure 8-20 Engine Start

After engine start is complete and the aircraft is being prepared for take-off.

BEFORE TAKE-OFF - Crossfeed Valves 1 and 4 are selected to OPEN allowing Engines 1 and 4 to receive fuel from the CWT.

This ensures Main Tanks 1 and 4 remain full of fuel giving maximum wing root load relief.

Engines 2 and 3 remain being supplied from their associated Main Tank.

This ensures that all engines are not fed fuel from the same source for the take-off phase. Refer to Figure 8-21.

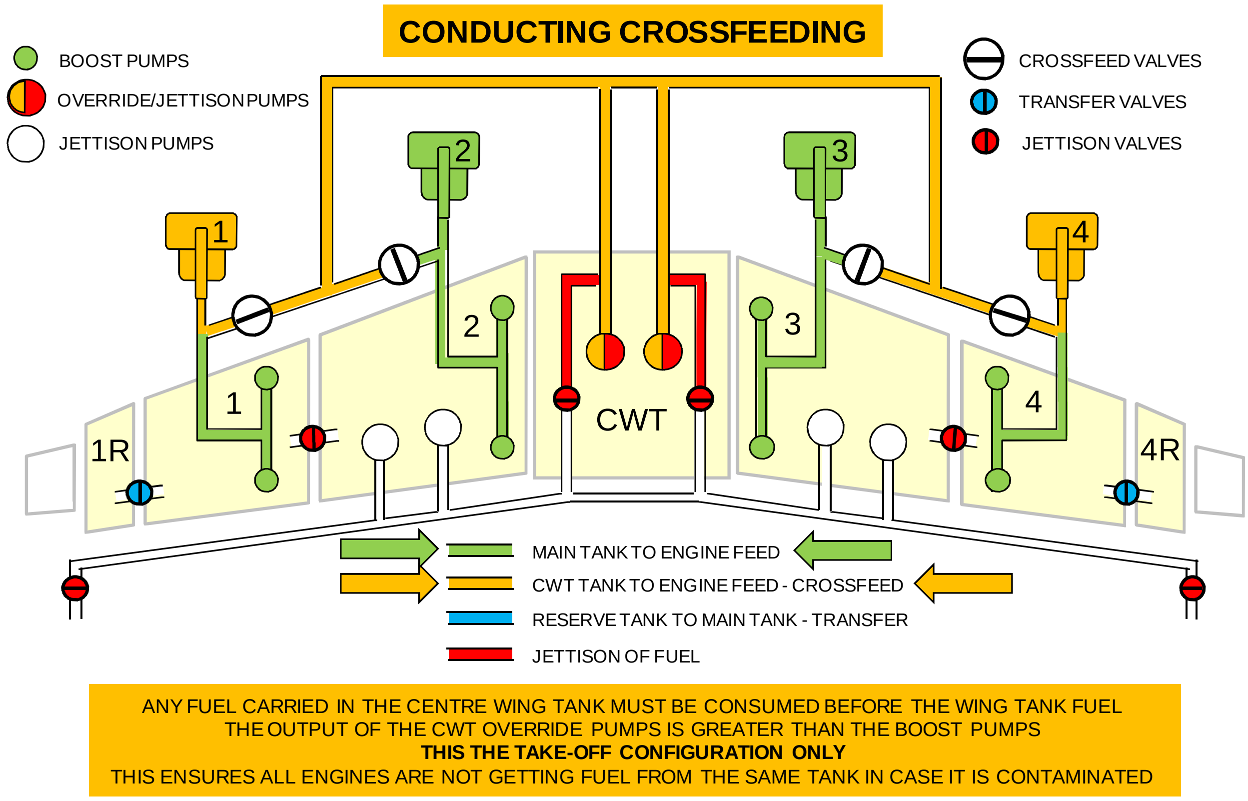

Figure 8-21 Take-off Only

After flaps are up and the Take-off Checks are complete.

AFTER TAKE-OFF – Crossfeed valves 2 and 3 are now also selected to OPEN allowing Engines 2 and 3 to also receive fuel from the CWT. This ensures all Main Tanks remain full of fuel giving maximum wing root load relief. Refer to Figure 8-22.

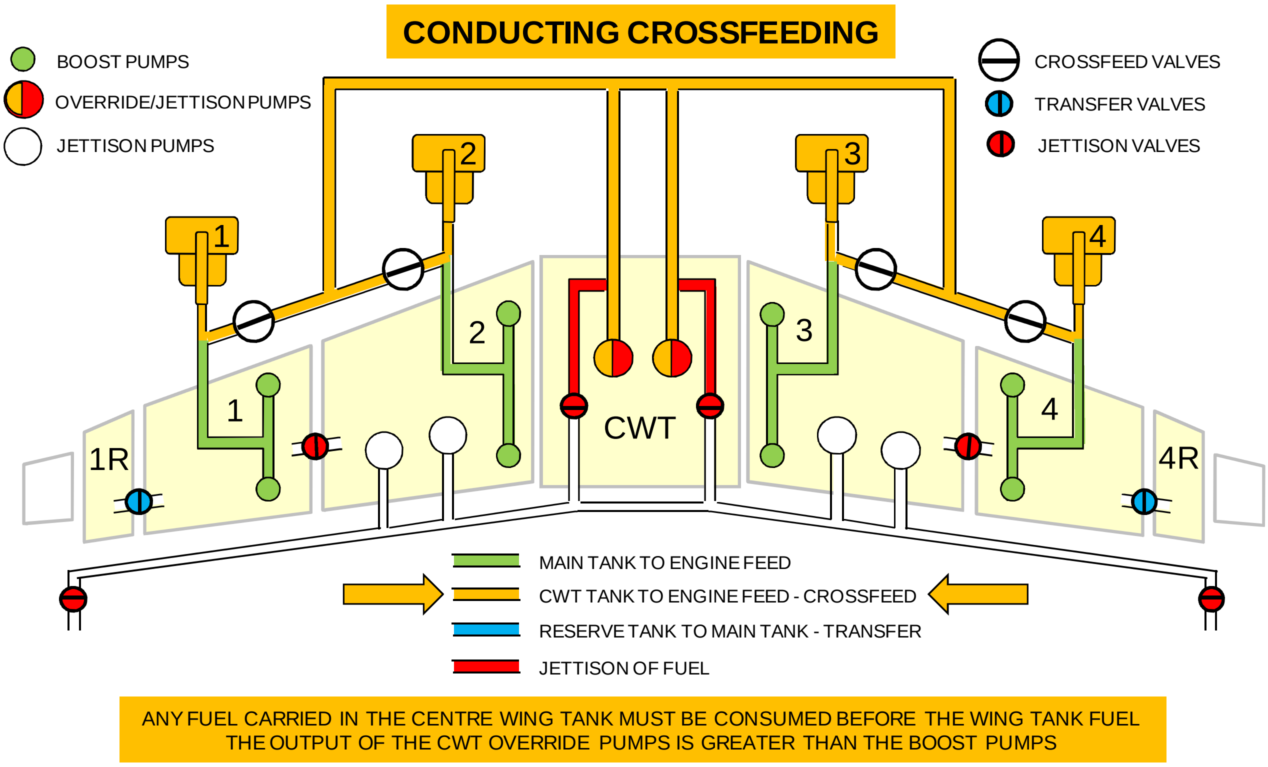

Figure 8-22 Climb and Cruise

At some point during the cruise when the CWT is empty.

Eventually all of the fuel in the CWT will be consumed and the “Low Pressure” caution lights will illuminate for the Override/Jettison Pumps.

The Override/Jettison Pumps are selected OFF and a new crossfeeding configuration is required.

Main Tanks 2 and 3 contain significantly more fuel that Main Tanks 1 and 4, therefore crossfeeding will need to be maintained to even up the Main Tank quantities.

AFTER CWT IS EMPTY – The Boost Pumps in Main Tanks 1 and 4 are turned OFF allowing Main Tanks 2 and 3 to supply fuel to all engines. Refer to Figure 8-23.

For interest, a small Scavenge Pump, not shown in the illustration is turned on to scavenge any remaining fuel from the CWT and transfer it to Main Tank 2.

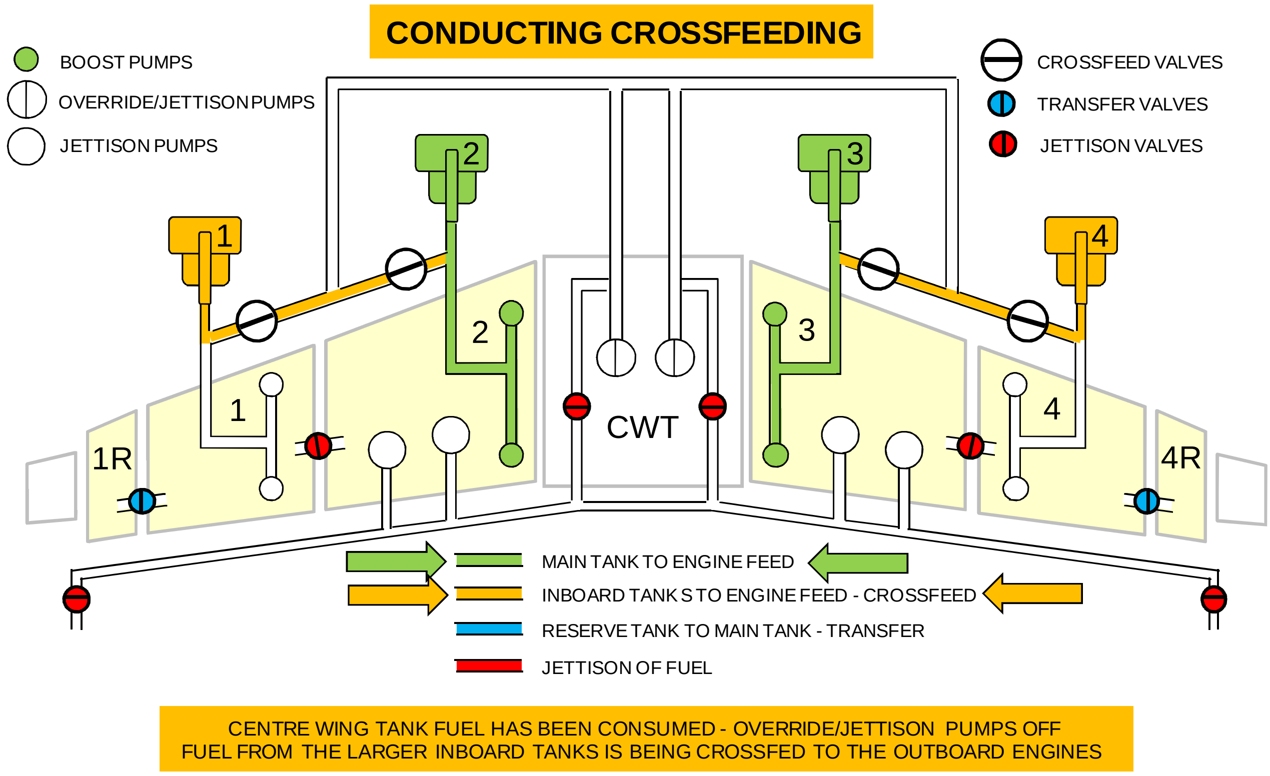

Figure 8-23 Cruise – CWT Empty

At some point during the cruise when the Main Tanks are equal.

When the fuel weight in Main Tanks 2 and 3 equals the fuel weight in Main Tanks 1 and 4 (plus the Reserve Tank fuel) the configuration is changed to suite the equal main tanks.

WHEN MAIN TANKS ARE EQUAL – Main Tanks 1 and 4 Boost Pumps are turned ON and all Crossfeed Valves CLOSED. Refer to Figure 8-24.

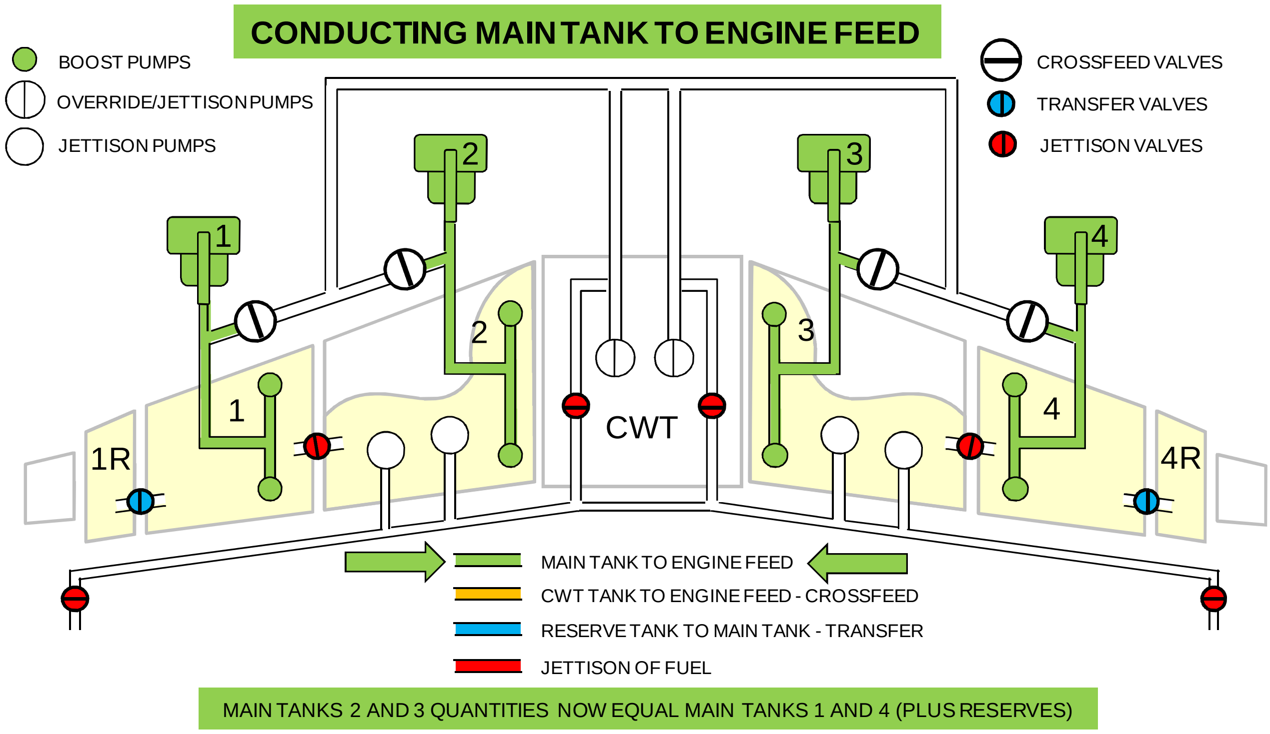

Figure 8-24 Cruise – Equal quantity of fuel remaining for each Engine

At some point during the cruise when nearing destination.

At the appropriate time towards the end of the flight reserve fuel is transferred to Main Tanks from the Reserve Tanks. When transfer is complete each engine will have an equal quantity of fuel in its associated Main Tank for approach and landing.

TRANSFER OF RESERVE FUEL – Reserve Transfer Valves 1 and 4 are selected OPEN. Refer to Figure 8-25.

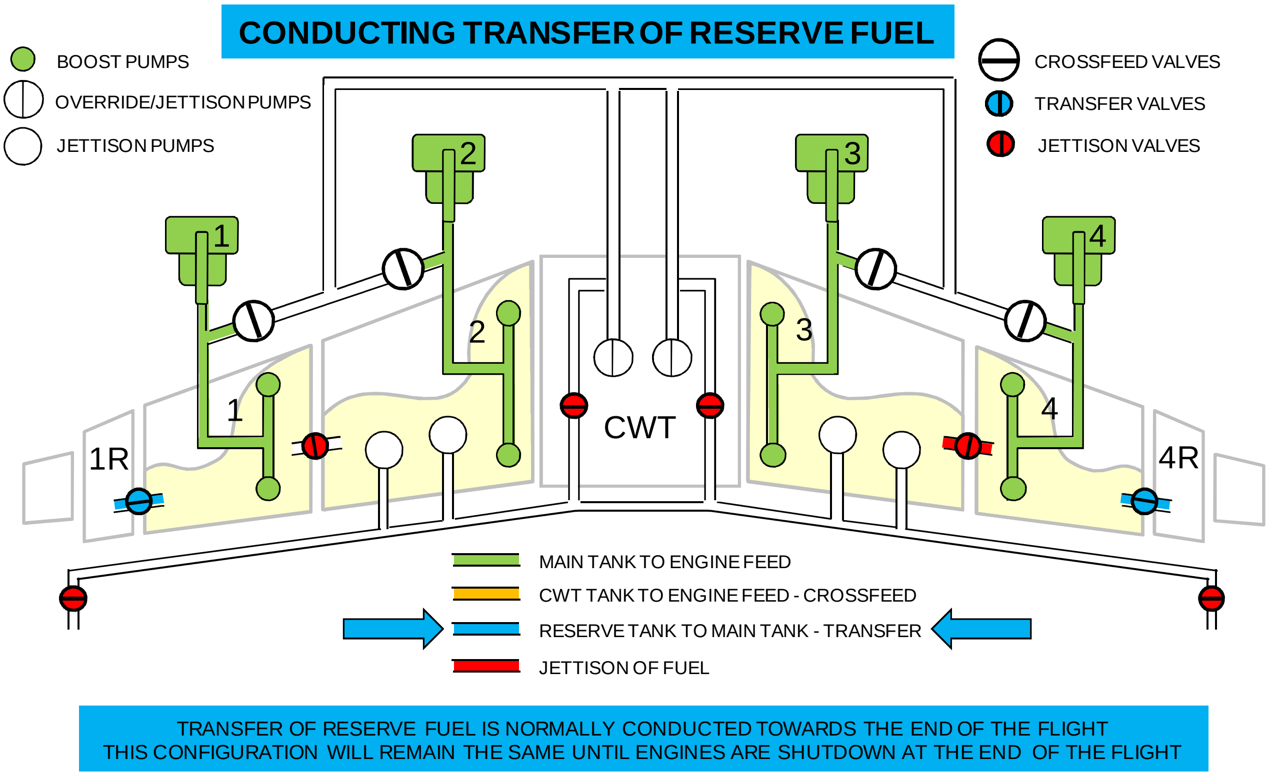

Figure 8-25 Cruise – Transfer of Reserve Fuel

The configuration changes are complete and each Main Tank has an equal amount of fuel for each engine during approach and landing. This configuration will remain the same for the remainder of the flight.

Refer to Figure 8-26, Fuel Control Panel, to see how the configuration changes were carried out.

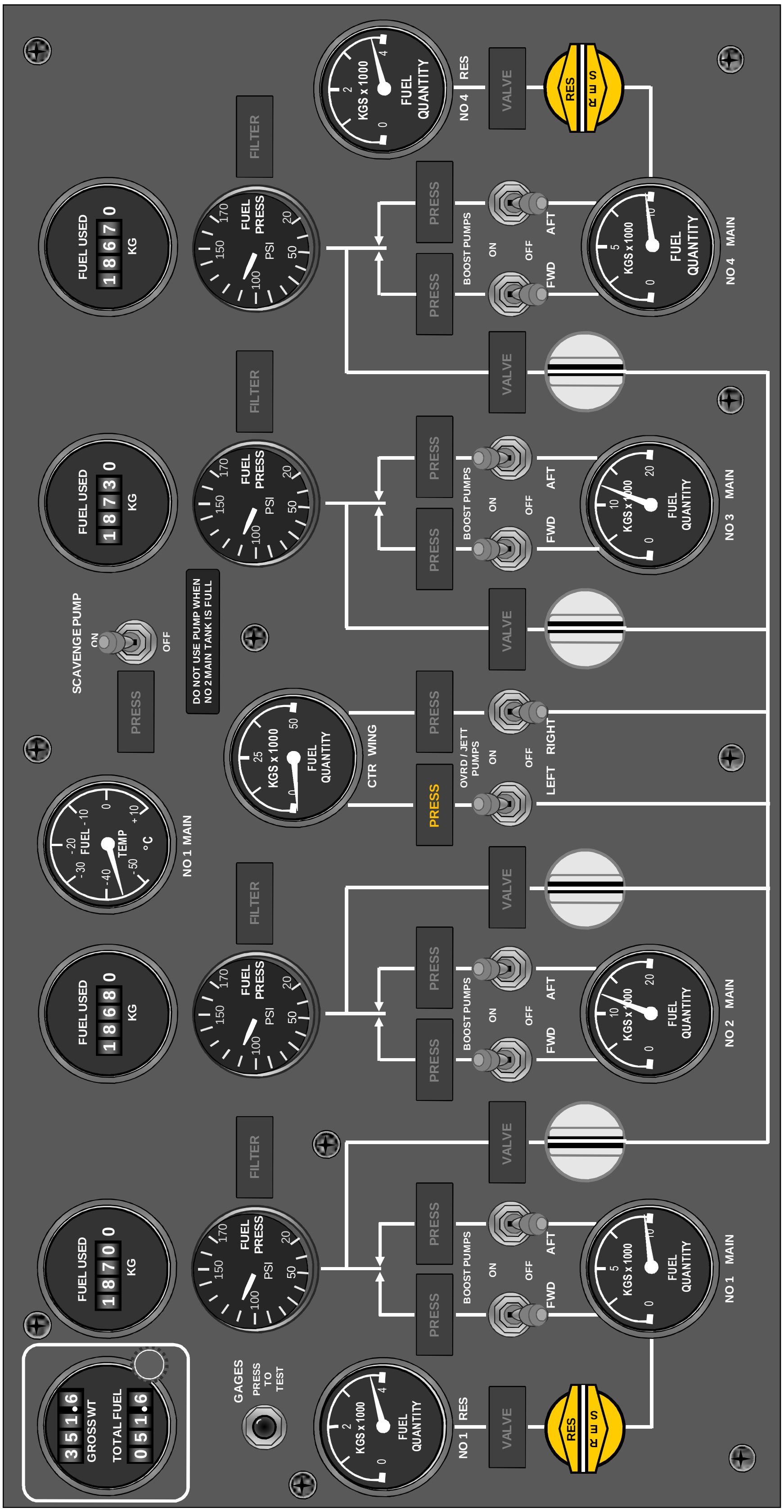

Figure 8-26 Fuel Control Panel

FUEL JETTISON

Fuel Jettison Requirement

In transport category aircraft it may be necessary to jettison fuel in case of an in-flight emergency, to reduce the AUW of the aircraft for landing following an in-flight malfunction or to allow the weight of the aircraft to be reduced to maintain minimum safe height following an engine failure. To facilitate this some aircraft are equipped with a system to allow for fuel to be jettisoned whilst airborne. These requirements are laid down in JAR 25.1001.

The following page is a copy of JAR 25.1001 - Fuel Jettison System.

1. A fuel jettison system must be installed on each aeroplane unless it can be shown that the aeroplane meets the requirements of JAR 25.119 and JAR 25.121 (d) at maximum take-off weight, less the actual or computed weight of fuel necessary for a 15 minute flight consisting of a take-off, go-around, and landing at the airport of departure with the aeroplane configuration, speed, power and thrust the same as that used in meeting the applicable T/Off, approach, landing and climb performance requirements of JAR-25.

2. If a fuel jettison system is required it must be capable of jettisoning enough fuel within 15 minutes, starting with the weight given in subparagraph (a) of this paragraph, to enable the aeroplane to meet the climb requirements of JAR 25.119 and JAR 25.121 (d), assuming that the fuel is jettisoned under the conditions, except weight, found least favourable during the flight tests prescribed in sub-para (c) of this paragraph.

3. Fuel jettison must be demonstrated beginning at maximum take-off weight with wing-flaps and landing gear in and up-

a) A power off glide at 1.4.Vs

b) A climb at one engine inoperative best rate of climb speed, with the critical engine inoperative and the remaining engines at maximum power.

c) During the flight tests prescribed in sub-paragraph (c) of this paragraph, it must be shown that:-

i. The jettison system and its operation are free from fire hazard.

ii. The fuel discharges clear any part of the aeroplane.

iii. Fuel or fumes do not enter any part of the aeroplane.

iv. The jettison operation does not adversely affect the controllability of the aeroplane.

FUEL JETTISON SYSTEMS

A fuel jettison system normally consists of:

- Jettison Pumps, electrically powered, located in the aircraft fuel tanks,
- Jettison Control Valves enabling fuel to be dumped from selected tanks for balance control,
- A jettison manifold running from the Control Valves to the Jettison discharge nozzle(s),
- Jettison nozzle Control Valves, and
- a jettison nozzle or mast, which is sometimes retractable.

It is common for the refuel manifold to be used as a jettison manifold whilst airborne to save weight on additional piping. The manifold must be modified with valves (nozzle valves) fitted on the outboard ends of the manifold. In this case the valves would be automatically closed on landing through the squat switches to allow for refuelling operations. On other systems the fuel to be jettisoned is transferred to the inboard tanks and jettisoned from these tanks through separate manifolds protruding through the rear wing beam and into the airflow.

Referring to the fuel system previously used in this Chapter it can be seen that the jettison system consists of two **JETTISON PUMPS** in each inboard tank (Main Tanks 2 and 3) and two **OVRD/JETTISON PUMPS** in the CWT.

All jettison pumps are connected to the **JETTISON MANIFOLD**. The Main Tank Jettison Pumps are connected directly to the jettison manifold while the CWT Pumps are connected through **JETTISON (control) VALVES** which must be opened. Fuel from Main Tanks 1 and 4 is transferred by gravity through connecting **JETTISON (transfer) VALVES**.

The Jettison pumps are controlled by switches on the flight deck, and may be turned ON and OFF as required to maintain fuel balance and quantity. The jettison pumps are supplied through a **JETTISON STANDPIPE** to allow an adequate reserve of fuel left in the tanks after jettison. Fuel is discharged from the jettison manifold through the **JETTISON NOZZLES** which are controlled by switches in the flight deck.

Jettison Nozzles are typically fitted with spark arrestors to stop any ignited fuel returning back through the nozzle. Refer to Figure 8-27.

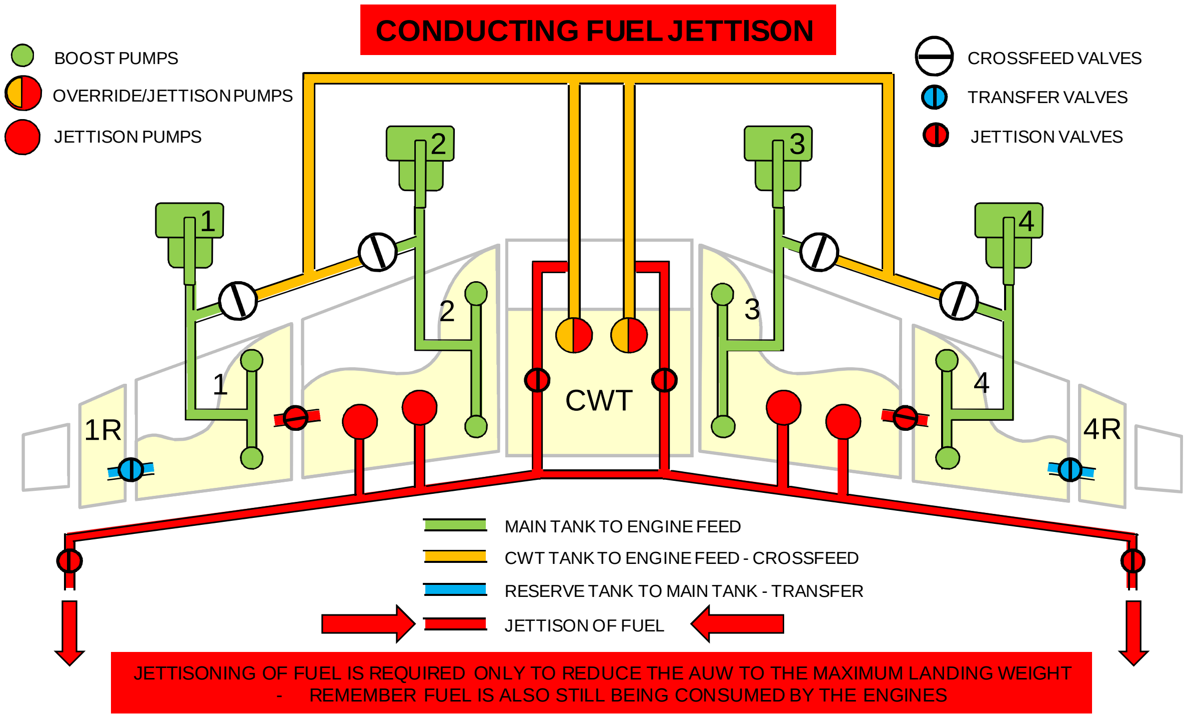

Figure 8-27 Fuel Jettison

FUEL JETTISON PRECAUTIONS

It is important to realise that fuel jettisoning can create environmental problems. Many countries have very strict rules regarding jettisoning of fuel, and correct authorisation from Air Traffic Control must be obtained prior to commencing. It is also important for safety reasons to realise that fuel may ignite from external sources such as ground fires, or from static electricity or lightning. Jettisoning fuel in a circular pattern whilst descending may lead to the aircraft flying through the fuel it is jettisoning, and should be avoided.

Flap position may also have an adverse affect on jettison operations, allowing fuel to be blown into the exhaust area of the engines. Radio and radar may also impose a serious fire hazard if used during jettison, and special procedures may have to be used to maintain positional information with Air Traffic Control authorities.

FUEL JETTISON PROCEDURES

Prior to commencing a fuel jettison the crew should work out the fuel requirements for the aircraft to make a safe recovery to a suitable airfield with suitable reserves. On some modern aircraft the fuel quantity required after jettison can be pre-programmed into the fuel management system, and the pumps will automatically stop when that level is reached.

On some aircraft it will be necessary to place all engines in normal tank-to-engine feed and discontinue the use of crossfeed to ensure correct engine operation. Providing that all the safety precautions referred to in the paragraph above are considered, fuel jettison can now commence.

Remember also that passengers should be made aware of the situation as fuel jettisoning will be seen from the cabin. Refer to Figure 8-28.

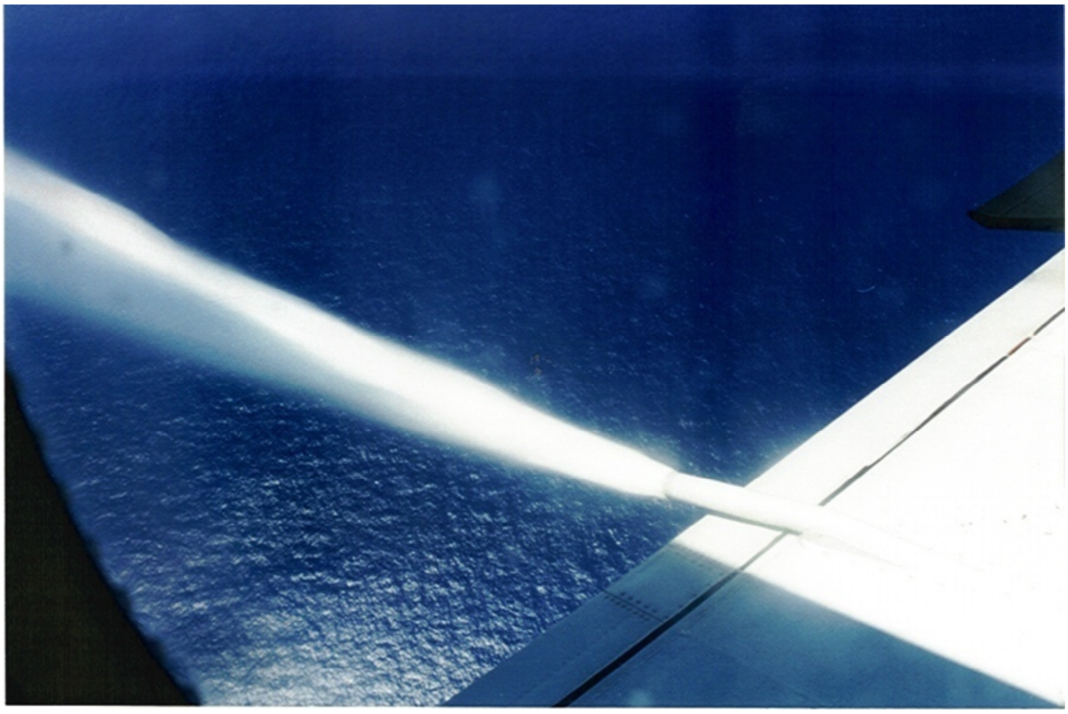

Figure 8-28 Fuel being Jettisoned

During the jettison of fuel it is important to monitor the lateral and longitudinal balance limits for the aircraft type and to ensure that sufficient fuel remains to conduct a safe landing with required reserves.

It may be necessary to turn pumps Jettison Pumps OFF to maintain longitudinal and lateral balance limits. After completing the jettison all switches should be returned to the OFF/NORMAL position, and if required, crossfeed commenced, to ensure lateral balance and correct engine operation is maintained.

Refer to Figure 8-29, Fuel Jettison Control Panel, to see how jettison was carried out.

Figure 8-29 Fuel Jettison Control Panel

FUEL SYSTEM MANAGEMENT

In older large commercial aircraft fuel management was usually handled by the Flight Engineer but in modern aircraft fuel management is actioned by computers with almost no pilot input required.

Typically the fuel system on modern aircraft is displayed on EICAS or ECAM thus illuminating the need for gauges to display fuel quantity, pressure, temperature, flow rate and fuel usage. This of course significantly reduces the size of the Fuel Control Panel in the cockpit.

Refer to Figures 8-30, 8-31 and 8-32 as examples of modern aircraft fuel management display and control.

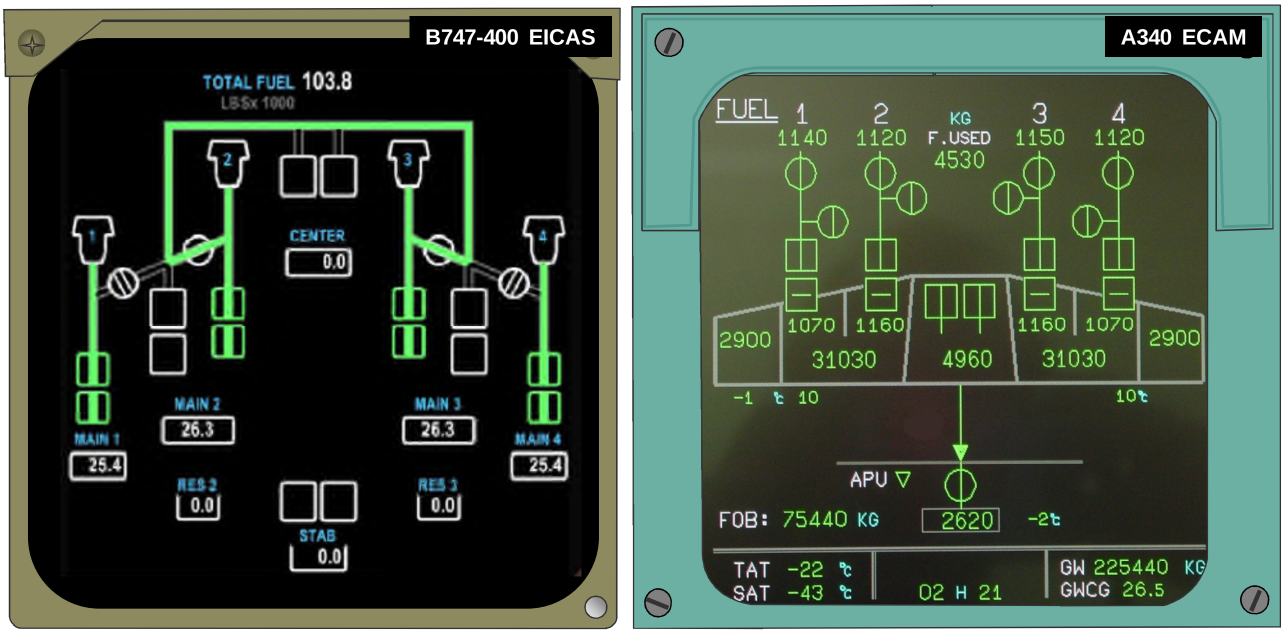

Figure 8-30 Fuel System EICAS and ECAM Displays

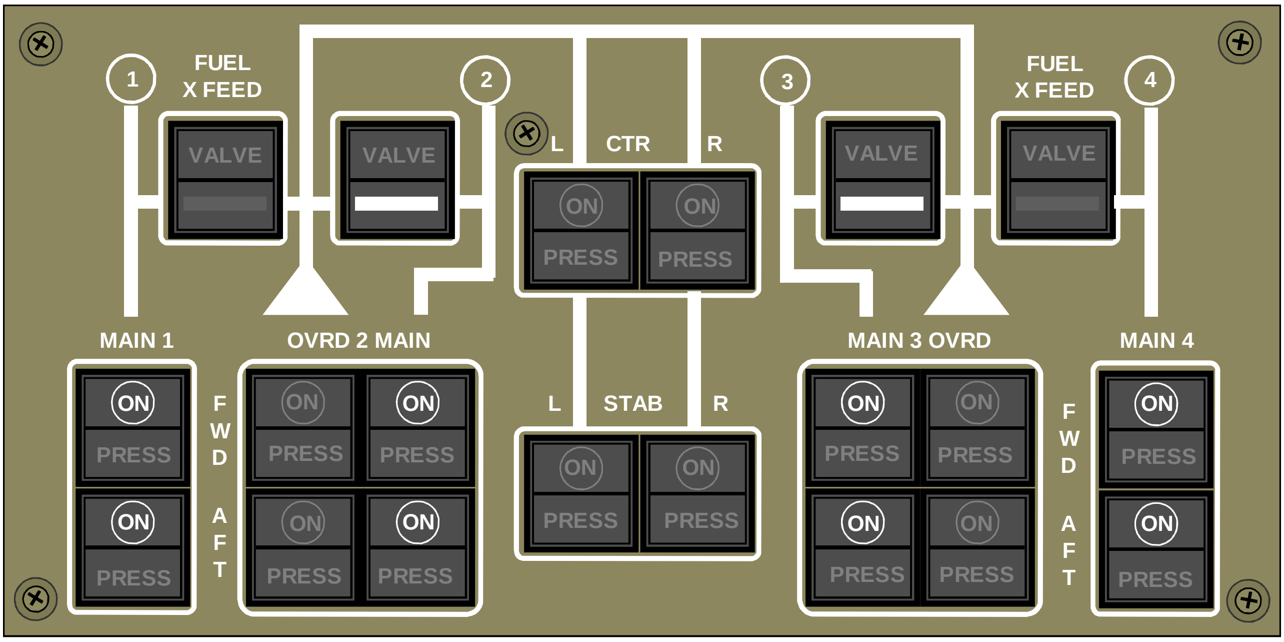

Figure 8-31 B747-400 Fuel Control Panel

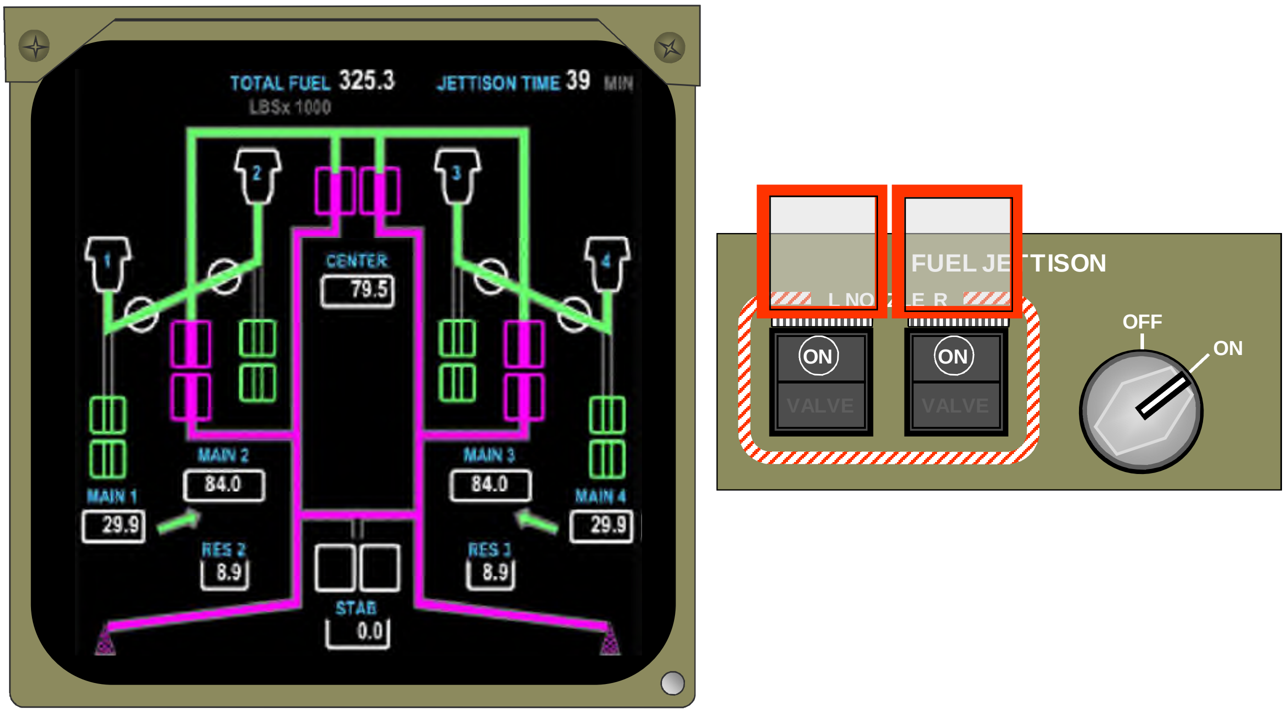

Figure 8-32 B747-400 Fuel Jettison Display and Control Panel

Even when under computer control it is imperative that pilots' maintain a full understanding of the fuel system and are able to monitor the computer operation through all phases of flight. Pilots should be aware of configuration changes taking place and monitor for abnormal situations such as lateral fuel imbalance, longitudinal C of G limitations and wing root loading.

LATERAL IMBALANCE

Most large aircraft fitted with wing tanks have specified maximum imbalance limits between opposing wing tanks, both in the cruise and particularly for take-off. Operation outside the maximum limits may mean the aircraft becomes uncontrollable should an engine fail.

Careful attention must be paid to the operation of the aircraft fuel system after an engine is shutdown during flight, as that engine will not be reducing the fuel load in its Main Tank, and lateral imbalance limits may be exceeded resulting in possible loss of control.

LONGITUDINAL C OF G LIMITATIONS

On large swept wing aircraft the change in C of G position as fuel is burnt is quite marked, and with the incorrect fuel usage sequence it would be possible to move the aircraft's C of G position to outside the normal operating range for landing.

WING ROOT LOADING

When operating an aircraft with tanks contained within the fuselage or tailplane, fuel usage becomes critical. Fuel carried in the wings adds strength and rigidity to the wing structure and helps reduce wing up-bending and the stresses on the wing root area.

If we reduce the wing tank fuel before reducing fuel in the fuselage or tailplane, we are imposing severe loads on the wing roots that may exceed the maximum allowable zero fuel weight limitation of the aircraft.

Correct fuel usage for a large commercial jet would be to feed from the tail tank first, then from the centre section tanks and then, after balancing the wing tank fuel, maintain this balance with direct tank-to-engine feed.

FUEL INDICATION SYSTEMS

Fuel quantity indicators provide the quantity of fuel in each of the aircraft tanks. These are usually of the capacitive system type which measures weight rather than volume, as the energy in the fuel (calorific value) is directly proportional to the weight.

Normal Cockpit Indications

This is one of the mandatory instruments for all powered aircraft, and can vary in type from the simple cork float riding on top of the fuel to the complex dielectric systems in today's modern aircraft.

The most common types of fuel quantity indicating systems are;

- the electrical ratio type, used on reciprocating engined aircraft to measure volume, and
- the capacitance type, used mainly on gas turbine powered aircraft, where weight rather than volume is required.

MEASURING VOLUME

The electrical ratio type system operates by converting the position of the float in the tank to a resistive signal on a tank transmitter unit. A simple example of this type of system is the wiper arm type often found in automobile fuel systems, where the resistance across the wiper arm varies from full to empty. The signal is sent to the flight station where a gauge converts the signal, usually through another wiper arm to a useable value. Refer to Figure 8-33.

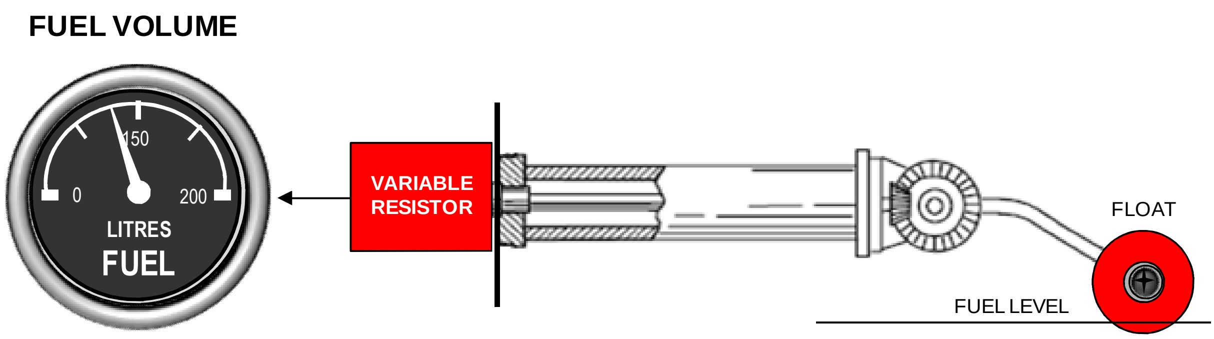

Figure 8-33 Float Type Sender Unit

MEASURING WEIGHT

The capacitive type system employs tubes which act as capacitors. There may be up to twenty probes in a large aircraft tank to allow for the tank's depth and shape. The probes are fitted between the upper and lower surfaces of the tank. When the tanks are empty air will fill the probes and when full fuel will act as the dielectric. The change in dielectric changes the capacitance of the circuit, which is measured by a capacitance bridge circuit.

On large systems the capacitances are summed to give a total of the tank capacity. As the density of the fuel affects its dielectric constant it also affects the capacity of the probe. The system can therefore measure fuel weight rather than volume.

The system can be further modified to adjust fuel reading to allow for changes in fuel temperature, density and specific gravity through the use of a compensator system that will adjust the reference voltage to the bridge circuit for various fuels. Refer to Figure 8-34.

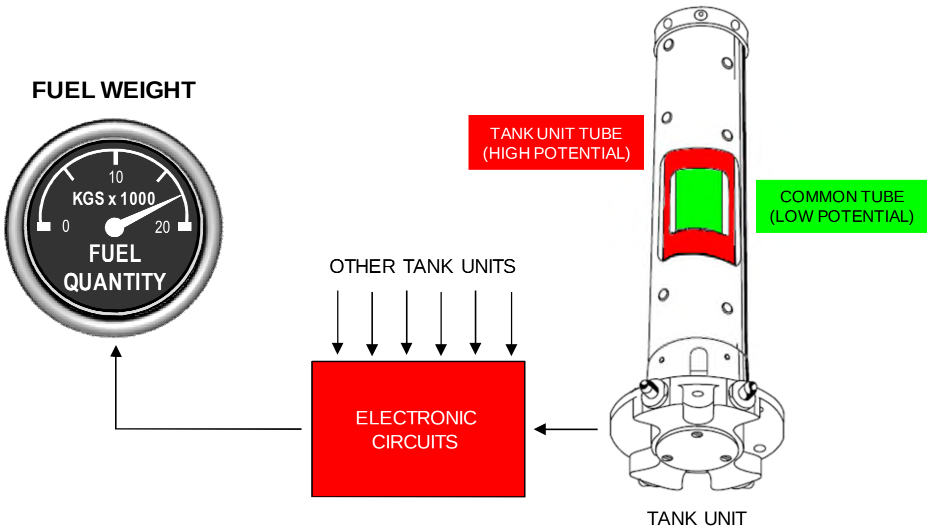

Figure 8-34

Capacitive Type Indicating System

PHYSICAL CHECK METHODS

When cockpit fuel indications are in doubt or individual tank gauges are inoperative a physical check of fuel tank quantity is possible by using the methods described below. When these methods are applied the aircraft must be as level as possible for an accurate reading to be obtained.

DIPSTICKS

Small aircraft carry measuring rods or sticks which are calibrated to read the quantity of fuel in individual tanks. The rods are put into the tank through the over-wing filler caps, the fuel level is referenced by the wet mark left on the stick and a reading of fuel quantity can be obtained from the stick.

Most large commercial aircraft are fitted with a system that enables checking of the fuel tank quantity from the underside of the wing. There are a number of types such as Dripsticks, Magnasticks and Sight Sticks.

DRIPSTICKS

Dripsticks are permanently fitted inside the tank through the underside of the wing. Each tank may have more than one dripstick to allow readings to be taken for different levels in a dihedral wing.

By unlocking and slowly withdrawing a hollow calibrated rod or stick from inside the tank, fuel will eventually begin to drip out from the base of the rod as it submerges below the fuel level in the tank.

At this point a reading of quantity may be obtained from the calibrated rod where it exits the locking assembly.

After a reading has been taken the stick is pushed back into the tank and locked securely for flight. Refer to Figure 8-35.

Large aircraft will have numerous dripsticks in each wing tank and readings will need to be converted from volume (from the stick) to weight as that is the measurement used in large aircraft.

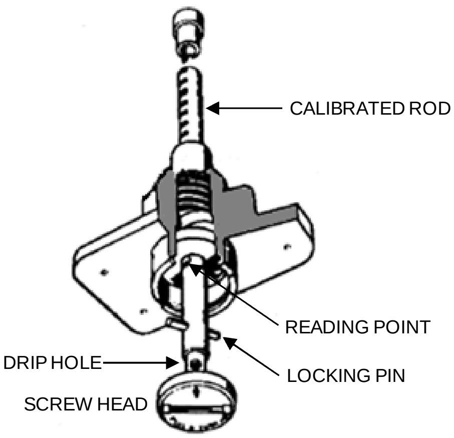

Figure 8-35 Dripstick

MAGNASTICKS

Magnasticks are permanently fitted to the aircraft and are unlocked and withdrawn from the tanks in the same manner as a dripstick, exposing a calibrated rod.

Inside the tank a floating doughnut shaped magnet surrounds the calibrated rod. The top of the calibrated rod also contains a magnet and as it is slowly withdrawn from the underside of the wing the operator will feel the magnets attach when the fuel surface level is reached.

Similar to the Dripstick a reading of quantity is taken at the locking point and the calibrated rod is pushed back into the tank and locked for flight. The floating doughnut magnet will remain floating on the fuel surface. Large aircraft will have numerous magnasticks in each wing tank and readings will need to be converted from volume (from the stick) to weight as that is the measurement used in large aircraft. Refer to Figure 8-36.

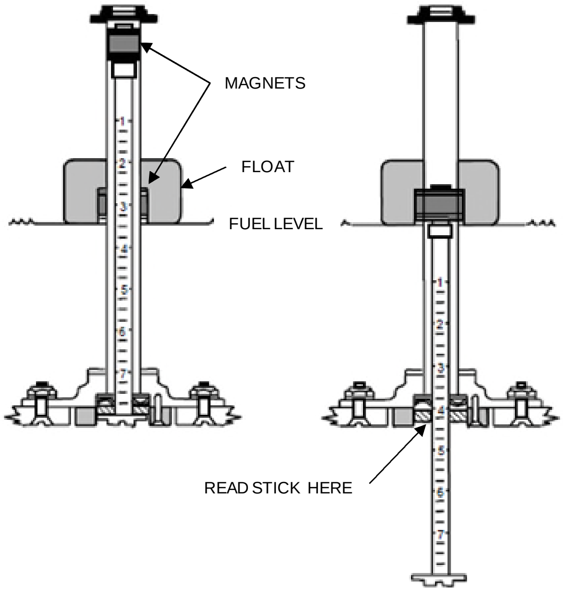

Figure 8-36 Magnastick

SIGHT STICK

Also similar to the previously mentioned methods is the Sight Stick. A permanently fitted calibrated rod is withdrawn from the underside of the tank. As slow withdrawal takes place the operator views a prism located at the bottom of the hollow calibrated rod which is allowing observation of the top of the rod. As the rod submerges into the fuel a change of light occurs at the prism. Once again a reading is taken from the rod and it is pushed back into the tank and secured. Refer to figure 8-37.

Figure 8-37 Sight Stick

FUEL FLOW

Fuel flow metering systems are designed to provide the flight crew with continuous indications of;

- the current fuel flow to the individual engine(s), and
- the amount of fuel each engine(s) has consumed since it was started.

A typical flowmeter consists of two cylinders placed in the fuel stream so that the direction of fuel flow is parallel to the axis of the cylinders. The upstream cylinder, called the impeller, is driven at a constant speed by a motor. This imparts a swirl to the fuel and this swirl drives the turbine which is restrained by a spring. The amount of angular movement of the turbine is proportional to the fuel flow. The turbine position is transmitted to the flight deck indicator by means of a syncro system. Fuel flow meters are designed so that should they fail, full fuel flow will be delivered to the engine. Refer to Figure 8-38.

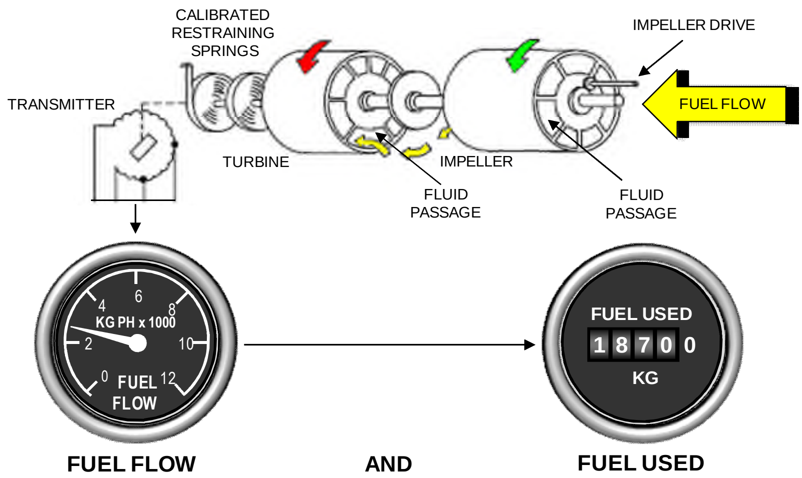

Figure 8-38 Fuel Flow Meter and Indications

FUEL HEATING

Operation at high altitude brings many problems, not the least of which is the problem of temperature. This affects the kerosene fuels used in gas turbine engines by causing any water contained in the fuel to freeze and by causing solid wax like particles to form with fuel temperature below -40°C.

<u>Either of these problems can cause the fuel filters to become blocked.</u>

To prevent the formation of wax an icing inhibitor can be added to the fuel, and this also lowers the minimum temperature at which the fuel may be used from -40°C to -47°C.

To prevent water from blocking filters and affecting engine operation, a fuel heating system is usually fitted. These systems usually use either hot bleed air from the engine or hot engine oil on its way back to the oil tank, or a combination of both. Both systems are usually fully automatic and are thermostatically controlled. Refer to Figure 8-39.

Manual control systems usually incorporate a "Filter Blocked" light in the flight deck which will indicate to the crew that fuel heat is required.

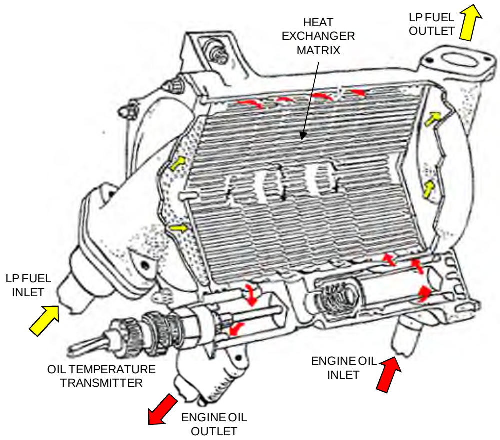

Figure 8-39 Fuel Oil Heat Exchanger

Many commercial airliners have fully automatic fuel heating systems that use engine bleed air to heat fuel, as well as the fuel/oil heat exchanger.

As any air taken off the engine reduces the power output from the engine, fuel flow will have to be increased to re-establish the previous power setting. To alert the crew that the automatic fuel heat system is operating, a light is included. In manual systems an ice light is used to alert the crew to the presence of ice, and a manual "On/Off" switch can be selected ON.

FUEL RESERVES

Any useable fuel on board the aircraft that is not required for the actual flight, from starting engines to engines off can be regarded as fuel reserves for the flight.

The law regarding fuel required for a flight simply says that the aircraft Captain should be satisfied that sufficient fuel is being carried so that the flight and all foreseeable contingencies can be carried out. For Regular Public Transport operations the fuel requirements must be conducted in accordance with the operator’s fuel policy contained in the Operations Manual for the aircraft type, after first having been approved by the appropriate Aviation Authority. The CAA in the UK publishes a guide as to what is acceptable for inclusion in the Operator’s Manual. This guide indicates that the flight should be planned to arrive overhead the destination with sufficient fuel to:

- make an approach to land.
- carry out a missed approach.
- fly to an alternate aerodrome.
- hold at the alternate and then carry out an approach and landing, recognising:
    - a) the minima for propeller-driven aircraft.
    - b) a minima of 1500ft in ISA conditions for jets, and
- allow for contingencies that cause more fuel to be required.

MINIMUM FUEL

With correct flight planning and adequate reserve fuel, the aircraft should be landing with the remaining fuel levels in the main tanks well above the minimum for safe engine operation.

Circumstances may arise when main tank fuel levels are abnormally low for final approach and landing. The Aircraft's Operating Manual will provide a checklist for this situation which usually involves a change to the fuel system configuration and careful operation of the aircraft. Refer to figure 8-40 as an example Minimum Fuel Checklist.

MINIMUM FUEL OPERATION

E	All Main Tank Boost Pump Switches	ON
E	All Crossfeed Valves	OPEN
C	Nose Up Body Angle	8° MAX
ALL	Go-around Procedure	REVIEW

- Do not use go-around mode on flight director or go-around mode on autopilot.
- Apply thrust slowly and smoothly (avoid rapid acceleration of aircraft).
- Maintain MIM nose up body angle required for safe climb gradient.
- Retract flaps to 20 and maintain VREF + 30 KIAS or higher throughout go-around.
- Retract landing gear at positive rate of climb.
- In any main tank boost pump low pressure lights illuminate, do not select boost pump switches OFF.
- If aft boost pump low pressure lights illuminate, reduce nose up body attitude.

CHECKLIST COMPLETE

* * * * *

Figure 8-40 Example Minimum Fuel Procedure

FUEL SYSTEM TERMINOLOGIES AND DEFINITIONS

The following defines old and/or common terms that you may encounter with reference to fuel systems. Refer to Figure 8-41.

TERM REFERRED	DEFINITION
Fuel Boiling	The temperature at which fuel boils will vary with the pressure on its surface. As an aircraft climbs, the pressure on the surface of the fuel reduces and with that reduction comes an increased likelihood that the fuel will boil and form vapour. The vapour locks that this effect causes will effectively cut off the fuel supply to the engine with the inevitable result that the engine will stop.
Vapour lock	Associated more with piston engines but is the result of the above.
Fuel Dumping	Same as fuel jettison.
Fuel Crossfeed	Feeding fuel from a tank (other than the MAIN tank) to an engine.
Fuel Transfer	Moving fuel from one tank to another tank.
Fuel Trimming	Moving fuel by transferring tank to tank for the purpose of keeping the CofG in the most desirable position for cruise.
Fuel Tankering	Carrying fuel that is required for the next sector(s) rather than refuelling at each port. Usually due to fuel cost and or airport fuel delivery charges.
Fuel Ballast	Carrying fuel in a specific tank to help maintain a CofG position. This fuel is treated as dead weight or load and is not used during the flight.
Fuel Heater-Strainer	Another common name for a Fuel/Oil Heat Exchanger.
Spar Valve	Another name for the Low Pressure (LP) Fuel Shut-off Valve for the engine.
LP Cock	Another name for the Low Pressure (LP) Fuel Shut-off Valve for the engine.
Firewall Shut-off Valve	Another name for the Low Pressure (LP) Fuel Shut-off Valve for the engine.
Entrained water	Another term for water particles suspended in fuel.
Fuel Common Code	Examples JET A, JET A1, JET B International
Fuel USA Code No.	Jet Petroleum examples, JP-4, JP-8 USA
Fuel NATO Code No	Examples F-34, F-35 Military
Fuel DERD Code No.	Directorate of Engineering Research and Development examples DERD 2453 United Kingdom

Figure 8-41 Fuel Terms and Definitions

FUEL SYSTEMS QUESTIONS

The following questions will examine your understanding of hydraulic systems and their operation. The answers may be found in the text or diagrams of this Handbook.

1. An integral fuel tank is one which is;

a. constructed of aluminium alloy and fitted in the fuselage.
b. incorporated in the aircraft wing structure.
c. constructed from reinforced sheeting.

2. AVGAS 100 LL is coloured;

a. red.
b. green.
c. blue.

3. AVTUR is generally available as JET A-1 and at +15°C has a specific gravity of;

a. 0.807.
b. 0.720.
c. 0.809.

4. Compared to AVGAS, MOGAS is;

a. less volatile and therefore more likely to cause vapour locking and carburettor icing.
b. more volatile and therefore less likely to cause vapour locking and carburettor icing.
c. more volatile and therefore more likely to cause vapour locking and carburettor icing.

5. JET A-1 fuel may have FSII added to;

a. prevent fungus growth and inhibit fuel icing.
b. reduce fire spread and inhibit fuel icing.
c. prevent fungus growth and intake icing.

6. AVTAG is;

a. an acceptable alternative to AVTUR.
b. gasoline for general use in turbo-prop aircraft.
c. a wide-cut fuel unacceptable for use in passenger carrying aircraft.

7. The colour coding for AVGAS refuellers and aircraft refuelling points is;

a. red, with white lettering and a blue line.
b. black, with white lettering.
c. red, with black lettering.

8. The colour coding for AVTUR refuellers and aircraft fuelling points is;

a. green, with white lettering.
b. black, with JP-4 in white lettering.
c. black, with JET A-1 in white lettering.

9. During over-wing refuelling;

a. the aircraft must be bonded to the refuelling vehicle and the fuel nozzle must be bonded to the aircraft structure.
b. the aircraft need only be bonded to the refuelling vehicle.
c. the fuel nozzle need only to be bonded to the aircraft structure.

10. The purpose of the booster pump in a fuel feed system is to provide a positive supply to the engine driven pump;

a. at all times.
b. during critical phases of flight.
c. during engine start only.

11. Fuel tanks are vented to atmosphere;

a. to prevent a partial vacuum forming.
b. to allow fuel to vent overboard on hot days.
c. to prevent hazardous vapour forming in the tank.

12. Fuel tanks on parked aircraft should be filled;

a. to prevent corrosion.
b. to prevent condensation.
c. to prevent fungus growth.

13. In a multi-engined aircraft fuel system, with all engines operating, normal procedure is;

a. each main tank supplies one engine.
b. all engines are supplied from a single main tank.
c. all tanks are permanently interconnected to supply all engines.

14. If both booster pumps in a tank fail;

a. the engine driven LP pump will continue to supply the engine under all operating conditions.
b. height may have to be reduced.
c. the affected engine will have to be shutdown.

15. Unusable fuel is;

a. contingency fuel for inflight emergencies.
b. fuel which is excess to the requirements of the planned flight.
c. fuel which the booster pumps cannot remove from the tank.

16. Fuel jettisoning is carried out;

a. through a separate system, using the jettisoning pump.
b. through the refuelling gallery using all the booster pumps.
c. through a jettisoning valve in the bottom of the fuel tank.

17. The usual fuel system indications in a large aircraft are;

a. tank contents and low pressure warning.
b. tank contents, tank temperature, LP fuel pressure.
c. tank contents, LP fuel temperature and pressure, fuel flow, system valve position, booster pump failure warning.

18. Fuel may be heated in order to prevent;

a. filter clogging due to waxing and ice crystals.
b. fuel freezing in the fuel tanks.
c. vaporisation in the fuel feed system.

19. In an engine oil/fuel heat exchanger, heat is transferred from;

a. fuel to lubricating oil.
b. lubricating oil to fuel.
c. hydraulic oil to fuel.

20. In a manually controlled fuel heating system, the warning lamp is activated by;

a. a temperature sensor at the booster pump outlet.
b. temperature sensors in the fuel tanks.
c. pressure differential across the fuel filter.