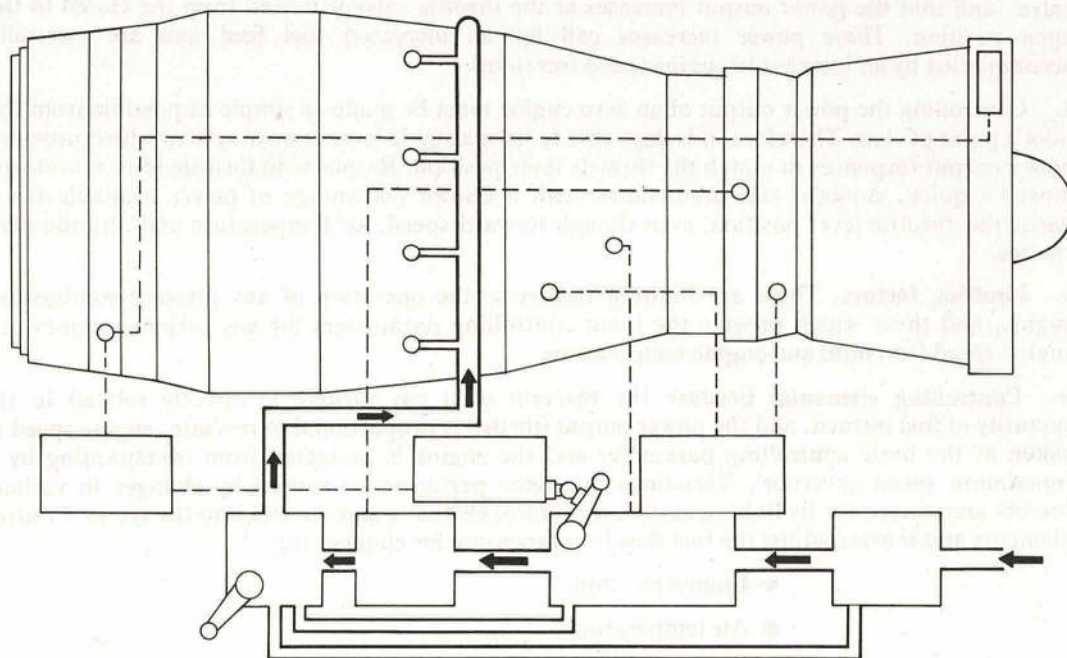


## CHAPTER 4

### GAS TURBINE ENGINE FUEL SYSTEMS



#### Objectives

1. The objective of this Chapter is to cover the relevant Skill and Knowledge Specifications (SAKS) for the trade of Aircraft Fitter (Propulsion) in the subject of gas turbine engine fuel systems including:

- Fuel pumps
- Barometric controls
- Spill valves
- Fuel control units
- Max rev/min governors
- Throttle valves
- Acceleration control

#### Introduction

2. Chapter 3 of this section introduced the requirements for gas turbine engine and propeller

turbine engine fuel systems. In this Chapter we continue by describing each type of fuel system in greater detail to cover fully the needs of the propulsion fitter. Gas turbine engine fuel systems are categorised under the following headings:

- Pressure control fuel systems
- Flow control fuel systems
- Combined acceleration and speed control fuel systems
- Pressure ratio control fuel systems

### Engine Control

3. Before delving into the operation of individual and somewhat complex fuel systems, it is necessary to consider the objectives to be achieved by a fuel system. In this respect, it is generally known that the power output of an internal combustion engine is varied by operating a 'throttle valve', and that the power output increases as the throttle valve is moved from the closed to the open position. These power increases call for an increased fuel feed and are generally accompanied by an increase in engine speed (rev/min).

4. Controlling the power output of an aero engine must be made as simple as possible from the pilot's point of view. Therefore, it is desirable to have a single lever control system which provides power output responses to match the throttle lever position. Response to throttle lever movement must be quick, smooth, and predictable, with a known percentage of power available for a particular throttle lever position, even though forward speed, air temperature and altitude may change.

5. **Limiting factors.** There are limiting factors to the operation of any internal combustion engine, and those which provide the main controlling parameters for gas turbine engines are engine speed (rev/min) and engine temperature.

6. **Controlling elements.** Because the rev/min of a gas turbine is directly related to the quantity of fuel burned, and the power output (thrust) is proportional to rev/min, engine speed is taken as the basic controlling parameter and the engine is protected from overspeeding by a 'maximum speed governor'. Variations in engine performance caused by changes in various factors are catered for by linking automatic control elements and sensors into the system. Control elements and sensors adjust the fuel flow to compensate for changes in:

- Engine rev/min
- Air temperatures
- Air pressure (barometric pressure)
- Turbine gas temperatures
- Aircraft forward speed
- Throttle position (engine acceleration)

7. No matter how the fuel flow is controlled, the fuel system must provide the engine with fuel in a condition suitable for combustion, and in quantities to provide the engine thrust selected by the throttle lever. Because the fuel flow rate must change to satisfy the variants listed in para 6, automatic controlling devices are included in the system to cater for all changes except basic power selection; power selection is achieved by manual operation of the throttle (or power) lever.

8. **Fuel shut off.** Once ignited, the flame in the combustion chamber burns continuously until the fuel flow ceases; to stop the engine, the fuel flow must be interrupted and, therefore, to shut down the engine, a fuel 'shut-off' valve is provided in the form of the 'high pressure cock'. Some manufacturers connect the high pressure (HP) cock and the throttle valve to the same lever to give 'single lever control' of the engine.

## FUEL FLOW CONTROL

9. The control of the fuel flow between the fuel pump and the engine burners may be:

- Hydro-mechanical
- Mechanical
- Electronic

10. **Hydro-mechanical principle.** The method of controlling fuel flow in most modern fuel systems is hydro-mechanical — *ie* the fuel is used in the hydraulic sense to transmit control impulses and to provide the power needed for changing the fuel pump output to meet varying engine demand. This type of control is based upon the fact that the amount of fluid flowing through an orifice depends upon the area of the orifice and the square root of the pressure drop across the orifice. Thus the amount of fuel flowing through the orifice can be varied by changing:

- The area of the orifice
- The pressure drop across the orifice

11. **Mechanical control.** Some later types of fuel systems, such as 'Acceleration and Speed Control Systems', are designed to operate under mechanical controls or combined mechanical or hydro-mechanical control.

12. **Electronic control.** At the present time computerised electronic control of engine fuel systems is used mainly in helicopters, such as the Whirlwind, Wessex and Sea King.

### Fuel System Components

13. Each fuel system is built up from a number of components which can be studied independently and then dove-tailed into a complete fuel system. The minimum number of components for a functional fuel system will be:

- A high pressure fuel pump.
- A number of automatic controlling devices combined into a fuel control unit (FCU).
- Suitable flexible and rigid pipe lines to contain the flow.
- A number of fuel burners.
- A manually operated throttle valve.

### Fuel Pumps

14. **Types of fuel pumps.** The high pressure fuel pump used in gas turbine engine fuel systems will be one of the following types:

- Variable stroke multi-plunger (reciprocating piston).
- Spur gear, with a pressure relief valve controlled output.

### Variable Stroke Multi-plunger Fuel Pump

15. These fuel pumps are in more general use than the spur gear pump and their output is controlled by changing the angle of an integral camplate which, in turns, alters the length of the pumping stroke to adjust the fuel delivery into the system. The control elements and devices in the system act to bring about changes in camplate angle, and changes in fuel flow are always brought about by altering the camplate angle. Thus all the controlling devices are in some way connected to the camplate mechanism and interact with the fuel pump. The connection is usually hydraulic and this is why the control is classified as hydro-mechanical. Just how control of the pump output can be achieved is described in the following paragraphs and illustrated in Fig 2.4.1.

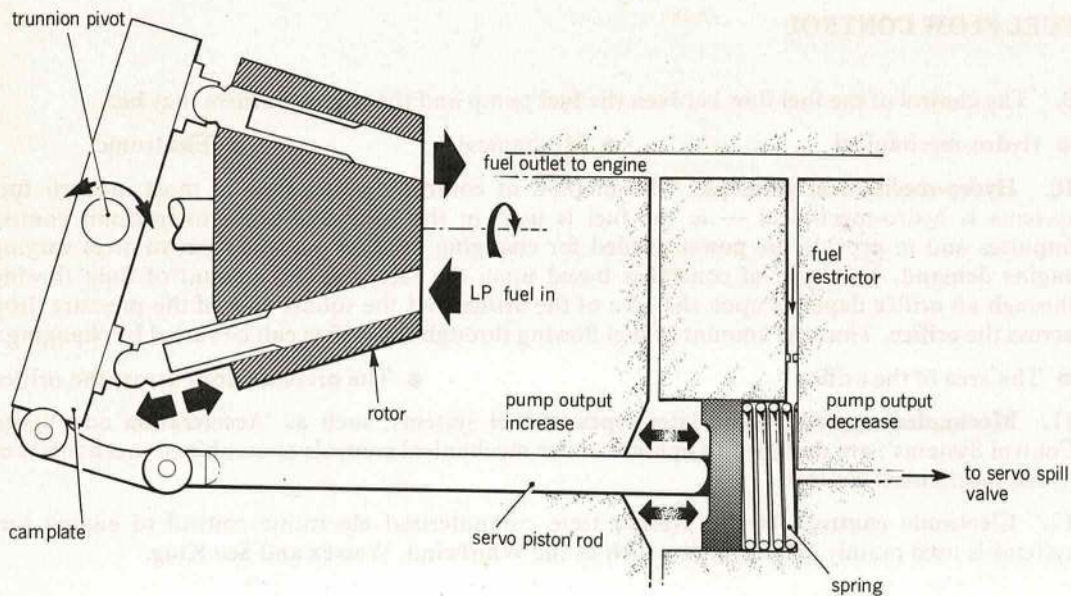


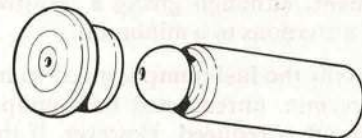
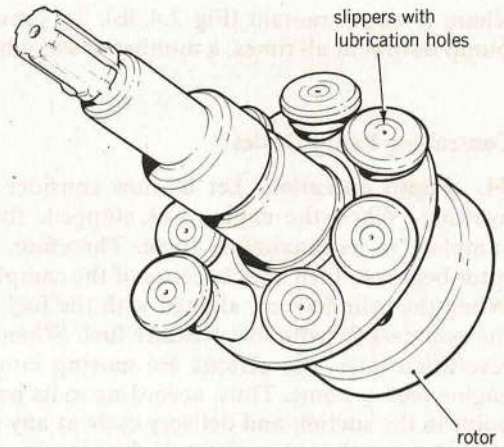
Fig 2.4.1 Camplate operation

16. **The camplate mechanism.** The camplate provides a hardened circular track against which the ends of the pumping pistons are bedded. It is mounted in trunnion bearings, at right angles to the pump rotor, so that the angle between the track and the adjacent face of the rotor can be altered to give a pumping stroke to the pistons as the rotor rotates.
17. The angle of the camplate is altered by the spring loaded servo piston which is moved hydraulically by fuel pressure. The servo fuel pressure is varied by the controlling devices within the fuel system so that pump output is constantly adjusted to suit the fuel flow requirements of the engine. Maximum output occurs when the camplate angle is at maximum.
18. **The rotor.** The tapered rotor is bored to accommodate seven hardened steel pumping pistons in cylinders which are stepped down to terminate as seven holes in the flat face that is located against the fixed plates in the pump casing. Two kidney shaped ports in the fixed plate communicate with the fuel inlet and outlet passages of the fuel pump and also align with the holes leading into the rotor cylinders.
19. The rotor is held against the port face by the pressure of the piston return springs and, when the pump is working, by the action of fuel pressure acting upon the stepped surfaces of the cylinder bores. Jointly, these pressures provide a sealing force between the rotor and the ports in the end plate.
20. The rotor is bored along its axis and the outer, camplate end, hole is splined to receive the fuel pump drive shaft. The hole bored from the other end of the rotor aligns with a fuel inlet port and communicates with seven passages drilled radially, one between each pair of cylinders. This hole is fed with low pressure fuel which passes out through the radial passage to become a controlling influence for the engine's maximum speed governor (*see para 43*).
21. **Pistons.** The hardened steel pumping pistons, accommodated in the rotor cylinders, are hollow. Return springs fit inside the pistons to retain the outer ends of the piston in contact with the track of the camplate. The outer end of each piston terminates in a ball and articulated pad which makes contact with the camplate and allows for its changing angles. A small diameter hole leads from inside each hollow piston and permits a flow of low pressure fuel to lubricate and cool the ball, slipper pad, and camplate (*Fig 2.4.2*).

22. **Servo piston.** A servo piston is fitted into a cylinder cast integral with the pump casing. A strong spring is fitted to one side of the piston head so that the piston is biased towards the pump's maximum output position. When the pump is stationary, and there is no fuel pressure, the spring moves the servo piston to the end of its cylinder and, because the servo piston is linked to the camplate, it puts the pump into the maximum fuel output position — *ie* camplate at its maximum angle. If the servo piston was subjected only to spring pressure, the fuel pump would remain in the maximum output position and no fuel flow corrections would be made.

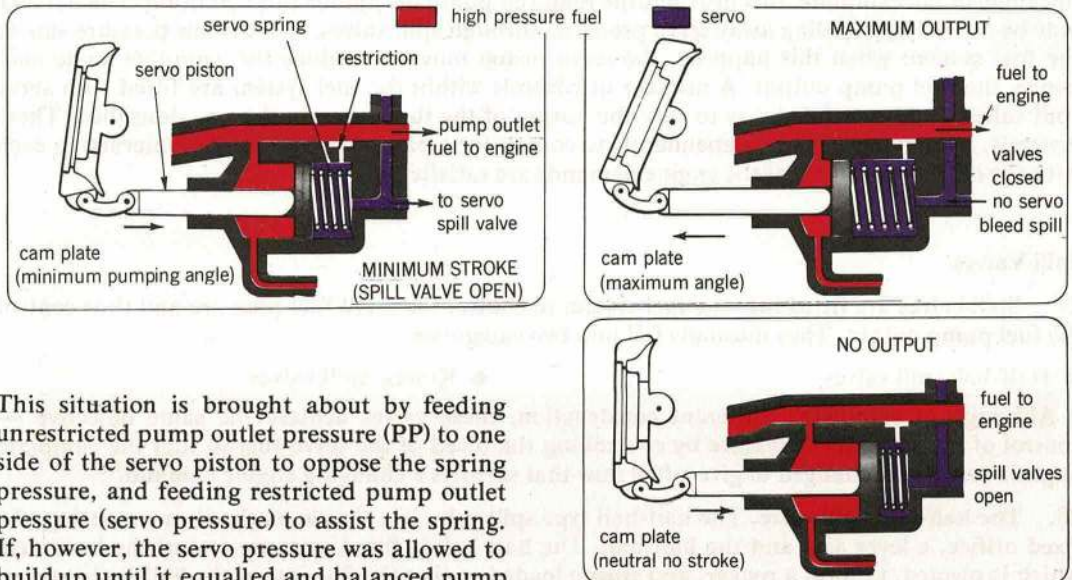
23. **Forces acting on the servo piston.** When the fuel pump is running, the servo piston is influenced by the forces shown in Fig 2.4.3 where it can be seen that:

- Spring pressure
  - Servo fuel pressure
  - Pump outlet pressure
- Work together to increase the pump output.
- Working always to reduce pump output.



piston and slipper

Fig 2.4.2 Rotor and pistons



This situation is brought about by feeding unrestricted pump outlet pressure (PP) to one side of the servo piston to oppose the spring pressure, and feeding restricted pump outlet pressure (servo pressure) to assist the spring. If, however, the servo pressure was allowed to build up until it equalled and balanced pump outlet pressure, the spring pressure would move the pump to maximum output position

Fig 2.4.3 Forces acting upon the servo piston

where it would remain (Fig 2.4.3b). To prevent this happening, and to provide control of the pump output at all times, a number of servo bleeds are fitted into the system.

### Controlling Pump Outlet

24. **Pump operation.** Let us now consider the conditions that exist when the fuel pump is working. When the engine was stopped, the spring acting upon the servo piston moved the camplate to its maximum angle. Therefore, when the engine is next cranked for starting, the rotor begins to turn and, because of the camplate angle, the pistons reciprocate in their cylinders. When the cylinders are aligned with the fuel inlet port, the pistons are moving outwards so that the cylinders fill with low pressure fuel. When the cylinders align with the outlet port, half a rotor revolution later, the pistons are moving into their cylinders so that the fuel is forced into the engine feed systems. Thus, according to its position on the camplate, each piston is at a different point in the suction and delivery cycle at any given time. The inlet and outlet ports are elongated so that more than one piston is drawing in, or delivering fuel, at the same time. This pumping arrangement, although giving a 'positive displacement' action to the pump, reduces the fuel pressure pulsations to a minimum.

25. Initially the fuel pump is given its maximum output but, after light up, as the engine settles to idle rev/min, unrestricted fuel pump outlet pressure is felt on the servo piston and the fuel pump output is reduced. However, if the servo piston was allowed to move until there was no angle between the rotor face and the camplate the pistons would have no stroke and fuel delivery would cease. Obviously, some pumping angle must be retained and it must satisfy the fuel flow requirements of the engine at that time. Controlling the movement of the servo piston, to maintain constant engine speed, is the basic principle used in the design of a fuel system.

26. **Controlling the camplate angle.** As stated in para 23, the force acting on one side of the servo piston is the combined effort of a spring and servo fuel pressure. This force is opposed by fuel at pump outlet pressure which applies a force to the other side of the piston head. The servo piston takes up a position at which the forces acting each side of it are balanced and, by moving the angle of the camplate, this provides the required pump output for this condition. The balance may be altered by bleeding away servo pressure, through spill valves, into the low pressure side of the fuel system; when this happens, the servo piston moves to reduce the camplate angle and, hence, the fuel pump output. A number of controls within the fuel system are fitted with servo spill valves and have the ability to vary the output of the fuel pump in the way described. These controls, although working independently to correct for a particular variant, are interacting each with the other to ensure that the engine demands are satisfied.

### Spill Valves

27. Spill valves are fitted into the fuel system to control the servo fuel pressure and thus control the fuel pump output. They normally fall into two categories:

- Half-ball spill valves
- Kinetic spill valves

Although of completely different construction, these valves achieve the same objective — control of the servo fuel pressure by controlling the bleed of the servo fuel so that the camplate angle is constantly changed to give a fuel flow that satisfies a changing engine demand.

28. **The half-ball spill valve.** The half-ball type spill valve is a simple mechanism consisting of a fixed orifice, a lever arm and the half-ball. The half-ball is fitted into one end of the lever arm which is pivoted, to form a rocker, and spring loaded so that the flat face of the half-ball seats on the outlet orifice. The spring loading is such that the spill valve is biased towards the closed position (Fig 2.4.4).

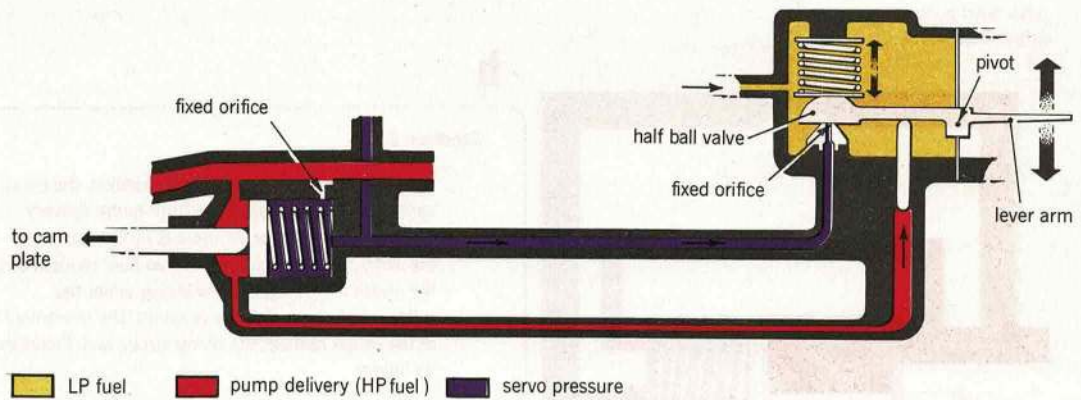


Fig 2.4.4 Half-ball spill valve

However, the spill flow can be increased by moving the half-ball away from the fuel outlet and decreased by moving it nearer to the fuel outlet; if the half-ball is seated firmly onto the orifice it can stop the spill flow altogether and the valve is closed. A controlling device applies force to the pivoted lever. This force:

- Overcomes the spring pressure to open the spill valve when the engine requires *less* fuel.
- Assists the spring to close the spill valve when the engine requires *more* fuel.

29. **Kinetic spill valve.** The kinetic spill valve consists of two carefully aligned but opposing fuel outlets with an interrupter blade which can be moved into the space between them (Fig 2.4.5). One outlet is connected to the servo fuel and is the servo spill (or bleed) orifice. The second outlet receives pump outlet fuel which issues from the orifice as a high velocity jet. Uninterrupted, the pump outlet fuel discharges on to the face of the servo bleed orifice and the kinetic energy so produced prevents any servo bleed — (*ie* spill valve closed). This increases the servo pressure and also the fuel pump outlet. To open the spill valve, the interrupter blade is inserted between the two outlets so that it deflects the high velocity fuel jet and allows a servo bleed (spill valve open). The servo bleed progressively increases as the blade is inserted and the spill valve is wide open when all the high velocity fuel is deflected; the servo bleed is then at

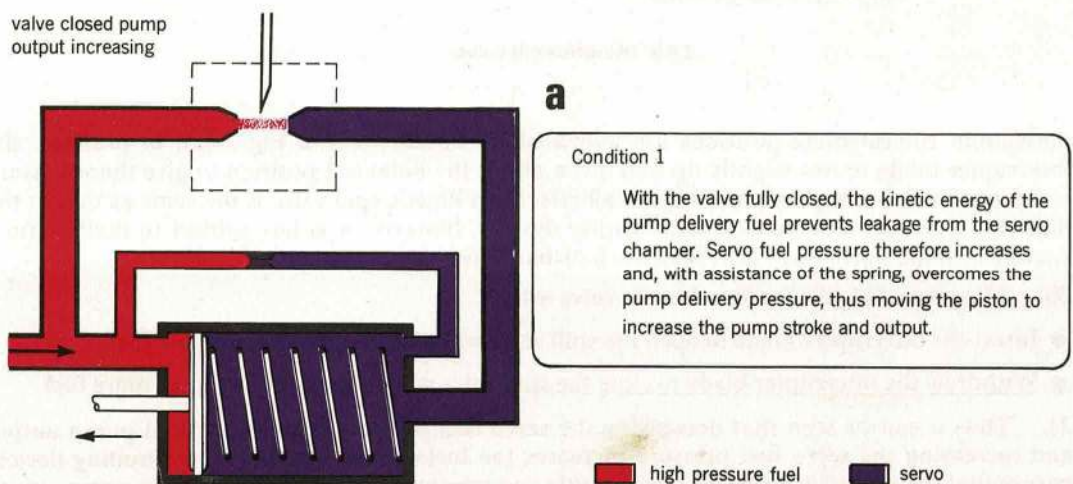
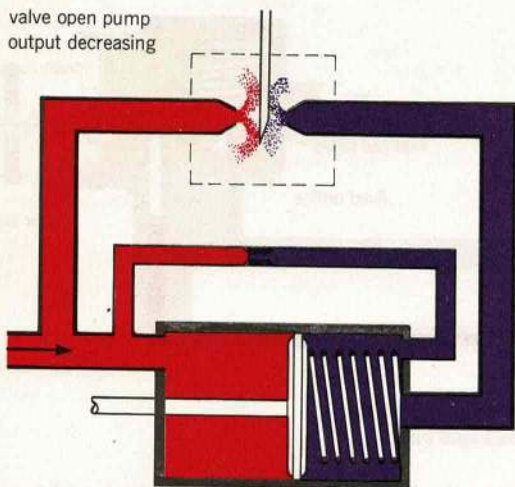


Fig 2.4.5 Kinetic spill valve

valve open pump  
output decreasing

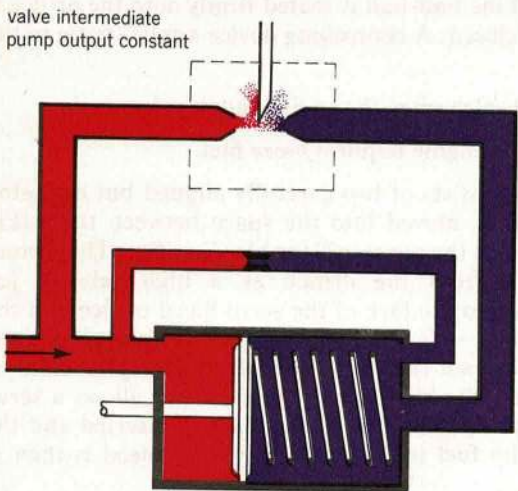


**b**

Condition 2

With the kinetic valve in the open position, the blade separates the opposing flows from pump delivery and the servo cylinder. As there is no opposition to the servo flow, the volume of servo fluid reduces and the piston moves against the spring under the influence of pump delivery pressure. The movement of the piston reduces the pump stroke and, therefore, its output.

valve intermediate  
pump output constant



■ high pressure fuel    ■ servo

**c**

Condition 3

Under steady running conditions, the valve assumes an intermediate position such that the servo fuel and spring pressures exactly balance the pump delivery pressure.

2.4.5 Kinetic spill valve

maximum. Intermediate positions are indicated by Condition 3 in Fig 2.4.5; in practice, the interrupter blade moves slightly up and down about the balanced position to give the necessary variations in fuel pump output. The overall effect of a kinetic spill valve is the same as that of the half-ball type and it is controlled by similar devices, however, it is less subject to malfunction, caused by small particles of grit, than the half-ball valve.

30. The controlling device for a kinetic valve will:

- Insert the interrupter blade to open the spill valve when the engine requires less fuel.
- Withdraw the interrupter blade to close the spill valve when the engine requires more fuel

31. Thus it can be seen that decreasing the servo fuel pressure reduces the fuel pump output and increasing the servo fuel pressure increases the fuel output. Automatic controlling devices ensure that the servo fuel pressure is constantly and progressively altered so that the pump output meets the engine demand.

## Barometric Pressure Control (BPC)

32. Increases in an aircraft's forward speed, or an increase in atmospheric pressure will increase the pressure of the air in the engine air intake, and there will be an increased flow of air through the engine. To match the increased airflow the engine will require more fuel. Decreased air pressure in the air intake will reduce the airflow through the engine and reduce the fuel demand.

33. Fig 2.4.6 shows how a spill valve can be connected into a fuel system and controlled by a pressure sensing unit which is subjected to air intake pressure. This type of barometric pressure control (BPC) uses the hydro-mechanical functions of the fuel system to make fuel flow corrections proportionate to changes in atmospheric pressure and aircraft forward speed.

34. The light alloy casing of the BPC is divided into two chambers by a vertical metal diaphragm which is pierced to accept the rocker arm and then sealed by bonded rubber. The rocker arm pivots on the diaphragm and protrudes into both the pressure chamber and fuel chamber of the control unit.

The part of the rocker arm that protrudes into the fuel chamber carries the half-ball valve so that the flat face of the ball can close the servo bleed orifice. A strong spring is fitted between the top of the chamber and the rocker arm, loading the valve towards the closed position. The spring is opposed by pump outlet pressure fuel which acts upon a diaphragm and, through a piston and push-rod, applies an opening force to the spill valve which, when open, bleeds servo fuel back into the low pressure side of the fuel system.

35. In the pressure chamber an evacuated capsule is fitted so that it bears upon the end of the rocker arm.

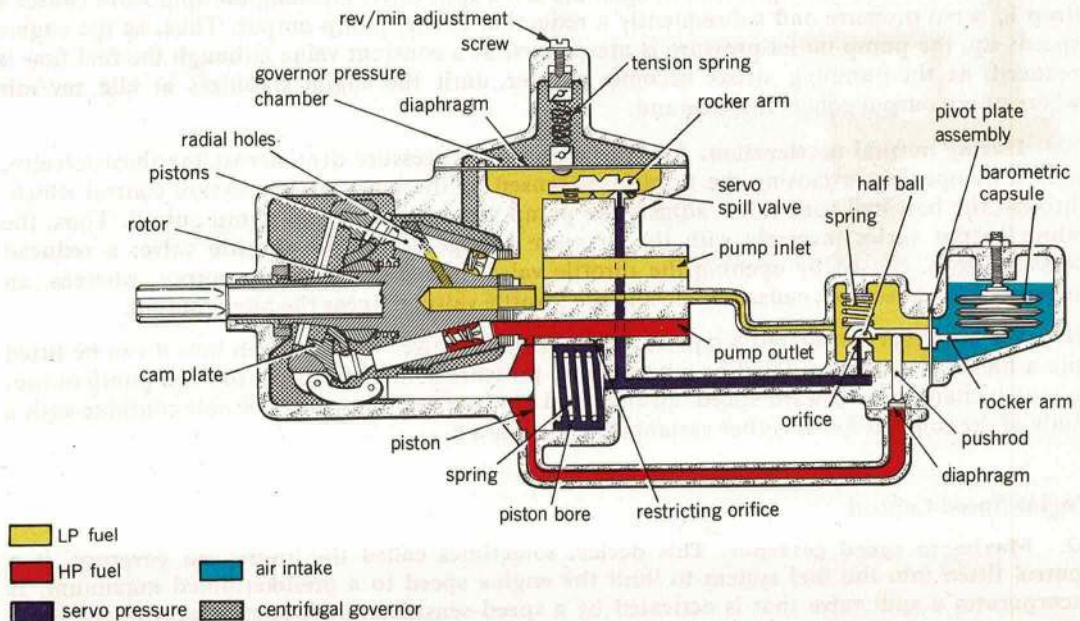


Fig 2.4.6 Barometric control of fuel pump output

The capsule is subjected to engine air intake pressure changes and it provides a means of varying the effecting loading on the half-ball spill valve.

## Operation of BPC

36. **Air pressure increasing.** An increase in air intake pressure is felt by the evacuated capsule causing it to reduce in length and offer less resistance to spring pressure. The spring is now able to over-ride the force applied by fuel pressure and move the rocker arm down to close the spill valve. The reduction of servo bleed increases the servo pressure acting upon the servo piston, with the result that fuel pump output is increased to match the increase in airflow through the engine. The increased pump outlet pressure, acting through the push-rods, returns the spill valve to the sensitive position.

37. **Air pressure decreasing.** Decreasing air intake pressure will cause the evacuated capsule to increase its length and apply an opening force to the rocker arm. The spill valve opens and the increased bleed reduces the servo pressure acting upon the servo piston. The servo piston moves and reduces the pump output by an amount that is proportional to the reduced airflow through the engine. The decreased fuel outlet pressure balances the forces acting upon the rocker arm and the spill valve returns to the sensitive position.

38. The barometric pressure control inter-acts with the other components in the system and is, to some extent, a flow control valve; this action is explained in the following paragraphs.

39. **During engine starting.** When the engine is at rest, and initially during the starting cycle, the camplate in the fuel pump is at the maximum pumping angle. By inter-action between the BPC and the fuel pump the angle of the camplate is varied to provide the fuel flow necessary for accelerating the engine safely to idle speed. After 'light up' the engine speed increases, with the fuel pump on full stroke and, because the throttle orifice is small, there is a very rapid rise in fuel pressure. This pressure is felt by the pushrod diaphragm in the BPC which, at a pre-determined pressure value, causes the pushrod to open the servo spill valve. Opening the spill valve causes a drop in servo pressure and subsequently a reduction in fuel pump output. Thus, as the engine speeds up, the pump outlet pressure is maintained at a constant value although the fuel flow is reduced, as the pumping stroke becomes shorter, until the engine stabilizes at idle rev/min where pump output equals fuel demand.

40. **During normal acceleration.** Any variation of the pressure drop across the throttle valve, caused by opening or closing the throttle, is sensed by the barometric pressure control which, through the half-ball spill valve, adjusts the pump servo pressure and pump output. Thus, the pump output varies inversely with the pressure change across the throttle valve; a reduced pressure drop, caused by opening the throttle valve, increases the pump output, whereas, an increased pressure drop, caused by closing the throttle valve, reduces the pump output.

41. We have just considered a typical action of a spill valve. We have seen how it can be fitted into a fuel system and actuated by a barometric pressure control to adjust the fuel pump output to match changes in forward speed, altitude and atmospheric pressure. We now continue with a study of the controls for the other variants listed in para 6.

## Engine Speed Control

42. **Maximum speed governor.** This device, sometimes called the 'overspeed governor' is a control fitted into the fuel system to limit the engine speed to a predetermined maximum. It incorporates a spill valve that is activated by a speed-sensitive diaphragm to control the servo pressure proportional to engine rev/min (Fig 2.4.7). The control is built into the fuel pump casing and consists of:

- A speed sensitive diaphragm loaded by a tension spring.
- A spring loaded rocker arm.
- A spill valve to control system servo pressure.

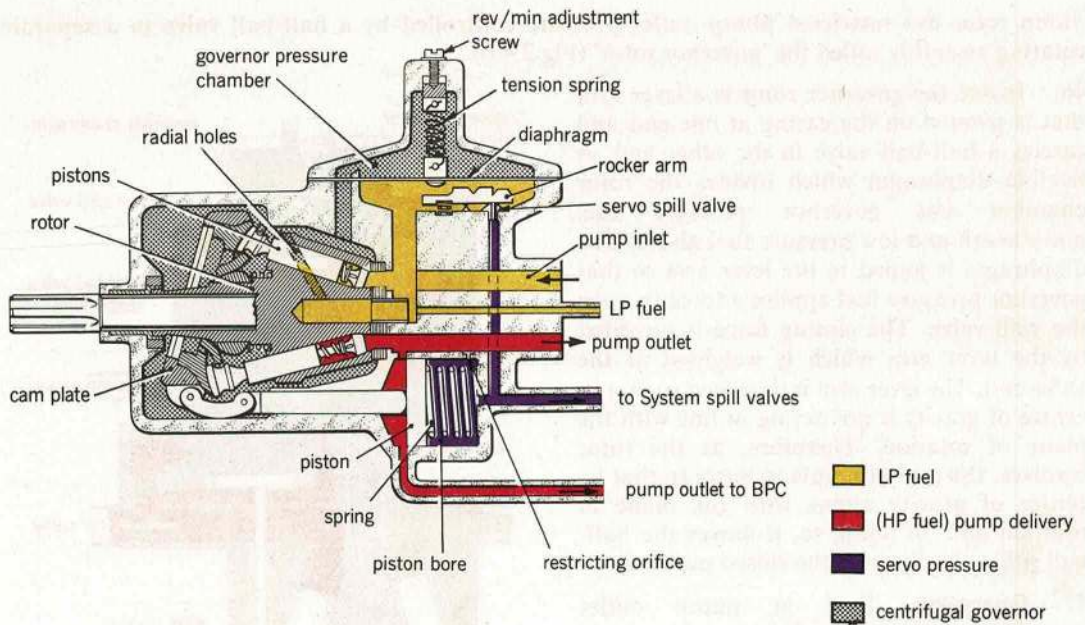


Fig 2.4.7 Maximum speed governor (centrifugal)

43. **Operation.** The low pressure fuel which enters the central bore of the pump rotor (*see also* para 20) flows outwards through the radial drillings into the pump casing where an internal duct leads into the pressure chamber above the governor diaphragm. This fuel, contained in a closed chamber, is called 'governor pressure fuel' because its pressure is increased by the centrifugal action of the spinning rotor until it exerts sufficient force upon the governor diaphragm to open the spill valve. The forces acting upon the governor spill valve are:

- **Closing forces.**
  - a. The rocker spring.
  - b. The diaphragm spring.
  - c. Low pressure fuel under the diaphragm.
- **Opening forces.** a. Governor pressure fuel.

44. The forces acting upon the governor spill valve are such that, for normal running conditions, the valve remains firmly closed and has no effect upon the engine's performance. However, as the engine's speed increases towards the permitted safe maximum, the fuel pump rotor imparts progressively more centrifugal energy to the governor fuel and brings the maximum speed control into the sensitive position. When the engine reaches the design maximum rev/min, the governor pressure fuel applies a force sufficient to deflect the diaphragm onto the end of the rocker arm so that the spill valve opens. The fuel bleed through the spill valve reduces the servo pressure which in turn reduces the pump output so that the engine cannot exceed its safe maximum speed.

45. **Hydro-mechanical governor.** Many later fuel systems use an improved maximum speed governor with hydro-mechanical control. These governor units provide more accurate speed control because they are not affected by the specific gravity of the fuel; centrifuging the fuel is no longer the key to engine speed control. The fuel pressure (governor pressure) acting against the spring on the top side of the governor diaphragm is not centrifuged fuel from the

pump rotor but restricted pump outlet pressure controlled by a half-ball valve in a separate rotating assembly called the 'governor rotor' (Fig 2.4.8).

46. Inside the governor rotor is a lever arm that is pivoted on the casing at one end and carries a half-ball valve in the other end. A flexible diaphragm which divides the rotor chamber has governor pressure fuel underneath and low pressure fuel above. The diaphragm is joined to the lever arm so that governor pressure fuel applies a force to open the spill valve. The closing force is provided by the lever arm which is weighted at the valve end. The lever arm is designed so that its centre of gravity is not acting in line with the plane of rotation. Therefore, as the rotor revolves, the arm attempts to move so that its centre of gravity aligns with the plane of rotation and, in doing so, it moves the half-ball spill valve towards the closed position.

47. **Operation.** Fuel at pump outlet pressure passes through a restrictor to become governor pressure fuel. As such it is ducted to the following points in the governor unit:

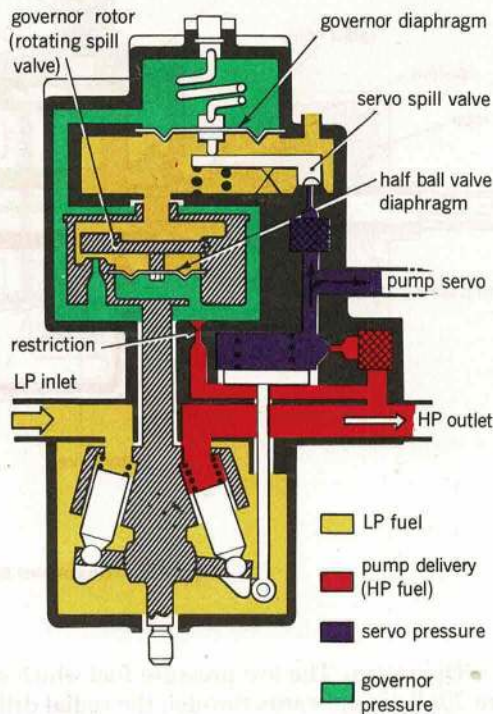
- Under the governor rotor diaphragm.
- To the spring side of the governor maximum speed diaphragm.
- To the spill valve in the governor rotor.

48. The governor rotor is geared to the fuel pump drive and, as the engine accelerates, the rotor speed increases. The rotor lever arm applies a closing force to the spill valve but the governor pressure fuel, acting under the rotor diaphragm, is sufficient to keep the valve open. However, as the engine speed increases, the rotor spill valve is progressively brought nearer to the closed position with the effect that governor fuel pressure increases. The increase in governor fuel pressure is felt upon the governor diaphragm and it brings the unit into a sensitive position. At the design maximum speed of the engine the governor rotor spill valve is closed and governor fuel pressure is sufficient to cause the governor diaphragm to open the servo spill valve. This action restricts the fuel pump output to the amount of fuel required to produce the correct maximum engine rev/min.

49. **Adjustment.** Before explaining the max rev/min adjustment it must be stressed that these notes are general and are not an authority to carry out this adjustment to any particular aero engine. Before attempting an adjustment, consult the appropriate Air Publication Vol 1 & 6.

50. Certain factors affect the maximum speed of an aero engine and the max rev/min may need adjusting after:

- The engine has been installed in the airframe.
- Initial flight test.
- Any part of the fuel system has been renewed.
- An unsatisfactory report by a pilot.



2.4.8 Hydro-mechanical governor

- Routine servicing.

To correct the max rev/min setting, an adjuster is fitted on top of the governor casing. Adjustment affects the tension of the governor spring and thus the force required to open the spill valve. The adjuster is screwed in to increase the max rev/min and OUT to reduce max rev/min. The amount of adjustment required is one complete turn for 3% increase or decrease in engine rev/min and the adjuster is to be locked after each adjustment before testing the engine. Maximum speed adjustments should be recorded in the MOD Form 700.

### Engine Acceleration

51. The smooth running of an internal combustion engine depends upon the fuel/air ratio being correct and, in this respect, the gas turbine engine is no exception. When the throttle is opened to accelerate a gas turbine engine, fuel flow to the burners will increase before there is any increase in airflow; the mixture becomes rich as a result and the balance between airflow and fuel flow is upset. Some degree of mixture richness is necessary to start the process of acceleration and this is called 'over-fuelling'. Engines are designed to cope with small amounts of over-fuelling but excessive over-fuelling is harmful in that it causes:

- High jet pipe temperatures.
- Compressor stall and surge.
- In extreme cases, flame extinction.

52. **Acceleration control.** If the throttle lever could be advanced very slowly, an engine could accelerate to match the slowly increasing fuel flow and no problems would arise but, without control of the fuel flow, rapid advancing of the throttle lever would cause excessive over-fuelling. Therefore, to enable a pilot to 'slam open' the throttle in an emergency and obtain the fastest safe acceleration, an automatic control is fitted. It is called the 'acceleration control unit' (ACU) or, in some fuel systems, the 'air fuel ratio control' (AFRC). After rapid advancement of the throttle lever, the ACU/AFRC controls the rate at which the fuel flow to the burners can increase and thus the rate of acceleration.

**Note.** In the following paragraphs, the term acceleration control unit (ACU) embraces both types of unit which have but a common objective: the fastest safe acceleration of the engine.

### The Acceleration Control Unit (ACU)

53. The ACU is, in many respects, similar in construction to the barometric pressure control (see para 32), but it is designed to operate only during engine acceleration. Fig 2.4.9 shows a simple form of ACU; its similarity to the BPC should make its operation easy to understand. Although later ACUs are more complicated, the principle and objective are the same.

54. **Description.** The capsule chamber in the ACU is vented to ambient atmospheric pressure and, thus, the control is not affected by forward speed. A rod connects the base of the capsule and the end of the rocker arm to a flexible diaphragm which seals the base of the capsule and provides a second chamber within the same casing. Air at compressor delivery pressure is fed into the chamber under the diaphragm so that it can exert a closing force on the spill valve rocker lever. Metered fuel applies an opening force to the other end of the rocker, and, thus, a balance can be achieved between airflow through the engine and fuel flow. If we examine Fig 2.4.9 we can see that the forces acting upon the ACU spill valve are:

- **Opening forces.** (a) metered fuel.
- **Closing forces.** (a) air at compressor delivery pressure.  
(b) spring pressure.

● **Balancing force.** (a) air at atmospheric pressure.

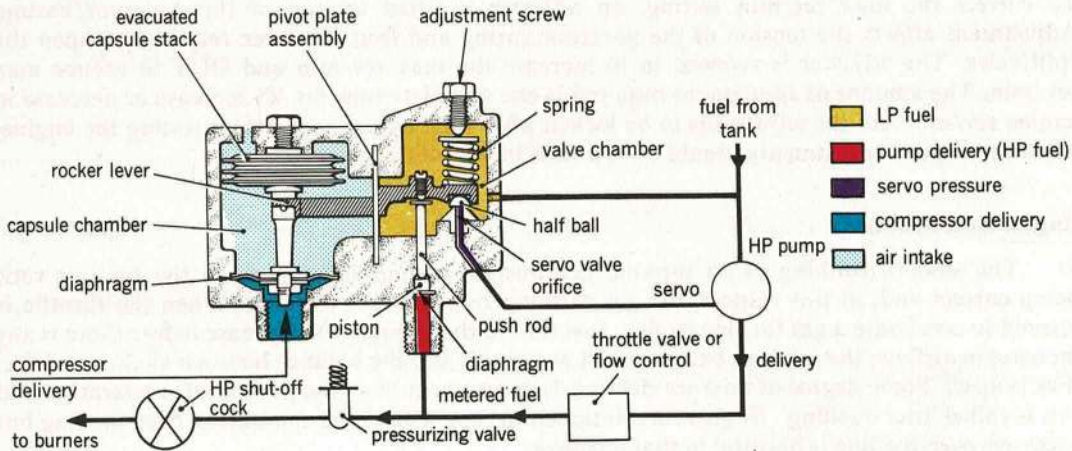


Fig 2.4.9 Acceleration control unit

55. **Operation.** When the engine is running at a steady speed, the acceleration control is inoperative, the spill valve is closed and the ACU has no effect on the function of the fuel system. However, when the throttle lever is advanced quickly, the metered fuel pressure increases. This has two effects; it:

- Increases the burner pressure.
- Applies an opening force to the ACU spill valve.

The increased burner pressure provides the extra fuel necessary to speed up the engine and, simultaneously, the pressure felt on the rocker arm opens the spill valve to limit the fuel pump output and prevent excessive over-fuelling. As the engine accelerates, the compressor delivery air pressure increases and, acting upon the diaphragm, applies a closing force to the ACU spill valve which now tends to increase the fuel pump outlet and balance airflow against fuel flow. Thus, the acceleration control unit provides an increased fuel feed that is proportional to the increased airflow through the engine and the fastest safe acceleration is achieved; the control is balanced for changes in atmospheric pressure by the evacuated capsule.

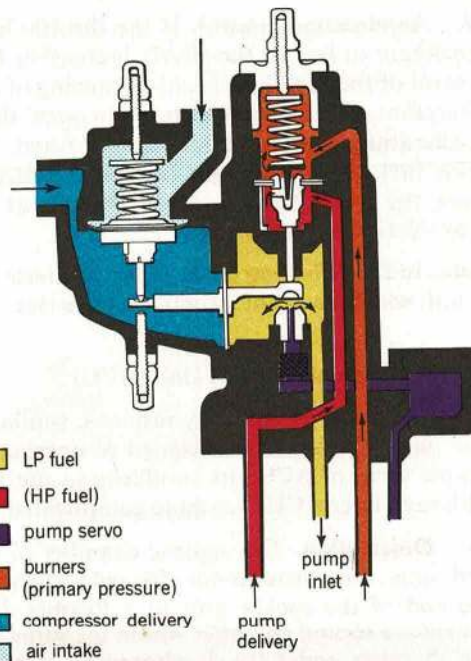


Fig 2.4.10 Acceleration control by differential pressure

56. A later ACU is shown in Fig 2.4.10 where it can be seen that the opening force applied by the fuel pressure push-rod has been replaced by a differential pressure device. This device senses the pressure difference between pump output and metered fuel pressure and balances pump

output against compressor delivery. Derivations of this type of ACU are to be found in many current fuel systems.

### Dashpot Throttle Control

57. Fuel systems on some later engines, such as the 'Adour', use a different method of acceleration control with a special type of throttle valve fulfilling the function of an ACU. This device, called a dashpot throttle, is part of the fuel control unit (FCU). As shown in Fig 2.4.11, it consists of:

- A **ported sleeve**, made with a cylinder at one end, high pressure fuel feed ports at the other end, and throttle servo ports in between.
- A **cylindrical floating throttle valve**, with throttle servo fuel ports along its length; it has a piston at one end, to fit into the bore of the cylinder provided by the ported sleeve.
- A **stepped control valve** which slides in the bore of the throttle valve, and is linked to the throttle lever by a rack and pinion arrangement.

Movement of the cockpit lever slides the control valve along the throttle bore to control the flow of throttle servo fuel and, indirectly, the position of the throttle valve. A coil spring locates against a shoulder on the control valve and loads the throttle towards the closed position.

58. **Operation.** When the throttle lever is moved towards the closed position, the throttle valve is moved mechanically towards the idle rev/min setting and, as it moves, it automatically aligns ports so that throttle servo fuel bleeds freely away into the low pressure side of the system. The servo spring and fuel at throttle control pressure continue to apply a closing force to the throttle valve piston (Fig 2.4.11).

59. When the throttle lever is advanced to the open position, two distinct stages of acceleration follow. One stage of acceleration provides a lesser degree of over-fuelling than the other. The two stages are:

- **Initial acceleration.** The engine can accept small amounts of over-fuelling.
- **Final acceleration.** The engine can accept greater amounts of over-fuelling.

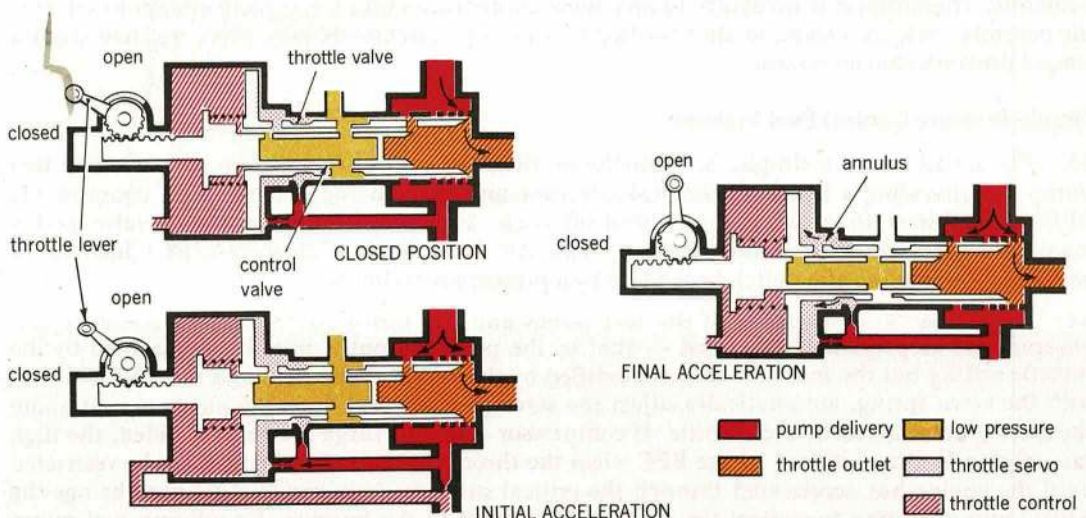


Fig 2.4.11 Dashpot throttle control

60. **Initial acceleration.** Moving the throttle lever towards the open position slides the control valve along the bore of the throttle valve until it closes the throttle servo fuel outlet. The subsequent rise in servo fuel pressure is sufficient to overcome the closing forces and move the throttle valve towards open. Thus, differential pressures are acting across the throttle valve piston and the speed of the throttle opening is dependent upon the pressure difference. As the throttle valve moves, it progressively uncovers fuel feed ports to increase the fuel flow to the engine. It also re-opens the throttle servo bleed to balance the pressure acting upon the piston so that the throttle valve is positioned to provide the power selected with a degree of over-fuelling that is acceptable.

Uncovering the fuel feed ports changes the value of the pressure drop across the throttle valve. Proportional differential pressures are relayed to a flow control unit where they act upon a diaphragm tending to close a servo spill valve in the main system, and the fuel pump output is increased to match the rate at which the engine can accelerate.

61. **Final acceleration.** Regardless of how quickly the throttle lever is advanced, the initial acceleration phase prevents excessive over-fuelling and engine surge. However, as the rev/min builds up, the engine reaches a state at which it is able to accept a greater degree of over-fuelling and an increased rate of acceleration. When this stage is reached, the throttle valve uncovers an annulus in the ported sleeve which feeds extra servo fuel to the throttle valve piston. The extra servo fuel, fed through a single restrictor and a second orifice, speeds the movement of the throttle valve to quickly uncover more fuel feed ports; this increases the fuel flow to the burners and thus increases the rate of acceleration. The change in pressure drop across the throttle valve is relayed to the flow control unit and, again, the fuel pump output is increased to match the engine demand.

## FUEL SYSTEMS

62. In the preceding paragraphs, explanations have been given for the operation and construction of each of the various control elements in a fuel system. Each controlling element is designed to make corrections for a particular variant. However, the system as a whole depends upon inter-action between these elements in order to proportion the fuel correctly to meet engine demands. Therefore, it is necessary to link these components into a complete system to see how the controls work, as a team, to alter the fuel flow as engine demands vary. First, we shall study a simple pressure control system.

### Simple Pressure Control Fuel Systems

63. Fig 2.4.12 shows a simple, but functional, pressure control fuel system with a single fuel pump incorporating a hydro-mechanical governor unit. A combined control unit contains the BPC, a combined throttle valve and shut-off cock, a fuel distributor, a dump valve and a maximum jet pipe temperature control. The Air Fuel Ratio Control (AFRC) includes a compressor pressure ratio switch backed up by a pressure ratio limiter.

64. **Operation.** The operation of the fuel pump and the hydro-mechanical maximum speed governor are as previously described — that is, the pump output is initially determined by the throttle setting but the fuel flow is then modified by the action of the BPC and the AFRC which, with the servo spring, automatically adjust the servo pressure and, thus the pump output about the setting determined by the throttle. If compressor stall and surge are to be avoided, the high rate of over-fuelling induced by the BPC when the throttle is opened quickly, must be restricted until the engine has accelerated through the critical surge rev/min range. This need brings the AFRC into operation to control the amount of fuel fed to the burners. By relating fuel pump delivery to the mass airflow through the engine, the AFRC provides the engine with a fuel flow which provides the fastest possible surge-free rate of acceleration.

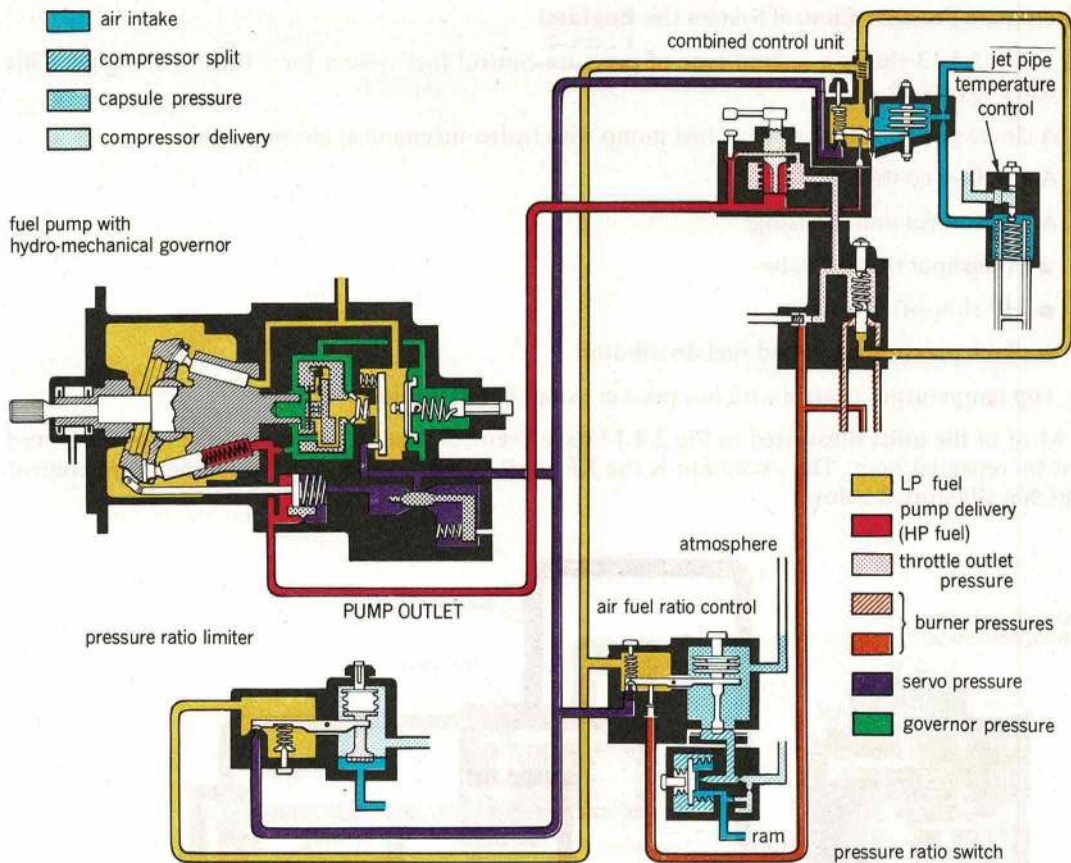


Fig 2.4.12 Pressure control fuel system

65. **Pressure ratio switch.** This unit, often built into later acceleration controls, measures the compression ratio of the engine compressor and, in the system illustrated, it controls the value of the air pressure acting under the AFRC diaphragm and thus assists in matching fuel flow to air flow. During the initial acceleration phase, the pressure ratio switch is open and the pressure acting under the diaphragm is reduced to a value less than that of the compressor delivery. After the engine has accelerated through the critical surge range, the compression ratio is such that the pressure ratio switch closes and compressor delivery pressure is fed to the AFRC diaphragm. This increases the fuel flow and speeds up the final phase of acceleration.

66. **Pressure ratio limiter.** The pressure ratio limiter measures the difference between ram air pressure and compressor delivery pressure. If the pressure difference exceeds the design value, the pressure ratio limiter signals the fuel pump to reduce fuel output. This action is particularly valuable in promoting smooth engine running during high altitude, high speed flight.

67. **Top temperature control.** Protection against excessively high jet-pipe temperature is provided by a temperature-sensing element which, at a pre-determined temperature, will direct compressor delivery air through a venturi which communicates with the air in the BPC capsule chamber. Passing air through the throat of the venturi causes a drop in pressure to be sensed by the BPC capsule and this results in a reduced output of the fuel.

AI 15

*Flow*

**Alternative Pressure Control System (Jet Engines)**

68. Fig 2.4.13 shows a second type of ~~pressure~~ <sup>FLOW</sup> control fuel system for a turbo-jet engine. This system consists of:

- A single positive displacement fuel pump with hydro-mechanical governor unit.
- A fuel flow control unit.
- A fuel control unit, housing:
  - A dashpot throttle valve.
  - HP shut-off valve.
  - Back pressure valve and fuel distributor.
- Top temperature control with low pressure shaft speed limiter.

Most of the units illustrated in Fig 2.4.13 have been considered earlier and the operation need not be repeated here. The exception is the LP shaft speed limiter and top temperature control, which is illustrated below.

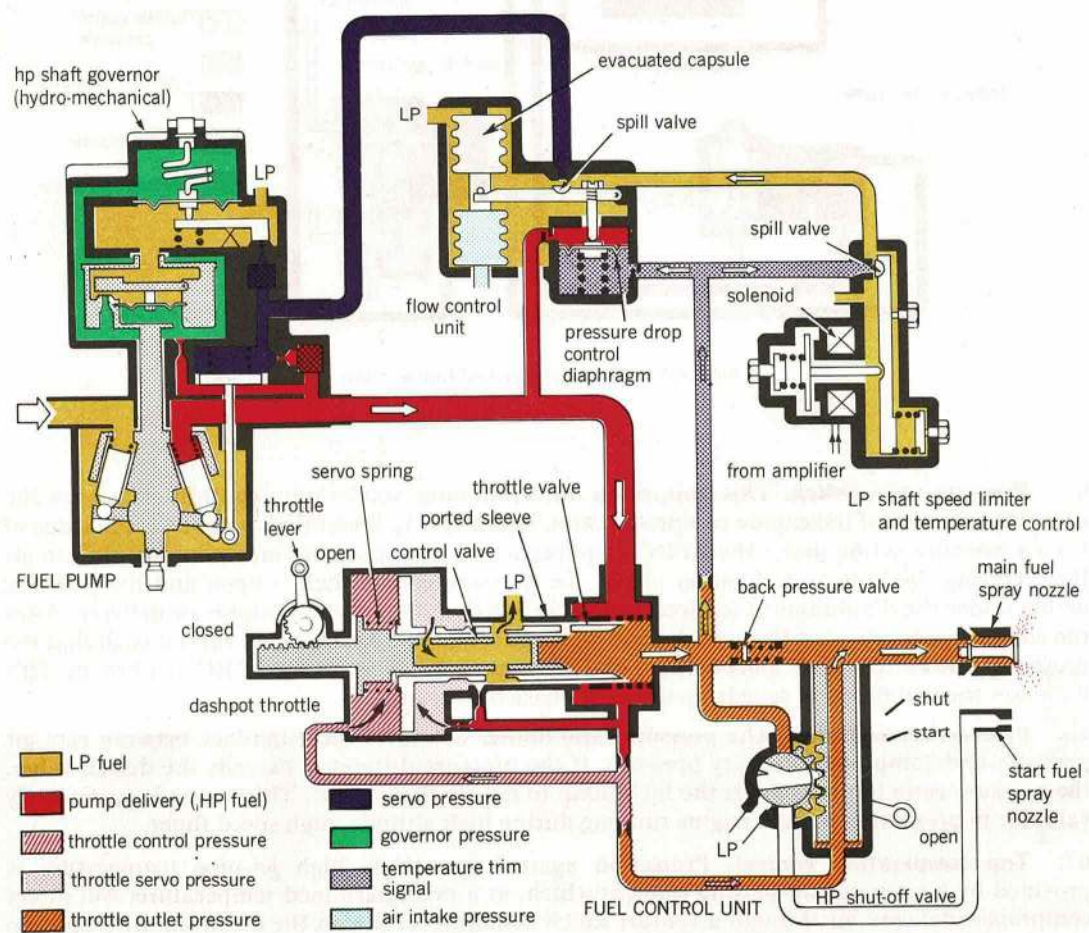


Fig 2.4.13 ~~Pressure~~ <sup>FLOW</sup> control fuel system with dashpot throttle

69. **LP shaft speed limiter and top temperature control.** When the turbine gas temperature (TGT) reaches a pre-determined value, further temperature increase is automatically prevented by restriction of the fuel pump output. The gas temperature acts upon a thermocouple located in the burner chamber and this generates an electrical voltage which after amplification operates a solenoid valve in the temperature control. The solenoid opens a spill valve to increase the pressure drop acting across the pressure drop control diaphragm. The flow control spill valve then opens to reduce pump servo pressure and, by doing so, brings about a reduction in fuel pump output. When this fuel system is used for a two spool engine, the LP limiter is linked into the system to prevent over-speeding by the LP compressor. An amplified electrical speed signal is fed to the solenoid valve, and fuel flow is corrected in the same manner as for gas temperature control.

*ALIS* *FLOW*  
**Pressure Control System Turbo-propeller Engine**

70. The type of *FLOW* *pressure* control system fitted to a turbo-propeller engine is shown in Fig 2.4.14. The rate of engine acceleration is restricted by a propeller speed control (in propeller unit) and the fuel pump output is controlled by servo spring pressure and the spill valves in the fuel control unit (FCU) which adjust the pump stroke and give a fuel flow to satisfy the engine demand.

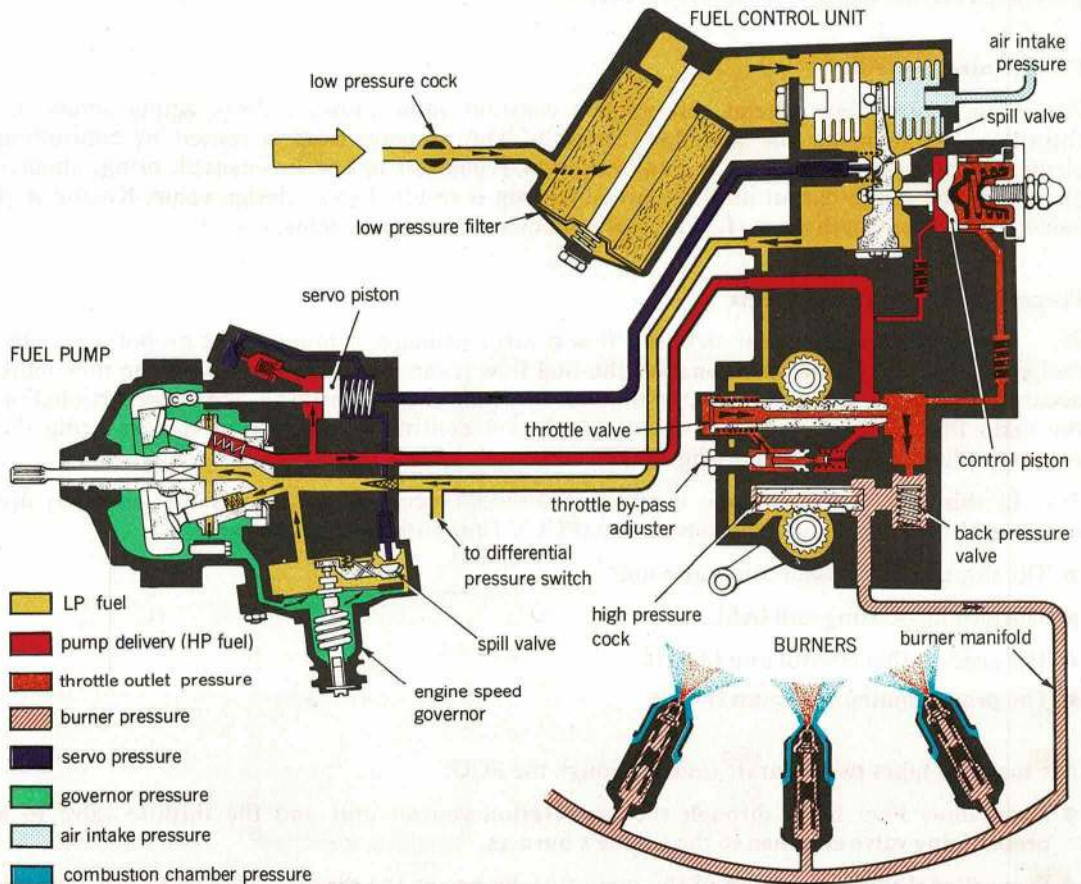


Fig 2.4.14 Fuel system for turbo-propeller engine

71. **Operation.** Under steady running conditions, below governor speed and with a constant air intake pressure, the spill valve in the flow control unit is in the sensitive position, creating a balance of forces across the fuel pump servo piston and thus ensuring a steady rate of fuel delivery to the throttle valve.

When the throttle is opened slowly, the pressure drop across the throttle valve falls and causes the FCU spill valve to close so that both servo pressure and pump delivery are increased. The increased flow of fuel restores the pressure drop across the throttle valve, the spill valve returns to its sensitive position, and the fuel pump stabilizes its output to provide the speed selected by the throttle position. The sequence is reversed when the throttle is closed.

72. **Changes in altitude and forward speed.** A reduction of air intake pressure, due to a reduction in forward speed or an increase in altitude, causes the flow control capsule to expand, and increase the rate of servo bleed. This reduces fuel pump delivery until the fuel flow matches the changed airflow and the spill valve returns to the sensitive position. Conversely, an increase in air intake pressure reduces the bleed from the spill valve and increases the fuel flow.

73. **Engine speed governor.** The engine speed governor prevents the engine from exceeding its maximum speed limitations, and the governor spill valve acts also as a safety relief valve. If the fuel pump delivery pressure exceeds its maximum controlling value, the servo pressure, acting through the orifice area of the spill valve, forces the valve open regardless of the engine speed and prevents a further increase in delivery pressure.

### Flow Control Systems

74. Flow control fuel systems rely upon a constant value pressure drop, acting across the throttle valve, to meter the fuel flow correctly. The pressure drop is sensed by controlling elements within the fuel system and any variation, regardless of how it is caused, brings about a change in fuel pump output until the pressure drop is restored to its design value. Kinetic spill valves usually control the servo fuel pressure in flow control fuel systems.

### Proportional Flow Fuel Systems

75. A more practical application of the 'flow control' principle is found in the proportional flow fuel systems — a system which enables the fuel flow trimming devices to adjust the flow more accurately. A small fuel flow is created that has the same characteristic as, and is proportional to, the main flow. This proportional flow is used as a controlling element when measuring the amount of fuel fed to the engine (Fig 2.4.15).

76. In this fuel system, all the controlling devices, except the engine speed governor, are contained in one combined fuel control unit (FCU). The controlling devices are:

- The throttle and pressurizing valve unit.
- The altitude sensing unit (ASU).
- The acceleration control unit (ACU).
- The proportioning valve unit (PVU).

The fuel flow takes two separate routes through the FCU:

- **Main flow.** Fuel flows through the acceleration control unit and the throttle valve to a pressurizing valve and then to the engine's burners.
- **Proportional flow.** A portion of the main flow by-passes the throttle valve and flows through the proportioning valve, and then through a sensing valve, in a barometric control, back to the inlet side of the fuel system.

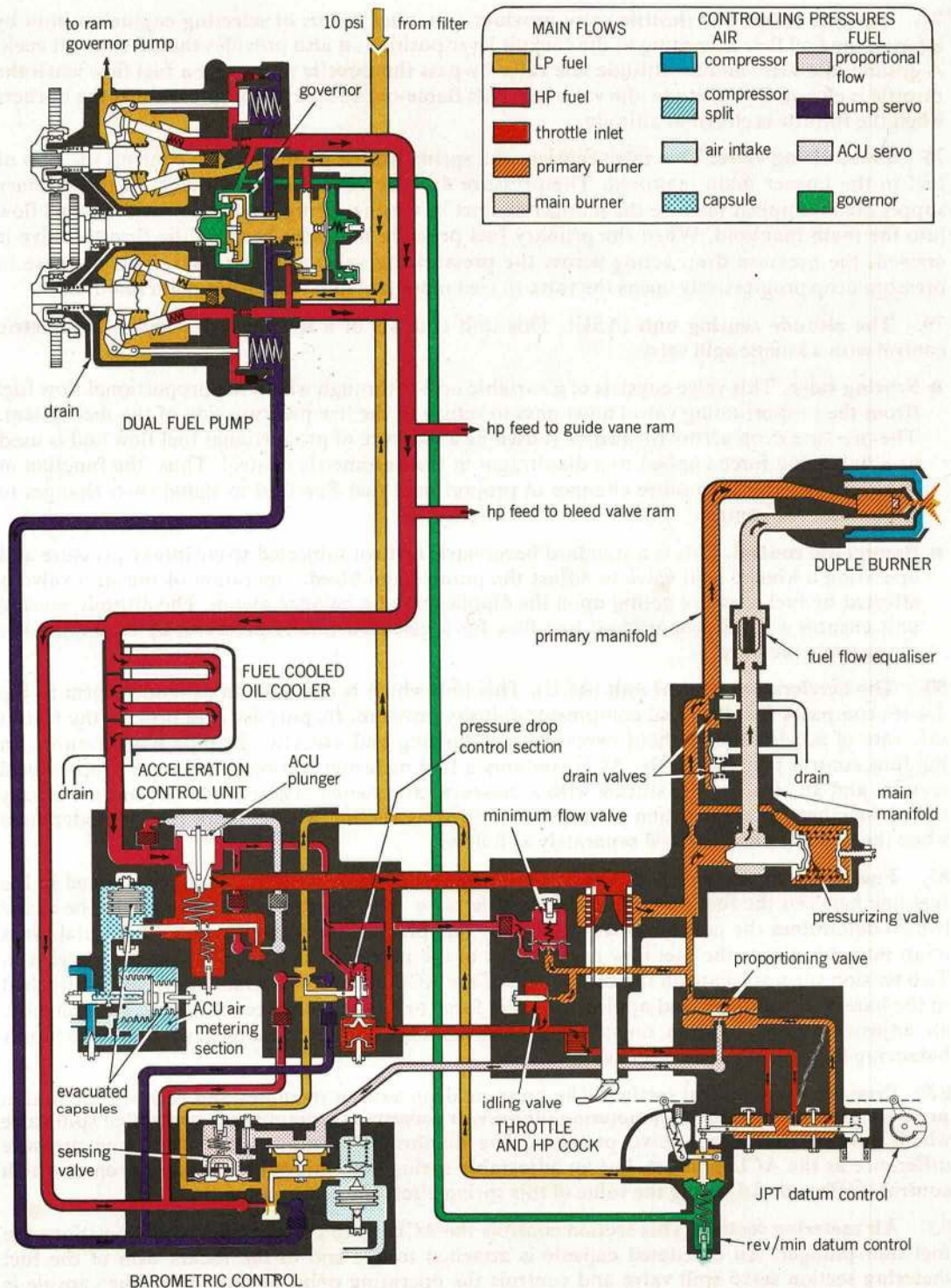


Fig 2.4.15 A proportional flow control system

77. **Throttle valve.** The throttle valve provides a manual means of selecting engine rev/min by altering the fuel flow according to the cockpit lever position; it also provides the HP shut-off cock. A ground idle valve and an altitude idle valve by-pass the throttle to provide a fuel flow when the throttle is closed. The altitude idle valve prevents flame-out caused by low pressure at the burners when the throttle is closed at altitude.

78. **Pressurizing valve.** This valve consists of a spring loaded plunger which controls the flow of fuel to the burner main manifold. The pressure drop across a fixed restrictor, in the primary supply line, is applied to move the plunger against its closing spring; and this provides a fuel flow into the main manifold. When the primary fuel pressure increases because the throttle valve is opened, the pressure drop acting across the pressurizing valve also increases. This increase in pressure drop progressively opens the valve to feed more fuel into the burner main manifold.

79. **The altitude sensing unit (ASU).** This unit consists of a sensing valve and a barometric control with a kinetic spill valve.

- **Sensing valve.** This valve consists of a variable orifice through which the proportional flow fuel (from the proportioning valve) must pass to return to the low pressure side of the fuel system. The pressure drop across the orifice is used as a measure of proportional fuel flow and is used as a balancing force applied to a diaphragm in the barometric control. Thus, the function of this sensing valve is to sense changes in proportional fuel flow and to signal such changes to the barometric control.

- **Barometric control.** This is a standard barometric control subjected to air intake pressure and operating a kinetic spill valve to adjust the pump servo bleed. Operation of the spill valve is effected by fuel pressure acting upon the diaphragm of a balance piston. The altitude sensing unit ensures a fixed proportional fuel flow for a given air intake pressure, by regulating the pump servo pressure.

80. **The acceleration control unit (ACU).** This unit which is re-drawn in expanded form in Fig 2.4.16, compares fuel flow and compressor delivery pressure. Its purpose is to provide the fastest safe rate of acceleration without excessive over-fuelling and excessive jet pipe temperatures. In the flow control fuel system the ACU contains a fuel metering section, a pressure drop control section, and an air metering section with a pressure ratio switch. These three sections are closely linked together for acceleration control but their construction will be more readily understood when the sections are described separately as follows.

81. **Fuel metering section.** A profiled plunger slides in a ported sleeve that is positioned in the fuel line between the fuel pump and the throttle valve. The position of the plunger in the sleeve (which determines the port area) is governed by fuel pressures acting upon the differential areas of an integral piston; the fuel flow is a product of the port area and the pressure drop across it. Two tension springs locate on the rocker arm of the ACU servo spill valve. One spring is attached to the base of the plunger and applies a closing force to it, whilst the second spring is attached to an adjuster accessible from outside the unit. The springs are arranged so that they apply balancing forces to the ACU servo spill valve.

82. **Pressure drop control section.** The pressure drop section regulates and restores the design pressure drop value to the fuel metering plunger. It consists of a diaphragm-controlled spill valve which governs fuel pump servo pressure. The diaphragm is subjected to the same pressure difference as the ACU plunger, but an adjustable spring determines the pressure drop at which control is effected. Adjusting the value of this spring alters the acceleration time.

83. **Air metering section.** This section controls the ACU servo fuel pressure which positions the fuel flow plunger. An evacuated capsule is attached to one end of the rocker arm of the fuel metering section servo spill valve and controls the operating point of this valve. The capsule is subjected to compressor delivery air pressure which is varied by the pressure ratio switch — in such a way that, during the initial acceleration phase, the capsule receives about half the

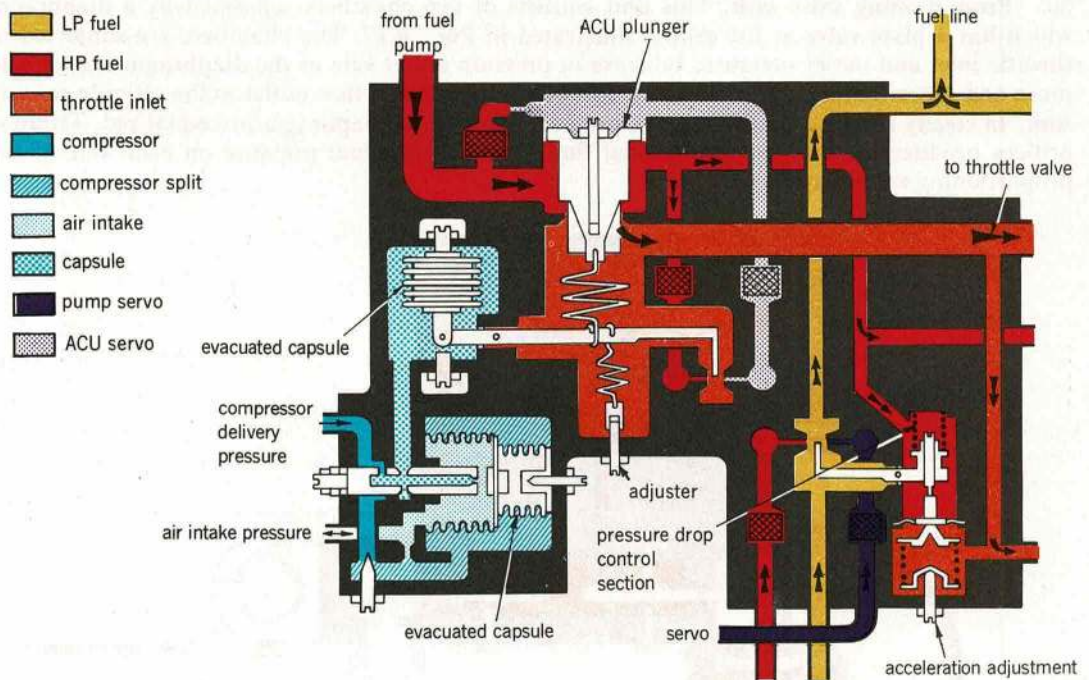


Fig 2.4.16 Acceleration control (proportional flow system)

compressor delivery pressure and, for final acceleration, full compressor delivery pressure (see later).

84. **Operation of the ACU.** Rapid opening of the throttle valve results in:

- Increased fuel pump output.
- An increase in the pressure drop across the fuel metering plunger.
- An increase in the pressure drop across the pressure drop control diaphragm.

When the pressure drop exceeds the value of the diaphragm spring setting in the pressure drop control, the servo spill valve opens to reduce the fuel pump output, thus restoring the pressure drop across the fuel metering plunger to a value that will provide sufficient over-fuelling for acceleration, without producing excessive jet pipe temperatures.

85. The increasing engine speed increases the compressor delivery pressure and more fuel is needed to match the increased airflow. The fuel flow is adjusted by the effect of the increased air pressure upon the evacuated capsule in the air metering section. The greater pressure reduces the length of the capsule and opens the fuel metering servo spill valve. This reduces the ACU servo pressure and allows the plunger to rise to increase the fuel flow. The plunger will continue to move until the spring tension balances the new capsule loading and returns the spill valve to the sensitive position. This sequence repeats until the engine reaches a speed at which greater over-fuelling is acceptable. At this point, the plunger profile aligned with the port area, creates a sharp increase in the rate of over-fuelling to provide faster acceleration during the final phase. Depending upon altitude, the pressure ratio switch closes at about this engine speed and full compressor pressure is fed to the evacuated capsule.

86. **Proportioning valve unit.** This unit consists of two chambers separated by a diaphragm which has a plate valve at the centre, illustrated in Fig 2.4.17. The chambers are subjected to throttle inlet and outlet pressure. Increase in pressure either side of the diaphragm causes it to move and reposition the plate valve to control the proportional flow outlet to the altitude sensing unit. In steady running conditions, the pressures across the diaphragm are equalized. Trimmer orifices produce the correct proportional flow to maintain equal pressure on each side of the proportioning valve diaphragm.

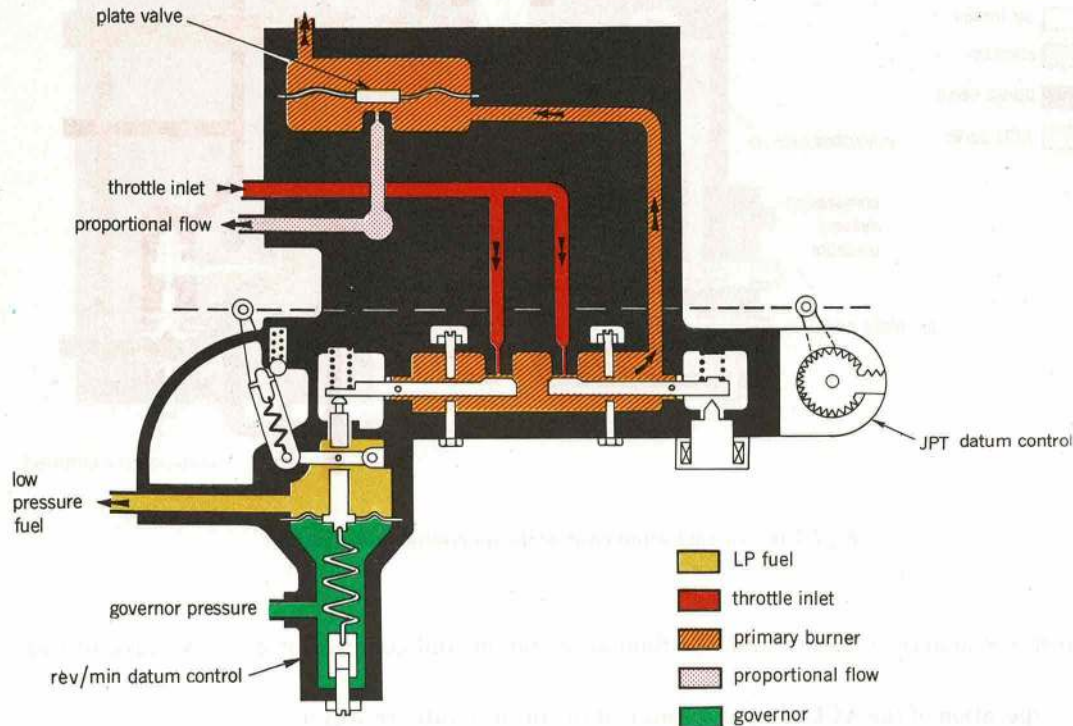


Fig 2.4.17 Proportioning valve unit

87. **Turbine gas temperature (top temperature control).** If the gas temperature exceeds its maximum safe value, jet pipe thermocouples provide a current which progressively energises a solenoid in the proportioning unit. This moves a rocker arm to increase the fuel flow through one of the restrictors, thus increasing the proportional flow. The increased proportional flow is felt by the ASU and the ASU spill valve is opened to reduce the fuel pump output, the reduced fuel flow preventing any further increase in gas temperature.

### Maintenance

88. The fuel systems components are mounted on the engine casing (where space permits) and require specially tailored pipelines and joints (Fig 2.4.18). Repair is by replacement and no work should be carried out without consulting the maker's recommendations and the relevant Air Publication. Checks are made from time to time for fuel contamination and the system will require bleeding to remove air after replacement of any fuel system components.

89. **Adjustments.** Adjustments may be made, within the recommended tolerances, to acceleration times, idle rev/min, and the maximum rev/min. The number of adjustments vary from system to system and may differ with the engine type; this is one reason why you must

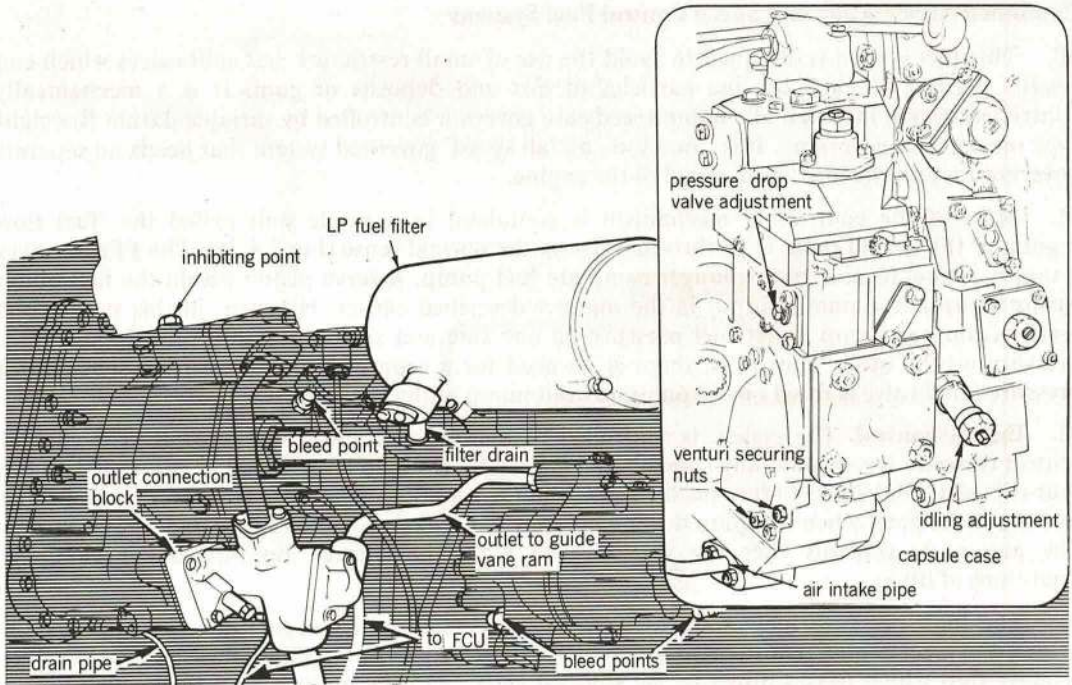


Fig 2.4.18 Fuel system servicing

consult the appropriate AP. An example of adjustments required on one engine is shown in Fig 2.4.19.

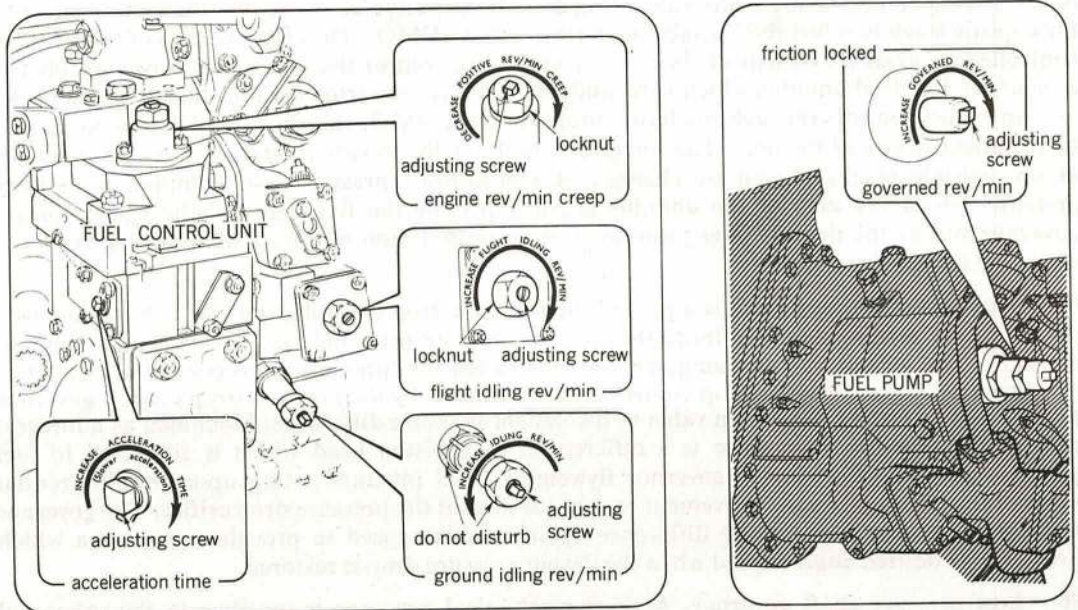


Fig 2.4.19 Fuel system adjustments

## Combined Acceleration and Speed Control Fuel Systems

90. This fuel system is designed to avoid the use of small restrictors and spill valves which can readily become blocked by fine particles of dirt and deposits of gum. It is a mechanically controlled system in which all engine speeds are governor controlled by variable datum flyweight type mechanical governors. It is, therefore, an 'all speed' governed system that needs no separate governor to limit the maximum speed of the engine.

91. Most of the controlling mechanism is contained in a single unit called the 'fuel flow regulator' (FFR) and there is no throttle valve in the normal sense (Fig 2.4.20). The FFR receives a supply of fuel from a multi-plunger camplate fuel pump. A servo piston within the fuel pump casing controls the pump output in the manner described earlier. However, in this system, the servo piston has pump outlet fuel pressure on one side and spring pressure plus main burner pressure on the other side; thus, there is no need for a separate servo pressure system, but a pressure relief valve is fitted on the pump to limit pump outlet pressure.

92. **Engine control.** The system is controlled by manual and automatic controls. The cockpit control (throttle lever) manually controls the engine by a single lever which is connected to the shut-off valve (SOV) and to the speed governor in the fuel flow regulator. This lever is used when starting the engine, when stopping the engine, or when selecting engine speed and power output. The automatic controls vary the fuel flow to maintain selected rev/min under changing conditions of flight.

93. The high pressure fuel pump delivers fuel to the fuel flow regulator where the flow is adjusted to meet engine requirements. The fuel is delivered as two separate flows; a constant rate primary flow which passes direct to the shut-off valve; and the main burner flow which passes through the low pressure shaft governor before reaching the shut-off valve. Both fuel flows enter their respective manifolds and deliver fuel to the spray nozzles in the combustion chamber. When the SOV is moved to the closed position, the fuel supply to the spray nozzles is stopped and the contents of the fuel manifold are directed into the drain system.

94. **Fuel flow regulator.** The basis of the fuel flow regulator (FFR) is the provision of fuel ports in two sliding and revolving sleeve valves (Fig 2.4.20). A triangular port cut in the valve nearest to the capsule stack is called the 'variable metering orifice' (VMO). The effective area of the VMO is controlled by axial movement of the valve. Axial movement of the governor sleeve controls the area of the fuel feed annulus which surrounds the variable metering orifice. Fuel at pump outlet pressure flows inwards through the feed annulus and the VMO, and the rate of flow is controlled by the effective size of the hole. The VMO is moved axially, to vary its size, by changes in length of the capsule stacks caused by changes of atmospheric pressure and compressor delivery pressure, whilst the area of the annulus is controlled by the flyweights in the speed control governor and by the throttle lever position. The rev/min datum of the speed control governor is set by the throttle lever position.

95. The second rotating valve is a part of the pressure drop control governor. It has two outlet ports: one is rectangular and feeds the primary burner manifold; its effective area remains constant. The second port is triangular and it is called the 'pressure drop control orifice'. The effective area of the pressure drop control orifice is altered by the pressure drop control governor to maintain or restore the design value to the system pressure difference. Machined as an integral part of the pressure drop valve is a differential area piston head which is subjected to fuel pressure and the effect of the governor flyweights. Fuel pressure acting upon the differential areas of the piston give axial movement to vary the area of the pressure drop orifice. The governor flyweights balance the pressure difference against engine speed to provide a port area which provides the desired engine speed when the design pressure drop is restored.

96. **Low pressure shaft governor.** A third mechanical governor is sensitive to the rotational speed of the low pressure compressor. It can reduce the main burner fuel flow to prevent overspeeding of the LP compressor.

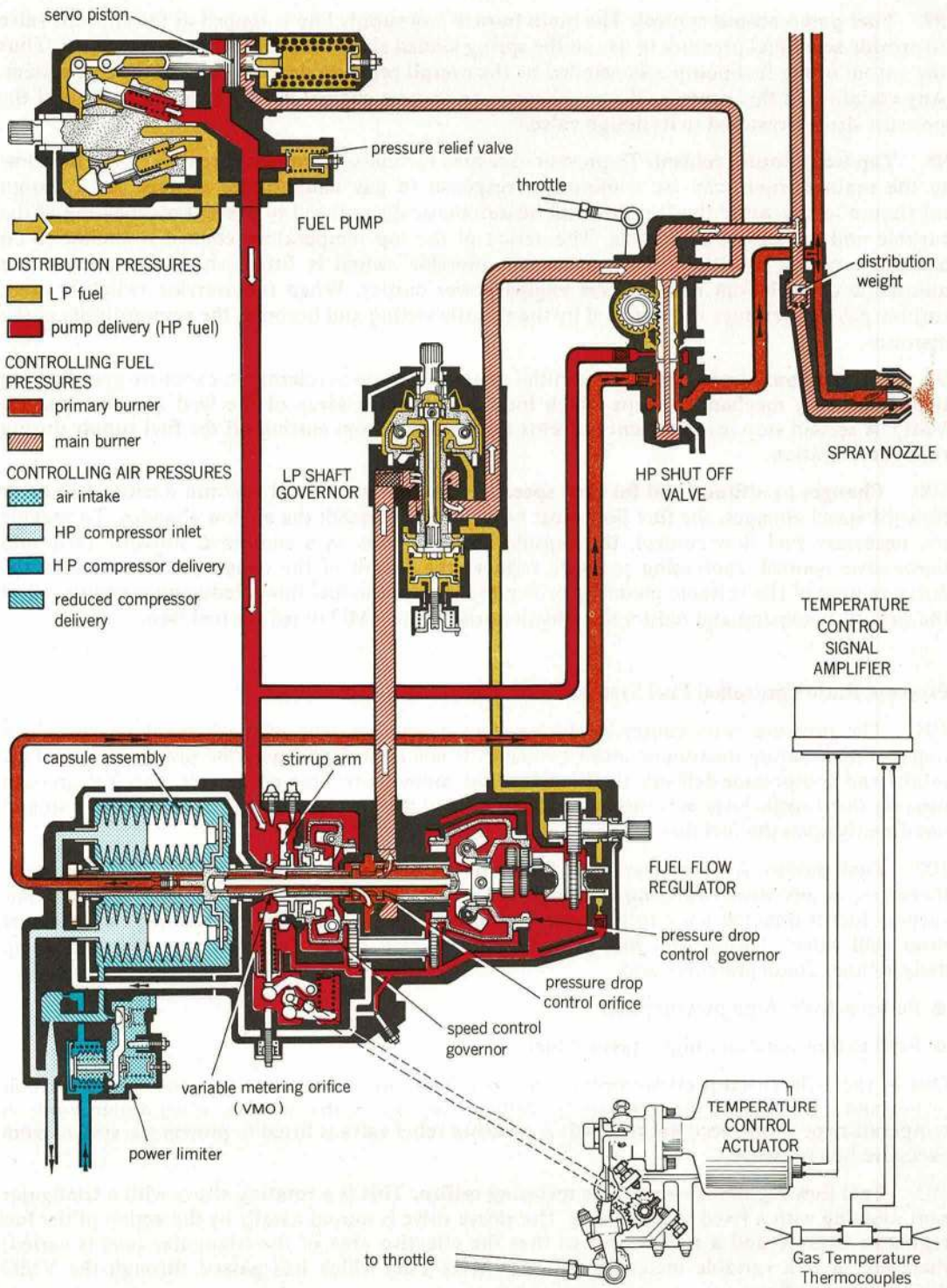


Fig 2.4.20 Combined acceleration and speed control fuel system

97. **Fuel pump output control.** The main burner fuel supply line is tapped at the shut-off valve to provide servo fuel pressure to use on the spring loaded side of the fuel pump servo piston. Thus the output of the fuel pump is controlled by the overall pressure drop existing in the fuel system. Any variation of this pressure drop will cause an inverse change in fuel pump output until the pressure drop is restored to its design value.

98. **Top temperature control.** To prevent excessive turbine gas temperature (TGT), the fuel flow to the main burners can be trimmed in response to gas temperature signals. At a design maximum temperature the fuel flow will be automatically reduced to prevent overheating of the turbine and exhaust system parts. The action of the top temperature control is similar to an alteration of the throttle lever position. An override switch is fitted which can prevent the automatic control from reducing the engine power output. When the override switch is used, turbine gas temperature is controlled by the throttle setting and becomes the responsibility of the operator.

99. **Acceleration control.** During the initial phase of a rapid acceleration, excessive over-fuelling is prevented by mechanical stops which limit the effective areas of the feed annulus and the VMO. A second stop arrangement prevents the governor from cutting off the fuel supply during rapid deceleration.

100. **Changes in altitude and forward speed.** To maintain constant rev/min during altitude or forward speed changes, the fuel flow must be adjusted to match the airflow changes. To provide the necessary fuel flow control, the capsule assembly acts as a combined pressure ratio and barometric control. Increasing pressure reduces the length of the capsules and increases the effective area of the variable metering orifice to increase the fuel flow. Reducing pressures allow the capsule to expand and reduce the effective area of the VMO to reduce fuel flow.

### Pressure Ratio Controlled Fuel Systems

101. The pressure ratio controlled fuel system is another type of mechanical system which requires no separate maximum speed governor. It is a system that uses the pressure ratio of air intake and compressor delivery air ( $P1/P4$ ) as the main controlling parameter, and it is unusual because the throttle lever acts mechanically to control the air bleed in the pressure ratio unit and not directly upon the fuel flow in the regulator unit (Fig 2.4.21).

102. **Fuel pump.** A spur gear type fuel pump provides the high pressure fuel flow and, therefore, at any steady running condition, the pump output exceeds the engine demand. The surplus fuel is directed back to the inlet side of the pump by a relief valve called the 'pressure drop spill valve'. Differential fuel pressures are created by two restrictors in the fuel pump delivery line. These pressures are:

- Pump delivery high pressure fuel.
- Feed to flow regulator high pressure fuel.

One of the differential pressure restrictors has a fixed area orifice but the other has a variable orifice and it works with the auxiliary throttling valve to trim the fuel flow when design limits of temperature or shaft speed are reached. A pressure relief valve is fitted to protect the system from excessive fuel pressure.

103. **Fuel flow regulator — variable metering orifice.** This is a rotating sleeve with a triangular port aligning with a fixed size annulus. The sleeve valve is moved axially by the action of the fuel regulator capsule and a rocker arm so that the effective area of the triangular port is varied; therefore, it is a variable metering orifice (VMO). Fuel which has passed through the VMO divides into two flows:

- The primary fuel flow.
- The main fuel flow.

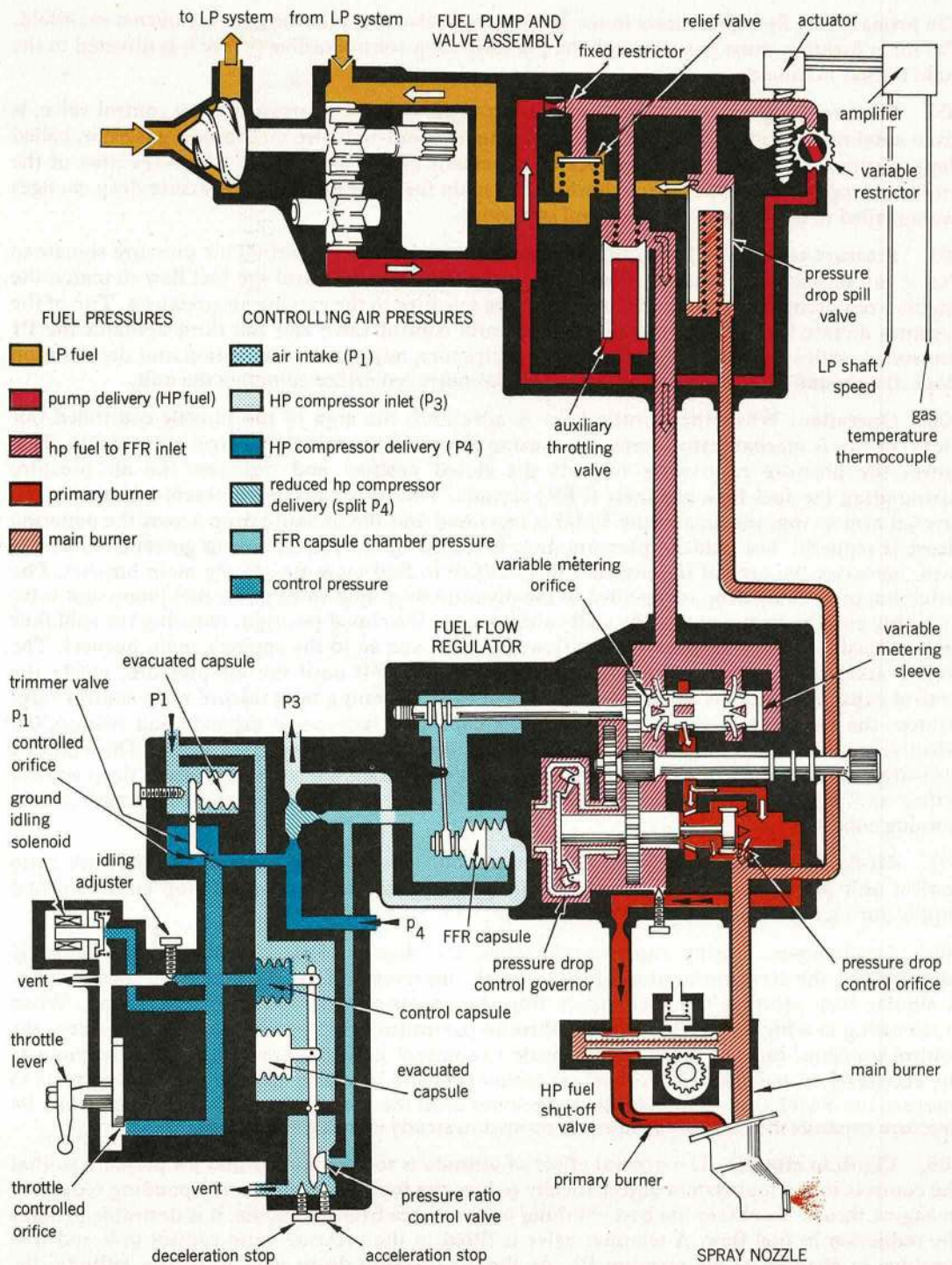


Fig 2.4.21 Pressure ratio controlled fuel system

The primary fuel flow goes direct to the HP shut-off valve and into the primary burner manifold. The main fuel flow must pass through the pressure drop control orifice before it is directed to the main burner manifold.

104. **Pressure drop control.** A second rotating valve, called the pressure drop control valve, is given axial movement by the flyweights of an engine speed-sensitive mechanical governor, called the pressure drop control governor. Axial movement of this sleeve valve alters the area of the pressure drop control orifice through which the main fuel flow must pass. Pressure drop changes are signalled to the pressure drop control spill valve.

105. **Pressure ratio unit.** This unit is designed to receive P1, P3 and P4 air pressure signals so that it can measure the mass air flow through the engine and control the fuel flow to match the engine's requirements. It contains three capsules sensitive to the varying air pressures. Two of the capsules dictate the position of the pressure ratio control valve and the third actuates the P1 controlled orifice trimmer valve. Calibrated restrictors, adjusters, acceleration and deceleration stops, the ground idling solenoid and the throttle controlled orifice complete the unit.

106. **Operation.** When the throttle lever is advanced, the area of the throttle-controlled (air bleed) orifice is mechanically increased, causing a drop in the value of control air pressure. This moves the pressure ratio valve towards the closed position and increases the air pressure surrounding the fuel flow regulator (FFR) capsule. The FFR capsule contracts and moves the pivoted arm so that the area of the VMO is increased and the pressure drop across the metering sleeve is reduced. The reduced pressure drop is sensed by the pressure drop governor which, in turn, increases the area of the pressure drop orifice to feed more fuel to the main burners. The reduction in pressure drop is signalled to the pressure drop spill valve in the fuel pump and valve assembly and the spring moves the spill valve towards the closed position, reducing the spill flow and increasing the fuel feed to the fuel flow regulator and so to the engine's main burners. The engine accelerates and increases the pressure ratio ( $P1/P4$ ) until the air pressure, inside the control capsule, opens the pressure ratio control valve. Opening the pressure ratio control valve reduces the air pressure surrounding the FFR capsule. The capsule expands and reduces the effective area of the VMO to increase the pressure drop to its original value. The restored pressure drop is sensed by the pressure drop governor, which adjusts the pressure drop control orifice and signals the pressure drop spill valve to take up a position consistent with steady running conditions.

107. **Mechanical stops.** During rapid acceleration, a mechanical stop in the pressure ratio control unit prevents excessive over-fuelling. A second similar mechanical stop ensures a fuel supply during rapid deceleration (Fig 2.4.21).

108. **Acceleration.** During rapid acceleration, the degree of over-fuelling is mechanically controlled by the acceleration stop which limits the movement of the pressure ratio control valve. A similar stop prevents the fuel supply from being cut-off during rapid deceleration. When accelerating to a higher  $P1/P4$  ratio, the throttle-controlled orifice is increased. This reduces the control pressure, causing the control capsule to contract until the pressure ratio valve contacts the acceleration stop. The FFR capsule chamber pressure increases and the capsule contracts to increase the VMO area. This condition continues until the new  $P1/P4$  ratio is reached, when P4 pressure expands the control capsule and returns to steady running conditions.

109. **Climb to altitude.** The normal effect of altitude is to decrease P1 and P4 pressure so that the controls in the fuel system automatically reduce the fuel flow with a corresponding reduction in engine thrust. To obtain the best climbing performance from an engine, it is desirable to delay the reduction in fuel flow. A trimmer valve is fitted in the pressure ratio control unit and it is sensitive to changes of air pressure P1. As the air pressure drops with increased altitude, the trimmer valve reduces the control air pressure, which acts upon the pressure ratio control valve, with the result that the area of the VMO is reduced at a slower rate and engine thrust is maintained at a fixed throttle setting.

**110. Top temperature and maximum shaft speed.** To prevent excessive turbine gas temperature and overspeeding of the compressor shafts, the auxiliary throttling valve is brought into use. It is actuated by differential fuel pressures and a spring. Under normal running conditions, the valve is held open by the spring and has no effect upon the function of the fuel system. But if the pressure drop is increased to a value greater than that used for steady running conditions, the throttling valve will restrict the fuel passage to the fuel flow regulator. Temperature and speed signals are transmitted as a voltage to an amplifier and, when the design limits of the engine are reached, the voltage is sufficient to drive an actuator and reduce the size of the variable restrictor in the pump output line. Reducing the fuel flow through the restrictor causes an increase in the pressure drop, sufficient to partially close the auxiliary throttling valve. The increased pressure drop is felt by the pressure drop spill valve which opens to restore the design pressure drop value. This reduces the fuel flow to the engine and prevents excessive turbine gas temperatures and overspeeding of the compressor shafts.

**111. Idling control.** With the throttle closed, the idling condition is determined by controlling the amount of air being vented through the idling adjuster and the ground idling solenoid valve. By closing the solenoid valve, a lower power condition for ground idling is obtained.

## CONCLUSION

**112.** We have now discussed the requirements which must be satisfied in a fuel system for a gas turbine engine. We have also discussed several systems of fuel flow control, including the automatic devices which cater for changes in forward speed, altitude and so on. Whatever method of control is employed, the objective has been to make sure that the correct quantity of fuel is introduced into the combustion chamber in the form of a finely atomized spray or as a vapour in order that it may readily combine with the oxygen from the engine air flow. The type of burners or spray nozzles used is entirely a matter of design (see p2.3.10 of this STTN). It is well to remember that if an atomizer is designed to atomize small fuel flows, it will require extremely high fuel pressures to pass a large flow through a small burner orifice, as in the case of the simplex burner. Alternatively, if a burner is designed to atomize a very large fuel flow, and it is only passing a small flow, the atomization of the fuel would be poor.

**113.** The main points about each of the three methods of controlling fuel that we have considered in this Chapter may be summarized as follows:

- In a pressure control system, a constant pump output pressure for any intake pressure is maintained. This constant fuel pressure is then reduced by a throttle valve operated by the pilot so as to produce the burner fuel pressure and, therefore, the fuel flow which will give the required engine rev/min. Any tendency for rev/min to change will be felt as a change in pump output pressure, which is then automatically restored so as to maintain the rev/min constant.
- With a simple flow control system, the pressure difference caused by the fuel flow through a throttle valve is sensed and kept constant for any given nacelle air pressure by changes in pump output. The constant pressure difference across the throttle valve ensures a constant fuel flow into the engine. Therefore, for fixed engine rev/min, the flame temperature remains constant.
- With the proportional flow control system, only a small proportion of the engine fuel flow is passed through the sensing and controlling section of the system. Fuel pump output is then regulated so that the total fuel flow changes in accordance with engine demand as dictated by proportional flow.

**114.** When discussing servo pressure control, this simply relates to a rubber sealed piston which works inside a cylinder. Its stem is connected to the camplate of the fuel pump by a link and pin, and the head of the piston is spring loaded to increase the camplate angle. The servo force is HP

fuel taken from the pump outlet and fed to both sides of the piston, that to the piston head first passing through a metering restrictor. The fuel on the piston head is called the servo fuel and its pressure is controlled by spill valves in the fuel system units.

115. Again, it must be stressed, that no adjustments or repairs to fuel systems are to be carried out without reference to the appropriate AP, and that absolute cleanliness is essential. Remember the words FOREIGN OBJECT DAMAGE (FOD) — make sure that, when you have completed work on the fuel system, all items, such as nuts, bolts, washers, locking wire and tools, have been accounted for. Check and check again.

116. When the fuel system is being checked, the fuel system units should be checked in the following order: (a) the fuel system units, (b) the fuel system units, (c) the fuel system units, (d) the fuel system units, (e) the fuel system units, (f) the fuel system units, (g) the fuel system units, (h) the fuel system units, (i) the fuel system units, (j) the fuel system units, (k) the fuel system units, (l) the fuel system units, (m) the fuel system units, (n) the fuel system units, (o) the fuel system units, (p) the fuel system units, (q) the fuel system units, (r) the fuel system units, (s) the fuel system units, (t) the fuel system units, (u) the fuel system units, (v) the fuel system units, (w) the fuel system units, (x) the fuel system units, (y) the fuel system units, (z) the fuel system units.

### CONCLUSION

117. The fuel system is a complex system which must be checked in a particular order. The fuel system units should be checked in the following order: (a) the fuel system units, (b) the fuel system units, (c) the fuel system units, (d) the fuel system units, (e) the fuel system units, (f) the fuel system units, (g) the fuel system units, (h) the fuel system units, (i) the fuel system units, (j) the fuel system units, (k) the fuel system units, (l) the fuel system units, (m) the fuel system units, (n) the fuel system units, (o) the fuel system units, (p) the fuel system units, (q) the fuel system units, (r) the fuel system units, (s) the fuel system units, (t) the fuel system units, (u) the fuel system units, (v) the fuel system units, (w) the fuel system units, (x) the fuel system units, (y) the fuel system units, (z) the fuel system units.

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