Chapter 13

FUEL CONTROL UNIT, TYPE CASC 101

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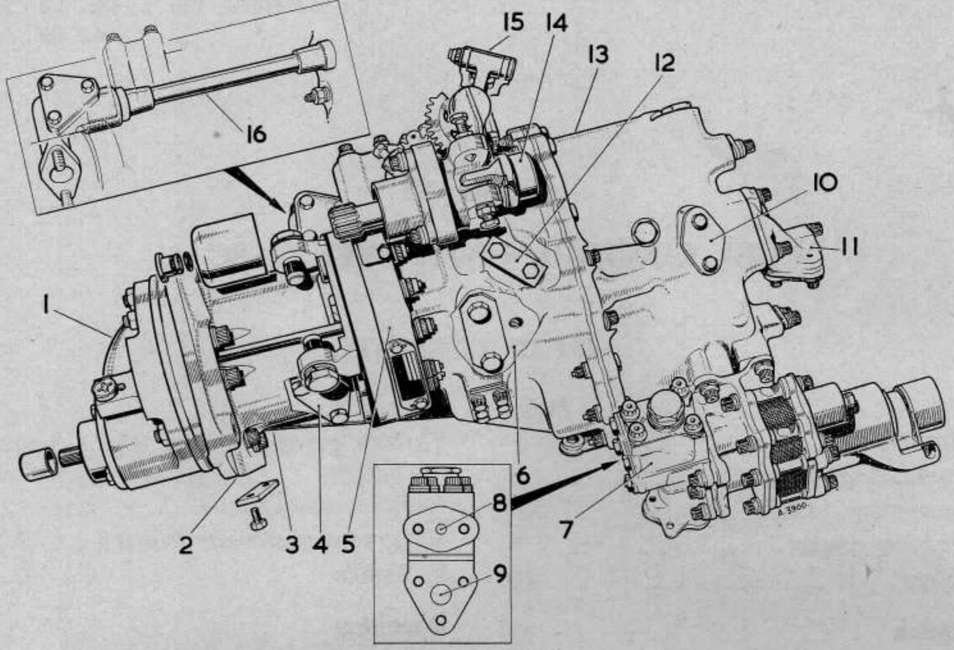

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Fig. 1. External view of control unit

Introduction

1. The fuel control unit is a mechanical combined acceleration and scheduling control (abbreviated to CASCMECH). It is impervious to dirt and icing effects, and has considerable anti-hysteresis properties; these features are due to the use of rotating components, the omission of half-ball valves and, as far as possible, the omission of all small restrictors.

2. Control is effected by means of variable-area orifices which meter the fuel flow in accordance with engine requirements, and by making use of the overall pressure drop incurred to control the displacement of the H.P. fuel pump (Sect. 2, Chap. 14 of this publication); there are two such orifices in series within the fuel control unit, and a third within the L.P. shaft governor (Sect. 14, Chap. 9 of this publication). This latter orifice, however, is of a fixed size under most normal running conditions and may for the purposes of this explanation be ignored.

3. Acceleration control is effected by making the area of the first orifice a function of engine compressor pressure; the pressure drop across this orifice is maintained proportional to the square of the speed of the H.P. compressor shaft by varying the area of the second orifice which is under the control of an acceleration governor.

4. A second governor (termed the scheduling governor) proportionally reduces the metering orifice area from its value during acceleration to that required during steady running (in accordance with signals from the pilot's throttle lever).

5. The following functions are performed by the fuel control unit:—

(1) The supply of fuel during acceleration is made to match the engine surge characteristics at all altitudes, thus ensuring a correct degree of overfuelling which allows the engine to accelerate as fast as possible, but never permits conditions to arise which would result in surge of the engine. The acceleration characteristic of the unit provides compensation for fuel density variations.

(2) During deceleration, the minimum fuel flow is set to limit undershooting of speed and to obviate the risk of flame extinction.

(3) Virtually isochronous governing is achieved; this means that each position of the throttle provides an almost constant H.P. shaft speed regardless of intake or ambient conditions.

(4) The fuel flow is split into the proportions required for the Duple type of fuel spray nozzle.

(5) A rise in engine idling speed characteristic can be obtained with altitude to suit engine requirements.

(6) Provision is made for the coupling of an over-ride control which reduces the throttle setting in the event of the turbine gas temperature rising beyond the safe limit.

Requirements of system

6. The general subject of gas turbine engine control is most conveniently considered under three headings; *steady running control*, which includes the problems of deciding what the engine steady running condition is required to be at a particular moment, and of maintaining the engine at this condition; *acceleration control* covering changes from one steady running condition to another; and thirdly, *protection of the engine* from overheating and over-stressing from various causes.

7. Since control of the engine is exercised by the amount of fuel fed to it, it follows that in the fuel flow system there must be three general types of device controlling the fuel flow, and corresponding in their functions to the three general headings given in para. 6. Before describing in detail the construction of the fuel control unit, the general way in which steady running and acceleration control is carried out will be described.

Steady running control

8. Shaft speed (rev/min) forms the most convenient measure of the output of an engine, and in the CASCMECH system, steady running control is carried out by a variable metering orifice, the area of which is regulated by a speed governor (driven from the engine H.P. compressor shaft) and compressor delivery pressure signals (which provide a direct measurement of air mass flow). The datum of the governor is set by the pilot's throttle lever so that for every setting of the lever there is a corresponding engine running speed.

Acceleration control

9. In changing from one running speed to another, the rate at which the engine accelerates must not be allowed to rise too high otherwise the compressor air flow patterns are abruptly upset in the effects known as 'stall' and 'surge' with consequent loss of power and possibility of engine damage. This protective function is carried out by the acceleration control.

10. The method used is to limit the fuel flow, during acceleration, to a value which is known to be just below that at which stall occurs. The onset of stall is affected by the engine speed (N) and by the temperature and pressure of the air entering the engine intake (T_1) and (P_1), so that in computing the safe maximum acceleration fuel flow (F) the control system must also take account of these factors.

Protection

11. The CASCMECH system protects the engine from excessive speed, and provision is made for an electronic top-temperature control that limits the fuel supply at extreme conditions of turbine gas temperature. In addition, the P_3 limiter, which forms part of the fuel control unit, provides a safeguard against excessive compressor delivery pressure.

DESCRIPTION (*fig.* 2 *and* 3)

12. For ease of description, the control unit is divided into seven main parts:

(1) Main drive gears

(2) Acceleration governor / pressure-drop control

(3) Scheduling control

(4) Turbine gas temperature (t.g.t.) control mechanism

(5) Capsule assembly

(6) Air potentiometer (or splitter)

(7) P_3 limiter

Main drive gears

13. The drive from the H.P. compressor shaft is taken through a serrated shaft and spur gears to an epicylic gear train that drives the acceleration and scheduling governors, and — at a much lower speed — the pressure-drop sleeve and variable metering orifice (V.M.O.) sleeve.

14. The epicyclic train consists of a planet carrier that mounts three double planet gears; the outer (larger diameter) planet gears are engaged with a stationary sun gear and with annular teeth around the inner diameter of the acceleration governor; the inner (smaller diameter) planet gears engage solely with a gear at the end of the pressure-drop sleeve.

15. Pressure balance is provided for the primary spur gear to offset the bias of low-pressure fuel and of the springs which load the carbon face seals at the end of the serrated shaft; thus, face wear on the main carbon bearing is much reduced.

16. A bleed circuit is provided in the gear housing through which a small proportion of pump output passes via a filter and restrictor, to the L.P. shaft governor, and from thence to the H.P. fuel pump inlet; this continued circulation of fuel purges any air from the system and provides a cooling flow.

Acceleration governor/pressure-drop control

17. Fuel flow from the scheduling control passes through two sets of slots in the pressure-drop sleeve; one set of slots is rectangular in form and feeds the primary fuel spray nozzles; the other set is of triangular shape and feeds the main fuel spray nozzles.

18. The pressure drop sleeve is moved axially in either direction whenever there is a difference between the force developed centrifugally by the acceleration governor weights and the force imposed by the fuel pressure drop across the closed end of the sleeve. The triangular slots which provide a passage for the main flow are so arranged that when the weight force exceeds the pressure-drop force, the area through which flow may pass is increased, and vice versa.

19. The pressure drop across the end of the sleeve is identically that across the scheduling control variable metering orifice (V.M.O.), and the V.M.O. area is responsive to a compressor pressure force exerted by the capsules (this force being a measurement of air mass flow). Thus the pressure-drop control orifice area varies with:—

(1) H.P. compressor shaft speed (causing the V.M.O. pressure drop to be proportional to the square of this speed).

(2) Compressor pressure force (as this also varies the V.M.O. pressure drop).

20. Hence, the overall system pressure-drop regulates the pump stroke through its servo system to provide a fuel flow that will match accurately the required acceleration conditions.

21. The acceleration governor consists of a carrier fitted with six fly-weights which are ball-race mounted upon pivot pins, these pins being retained by cotter pins; this assembly is surrounded by a shroud to prevent turbulence being caused by the rotation of the governor in the fuel (it will be remembered that rotation is caused by the planet gears of the epicyclic train which engage with teeth in the carrier).

22. Each flyweight has an arm which bears against the hardened face of a thrust collar; the opposite end of this collar is carbon faced to form a bearing surface with a flange on the pressure-drop sleeve.

23. As the carrier rotates and the flyweights swing outwards under centrifugal force, the arms of the weights attempt to move the thrust collar axially, which in turn attempts to move the pressure-drop sleeve in the same direction. Guided axial movement of the thrust collar is ensured by three small ball races which are evenly disposed around the outside of this part and which run in tracks machined in the weight carrier.

24. In addition to the functions already detailed, the acceleration governor also ensures that the same mass of fuel is supplied regardless of its specific gravity. This correction is made possible as the material from which the flyweights are made is light enough for buoyancy effects to influence the weight force, and therefore fuel flow, in accordance with fuel density. For example, when the fuel is of low density, the resultant weight force is greater; and for a given speed, a lower pressure drop results which gives an increased pump delivery.

25. Drive is transmitted from the acceleration governor to the scheduling control in the following manner. Gear teeth at the end of the acceleration governor engage with a spur gear which is connected to a similar gear engaging with the scheduling governor. A shaft passes through the centre of the pressure-drop sleeve and is positively fixed in this component; at the end remote from the sleeve, the shaft carries three equally-spaced ball races which engage with tracks machined in the V.M.O. sleeve. Thus the V.M.O. sleeve rotates with the pressure-drop sleeve, but is also capable of independent axial movement under the influence of the capsules (which sense a function of compressor pressure).

Scheduling control

26. Fuel flow from the pump passes through triangular slots in the V.M.O. sleeve; this sleeve being indirectly attached to two capsules which sense a function of compressor pressure ratio and therefore air mass flow. The sleeve can slide axially within a bearing in the housing (under the influence of the capsules) and has mounted upon it a collar which can also be moved axially by a throttle control spring force or by the scheduling governor force (according to the conditions). This sliding movement increases or decreases a gap between the collar and the bearing; the gap being coincident with, and giving partial opening of, the triangular slots in the sleeve.

27. Under acceleration conditions, the gap is held at its widest value by the spring force, and the combination of this gap with the trapezium-shaped openings through the triangular slots (the area of which vary with linear movement of the V.M.O. sleeve) provides the variable metering orifice.

28. The width of the gap between the collar and its bearing is varied by the balance between the throttle control spring force and a centrifugal force generated by the governor weights. Thus the gap varies in response to engine speed to govern the fuel supply, and the equilibrium position is virtually constant giving a fixed governed speed for every selected throttle setting; this comes about because the trapezoidal flow area is compensated for engine air mass flow.

29. Signals from the pilot's throttle lever or the turbine gas temperature (t.g.t.) control mechanism are fed through a pair of gear-toothed quadrants and a cam to a thrust lever which increases or decreases the force of a spring acting on a stirrup pivoted to the governor housing. A spring loaded cam follower reduces torque loads imposed on the cam by the stirrup spring. Two ball bearings mounted in the stirrup provide

KEY TO FIG. 2

1 MAIN DRIVE GEARS ASSEMBLY
2 PLANET GEARS ASSEMBLY
3 SUN GEAR
4 ACCELERATION GOVERNOR
5 THRUST COLLAR
6 ACCELERATION/PRESSURE-DROP CONTROL
7 PRIMARY TRANSFER GEAR
8 SECONDARY TRANSFER GEAR
9 SCHEDULING GOVERNOR
10 SCHEDULING-CONTROL LEVER ASSEMBLY
11 CAM FOLLOWER
12 CAM
13 IDLING ADJUSTMENT
14 INPUT LEVER
15 CAPSULE STIRRUP
16 CAPSULE
17 CAPSULE ASSEMBLY
18 SPHERICAL CARBON BEARING
19 V.M.O. BALANCE PLUNGER
20 MAXIMUM FLOW STOP HOLDER
21 MAXIMUM FLOW STOP
22 P_3 LIMITER AND AIR POTENTIOMETER ASSEMBLY
23 COMPOSITION-MATERIAL AIR SEAL
24 MAXIMUM DECELERATION STOP
25 MAXIMUM ACCELERATION STOP
26 VARIABLE METERING ORIFICE (V.M.O.) COLLAR
27 DASHPOT PISTON
28 SCHEDULING-CONTROL ASSEMBLY
29 VARIABLE METERING ORIFICE (V.M.O.) SLEEVE
30 PRESSURE-DROP SLEEVE
31 QUILL SHAFT
32 CREEP GEAR
33 PRIMARY SPUR GEAR
34 PRIMARY DRIVE SHAFT
35 QUILL SHAFT
36 MAIN SHAFT
37 FORKED LEVER
38 CAM THRUST LEVER
39 STIRRUP
40 THROTTLE CONTROL SPRING
41 LOCATING PIECE
42 CENTRE ROD

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rolling contact points with the V.M.O. collar, and a track machined in the collar engages a ball race carried on the housing so ensuring guided axial movement.

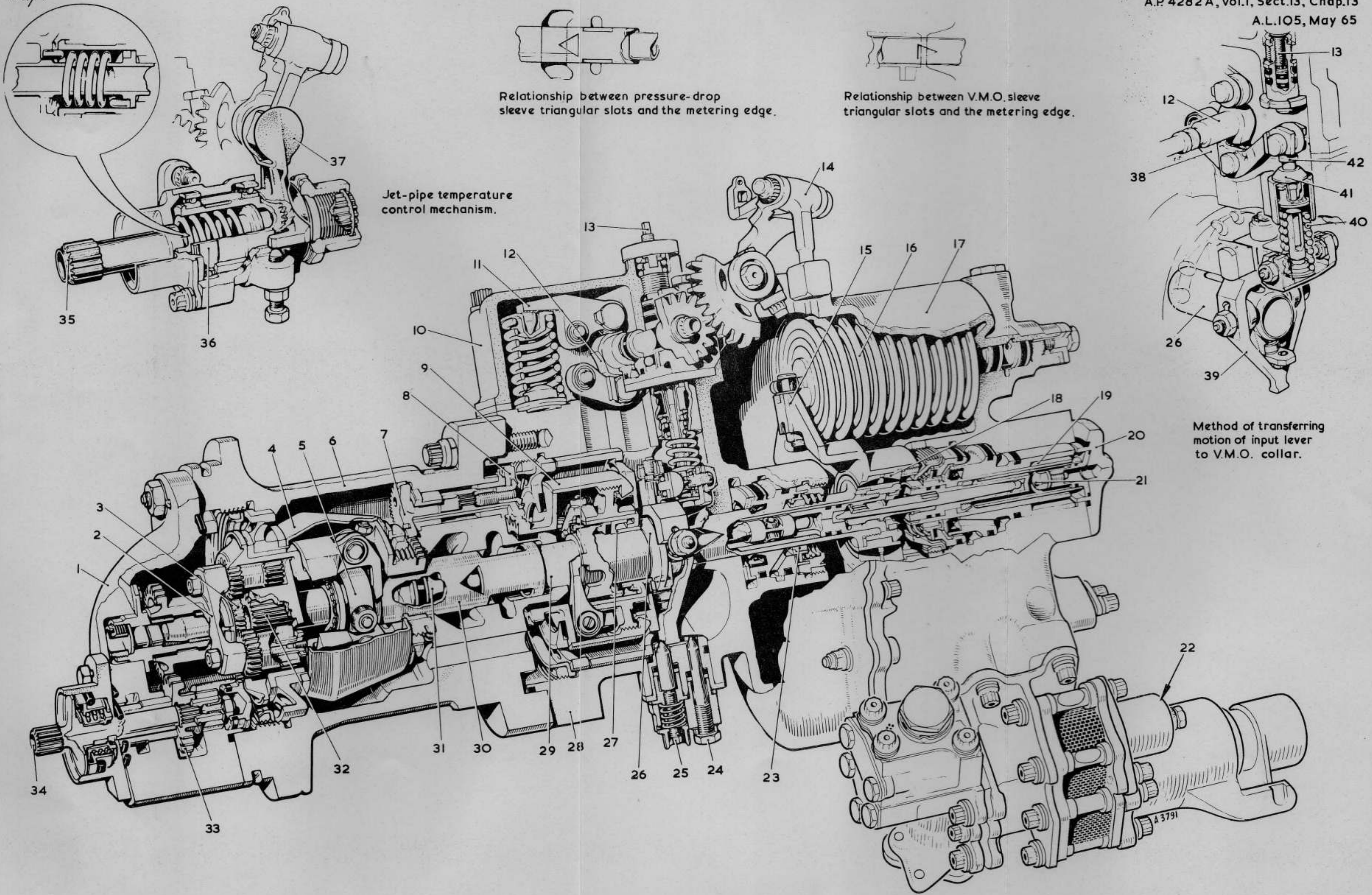
30. When the fuel temperature is high, expansion of the components increases the distance between the centres of the camshaft and of the governor assembly and, if this condition were allowed to go unchecked, the stirrup spring loading and the spring modulus would decrease, causing a reduction in engine speed. A fuel temperature compensating device is therefore fitted, through which the load of the cam thrust lever is transmitted to the spring; this device consists of a centre-rod contained within a locating piece, these two parts being made from materials having differing coefficients of expansion. Thus, as the fuel temperature increases, the centre-rod expands and thrusts against the locating piece which, in turn, thrusts against the spring and restores the loading dictated by the cam position.

31. The cam form is such that idling rev/min is obtained when the gear-toothed quadrants are at approximately mid travel and that movement either side of this position increases engine speed. Thus, since the reverse-thrust select lever is also linked to the cam-shaft input lever, the complete range of full forward thrust to full reverse thrust is obtained by moving the input lever in the same direction of rotation.

32. When the cam is moved towards the 'idling' position the thrust lever approaches, and finally contacts, an idling adjustment screw, the setting of which determines the idling speed of the engine; a spring-loaded locking collar provides automatic locking when the adjustment screw is set.

33. Maximum movement of the cam in either direction is determined by two adjustable stops which set the travel of the gear-toothed quadrants; two further adjustable stops limit movement of the stirrup and thus control the maximum and the minimum gap between the V.M.O. collar and the bearing.

34. The stop which controls the maximum gap (that is to say, the acceleration stop) is fitted with a keyed locking collar which provides automatic locking when adjustment is carried out; the deceleration stop is wire-locked.



Relationship between pressure-drop sleeve triangular slots and the metering edge.

Relationship between V.M.O. sleeve triangular slots and the metering edge.

Jet-pipe temperature control mechanism.

Method of transferring motion of input lever to V.M.O. collar.

Fig.2 Cutaway view of fuel control unit. Fig.2

35. The scheduling governor is of similar construction to the acceleration governor but has three flyweights instead of six; the arm of each flyweight bears against the hardened face of a thrust collar, and the opposite end of this collar is carbon faced to form a bearing surface with a dashpot piston which is keyed to the V.M.O. collar.

36. Thus, as the carrier rotates, and the flyweights swing outwards under centrifugal force, the arms of the weights attempt to move the dashpot piston and the V.M.O. collar in the same direction.

37. The centrifugal force however, is opposed by the spring force acting on the stirrup, therefore, if either the centrifugal force or the spring force alters from the balanced condition, the V.M.O. collar will move and so alter the V.M.O. gap width until the balance of forces is restored. Guided axial movement of the thrust collar is ensured by tracks which are machined in it to engage with three small ball races equally spaced around the inside of the carrier. The purpose of the dashpot piston is to prevent the governor from hunting, by acting as a hydraulic damper.

38. As previously described, rotation is transmitted from the pressure drop sleeve to the V.M.O. sleeve by a shaft carrying three ball races.

39. There is one further driven component to consider, namely the balance plunger; this is driven by the V.M.O. sleeve through a serrated coupling shaft. The balance plunger is subjected to the same fuel pressure as the inside of the V.M.O. sleeve (i.e. primary fuel spray nozzle pressure) and is therefore hydraulically balanced, so reducing to a minimum the resistance to axial movement and ensuring that no hydraulic forces are applied to the capsules. A push rod between the sleeve and the plunger transmits the thrust in order to relieve the shaft of any side loads due to possible slight misalignment.

40. Any leakage of fuel between the V.M.O. sleeve and its bearing returns to the H.P. fuel pump inlet (low pressure) and is prevented from entering the capsule air chamber by a garter seal carried in a seal housing. At the other end of the seal housing a composition material air-seal is fitted, this is self-aligning on the plunger and prevents high pressure air in the capsule chamber from entering the fuel drain. A rubber seal, onto which the composition seal is loaded, prevents leakage of air around this latter seal. If the fuel leaks past the garter seal, or if air leaks past the composition seal, the seepage is routed to the drain circuit.

Turbine gas temperature (t.g.t.) control mechanism

41. This mechanism is carried at the side of the scheduling-control housing and consists of a main shaft to which is keyed a forked lever and a quillshaft; this lever and shaft are pre-loaded by a torsion spring. The forked lever engages the main input lever, and the quillshaft engages a rotary actuator to which electrical signals are fed from the engine thermocouples; hence, an increase in turbine gas temperature beyond a pre-determined maximum is able to 'trim' the fuel supply accordingly. The torsion spring is provided as a safety device in order to restore the 'no trim' condition should the rotary actuator fail to do so; after such a failure, temperature trim would be effected by normal throttle control.

Capsule assembly

42. The unit contains two capsules which are bolted to the capsule housing at one end whilst the opposite ends are secured to a stirrup by means of pins fitted with self-aligning carbon bearings. The centre of the stirrup provides a housing for a self-aligning carbon bearing within which the end of the V.M.O. sleeve is mounted.

43. Each capsule is divided into two parts, the greater part being evacuated whilst the smaller is subjected internally to P_2 air pressure. Surrounding the capsules is air pressure at an intermediate value between P_2 and P_3, termed P_{3p}.

44. Under acceleration conditions, the increasing value of P_{3p} will compress the capsules to a degree proportional to P_{3p} and P_2, thus exposing a larger area of the triangular slots in the V.M.O. sleeve to the gap between the V.M.O. collar and bearing; a greater quantity of fuel is therefore allowed to pass through the slots at any given pressure drop set by the pressure drop sleeve orifice. During deceleration the reverse will apply.

45. The capsule assembly also acts as an altitude sensing unit as variation of ambient pressure will also effect P_2 and P_3.

46. Torque reaction from the self-aligning bearing at the centre of the capsule stirrup is taken by a ball race carried on the stirrup which engages a track in the capsule housing, thus preventing the capsules from binding when they are being compressed or extended.

47. A bore at the centre of the capsule housing accommodates a seal housing which carries a composition material air seal and a garter seal; the V.M.O. balance plunger passes through these parts, their function being as described under the scheduling control description. The maximum flow stop holder enters the end of the balance plunger and carries an adjustable stop which is set during the testing procedure to determine the maximum rearward travel of the V.M.O. sleeve and hence the maximum opening of the slots in this sleeve.

Air potentiometer (or splitter)

48. The purpose of the potentiometer is to ensure that, when accelerating, a lower value of P_{3p} (as compared with P_3) is used to operate the capsules at low rev/min. than at high rev/min. By this means, the rate at which the capsules move to vary the area of the slots in the V.M.O. sleeve is controlled so that the fuel supply is very closely matched to the engine surge characteristics particularly during the more critical acceleration conditions at the lower portion of the rev/min. range.

49. The potentiometer consists of a venturi in series with an orifice, P_3 air being applied upstream of the orifice whilst P_2 is applied downstream of the venturi; the signal pressure (P_{3p}) is tapped-off between the two.

50. It is a characteristic of air potentiometers that until the air flow through the second orifice has reached sonic velocity, the pressure ratio across the first orifice rises progressively. Thus the ratio of the intermediate pressure to the input pressure falls from unity down towards a desired final value which is achieved when the second or final orifice achieves sonic velocity. Hence the resultant values of P_{3p} rise slowly over the lower engine speeds and then more quickly as a final proportion of P_3.

51. The use of a venturi is a simple means of achieving sonic flow through the second orifice at a much lower pressure ratio than is possible with a plain orifice, giving a better match of the engine characteristics. The sizes of the air orifice and venturi are relatively large, which helps in reducing the effects of impurities in the air.

52. When the aircraft is landing on an aircraft carrier or on a short runway, there is an obvious need for the approach speed to be lower than would otherwise be the case; however, it is necessary under such conditions to stabilize the air flow across the wings in order that the aircraft shall not stall. This is achieved by the 'flap blowing' process, which entails compressed air being bled from the seventh stage of the high pressure compressor and blown across the surface of the wings.

53. With the aircraft flying at this critical speed, arrangements must be made to prevent loss of engine power consequent upon the bleed from the compressor, and it is with this end in view that a compensating device is incorporated in the air potentiometer. This device consists of a secondary orifice which is located alongside the normal P_3 metering orifice and, under normal flight conditions, is closed by a plate-valve at the end of a spring-loaded piston.

54. When the pilot brings into operation the 'flap blowing' system, seventh stage compressor air is also applied to the top of the spring-loaded piston, displacement of which opens the plate valve; an additional passage is now opened up for P_3 air, thus ensuring that the drop in P_3 pressure does not cause a corresponding drop in P_{3p} pressure. Fuel flow scheduled by the fuel control unit will therefore be insensible of the air bleed from the compressor.

P_3 limiter

55. At the upper end of the engine speed range with the aircraft flying at low altitudes and with low ambient temperature, conditions can arise where, although the engine has not attained maximum permissible rev/min., the air mass flow through the engine could be such as to cause P_3 pressure to exceed the figure for which the compressor casing is stressed, and also cause the thrust to overload the engine mountings. Under these conditions it is necessary to provide a control which overrides the scheduling control in order to limit compressor delivery pressure to a safe maximum; this is the function performed by the P_3 limiter.

56. The unit consists of a valve which is operated by a bellows assembly sensing P_3 pressure (surrounding the bellows) and atmospheric pressure (P_0) (inside the bellows). Normally the valve is closed but, when a pre-determined value of P_3-P_0 is reached, the bellows will be compressed against the spring load, causing the valve to open and so permit a proportion of P_{3p} air to bleed away to atmosphere. This reduces P_{3p} and relieves the load on the capsules, causing them to move to reduce the exposed area of the triangular slots in the V.M.O. sleeve, thereby controlling the engine speed to a value whereby the safe compressor delivery pressure will not be exceeded.

57. The thrust of the bellows assembly is taken through a push-rod which moves a lever, the load then being transmitted to a second (forked) lever carrying the valve assembly, the travel of this lever being limited by a stop screw. Both levers are mounted on a common hinge pin.

58. Since the valve assembly moves in an arc, but the valve seat is fixed, the valve is designed to be self-aligning; this is done by pivoting the valve about the end of a needle roller and lightly spring-loading it.

59. As P_3 reduces, the springs and the effect of P_0 inside the bellows will cause the bellows to extend and the valve to close, the levers and push-rod being thrust back by a return spring.

60. Since the P_3 limiter has no affect under normal flight conditions it is necessary to ensure before each flight, that the emergency factor is still available by functionally testing the unit. To enable this testing to be accomplished, it is necessary to simulate the excessive P_3 pressure; this is effected by a datum re-set device which reduces the load of the inner balance spring and hence causes the P_3 limiter valve to open at a lower value of P_3.

61. Under normal operating conditions, the plunger which loads the inner spring is locked in position by a number of balls, and the spring is held at the 'high datum' setting. When ground testing is to be carried out, a special tool (T.328918) is used which engages lugs on the spring housing and thrusts the locking sleeve outwards until a groove in its bore is coincident with the balls. This unlocks the plunger, and the balance spring is able to expand hence reducing the load applied in opposition to the P_3 pressure acting on the bellows.

62. With the locking sleeve in the 'unlocked' position the special tool is automatically prevented from becoming disengaged; this provides a safeguard against the aircraft taking off with the P_3 limiter at the reduced setting.

63. On completion of ground testing, the original loading of the inner spring is restored by the special tool thrusting the locking sleeve and the plunger inwards until the balls re-engage with the groove in the plunger; so locking the assembly at the 'high datum' setting. When the locking sleeve is fully home, the tool falls out of engagement with the spring-housing lugs, it cannot therefore inadvertently be left in position.

OPERATION (*fig.* 3)

64. With the aircraft on the ground, and the engine not running, atmospheric pressure acting on the capsules will cause them to assume a position whereby the triangular slots in the V.M.O. sleeve are partially open.

65. Upon starting the engine, the H.P. shaft will transmit drive to the fuel control unit governors, pressure-drop sleeve and V.M.O. sleeve, and to the H.P. fuel pump. Pump flow will then pass through the V.M.O. gap and from thence through the rectangular slots in the pressure-drop sleeve to the rear side of the V.M.O. balance plunger and to the primary fuel spray nozzles. At this stage there will be no flow to the main fuel spray nozzles, and this will not occur until the fuel pressure is high enough for efficient atomisation.

Note . . .

It should be explained that when the pump is at rest, it is at full stroke, and that the stroke will only reduce when a sufficient overall pressure drop has been achieved to overcome the stroke servo-mechanism spring loading. This overall pressure drop (in the region of 300 *lb/in^2) is attained first across the primary fuel spray nozzles at a low speed.*

66. As the speed of the H.P. shaft increases, P_3 pressure commences to build up, very shortly followed by P_2; the action of P_{3p} will then cause further slight collapse of the capsules, and the V.M.O. will be enlarged by a small amount. In consequence, the pressure drop across the V.M.O. will be reduced and, as already explained, this change in the V.M.O. pressure drop will also be felt across the closed end of the pressure-drop sleeve. When the engine speed has risen sufficiently for the acceleration governor centrifugal force to match the V.M.O. pressure drop, the main flow slots in the pressure drop sleeve will commence to open. As the slots open, the pressure drop across them will be sensed by the pump servo piston; this will move to increase the pump stroke, and flow.

67. Fuel flow now increases, with the acceleration control operative, the V.M.O. pressure drop and the acceleration governor centrifugal force opposing each other and moving the pressure-drop sleeve to cause correction of the fuel flow to maintain them in balance. When the engine speed has reached such a value that the scheduling governor centrifugal force balances the spring loading on the stirrup, the stirrup returns to a balanced position and partially closes the V.M.O. gap. The engine speed is now governed at the setting of the throttle; flow through the V.M.O. gap and the pressure-drop sleeve triangular slots (and the pressure drop across these slots) remaining constant, to give the engine idling condition, until a further throttle selection is made.

68. Upon further opening the throttle, a greater force is applied by the spring which acts upon the stirrup, hence the stirrup moves the V.M.O. collar and opens up the V.M.O. gap. Consequently there is a reduction in the pressure drop across the V.M.O., and also across the end of the pressure-drop sleeve which destroys the balance between this sleeve and the acceleration governor. The triangular slots in the pressure-drop sleeve therefore open to a greater degree with a consequent reduction in the pressure drop across them and across the V.M.O.; the reduced pressure drop across the H.P. fuel pump servo piston causes this to move and increase the pump stroke, causing a greater delivery of fuel to be circulated through the fuel control unit to the main fuel spray nozzles.

69. As the engine speed increases, the capsules collapse further, causing the V.M.O. to enlarge its area; hence there is once more a reduction in pressure drop across the V.M.O.; this in turn again destroys the balance between the pressure-drop sleeve and the acceleration governor, giving a greater opening of the triangular slots in this sleeve and again reducing the pressure drop across them, thus further increasing the H.P. fuel pump delivery.

70. This sequence continues until the engine reaches a speed which again brings the scheduling governor into balance with the throttle control spring; flow will then once more remain constant at a steady running condition unless one of the trims comes into operation or a further throttle selection is made.

Altitude trim

71. With the aircraft climbing at a fixed throttle setting it is necessary to compensate for reductions in atmospheric density, and hence reduction in air mass flow through the combustion chambers, by reducing the fuel supply to the main fuel spray nozzles, thus maintaining a constant air/fuel ratio.

72. The reduction in P_0 will of course bring about an automatic reduction of P_3 and P_2, and hence of P_{3p}; the capsules will consequently react to this and will expand, so reducing the area of the V.M.O. The pressure drop across the V.M.O., and therefore across the end of the pressure-drop sleeve, will thus increase and overcome the acceleration-governor weight force, consequently the pressure-drop sleeve triangular slots will be reduced in area, and the pressure drop across them increases; the increased pressure drop signal to the H.P. fuel pump servo now reduces the pump delivery until the pressure-drop sleeve and the acceleration governor forces are again in balance. This trimming of the fuel flow can continue until the V.M.O. and pressure-drop sleeve triangular slots are at minimum opening.

73. It will be seen that when the altitude minimum-flow condition is reached, any further increase in altitude (and attendant reduction in air density) will not affect the flow to the fuel spray nozzles, therefore the idling speed will increase due to the fuel/air ratio increasing; consequently the air pressure increases to suit combustion requirements.

Temperature trim

74. A departure from the fuel supply as set by the pilot's throttle lever is necessary to prevent the turbine gas temperature exceeding a predetermined maximum for a given engine speed. Such a temperature rise could be due to various causes, the most likely being a large bleed-off of compressor air.

75. Control is effected by averaging the signals from the engine thermocouples and balancing the result (in an amplifier) against a preselected value equivalent to the maximum permissible temperature. Any excess temperature signal causes the amplifier to operate an actuator which progressively modifies the selected throttle position on the control unit, thus effectively reducing the selected governor speed. When the temperature decreases, the actuator operates to return the throttle input lever to its original setting.

Fuel density compensation

76. The amount of fuel metered by the control unit is proportional to the square root of the density of the fuel; therefore, if no density compensation were provided, the lighter the fuel, the lower would be the mass passed to the engine.

77. It is therefore necessary to compensate for changes in density in order that the mass supplied to the engine (and hence the amount of heat evolved in the combustion chambers) shall be constant regardless of density. This is important as the calorific values for fuels of different densities vary at a given temperature, and the density of fuels also vary significantly with temperature.

78. It has already been seen that, under steady running conditions, the V.M.O. pressure drop is a function of the centrifugal force produced by the acceleration governor, and that the governor force is sensitive to fuel density.

79. Since the acceleration governor weights are immersed in fuel they are subjected to buoyancy forces. If a fuel of a lower specific gravity is used, the fuel will offer less resistance to the outward movement of the governor weights; therefore, at a given speed, the governor datum will, in effect, be raised and the pressure-drop sleeve will therefore be influenced to increase the area of its slots, creating a lower V.M.O. pressure drop. In consequence, the H.P. fuel pump servo pressure drop reduces, which increases the pump delivery. The reverse of this will, of course, apply if fuels of higher specific gravity are used.

80. Variations in fuel density affect the scheduling governor only very slightly since the weights of this are made from as heavy a metal as possible in order to produce a unique force for a given engine speed.

Isochronous governing

81. The steady running requirement of the engine is very closely matched by maintaining a constant width of the V.M.O. gap; this is achieved by balancing the centrifugal force of the scheduling governor against the load of a spring. Hence, each position of the throttle provides an almost constant H.P. shaft speed regardless of intake or ambient conditions; i.e. virtually isochronous governing is obtained.

82. Changes of intake pressure will not affect the steady running requirement, as an 'altitude-trim' effect would be produced as already described. Governed speed change with intake temperature is negligible if the acceleration schedule is always a fixed percentage above the engine steady state requirement.

RESTRICTED

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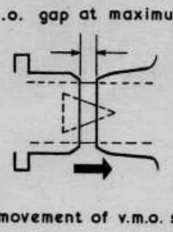
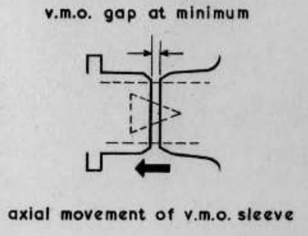
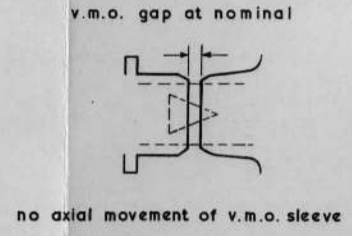
V.M.O. DURING ACCELERATION



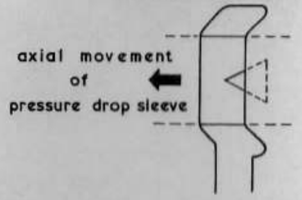
V.M.O. DURING DECELERATION



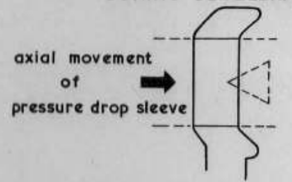
V.M.O. DURING STEADY RUNNING



PRESSURE-DROP SLEEVE
TRIANGULAR SLOTS
DURING ACCELERATION



PRESSURE-DROP SLEEVE
TRIANGULAR SLOTS
DURING DECELERATION



1 Primary drive shaft.
2 Acceleration governor.
3 Pressure drop sleeve.
4 V.M.O. sleeve.
5 Scheduling governor.
6 Stirrup.
7 Cam.
8 Input lever.
9 Idling adjustment.
10 Throttle control spring.
11 P3 limiter.
12 Air potentiometer.
13 V.M.O. balance plunger.
14 Capsule.
15 Maximum deceleration stop.
16 Maximum acceleration stop.
17 V.M.O. gap.
18 V.M.O. collar.

▩ PUMP DELIVERY PRESSURE

▒ MAIN FUEL-SPRAY NOZZLE PRESSURE

▩ PRIMARY FUEL-SPRAY NOZZLE PRESSURE

░ LOW PRESSURE

■ P3 AIR

▨ P2 AIR

▒ P3p AIR

░ PO ATMOSPHERIC

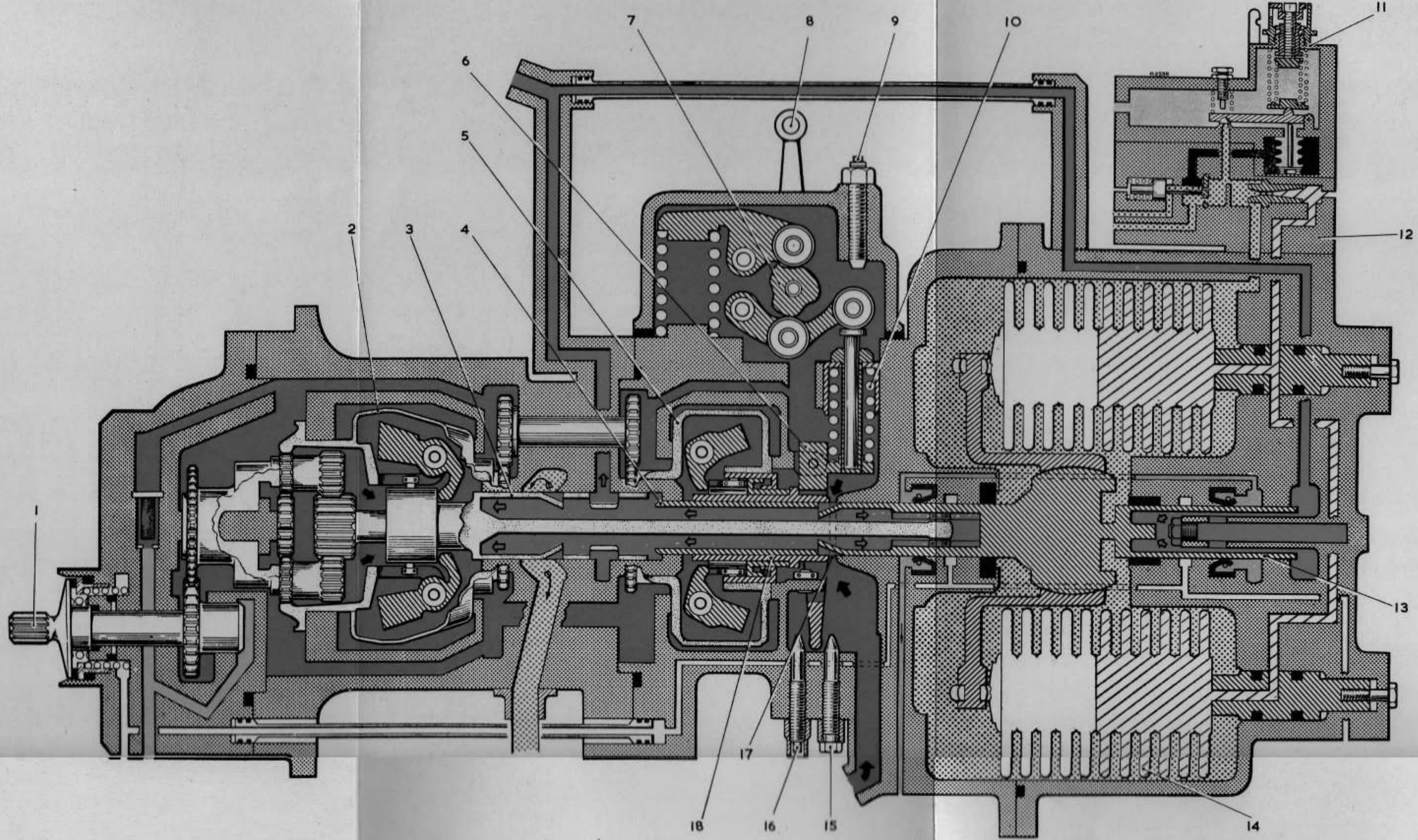


Fig. 3 Functional diagram of fuel control unit. Fig. 3


Instrument panel
from a
Mk4 Jet Provost
(XP558)