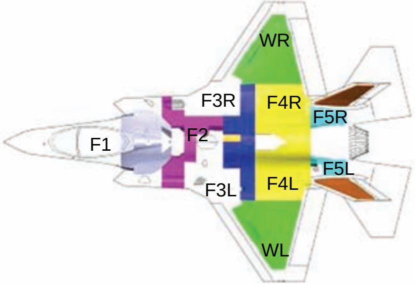


Seven tanks: Nominal 18,001b of fuel

F1 Centre Fuselage

F2 Centre Fuselage

F3 Engine Feed Tank (F3L & F3R) F4

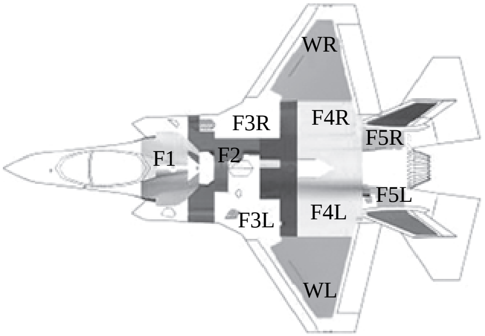
Wing carry-Throught (F4L & F4R) F5

Aft Fuselage (F5L & F5R)

WL Left Wing Box

WR Right Wing Box

Plate 2 Joint strike fighter fuel tank layout (Courtesy of BAE Systems) (See Figure 3.10) http://www.mecatronica.eesc.usp.br/wiki/upload/f/fa/2008_OK_Aircraft_Systems.pdf



Seven Tanks: Nominal 18,000 lb of fuel:

F1 Centre Fuselage

F2 Centre Fuselage

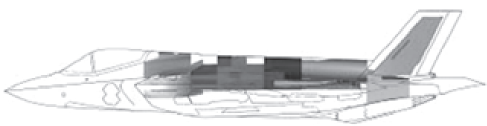
F3 Engine Feed Tank (F3L & F3R)

F4 Wing Carry-Through (F4L & F4R)

F5 Aft Fuselage (F5L & F5R)

WL Left Wing Box

WR Right Wing Box



3.5 Fuel System Operating Modes

The modes of operation described in the following paragraphs are typical of many aircraft fuel systems. Each is described as an example in a particular fuel system. Any system may exhibit many but probably not all of these modes. In an aircraft the fuel tanks and components have to compete with other systems, notably structure and engines for the useful volume contained within the aircraft profile. Therefore fuel tanks are irregular shapes and the layman would be surprised by how many tanks there are, particularly within the fuselage where competition for usable volume is more intense. The proliferation of tanks increases the complexity of the interconnecting pipes and certainly does not ease the task of accurate fuel measurement. As an example of a typical fighter aircraft fuel tank configuration see Figure 3.14 that shows the internal fuel tank configuration for EAP.

This is a simplified diagram showing only the main fuel transfer lines; refuelling and vent lines have been omitted for clarity. Whereas the wing fuel tanks are fairly straightforward in shape, the fuselage tanks are more numerous and of more complex geometry than might be supposed. The segregation of fuel tanks into smaller tanks longitudinally (fore and aft) is due to the need to avoid aircraft structural members. The shape of most of the fuselage tanks also shows clearly the impositions caused by the engine intakes. Furthermore as an experimental aircraft EAP was not equipped for in-flight refuelling nor was any external under-wing or ventral tanks fitted. It can be seen that a fully operational fighter would have a correspondingly more complicated fuel system than the one shown.

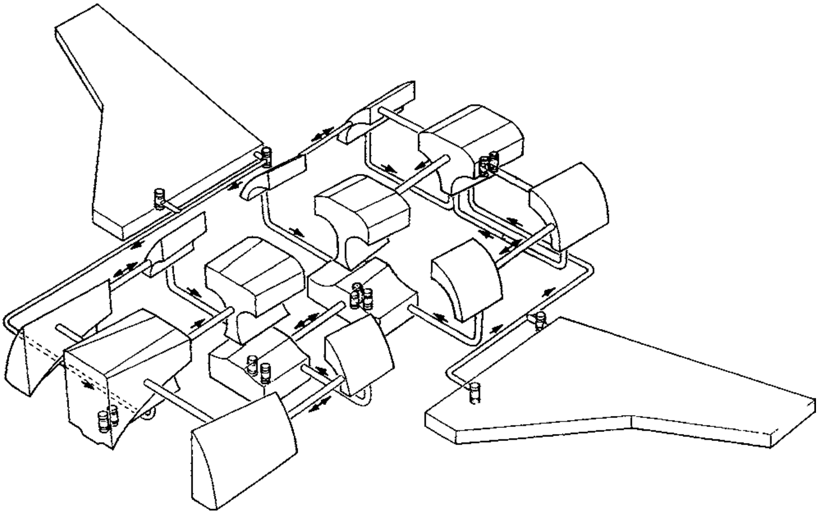


Figure 3.14 Simplified EAP fuel system (Courtesy of BAE Systems)

3.5.1 Pressurisation

Fuel pressurisation is sometimes required to assist in forcing the fuel under relatively low pressure from certain tanks to others that are more strategically placed within the system. On some aircraft there may be no need for a pressurisation system at all; it may be sufficient to gravity feed the fuel or rely on transfer pumps to move it around the system. On other aircraft ram air pressure may be utilised to give a low but positive pressure differential. Some fighter aircraft have a dedicated pressurisation system using high pressure air derived from the engine bleed system.

The engine bleed air pressure in this case would be reduced by means of pressure reducing valves (PRVs) to a more acceptable level. For a combat aircraft which may have a number of external fuel tanks fitted the relative regulating pressure settings of the PRVs may be used to effectively sequence the transfer of fuel from the external and internal tanks in the desired manner. For example, on an aircraft fitted with under-wing and under-fuselage (ventral) tanks it may be required to feed from under-wing, then the ventral and finally the internal wing/fuselage tanks. The PRVs may be set to ensure that this sequence is preserved, by applying a higher differential pressure to those tanks required to transfer fuel first.

In some aircraft such as the F-22, inert gas is used to pressurise the fuel tanks. Inert gas for this purpose can be obtained from an On-Board Inert Gas Generating System (OBIGGS).

3.5.2 Engine Feed

The supply of fuel to the engines is by far the most critical element of the fuel system. Fuel is usually collected or consolidated before being fed into the engine feed lines. The example in Figure 3.15 shows a typical combat aircraft, the fuel is consolidated in two collector tanks; one for each engine.

This schematic diagram may be reconciled with the EAP example depicted in Figure 3.14. The fuel transfer from the aircraft fuel tanks into the collector tanks is fully described in the fuel transfer section.

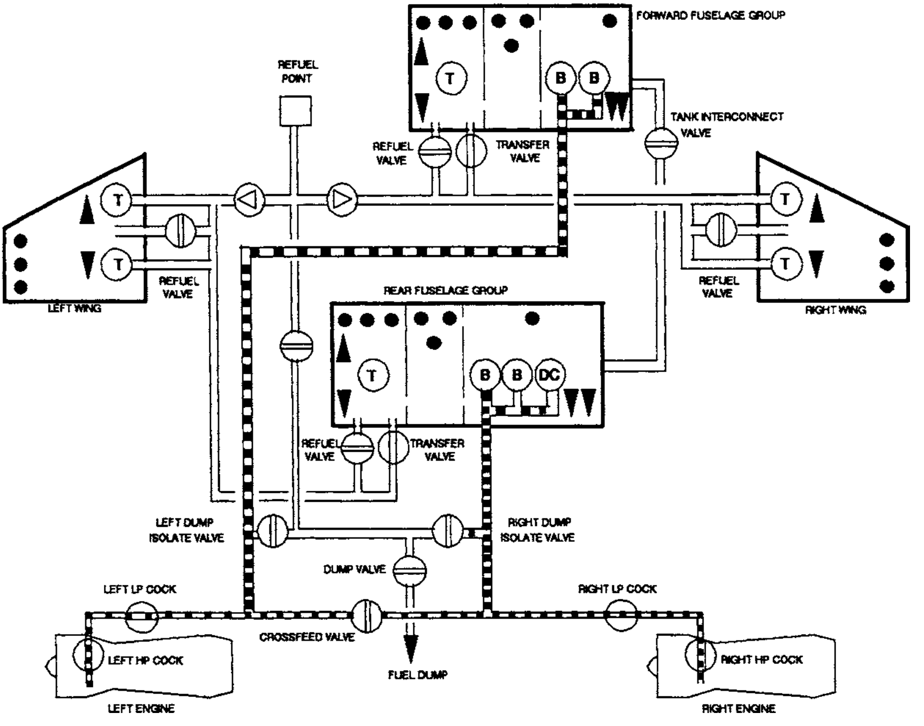


Figure 3.15 Typical fighter aircraft engine feed

The collector tanks may hold sufficient fuel for several minutes of flying, depending upon the engine throttle settings at the time. The contents of these tanks will be gauged as part of the overall fuel contents measuring system; however, due to the criticality of the engine of the engine fuel feed function additional measurement sensors are added. It is usual to provide low-level sensors that measure and indicate when the collector tanks are almost empty. These low-level sensors generate critical warnings to inform the pilot that he is about to run out of fuel and that the engine will subsequently flame out. The low-level warnings are a last ditch indication that the pilot should be preparing to evacuate the aircraft if he is not already doing so.

The collector tanks contain the booster pumps that are pressurising the flow of fuel to the engines. It is usual for two booster pumps to be provided so that one is always available in the event that the other should fail. Booster pumps are immersed in the fuel and for a combat aircraft the scavenge pipes feeding fuel to the pump inlets will have a provision such that a feed is maintained during inverted or negative-g flight. Note that the booster pump example shown in Figure 3.4 had such a facility. Booster pumps are usually powered by 115V AC three-phase motors of the type described in Chapter 5 – Electrical Systems. However the motor itself is controlled by a three-phase relay, the relay coil being energised by a 28V DC supply. An auxiliary contact will provide a status signal back to the fuel management system, alternatively a pressure switch or measuring sensor may be located in the delivery outlet of the pump which can indicate that the pump is supplying normal delivery pressure. Booster pumps are fuel lubricated and also have the capability of running dry should that be necessary.

Downstream of the booster pump is the engine high pressure (HP) pump which is driven by the engine accessory gearbox. Engine HP pumps are two-stage pumps; the first stage provides pressure to pass the fuel through heat exchangers and filters and to provide a positive inlet pressure to the second stage. The second stage supplies high pressure fuel (around 1500 to 2000 psi) to the engine fuel control system.

A number of shut-off valves are associated with the control of fuel to the engine. A pilot operated low pressure (LP) cock provides the means of isolating the fuel supply between the booster pump and the HP engine driven pump. This valve may also be associated with a firewall shut-off function which isolates the supply of fuel to the engine compartment in the event of an engine fire. A cross-feed valve located upstream of the LP cocks provides the capability of feeding both engines from one collector tank if necessary; in most cases the cross-feed valve would be closed as shown in Figure 3.15. The pilot may also operate a high pressure (HP) cock that has the ability to isolate the fuel supply on the engine itself. In normal operation both the LP and HP cocks re open allowing an unimpeded supply of fuel to the engine. The cocks are only closed in the case of normal engine shut-down or in flight following an engine fire.

3.5.3 Fuel Transfer

The task of fuel transfer is to move fuel from the main wing and fuselage tanks to the collector tanks. In commercial transport there tend to be fewer tanks of more regular shape and transfer pumps may merely be used for redistributing fuel around the tanks. In the example given in Figure 3.16 the fuselage and wing tanks for the Experimental Aircraft Programme (EAP) are shown. The main tankage comprises left and right wing tanks and forward and rear fuselage tanks.

Two transfer pumps are provided in each wing tank and two in each of the fuselage groups. Transfer pumps are usually activated by the level of fuel in the tank that they supply. Once the fuel has reached a certain level measured by the fuel gauging system, or possibly by the use of level sensors, the pumps will run and transfer fuel until the tank level is restored to the desired level. In the EAP this means that the forward and rear groups are replenished from the left and right wing tanks respectively in normal operation. The fuselage groups in turn top up the collector tanks with the aid of further transfer pumps. The tank interconnect valve also provides for fuel crossfeed from one fuel system (left/forward) to the other (right/rear) which allows fuel to be balanced between left and right or permits one system to feed both engines if the need arises. Transfer pumps operate in a similar fashion to booster pumps; they are also electrically operated by 115 VAC three-phase electrical power driving an induction motor. The duty cycle of the transfer pumps is not continuous like the booster pumps, rather their operation is a periodic on-off cycle as they are required to top up the relevant aircraft tanks subject to fuel demand.

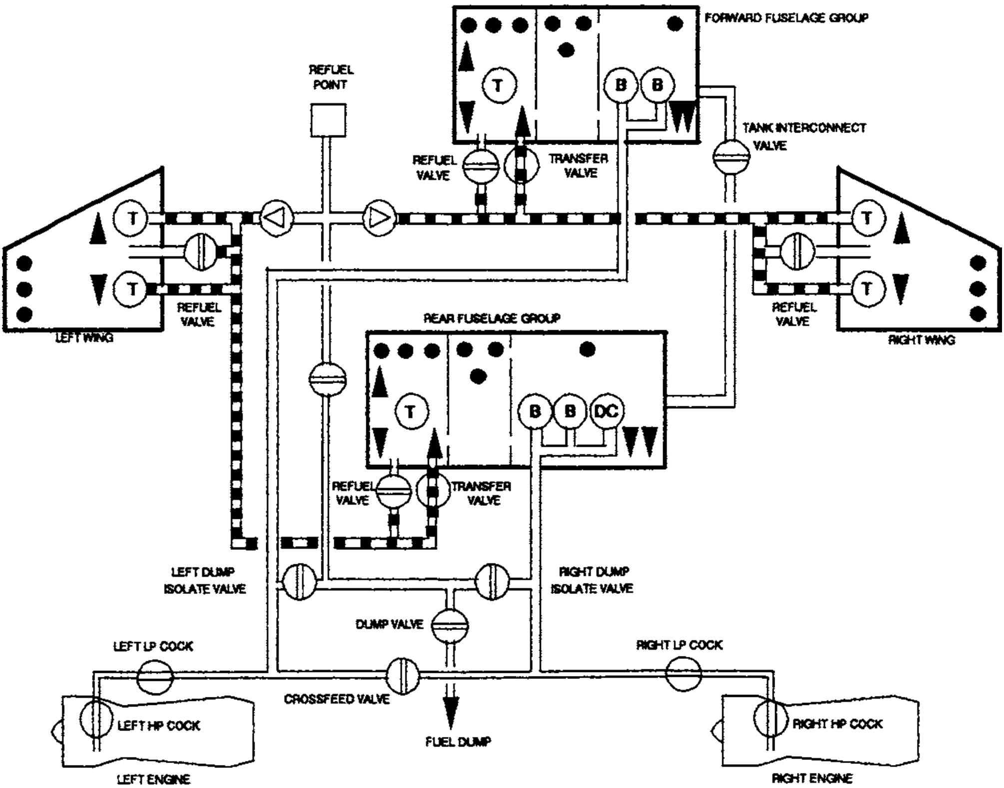


Figure 3.16 EAP fuel transfer operation

It should also be noted that fuel transfer in some aircraft may be performed in order to modify the fuel CG so that the aircraft longitudinal and lateral CG are kept within strict limits. This may be for economy reasons, to maintain an optimum trim, or it may be ensure that the Flight Control System (FCS) is able to interpret pilot inputs to obtain optimum performance without damaging the aircraft. This means that the fuel system and FCS must exchange information with appropriate integrity and this can significantly affect the design of each system. Examples of where this is implemented are highly agile aircraft such as Eurofighter Typhoon and F-35.