

TURBINE ENGINE FUEL SYSTEM—GENERAL REQUIREMENTS

The fuel system is one of the more complex aspects of the gas turbine engine. The variety of methods used to meet turbine engine fuel requirements makes reciprocating engine carburetion seem a simple study by comparison.

It must be possible to increase or decrease the power at will to obtain the thrust required for any operating condition. In turbine-powered aircraft this control is provided by varying the flow of fuel to the combustion chambers. However, turboprop aircraft also use variable-pitch propellers; thus, the selection of thrust is shared by two controllable variables, fuel flow and propeller blade angle.

The quantity of fuel supplied must be adjusted automatically to correct for changes in ambient temperature or pressure. If the quantity of fuel becomes excessive in relation to mass airflow through the engine, the limiting temperature of the turbine blades can be exceeded, or it will produce compressor stall and a condition referred to as "rich blowout." Rich blowout occurs when the amount of oxygen in the air supply is insufficient to support combustion and when the mixture is cooled below the combustion temperature by the excess fuel. The other extreme, "lean die-out," occurs if the fuel quantity is reduced proportionally below the air quantity.

The fuel system must deliver fuel to the combustion chambers not only in the right quantity, but also in the right condition for satisfactory combustion. The fuel nozzles form part of the fuel system and atomize or vaporize the fuel so that it will ignite and burn efficiently. The fuel system must also supply fuel so that the engine can be easily started on the ground and in the air. This means that the fuel must be injected into the combustion chambers in a combustible condition when the engine is being turned over slowly by the starting system, and that combustion must be sustained while the engine is accelerating to its normal running speed.

Another critical condition to which the fuel system must respond occurs during a slam acceleration. When the engine is accelerated, energy must be furnished to the turbine in excess of that necessary to maintain a constant r.p.m. However, if the fuel flow increases too rapidly, an overrich mixture can be produced, with the possibility of a rich blowout.

Turbojet, turbofan, and turboprop engines are equipped with a fuel control unit which automatically satisfies the requirements of the engine. Although the basic requirements apply generally to all gas turbine engines, the way in which individual fuel controls meet these needs cannot be conveniently generalized. Each fuel control manufacturer has his own peculiar way of meeting the engine demands.

JET FUEL CONTROLS

Fuel controls can be divided into two basic groups: (1) Hydromechanical and (2) electronic. The electronic fuel control is a combination of the two basic groups. Most fuel controls in use today are the completely hydromechanical type.

Regardless of the type, all fuel controls accomplish essentially the same functions, but some sense more engine variables than others. The fuel control senses power lever position, engine r.p.m., either compressor inlet pressure or temperature, and burner pressure or compressor discharge pressure. These variables affect the amount of thrust that an engine will produce for a given fuel flow.

Hydromechanical

Jet fuel controls are extremely complicated devices. The hydromechanical types are composed of speed governors, servo systems, sleeve and pilot valves, feedback or followup devices, and metering systems. In addition, electronic fuel controls incorporate amplifiers, thermocouples, relays, electrical servo systems, switches, and solenoids. Each fuel control must be studied if it is to be understood. However, it is not within the scope of this handbook to discuss each type. Instead, one type of electronic fuel control system and a typical hydromechanical fuel control will be discussed. In the discussion of each, the general purpose and operating principles are stressed. No attempt is made to give detailed operating and maintenance instructions for specific types and makes of equipment. For the specific information needed to inspect or maintain a particular installation or unit, consult the manufacturer's instructions.

Electronic

The principal components of the turboprop temperature datum system (Allison 501-D13 engine) are the temperature datum valve, coordinator, fuel control, speed sensitive control, fuel manifold drain valve, and electronic temperature datum control (see figure 3-43).

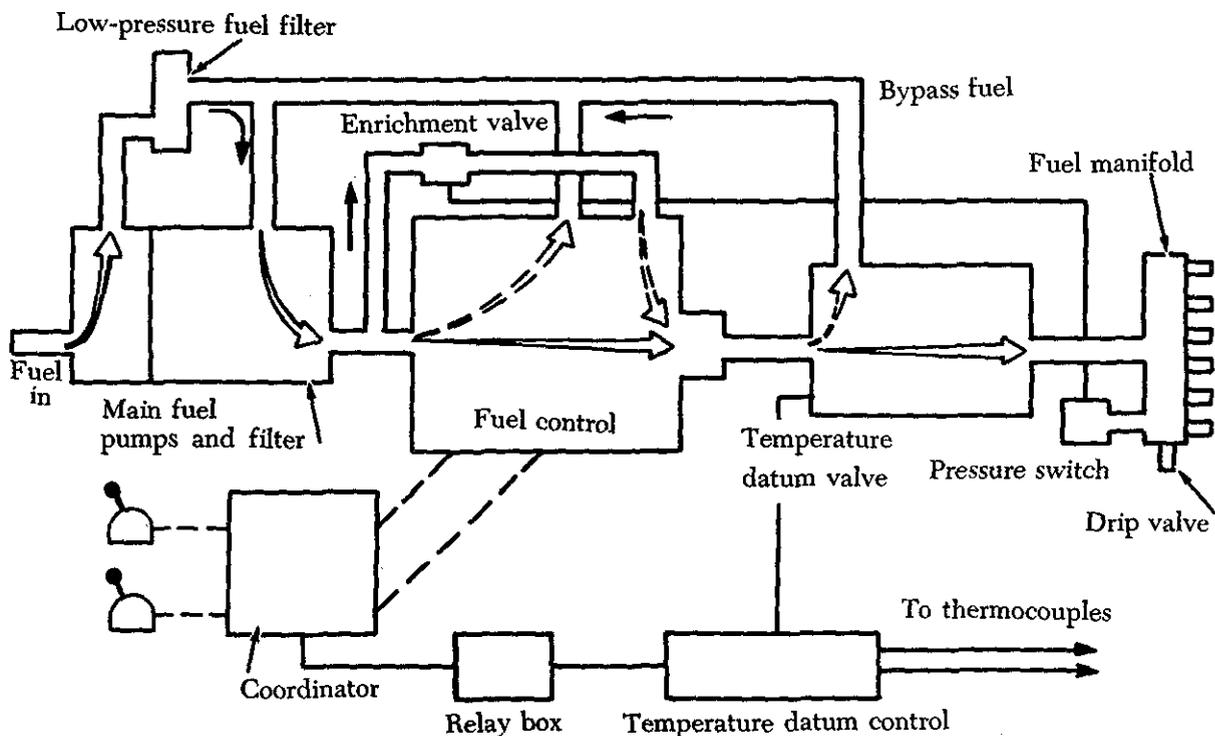


FIGURE 3-43. Allison 501-D13 engine fuel system schematic.

Temperature Datum Valve

The temperature datum valve (figure 3-44) is a fuel flow trimming device in the engine fuel system between the main fuel control and the engine fuel manifold. The datum valve, operating in conjunction with an associated electronic temperature datum control, trims metered fuel supplied from the main fuel control to maintain a preselected turbine inlet temperature.

The valve consists of a venturi, a regulator valve, a metering valve and sleeve assembly, and a pressurizing valve. The datum valve features a variable-take stop screw, actuated by a solenoid valve and a drive piston. This limits the total amount that engine fuel flow can be reduced.

The regulator valve maintains a pressure head

across the metering valve orifice proportional to the amount of fuel being supplied to the datum valve.

The metering valve is positioned in its sleeve and orifice by the datum valve motor in response to signals from the associated electronic control. Motor rotation is applied through reduction gearing to the metering valve drive pinion. The metering valve determines the percentage of fuel to be trimmed from the metered engine fuel supply and bypassed to the engine pumps.

The pressurizing valve is located immediately ahead of the datum valve fuel outlet. The valve is spring loaded to maintain a back pressure on the fuel system. The low-pressure side of the pressurizing valve is vented, through a damping bleed, to bypass pressure and the boost pump outlet. The

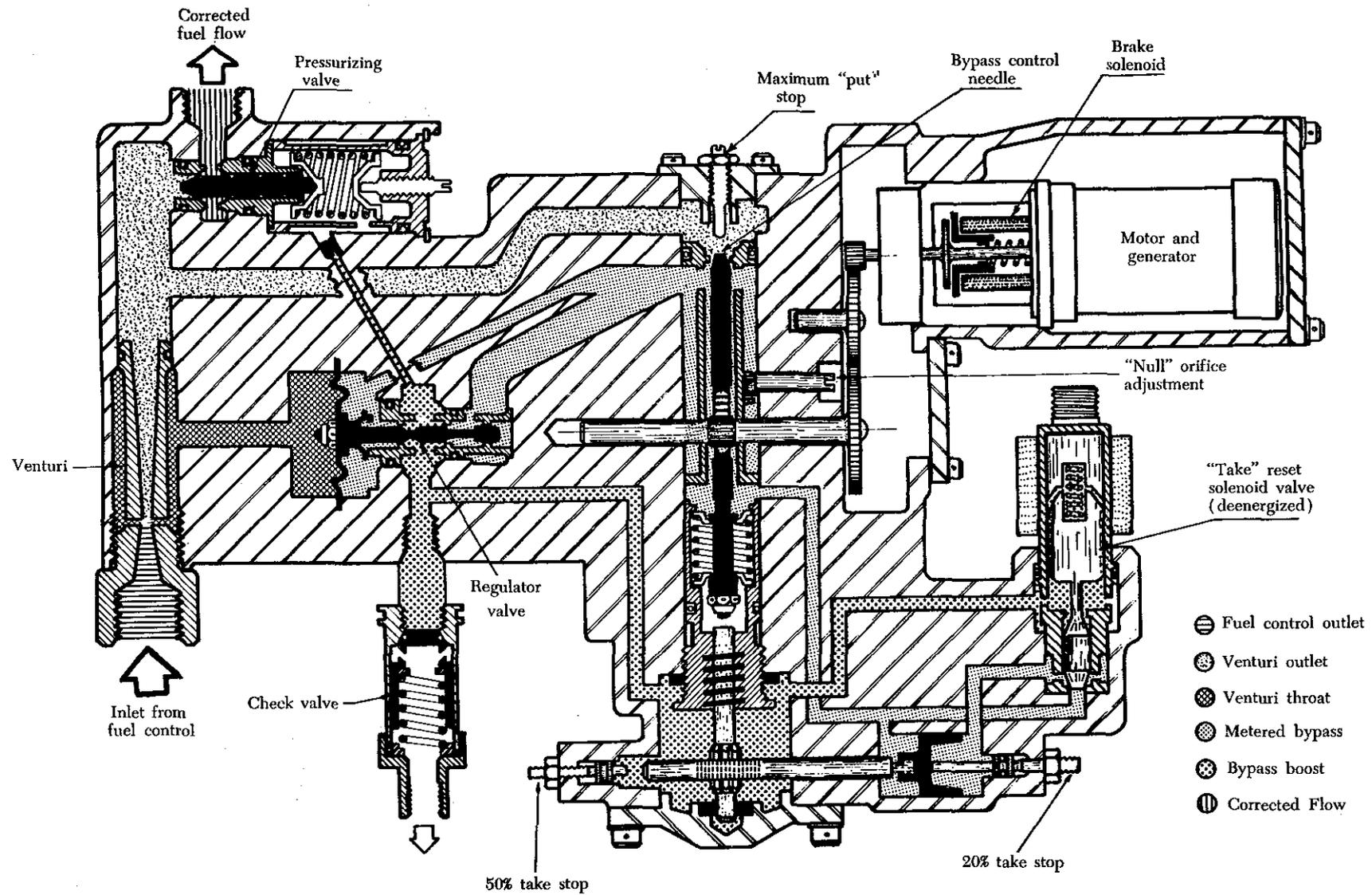


FIGURE 3-44. Temperature datum valve schematic.

damping bleed minimizes effects of fuel pressure surges on pressurizing valve operation.

The variable-take stop screw permits reduction in nominal fuel flow to the engine. The stop is positioned by a drive piston. A two-position solenoid valve directs fluid pressure to the drive piston, to establish the take position of the stop screw.

Venturi and Regulator Valve

Metered fuel under main fuel control outlet pressure enters the datum valve through a venturi. Fuel pressure at the venturi throat is sampled to provide a pressure signal inversely proportional to the amount of fuel entering the datum valve.

Fuel under venturi throat pressure is applied to one side of the regulator valve diaphragm to provide a valve-positioning force inversely proportional to fuel flow through the inlet venturi.

Fuel from the venturi outlet is channeled directly to the pressurizing valve at the datum outlet. The metering valve trims fuel in excess of engine requirements from this fuel flow and directs this excess fuel to the regulator valve. Fuel under venturi outlet pressure flows past the metering valve and through the metering valve orifice to the regulator valve. This fuel is bypassed through the opened valve to the bypass outlet and engine pump inlets. Simultaneously, metered bypass pressure is reduced until it becomes equal to venturi throat pressure on the opposite side of the diaphragm.

When metered bypass pressure equals venturi throat pressure on the opposite side of the regulator valve diaphragm, a regulated orifice bypassing excess engine fuel is established by the regulator valve. Simultaneously, the proper pressure drop for trimming from the venturi throat fuel supply is established across the metering valve orifice. At this balanced condition, the pressure rise from the inlet venturi throat to the venturi exit equals the pressure drop across the metering valve orifice.

When the metering valve is at the "null" position, approximately 20% of the total metered fuel supplied the datum valve is returned to the engine pumps.

Metering Valve

The metering valve is repositioned in its orifice from the "null" position to vary the percentage of fuel trimmed from venturi fuel in the datum valve, thus adjusting the amount of fuel delivered to engine burners. The metering valve is driven in either a "put" or "take" direction from the "null" position, according to engine temperature require-

ments. Metering valve positioning signals are supplied from an associated electronic control that senses the engine temperatures.

When the metering valve is driven towards its orifice, it moves in a put direction to reduce flow from the venturi throat to metered bypass. This causes fuel flow to the engine burners to be increased above the nominal 100% supplied when the metering valve is at the "null" position. Simultaneously, metered bypass pressure is reduced, permitting venturi throat pressure to reduce the regulator valve opening through which fuel is bypassed to the engine pumps. Metering valve orifice closing can continue until the metering valve contacts the maximum put stop. The maximum put stop is adjusted during datum valve calibration.

When the metering valve is driven away from its orifice, it moves in a take direction to increase the flow from the venturi throat to metered bypass. This causes fuel flow to engine burners to be reduced below that normally supplied when the metering valve is at the "null" position. Simultaneously, metered bypass pressure is increased to move the regulator valve diaphragm against venturi throat pressure, thus increasing the regulator valve opening through which fuel is bypassed to the engine pumps. Metering valve orifice opening can continue until the metering valve contacts the variable take stop. The variable take stop permits take action by the datum valve. Engine fuel flow can be reduced, providing maximum engine temperature protection during starting. When engine speed reaches and exceeds a preselected value, the solenoid valve on the datum valve is de-energized. Solenoid valve action repositions the variable take stop. Fuel flow can then be reduced sufficiently to reduce any normal over-temperature conditions during engine operation.

Motor Operation

The metering valve is positioned in its orifice by a two-phase motor within the datum valve. Motor operating voltage is supplied from the electronic control operating in association with the datum valve. The phase of voltage supplied to the motor determines the direction of motor rotation and subsequent metering valve movement. Voltage phase, in turn, is determined by the type of temperature correction required, i.e., if engine fuel flow should be increased to increase temperature, or reduced to lower temperature. Motor rotation is transmitted through reduction gears to the metering valve drive

gear on one end of the pinion shaft. The opposite end of the pinion shaft is welded to a tube carrying the metering valve drive pinion. This type of pinion shaft construction provides a torsion shaft that reduces shock on the reduction gear train and motor if the metering valve is driven against either stop.

Generator Operation

The datum valve motor has a generator coupled on the motor shaft. While the motor is driving the metering valve to change valve position, this coupled generator produces an a.c. voltage proportional to motor rotational speed. The a.c. voltage is fed back to the associated electronic control.

The phase of this a.c. voltage is determined by the direction of motor-generator rotation. Magnitude of the a.c. voltage is proportional to rotational speed. Thus, the feedback voltage provides a rate signal telling the electronic control the rate at which the metering valve is moving.

Within the electronic control, this voltage damps, or reduces, the temperature error signal that initiated motor rotation. The rate of error signal reduction is proportional to the rate at which the motor-generator is rotating. Error signal reduction causes a corresponding reduction of variable phase voltage supplied to the datum valve motor.

The error signal damping approximates dashpot action in achieving datum valve stability by reducing inertia force without loss of torque under stall conditions. Thus, as turbine inlet temperature approaches a corrected value, voltage to the motor is reduced and the motor stalls. When the motor stalls, the metering valve has been properly repositioned to provide a temperature-corrected fuel flow.

Motor Brake

A solenoid-operated brake is incorporated on the motor output shaft between the motor and the reduction gearbox. The brake is disengaged when the solenoid is energized, and engaged when the solenoid is de-energized. Brake operating voltage is controlled by engine, aircraft, and electronic control circuitry.

When the brake solenoid is de-energized and the brake engaged, spring loading holds the brake shoe against a disk on the power transmission shaft through the brake. This action prevents the motor from rotating even though variable-phase voltage is supplied to the motor.

When the solenoid is energized and the brake released, the brake armature, on which the brake

shoe is located, is lifted against spring force into the core of the solenoid. This releases the power transmission shaft and permits motor rotation to be applied to the reduction gearbox.

COORDINATOR

The coordinator bolts to the rear face of the fuel control and houses the power lever shaft, mechanical discriminator, manual fuel cutoff shaft, switches and actuating cams, temperature selector potentiometer, potentiometer drive gears, and the necessary electrical wiring.

The unit coordinates the propeller, electronic temperature datum control, and fuel control. It receives signals through linkage from the cockpit power lever and the cockpit emergency handle and transmits these signals to the fuel control and propeller regulator through a system of levers and links.

The potentiometer in the coordinator is driven from the power lever shaft through a gear set. Above a certain nominal coordinator position, the potentiometer schedules the turbine inlet temperature by sending an electrical signal for the desired temperature to the electronic temperature datum control.

The switch in the coordinator is actuated by a cam on the power lever shaft to transfer the function of the temperature datum control from temperature limiting to temperature controlling at a certain nominal coordinator position.

FUEL CONTROL

The fuel control is mounted on the accessories drive housing and is mechanically linked to the coordinator. The fuel control is designed to perform the following functions:

- (1) Provide a means of varying fuel flow to permit a selection of power that is coordinated with propeller blade angle and engine speed.
- (2) Regulate the rate of fuel metering during acceleration to prevent excessive turbine inlet temperature.
- (3) Control the rate of decrease of fuel metering during deceleration to prevent flameout.
- (4) Control engine and propeller speed outside the limits of operation of the propeller governor. This includes reverse thrust, low-speed ground idle, flight idle, and high-speed ground idle.
- (5) Provide a measure of engine protection during overspeed conditions by reducing fuel flow and turbine inlet temperature.

- (6) Provide a starting fuel flow schedule which, in conjunction with the temperature datum valve, avoids over-temperature and compressor surge.
- (7) Compensate for changes in air density caused by variations in compressor inlet air temperature and pressure.
- (8) Provide a means of cutting off fuel flow electrically and manually.

The fuel control senses compressor inlet pressure, compressor inlet temperature, and engine speed. Using these three factors and the setting of the power lever, the fuel control meters the proper amount of fuel throughout the range of engine operation. Pressure and temperature compensating systems are designed to maintain constant turbine inlet temperature as the compressor inlet conditions vary.

The fuel control is scheduled richer than the nominal engine requirements to accommodate the temperature datum valve which bypasses part of the control output when in the "null" position. This excess flow to the temperature datum valve gives it the capacity to add as well as subtract fuel to maintain the temperature scheduled by the coordinator potentiometer and the temperature datum control.

The control includes a cutoff valve for stopping fuel flow to the engine. The cutoff valve, which can be manually or electrically controlled, is actuated by mechanical linkage and an electrical actuator. The mechanical cutoff is tied in with the emergency control input linkage. Both must be in the "open" position to permit fuel flow. During an engine start, the motor-operated valve remains closed until the engine reaches a speed where the speed-sensitive control actuates and opens the motor-operated valve, permitting fuel flow to the engine.

SPEED-SENSITIVE CONTROL

The speed-sensitive control (figure 3-45) is mounted on the tachometer pad of the accessories housing. It contains three switches which are actuated at certain speeds by a flyweight system. During a start one switch turns on the fuel and ignition, parallels fuel pump elements, energizes the starting fuel enrichment system when fuel enrichment switch is on, and closes the drip valve; another switch shuts off the ignition, de-energizes the drip valve which is then held closed by fuel pressure, and shifts the fuel pumps from parallel to series operation; and still another switch shifts the temperature datum

control from start limiting and limits the temperature datum valve to a certain reduction of engine fuel flow.

FUEL MANIFOLD DRAIN VALVE

The fuel output from the temperature datum valve is connected to the fuel manifold. The manifold consists of sections of flexible steel braided hose which connect at the bottom of the engine to a drain valve. These sections connect directly to the fuel nozzles.

A spring-loaded, solenoid-operated drain valve is located at the bottom of the fuel manifold. It is designed to drain the manifold when the fuel pressure drops below a certain amount while the engine is being stopped to prevent fuel from dripping into the combustion chambers.

During the starting cycle, the valve is closed by energizing the solenoid. It is held closed by fuel pressure within the manifold when the engine is running.

SYSTEM OPERATION

The temperature datum control system is essentially a servo system. Thus, system operation is based on any error, or variation from desired engine temperature conditions. The electronic temperature datum control senses any temperature error and supplies an error-correcting signal to the two-phase servomotor in the associated temperature datum valve.

The reference to which engine temperatures are compared is established within the electronic control. This reference is a millivoltage equivalent to engine thermocouple-generated millivoltage for a desired temperature. Any variation between the reference and thermocouple-generated millivolts causes an error-correcting signal to be supplied to the temperature datum valve servomotor.

Three different reference temperature conditions are used during temperature datum control system operation. These conditions are normal limiting, start limiting, and controlling. Temperature value of the controlling reference temperature is scheduled as a function of power lever angle.

The normal limiting reference temperature is available throughout the entire operating range of the engine. It is the maximum safe engine-operating temperature. During limiting operation, engine temperature is prevented from exceeding this value by the temperature datum control system. The normal limiting temperature is effective throughout the power lever travel range below the angle at which

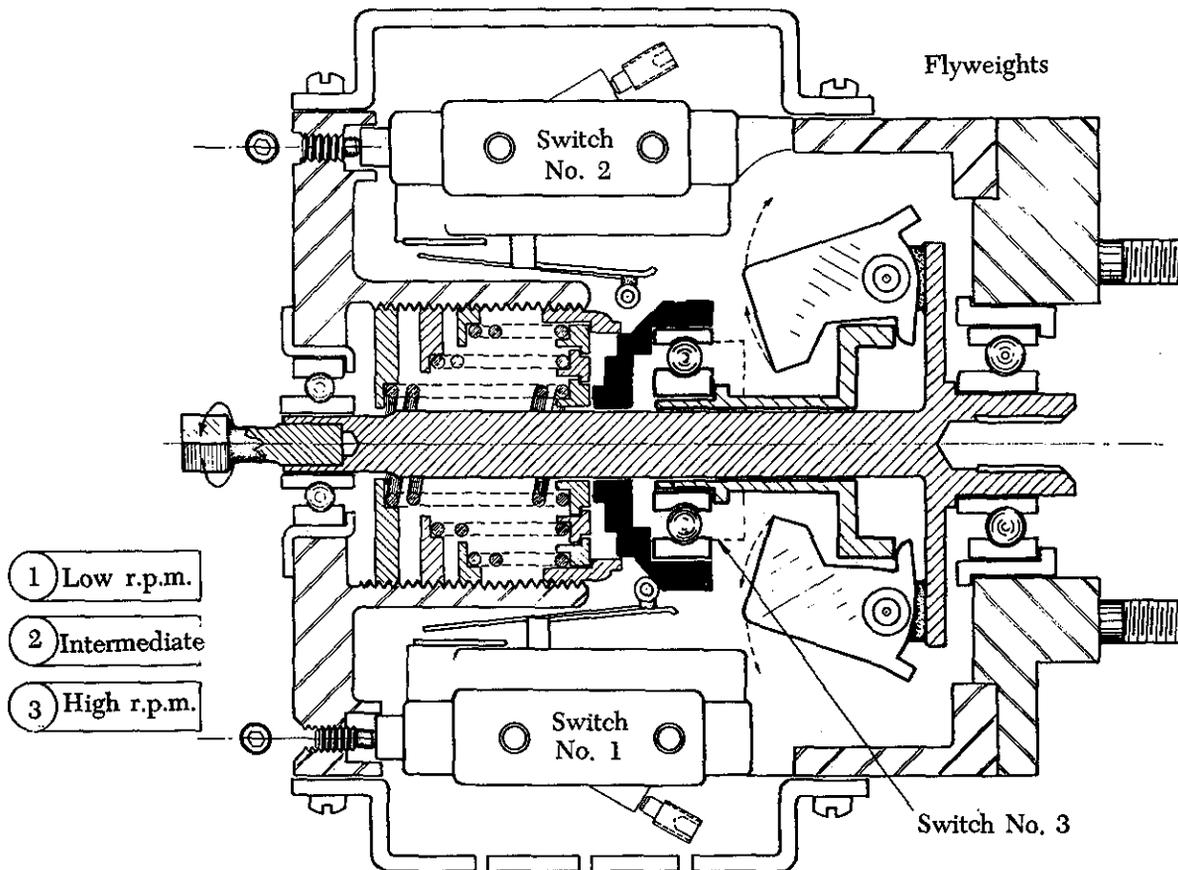


FIGURE 3-45. Speed-sensitive control.

crossover to controlling operation occurs, and whenever the aircraft temperature datum control switch is moved to the "locked" position, as during aircraft landing.

The start limiting temperature is effective only during engine starting and operation up to a pre-selected speed. Temperature value of the start limiting temperature is less than the normal limiting temperature. The start limiting temperature protects the engine from excessive temperature transients during engine starting.

Reference temperature is scheduled according to power lever angle in the controlling range of engine operation. Temperature value of the reference is scheduled according to desired engine power.

Either temperature limiting or temperature controlling operation is selected by engine and aircraft switches. The engine switches include a speed-sensitive switch and two power-lever-actuated switches in the engine coordinator. The aircraft switch is the pilot-actuated temperature datum control switch.

Engine switches select which limiting temperature value, normal or start, is effective, and switch the temperature datum control system from limiting to controlling operations.

The speed-sensitive switch selects the desired reference for start limiting operation during initial engine starting. The electronic control remains in the start limiting condition until the speed switch opens. When the speed switch opens, the electronic control is switched to normal limiting temperature operation.

The power-lever-actuated switches establish the power lever angle at which crossover from temperature limiting to temperature controlling operation occurs. At power lever angles less than the crossover point, these switches hold the temperature datum control system in limiting operation. After the crossover angle is reached and passed, these switches re-align the temperature datum control system for temperature controlling operation.

The temperature datum control switch provides for manually selecting a desired temperature datum

control system operating mode. When the temperature datum control switch is in the "locked" position, switching from start to normal limiting operation is effected. When the switch is in the "automatic" position, other conditions occur. The temperature datum control system is switched from controlling to limiting operation whenever the temperature datum control switch is moved to the "locked" position.

HYDROMECHANICAL FUEL CONTROL

The JFC (jet fuel control) schedules the quantity of fuel flow required by a turbojet engine. It provides fuel to the combustion chambers at the pressure and volume required to maintain the engine performance scheduled by power lever position. At the same time it limits fuel flow to maintain operating conditions within safe limits.

The JFC12-11 is an all-mechanical fuel control for the Pratt and Whitney turbojet engine. A schematic operating diagram is shown in figure 3-46.

The purpose of the JFC is to meter fuel to the engine to control r.p.m., prevent overheating and surging, and prevent either rich blowout or lean die-out. This is accomplished by supplying signals from engine r.p.m. (N_2) and burner pressure (P_B). The control then schedules fuel flow (W_f) in lbs./hr. to keep the engine running at the desired setting selected by the power lever and within the engine's operating limits.

Two control levers are provided. The power lever controls engine r.p.m. during all forward and reverse thrust operations. A fuel shutoff lever controls engine starting and shutdown by operating the fuel shutoff, windmill bypass feature, and manifold dump valve signal in the proper sequence.

When the power lever is moved to a selected setting, a certain percentage of available thrust is expected from the engine. Thrust results from the acceleration imparted to the mass of air flowing through the engine. Consequently, any variation in air density through changes in pressure or temperature will affect the thrust due to the change in mass airflow. In the range of engine operation from sea level to altitude, atmospheric pressure variations have a greater effect on air density than the changes in ambient temperature. For any steady state condition of engine operation (mass airflow through the engine constant), a definite amount of fuel is needed, and, therefore, the fuel/air ratio (W_f/P_B) will be constant.

A measure of airflow through the engine is given

by burner pressure. Burner pressure alone is a rough measure of airflow and is used to schedule fuel flow during deceleration to prevent lean die-out. During acceleration, fuel flow is scheduled as a function of r.p.m. and burner pressure to prevent rich blowout, surging, or overheating.

The equilibrium curve of an engine, illustrated in figure 3-47, indicates the job the fuel control must do. Fuel flow during starting is limited by the acceleration line and will drop off to the value required for idle operation as the engine r.p.m. increases to idle. This decrease in the fuel flow occurs along a droop line, which is a governing characteristic built into the fuel control for better control of r.p.m. without surging or hunting. The power lever position varies compression of a speeder spring to select the proper droop line setting.

To accelerate from idle to maximum, the power lever is moved forward. Fuel flow increases rapidly at first and then more gradually according to a schedule for acceleration that will avoid surge conditions and overheating the engine. Just before maximum is reached, fuel flow begins to decrease along a droop line so that the r.p.m. will level off at maximum without hunting.

For deceleration from maximum, the fuel flow drops abruptly to the minimum flow schedule and follows that back to idle. Although the minimum fuel flow ratio is shown as a straight line in figure 3-47, fuel flow varies with burner pressure and, thus, is higher at maximum r.p.m. than at idle r.p.m.

FUEL CONTROL DESCRIPTION

Metering System Operation

Fuel is supplied to the inlet of the fuel control unit from the aircraft tanks through a series of boost pumps. The fuel is passed through the screens and filters of the aircraft fuel system before it is directed to the fuel control. Fuel entering the inlet port of the fuel control unit passes through a coarse 200-mesh screen filter (see figure 3-48). If the filter becomes clogged, it will allow unfiltered fuel to bypass because it is spring loaded and will be lifted off its seat if the differential pressure across the screen becomes greater than 25 to 30 p.s.i. Some of the fuel that has passed through the coarse filter is directed to the fine filter. All high-pressure fuel used in the valves and servos of the fuel control passes through the fine filter. This filter is a 35-micron screen and is also spring loaded. If it becomes clogged, unfiltered fuel will bypass the filter when the differential pressure is 10 to 17 p.s.i.

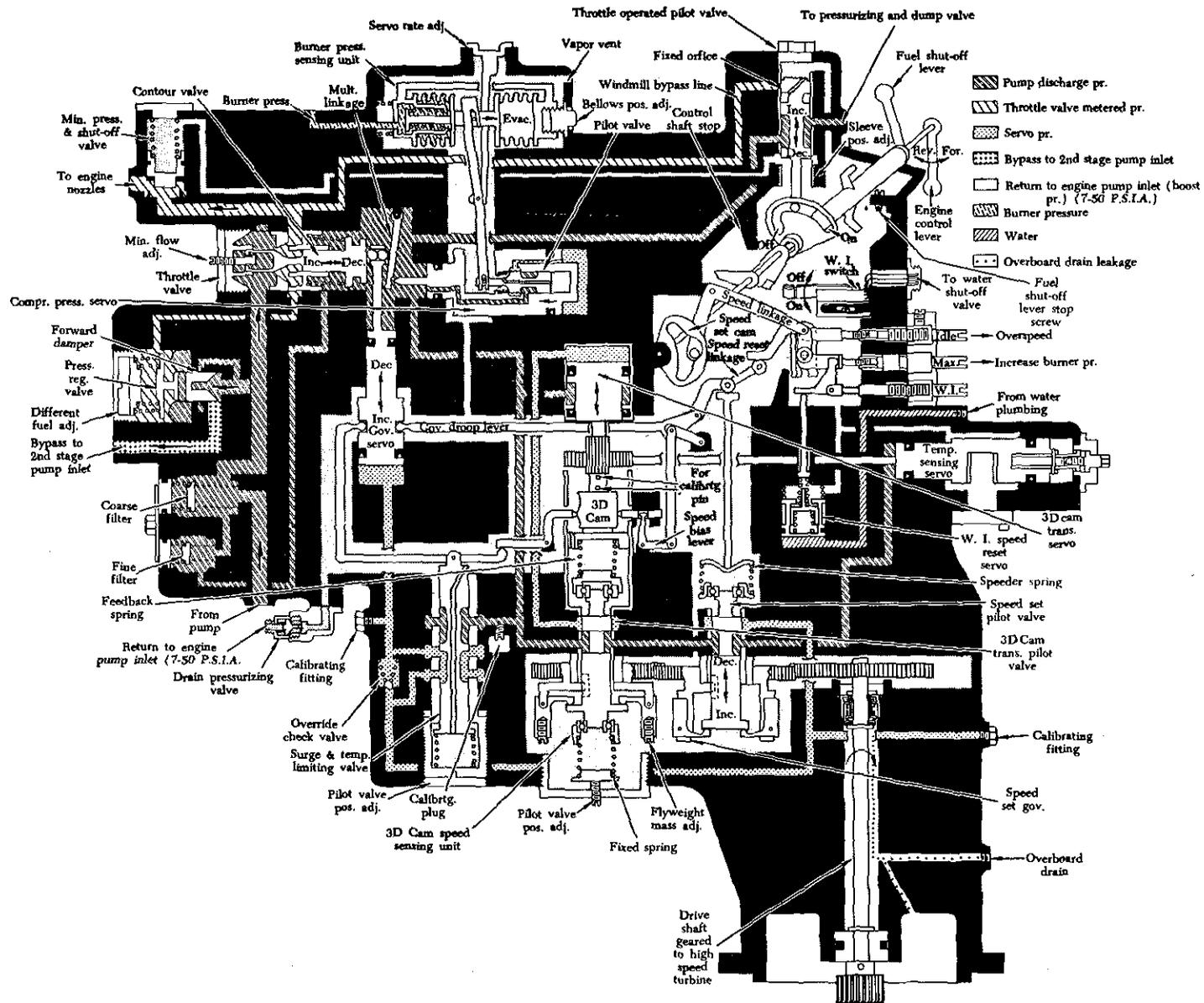


FIGURE 3-46. JFC12-11 schematic operating diagram.

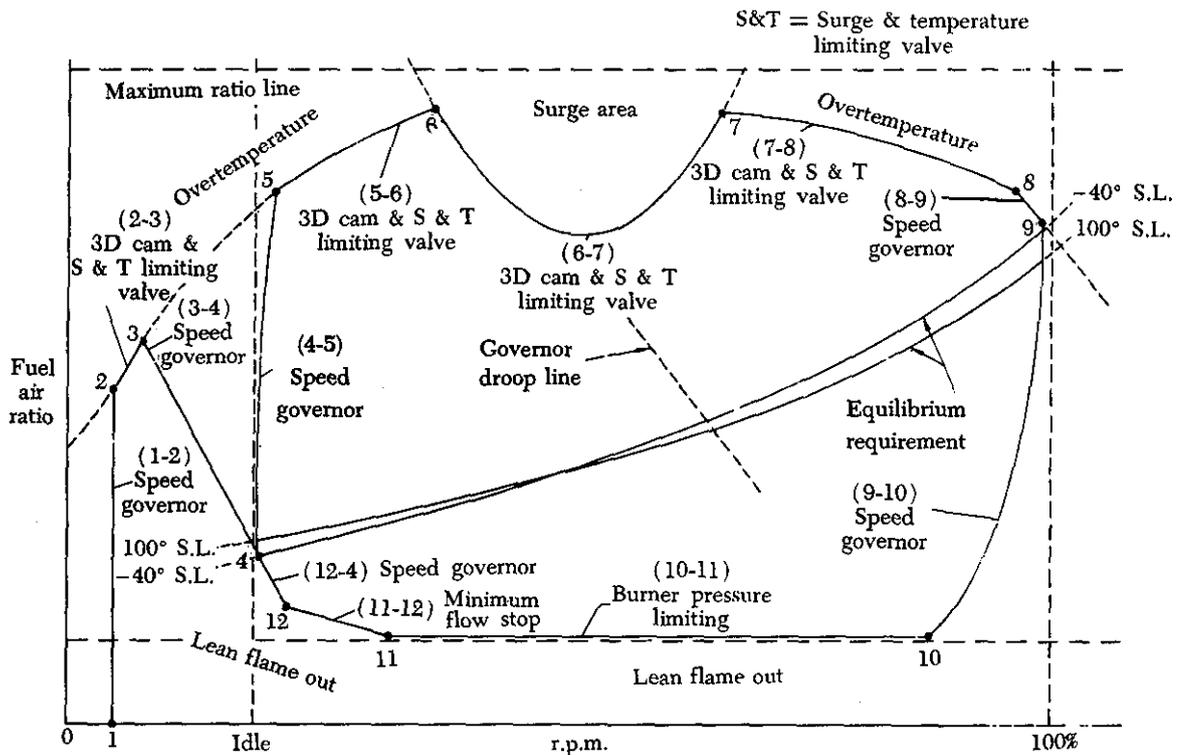


FIGURE 3-47. Engine operating conditions (equilibrium curve).

Pressure-Regulating Valve

The pressure-regulating valve diaphragm, shown in figure 3-48, is exposed on one side to pump output pressure and on the other side to the combined effect of throttle valve discharge pressure and a spring force preset to maintain the desired pressure drop across the throttle valve. The spring force is adjustable to allow compensation for use of various fuels. With a constant pressure drop across the throttle valve, flow through the throttle valve will be proportional to its orifice area. Any excess fuel above that required to maintain the set pressure differential is bypassed back to the interstage section of the supply pump. The damping orifice in the passage to the pressure-regulating valve minimizes valve chatter.

Throttle Valve

The throttle valve, figure 3-48, is the main metering valve. It consists of a spring-loaded, cylindrical contoured valve which moves within a sharp-edged orifice. This valve controls the main fuel flow from the engine pump to the fuel nozzles. Since a constant pressure differential is maintained across the throttle valve by the pressure regulating valve, each position of the valve represents a definite fuel flow regardless of throttle valve discharge pressure. A

positive minimum flow adjustment is provided on the throttle valve. The valve is spring loaded to its minimum flow position, but never closes completely. The throttle valve spring moves the valve in the decrease-flow direction, and the combined action of the compressor pressure servo and the governor servo moves the valve in the increase-flow direction. The throttle valve outlet directs the metered fuel to the minimum pressure and shutoff valve. The metered fuel also acts on the spring side of the pressure-regulating valve and is delivered to the throttle-operated pilot valve, where it can bypass to drain when the fuel shutoff lever is placed in the "off" position.

Shutoff and Minimum Pressure Valve

The shutoff and minimum pressure valve is a shuttle-type valve acted upon on one side by throttle valve discharge pressure and on the other by a combination of spring force and either high-pressure fuel during shutoff or JFC body drain pressure during normal operation. The spring also holds the valve closed following engine shutdown. During normal operation, when the spring side of the valve is backed up by body drain pressure, if the throttle valve discharge pressure falls below a preset value, the valve will move toward the "closed" position,

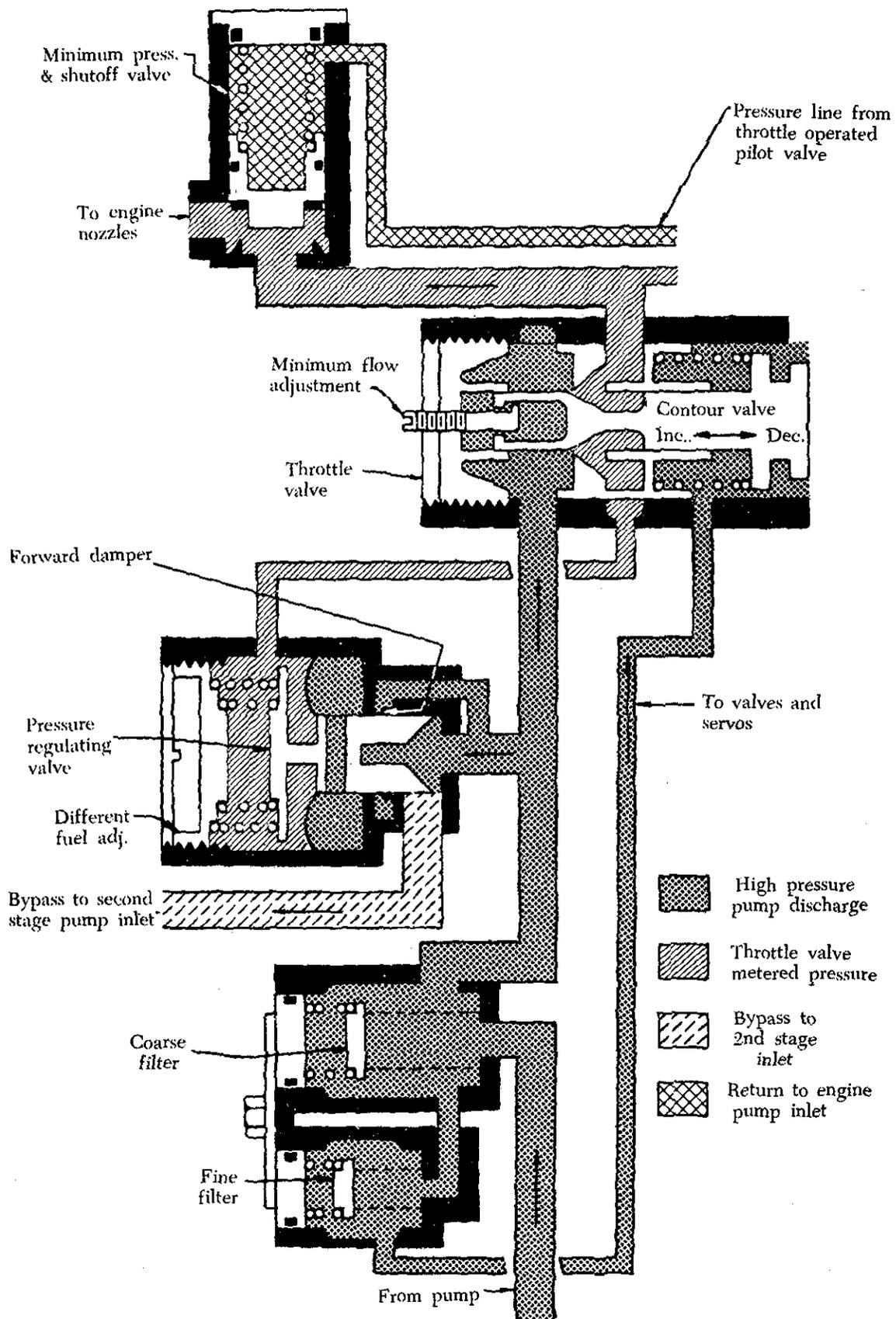


FIGURE 3-48. Metering system.

restricting flow from the fuel control until the throttle valve discharge pressure increases again to the preset value. This ensures that sufficient pressure is always available for operation of the servos and valves. The metered fuel flows from the minimum pressure and shutoff valve to the fuel outlet of the control and then to the manifold drain valve and the engine manifolds.

Throttle-Operated Pilot Valve

The pressure signal which actuates the shutoff and minimum pressure valve originates from the throttle-operated pilot valve (figure 3-49). In addition to this pressure signal, the throttle-operated pilot valve performs two other functions. The porting of this valve determines the sequence of these functions. This pilot valve is positioned by a cam mounted on a shaft rotated by the shutoff lever in the cockpit.

In the operating or "on" position, the pilot valve directs high-pressure fuel to the engine-pressurizing and dump valve, where it works against a spring to hold the dump valve closed. As previously mentioned, the spring side of the minimum pressure and shutoff valve is exposed to the body cavity drain, allowing the downstream pressure from the throttle valve to force the valve open. The third function of the throttle-operated pilot valve is to block the windmill bypass line.

When the fuel shutoff lever is moved to the "off" position, the pilot valve is repositioned by the cam. First, the windmill bypass line is opened. The pilot-operated throttle valve also directs high-pressure fuel to the spring side of the minimum pressure and shutoff valve, ensuring closing of the valve. The valve now allows the pressure line to the engine pressurizing and dump valve to drain into the body cavity, permitting the spring to open the valve, and any fuel in the engine manifold is drained.

During shutdown in flight, the engine windmills, and the engine-driven fuel pump continues to operate. Since the outflow from the fuel control is shut off, the pump output must be relieved. This may be done by the pump relief valve (1,000 p.s.i.) or by the fuel control. To avoid the conditions of high pump load and high temperature which accompany relief valve operation, the bypass function is performed within the fuel control at a minimum pressure.

The windmill bypass line brings metered fuel pressure (metered by the throttle valve) to a port in the throttle-operated pilot valve housing. If the pilot valve is positioned to shut off fuel flow to the

engine, metered fuel pressure is bled through the bypass line and pilot valve housing to the low pressure of the body cavity. Decreased metered fuel pressure also reduces the force on the spring side of the pressure regulator diaphragm. This allows the regulator valve to open more fully and bypass the pump output.

If a shutdown is made during a high-pressure operating condition (maximum power lever position), an orifice in the windmill bypass line is so designed that pressure in the body cavity cannot increase to a value that could damage the fuel control.

Computing System Operation

By positioning the main metering valve, the computing system selects a fuel flow for each condition of engine operation. This fuel flow is established by the position of the contour valve. Figure 3-50 is a schematic representation of the computing system. The units that comprise this system and their operation are described in the following paragraphs.

Burner Pressure Servo Assembly

The burner pressure servo assembly controls the position of the compressor pressure servo. The position of the compressor pressure servo provides the input to the multiplying linkage which acts upon the throttle valve. The burner pressure servo assembly consists of two bellows, one of which is vented to burner pressure and the other is evacuated. The two bellows are installed, diametrically opposed, on a rigid frame with their movable ends connected to a common link.

If burner pressure increases during operation, the left bellows extends. This motion is transmitted through a lever connected to the bellows link and moves the pilot valve in the compressor pressure servo. Motion of the pilot valve directs high-pressure fuel to the governor servo chamber. The cross-sectional area of the governor servo valve is larger at the servo chamber end than at the opposite end, which is acted upon by high-pressure fuel. Therefore, the increased pressure in the servo chamber causes the governor servo valve to move, thus changing the input to the multiplying linkage of the throttle valve. Assuming that the governor servo is stationary, an increase in burner pressure will cause an increase in fuel flow. As the compressor pressure servo moves, the fuel passage opened by the movement of the pilot valve is gradually closed so that the servo, by following the pilot valve, assumes a new equilibrium position.

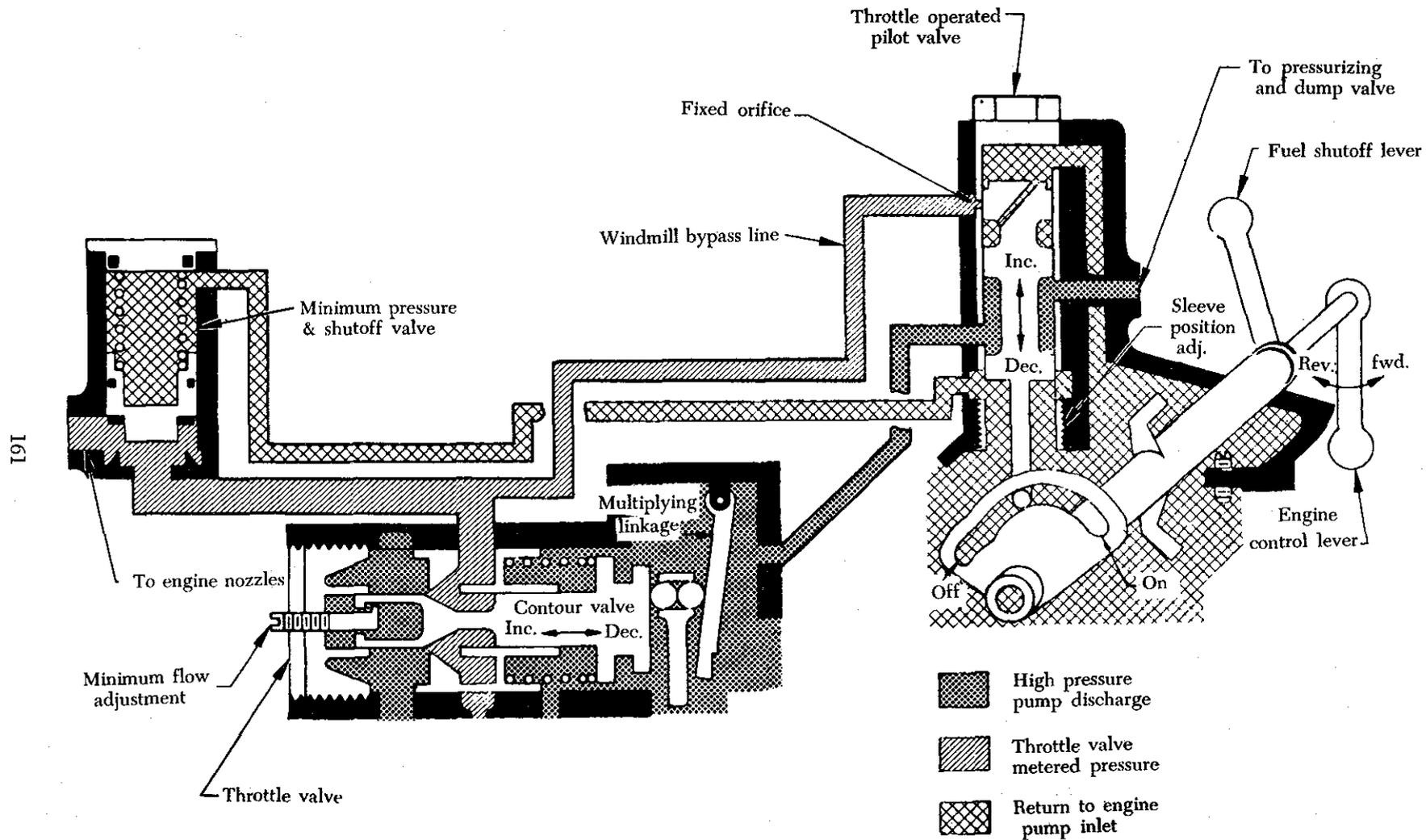


FIGURE 3-49. Throttle-operated pilot valve.

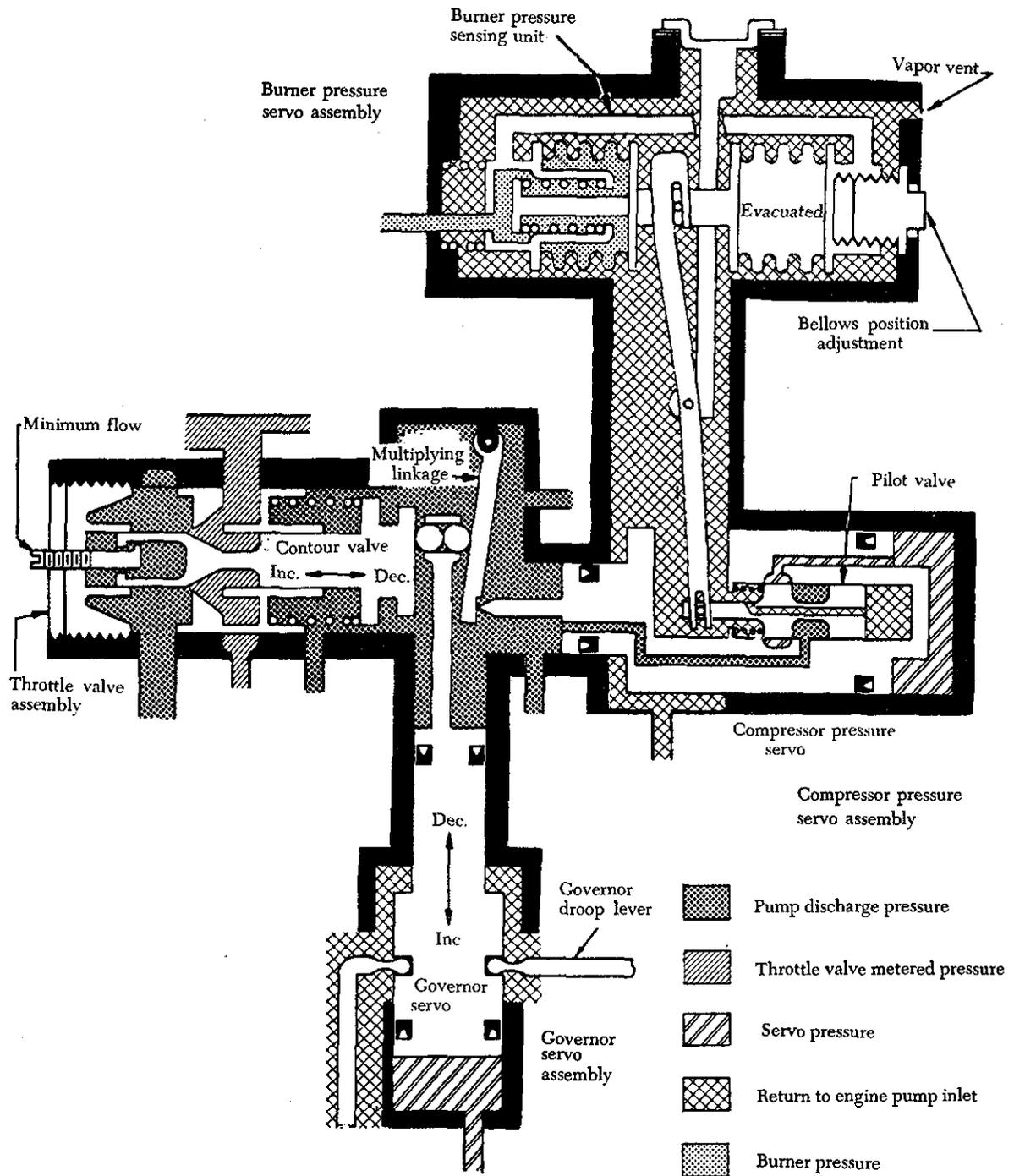


FIGURE 3-50. Computing system.

If burner pressure decreases, the bellows contracts, moving the pilot valve so that the governor servo chamber is drained to body pressure. High fuel pressure acting on the small area end of the governor valve servo moves the governor servo, thus changing the input to the multiplying linkage of the throttle valve. Assuming that the governor

servo is stationary, a decrease in burner pressure causes a decrease in fuel flow. The compressor pressure servo valve moves to a new equilibrium position as it again follows the pilot valve.

Governor Servo

The governor servo controls fuel flow as a func-

tion of set speed and engine speed, taking into account the effects of CIT (compressor inlet temperature) and engine operating limitations. The governor servo (figure 3-50) acts upon the throttle valve through the multiplying linkage and in conjunction with the compressor pressure servo. For a discussion of the governor servo operation, it will be assumed that the compressor pressure servo valve is stationary.

The governor servo is a shuttle valve with high-pressure fuel acting on a small area at one end and servo pressure from the pilot valve of the speed governor acting on the other end. If, because of a change in servo pressure, the force exerted by this pressure on the large area end of the governor servo is greater than that exerted by the high pressure on the opposite end, the governor servo moves and, through the multiplying linkage, allows the throttle valve to travel in the decrease-flow direction. Conversely, if the force exerted by the servo pressure is less than that exerted by the high pressure, the governor servo moves and drives the throttle valve in the increase-flow direction. The flow of servo fuel to the governor servo is controlled by (1) the speed governor and (2) the surge and temperature limiting pilot valve.

FUEL SCHEDULING SYSTEM

Speed-Set Governor

The speed-set governor (figure 3-51) controls the position of the governor servo. It is a centrifugal, permanent-droop type governor driven by the engine high-speed rotor (N_2) through a gear train. As engine speed increases, the flyweights tend to move outward, lifting the speed set pilot valve. Conversely, when engine speed decreases, the flyweights move inward and the pilot valve is lowered. The power lever in the cockpit positions the speed-setting cam in the fuel control unit to manipulate a system of levers and thus control the compression of the speeder spring. The speeder spring exerts force on the speed-set pilot valve. The condition of "on-speed" indicates the speeder spring force and the flyweight force are equal.

When the r.p.m. exceeds that for which the power lever is set, the flyweights of the speed-set governor move out, lifting the pilot valve. This meters high-pressure fuel to the governor servo through the override check valve. The servo moves upward, causing a decrease in fuel/air ratio. As the governor servo position is altered, the droop lever moves about a pivot point. Movement of the

droop lever alters the speeder spring compression. The speeder spring force on the pilot valve and the r.p.m. centrifugal force on the flyweights balance, resulting in an "on-speed" equilibrium condition.

Conversely, if the high compressor r.p.m. is lower than the power lever setting demands, the flyweights move in, allowing governor servo pressure to drain to boost pressure. This permits the high-pressure fuel on the opposite end of the servo to shift it downward to increase fuel/air ratio. Repositioning the droop lever alters speeder spring force. The flyweight and speeder spring forces will again balance to an "on-speed" condition.

Operating conditions are not constant; thus, the position of the equilibrium curve may change. This curve is illustrated in figure 3-47. Speed-set governor droop characteristics are utilized to provide new on-speed settings. For example, dense air may load the engine compressor, causing speed to decrease. In this case the flyweight force is less than the speeder spring force, and the pilot valve moves down to increase fuel flow. This corrects the drop in r.p.m. The droop lever decreases speeder spring force on the pilot valve. The droop lever sets the slightly lower final r.p.m. as the system comes "on-speed" for the new equilibrium condition.

The operating conditions may cause the engine speed to increase. Fuel flow is decreased to correct the condition, but the droop lever resets the speed-set governor to an "on-speed" condition at slightly higher r.p.m. The droop characteristics indirectly control maximum turbine temperature by limiting turbine r.p.m.

Starting

During start, a proper amount of fuel must be supplied to ensure rapid starts while maintaining turbine inlet temperatures within specified limits.

When starting an engine, the fuel shutoff lever is not moved until approximately 12 to 16% r.p.m. is indicated on the tachometer. At this speed the shutoff lever is moved to the "on" position. The light-up speed has now been attained, but cranking must continue until the engine can accelerate beyond its self-sustaining speed. When the shutoff lever has been advanced to the "on" position, acceleration proceeds as follows: (1) the power lever calls for maximum increase of fuel flow, and (2) the speed-set cam positions the speed linkage so that the speed-set governor speeder spring is compressed beyond the force required to counterbalance the forces of the centrifugal flyweights.

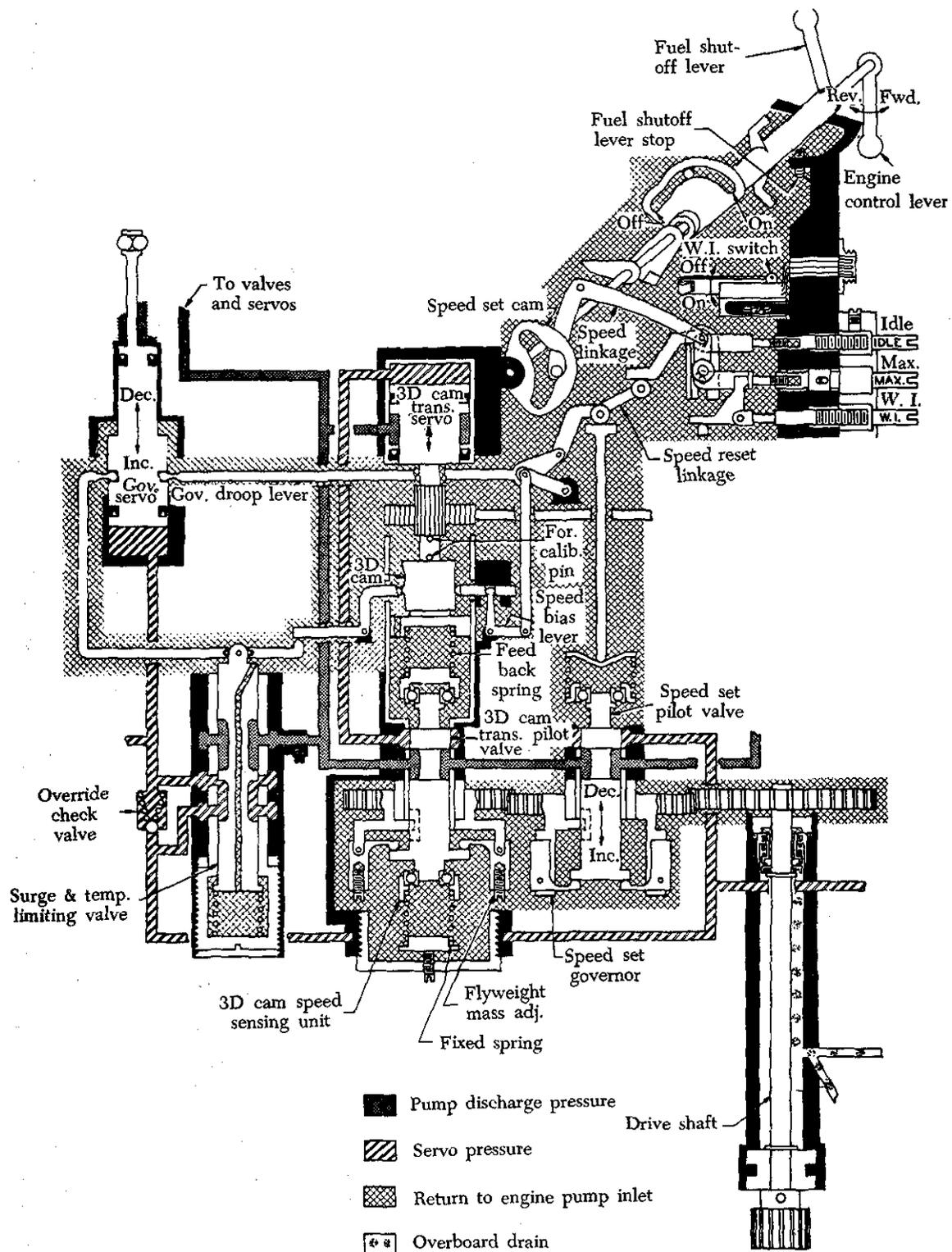


FIGURE 3-51. Scheduling system.

At start, the flyweights are turning so slowly that the speeder spring force is greater than the flyweight force, and the speed-setting pilot valve is moved down. This exposes the governor servo pressure line to body drain, and the high pressure at the opposite end of the governor servo drives the servo downward to increase fuel flow. This action is represented by points 1 and 2 in figure 3-47.

Surge and Temperature Limiting Valve

This limiting valve (figure 3-51) overrides the action of the speed governor during rapid accelerations to ensure that surge and temperature operational limits of the engine are not exceeded. The position of the limiting pilot valve is controlled by a linkage. The linkage is actuated by the governor servo position and by engine r.p.m. and compressor inlet temperature.

During steady state operation, a passage through the limiting valve is open between the speed governor and the governor servo, allowing a flow of fuel so that the governor servo will be controlled by the speed governor. During rapid accelerations, however, the limiting pilot valve is moved to restrict or block this passage. Pressure is thus metered across the land of the limiting pilot valve, which will move the governor servo to control the fuel flow to the engine at the maximum safe rate.

As the engine reaches the set r.p.m., the speed governor will direct high-pressure fuel to the governor servo to decrease fuel flow. Since the passage through the limiting pilot valve may still be blocked, an override check valve is provided so that the high-pressure fuel can bypass the blocked passage, reach the governor servo, and decrease the fuel flow to avoid speed overshoot. As the governor servo moves to decrease fuel flow, the limiting pilot valve will be returned to the "steady state" operating position.

Three-Dimensional Cam and Translating Unit

The three-dimensional cam operates through linkages to provide a speed surge limit input to the surge and temperature limiting valve and a force input to the speed governor speeder spring. The 3-D cam is actually two cams on a common shaft. Two separate contours (cams) have been machined on its surface. One contoured surface biases the surge and temperature limiting valve position. The other cam surface is ineffective in the JFC12-11 fuel control. The 3-D cam and translating unit are shown in figure 3-52.

Engine r.p.m. is sensed by a centrifugal flyweight

speed-sensing unit driven by the engine through a gear train. A pilot valve is balanced between a fixed spring and flyweight forces. The flyweights do not move the 3-D cam directly. The cam is positioned by the 3-D cam translational servo connected to the cam. The cam servo has high-pressure fuel (7-50 p.s.i.) acting on its small area at all times. The large area of the 3-D cam servo either is acted upon by high-pressure fuel from the engine fuel pump or is vented to the fuel control body drain.

As engine speed increases, the flyweights move outward. The force of the flyweights plus the feedback spring moves the pilot valve downward, compressing the fixed spring. The pilot valve opens the port from the large area of the 3-D cam servo. When the servo pressure in the chamber is directed to the body drain cavity, the high-pressure fuel acting on the small area lifts the cam servo piston and cam upward. As the cam translates (moves vertically), the force on the feedback spring is decreased. This increases the net force opposing the flyweight force. The result is that the pilot valve re-centers itself and the cam servo stops moving.

When engine speed is reduced, the fixed spring forces the flyweights inward, allowing the fixed spring to displace the pilot valve upward. This directs high-pressure fuel to the cam servo chamber. The servo and the cam move downward. As the cam translates, the increased force on the feedback spring re-centers the pilot valve.

Engine Overspeed Protection

If the r.p.m. signal to the fuel control is disrupted, the speed-set governor will react as though an engine underspeed condition exists. The speeder spring forces the pilot valve down and dumps governor servo pressure. The governor servo calls for more fuel, which tends to overspeed the engine.

The 3-D cam translating pilot valve is also positioned by an r.p.m. signal. With the r.p.m. signal disrupted, the fixed spring pushes the pilot valve upward. High-pressure fuel is directed through the pilot valve and forces the cam servo and 3-D cam downward to the zero % r.p.m. position. The cam contour at zero % r.p.m. provides a known, constant fuel flow. This action prevents the scheduling of excess fuel and protects the engine against overspeed if the fuel control drive fails.

Engine Acceleration

The acceleration schedule is shown as points 4, 5,

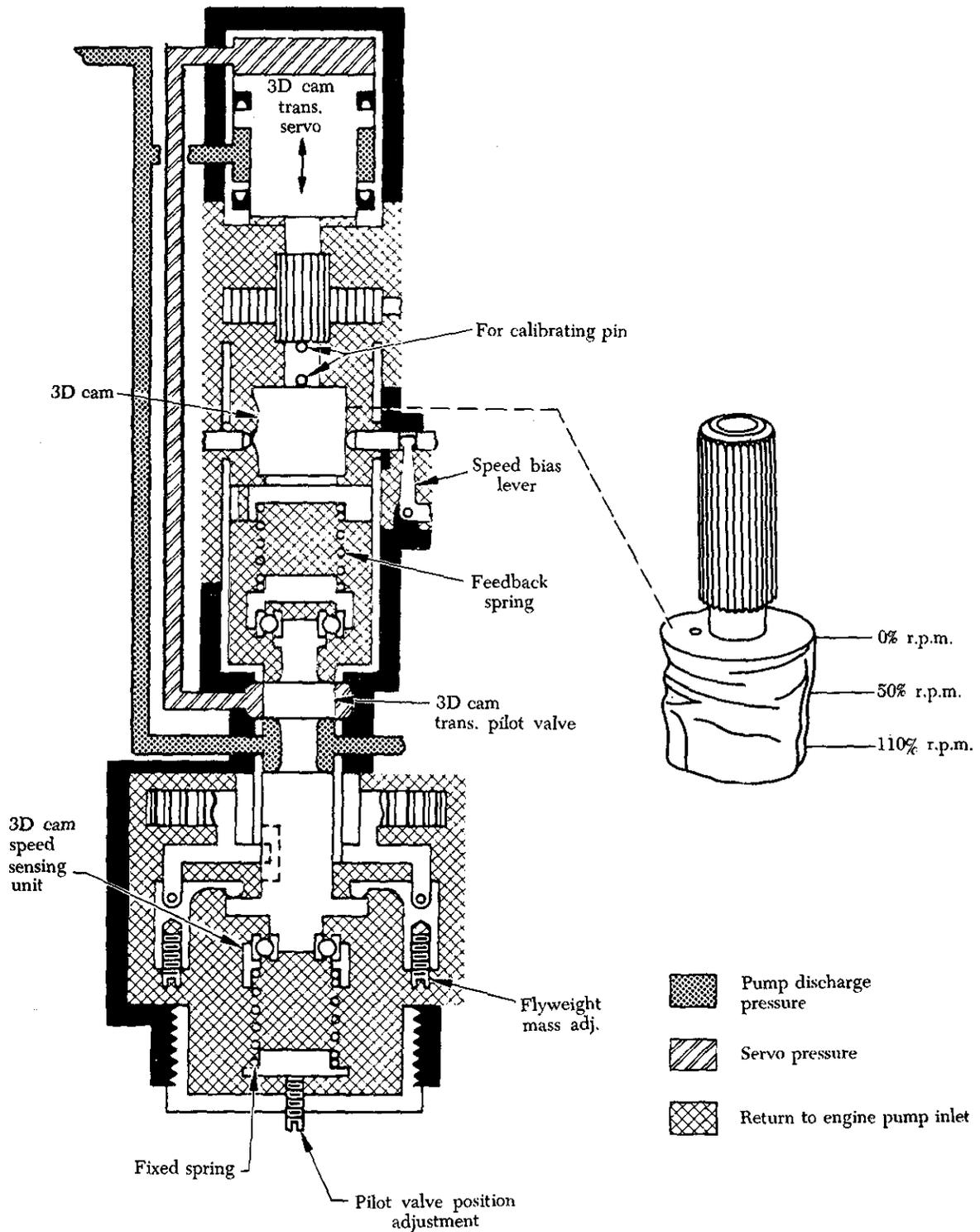


FIGURE 3-52. Three-dimensional cam and translating unit.

6, 7, 8, and 9 in figure 3-47. Governor servo positioning is similar to that of the starting schedule.

At "idle," the engine is operating at the left end of the equilibrium curve at point 4. To initiate

acceleration, the power lever in the cockpit is moved toward "takeoff," causing an immediate jump in fuel flow.

As the power lever is moved, the speed-set cam

increases the load on the speeder spring. This increase of speeder spring force causes the speed governor pilot valve to move down, allowing servo pressure to drain from the large area end of the governor servo. High pressure at the opposite end forces the governor servo down to increase fuel/air ratio. This action is represented between points 4 and 5.

Fuel scheduling during acceleration from points 5 and 8 is similar to the operation discussed under starting with the power lever set at idle.

Beyond point 8, governor-droop characteristics reduce the fuel/air ratio as compressor speed increases until equilibrium operation is achieved at point 9.

Engine Deceleration

When deceleration is desired, the power lever in the cockpit is retarded, reducing the speeder spring compression. The speed governor pilot valve moves up (from centrifugal forces), and high-pressure fuel is directed to the underside of the governor servo through the override check valve. This moves the governor servo up to minimum ratio, represented as point 10 in figure 3-47. The fuel flow from point 10 - 11 is determined by the position of the compressor pressure servo. The burner pressure schedules the fuel flow as the engine drops in r.p.m. This continues until the throttle valve itself comes against its minimum flow stop, where it can close no further. This is point 11 - 12 on the curve. The minimum flow limit represents the minimum self-sustaining ability of the engine. The minimum fuel/air ratio is scheduled to avoid the lean flameout areas.

WATER INJECTION RE-SET SYSTEM

On warm days, thrust is reduced because of the decrease in air density. This can be compensated for by injecting water at the compressor inlet or diffuser case. This lowers the air temperature and increases air density. A microswitch in the fuel control is actuated by the control shaft when the power lever is moved toward the maximum power position.

A water injection speed re-set servo, figure 3-53, re-sets the speed adjustment to a higher value during water injection. Without this adjustment, the fuel control would decrease r.p.m. so that no additional thrust would be realized during water injection.

The servo is a shuttle valve which is acted upon by water pressure during water injection. Movement of the servo displaces a lever on the cam-oper-

ated lever linkage to the speed governor speeder spring, increasing the force of the speeder spring and increasing the set speed. Because the resulting r.p.m. will usually be higher while water is flowing, increased thrust during water injection is ensured.

If the water injection system is not armed in the cockpit or if there is no water available, nothing happens when the water injection switch in the fuel control unit is actuated. When water is available, a portion of it is directed to the water injection speed re-set servo.

JET FUEL CONTROL MAINTENANCE

The repair of the jet fuel control is very limited. The only repairs permitted in the field are the replacement of the control and adjustments afterwards. These adjustments are limited to the idle r.p.m. and the maximum speed adjustment, commonly called trimming the engine. Both adjustments are made in the normal range of operation.

During engine trimming the fuel control is checked for idle r.p.m., maximum r.p.m., acceleration, and deceleration. The procedures used to check the fuel control vary depending on the aircraft and engine installation.

The engine is trimmed in accordance with the procedures in the maintenance or overhaul manual for a particular engine. In general, the procedure consists of obtaining the ambient air temperature and the field barometric pressure (not sea level) immediately preceding the trimming of the engine. Care must be taken to obtain a true temperature reading comparable to that of the air which will enter the engine. Using these readings, the desired turbine discharge pressure or EPR (engine pressure ratio) reading is computed from charts published in the maintenance manual.

The engine is operated at full throttle (or at the fuel control trim stop) for a sufficient period of time to ensure that it has completely stabilized. Five minutes is the usual recommended stabilization period. A check should be made to ensure that the compressor air-bleed valves have fully closed and that all accessory drive air bleed for which the trim curve has not been corrected (such as a cabin air-conditioning unit) has been turned off.

When the engine has stabilized, a comparison is made of the observed and the computed turbine discharge pressure (or EPR) to determine the approximate amount of trimming required. If a trim is necessary, the engine fuel control is then adjusted to obtain the target turbine discharge pressure or EPR on the gage. Immediately following

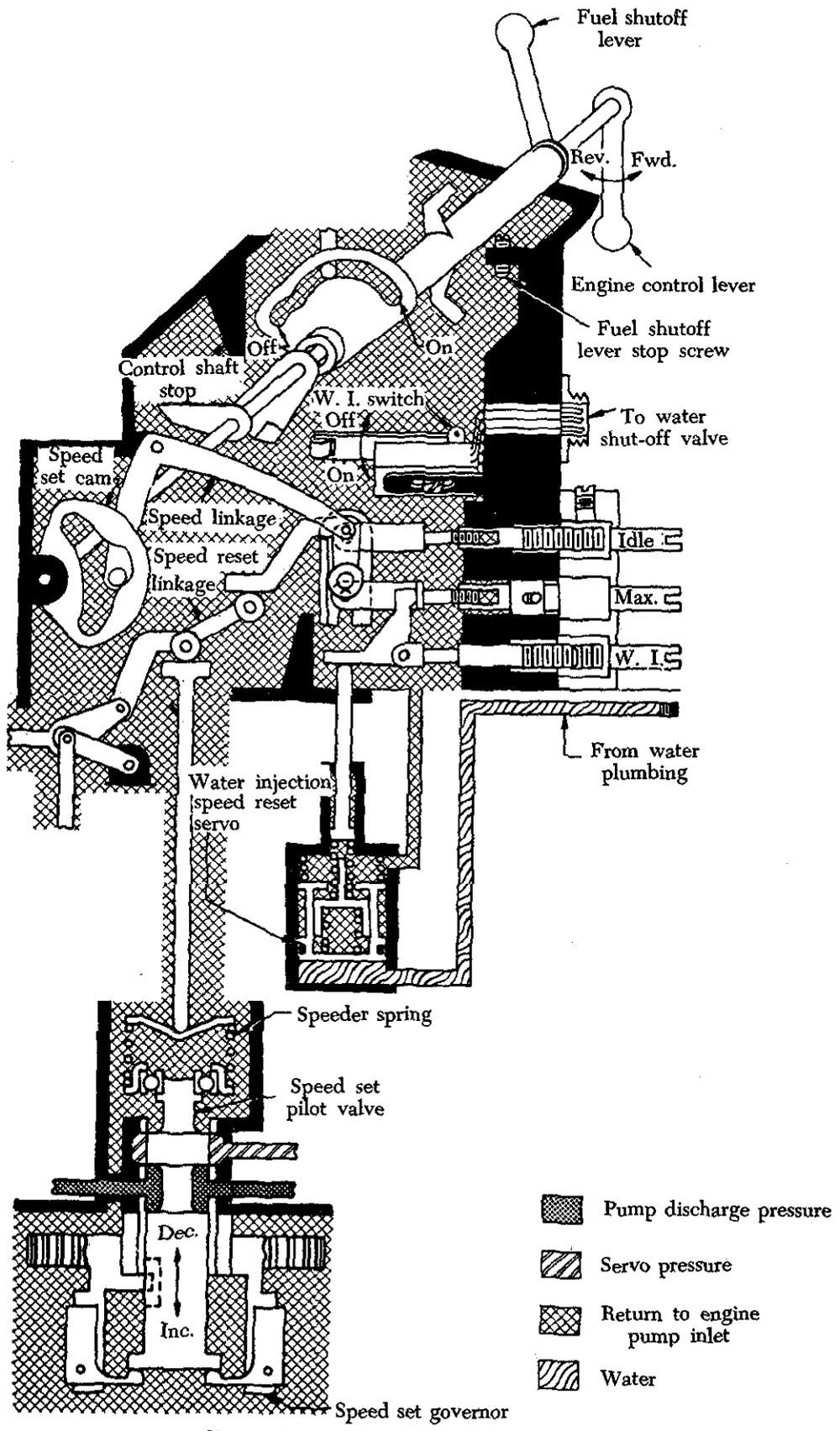


FIGURE 3-53. Water injection re-set system.

the fuel control adjustment, the tachometer reading is observed and recorded. Fuel flow and exhaust gas temperature readings should also be taken.

On Pratt and Whitney engines, using a dual-spool compressor, the observed N_2 tachometer reading is next corrected for speed bias by means of temperature/r.p.m. curve. The observed tachometer reading is divided by the percent trim speed obtained from the curve. The result is the new engine trim speed in percent, corrected to standard day ($59^\circ F.$ or $15^\circ C.$) temperature. The new trim speed in r.p.m. may be calculated when the r.p.m. at which the tachometer reads 100% is known. This value may be obtained from the appropriate engine manual. If all these procedures have been performed satisfactorily, the engine has been properly trimmed.

Engine trimming should always be carried out under precisely controlled conditions with the aircraft headed into the wind. Precise control is necessary to ensure maintenance of a minimum thrust level upon which the aircraft performance is based. In addition, precise control of engine trimming contributes to better engine life in terms of both maximum time between overhaul and minimum out-of-commission time due to engine maintenance requirements. Engines should never be trimmed if icing conditions exist.

ENGINE FUEL SYSTEM COMPONENTS

Main Fuel Pumps (Engine-Driven)

Main fuel pumps deliver a continuous supply of fuel at the proper pressure and at all times during operation of the aircraft engine. The engine-driven

fuel pumps must be capable of delivering the maximum needed flow at high pressure to obtain satisfactory nozzle spray and accurate fuel regulation.

Fuel pumps for turbojet engines are generally positive displacement gear or piston types. The term "positive displacement" means that the gear or piston will supply a fixed quantity of fuel to the engine for every revolution of the pump gears or for each stroke of the piston.

These fuel pumps may be divided into two distinct system categories: (1) Constant displacement and (2) variable displacement. Their use depends on the system used to regulate the flow of fuel to the fuel controls. This may be a pressure relief valve (barometric unit) for constant displacement (gear) pumps, or a method for regulating pump output in the variable displacement (piston) pumps.

Constant Displacement Pump

Gear-type pumps have approximately straight line flow characteristics, whereas fuel requirements fluctuate with flight or ambient air conditions. Hence, a pump of adequate capacity at all engine operating conditions will have excess capacity over most of the range of operation. This is the characteristic which requires the use of a pressure relief valve for disposing of excess fuel. A typical constant displacement gear-type pump is illustrated in figure 3-54. The impeller, which is driven at a greater speed than the high-pressure elements, increases the fuel pressure from 15 to 45 p.s.i., depending upon engine speed.

The fuel is discharged from the boost element (impeller) to the two high-pressure gear elements. Each of these elements discharges fuel through a

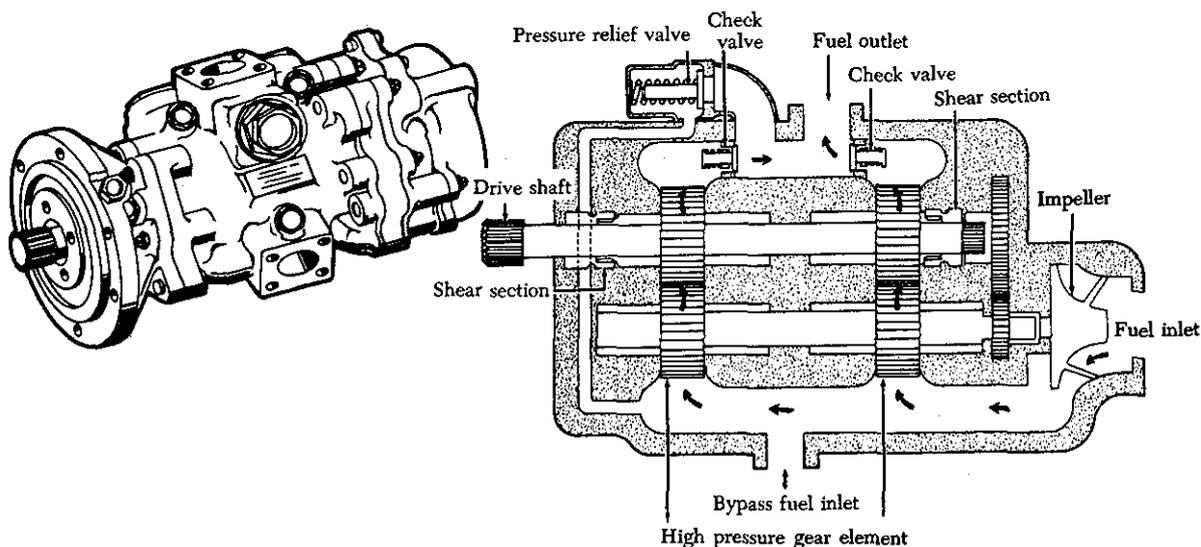


FIGURE 3-54. Engine-driven fuel pump.

check valve to a common discharge port. The high-pressure elements deliver approximately 51 gallons per minute at a discharge pressure of 850 p.s.i.g.

Shear sections are incorporated in the drive systems of each element. Thus, if one element fails, the other element continues to operate. The check valves prevent circulation through the inoperative element. One element can supply enough fuel to maintain moderate aircraft speeds.

A relief valve is incorporated in the discharge port of the pump. This valve opens at approximately 900 p.s.i. and is capable of bypassing the total flow at 960 p.s.i. This allows fuel in excess of that required for engine operation to be recirculated. The bypass fuel is routed to the inlet side of the two high-pressure elements.

Variable Displacement Pump

The variable displacement pump system differs from the constant displacement pump system. Pump displacement is changed to meet varying fuel flow requirements; that is, the amount of fuel discharged from the pump can be made to vary at any one speed. With a pump of variable flow, the applicable fuel control unit can automatically and accurately regulate the pump pressure and delivery to the engine.

Where variable displacement pumps are installed, two similar pumps are provided, connected in parallel. Either pump can carry the load if the other fails during normal parallel operations. At times one pump may be insufficient to meet power requirements. Pump duplication increases safety in operation, especially during takeoffs and landings.

The positive displacement, variable-stroke type pump incorporates a rotor, a piston, a maximum speed governor, and a relief valve mechanism.

Fuel Heater

Gas turbine engine fuel systems are very susceptible to the formation of ice in the fuel filters. When the fuel in the aircraft fuel tanks cools to 32° F., or below, residual water in the fuel tends to freeze when it contacts the filter screen.

A fuel heater operates as a heat exchanger to warm the fuel. The heater can use engine bleed air or engine lubricating oil as a source of heat. The former type is called an air-to-liquid exchanger, and the latter type is known as a liquid-to-liquid exchanger.

The function of a fuel heater is to protect the engine fuel system from ice formation. However, should ice form, the heater can also be used to thaw ice on the fuel screen.

In some installations the fuel filter is fitted with

a pressure-drop warning switch, which illuminates a warning light on the cockpit instrument panel. If ice begins to collect on the filter surface, the pressure across the filter will slowly decrease. When the pressure reaches a predetermined value, the warning light flashes on.

Fuel deicing systems are designed to be used intermittently. The control of the system may be manual, by a switch in the cockpit, or automatic, using a thermostatic sensing element in the fuel heater to open or close the air or oil shutoff valve. A fuel heater that is automatic in operation is illustrated in figure 3-55.

Fuel Filters

A low-pressure filter is installed between the supply tanks and the engine fuel system to protect the engine-driven fuel pump and various control devices. An additional high-pressure fuel filter is installed between the fuel pump and the fuel control to protect the fuel control from contaminants.

The three most common types of filters in use are the micron filter, the wafer screen filter, and the plain screen mesh filter. The individual use of each of these filters is dictated by the filtering treatment required at a particular location.

The micron filter (figure 3-56) has the greatest filtering action of any present-day filter type and, as the name implies, is rated in microns. (A micron is the thousandth part of 1 millimeter.) The porous cellulose material frequently used in construction of the filter cartridges is capable of removing foreign matter measuring from 10 to 25 microns. The minute openings make this type of filter susceptible to clogging; therefore, a bypass valve is a necessary safety factor.

Since the micron filter does such a thorough job of removing foreign matter, it is especially valuable between the fuel tank and engine. The cellulose material also absorbs water, preventing it from passing through the pumps. If water does seep through the filter, which happens occasionally when filter elements become saturated with water, the water can and does quickly damage the working elements of the fuel pump and control units, since these elements depend solely on the fuel for their lubrication. To reduce water damage to pumps and control units, periodic servicing and replacement of filter elements is imperative! Daily draining of fuel tank sumps and low-pressure filters will eliminate much filter trouble and prevent undue maintenance of pumps and fuel control units.

The most widely used filter is the 200-mesh and

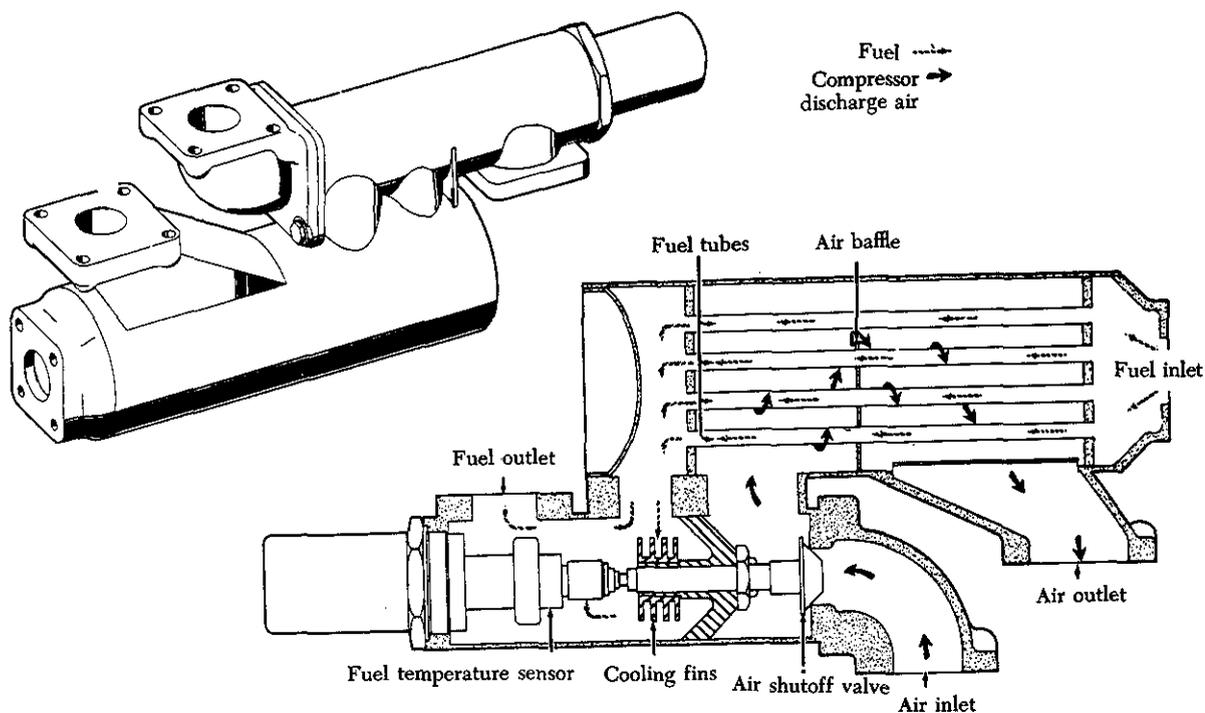


FIGURE 3-55. Fuel heater.

the 35-mesh micron filters. They are used in fuel pumps, fuel controls, and between the fuel pump and fuel control where removal of micronic-size particles is needed. These filters, usually made of fine-mesh steel wire, are a series of layers of wire.

The wafer screen type of filter (figure 3-57) has a replaceable element, which is made of layers of screen disks of bronze, brass, steel, or similar mate-

rial. This type of filter is capable of removing micronic-size particles. It also has the strength to withstand high pressure.

The plain screen mesh filter is the most common type. It has long been used in internal-combustion engines of all types for fuel and oil strainers. In present-day turbojet engines it is used in units where filtering action is not so critical, such as in fuel lines before the high-pressure pump filters. The mesh size of this type of filter varies greatly according to the purpose for which it is used.

Fuel Spray Nozzles and Fuel Manifolds

Although fuel spray nozzles are an integral part of the fuel system, their design is closely related to the type of combustion chamber in which they are installed. The fuel nozzles inject fuel into the combustion area in a highly atomized, precisely patterned spray so that burning is completed evenly and in the shortest possible time and in the smallest possible space. It is very important that the fuel be evenly distributed and well centered in the flame area within the liners. This is to preclude the formation of any hot spots in the combustion chambers and to prevent the flame burning through the liner.

Fuel nozzle types vary considerably between engines, although for the most part fuel is sprayed into the combustion area under pressure through small orifices in the nozzles. The two types of fuel nozzles

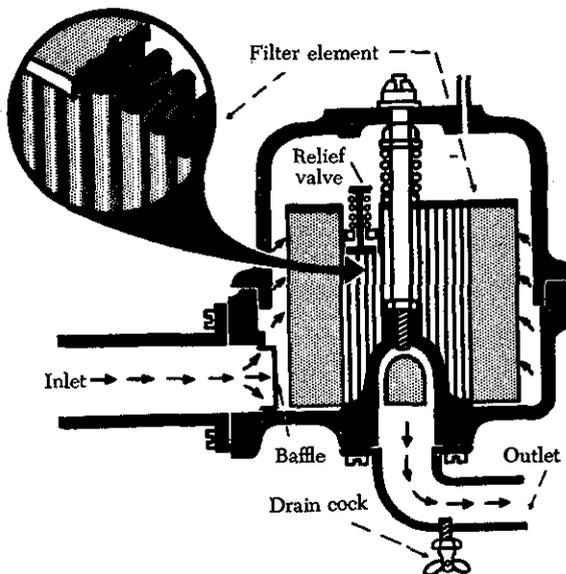


FIGURE 3-56. Aircraft fuel filter.

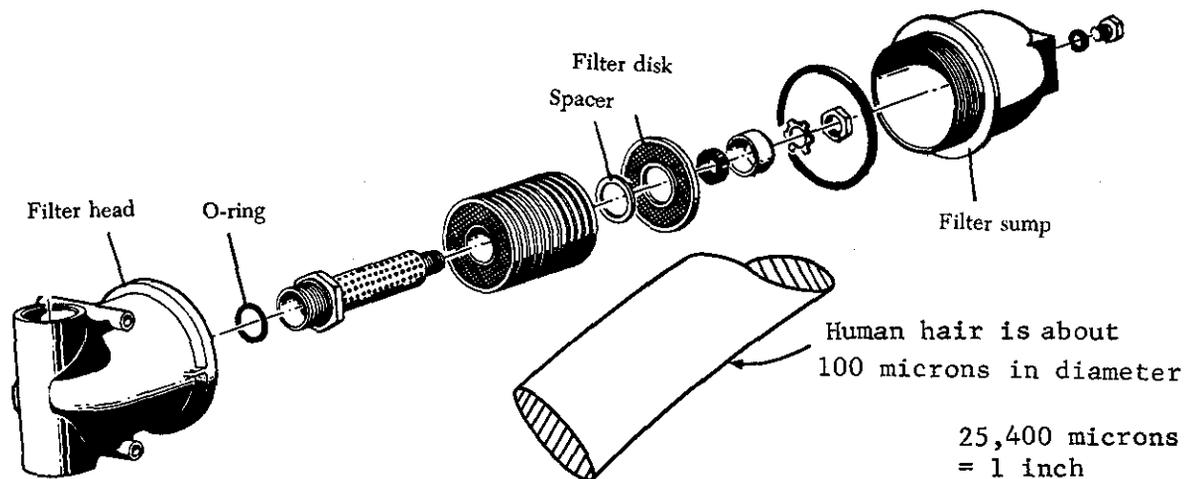


FIGURE 3-57. Wafer screen filter.

generally used are the simplex and the duplex configurations. The duplex nozzle usually requires a dual manifold and a pressurizing valve or flow divider for dividing primary and main fuel flow, but the simplex nozzle requires only a single manifold for proper fuel delivery.

The fuel nozzles can be constructed to be installed in various ways. The two methods used quite frequently are: (1) External mounting wherein a mounting pad is provided for attachment of the nozzles to the case or the inlet air elbow, with the nozzle near the dome; or (2) internal mounting at the liner dome, in which case the chamber cover must be removed for replacement or maintenance of the nozzle.

Simplex Fuel Nozzle

The simplex fuel nozzle was the first type nozzle used in turbojet engines and was replaced in most installations with the duplex nozzle, which gave better atomization at starting and idling speeds. The simplex nozzle (figure 3-58) is still being used to a limited degree. Each of the simplex nozzles consists of a nozzle tip, an insert, and a strainer made up of fine-mesh screen and a support.

Duplex Fuel Nozzle

The duplex fuel nozzle is the nozzle most widely used in present-day gas turbine engines. As mentioned previously, its use requires a flow divider, but at the same time it offers a desirable spray pattern for combustion over a wide range of operating pressures. A nozzle typical of this type is illustrated in figure 3-59.

Flow Divider

A flow divider in each nozzle creates primary and secondary fuel supplies which are discharged through separate, concentric spray tips, thus providing the proper spray angle at all fuel flows. Fuel enters the inlet of the nozzle and passes through a

screen. A drilled passage in the nozzle stem directs the fuel through a second screen and into the primary spin chamber. The entry ports to the spin chamber are drilled to cause an abrupt change in direction of the fuel as it enters the chamber, thus, imparting a spinning motion to the fuel. The spinning motion of the fuel establishes the spray angle and aids in atomization of the fuel for better combustion. Fuel from the spin chamber is discharged through the primary spray tip into the combustion liner.

Operating Principle

When fuel pressure reaches approximately 90 p.s.i.g., the pressure opens the flow divider and fuel is directed into a second drilled passage in the stem. Fuel from the secondary passage is directed into the secondary spin chamber. Spinning fuel from the secondary spin chamber is discharged through the secondary spray tip into the combustion liners. Figure 3-60 illustrates the spray pattern of a typical duplex nozzle.

A small quantity of air is scooped out of the main airstream by the shroud around the nozzle tip, to cool the nozzle tip. In addition, the cooling airflow improves combustion by retarding the accumulation of carbon deposits on the face of the nozzle, and by providing some of the air for combustion, which

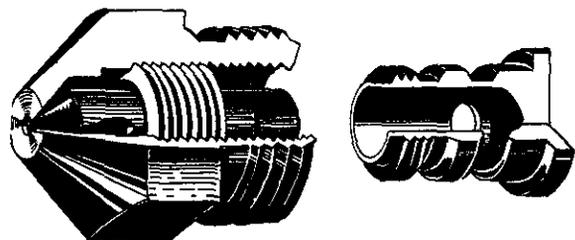


FIGURE 3-58. A typical simplex fuel nozzle.

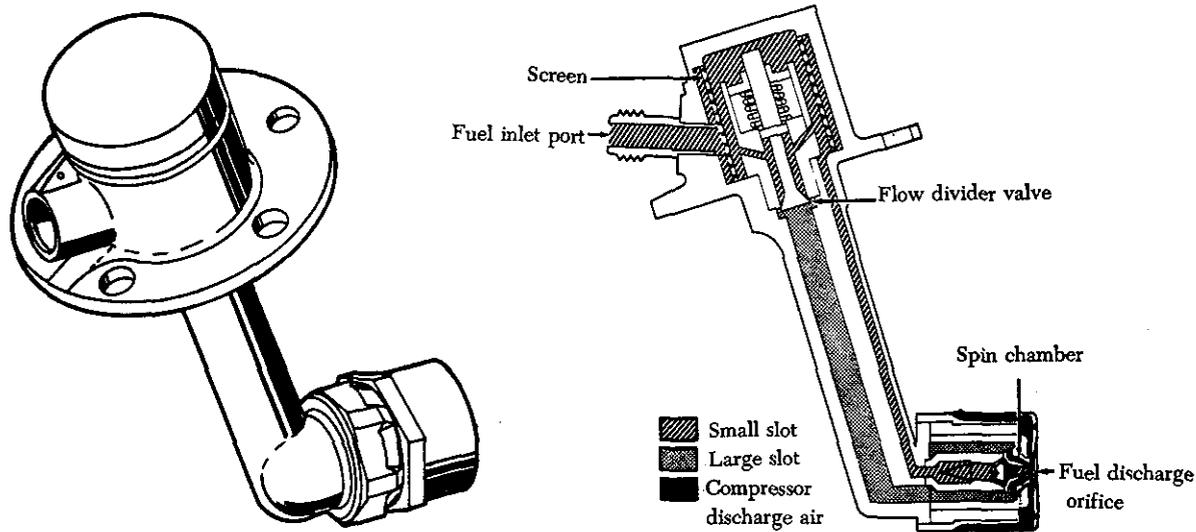


FIGURE 3-59. Duplex fuel nozzle.

helps contain the fire in the center of the liner.

Fuel Pressurizing and Dump Valves

The fuel pressurizing valve is usually required on engines incorporating duplex fuel nozzles to divide the flow into primary and main manifolds. At the fuel flows required for starting and altitude idling, all the fuel passes through the primary line. As the fuel flow increases, the valve begins to open the main line until at maximum flow the main line is passing approximately 90% of the fuel.

Fuel pressurizing valves will usually trap fuel forward of the manifold, giving a positive cutoff. This cutoff prevents fuel from dribbling into the manifold and through the fuel nozzles, eliminating

to a major degree after-fires and carbonization of the fuel nozzles. Carbonization occurs because combustion chamber temperatures are lowered and the fuel is not completely burned.

A typical example of this arrangement is the fuel pressurizing and dump valve used on the Pratt and Whitney JT3 engine. This valve performs two major functions as indicated by its name: (1) During engine operation it divides metered fuel flow into two portions, primary and secondary, as required for atomization at the fuel nozzles; and (2) at engine shutdown it provides a dump system which connects the fuel manifolds to an overboard drain.

A flow divider performs essentially the same function as a pressurizing valve. It is used, as the name implies, to divide flow to the duplex fuel nozzles. It is not unusual for units performing identical functions to have different nomenclature between engines.

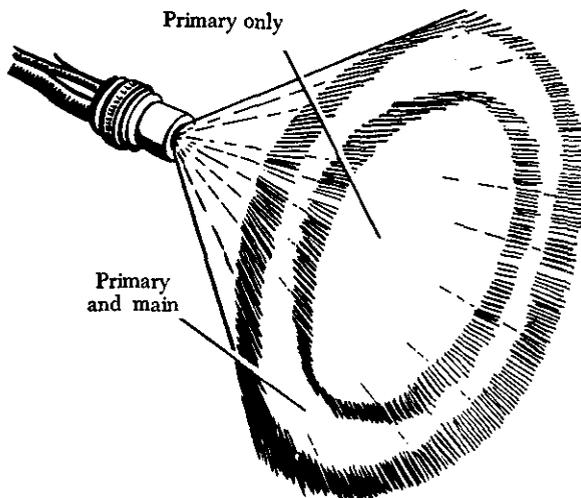


FIGURE 3-60. Duplex nozzle spray pattern.

Drain Valves

The drain valves are units used for draining fuel from the various components of the engine where accumulated fuel is most likely to present operating problems. The possibility of combustion chamber accumulation with the resultant fire hazard is one problem. A residual problem is leaving lead and/or gum deposits, after evaporation, in such places as fuel manifolds and fuel nozzles.

In some instances the fuel manifolds are drained by an individual unit known as a drip or dump

valve. This type of valve may operate by pressure differential, or it may be solenoid operated.

The combustion chamber drain valve drains either fuel which accumulates in the combustion chamber after each shutdown or fuel that may have accumulated during a false start. If the combustion chambers are the can type, fuel will drain by gravity down through the flame tubes or interconnector tubes until it gathers in the lower chambers, which are fitted with drain lines to the drain valve. If the combustion chamber is of the basket or annular type, the fuel will merely drain through the airholes in the liner and accumulate in a trap in the bottom of the chamber housing, which is connected to the drain line.

After the fuel accumulates in the drain lines, the drain valve allows the fuel to be drained whenever pressure within the manifold or the burner(s) has been reduced to near atmospheric pressure. It is imperative that this valve be in good working condition to drain accumulated fuel after each shutdown. Otherwise, a hot start during the next starting attempt or an after-fire after shutdown is likely to occur.

FUEL QUANTITY INDICATING UNITS

Fuel quantity units vary from one installation to the next. A fuel counter or indicator, mounted on the instrument panel, is electrically connected to a flowmeter installed in the fuel line to the engine.

The fuel counter, or totalizer, is similar in appearance to an automobile odometer. When the aircraft is serviced with fuel, the counter is manually set to the total number of pounds of fuel in all tanks. As fuel passes through the measuring element of the flowmeter, it sends electrical impulses to the fuel counter. These impulses actuate the fuel counter mechanism so that the number of pounds passing to the engine is subtracted from the original reading. Thus, the fuel counter continually shows the total quantity of fuel, in pounds, remaining in the aircraft. However, there are certain conditions which will cause the fuel counter indication to be inaccurate. Any jettisoned fuel is indicated on the fuel counter as fuel still available for use. Any fuel which leaks from a tank or a fuel line upstream of the flowmeter is not counted.

WATER OR COOLANT INJECTION

The sensitivity of turbine engines to compressor inlet temperature results in an appreciable loss of available thrust, or power in the case of a turboprop engine, on a hot day. It is sometimes necessary to

augment the thrust output. Water injection is a means of increasing engine thrust. It reduces hot section temperatures, fuel flow can be increased and greater thrust thereby obtained.

Thrust increase is particularly desirable at take-off when an aircraft engine is called upon for the greatest output of power, therefore the water injection system is designed to function only at high engine power.

The effect upon engine thrust depends upon the type of coolant used, the proportion of the ingredients, and the quantity of the coolant flow. For effective cooling, a liquid with a high heat of vaporization is required. Water, is the most desirable coolant. Alcohol is added occasionally in varying proportions, either to lower the freezing point of the coolant or to eliminate the need for separate enrichment of the fuel mixture, which might be necessary if only pure water were used. When alcohol is added, some small amount of additional thrust may be produced as the alcohol is burned. However, the efficiency of the combustion of the alcohol is usually quite low. The heating value of methyl or ethyl alcohol is only about half that of kerosene or gasoline. Most of the flow of the alcohol/air mixture will not pass through that part of the combustion zone where temperatures are high enough to support efficient combustion of the weak alcohol/air mixture.

Very few powerplants using water injection are in use today.

Water Injection System Operation

A typical dual water injection system is illustrated in figure 3-61. The dual system is actually two independent systems. One system injects water at the compressor inlet section of the engine. Thrust is augmented largely through the effect of increasing mass airflow. The other system injects water into the engine diffuser case. This system increases thrust largely through the cooling principle which permits higher fuel flows.

The water injection system is designed for dual operation at ambient temperatures above 40° F. (5° C.). At temperatures up to 40° F., compressor inlet injection should not be used because of the hazardous inlet icing that could occur.

Water from the aircraft tank system is routed to two shutoff valves which govern flow to the two water injection controls. The shutoff valves are armed by the actuation of a cockpit switch. The selected valve(s) open or close upon receipt of an electrical signal from the fuel control water injection switch. With the power lever advanced to

takeoff, this switch supplies an "open" signal to the selected shutoff valve(s). Conversely, when the power lever is retarded below the water turn-on point, the switch supplies a "close" signal to the shutoff valve(s).

Water from the open shutoff valve flows to the water injection controls. Since the water injection system is used only when power settings are at, or near, their maximum, the controls do not vary or meter water flow. Instead, they maintain a constant pressure head across a fixed orifice, thereby maintaining a constant water flow to the engine.

Water from the compressor inlet water injection

control is directed to a manifold and is sprayed directly into the compressor at this point. Water from the diffuser case control passes through a check valve and is then directed to a split manifold from which it is sprayed into the diffuser case. When the water injection system is not in use, the check valve prevents high-temperature compressor discharge air from backing up into the water injection system plumbing, where it might damage the controls or valves.

Drain valves located downstream of the water shutoff valves drain the engine water lines when the injection system is turned off, thus preventing water from freezing in these lines.

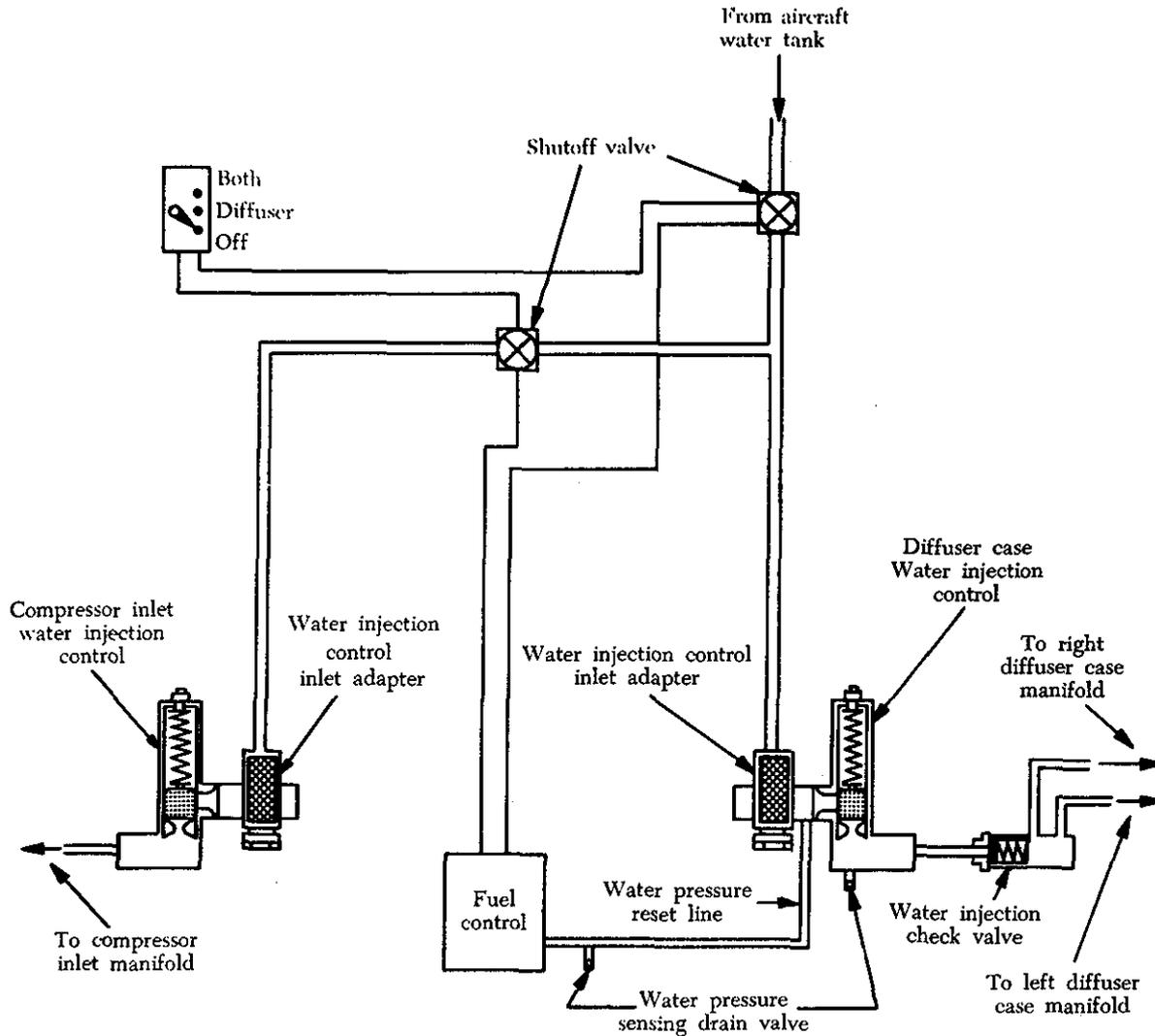


FIGURE 3-61. A typical water injection system.