Chapter Three

THE FUEL SYSTEM

Contents

Illustrations

THIS CHAPTER contains a general description of the dual Lucas pump fuel system fitted to the engine. The ignition system equipment, which does not concern the operation of the fuel system during normal running, is described separately in chapter 4.

Fig. 1 and 2 are views intended to show the disposition of the fuel system components on the engine. Fig. 3 is a diagrammatic arrangement of the fuel system and is coloured to indicate the fuel flow and pressure existing in various parts of the system under normal running conditions.

This chapter does not describe the detailed construction and principle of operation of each individual fuel system component for which reference should be made to Chapters 39 to 44 of this handbook.

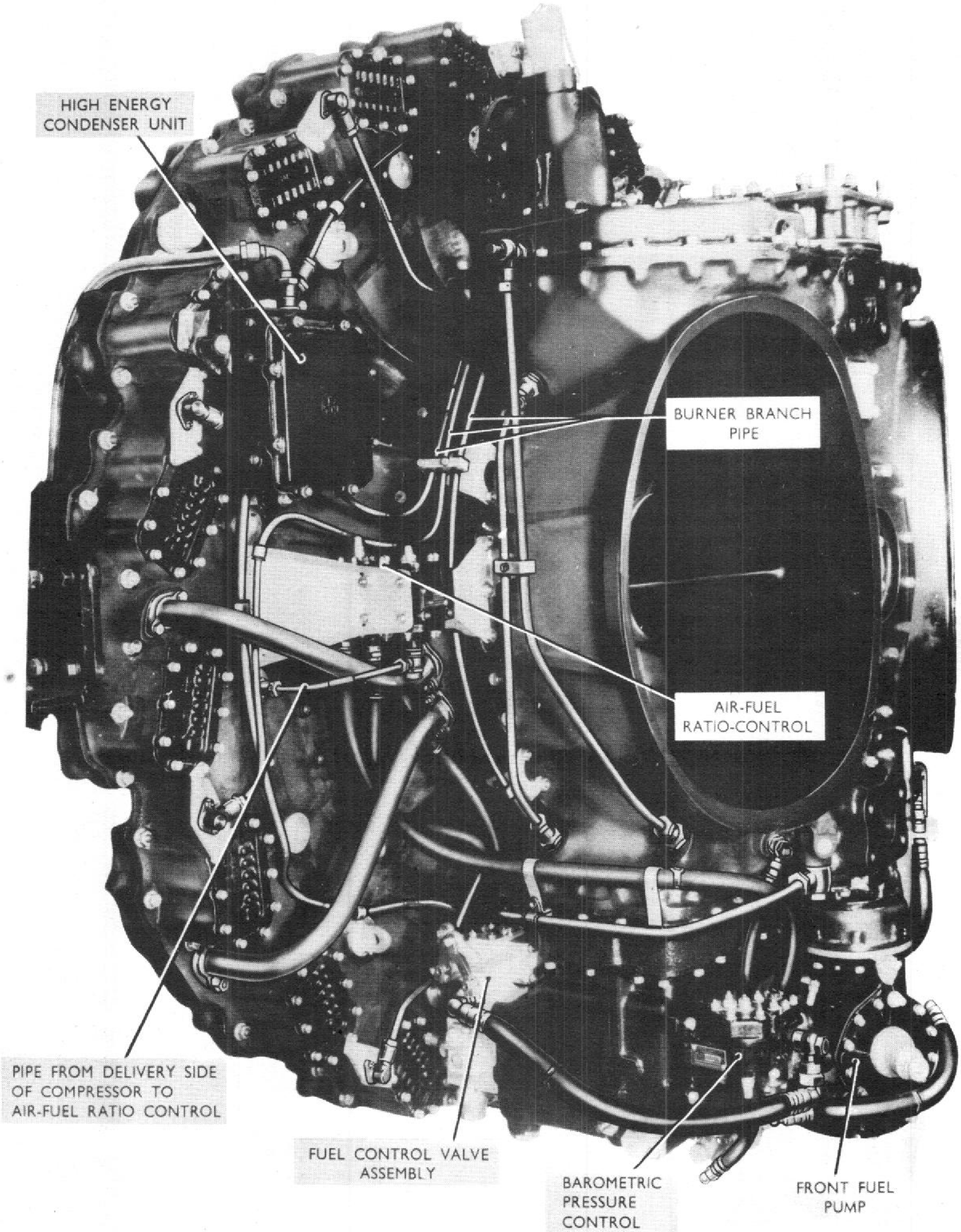

Fig. 1. Fuel system components on starboard side of engine.

CONTROLS

Engine speed, and thus the thrust developed is controlled by a lever in the cockpit which is linked to a throttle valve, or tapered needle, in the control box; the needle providing a variable orifice through which the fuel delivered by the engine-driven fuel pumps is metered to the burners. The throttle valve is designed so that over the first part of its travel there are equal increments of r.p.m. for equal amounts of lever movement whilst over the latter part of its travel, at higher engine speeds, there are equal increments of thrust, not r.p.m., for equal amounts of lever movement. To enable the small fuel flow required for idling to be adjusted conveniently, there is a subsidiary orifice, adjustable on the ground by a pointed screw, which by-passes the throttle control orifice.

To enable the engine to be stopped, a lever in the cockpit is connected to a high pressure fuel shut-off valve in the control box, between the throttle valve and the outlet, which shuts off the high pressure fuel supply to the burners.

A servo isolating valve is fitted to the front fuel pump and provides a safeguard against failure of either fuel pump, or of the barometric pressure control, the air-fuel ratio control, or the servo connecting pipes. The control is operated by moving the fuel pump isolating switch in the cockpit, to the ON position. To ensure protection against failure during take-off, the switch must be placed in the ON position prior to take-off and returned to the OFF position as soon as the aircraft has attained its correct climbing speed and a safe height.

To reduce risk of damage to the engine by incorrect operation of the controls, the barometric pressure control and the air-fuel ratio control, in conjunction with the fuel pump servo mechanism, automatically adjust the fuel supply to the burners to meet all changes of throttle setting; compensation is also provided for changes in altitude, ram pressure in the air-intake, and air mass flow through the engine (in effect compressor delivery pressure) during acceleration. Overspeeding of the engine is prevented by a governor mechanism which is integral with the fuel pumps.

FUEL SYSTEM COMPONENTS

LOW PRESSURE FUEL FILTER

The low pressure fuel filter is a Vokes fabric filter mounted on the port side of the diffuser casing.

FUEL PUMPS

The fuel pumps are mounted with their driving shafts vertical, on the under face of the bottom wheelcase, one behind the other. These pumps are of the positive displacement, variable stroke, multi-plunger type, and each incorporates a servo control, overspeed governor, and relief valve mechanism. Each pump is driven at 0·369 engine speed through a train of gears. A solenoid-operated servo isolating valve is fitted to the front pump to provide an additional safety factor during take-off, or in emergency conditions, by isolating the control system of one pump, so that delivery of fuel to the burners will not be interrupted in the event of failure of the barometric pressure control, the air-fuel ratio control, or the servo connecting pipes.

In the event of failure of either fuel pump, the working pump will maintain the fuel supply. Each pump is fitted with a non-return valve in its outlet port to prevent fuel at high pressure being circulated into the pump that has failed, which would cause it to motor and thereby reduce the effective delivery pressure of the working pump. As already stated, each pump incorporates its own overspeed governor mechanism. It is customary to set the governor mechanism in one pump to control at a higher engine speed than that in the other, so that maximum r.p.m. can be reached without a conflict for control.

Normally the pump delivery pressure, and therefore the actual delivery, is controlled by

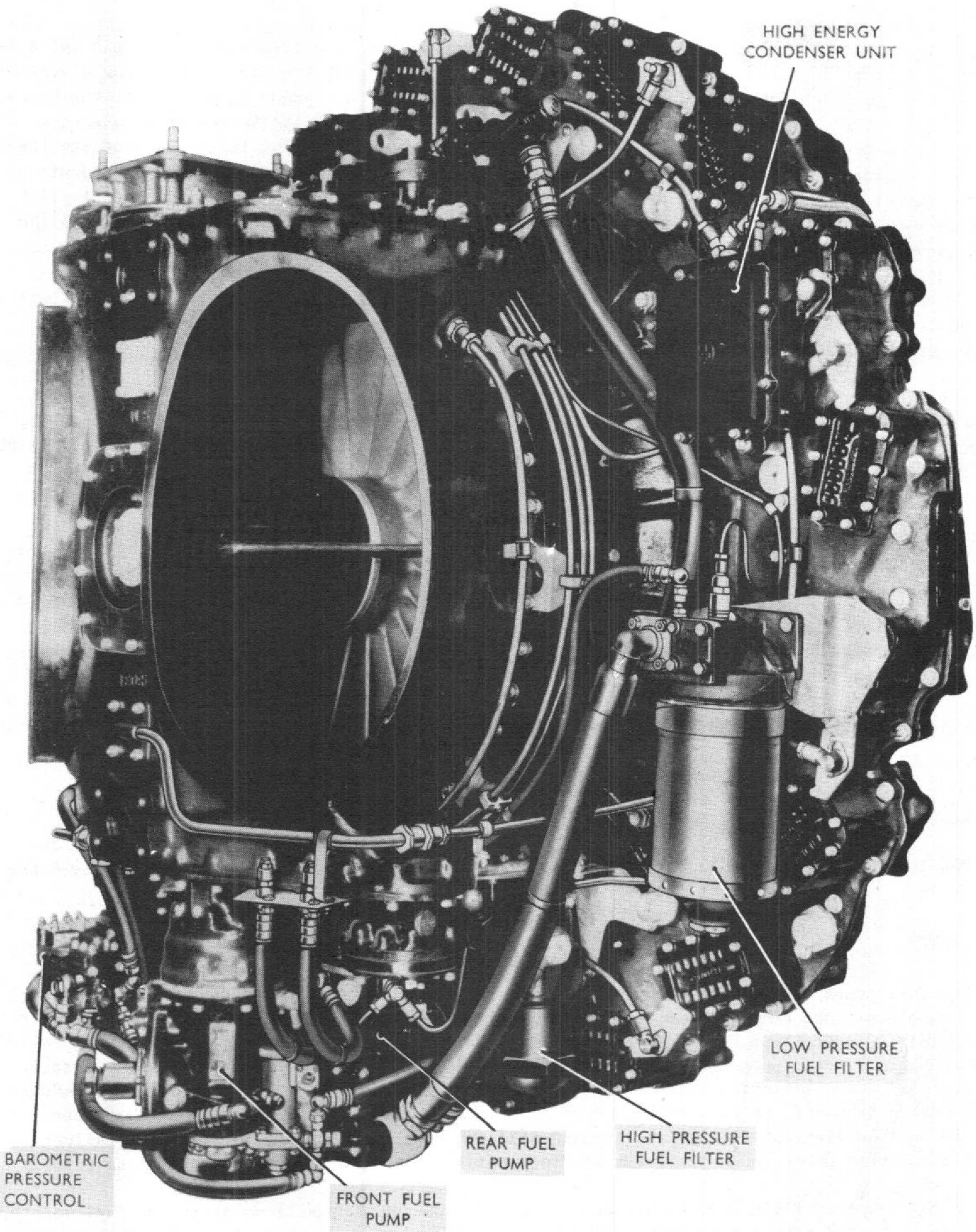

Fig. 2. Fuel system components on port side of engine.

the barometric pressure control through the pump servo control mechanism. During acceleration the barometric pressure control would permit the pump delivery to increase more rapidly than the air mass flow through the combustion chambers. To safeguard against such temporary over-fuelling, and consequent overheating of the engine, an air-fuel ratio control is fitted. In these circumstances, the air-fuel ratio control over-rides the barometric pressure control and, acting through the pump servo control mechanism, restricts the fuel pump delivery to that appropriate to the air flow through the combustion system.

The pump servo control mechanism contains a spring-loaded piston which is responsive to servo pressure (regulated by the barometric pressure control, or the air-fuel ratio control during acceleration) pump delivery pressure, and governor pressure. The servo piston alters the stroke, and hence the delivery, of the pump in response to the varying requirements of the engine as determined by changes in throttle setting, altitude, ram pressure in the air-intake and air mass flow. Attempts to overspeed, and excessive pressure in the delivery line such as might be caused by an obstruction in a pipe or orifice, are also controlled by the servo mechanism.

BAROMETRIC PRESSURE CONTROL

The barometric pressure control is mounted underneath the bottom wheelcase on the front of the sump. It is connected by flexible pipes to the servo outlet on the front fuel pump and thence to the servo outlet on the other pump. Connection is also made to the inlet side of the fuel pumps via the control box spill pipe (fuel return to pump inlet), and to the delivery side of the pumps. The two fuel pumps are connected in parallel and, so long as they are functioning normally, or the isolating valve has not been closed, the B.P.C. is in communication with both.

When the engine is running, there is a small intermittent flow of fuel through the servo pipe and the B.P.C to the fuel pump inlet, which balances the quantity of fuel entering the servo system from the delivery side of the pump through a calibrated orifice in each pump. A filter in the servo connection of the B.P.C. prevents the entry of foreign matter. There is no flow in the high pressure delivery pipe from the pump to the B.P.C. which simply acts as a pressure transmitter.

The B.P.C. contains an evacuated capsule stack which is subjected to ram air pressure in the air-intake. This capsule stack, in conjunction with a piston which is subjected to fuel pump delivery pressure via the pump delivery to B.P C. pipe, varies the effective size of the orifice through which fuel escapes from the servo system through the B.P.C. to the fuel pump inlet, and thus regulates the servo pressure. Thus the B.P.C. is able to adjust the fuel pump delivery pressure so that it is always proportional to the ram effect in the air-intake. By this means the fuel pump stroke and consequently the delivery pressure and the actual delivery, is varied to meet changes in engine speed, altitude and forward speed. The fuel pumps therefore, deliver the exact quantity of fuel required by the engines.

To safeguard against temporary over-fuelling during acceleration, an air-fuel ratio control is arranged to over-ride the B.P.C. whenever the fuel delivery to the burners tends to exceed that appropriate to the air mass flow through the combustion system. For this purpose the air mass flow can be regarded as approximately proportional to the compressor delivery pressure.

AIR-FUEL RATIO CONTROL

The air-fuel ratio control is mounted on a bracket on the starboard side of the air-intake. It is connected by flexible pipes to the pump servo system connection on the B.P.C. and to the inlet side of the fuel pumps via the control box spill pipe (fuel return to pump inlet), and to the delivery (metered fuel pressure) side of the control box. This unit is similar in construction and operation to the B.P.C. but has in addition a diaphram which is subjected to compressor delivery pressure. The evacuated capsule stack in the air-fuel ratio control is subjected to barometric pressure only and is not, therefore, influenced by changes in forward speed.

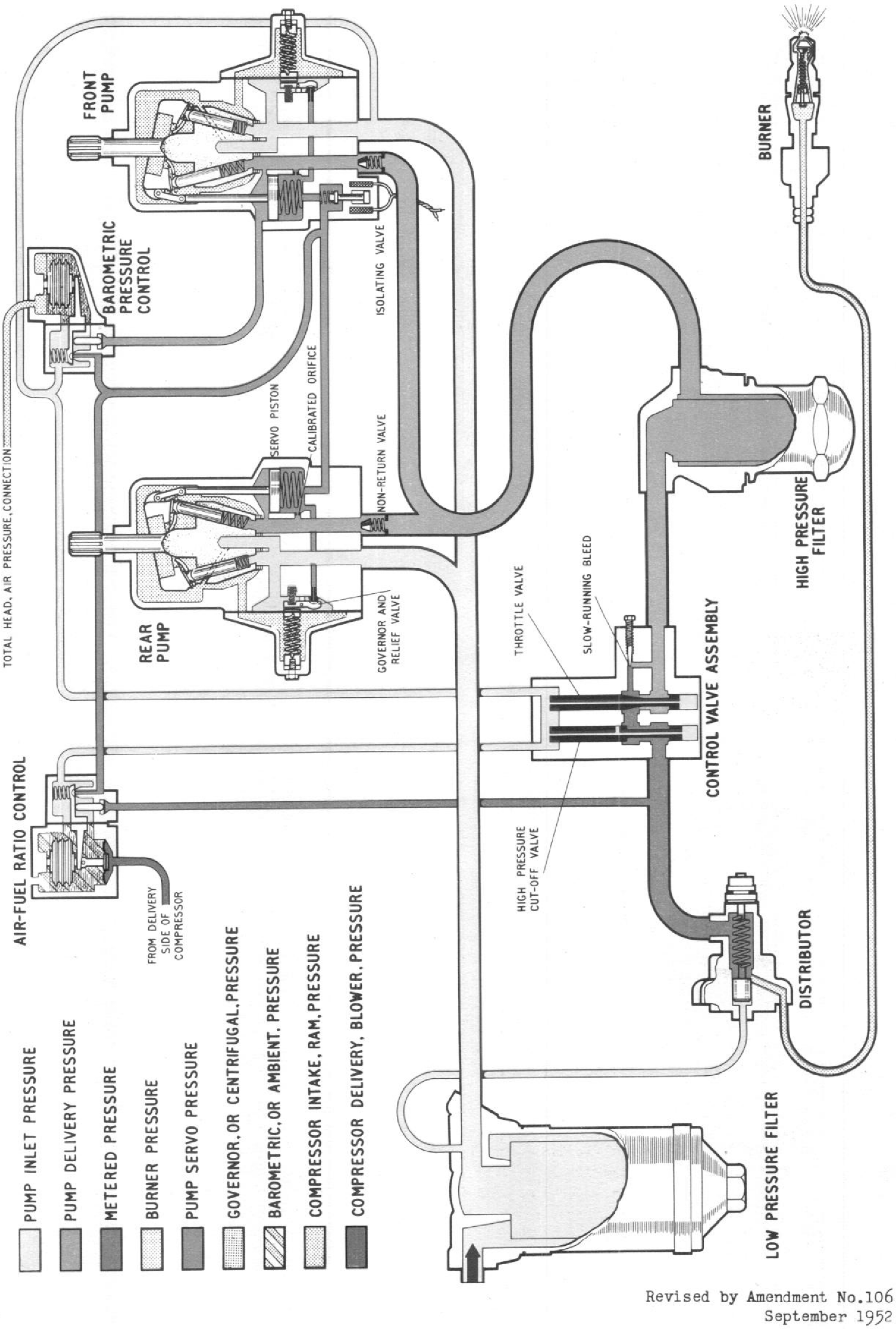

Fig. 3. Diagram of fuel system.

When the engine is running normally, the air-fuel ratio control is inoperative and has no effect on the functioning of the system. During acceleration, however, the change in the ratio between the metered fuel pressure, acting on the piston in the air-fuel ratio control via the connection to the outlet side of the control box, and the compressor delivery pressure acting on the diaphragm, permits sufficient fuel to escape from the pump servo system, through the servo pipe and the air-fuel ratio control, to balance the fuel entering the servo system from the delivery side of the pumps through the calibrated orifice in each pump, and so over-rides the B.P.C. Thus, the air-fuel ratio control prevents temporary over-fuelling, and consequent over-heating of the engine, during acceleration. The capsule stack provides automatic compensation for changes in barometric pressure. A filter in the servo connection of the air-fuel ratio control prevents the entry of foreign matter. At no time is there any flow in the metered pressure pipe (control box outlet to air-fuel ratio control pipe) which simply acts as a pressure transmitter.

CONTROL BOX

The control box, which is mounted on the starboard side of the bottom wheelcase, contains the throttle valve and the high pressure cut-off valve; there is also an adjustable slow-running bleed in parallel with the throttle valve. To obviate the risk of hydraulic hammer due to the sudden closing of the delivery passage to the burners, the cut-off valve is arranged so that when it is in the off position it diverts the fuel delivery back to the inlet side of the fuel pumps. The control box is officially designated the "Fuel Control Valve Assembly".

HIGH PRESSURE FUEL FILTER

The high pressure fuel filter is mounted on the port side of the engine. It is of the wire-wound Purolator type and is situated in the fuel delivery line between the fuel pumps and the control box. This filter protects the control box and the small apertures in the flow distributor and the burners from blockage by minute particles which might pass through the low pressure fuel filter.

FLOW DISTRIBUTOR

The flow distributor, which is mounted on the part side of the engine, forms the junction between the main fuel delivery pipe from the control box and the ten individual pipes leading to the burners. It is designed to distribute the fuel flow correctly under all conditions to each of the ten burners. To provide the different flow required in individual combustion chambers, restrictors are fitted in the fuel passages which are connected to the individual burners.

BURNERS

A 'Duplex 2' burner is inserted into each combustion chamber through a boss cast at the junction of the two entry ducts of the twin-entry expansion chamber. Ten individual, small bore, rigid pipes lead from the flow distributor to brackets on the diffuser casing and each is connected to its individual burner by a short length of flexible pipe behind each bracket. The burners are able to deal with a wide range of fuel flows satisfactorily and so permit of efficient operation at very high altitudes, where the fuel flow required is very low.

OPERATION OF FUEL SYSTEM

Fuel is supplied to the low pressure fuel filter on the engine by normal immersed fuel tank booster pumps through a low pressure fuel cock, or fuel shut-off valve. These are airframe components; the engine portion of the fuel system commencing at the low pressure fuel filter. The fuel passes through the low pressure filter to the two engine-driven fuel pumps and thence, at a comparatively high pressure, through the high pressure fuel filter and the control box which contains the throttle and high pressure cut-off controls. From the control box, the fuel passes to the flow distributor, whence individual pipes lead to each of the ten burners.

Before starting the engine for the first time, or whenever the fuel system has been drained or disconnected for a servicing operation, it is necessary to bleed the air out of the fuel pumps as described under priming the fuel system in Chapter 8. When the low pressure cock is turned on and the tank booster pumps switched on, it may be assumed that all those passages connected to the low pressure side of the fuel system, which is coloured yellow in fig. 3, are filled with fuel at booster pump pressure.

STARTING

The engine is normally started with the throttle valve in the slow-running position and the H.P. fuel cut-off valve in the ON position. When the turbo-starter rotates the engine, fuel is pumped through the control box and, as soon as a pressure approximating to 100 lb. per sq. in. is built up on the outlet side of the control box, the piston in the flow distributor moves against its spring loading. This uncovers the metering slots in the distributor, and allows fuel to flow through the individual pipes to the ten burners. The surface discharge plugs ignite the fuel discharging from the burners in No. 3 and 10 combustion chambers, and the flame spreads to the other eight combustion chambers through the inter-connecting passages. The starter assists the engine to accelerate to its self-sustaining speed.

NORMAL RUNNING

The thrust developed by the engine depends on the quantity of fuel being burnt. Thus, at a constant barometric pressure, an increase in thrust requires an increased flow of fuel to the burners. At altitude, however, due to the reduced density of the air, less fuel is required for any given throttle opening than at sea level. Similarly, when climbing at a constant throttle setting a diminishing amount of fuel is required.

The barometric pressure control, in conjunction with the servo piston mechanism in the fuel pumps, automatically adjusts the fuel pump delivery pressure, and the fuel flow, to meet changes in throttle setting, altitude and forward speed. During acceleration, the air-fuel ratio control temporarily over-rides the barometric pressure control to prevent over-fuelling, and consequent overheating of the engine; at all other times the air-fuel ratio control is inoperative.

Provided the throttle setting remains unchanged, when the aircraft is flying at a constant altitude, or more correctly at a constant barometric pressure, the escape of fuel through the B.P.C. controls the pressure in the servo system so that the forces acting on the servo piston are in equilibrium, with a very small flow of fuel through the servo pipe and the B.P.C. back to the inlet side of the pump. The pressure in the servo system is less than pump delivery pressure by approximately the value of the spring loading on the servo piston. The fuel pump delivery pressure, which is the same as the pressure on the inlet side of the control box, is automatically maintained at a pressure sufficient to maintain this equilibrium. If, under these conditions, the throttle is opened further, the consequent momentary reduction in the fuel pump delivery pressure below that pressure required to maintain the equilibrium, causes the servo orifice in the B.P.C. to be closed. The fuel pressure on either side of the servo piston in each fuel pump becomes balanced and the spring loaded servo pistons move so that the pump stroke and consequently the delivery and pressure is increased, until the forces are once again in equilibrium. Conversely, any rise in pump delivery pressure, such as will occur momentarily when the throttle is closed, causes the servo orifice to be opened further and the decreased fuel pressure in the pump servo system permits the servo pistons to move so as to decrease the pump stroke, delivery and pressure, until normal equilibrium is restored.

If, however, the aircraft is climbing at a constant throttle setting, the decreasing barometric pressure, due to the increasing altitude, reacts on the evacuated capsule stack within the barometric pressure control so that the servo orifice in the B.P.C. is opened, the equilibrium of the servo pistons is upset and the pump servo mechanisms decrease the pump stroke, delivery and pressure, until equilibrium is restored at the new air-intake pressure. Thus, the fuel pressure on the inlet side of the control box and the flow to the burners is reduced

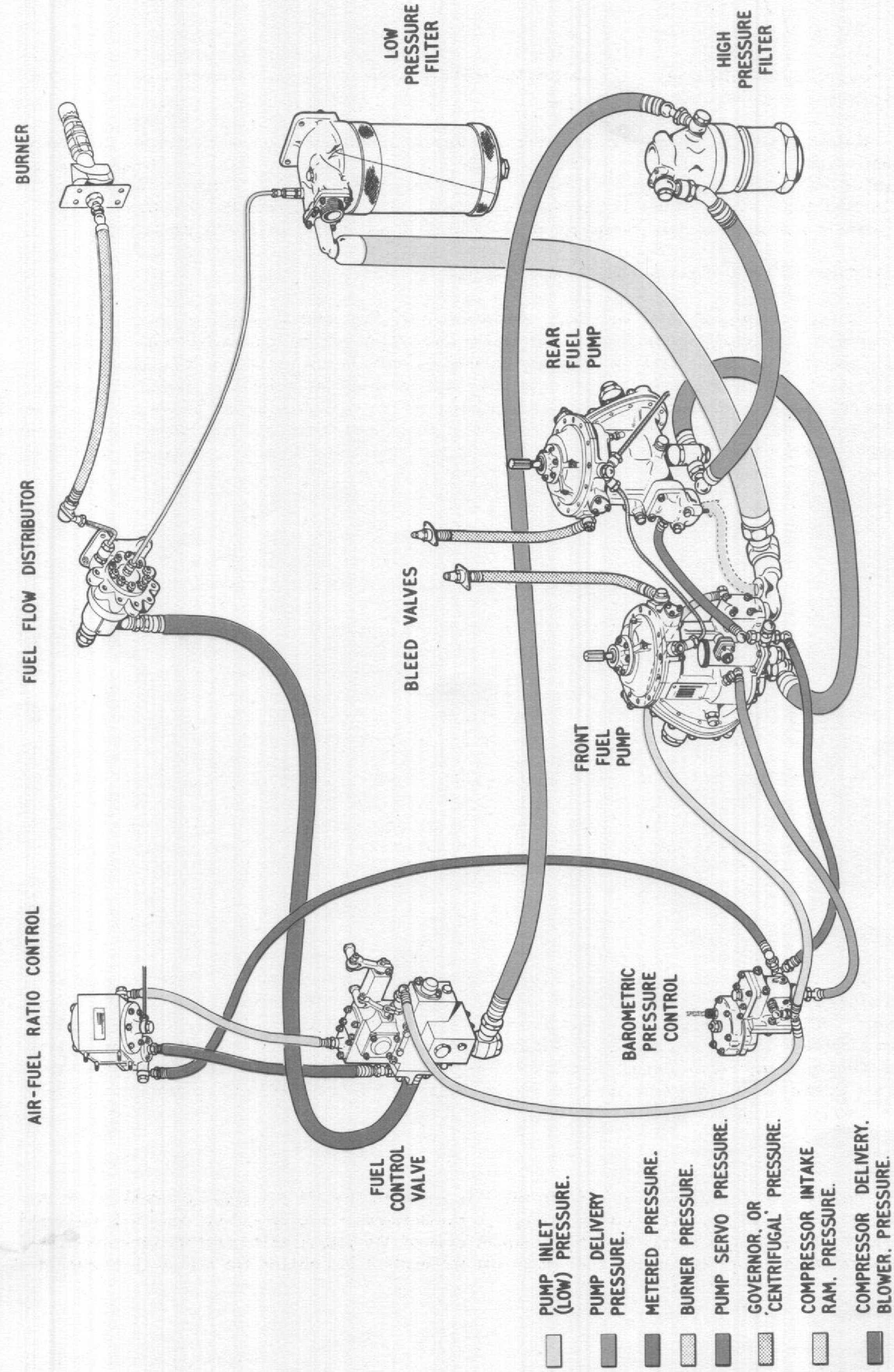

Fig. 4. Pictorial diagram of fuel system piping.

correspondingly, Similarly, with decreasing altitude, or increasing barometric pressure, the reverse action takes place.

To compensate for changes in ram effect in the engine air-intake due to changes in forward speed of the aircraft, the capsule chamber in the B.P.C. is connected to a total head pressure point which faces forwards and receives the full effect of the speed of flight. As flying speed increases, the pressure in the capsule chamber rises slightly and the fuel flow to the burners is increased to take advantage of the increased air mass flow due to ram effect.

PREVENTION OF OVER-FUELLING DURING ACCELERATION

To increase engine speed and therefore thrust, more fuel must be supplied to the burners. The greater the percentage of fuel to air in the combustion system, the higher will be the temperatures throughout the system. The flow of fuel depends on the setting of the pumps and the throttle, but the flow of air depends upon the speed at which the compressor impeller rotates. There is, inevitably, some lag between the increase of the fuel flow to the burners to initiate acceleration to a higher speed and the increase of the air flow through the combustion system as a result of the higher engine speed. Although some increase in the ratio of fuel to air is essential in order to accelerate the engine, the rate of increase in fuel supply must be strictly controlled since an excess of fuel would cause high engine temperatures.

When the throttle is opened to increase engine speed, the B.P.C., in conjunction with the pump servo mechanism, attempts to increase the pump output to suit, and it is at this stage that the air-fuel ratio control which is subjected to compressor delivery pressure, (in effect air mass flow through the combustion system) and to metered fuel pressure comes into operation. Provided the metered fuel pressure is within the designed proportion to the compressor delivery pressure, the unit is inoperative but, during acceleration, the metered fuel pressure tends to rise above that appropriate to the air flow through the combustion system. This reacts on the air-fuel ratio control so that the servo orifice therein is opened to permit the escape of fuel from the pump servo system and thus to over-ride the B.P.C. and limit the extent to which the pump servo mechanism can increase the pump stroke, delivery and pressure. By this means the fuel flow to the burners during acceleration is kept within a designed proportion to the air mass flow. As the engine speed rises and the compressor delivery pressure increases, this pressure reacts on the diaphragm in the air-fuel ratio control which tends to cause the servo orifice therein to close, so that the pressure in the pump servo system rises and the servo mechanism increases the pump stroke, delivery and pressure. As soon as the compressor delivery pressure reaches the necessary value, the air-fuel ratio control again becomes inoperative and the B.P.C. resumes control.

OVERSPEEDING

Each fuel pump contains its own integral overspeed governor mechanism. When the pump is running, radial ports in the pump rotor create a 'centrifugal' fuel pressure within the pump casing. This 'centrifugal' fuel pressure, which increases with increasing engine speed acts on a diaphragm in the pump and, at a predetermined engine speed, opens an orifice which permits fuel from the pump servo system to escape to the inlet side of the pump. This allows the servo piston in the pump to decrease the pump stroke, delivery and pressure, and so prevents any further increase in engine speed.

STOPPING

When the high pressure fuel cut-off valve is moved to the OFF position by operation of the control in the cockpit, the delivery passage to the burners is closed and all the fuel delivered by the fuel pumps is diverted back to the inlet side of the pumps; this prevents excessive fuel pressure building up between the fuel pumps and the control box whilst the engine is slowing down.

FUEL PUMP ISOLATING CONTROL

Both pumps are normally subject to the same degree of control and thus equally contribute to the fuel requirements of the engine. In the event of failure of either pump, the B.P.C., the air-fuel ratio control, or the connecting servo pipes, the delivery of the serviceable pump would be related to that of the defective one. Therefore, both pumps would tend to be moved by their servo mechanisms to the zero delivery position. To safeguard against this occurring during take-off, the fuel pump isolating switch must be switched on before take off. This energises the solenoid on the front fuel pump and closes the isolating valve. The switch is returned to the OFF position as soon as the aircraft has attained a safe height.

When both pumps are functioning normally, the non-return valves in the delivery outlet ports are kept open by the fuel flow and both pumps are controlled by the B.P.C., or, during acceleration, by the air-fuel ratio control. Under these conditions, when the isolating valve is closed the front fuel pump servo mechanism is cut off from the B.P.C. and the air-fuel ratio control, and the pump operates, therefore, at maximum delivery, subject to the limit imposed by the relief valve and governor mechanism. The servo mechanism of the rear fuel pump, being still controlled by the B.P.C., or air-fuel ratio control, automatically reduces the delivery of this pump until it is supplying only the difference between the fuel requirements of the engine and the delivery of the front pump. This normally means that the rear pump will be at zero delivery as, other than in exceptional circumstances, one pump alone is capable of supplying the full requirements of the engine.

If failure of the rear fuel pump, the B.P.C., the air-fuel ratio control, or the servo pipes should occur when the isolating valve is in the closed position, the front pump continues to operate at full delivery as described in the preceding paragraph. Failure of the front pump would, however, cause a drop in the pump delivery pressure transmitted to the B.P.C., which will then be isolated from the effect of the rear fuel pump delivery pressure by the non-return valve in the front pump outlet port. Therefore, the servo mechanism in the rear fuel pump will automatically bring that pump to full delivery and ensure the continued delivery of fuel to the burners.

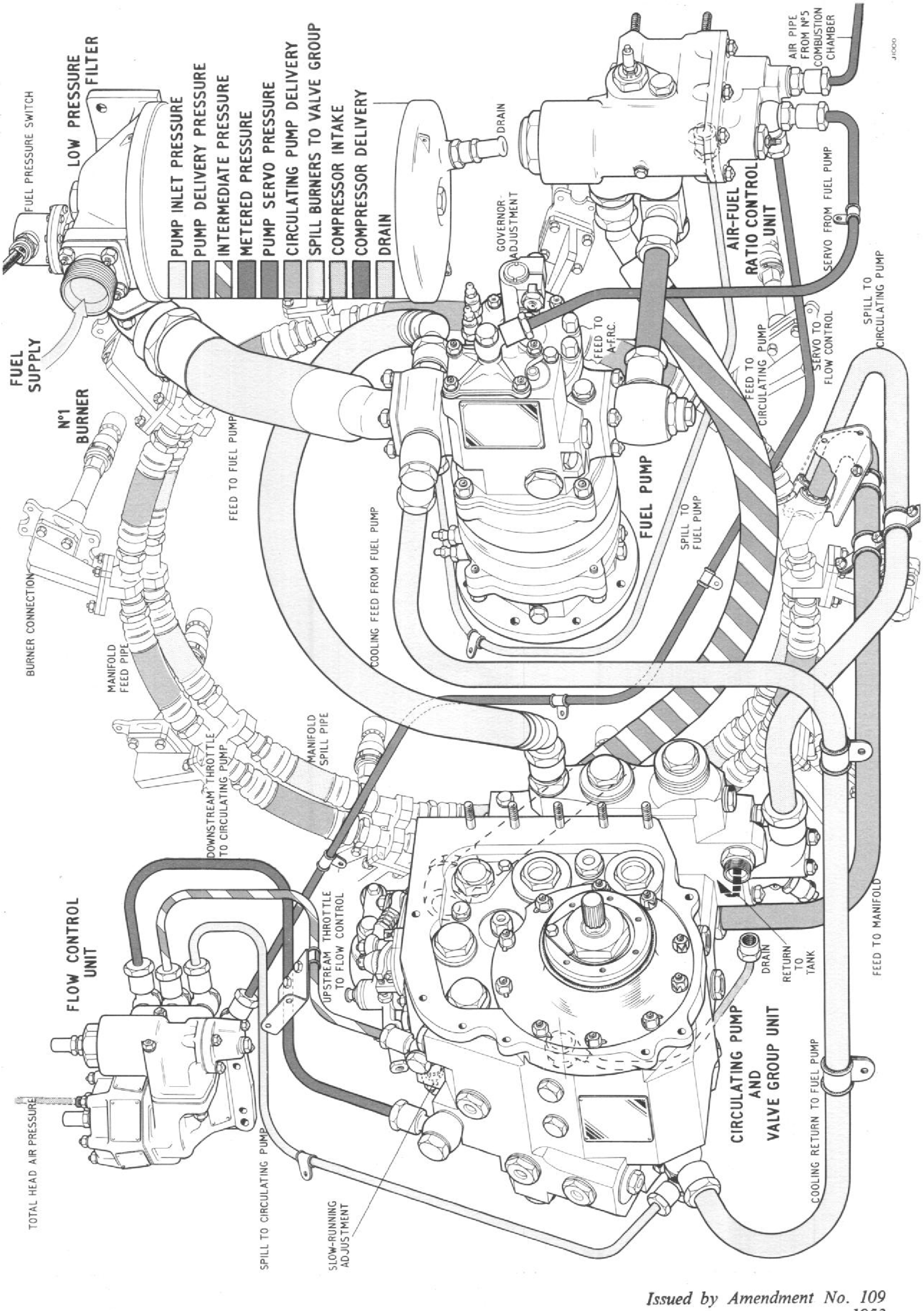

Fig. 5. Pictorial diagram of Dowty spill-flow fuel system.


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