PART 1 : SECTION 3

CHAPTER 6

FUEL SYSTEMS

Introduction

1. This chapter deals with those parts of the fuel system that are more closely associated with the engine. Those parts of the system that concern fuel tanks, cockpit controls, etc., are covered in Section 6, Chapter 2. All pilots should have a knowledge of the general working principles of the fuel systems of their aircraft ; if the broad working and limitations of the fuel system are known and understood the result is more intelligent and sympathetic engine handling both on the ground and in the air.

Requirements of a Fuel System

2. The primary requirement of a gas-turbine fuel system is to deliver a continuous supply of finely atomized fuel to the combustion chambers and to give the highest possible combustion efficiency. Other requirements are :—

(*a*) A means of controlling the supply of fuel so that the engine r.p.m. and power can be regulated.

(*b*) The ability to maintain a selected engine speed ; the rate of delivery of the fuel must be automatically controlled according to the altitude, since the fuel requirement decreases with increase in altitude.

(*c*) Control of turbine and compressor speeds, and prevention of excessive temperatures.

3. Fuel systems vary considerably according to the design and power of the engine and the type of aircraft in which the engine is to be used. However, the basic needs are much the same for all engines, and are :—

(*a*) A pump to supply fuel at high pressure. Often two pumps are fitted to obtain high delivery rates and as a safeguard against the failure of one pump.

(*b*) An altitude control unit to regulate the fuel supply according to the engine requirement with changes of altitude.

(*c*) A high-pressure fuel cock to stop the engine.

(*d*) A throttle control.

(*e*) Burners to atomize the fuel for combustion.

In addition, various refinements such as acceleration control units (A.C.U.) and other safety devices are incorporated in most systems.

Methods of Controlling the Fuel Flow

4. The most used principle of operation of gas-turbine fuel systems is known as *open loop control.* This form of control anticipates the amount of fuel an engine will require for a given r.p.m. and altitude, and arranges for the requisite amount to be metered to the engine under the control of the pilot. In this system (Fig. 1) the pilot has control of the throttle, the setting of which determines the amount of fuel flowing to the engine. Any change in air temperature or pressure requires an alteration in the fuel flow, and this is effected automatically by a barometric control as height and speed vary. The effect of a change in fuel flow is to cause a change in engine r.p.m. and therefore power output, or alternatively to keep a constant r.p.m. setting and power output with change of air pressure and temperature.

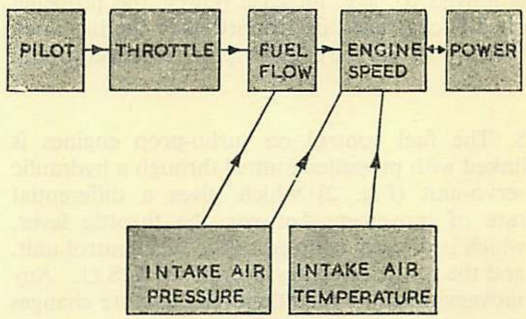


Fig. 1.
Block Diagram of an Open-Loop Flow Control.

5. To meet the requirements of para. 2(c) an overspeed governor is needed to prevent the maximum r.p.m. setting being exceeded.

6. Temperature control (Chap. 8) is an efficient method of control of the power output of the gas-turbine engine, as both the turbine temperature and j.p.t. are governing factors in the engine operation. It is, however, difficult to provide this form of control at low r.p.m. because of the low efficiencies of the turbine and compressor at these speeds which cause an inherent rise in engine temperatures, so that a misleading signal is transmitted to the control. Temperature control may be either automatic or manual, and both systems are based on the

spilling of a measured amount of fuel from the flow control unit, until the fuel flow is such that the indicated j.p.t. is the same as that selected. The automatic control unit is operated electrically through a magnetic amplifier and a solenoid, while the manual type is a direct rheostat control, the spill being set to the desired value manually. In both cases the indicated j.p.t. is measured by jet-pipe thermo-couples.

7. It will be realized that the r.p.m. of the turbo-prop engine can be controlled and varied independently of the fuel supplied, by changing the propeller pitch and so altering the torque. This is accomplished by a C.S.U. similar to that used on the piston engine. The C.S.U. controls the propeller pitch in such a way as to maintain the engine r.p.m. at a preselected ideal value, *i.e.* the engine is "constant speeding". It must be appreciated that, at a given power setting, the C.S.U. changes the propeller pitch only when there is a difference between the indicated and the ideal engine speeds. This means that there is a time lag before the change in pitch restores the r.p.m. to the ideal value. When the throttle is moved to, say, increase power, the propeller pitch is coarsened in proportion to the increased fuel flow so that the engine r.p.m. remain constant.

8. The fuel control on turbo-prop engines is linked with propeller control through a hydraulic servo-unit (Fig. 2) which gives a differential rate of movement between the throttle lever, which is directly coupled to the fuel control unit, and the r.p.m. selecting lever of the C.S.U. Any movement of the throttle lever therefore changes the settings of both the fuel control unit and the C.S.U.—the former directly and over the full range of manual fuel control, the latter through the action of the servo-unit—over the range of r.p.m. selection governed by the servo-unit.

Types of Fuel Systems

9. There are two main types of fuel systems used in gas-turbine engines :—

(*a*) Pressure-controlled systems.

(*b*) Flow-controlled systems.

Pressure-Controlled Systems

10. In pressure-controlled systems the pressure in the fuel line depends on the altitude, thus giving the required relationship between burner flow and altitude under full throttle and maximum r.p.m. conditions. To obtain a lower r.p.m. a throttle control unit is interposed between the fuel pump and the burners, so that the fuel flow at the burner may be varied. The desired relationship between the pressure in the fuel line and altitude is obtained by using a variable-stroke pump, the displacement of which is automatically varied so as to give the desired relationship between the fuel-line pressure and total pressure ; the pump pressure is constant at a given height regardless of the throttle position. The automatic variation of pump pressure with altitude is controlled by a barometric pressure control (B.P.C.) which is subject to nacelle pressure (nacelle pressure is the ram pressure at the air-intake of the engine compressor and varies with air temperature, barometric pressure, and aircraft speed) ; so that change in altitude, speed, or atmospheric conditions, results in a corresponding increase or decrease in pump delivery pressure (see para. 33).

Flow-Controlled Systems

11. The flow-controlled system also makes use of a variable-stroke fuel pump, but an additional metering orifice with a relatively small pressure drop is placed in the fuel line, and the pressure drop across this orifice is made to control the fuel delivered to the burners. In older types of flow-controlled units this orifice is under the control of the pilot, and the pressure across it is balanced against the nacelle pressure. Flow-

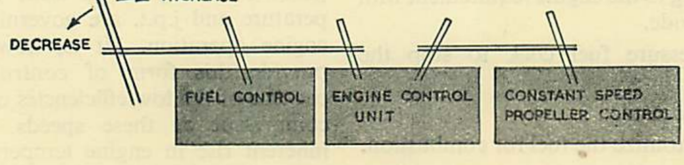


Fig. 2. Diagrammatic Arrangement of Servo-Control.

controlled systems are particularly suitable for turbo-prop aircraft operating up to 30,000 feet. A later type of unit, known as the full-range flow control, is used for turbo-jet engines operating up to 60,000 feet. (see para. 50).

12. Flow-controlled units reduce the pump pressure at throttle openings below fully open, the pump pressure never exceeding the burner pressure by more than about 200 lb./sq. in. (With the B.P.C. in the pressure-controlled system the pump pressure is constant at any given altitude regardless of the throttle setting or burner pressure.) The work which the pump is called upon to perform is thus reduced, and its effective life is lengthened.

Working of a Typical Fuel System

13. The following paragraphs deal with the working of a typical gas-turbine fuel system incorporating some of the components described later in this chapter. Since the systems used on individual engines may differ, the subject can be treated only in general terms and using one combination of components, but the basic principles will be the same for all engines. Reference should be made to the relevant air publication for details of specific engine fuel systems.

14. The amount of fuel required by a gas-turbine engine is directly related to the mass airflow through the engine and is a function of many variable quantities such as engine r.p.m., altitude, inlet air temperature, aircraft speed, and combustion efficiency. To achieve peak efficiency from the engine, the fuel flow must be regulated to cater for these variable conditions. Starting must be easy, and slow running at altitude must be satisfactory with no tendency towards flame extinction.

15. The injection of controlled quantities of fuel into a moving airstream, in a manner that ensures continuous and rapid burning, requires efficient atomization over a wide range of fuel flows ; this may be accomplished by using variable burner orifices at an almost constant pressure, or fixed burner orifices at varying pressures. Practical considerations of design and manufacture favour the use of fixed orifices : the limitations of this type while at low fuel flows at starting and idling speeds have been overcome by the use of components which ensure that a minimum pressure for efficient combustion is maintained in the burner fuel line at all engine speeds and altitudes.

16. Other methods of injection include the use of burners with two orifices, a small one for starting and idling flows and a larger one for higher fuel flows. This type of burner requires a unit, known as a pressurizing valve, which cuts off the flow to the larger orifice at low fuel flows and allows a continuous fuel flow through the smaller orifice ; at a certain higher pressure it permits additional fuel to flow through the larger orifice.

Methods of Controlling the Fuel Flow to the Throttle

17. A steady flow of fuel at controlled pressure is supplied by one or two high-pressure pumps in conjunction with a throttling device under the control of the pilot. Two methods are used to control the fuel flow to the throttle. One uses a high-pressure constant-delivery pump in conjunction with a unit called a barostat, which bypasses excess fuel back to the pump inlet according to pump outlet pressure which is determined by the throttle position. The other method uses a high-pressure variable-delivery pump employing a servo-mechanism controlled by a separate unit called the barometric pressure control (B.P.C.). The B.P.C. varies the fuel flow to the burners by sensing momentary changes in the pump outlet pressure caused by movement of the throttle. The barostat and the B.P.C. both compensate the fuel flow for changes in aircraft speed (ram effect) and altitude.

Stopping the Engine

18. To stop the engine the fuel supply to the burners is cut off by a cock which also allows the fuel supplied during the running-down period to be returned to the pump inlet. The fuel remaining in the burner line and combustion chambers after flame extinction is drained away to eliminate the possibility of the accumulated loose fuel burning in the combustion chambers and jet-pipe when restarting the engine. This is usually done by drain pipes from the combustion chambers to a non-return valve which permits the fuel to drain away to atmosphere when the engine has stopped.

COMPONENTS OF FUEL SYSTEMS

Fuel Pumps

19. Early gas-turbine engines are fitted with a constant-displacement pump which operates in conjunction with a barostat or barometrically-controlled bypass. It has been found that such

a system has serious limitations, and to meet the wide range of fuel flows required by the engine at varying altitudes and powers, a variable-stroke pump with a suitable control system is best. A number of basic sizes of fuel pump have been produced to provide the flow required by engines of various power outputs. Although differing in appearance, all pumps employ similar essential constructional features.

20. A fuel pump consists of a rotor and a number of inclined cylinder bores in which spring-loaded pistons are fitted (Fig. 3). As the rotor revolves, the inner ends of the cylinders are opened in turn to the fixed inlet and outlet ports of the main pump body. The outer ends of the pistons have rounded heads which are held in contact with a shaped circular cam-plate by the return springs. The angle between the axis of the cam and rotor is variable, so that the piston stroke, and thus the output of the pump, can be altered. To control this angle, the cam-plate (Fig. 4) is rigidly mounted in a ring which is pivoted on a pair of diametrically opposed pivots.

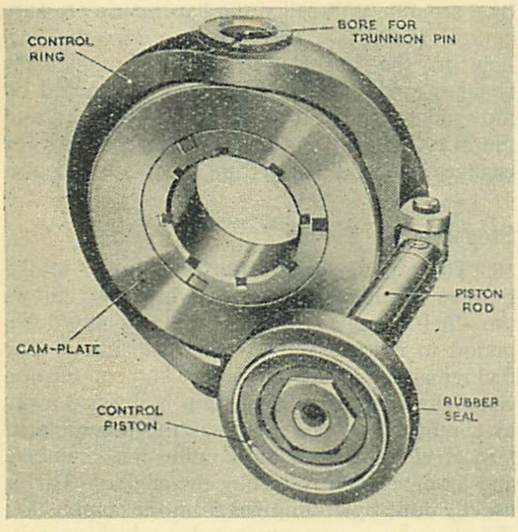
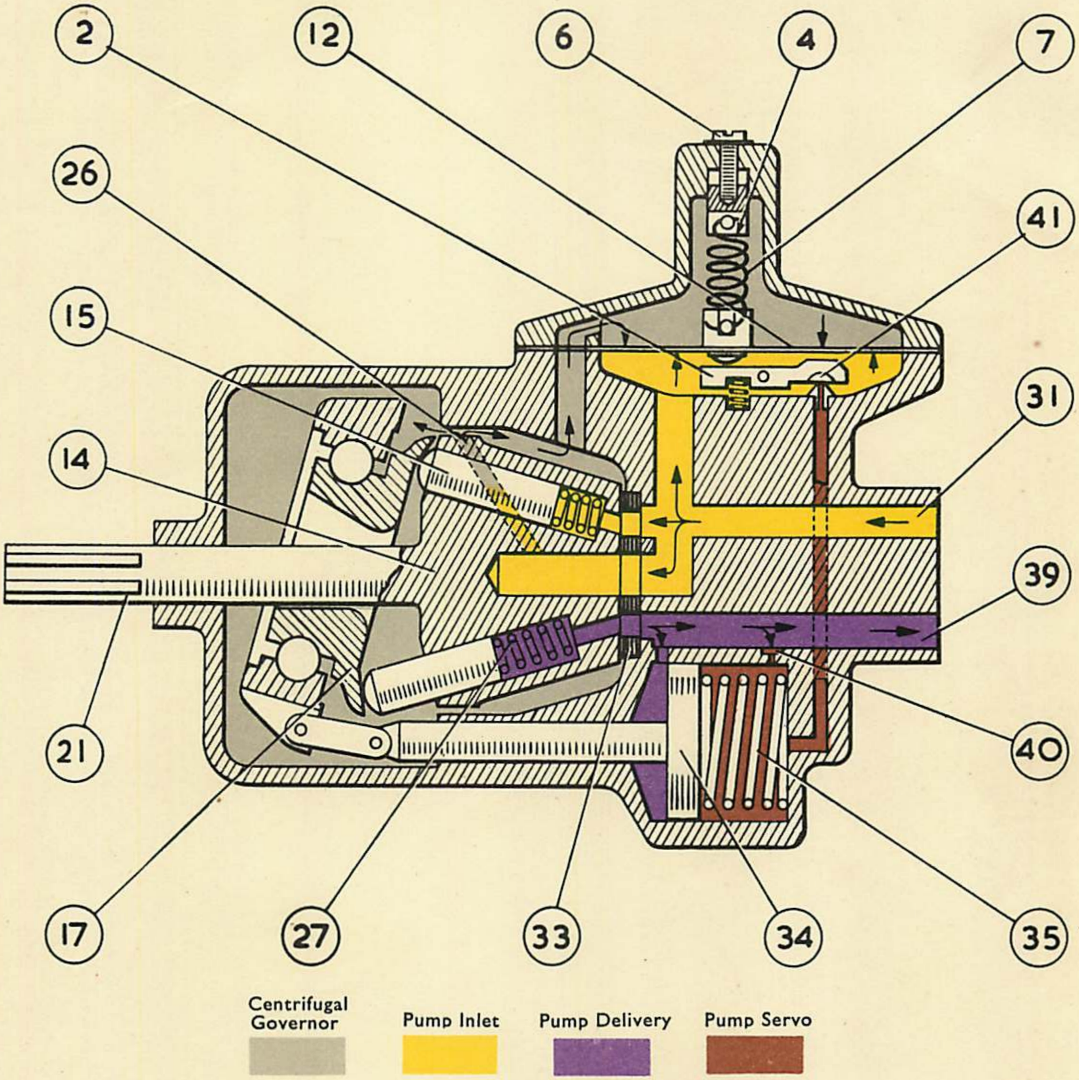


Fig. 4.
Control Piston, Cam Plate, Control Ring, and Bearing Assembly of a Fuel Pump.

21. As shown in Fig. 3, the ring is connected to a rod carrying a piston within a cylinder housing in the pump-body casting. The cylinder, on the rod side of the piston, is continually subjected to the delivery pressure from the pump and there is also a small calibrated leak into the cylinder (Fig. 3(40)) on the other side of the piston (the servo cylinder). This outer, or servo, portion of the cylinder is completely closed, apart from connections to appropriate control orifices. One such orifice is shown in Fig. 3; it is opened by the overspeed governor. This control orifice, known as the amplifier valve (Fig. 3 (41)) prevents excessive pressure building up if the fuel delivery line becomes obstructed. A pair of springs behind the piston tend to move it towards the position of maximum delivery and are assisted in doing so by fuel delivery pressure entering through the restricting orifice (40) and acting on the piston head. Other control orifices, which lead to such units as the B.P.C. and acceleration control unit (A.C.U.), each regulate the pump delivery in accordance with the operating conditions which it is part of their function to measure. When all the control orifices are closed the servo-cylinder is sealed and the pressures on both sides of the calibrated leak are equal (*i.e.* there is no pressure drop across the leak). At the same time there is no pressure difference across the control piston since both sides are being subjected to outlet pressure from the pump, so that the cam-plate will occupy the full-stroke position. If, however, any control orifice in the system is opened, the pressure in the servo cylinder falls and the higher pressure on the rod side of the piston causes the piston to compress the spring (35) and move the cam-plate to a smaller angle, so cutting down the stroke of the pistons and the pump delivery.

Overspeed Governor

22. The overspeed governor in the pump is typical of the methods used to operate these devices. The speed-sensing element consists of a flexible diaphragm (12) in the governor chamber, subjected on one side to the pressure (in the form of a centrifugal pressure rise) created in a series of radial holes (26) drilled in the rotor and containing fuel from the pump inlet connection, and on the other side to the inlet pressure itself. The pressure difference, and hence the force exerted on the diaphragm, is proportional to the square of the rotor r.p.m. Normally the force is balanced, or exceeded, by the loading of the helical spring on the diaphragm. As soon as the pressure difference overcomes this loading, the diaphragm is deflected, causing a small hardened button to engage the tail of a rocker lever, in the head of which is fitted a swivelling half-ball which normally tends to keep the control orifice closed (41). Movement of the lever uncovers the orifice so that fuel under pressure escapes



KEY TO FIG. 3

2. Rocker assembly
4. Spring assembly
6. Adjustment screw
7. Helical spring
12. Diaphragm
14. Rotor
15. Piston
17. Cam plate
21. Splined quill shaft
26. Radial holes
27. Return spring
31. Pump inlet
33. Insert
34. Control piston
35. Springs
39. Pump outlet
40. Restricting orifice
41. Amplifier valve

Fig. 3. Sectional Drawing of a Fuel Pump

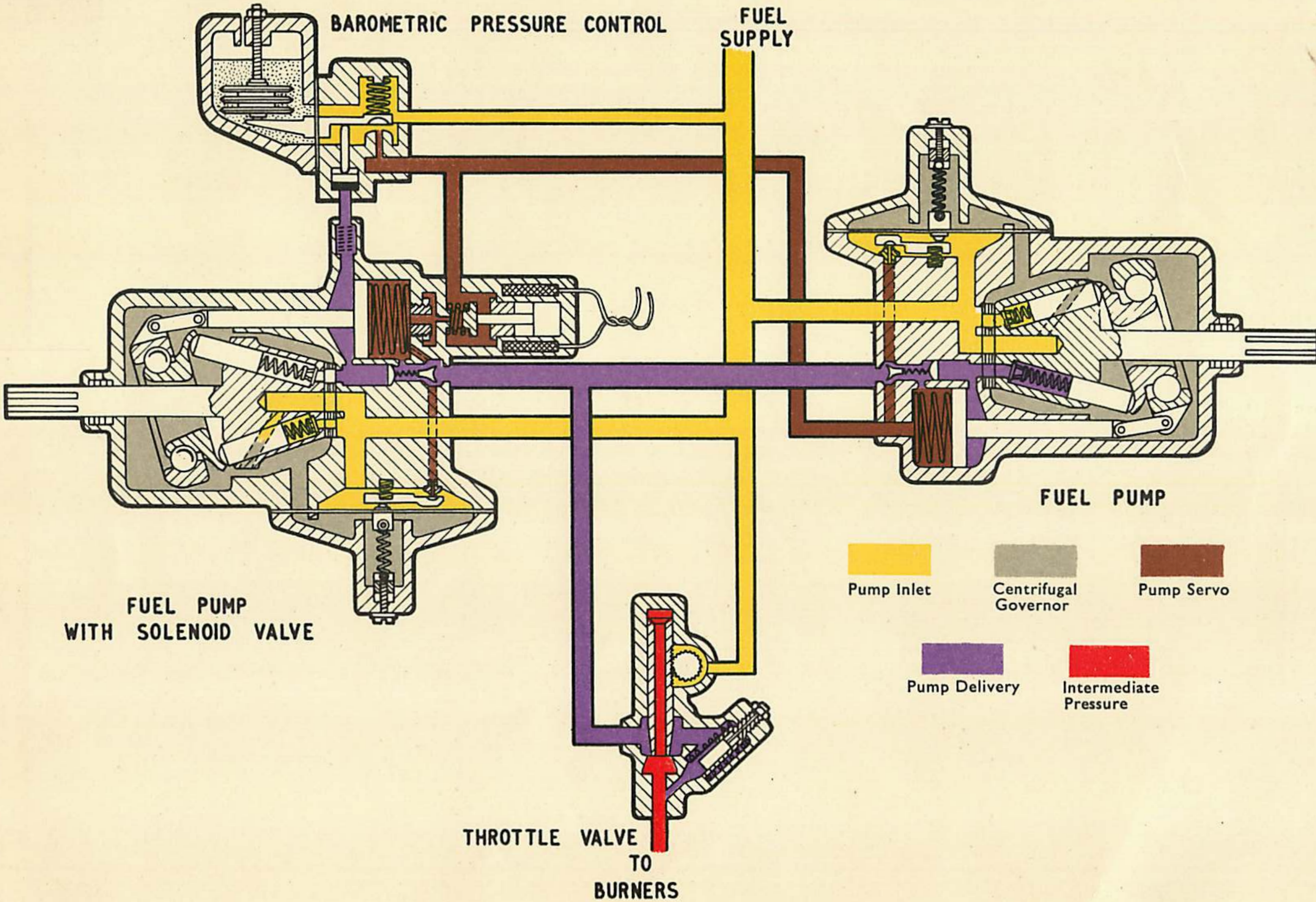


Fig. 5. Dual Fuel Pumps in a Fuel System

from the servo portion (35) of the cylinder, thereby causing the control piston to move to reduce the inclination of the cam-plate, and hence the stroke of the rotor pistons, which will decrease the delivery from the pump and thus prevent any further rise in rotational speed.

Isolating Valve

23. A solenoid-operated isolating valve unit may be fitted to the base of the control-piston cylinder casing. It has an inlet union for connection to the servo cylinder of the other pump when two pumps are fitted. The unit also has an outlet union for connection to the servo valve of the B.P.C. The isolating valve consists of an orifice opening to the pump servo-cylinder above the control piston through which fuel is fed at servo-pressure to the B.P.C. When the solenoid is energized, a valve plate, which is normally held clear of the orifice by a spring, is moved by the solenoid-plunger and push-rod to close the orifice, thereby isolating the pump from the monitoring actions of its servo-control system (with the exception of the overspeed governor) and permitting it to operate at full stroke. During normal operation the valve remains open, and fuel at servo-pressure from the pump control cylinder passes to the outlet which is connected to the B.P.C. (and to the servo cylinder of the other pump, when fitted).

24. On engines with a single fuel pump, the isolating valve is primarily intended as a means of restoring power in flight in the event of a sudden drop in engine r.p.m. caused by failure of the servo-system, which leads to the piston moving to minimum stroke. It may also be used as a safeguard against total failure of the system during take-off.

Dual Pumps

25. To meet the fuel requirements of some engines, two pumps (Fig. 5) are fitted, and it is common practice for one pump to incorporate an isolating valve (*e.g.* the pumps fitted to the Avon engine). Each pump is a self-contained unit with a common delivery, and with the servo-control system of each pump interconnected. The pumps each incorporate a non-return valve, relief valve, an overspeed governor, and a servo-control mechanism. The relief valve serves as a safeguard against the harmful effects of excessive output pressure due to an obstruction in the line or inadvertent closing of a valve. The pump overspeed governors are normally adjusted to operate at slightly different values, usually about 50 r.p.m. (engine speed) apart, to prevent the pumps from striving to gain control and therefore setting up a potential source of instability. Under normal conditions the maximum engine r.p.m. are controlled at the lower setting.

26. Another type of dual pump, which has the same working principles as described above, incorporates several extra features. Each of the two units, whilst having interconnected servo-control and a *common* governor, incorporates its own separate relief and non-return valves. The advantage of a common governor for the two pump elements is that one signal only is given to the governor diaphragm ; this eliminates the possibility of surging if two diaphragms were fitted. The tolerance of the governor setting is 25 r.p.m. at maximum governor settings.

Function of the Isolating Valve in Dual-Pump Systems

27. Knowledge of the working of the B.P.C. (paras. 33 and 34, and Fig. 7) is necessary to understand the function of the isolating valve in the dual-pump system. When the valve is energized, thus isolating the servo-system of that particular pump from any external bleed, the isolated pump delivers fuel only under the control of its own servo-system, *i.e.* at full stroke ; the other pump delivers fuel under the control of its servo-system in conjunction with the B.P.C. Since the total pump delivery pressure acts on the B.P.C., any change in this pressure causes the B.P.C. to attempt to compensate for that change by increasing or decreasing the flow from the only pump it now controls. It can thus be seen that operating the isolating valve separates the flow control of the two pumps, making one available in the event of defective operation of the other servo-system.

28. With the isolating valve lifted (not energized), any damage causing a servo-system breakdown with loss of servo-pressure increases the pressure drop across the control pistons in both pumps, so that they tend to move the cam-plate to the position for neutral stroke (no fuel output). A rapid loss in engine power will occur unless the pilot quickly closes the isolating valve, whereon the system continues to function on one pump. Failure of the servo-system or " non-solenoid " pump results in only the solenoid pump working, without the B.P.C. If the failure involves the " solenoid " pump, then fuel requirements will be met by the " non-solenoid " pump. In each case the defective pump reverts

to minimum flow and pressure, and a non-return valve in its outlet connection prevents high-pressure delivery from the working pump being bypassed through the failed pump.

29. The most serious occasion when pump failure can occur is during take-off. To avoid the danger of a time-lag in the engine pick-up speed after failure, the isolating valve may be operated before take-off, so that one pump only, operating at maximum (governed) speed, is used. A more detailed description of the isolating valve and its role in the engine fuel system is given in the relevant engine air publication. Instructions on the use of the isolating valve are given in Pilots' Notes for the aircraft type. At high altitudes, or in certain special circumstances, the isolating valve must be used with caution ; the sequence of events following operation of the isolating valve in a sound system is necessarily different from that after its operation in a system in which actual failure has occurred (see Chapter 12).

30. Fig. 5 shows a typical dual-pump system in which the fuel pumps are fitted with non-return valves in the outlet connection. Thus if one pump should fail owing to a sheared driveshaft, fuel at delivery pressure from the functioning pump is prevented from entering the failed pump ; if this were not done the failed pump would motor and return fuel to the low-pressure side of the system. If the failure affects the control system the non-return valve prevents fuel at delivery pressure from leaking through the failed pump when the isolating valve switch is set to isolate, and reduces the effective working pressure of the sound pump. Some special installations incorporating two pumps provide a servo-isolating valve for each pump. This makes available the full output from both pumps (up to the governed capacity), during take-off, on occasions when additional fuel supply is required for reheat or water injection, or if failure of the control system or its pipework occurs.

31. Other fuel pumps are the unidirectional, self-priming, rotary piston-type ; and the gear-type. Descriptions of these may be found in Volumes 1 of A.P. 4282 and A.P. 4282A respectively.

Barostat

32. The barostat (Fig. 6) is a fuel relief valve, operation of which is controlled by the air pressure at the engine intake. It is normally used in conjunction with a fixed-stroke pump, and consists of a body casting divided into two main compartments, one housing the relief valve which is loaded by a spring against a main piston, and the other containing a barometric capsule stack. The capsule stack operates the pilot valve to adjust the fuel flow to or from the space above the piston in such a way that the position of the piston depends on the length of the barometric capsule. A proportioning valve regulates the rate of fuel flow to the pilot valve system, and a ball-type relief-valve (not shown in Fig. 6) prevents the pressure from the proportioning valve exceeding a certain figure. Details of the barostat are in Volume 1 of A.P. 4282A. Barostats are used in early fuel systems, and have been replaced by the barometric pressure control.

Barometric Pressure Control (B.P.C.)

33. In contrast with the barostat, which regulates the delivery of a constant-output pump by spilling excess fuel back to the tanks, the B.P.C. keeps the pump delivery pressure at a figure proportional to the air pressure in the engine nacelle intake. By this means the pump delivery pressure is controlled to suit engine requirements dictated by speed, altitude, or atmospheric conditions. A decrease in nacelle pressure due to increased altitude or decreased aircraft speed causes a corresponding decrease in the pump delivery pressure.

34. The B.P.C. (Fig. 7) consists of an evacuated capsule subject to nacelle pressure ; it operates on a lever system balanced by fuel pressure acting on a small diaphragm. The lever also carries a valve which controls the pump stroke through the pump servo line ; opening the valve bleeds off pressure from the top of the servo-cylinder piston and reduces the stroke ; closing the valve increases the stroke. In this way the fuel-pump delivery can be regulated to compensate for all changes of altitude, ram pressure at the air-intakes, and air-mass flow through the engine during acceleration.

Acceleration Control Unit

35. The amount of fuel supplied to the engine while the throttle is being opened must be carefully controlled to avoid excessive jet-pipe temperature, possible compressor surge, and flame extinction due to over-fuelling. Extra fuel is needed to cause an acceleration ; but because the rate of acceleration is governed by the inertia of the rotating parts, too-rapid opening of the throttle would result in a fuel

supply greater than that required for the engine speed. (The engine speed takes some time to build up to the r.p.m. proportional to the fuel flow demanded by the throttle setting.) This results in high temperatures, and the possibility of compressor surge, etc. To counter the possibility of over-fuelling, an acceleration control unit (A.C.U.) is incorporated together with a metering valve unit, which controls the rate of acceleration by limiting the rate at which fuel output from the H.P. pump builds up after a rapid throttle opening. The A.C.U. (top right of Fig. 8) operates by bleeding fuel from the pump's servo-system through a half-ball valve, so controlling the stroke and output of the pump. The metering valve unit (centre of Fig. 8) creates a fuel pressure difference which is proportional to the pump delivery flow. This pressure difference is applied across a small diaphragm in the A.C.U. The A.C.U. is set so that, under steady running conditions, the effect of the engine-compressor pressure on a large diaphragm overcomes the fuel pressure difference across the small diaphragm (both diaphragms being in opposition); consequently the half-ball valve is held on its seating.

36. Opening the throttle causes the B.P.C. to increase the pump output, which in turn increases the pressure difference across the metering valve unit. If the throttle is opened slowly the rising engine-compressor pressure continues to overcome the increasing fuel pressure difference felt on the acceleration control, and the control will not operate. Rapid opening causes the pump output to rise faster than compressor pressure, and this causes an unbalanced force on the acceleration-control rocker arm, which opens the half-ball valve and bleeds the servo-system, thus limiting the pump stroke and reducing the pump output, *i.e.* the air/fuel ratio is kept proportional to the r.p.m. As engine speed increases, the increasing compressor pressure progressively overcomes the increased pressure difference, until the half-ball valve is again on its seating and the engine is running steadily at the higher r.p.m. selected by the new throttle position.

Metering Valve Unit

37. The metering valve unit (centre of Fig. 8) has a metering valve and a bypass valve which are calibrated to set up a fuel pressure difference across the unit. The metering valve remains open over the whole operating range of the engine, but the bypass valve (the upper valve) opens only at high fuel flows when the engine will accept, momentarily, richer air/fuel mixtures without excessive j.p.t. or surge. After the bypass valve has opened, the rate of increase of the pressure difference with further increase in fuel flow rises more slowly. The A.C.U. therefore allows a higher air/fuel ratio and consequently a greater rate of acceleration at high flows. Early A.C.Us. have no altitude compensation, and the control becomes progressively less effective at altitudes above 5,000 feet. Later models are altitude compensated and are effective at all altitudes.

Air/Fuel Ratio Control (A.F.C.)

38. The air/fuel ratio control unit is designed to keep fuel delivery to the burners proportional to the compressor pressure, and thereby to the mass airflow through the engine. The A.F.C. prevents the possibility of compressor surge during acceleration, which might otherwise occur if there was an excessive supply of fuel. It also prevents flame extinction through an excessively rich mixture under the same conditions. Fig. 9 shows the air/fuel ratio control. It is fitted in some fuel systems in place of the A.C.U. and operates in a similar manner.

39. Under steady running conditions the unit is inoperative. During normal acceleration the system is in equilibrium, with the half-ball in the servo-valve orifice just floating. The pump delivery is sufficient to balance the compressor pressure and a predetermined air/fuel ratio is set up. If the pump delivery increases disproportionately, the push-rod is forced up to raise the rocker lever and half-ball and so bleed off servo-pressure until the pump stroke is proportional to the compressor pressure.

Throttle Control

40. Throttle control is effected by a precisely calibrated metering orifice by which the pilot can manually vary the fuel flow to the burner system, and so control engine r.p.m. It comprises a shaped plunger, moved axially by means of a rack-and-pinion mechanism to vary the effective annular flow area between the plunger and an orifice plate. Throttle valves are often incorporated in composite fuel-control units.

High-Pressure (H.P.) Cocks

41. H.P. cocks are used to stop the engine by cutting off the fuel supply to the burners. Important requirements are ease of operation, particularly at high pressure (to facilitate emergency shut-down), and some provision for

bypassing fuel during running down of the engine. Frequently a passage is provided for dumping to atmosphere any fuel remaining in the burner system. Two types of H.P. cock are in general use and are usually incorporated in other control units to eliminate unnecessary pipe connections and possible leakage points. The *linear-motion plunger type* is dealt with under flow controls. The other is the *rotary plunger type* described with the combined accumulator unit elsewhere in this chapter. Both types of cock may be manually or electrically controlled.

Low-Pressure (L.P.) Cocks

42. Fuel-tank cocks, and any cock that is under the pilot's control and is installed in the fuel system between the fuel tanks and the engine-driven pumps, are known as low-pressure cocks. The L.P. cocks are either manually or electrically controlled. In some aircraft electrically controlled low-pressure cocks, when opened, operate a micro-switch to bring into operation the fuel booster pump. The L.P. cock on some installations is connected to the refuelling cocks.

Low-Pressure Filter

43. A typical low-pressure filter comprises a filter body casting, a bowl, and a filter element. The body casting has separate fuel inlet and outlet connections. The bowl and filter element are of the standard Tecalemit type and the element is a star-section felt filter reinforced with wire gauze and supported on a helical spring.

Minimum-Burner-Pressure Unit

44. While an aircraft climbs at constant r.p.m., the mass flow of air through the engine becomes less owing to the falling density, and the fuel supply has to be reduced accordingly to keep the air/fuel ratio constant. This is done by the B.P.C. progressively reducing the fuel pressure to the burners and consequently the quantity of fuel passing into the combustion chambers. While idling at high altitude the burner pressure reduction would be enough to affect the stability and strength of the burning mixture, and flame extinction would occur if the throttle were suddenly closed or mishandled when opening up. The minimum-burner-pressure unit eliminates this possibility by preventing the burner pressure dropping below the minimum necessary to ensure satisfactory combustion under any condition. As a result of this action, however, the idling r.p.m. increase slightly with altitude. The unit is illustrated in Fig. 11, and its manner of operation is described later in this chapter.

Accumulator

45. The purpose of the accumulator, which incorporates an H.P. cock and trip valve assembly, is to provide an additional supply of fuel to the burners during the starting period, when the r.p.m. are too low to supply a readily ignitable spray at the burners. The H.P. cock controls the fuel supply to the burners and is the only means by which the engine can be stopped. The trip valve is provided to isolate the fuel supply when starting the engine until a predetermined fuel pressure has been built up in the cylinder by the pumps, at which point the full charge is released to the burner manifold. The increased flow and pressure ensures a satisfactory light-up, and takes care of the first stages of acceleration, after which the normal fuel flow from the pump is adequate for engine requirements. The accumulator and minimum-burner-pressure valve are only necessary in fuel systems using Simplex burners. (See Chapter 4, " Combustion Systems ".)

Pressurizing Valve and Shut-Off Cock

46. In fuel systems having Duple or Duplex burners, a unit known as a pressurizing valve (Fig. 8), which incorporates a shut-off (high-pressure) cock, is necessary. Duplex burners usually need two pipelines (manifolds) to lead fuel from the pressurizing valve to the ring of burners. One manifold, the primary, carries a flow of fuel at all times when the engine is running ; the other manifold, the main, carries a fuel flow only when the pressurizing (splitter) valve is open. The rack-operated H.P. cock is situated between the throttle valve and the pressurizing valve. When the H.P. cock is closed any fuel remaining in the two manifolds and burners is spilled to atmosphere through drain holes in the pressurizing-valve assembly, which is therefore mounted at a position lower than the manifold rings.

Flow Distributor

47. The flow distributor is used in some fuel systems instead of a pressurizing valve. It is designed to meter the fuel evenly to each burner and can be used to advantage with any type of burner. On systems having Duplex 2 or Simplex burners the flow distributor serves essentially as a flow equalizer to each burner. With Duplex 1 and Duplex 3, or any burner that uses two fuel-supply manifolds, the flow distributor serves as a pressurizing (splitter) valve and so corrects fuel pressure variations in the separate main manifolds to each burner. The primary flow to the burners is tapped from the inlet to the flow distributor and so is unaffected by this control.

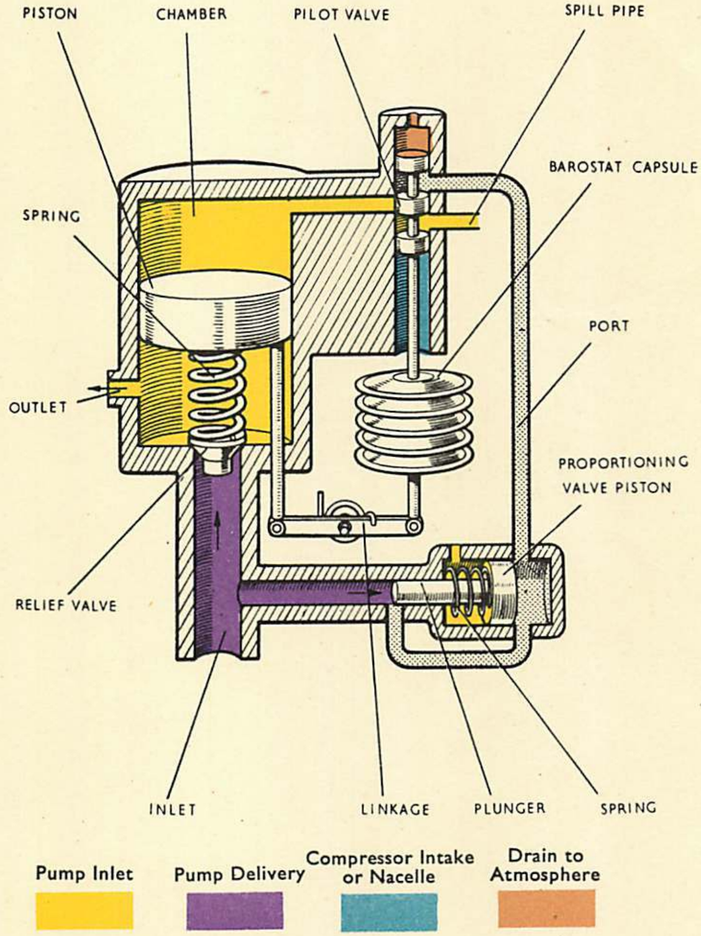


Fig. 6. Sectioned Perspective of a Barostat

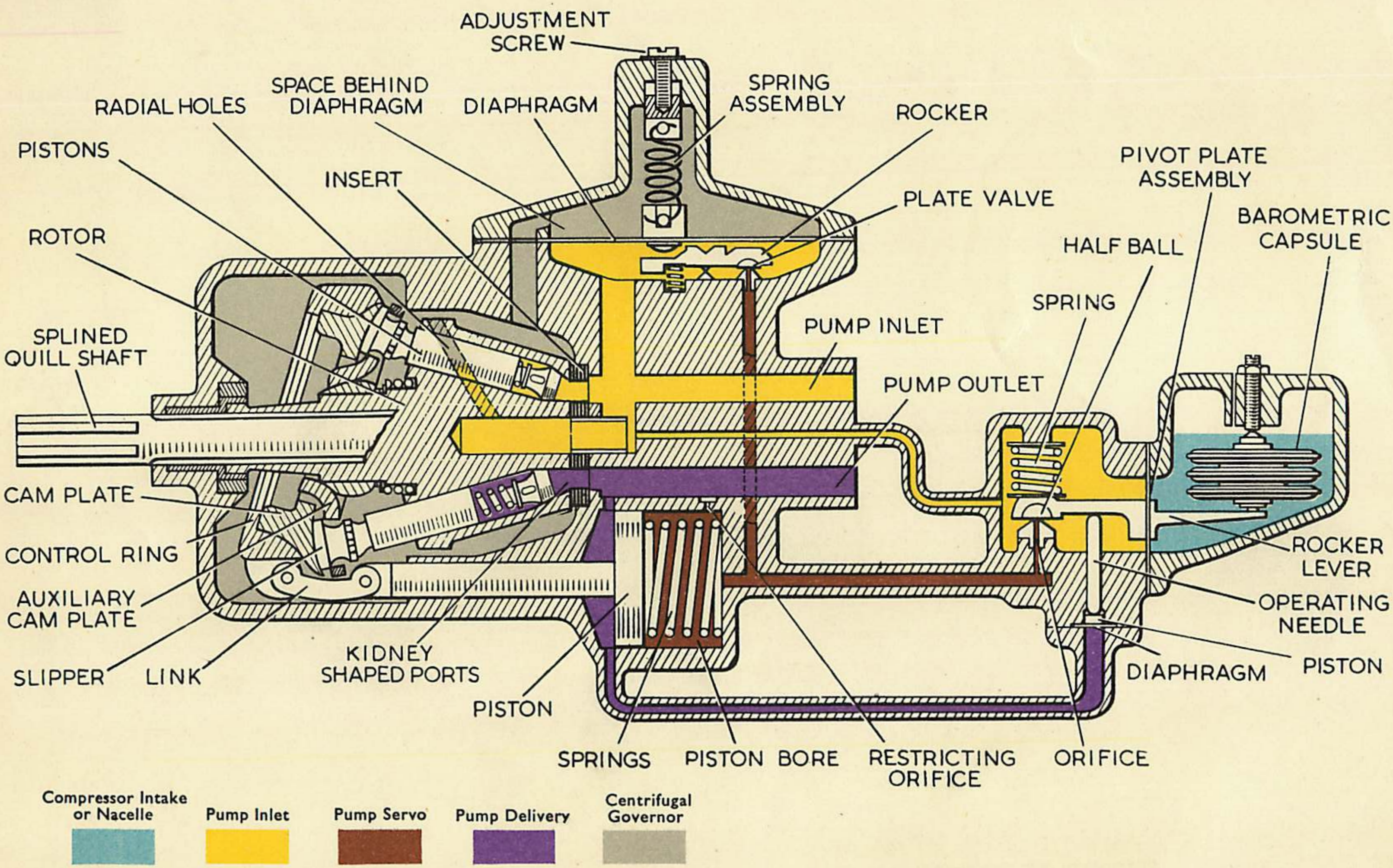


Fig. 7. Barometric Pressure Control and High-Pressure Pump — Servo System

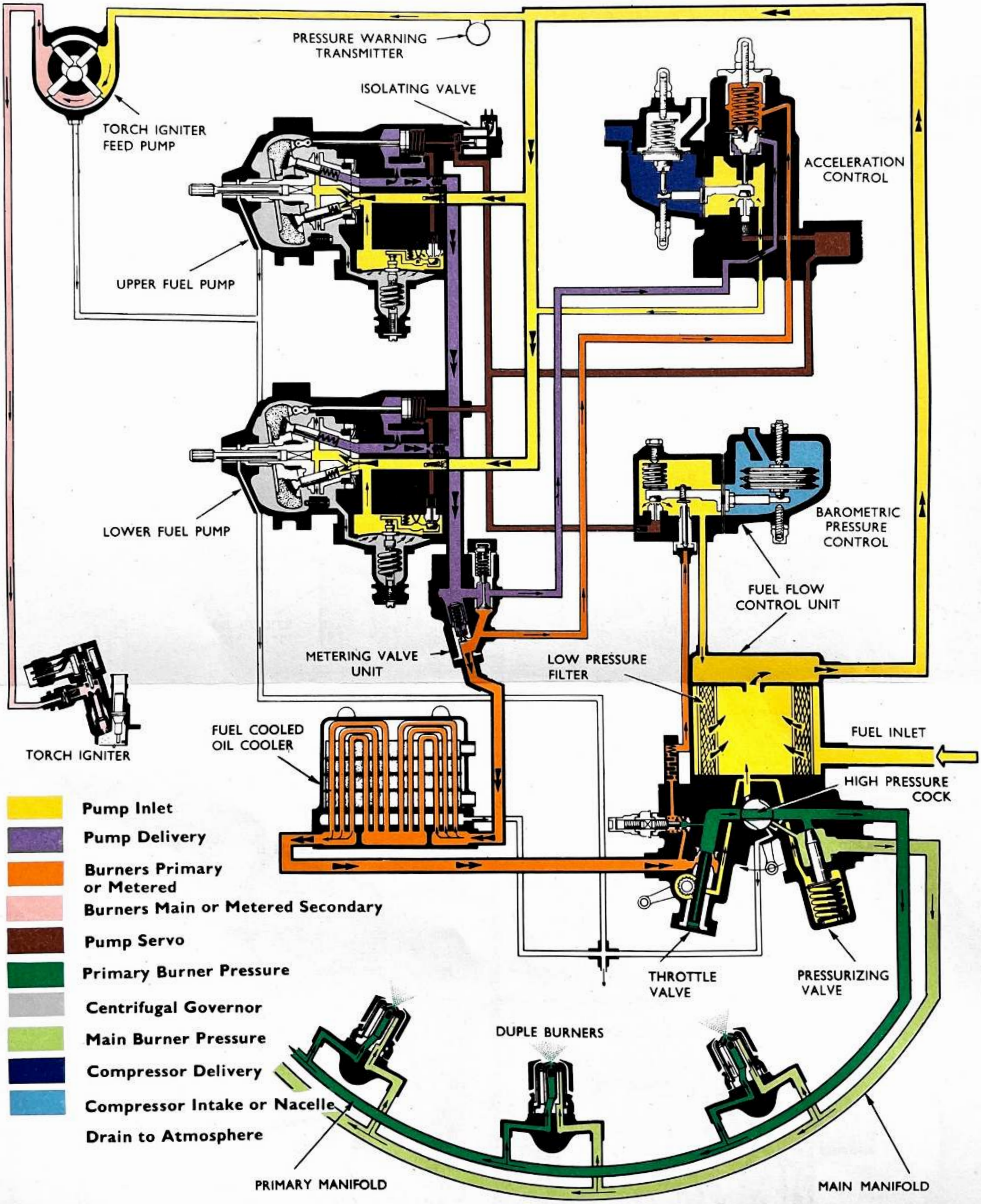


Fig. 8. Acceleration Control Unit in a Typical Fuel System

KEY TO FIG. 9

1. Evacuated capsule stack
2. Pivot plate assembly
3. Adjustment screw
4. Adjustment screw
5. Spring
6. Valve chamber
7. Half ball
8. Servo valve orifice
9. Push rod
10. Piston
11. Diaphragm
12. Rocker lever
13. Diaphragm
14. Capsule chamber
15. H.P. pump
16. Throttle valve or flow control
17. Pressurizing valve
18. H.P. shut-off cock

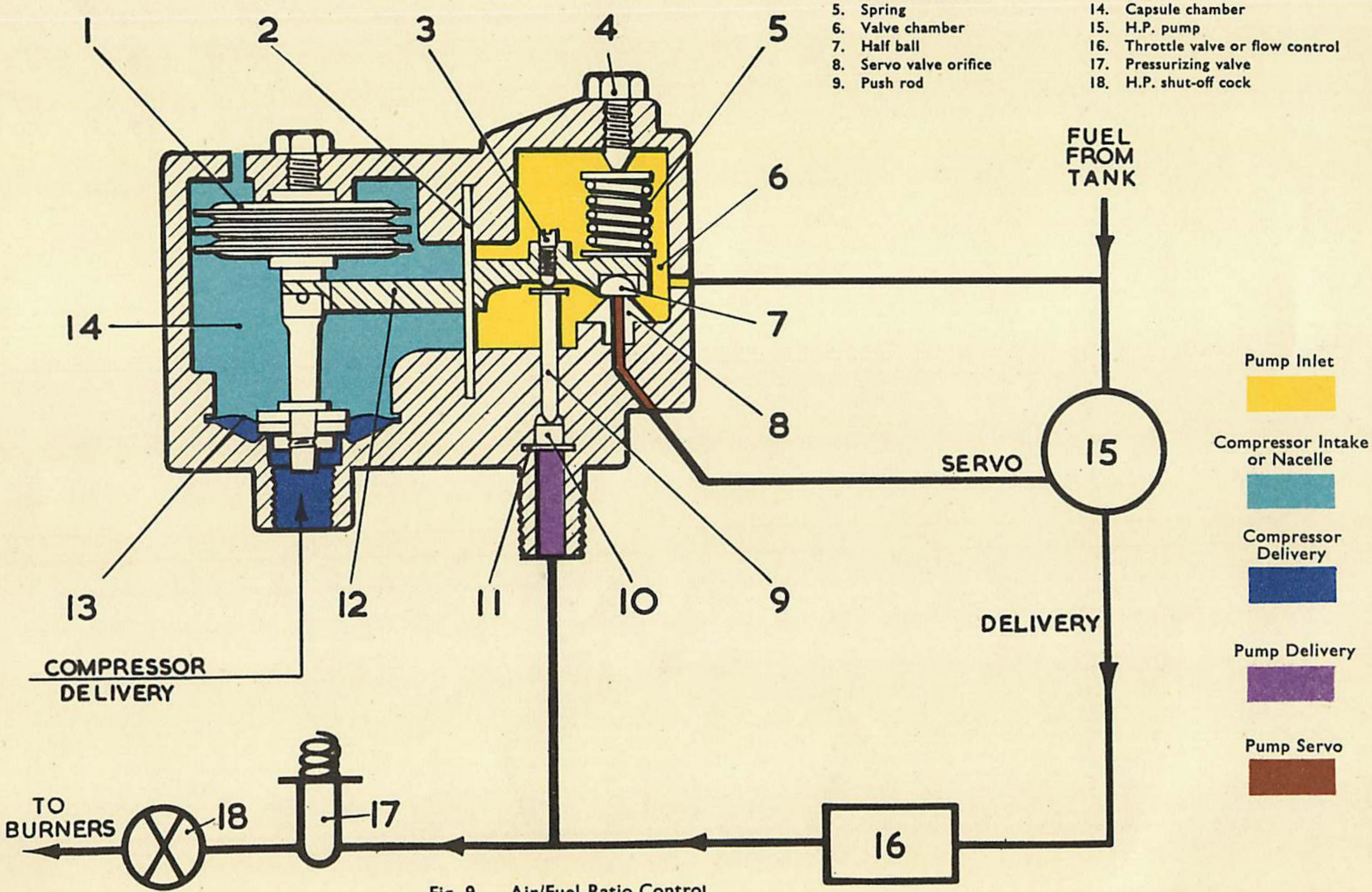


Fig. 9. Air/Fuel Ratio Control

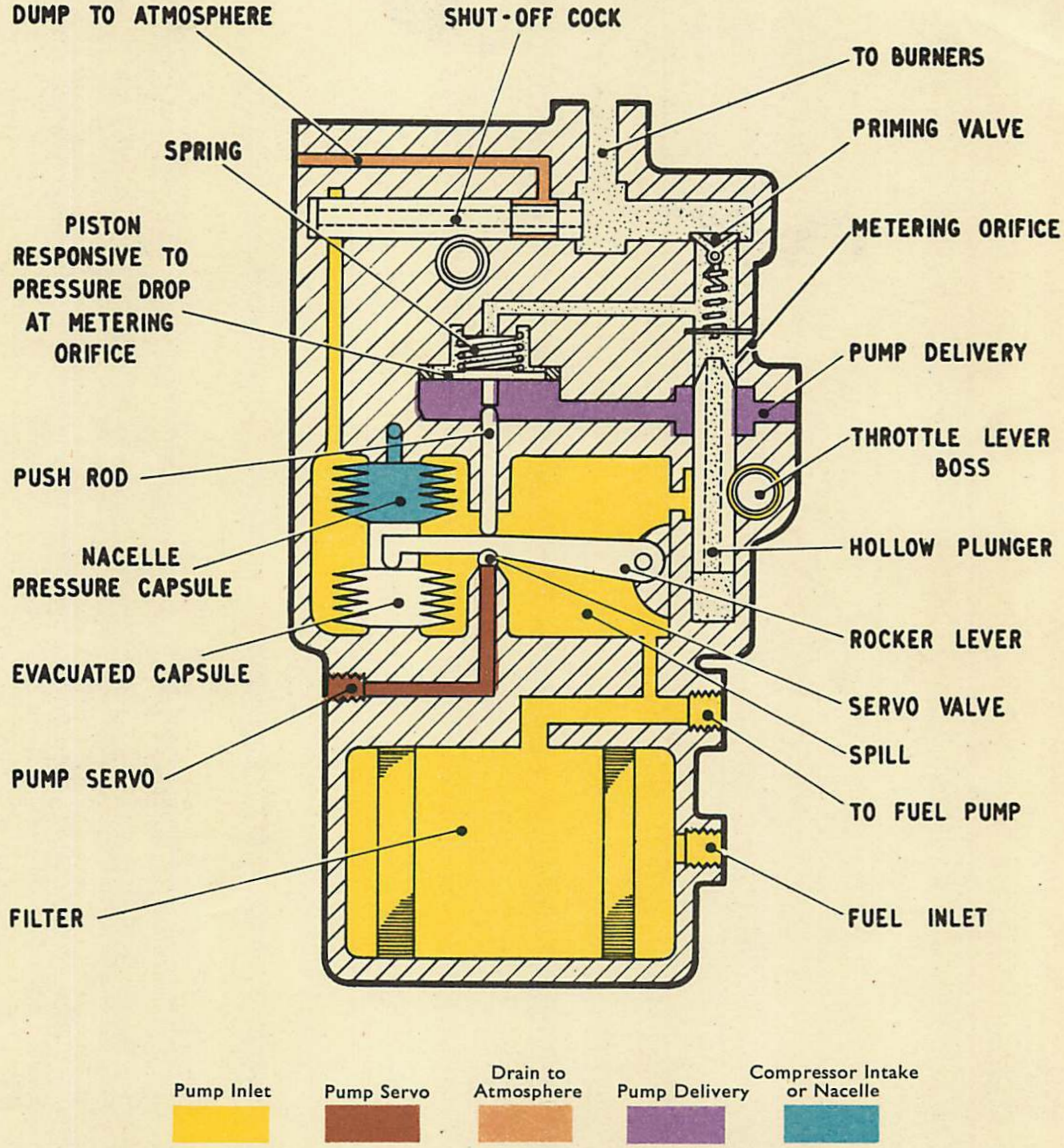


Fig. 10. Simple Flow Control

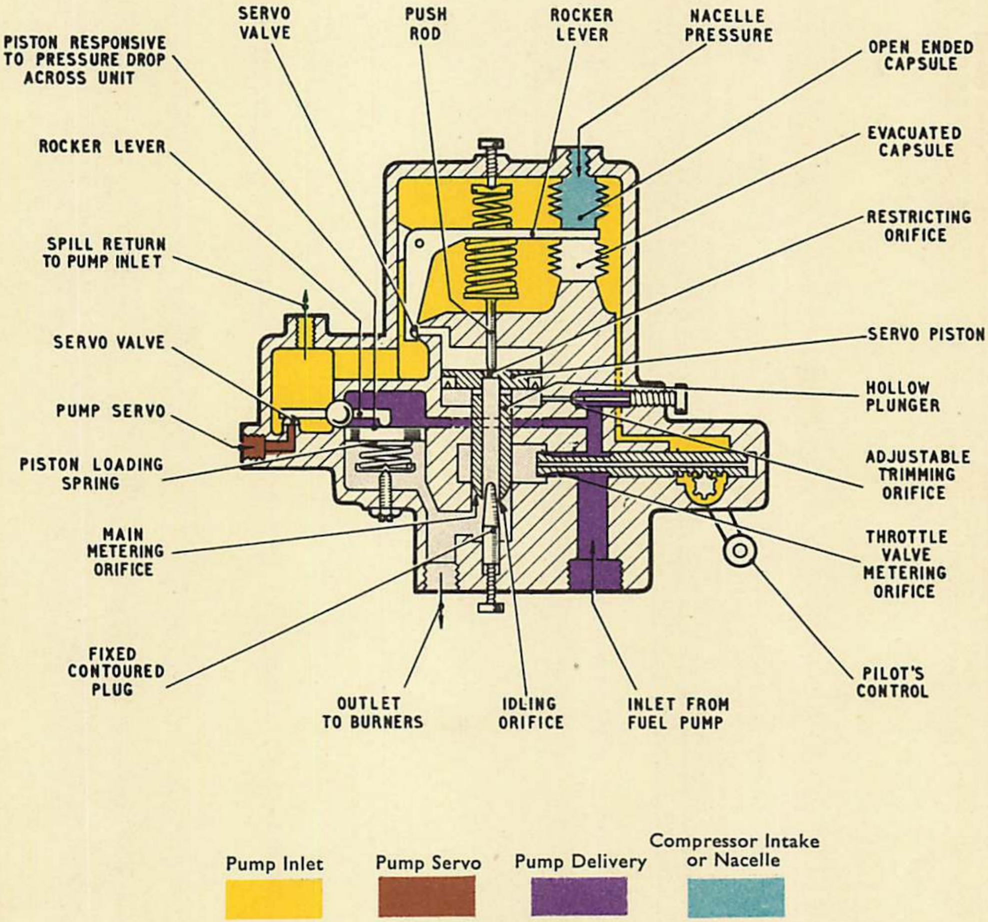
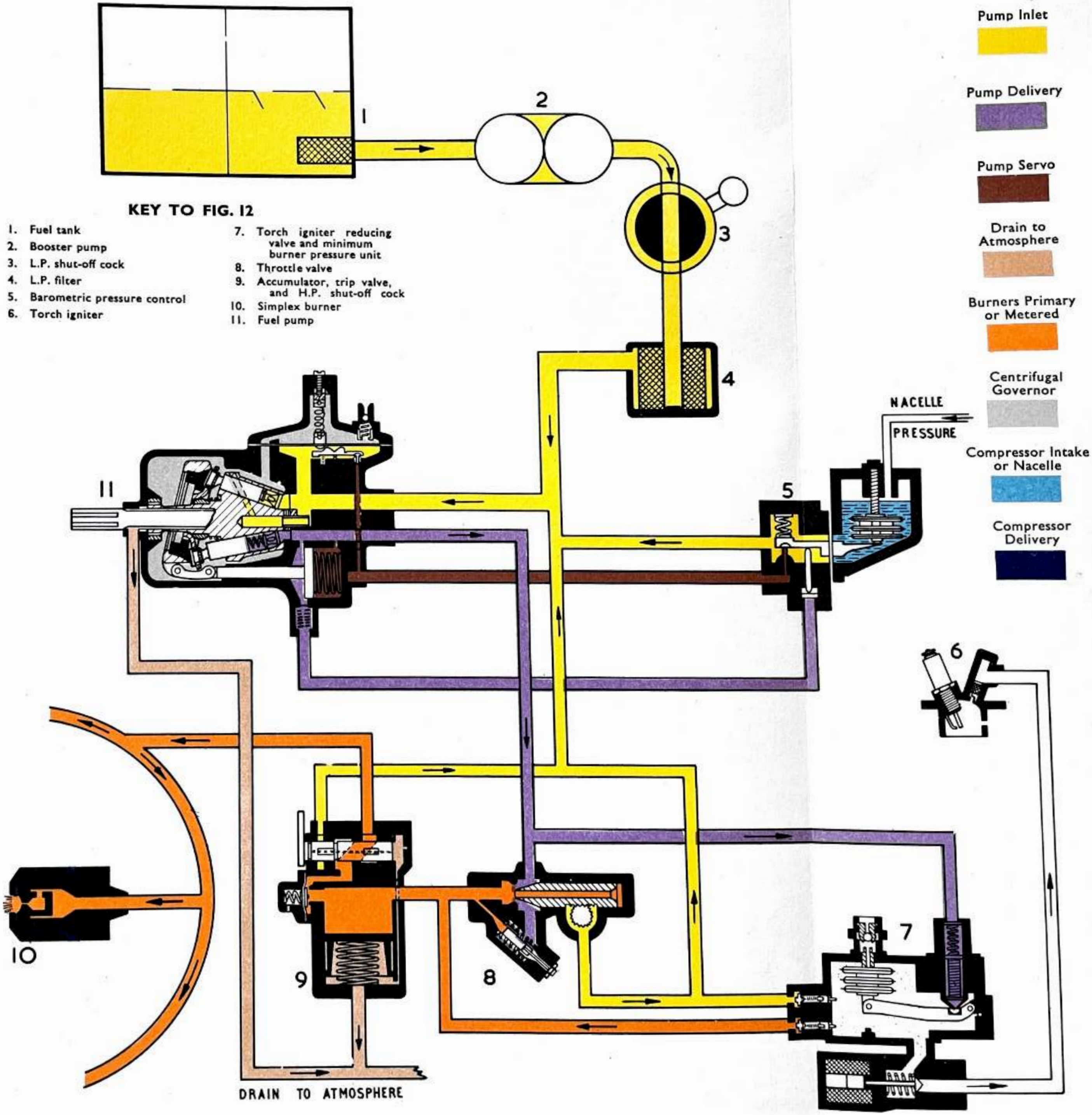


Fig. 11. Full-Range Flow Control



KEY TO FIG. 12

1. Fuel tank
2. Booster pump
3. L.P. shut-off cock
4. L.P. filter
5. Barometric pressure control
6. Torch igniter
7. Torch igniter reducing valve and minimum burner pressure unit
8. Throttle valve
9. Accumulator, trip valve, and H.P. shut-off cock
10. Simplex burner
11. Fuel pump

Fig. 12

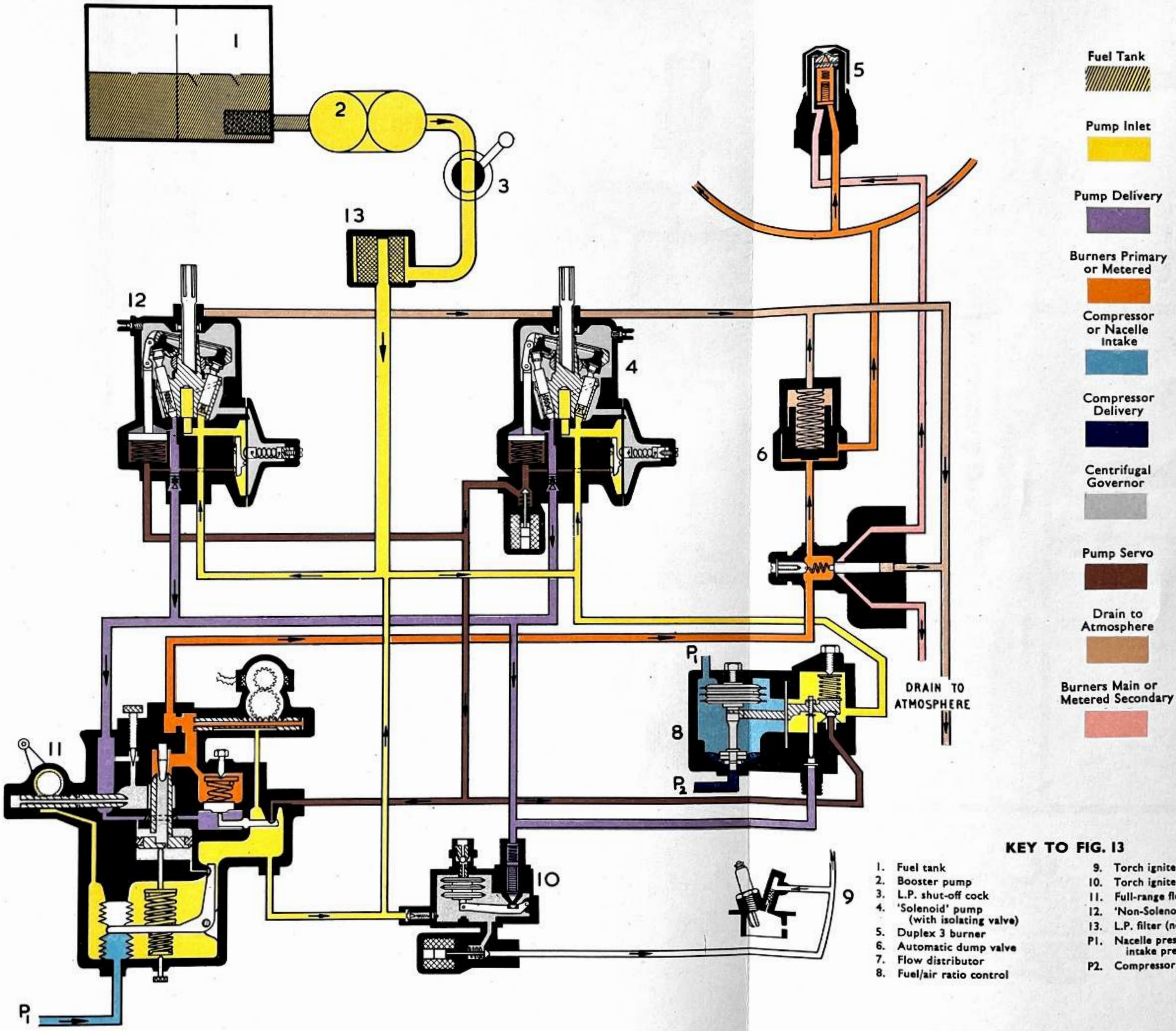


Fig. 13. Dual Pump Flow-Control System

KEY TO FIG. 13

1. Fuel tank
2. Booster pump
3. L.P. shut-off cock
4. 'Solenoid' pump (with isolating valve)
5. Duplex 3 burner
6. Automatic dump valve
7. Flow distributor
8. Fuel/air ratio control
9. Torch igniter
10. Torch igniter reducing valve
11. Full-range flow control
12. 'Non-Solenoid' pump
13. L.P. filter (normally part of 11)

P1. Nacelle pressure (compressor intake pressure)

P2. Compressor delivery pressure

Universal Fuel Governor

48. A universal fuel governor, which operates in conjunction with the fuel pump and compensates for fuels of varying density (specific gravity), is fitted to some fuel systems. The unit ensures a constant overspeed-governor pressure for a given maximum engine r.p.m., irrespective of the density of the fuel.

COMBINED CONTROL UNITS

Simple Flow-Controlled Unit

49. The combined control unit is used on turbo-prop engines having a maximum operating height of up to 30,000 feet. By combining into one unit a throttle valve, a shut-off (H.P.) cock, a low-pressure filter, and an altitude-responsive flow control, a very compact installation is obtained. External pipes are reduced to a minimum, all necessary spill and pressure connections being provided by drilled passages in the control-unit casing. Fig. 10 illustrates a simple flow-controlled unit.

Full-Range Flow-Controlled Units

50. Having all the advantages of the simple flow-controlled unit, the full-range type maintains good matching characteristics over the full range of operation and is intended for use on all aircraft flying up to an altitude of 60,000 feet. It is unaffected by the pressure characteristics of other fuel-system components and can handle fuel flows of the order of 1,000 gallons per hour. The unit (Fig. 11) comprises a manually-operated throttle valve with an idling bypass, an automatic variable-flow orifice (by means of which a servo-system controls fuel flow in accordance with nacelle air pressure conditions), and a pressure-responsive piston which is susceptible to variations in the pressure drop (inlet/outlet pressure) across the complete unit and controls one of the fuel-pump servo-system orifices accordingly. In the delivery connection is a high-pressure cock which may be manually or electrically controlled. The cock affords a bypass to the low-pressure side of the system when closed. The composite unit also includes a low-pressure high-capacity filter, but this has been omitted from the diagram for the sake of clarity.

DESCRIPTION OF A TYPICAL FUEL SYSTEM

Introduction

51. Fig. 12 shows a typical pressure-controlled fuel system, having a single variable delivery pump, B.P.C., accumulator, minimum-burner-pressure valve, throttle valve, and Simplex burners. An electrically-driven booster pump supplies fuel at low pressure from the tank, via a low-pressure cock and filter, to the high-pressure fuel pump. Low-pressure fuel is tapped from this line and taken to the torch-igniter feed pump and then to the torch igniters. A connection for a low-pressure warning light is provided on the inlet side of the torch-igniter feed pump.

52. Fuel from the high-pressure fuel pump is fed to the throttle valve (para. 40). There are two leads from the fuel pump to the B.P.C., one of which supplies fuel at output pressure, and the other at pump servo-pressure (para. 33). Between the high-pressure fuel pump and the throttle valve a supply at pump output pressure is taken to the inlet side of the minimum-burner-pressure valve (para. 44). After passing the throttle valve the fuel passes into the fuel accumulator (para. 45), and then through the trip valve and H.P. shut-off cock to the burner manifold and burners. When idling at altitude with the throttle closed, fuel passes from the minimum-burner-pressure valve to the inlet side of the fuel accumulator, then through the accumulator to the burners, thus bypassing the throttle. Surplus fuel from the minimum-burner-pressure valve is returned to the high-pressure fuel pump.

How the System Operates

53. Before starting, the L.P. cock is opened and the L.P. booster pump switched on. This permits fuel from the tank to pass through the L.P. filter to the H.P. pump. The H.P. cock should be opened at the time recommended in Pilots' Notes. Switching on the booster pump operates the low-pressure warning light, which goes out when a preset pressure is reached in the low-pressure system. Assuming that an electric starter is used, the starter button should then be pressed for two seconds. This energizes the torch-igniter feed pump and the starter motor simultaneously, the solenoid-operated igniter fuel valves in the torch igniters are opened, and a high-tension current is supplied to the sparking plugs.

54. For a few seconds the starter-motor electric supply is fed through a resistance, and the engine therefore accelerates slowly. During this period fuel from the torch-igniter fuel pump passes to

the torch igniters, which inject it as a fine spray into the flame tubes. Entering the combustion chamber the fuel mixes with air at atmospheric pressure, and the mixture is then ignited by the sparking plugs. The torch igniters continue to inject this burning mixture into the flame tubes until the starting cycle is complete.

55. At the end of the slow acceleration period full voltage is supplied to the starter motor, rapidly increasing the r.p.m. of the engine and fuel pump. Fuel that has been passing through the throttle valve into the accumulator gradually builds up sufficient pressure to force the accumulator piston to the end of its stroke and thus fill the accumulator cylinder. When the accumulator cylinder is full, the fuel pressure continues to rise, exerting pressure on the trip-valve, causing it to open fully, and allowing the contents of the accumulator to be released. The accumulator piston will rise under the influence of its spring, forcing the fuel through the trip-valve and the H.P. cock to the manifolds and burners. This boosted fuel to the burners is necessary to ensure a suitable quantity of readily ignitable fuel spray to start the engine. While the engine is running, fuel continues to flow through the accumulator.

56. The function of the burners is to atomize the fuel into the smallest possible droplets to obtain the maximum area for evaporation. A swirl-type atomizer is therefore used in each Simplex burner ; it consists of a vortex chamber into which fuel enters in a tangential direction, the fuel then leaving the atomizer in the form of a hollow cone spray through an axial orifice. Each flame tube has a burner ; the fuel spray from each burner atomizer being injected into its respective flame tube, where it is mixed with air in the correct ratio for combustion. This air is supplied by the compressor (rotated initially by the starter motor), the air entering the flame tubes through holes in the forward end of the tubes.

57. The mixture injected into those combustion chambers with a torch igniter is now ignited by the flame from their torch igniters, and spreads through the combustion chamber interconnectors to the remaining combustion chambers. When this happens the engine is said to light up, and combustion is then continuous. The expanded hot gases are accelerated rearwards and pass from the combustion chambers through the nozzle boxes and fixed guide vanes to the turbine blades. At this point in the starting cycle the gas speed and pressure through the turbine blades is still insufficient for the turbine to drive the compressor without assistance ; the starter motor therefore continues to assist rotation until the r.p.m. are high enough to disengage the driving mechanism. The engine then continues to run under its own power, gradually increasing r.p.m. until the idling r.p.m. are reached.

58. At the end of the starting cycle the starter panel automatically cuts off the electrical supply to the starting system ; the torch-igniter feed pump therefore stops, the torch-igniter solenoid valves close to cut off the fuel supply to the torch igniters, and the H.T. current is cut off from the sparking plugs ; simultaneously, the current to the starter motor is cut off.

Ground Running

59. Until idling speed has been attained, the throttle valve is closed and only a limited quantity of fuel passes through the throttle valve to the burners. The burner atomizers, having fixed orifices, therefore pass a fuel flow that is governed by the fuel pressure at the burner manifolds. Opening the throttle valve causes the pressure in the burner lines to increase from roughly 20 lb./sq. in. at idling speed to over 1,000 lb./sq. in. at maximum r.p.m. Under these conditions there is a fall in input pressure to the throttle valve unless the output from the H.P. fuel pump increases immediately. The momentary fall in pressure that does occur causes the B.P.C. to reduce the bleed from the pump-servo, which then increases the fuel pump output.

60. The B.P.C. unit communicates with both the spring-loaded side of the fuel-pump servo-control piston and with the high-pressure side. In the example being considered the momentary fall in fuel-pump output causes the B.P.C. half-ball valve to reduce the orifice, consequently bleeding away less servo-pressure ; the pump-servo piston will move to lengthen the stroke of the pump. When the throttle valve is closed, fuel pressure on the input side of the throttle valve increases momentarily ; this increase is felt by the B.P.C. rocker arm which rises and increases the opening of the half-ball orifice, allowing the fuel at servo-pressure to bleed away and reduce the stroke of the pump.

In Flight

61. Since air density and pressure decrease with altitude, when an aircraft climbs at constant r.p.m. the mass airflow through the engine

becomes less. To keep the fuel/air ratio constant, the supply to the burners must be reduced in proportion with the reduced airflow. As previously explained, the B.P.C. varies the output from the H.P. fuel pump, dependent on the input pressure at the throttle valve ; but assuming the aircraft is climbing at a fixed throttle opening, this variation in pressure does not occur. It is still necessary, however, to reduce the fuel flow from the H.P. pump, and this is done by a capsule unit incorporated in the B.P.C. Air at intake (nacelle) pressure is admitted to the capsule chamber and, depending on the rise or fall in pressure, the loading on the capsule stack increases or decreases. With a reduction in intake pressure the capsule stack expands and pushes down the B.P.C. rocker arm, which is pivoted about its centre ; the half-ball then rises and increases the servo-bleed, thus allowing the fuel-pump piston to move and reduce the stroke and output of the pump.

Idling at Altitude

62. When idling at high altitude the pressure reduction at the burners, caused by closing the throttle valve and the action of the B.P.C., is such that the spray characteristics at the atomizers suffer, and flame extinction can occur if the throttle is opened too rapidly. To obviate this possibility, the minimum-burner-pressure valve in the system prevents the fuel pressure dropping below the minimum figure necessary to ensure combustion.

63. During starting, when the engine is rotated by the starter motor, fuel from the H.P. fuel pump enters the minimum-burner-pressure unit through its inlet valve, and builds up a pressure which acts on the capsule within the unit until, at a set figure, the inlet valve closes. There is now a pressure difference across the spring-loaded valve communicating with the burner-pressure line which keeps the burner valve closed ; consequently there is no flow through the unit on the ground or at low altitude. This condition is maintained until an altitude of about 5,000 feet is reached ; above this height the minimum-burner-pressure unit begins operating when the throttle valve is closed to the idling position. When the throttle valve is closed there is a reduction in burner pressure, which reaches a stage where the pressure drop across the minimum-burner-pressure outlet valve exceeds tension-spring pressure ; the valve then gradually opens and feeds fuel from the unit to the burners via the accumulator, bypassing the throttle valve. At greater altitudes the reduction in pressure causes the capsule stack to expand further and allow more fuel to pass to the burners.

64. As a result of this supplementary fuel supply to the burners the idling r.p.m. progressively increase with altitude. It can be seen from the foregoing that the B.P.C. controlled output from the H.P. fuel pump, together with the action of the minimum-burner-pressure unit, ensures correct fuel pressure for satisfactory combustion at small throttle openings at all altitudes.

Fuel Drain Systems

65. To ensure a satisfactory start all fuel must be drained from the combustion chambers and fuel system when the engine is stopped after the previous run, and so a fuel drain system is needed. The combustion-chamber drain system varies between types of engines but, in general, fuel is drained from the upper combustion chambers, through the intermediate chambers to the lower chambers, and then through a non-return valve to atmosphere. The valve is made to close when combustion chamber pressure rises, and to open to dump any residual fuel to atmosphere when the engine stops. This prevents overheating due to the presence of unburnt fuel in the combustion chambers when starting.

66. When the H.P. cock is closed to stop the engine, the fuel supply to the burners is cut off and bypassed along a slot in the H.P. cock rotor to the inlet side of the H.P. pump. As the engine r.p.m. fall, the pressure in the accumulator also falls and the accumulator piston therefore moves to discharge the fuel through the open trip valve to the inlet side of the H.P. fuel pump. Surplus fuel from the burners and burner manifolds passes back through holes in the H.P. cock rotor and down a passage in the accumulator body into the end cap on the spring side of the piston. Fuel passing the accumulator piston seal, drains into the end cap and joins the fuel from the burners, and then passes to atmosphere. Fuel that may leak from the H.P. fuel-pump drive-shaft gland and from the throttle-valve housing passes to the drain connection at the bottom of the accumulator and, together with the fuel from the accumulator, drains to atmosphere on the outside of the engine nacelle.

Typical Dual Pump Full-Range Flow Control

67. A typical dual pump full-range flow control system using Duplex 3 burners is illustrated in Fig. 13. Fuel from the tank is passed by the fuel tank booster pump via the L.P. shut-off cock and the L.P. filter to the dual fuel pumps. From the two fuel pumps the H.P. fuel supply is fed to the flow control unit, the torch-igniter reducing valve, and the air/fuel ratio control. Depending on the altitude and the forward speed of the aircraft, the flow control increases or decreases the supply of fuel from the pumps to the flow distributor. Fuel from the distributor is passed to the burner through the primary or both manifolds. Any tendency for the pumps to overfuel the engine during acceleration is counteracted by the air/fuel ratio control unit. Fuel supply to the torch igniter is controlled by the torch-igniter control ; but most fuel systems now incorporate high-energy ignition, and in these cases the torch-igniter reducing valve and the torch igniters are not fitted.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