

# Chapter I

## TYPICAL FUEL SYSTEMS

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#### INTRODUCTION

1. This chapter deals with the general functioning of a gas-turbine fuel system incorporating some of the components described separately in this Air Publication. As systems applied to individual engines may differ, the subject can only be treated in general terms and using one combination of components, but the basic principles will in all cases be the same. Reference should be made to the relevant Air Publication for details of the fuel system of any specific engine.

#### BASIC PRINCIPLES

2. The amount of fuel required by a gas-turbine aero-engine is directly related to the mass air flow through the engine and is a function of many quantities, such as engine speed, altitude, inlet air temperature, aircraft speed and combustion efficiency. This necessitates the fitting of a number of units to control the fuel supply to the combustion chambers and thus ensure satisfactory operation over a wide range of aircraft speeds and altitudes. In addition, starting must be easy, and slow-running at altitude must be positive, with no tendency for flame extinction to occur.

3. 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 almost constant pressure, or fixed burner orifices at varying pressure. Practical considerations of design and manufacture at present favour the use of fixed orifices, and limitations of this type, during 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 speeds and altitudes.

4. Other methods include the use of burners having orifices designed for different pressure stages, e.g., a small orifice for starting and idling flows, and a larger one for the higher fuel flows. These burners will require a unit which cuts off the flow to the larger orifice at low fuel flows, and allows continuous fuel flow through the smaller orifice until, at a predetermined pressure, it permits additional fuel to flow through the larger orifice. This unit is known as a pressurising valve.

5. The problem of producing varying fuel flows at controlled pressure is met by using a high-pressure pump (or pumps) in conjunction with a throttling device under the control of the pilot. Two methods are used to control the fuel to the throttle; one, using a high pressure pump of constant delivery in conjunction with a unit (barostat) which by-passes excess fuel back to the pump inlet, according to pump outlet pressure, as determined by the throttle position. The other

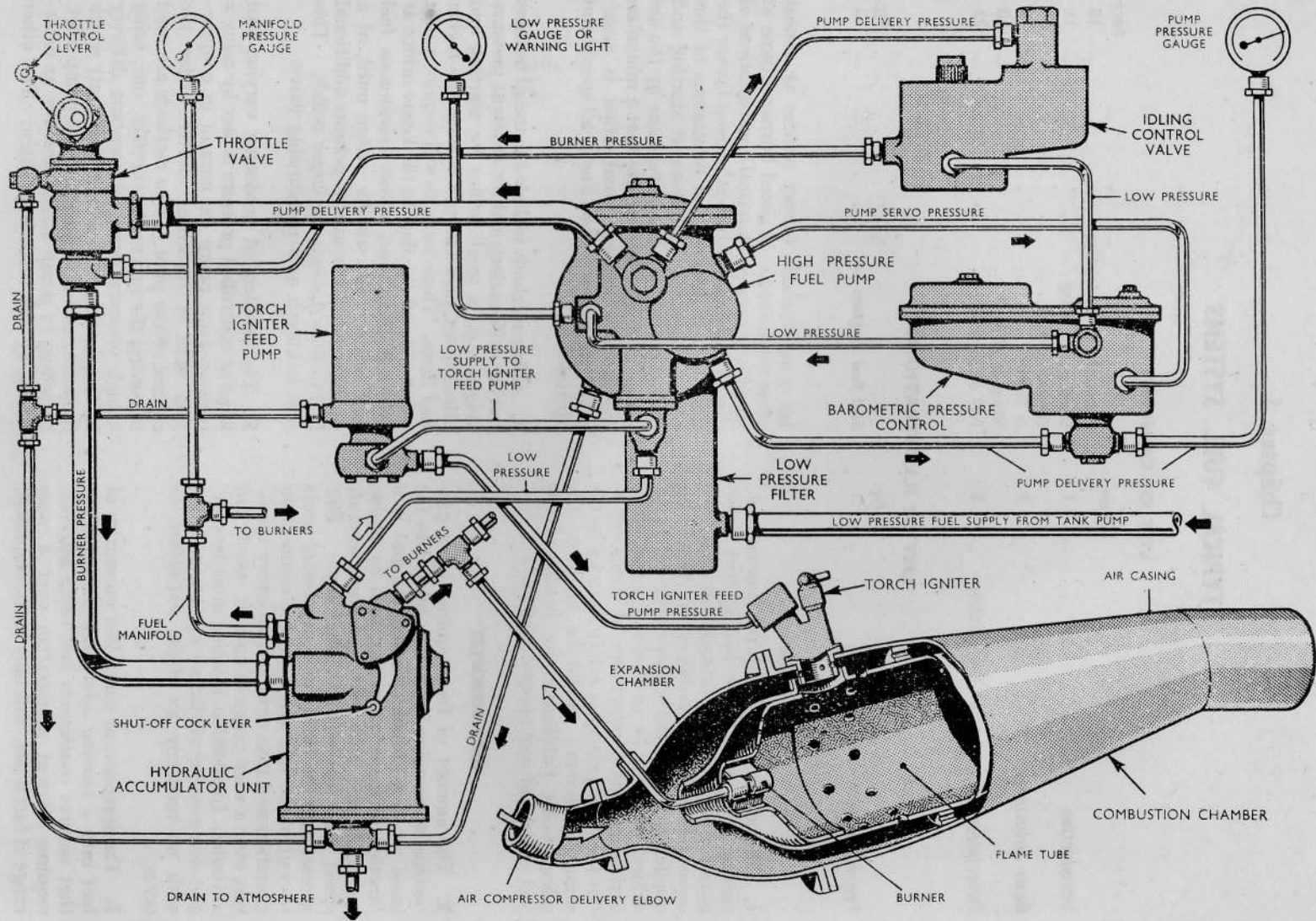


Fig. 1. Typical fuel system

method using a high-pressure variable delivery pump employing a servo mechanism, under the control of a separate unit, called the barometric pressure control (B.P.C.); this unit varies the fuel flow according to momentary changes in pump outlet pressure produced by movement of the throttle. Both the barostat and the B.P.C. also provide compensation of fuel flow with changes in aircraft forward speed (ram effect) and altitude.

6. To initiate the flame when starting, a high tension spark produced by a booster coil is used to ignite the sprays from the burners. The fuel spray from the main engine burners is not easily ignited at very low flows, therefore a separate spray from a subsidiary burner, giving good atomization under these conditions, is ignited by the spark and directed across the main spray. Flame propagation through the combustion system then ignites the sprays from the remaining burners. The sparking plug and subsidiary burner are fitted as a unit (torch igniter) to a convenient point in the combustion system (two-units are normally used) and receive their fuel supply from a separate electrically-driven pump, or from a tapping from the pressure side of the H.P. pump.

7. To stop the engine, the fuel supply to the burners is cut off by a cock which also permits the fuel, being pumped during the running down period, to be returned to the pump inlet. The fuel remaining in the burner line and the combustion chambers after flame extinction, is drained away to eliminate the possibility of excessive burning in the combustion system and jet pipe on restarting the engine. This is usually effected through 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.

#### DESCRIPTION OF A TYPICAL FUEL SYSTEM

8. Housed in the fuel tank is an immersed electrically driven low pressure fuel pump; this pump feeds fuel at low pressure, through a low pressure cock in the feed pipe, to a low pressure filter. Fuel from the filter then passes to a high pressure positive displacement fuel pump (Sect. 2). Between the low pressure filter and the high pressure fuel pump is a connection for supplying fuel at low pressure to the torch igniter feed pump, and then to the torch igniters (Sect. 8). A

connection for a low pressure warning light is provided on the inlet side of the torch igniter feed pump.

9. Fuel from the main outlet of the high pressure fuel pump is fed to the throttle valve (Sect. 6). Two connections on the fuel pump supply fuel at pump output pressure and at pump servo pressure to the B.P.C. (Sect. 3). Between the high pressure fuel pump and the throttle valve is a connection for supplying fuel at pump output pressure to the inlet side of the idling control valve unit, also known as the minimum burner pressure valve (Sect. 9). Fuel allowed to pass the throttle valve passes into the fuel accumulator (Sect. 5), and then through the trip valve and high pressure shut-off cock to the burner manifolds and burners. Under idling conditions at altitude fuel passes from the idling control valve unit to the inlet side of the fuel accumulator, then through the accumulator to the burners (Sect. 7). Excess fuel from the idling control valve unit, released by its relief valve, is returned to the inlet side of the high pressure fuel pump.

#### PRINCIPLE OF OPERATION

10. The following paragraphs describe the manner in which pressures and flows are controlled by the inter-relation of the various components of a typical fuel system, employing Simplex burners, variable-delivery pump, B.P.C., hydraulic accumulator, and idling control valve.

#### Starting and idling

11. Prior to starting the engine, the low pressure cock is moved to the open position and the fuel tank pump switched on. These operations permit fuel from the tank to pass at low pressure, through the low pressure filter to the high pressure fuel pump. The high pressure shut-off cock should be opened either before or early in the starting cycle, as described in the relevant starting instructions. Switching on the tank pump switch will operate the low pressure warning light, which will remain alight until a suitable pressure has been built up in the low pressure system. When the requisite pressure has been attained, the warning light will go out; at this stage the starter button is pressed for a period of two seconds. On releasing the starter button, the torch igniter feed pump and the starter motor are simultaneously

energised, the solenoid operated igniter fuel valves in the torch igniters are opened, and a high tension current supplied to the sparking plugs. For a few seconds the starter motor electric supply is fed through a resistance, consequently the engine will rotate slowly. During this period, fuel from the torch igniter fuel pump will pass, via the igniter fuel valves, to the torch igniters, which inject it as a fine spray into the flame tubes. On entering the combustion chamber the fuel mixes with air at atmospheric pressure; this 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 completed.

**12.** At the end of the slow motoring period, full voltage is applied to the starter motor thus increasing the speed of the engine and the pressure from the fuel pump. Fuel that has been passing through the throttle valve into the accumulator, will gradually build up a pressure sufficient to force the accumulator piston to the end of its stroke and thus fill the accumulator cylinder. As the fuel pressure will continue to rise after the cylinder is full, the additional pressure will be exerted on the trip valve; this pressure will cause the trip valve to open and fill the burner fuel lines; the back pressure from the burner lines will then cause the trip valve to open fully and allow the contents of the accumulator to be released. The piston will therefore rise under pressure from the piston spring and force the fuel through the trip valve and the high pressure shut-off cock to the manifolds and burners. This boost of fuel to the burners is necessary to ensure a readily ignitable fuel spray of sufficient duration to start the engine. Throughout the running period of the engine, fuel will continue to flow through the accumulator, which will remain fully charged.

**13.** The function of the burners is to break up the fuel into the smallest possible droplets, in order to expose the maximum area for evaporation. A swirl type atomizer is therefore used in each Simplex burner, and consists of a vortex chamber into which fuel enters in a tangential direction, the fuel then leaving the atomizer through an axial orifice in the form of a hollow cone spray.

**14.** Each flame tube is provided with a burner, the fuel spray from each burner atomizer being injected into its respective flame tube, where it mixes with air in correct ratio for combustion. This air is supplied by

the compressor, rotated by the starter motor, the air entering the flame tubes through holes in the forward end of the tubes.

**15.** The mixture injected into those combustion chambers fitted with a torch igniter, is now ignited by the flame from their respective torch igniters, this burning mixture then spreads through the combustion chamber interconnectors to the remaining combustion chambers. At this stage, the engine is said to "light up", and combustion is then continuous. The hot gases which have expanded as a result of combustion, increase in velocity 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 insufficient for the turbine to develop the necessary power to drive the compressor without assistance; the starter motor therefore continues to assist rotation until the engine speed is sufficient to disengage the driving mechanism. The engine will then continue to run under its own power, gradually increasing in speed until the idling r.p.m. is reached.

**16.** At the conclusion of the starting cycle, the starter panel (*A.P.1095C, Vol. 1*) automatically cuts off the electric supply to the starting system, the torch igniter feed pump will therefore stop, the torch igniter solenoid valves will close to cut off the fuel supply to the torch igniters, and the H.T. current will be cut off from the sparking plugs; simultaneously, the current will be cut off from the starter motor.

#### **Ground running**

**17.** During the starting cycle, and until idling speed has been attained, the throttle valve remains in the closed position and only a small quantity of fuel will pass through the throttle valve to the burners. The burner atomizers have a fixed orifice, therefore the quantity of fuel they pass will depend on the fuel pressure in the burner manifolds. Opening the throttle valve will allow the pressure in the burner lines to increase from roughly 20 lb. per sq. in. at idling speed to over 1,000 lb. per sq. in. at maximum r.p.m. depending on the speed of the engine. Removal of restriction on fuel flow to the burners, by opening the throttle valve will permit burner pressure to increase. Under these conditions, there will be a fall in input pressure to the throttle valve unless the output from the high pressure fuel pump

increases without delay. The momentary fall in pressure that does occur, causes the barometric pressure control to reduce the bleed from the pump servo which then adjusts the output of the fuel pump.

**18.** The B.P.C. unit is in communication with the spring-loaded side of the fuel pump servo control piston and with the high pressure side of the servo piston. In the present case, the momentary fall in fuel pump output will cause the B.P.C. half-ball valve to restrict the orifice, consequently it will bleed away less servo pressure, and the pump servo piston will move to lengthen the stroke of the pump. Fuel pressure on the input side of the throttle valve will increase momentarily when the throttle valve is closed, this increase being communicated to the B.P.C. rocker arm which will rise and increase 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**

**19.** The density and pressure of the air decreases with increase in altitude, consequently when an aircraft climbs at constant r.p.m. the mass air flow through the engine will become less. In order to keep the ratio of fuel to air constant the amount of fuel going to the burners must be reduced to correspond with the reduction in air flow. As previously explained, the B.P.C. varies the output from the high pressure fuel pump, dependent on the input pressure to the throttle valve, but assuming the aircraft is climbing at a fixed throttle opening, this variation in pressure will not occur. It is still necessary, however, to reduce the fuel flow from the high pressure pump, and this is accomplished by a capsule unit incorporated in the B.P.C. Air at intake pressure is admitted to the capsule chamber, and, depending on the rise or fall in pressure, the loading on the capsule stack will increase or decrease. With a reduction in intake pressure, the capsule stack will expand and push down the B.P.C. rocker arm, which is pivoted about its centre; the half ball will then rise and increase the servo bleed, thus allowing the fuel pump piston to move and reduce the pump stroke.

#### **Idling at altitude**

**20.** At extreme conditions of idling r.p.m. at high altitude, the reduction in pressure to the burners consequent upon the closing of

the throttle valve and the action of the B.P.C. will be such that the spray characteristics at the atomizers would suffer, and flame extinction may occur if the throttle is mishandled when opening up. To obviate this possibility, an idling control valve unit (I.C.V.) is incorporated in the fuel system to prevent the fuel pressure dropping below the minimum figure necessary to ensure combustion.

**21.** When the engine is rotated by the starter motor, fuel from the high pressure fuel pump enters the I.C.V. unit through its inlet valve, and builds up a pressure which acts on the capsule within the I.C.V. until, at a predetermined figure, the inlet valve closes. The pressure difference acting across a valve communicating with the burner pressure line, plus tension spring pressure, will keep the burner valve closed, consequently on the ground or at low altitude there is no flow through the unit. This condition is maintained until the aircraft reaches an altitude of approximately 5,000 feet, where the I.C.V. will commence operating when the throttle valve is closed to the idling position. With the closing of the throttle valve there is a reduction in burner pressure, which eventually reaches a stage where the pressure drop occurring across the idling control outlet valve exceeds tension spring pressure; the valve then starts to open and feeds fuel from the unit to the burners via the accumulator, by-passing the throttle valve. At greater altitudes, the reduction in ambient pressure will cause the capsule stack to expand further and allow more fuel to pass to the burners.

**22.** As a result of this supplementary fuel supply to the burners, the idling r.p.m. will progressively increase with altitude. It will be observed from the foregoing that the automatically controlled output from the high pressure fuel pump, together with the functioning of the idling control valve unit, will ensure correct fuel pressure for satisfactory combustion at low throttle openings at all altitudes.

#### **Fuel drain system**

**23.** 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, consequently a fuel drain system is incorporated. The combustion chamber drain system will vary with different types of engine but generally,

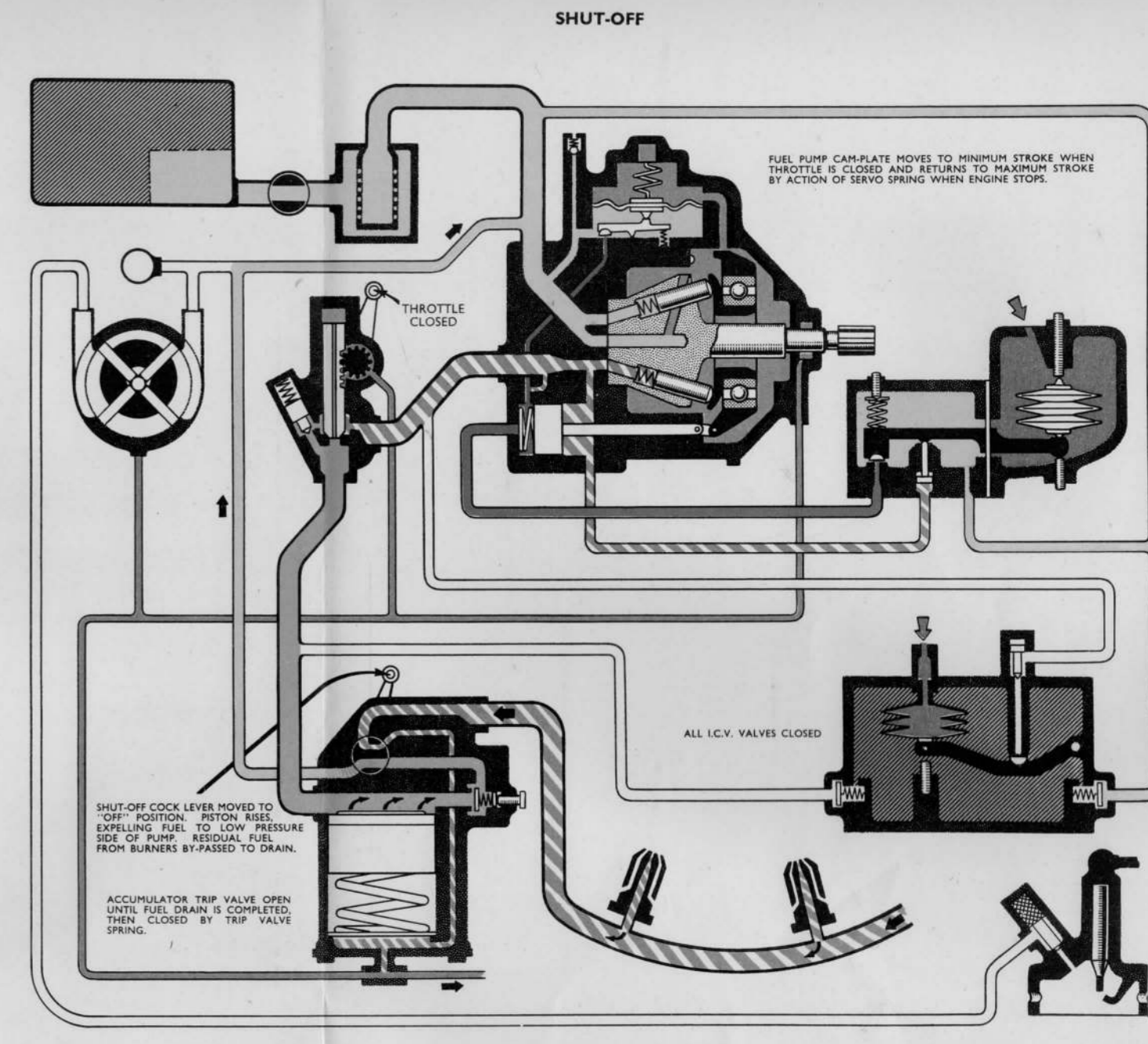
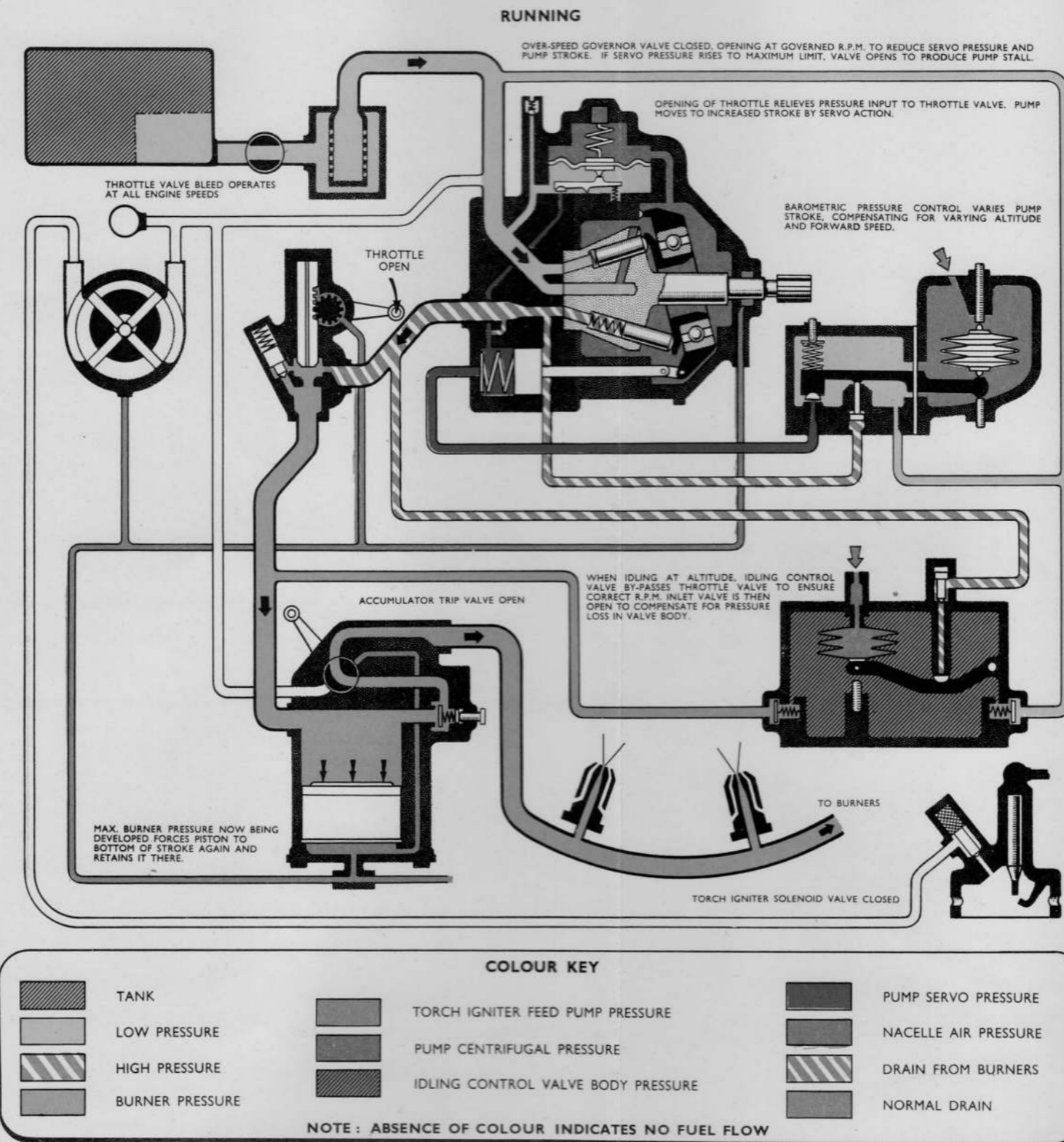
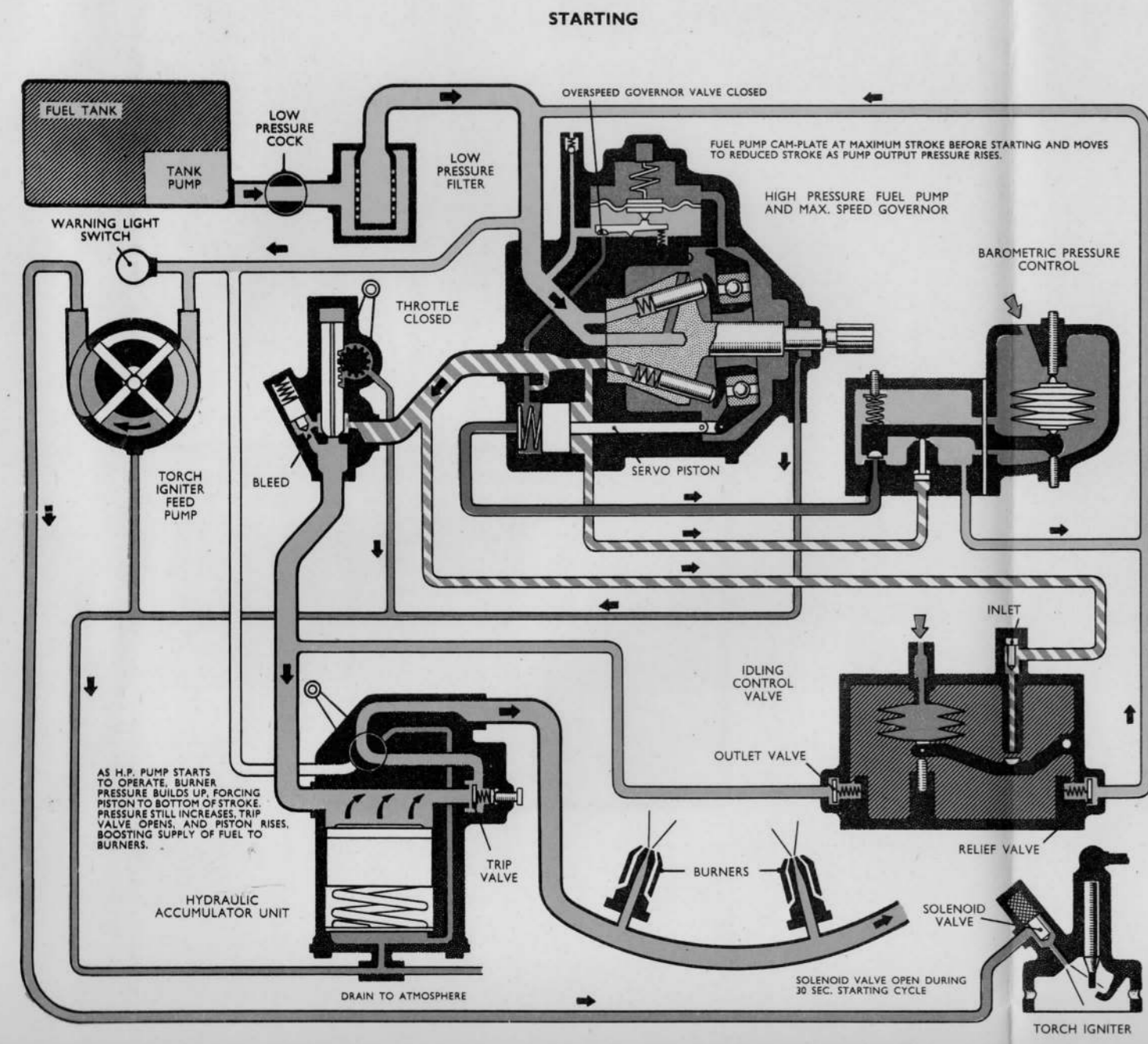


FIG. 2. FUEL FLOW DIAGRAM

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 arranged to close when combustion chamber pressure rises, and open when the engine stops to convey residual fuel to atmosphere; this prevents the possibility of overheating when starting, due to the presence of unburnt fuel in the combustion chambers.

**24.** When the high pressure shut-off cock is closed to stop the engine, the fuel supply is cut off from the burners and by-passed along a slot in the high pressure cock rotor to the inlet side of the high pressure fuel pump. Slowing down of the engine will cause the pressure in the accumulator to fall, and the

accumulator piston will therefore move to discharge the fuel through the open trip valve to the inlet side of the high pressure fuel pump. Surplus fuel from the burners and burner manifolds will pass back through holes in the high pressure cock rotor and down the vertical passage in the accumulator body, into the end cap. Fuel passing the accumulator piston seal will drain into the end cap and join the fuel from the burners and then pass to atmosphere. Fuel which may leak from the high pressure fuel pump drive shaft gland and from the throttle valve housing will pass to the drain connection on the bottom of the accumulator and, together with fuel from the accumulator, pass to atmosphere on the outside of the engine nacelle.

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