

## CHAPTER 8

# THRUST AUGMENTATION

### Objectives

1. The aim of this Chapter is to provide the propulsion fitter with sufficient information about thrust augmentation to cover his trade requirements and to satisfy the relevant Skill and Knowledge Specifications (SAKS) in this subject. After a careful study of this Chapter, you should be able to:

- Describe the components used in a re-heat system and state their purpose.
- Understand the amount of servicing required and the safety precautions to be taken when servicing a re-heat system.
- Describe the effect of water injection upon the thrust of a gas turbine engine.
- Describe two water injection systems.

### Introduction

2. **The need.** There are occasions when an aircraft requires power in excess of the normal maximum thrust provided by its gas turbine engine. Therefore, the need arises for some method of increasing, for short periods, the total thrust available without resorting to a larger engine. There are also situations, such as take-off from high altitude airfields with high ambient temperatures, when the problem is one of obtaining and maintaining the design maximum thrust rather than improving upon it.

3. **Available methods.** There are two main methods of boosting the power output of a gas-turbine engine without increasing its size. These are:

- **Re-heat.** This is normally used for short periods such as during take-off, climb, acceleration; it is a system that is grossly extravagant with fuel. Because the re-heat burners are fitted in the jet pipe behind the turbine unit, the re-heat system, is sometimes called 'after-burning'. However, because after-burning can also be used to mean something else, we shall use the term re-heat in this Chapter.
- **Water or water/methanol injection.** Water or water/methanol injection can be used for longer periods than re-heat, and is used mainly as a means of restoring engine power which has, for one reason or another, been temporarily reduced.

### RE-HEAT

4. **Purpose.** Re-heat is a system fitted to a gas turbine engine as a means of increasing the total thrust obtainable from an engine of a given size. Because it is extravagant with fuel it is suitable to be used for brief periods only; nevertheless, re-heat allows flexibility in handling military aircraft because the extra power can be used when it is needed to improve the rate of climb and, in general, improve the combat capability of an aircraft.

5. **Principle.** The principle of re-heat is similar to that of the gas turbine engine itself—*ie* thrust is obtained as a reaction from accelerating a mass of air through the engine. Re-heat obtains extra thrust from accelerating the exhaust gases in the jet pipe behind the turbine.

The exhaust gases contain oxygen provided by the unburnt cooling air and, by adding burning fuel, they can be 're-heated' to cause an increase in velocity with a substantial gain in useful thrust. A ring of fuel burners is mounted in the jet pipe and fed with fuel from the aircraft tanks, so that the exhaust acts like a ram jet (see Figs 2.1.9 and 2.2.25).

6. **Revision of thrust.** As the air flows through the engine it undergoes many changes in speed, direction and pressure. However, as we learnt in Chapter 1 of this Section, the useful thrust depends upon the mass of air passing through the engine and upon the change in velocity between the air at the intake and that at the exit of the propelling nozzle. For a constant mass airflow, anything which increases the difference between the final velocity and the initial velocity will give an increase in thrust. Re-heat does just this: by burning fuel in the exhaust system behind the turbine we are creating a ram jet which increases the final velocity of the airflow; this in turn, increases the effective thrust from an engine of a given size.

7. **Re-heat thrust gain.** The amount of thrust gained from re-heat depends upon the amount of heat that can safely be added to the exhaust gas without exceeding the temperature limits. Thrust increase can be calculated from the temperature ratio between the temperature of the gases before and after re-heat. If we take a certain engine, we find that the gas temperature before re-heat is 913K (absolute temperature) and, after re-heat, it is 1542K. The temperature ratio is  $1542/913 = 1.69$ . Fig 2.8.1 is a graph of percentage thrust increase against temperature ratio for gas turbine engines and, from this graph, we see that a temperature ratio of 1.69 gives a 30% increase in thrust.

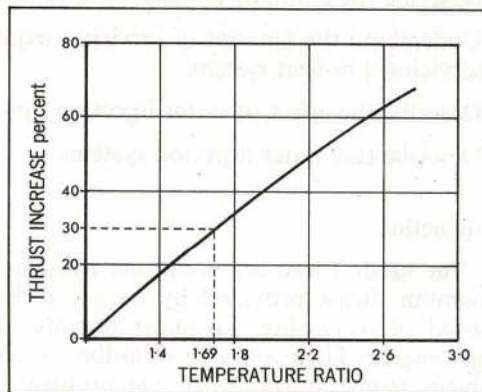


Fig 2.8.1 Thrust increase and temperature ratio

8. **Re-heat and by-pass engines.** When re-heat is fitted to a by-pass engine much greater thrust increase can be obtained. This is because the gas temperature before re-heat is much lower and, hence, the temperature ratio is much higher. Gains in the region of 70% increase in static thrust are readily obtained, with greater gains in thrust at high forward speeds. The limiting factor is the temperature which the jet pipe can withstand.

9. **The advantage of re-heat.** Re-heat provides the best means of substantially increasing the thrust of an engine for short periods. The advantages are those of improved take off, rate of climb, air speed and general combat performance. Re-heat can be selected or cancelled at will by moving the throttle lever into or out of the re-heat position; later re-heat systems provide for varying amounts of re-heat.

10. **The disadvantages of re-heat.** Because of the additional fittings the diameter of the re-heat jet pipe is greater than that of a standard jet pipe for the same engine. Therefore, drag may be increased because the overall frontal area of the engine is increased. There is also a small weight penalty and the maximum continuous thrust is slightly reduced by the drag of the re-heat fittings inside the pipe. Re-heat is grossly extravagant with fuel.

### Propelling Nozzles

11. The design of the jet pipe and nozzle area has a considerable influence upon the overall useful thrust produced by a gas turbine engine. Generally, the jet pipe and the propelling

nozzle match the gas flow characteristics of the engine so that the final pressure and velocity of the gas produces the greatest amount of useful thrust. Thus the area of the propelling nozzle is very important and it must be designed to match the airflow characteristics of the engine if it is to obtain the desired balance between pressure, temperature, and thrust.

12. A fixed area propelling nozzle, as fitted to non-re-heat engines, is a compromise designed to provide an acceptable amount of thrust without being ideal for all engine speeds. The size of a fixed nozzle is chosen to provide its greatest efficiency at high cruising and maximum power rev/min but, undoubtedly, a variable area nozzle would be more efficient.

13. **Re-heat nozzles.** If re-heat was fitted to an engine with a standard sized fixed area propelling nozzle, the expansion of gases caused by the use of re-heat would increase the pressure in the jet pipe and reduce the pressure drop across the turbine (turbine expansion ratio). A reduced turbine expansion ratio will slow down the turbine and consequently lower the engine power. To avoid a rise in pressure at the turbine outlet, the area of the propelling nozzle must be enlarged when re-heat is in use. Thus, the propelling nozzle of a re-heat engine must be able to provide a nozzle area suitable for normal running without re-heat and a larger nozzle area when re-heat is used. Re-heat can be selected only after the throttle lever has passed through a normal 100% position. Therefore, the smallest nozzle area must be efficient at normal maximum power and the larger nozzle area must cater for the re-heat gas flow. If the amount of re-heat can be varied, then the re-heat nozzle must change to match the amount of re-heat selected. There are two main types of re-heat propelling nozzles in use:

- A two position nozzle.

- A variable area nozzle.

14. **The two position nozzle.** These nozzles are either 'closed' for non-re-heat running or 'open' when re-heat is in use. They provide no intermediate position and are used only with non-variable re-heat; because of this, these nozzles have limited application. The area of the propelling nozzle is altered by two hinged fittings called 'eyelids' (Fig 2.8.2). When the eyelids are closed they provide the smaller non-re-heat nozzle area and when they are opened they move clear and allow a fixed size nozzle to provide the larger outlet area for the re-heat gases.

- **Operation.** Each eyelid is moved by two actuators (or pneumatic rams). Synchronizing linkages ensure equal and balanced movement of the eyelids whenever the nozzles change from one area to another (Fig 2.8.2).

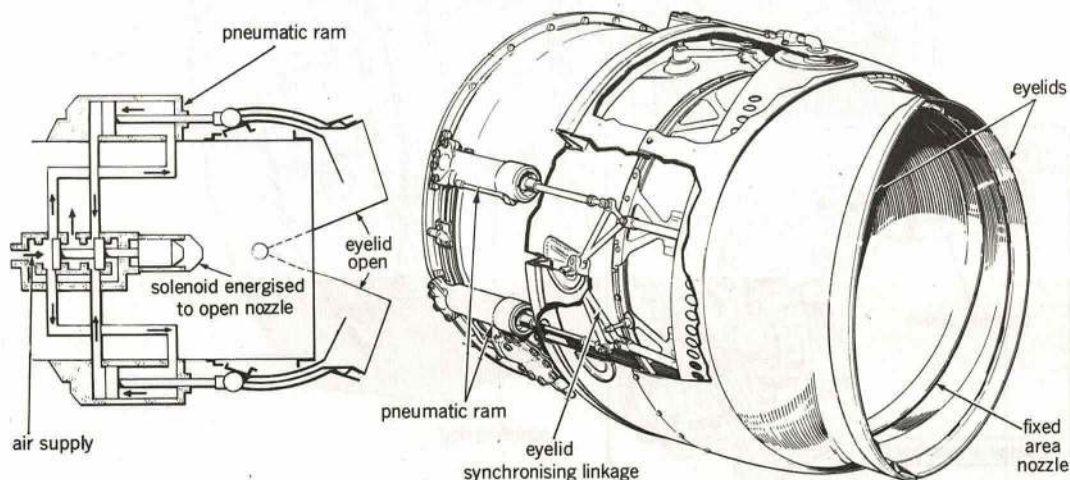


Fig 2.8.2 Two position re-heat nozzle

15. **Variable area nozzles.** This improved propelling nozzle is suitable for use with controllable re-heat systems because it can provide a variable nozzle area to match the amount of re-heat selected. The circular continuity of the nozzle is maintained by a system of hinged flaps. The nozzle area is reduced by positive mechanical means but it is enlarged by the exhaust gas pressure acting upon the inside surface of the flaps.

● **Description.** A ring of hinged master flaps is interleaved with a ring of hinged sealing flaps to provide a variable area propelling nozzle. Each flap is hinged at its forward edge so that the rear edge can move inwards to reduce the nozzle area, or outwards to increase the nozzle area. There is a roller mounted on the outside surface of each master flap to make contact with the inside surface of a conical 'actuating ring' which surrounds the nozzle flaps. A number of screw jacks give the conical actuating ring a limited axial movement so that the ring controls the area of the propelling nozzle (Fig 2.8.3).

There is one screwjack to each master flap and each jack has a spur gear pinion in mesh with the teeth of an annular gear which is driven by a reversible air motor mounted on the

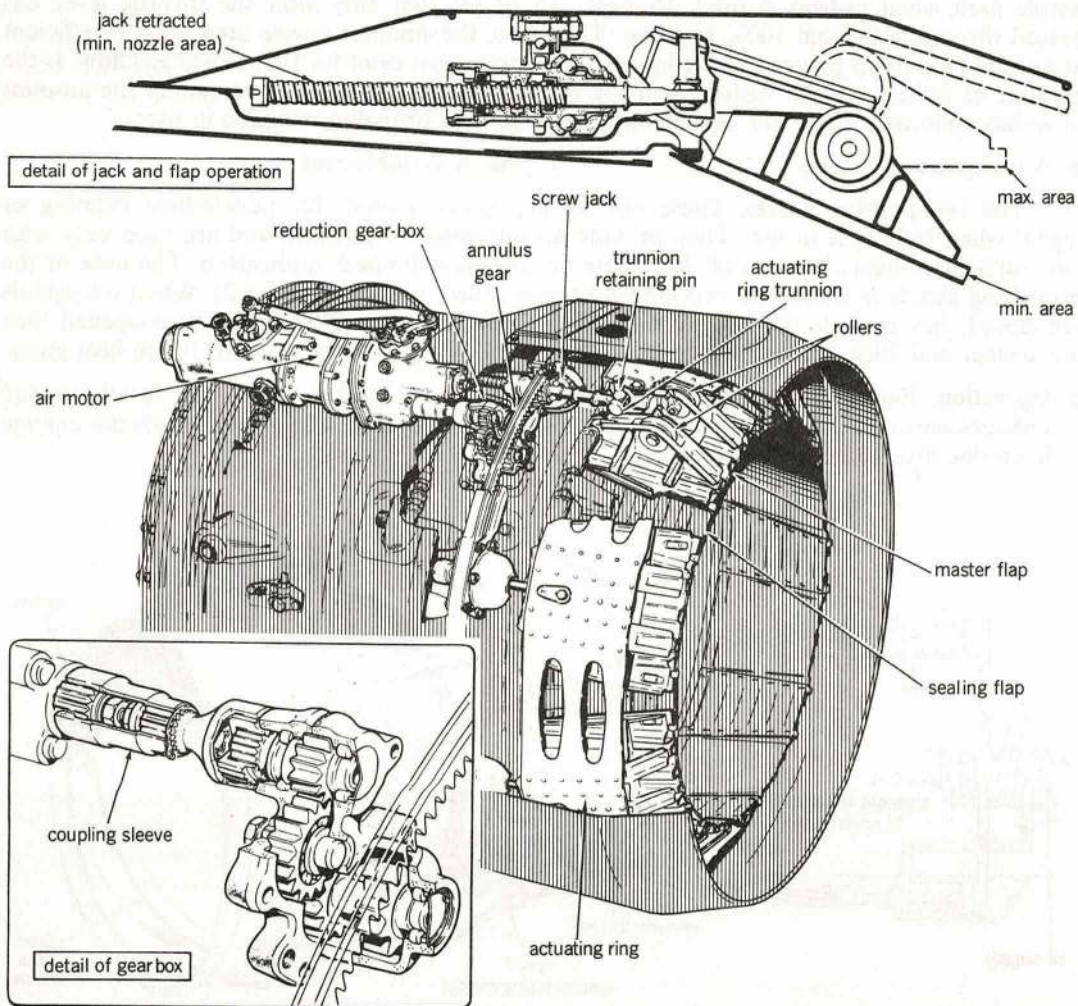


Fig 2.8.3 Variable re-heat propelling nozzle

outside of the jet pipe. A reduction gear between the air motor and the annulus gear enables the air motor to run at a speed which produces sufficient power to ensure operation of the nozzle mechanisms.

- **Operation.** A careful study of Fig 2.8.3 will show that, when the annulus gear turns, it causes the jacks to retract or extend depending upon the direction in which the gear turns. When the jacks are retracting, the actuating ring is being moved forward and the nozzle area is reducing. When the jacks are retracted, the nozzle is at its minimum area position; this is the no re-heat maximum rev/min position. When the throttle lever is advanced to the maximum re-heat position the air motor control unit directs pressure air to drive the air motor so that the annulus gear moves to extend the screw jacks and open the nozzle flaps to give the greatest nozzle area. Thereafter, the air motor control unit signals the air motor to adjust the nozzle area to suit the amount of re-heat selected.

### The Re-heat Jet Pipe

16. **Description.** The re-heat jet pipe is supported at the rear by trunnion mountings and at the front, it slides over the rear end of the intermediate jet pipe (Fig 2.8.4). A sealing ring ensures a gas tight connection between the two pipes, whilst permitting the axial movement necessary to allow for thermal expansion and contraction caused by changes in the temperature of the exhaust gases. Much of the re-heat equipment is fitted inside the pipe but some is mounted on the outside; the propelling nozzle is attached to the rear of the re-heat jet pipe. Made from heat resisting steel with welded joints, the re-heat jet pipe is double skinned and larger in diameter than a standard pipe for the same engine. The larger size is necessary to slow down the gas flow, build up the pressure and cater for the re-heat equipment and burners. A layer of insulating air covers the inner skin and is maintained by a cooling air flow through the space between the skins. To further protect the airframe from excessive heat, the outer skin is surrounded by a heat shield and the nozzle mechanism is encased in a nozzle shroud. An inner circular heat shield is fitted aft of the burner ring; this heat shield consists of overlapping corrugated sleeves. The shield is perforated and corrugated to assist with cooling and also to provide stable combustion; furthermore, it reduces both noise and vibration. This arrangement provides improved cooling for the hot region behind the burners whilst external cooling is achieved by an induced airflow between the re-heat pipe and the aircraft structure.

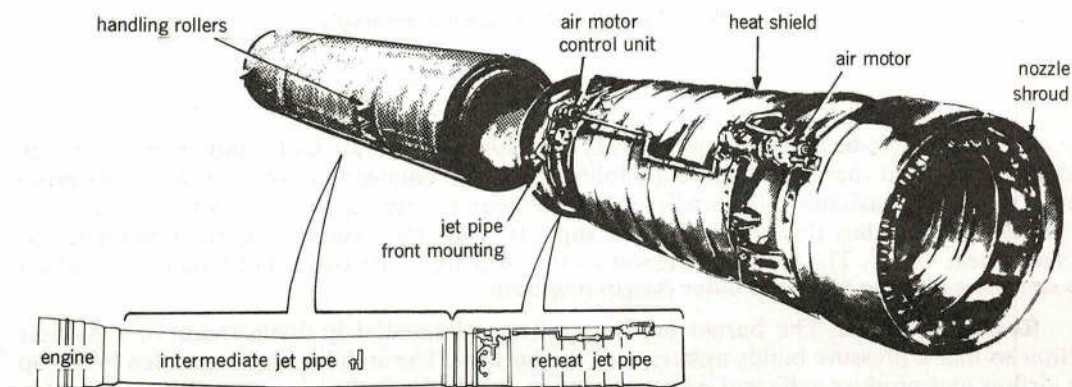


Fig 2.8.4 Re-heat jet pipe

17. **Re-heat flame.** Before looking at the re-heat burners and fuel supply systems we must consider the problem of establishing and stabilizing the re-heat flame. In the re-heat jet pipe, where the flame must burn, the gas flow has a speed of the order of 500 mph (750 ft/sec to

1200 ft/sec). In effect, we are trying to burn fuel in a 'wind tunnel' and the problems are a magnification of those already described in Chapter 2, para 46. Any attempt to establish a flame in the re-heat jet pipe will not succeed unless the airflow can be slowed locally and its pressure increased. Therefore, the burner system must include some type of diffuser equipment.

18. **The burner assembly.** The construction of the re-heat burner assembly varies from one manufacturer to another. However, the burner assembly shown in Fig 2.8.5 is typical of those now in use. This assembly consists of three concentric fuel manifolds, two concentric 'V' section flame stabilizing gutters, and a number of support struts; it is built upon a tubular centre piece. There are three long struts interspaced with three short struts and welded to the centre tube with 60° spacings. These struts locate and secure the burner assembly into the re-heat pipe.

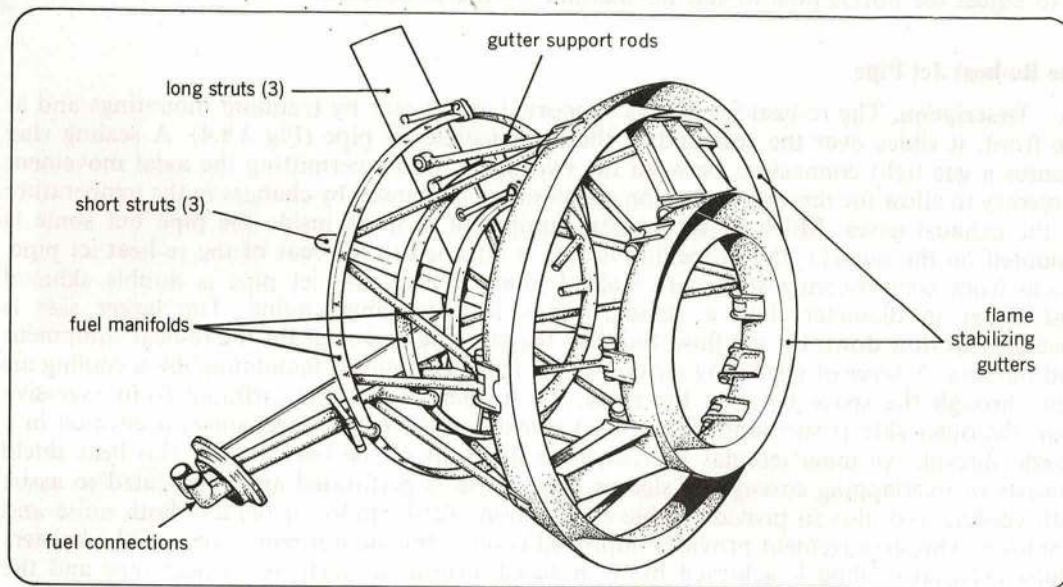


Fig 2.8.5 Typical re-heat burner assembly

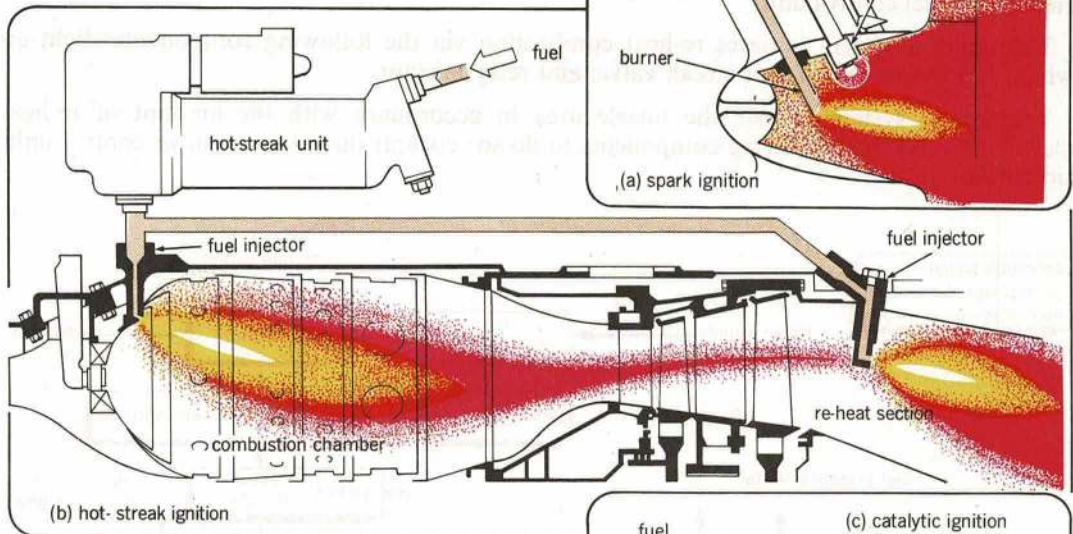
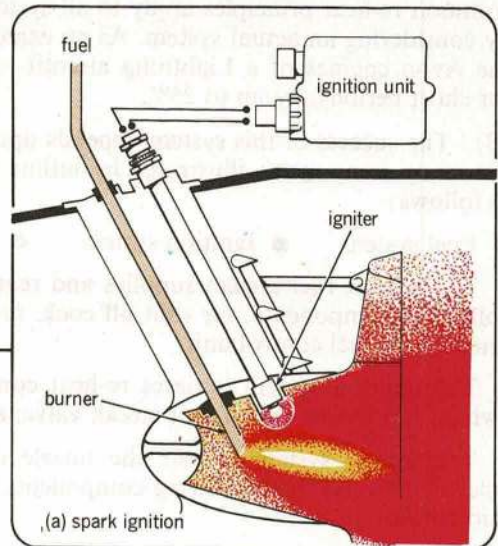
19. **Fuel flow.** A re-heat fuel pump receives fuel from the aircraft tanks and feeds it through two supply lines to the re-heat fuel manifolds. Fuel pipe connections are located at the point where the burner assembly is secured to the re-heat jet pipe and two rigid fuel pipes are positioned immediately downstream of the support strut; the strut shelters the fuel pipes and acts as a heat shield. The fuel pipe nearest to the strut feeds the two smaller manifolds whilst the downstream pipe feeds the outer (large) manifold.

20. **Re-heat operation.** The burner unit is positioned immediately downstream of a diffuser section so that a pressure builds upstream of the burners. The stabilizing gutters then break up the airflow and produce sufficient eddy currents to enable the flame to survive. When re-heat is selected, high pressure fuel is fed to the manifolds and sprayed into the re-heat pipe through the many jets in the manifolds. A suitable means of igniting the fuel is used (*see* para 21), and the flame is held in position by the action of the stabilizing gutters. For full re-heat, all the manifolds are spraying fuels but, for a reduced amount of re-heat, fuel is fed to the two inner manifolds only.

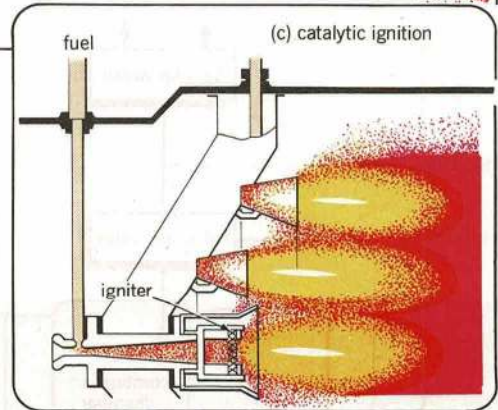
21. **Re-heat ignition.** The atomized fuel spray is fed into the re-heat jet pipe and ignited by one of three methods:

- Spark ignition
- Hot streak ignition
- Catalytic ignition.

a. **Spark ignition.** Spark ignition for re-heat fuel is similar to normal engine ignition. Light-up is obtained by using a pilot fuel burner and an igniter plug. The igniter plug is fitted downstream of the pilot burner in a conical fitting that is a part of the re-heat system. The core provides airflow conditions suitable for light-up and, when fuel is sprayed from the pilot burner, it is carried on to the igniter plug and ignition takes place (Fig 2.8.6a).



b. **Hot streak ignition.** The hot streak ignition system is more often called 'hot shot' ignition. It consists of two fuel injectors; one sprays fuel into the engine combustion system and the other sprays fuel into the re-heat region of the re-heat jet pipe (Fig 2.8.6b). Spraying additional fuel into the main combustion area causes an elongated flame and a 'hot streak' flame reaches, and ignites, the re-heat fuel. The turbine blades are not damaged because the hot streak flame is of short duration.



c. **Catalytic ignition.** Catalytic ignition is achieved by use of a platinum/rhodium element (Fig 2.8.6). Atomized fuel is sprayed over the element and a chemical reaction causes spontaneous ignition.

Fig 2.8.6 Re-heat ignition

## RE-HEAT SYSTEMS

22. Having dealt with re-heat in a general way it is now time to see how a specific system works. Although re-heat systems differ in detail from one type of engine to another, some common re-heat principles apply to all systems. These applications can best be demonstrated by considering an actual system. As an example, we shall consider the re-heat system fitted to the Avon engines of a Lightning aircraft—a system that improves the engine performance, for short periods, by up to 25%.

23. The success of this system depends upon the timing of the various inter-actions between the many components illustrated in outline in Fig 2.8.7. Four sub-systems may be identified, as follows:

- Fuel system
- Ignition system
- Nozzle system
- Trip system.

The re-heat fuel system supplies and regulates the fuel flow to the re-heat burners via the following components: air shut-off cock, re-heat fuel pump, servo bleed unit/re-heat throttle, and re-heat fuel control unit.

The ignition system initiates re-heat combustion via the following components: light-up switch, hot streak switch, hot streak valve, and relay injector.

The nozzle system adjusts the nozzle area in accordance with the amount of re-heat selected and uses the following components to do so: cockpit throttle, air motor control unit, and air motor.

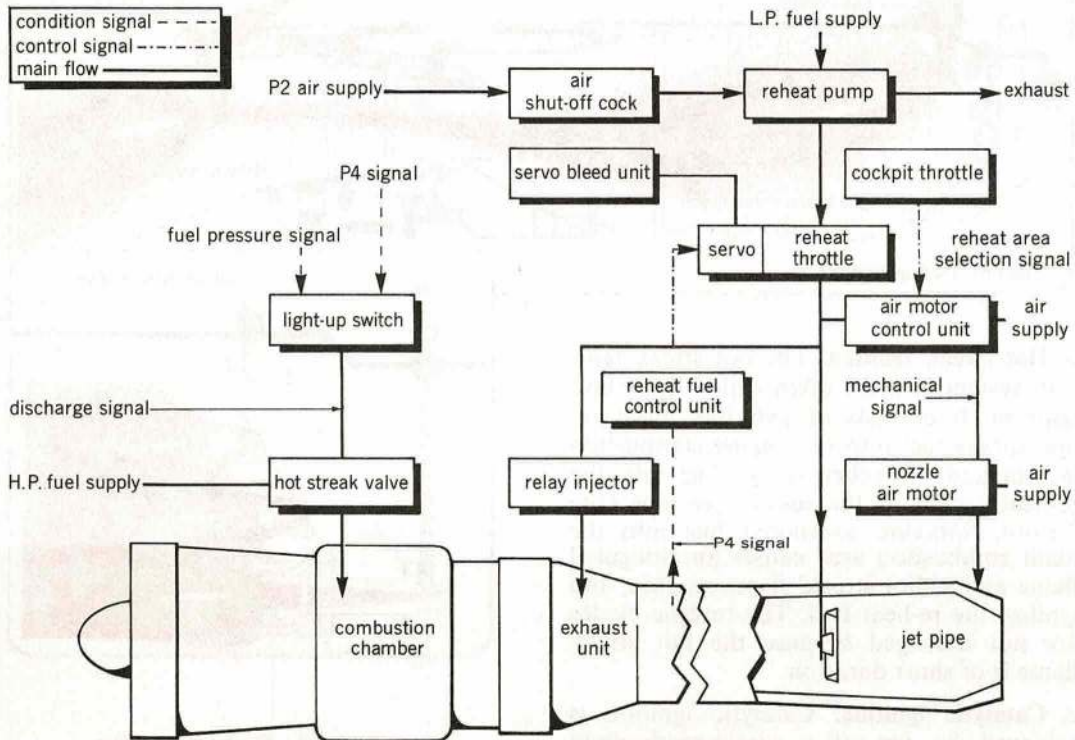


Fig 2.8.7 Re-heat system (interaction)

The trip system automatically cancels re-heat if it senses a serious fault in the system. It does so by monitoring various signals at certain critical points in the system.

We shall now consider each of these sub-systems in turn.

### Fuel System

24. **Fuel circuit.** Examination of Fig 2.8.8 on p 2.8.24 will show that fuel from the aircraft fuel tanks (low pressure fuel inlet) is supplied to a turbo fuel pump—which is driven by an air supply (P2) controlled by an electrically selected air shut-off cock. The pump output is supplied via the throttle plunger in the pump and the burner staging valve in the air motor control unit to the fuel manifolds in the re-heat burners.

25. **Fuel control.** The amount of fuel fed to the re-heat burner system is controlled by a servo throttle plunger which is fitted into the turbo fuel pump housing. The servo pressure acting upon the throttle valve is controlled by a bleed valve solenoid and by a re-heat fuel control unit. When re-heat is not in use, the bleed valve is open and the servo fuel is spilled into the low pressure side of the system.

26. When fuel has passed the throttle plunger it divides and feeds fuel to the air motor control unit and also to the hot-streak relay injector. The fuel flowing to the air motor control unit provides servo fuel for operation of the unit and also a fuel feed to the burner staging valve. The burner staging valve divides the re-heat fuel feed and directs it along two pipelines. One line feeds the inner two fuel manifolds and is in use whenever re-heat is selected. The other line leads fuel to the larger, outer, fuel manifold and is in use only when full re-heat is selected. In other words, both fuel lines are in use for full re-heat, but only the fuel feed to the two smaller manifolds is needed for minimum re-heat.

### Ignition System

27. This 'all fuel' ignition system is operated by three components; these are: the 'light-up' switch, the 'hot streak' valve, and the relay injector. The fuel spray from the re-heat fuel manifolds is ignited by a streak of flame that originates in the engine's combustion system (see para 21b). The streak of flame is produced by a discharge of fuel from the hot streak unit. This unit discharges a calibrated amount of fuel into number one flame tube when it receives a suitable signal from the re-heat light-up switch (Fig 2.8.8). To back up the hot streak, and to sustain the flame, the relay injector sprays supplementary fuel into the main engine jet pipe downstream of the turbines. It is the continuation of the flame, caused by the supplementary fuel, that ignites the re-heat fuel in the re-heat jet pipe. Injecting fuel downstream of the turbine reduces the amount of extra fuel needed in the flame tube and prevents overheating of the turbine assembly.

### Nozzle System

28. The area of the propelling nozzle is altered by a mechanism that is powered by an air motor mounted on the nozzle casing (Fig 2.8.8). The air motor is controlled by a linkage connected to the air motor control unit. When re-heat is selected, an electrical 're-heat selected' signal is passed to the air motor control unit which operates the air motor to adjust the re-heat nozzle area.

29. **Re-heat control.** Selecting re-heat mechanically connects the pilot's throttle lever to the air motor control unit and places the re-heat nozzle area directly under the control of the throttle lever. Thereafter, when the throttle lever is moved, the nozzle will automatically move to an area suitable for the amount of re-heat selected.

## Automatic Trip System

30. The automatic trip device is fitted as a safety, or fail safe, system in case of re-heat or allied failure (see Fig 2.8.9). This system will cancel re-heat in any of the following conditions:

- **Low fuel inlet pressure.** If the fuel inlet pressure drops below a predetermined value, re-heat is cancelled by a fuel switch which signals the trip relay and gives a fuel warning. The trip relay initiates re-heat shut down to ensure that the engine-driven fuel pumps are not robbed of fuel by the re-heat system.
- **Engine flame out.** The drop in jet pipe pressure caused by an engine flame out is felt by a pressure sensitive microjet which signals the trip relay to shut down the re-heat system.
- **Excessive jet pipe temperature.** If the jet pipe temperature exceeds the safe maximum value, an amplified electrical voltage signals the trip relay and also indicates excessive temperature on the cockpit gauge. The trip relay shuts the re-heat system down.
- **Re-heat—failure to light-up.** If, when selected, re-heat does not light up, there are two fail safe devices fitted for cancelling re-heat. Which device is effective depends upon the type of failure and whether the ignition system operates or not. The failures are:
  - **The ignition operates.** If the ignition system operates but does not achieve a 'light-up', the microjet switch contacts remain at weak and re-heat cancels as it does in a flame out condition.
  - **The ignition fails.** If the ignition system does not operate because of a faulty 'light-up' switch, or similar failure, a time switch cancels re-heat after 5 seconds.

31. Under any of the above-mentioned conditions, the cancel signal must endure for two seconds before the trip relay operates to cancel re-heat. When the relay operates, Fig 2.8.9 shows that:

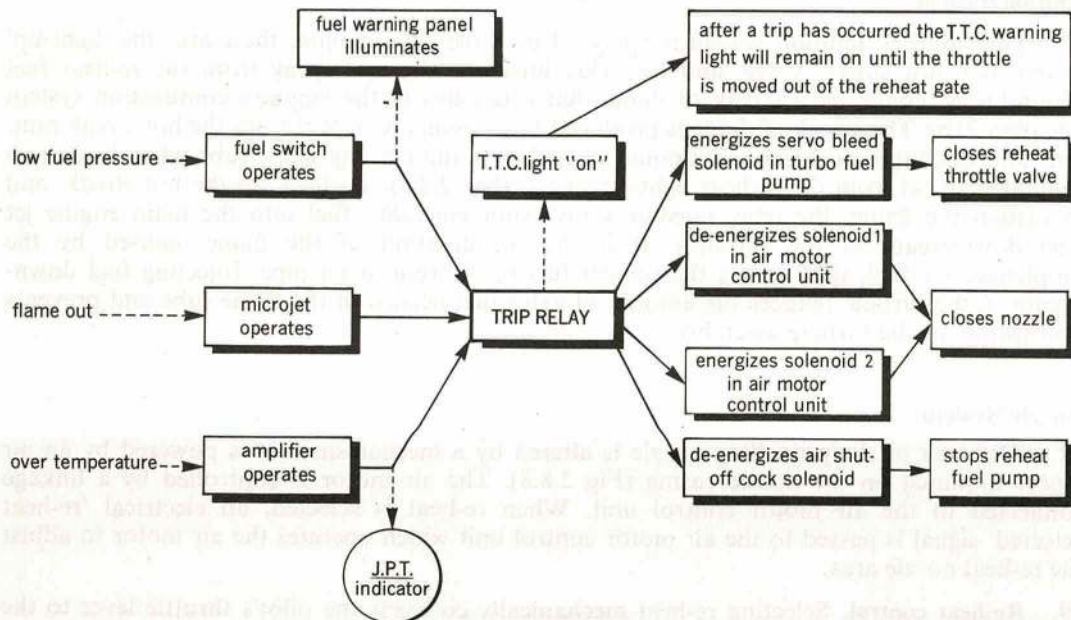


Fig 2.8.9 Re-heat trip system

- A cockpit panel warning light comes on.
- The bleed solenoid in the re-heat turbo fuel pump is energized and this closes the throttle plunger to cut off the supply of re-heat fuel.
- Solenoids in the air motor control unit operate the air motor which, in turn, closes the nozzle to the non-re-heat position.
- The air shut-off cock is de-energized and this shuts down the re-heat turbo fuel pump.

To cancel the warning the throttle lever must be moved back through the gate to the non-re-heat position.

### ELECTRICAL CO-ORDINATION (see also Fig 2.8.8 on p 2.8.24)

32. To operate the re-heat system successfully, the nozzle operation, fuel flow and ignition system must be synchronized. This is done electrically, the whole re-heat system being triggered when the pilot's throttle lever is moved through the 'gate' into the re-heat position. When this happens, a re-heat throttle micro switch is operated and this supplies power to the electrical parts of the re-heat circuit (Fig 2.8.10). The result is as follows:

- A solenoid in the air motor control unit is energized and this connects the air motor directly to the pilot's throttle lever to open the nozzle as required by the amount of re-heat selected. The nozzle position is also indicated on a cockpit panel.
- The air shut-off cock is energized to operate the turbo fuel pump, and the servo bleed solenoid in this pump is de-energized, to provide a supply of fuel through the burner staging valve in the air motor control unit to the re-heat fuel manifolds.
- The hot streak unit and the hot streak relay injector are both energized to provide ignition.

When injection, fuel, and nozzle operations are all completed as described above, the re-heat lights up, as indicated in Fig 2.8.10.

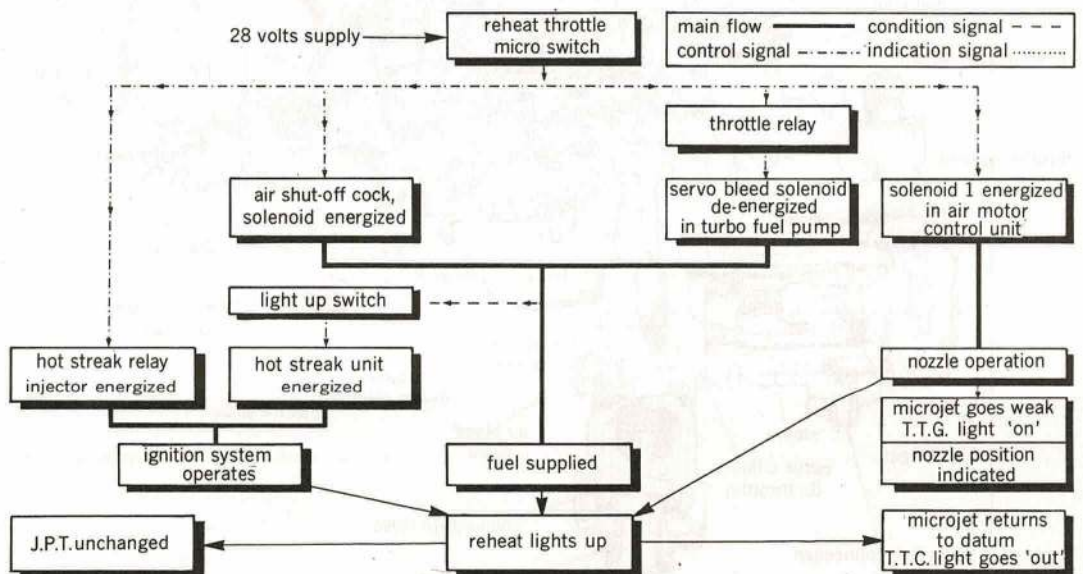


Fig 2.8.10 Re-heat operation (electrical)

## NON RE-HEAT OPERATION

33. Because the engines being considered are fitted with variable area propelling nozzles, the variable properties of the nozzle can also be used with advantage in the non-re-heat running conditions. Economy is achieved by varying the nozzle area for non-re-heat running. Up to power selections of 95% rev/min, the air motor control unit calls upon the air motor to provide a larger nozzle area; above 95% the nozzle is moved to the smaller non-re-heat 'take-off' area. The changeover from cruise nozzle area to take-off area takes place when the rev/min switch sends a speed condition electrical signal to the air motor control.

34. **Changeover stability.** When the nozzle area is changed, it causes a small temporary drop in engine speed which could cause instability if the change took place always at the same rev/min. To prevent instability, the rev/min switch is set to signal for a nozzle change at 95% rev/min on acceleration and at 87% rev/min on deceleration.

## SYSTEM COMPONENTS

### Fuel Pump

35. The high pressure turbo fuel pump which supplies the re-heat fuel is an airframe mounted component. It is a self-contained unit with a centrifugal fuel pump driven by a two stage axial

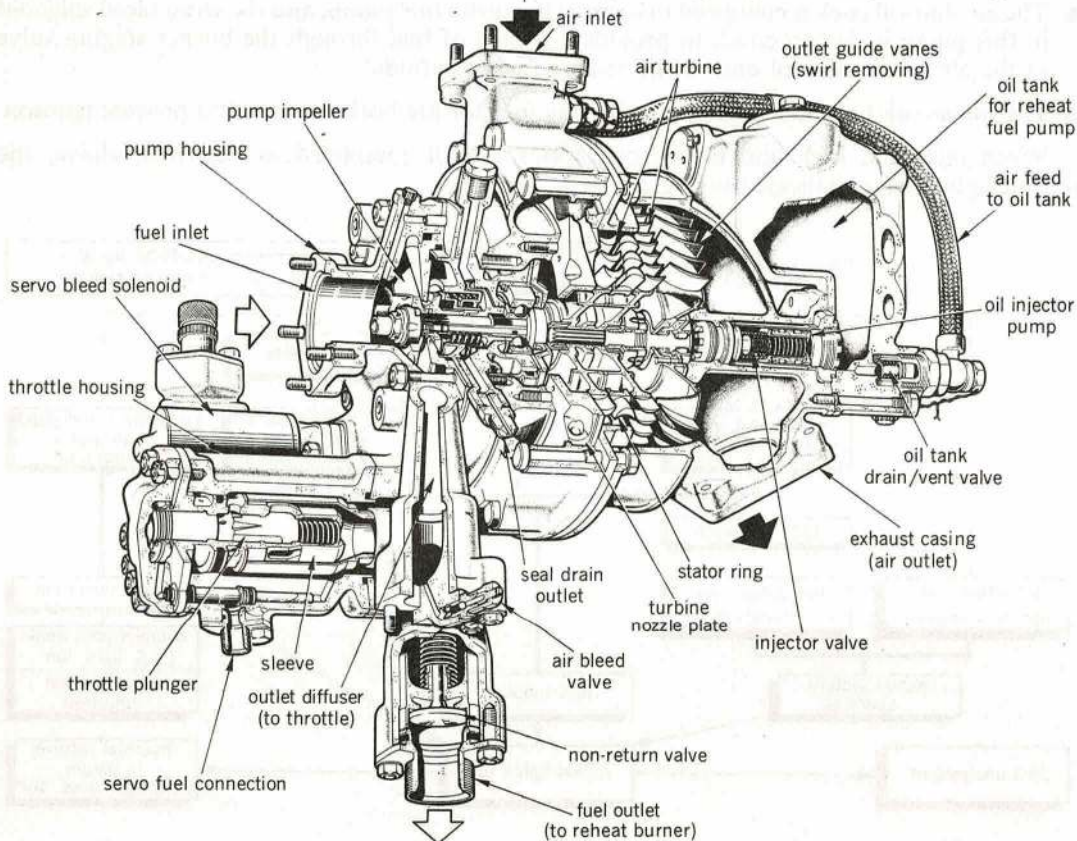


Fig 2.8.11 Re-heat fuel pump

flow air driven turbine (Fig 2.8.11). The air supply is controlled by an air shut-off cock that is mounted on the engine casing and is automatically opened when re-heat is selected. The turbo-pump carries its own oil supply, and oil is fed to the bearings by an air pressure operated oil injector pump. The fuel inlet, from the aircraft fuel system, is into the eye of the centrifugal pump impeller, and the fuel outlet to the re-heat burners is through an outlet port in the throttle valve housing.

### The Air Shut-off Cock

36. The air shut-off cock is mounted on the left side of the compressor casing where it receives P2 air from the engine compressor (Fig 2.8.12). Its purpose is to control the flow of air that powers the air turbine of the fuel pump. The light alloy casing provides an air inlet port, an air outlet port and two axially aligned cylinders with different diameter bores. Two pistons and the valve of the shut-off cock are assembled on to a through bolt to form a floating valve assembly with one piston in each cylinder. The outer end of the small diameter cylinder is vented to atmosphere to allow free movement of the floating assembly. P2 air enters through the inlet port into the space between the two pistons and, when the cock is open, the air continues to the inlet side of the fuel pump air turbine.

37. **Operation.** We shall now see that the P2 air pressure provides the force which opens the valve of the shut-off cock. Calibrated holes in the larger piston allow a controlled flow of air to pass through the piston into the outer end of the cylinder. A duct leads the bleed air to a solenoid operated bleed valve which, when open, allows the air to flow out of the housing without applying pressure to the outer face of the piston. When the solenoid is energized the valve is open and the bleed air is spilled to atmosphere; thus, the force acting on the inner face of the larger piston is greater than the force acting on the small piston and the shut-off cock is held open. When the solenoid is de-energized the bleed valve is closed and the forces acting upon the floating piston assembly moves the valve to the shut-off position. Therefore, we find that:

- When the solenoid is energized, the shut-off cock is open and the fuel pump is operating; this is the re-heat situation.

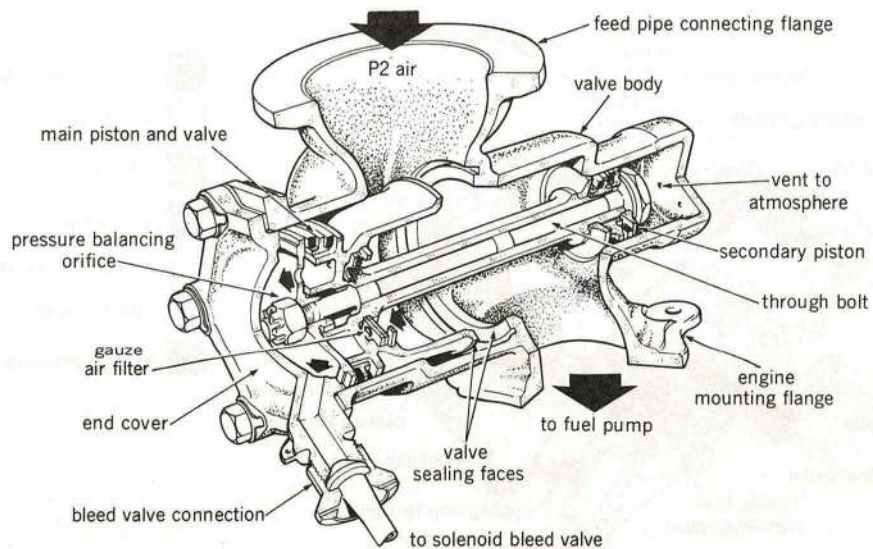


Fig 2.8.12 Air shut-off cock

- When the solenoid is de-energized, the shut-off cock is closed; this is the non-re-heat situation.

### Throttle Valve

38. The re-heat throttle valve is operated hydraulically and has no mechanical connections. It is situated at the fuel pump outlet and consists mainly of a profiled plunger operating inside a ported sleeve and spring loaded to the closed position (Fig 2.8.11 and Fig 2.8.8). The pump outlet pressure is led to the ported sleeve and, through restrictors, to act as throttle servo pressure on the end of the throttle valve remote from the spring; thus, servo pressure fuel opposes the closing pressure of the plunger spring. Throttle servo pressure is controlled by two spill valves; one spill valve is mounted on the fuel pump casing and is solenoid operated. In the non-re-heat position this solenoid is energized to hold the servo spill valve open. The open spill valve removes the servo pressure from the end of the plunger so that the spring can keep the re-heat throttle closed. When re-heat is selected, the solenoid is de-energized to close the spill valve, thus causing a build-up of servo pressure sufficient to open the throttle valve. This spill valve is either opened or closed and no provision is made for variations. Therefore, to obtain variable throttle positions, we must look to the second servo spill valve. This valve is situated in the re-heat fuel control unit and is capable of providing varied throttle servo pressure.

### Re-heat Fuel Control Unit

39. The spill valve in the re-heat control unit is the second of the two throttle servo spill valves referred to in para 38. It controls the throttle position and fuel flow for variable amounts of re-heat. The half ball spill valve is controlled by a diaphragm which is subjected to the following forces:

- Closing forces:  $\left. \begin{array}{l} \text{spring pressure} \\ \text{split P2 pressure} \end{array} \right\}$  —forces tending to increase re-heat fuel flow.
- Opening forces: exhaust (P4) pressure—a force tending to decrease re-heat fuel flow.

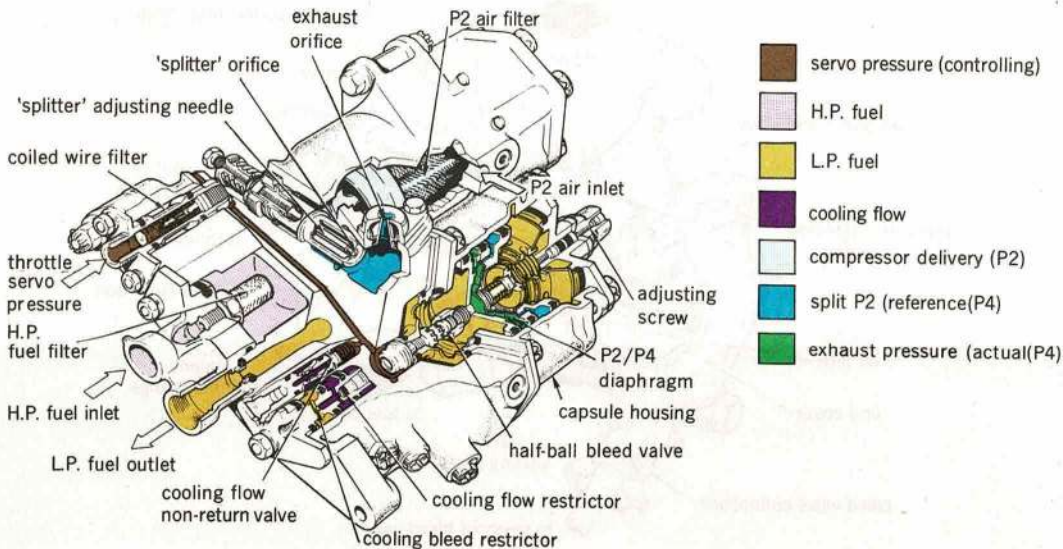


Fig 2.8.13 Re-heat fuel control unit

The spill valve will continue to move and vary the position of the throttle valve until the forces acting upon the diaphragm are in balance (Fig 2.8.13). Thus we have a means of catering for variable re-heat related to P4 pressure. A build-up of exhaust (P4) gas pressure can have an adverse effect upon engine performance and leading jet pipe pressure (P4) to the opening side of the spill valve diaphragm will prevent re-heat from causing such a pressure rise.

40. **Selecting increased re-heat.** Immediately an increase in re-heat is selected, the propulsion nozzle area is increased and this causes a drop in the value of P4 pressure. Decreasing P4 pressure upsets the balanced forces acting upon the re-heat fuel control unit diaphragm, allowing the combined efforts of the diaphragm spring and split P2 pressure to close the servo bleed and, by increasing the throttle servo pressure, increase the re-heat fuel flow with a corresponding increase in re-heat thrust. The sequence is reversed when a decrease in re-heat is selected.

### Rev/Min Switch

41. The rev/min switch is mounted on the compressor casing and provides an engine speed sensitive signal for the air motor control unit when the engine is running without re-heat; this allows the selection of a correct nozzle area for the prevailing conditions. The switch is sensitive to engine

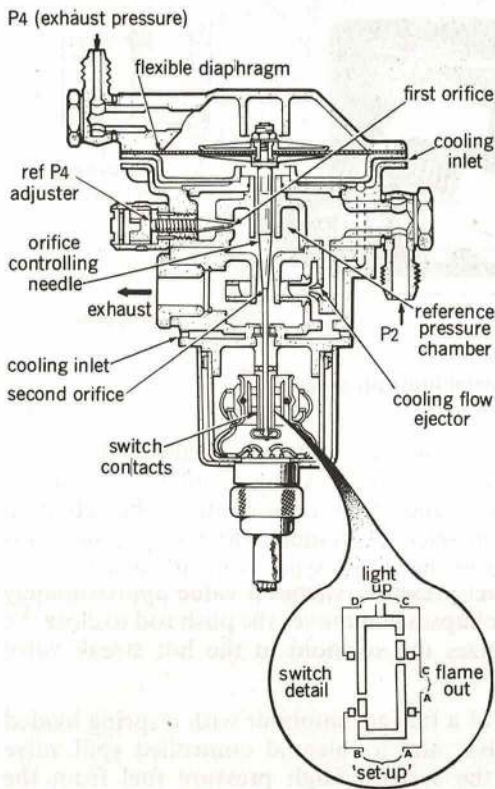


Fig 2.8.15 Microjet switch

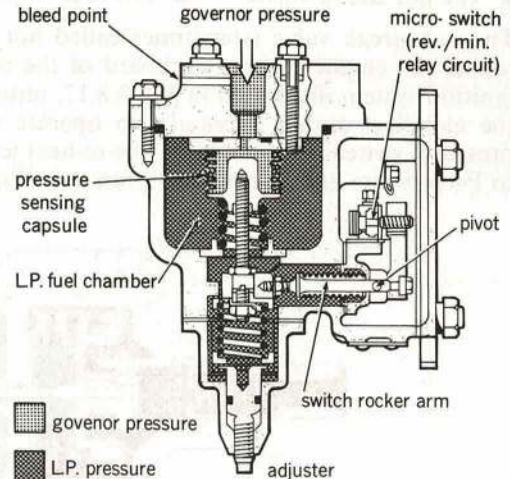


Fig 2.8.14 Rev/min switch

governor fuel pressure which it uses as a measure of engine speed (Fig 2.8.14). A micro switch within the rev/min unit operates electrical contacts so that a signal is sent to the air motor control unit at 95% rev/min as the engine accelerates and at 87% rev/min when the engine decelerates. These signals cause the air motor control unit to select nozzle areas to suit the engine running conditions:

- At 95% the nozzle area is reduced to the non-re-heat 'take-off' position.
- At 87% and below the nozzle area is increased to give an area suitable for economical cruising (see also para 34).

### Micro-jet Switch

42. Mounted on the port side of the compressor casing, this unit contains switch contacts which are opened or closed by the

movement of a needle attached to a flexible diaphragm (Fig 2.8.15). The diaphragm is subjected to P4 (exhaust) pressure on one side, and by split P2 (from compressor) on the other. To prevent split P2 building up to P2 pressure the needle is profiled to permit a calibrated bleed to atmosphere. This switch senses any fall in P4 pressure (eg due to flame out) and causes the TTC warning light to come ON. If re-heat does not light up and increase P4 pressure, the micro jet switch will initiate a re-heat shut-down sequence (see para 31).

### Hot Streak Ignition

43. The hot streak ignition can be considered as a system requiring an interaction between the following three components:

- The hot streak valve.
- The relay injector.
- The light up switch.

The hot streak valve (sometimes called hot shot) and the relay injector are mounted at the top of the engine casing, starboard of the centre line. They constitute the main parts of the ignition system illustrated in Fig 2.8.17, although the contacts in the light up switch complete the electrical circuit necessary to operate the hot streak valve. The light up (differential pressure) switch is mounted on the re-heat jet pipe forward of the burner unit and is subjected to P4 pressure and re-heat fuel pressures (Fig 2.8.16).

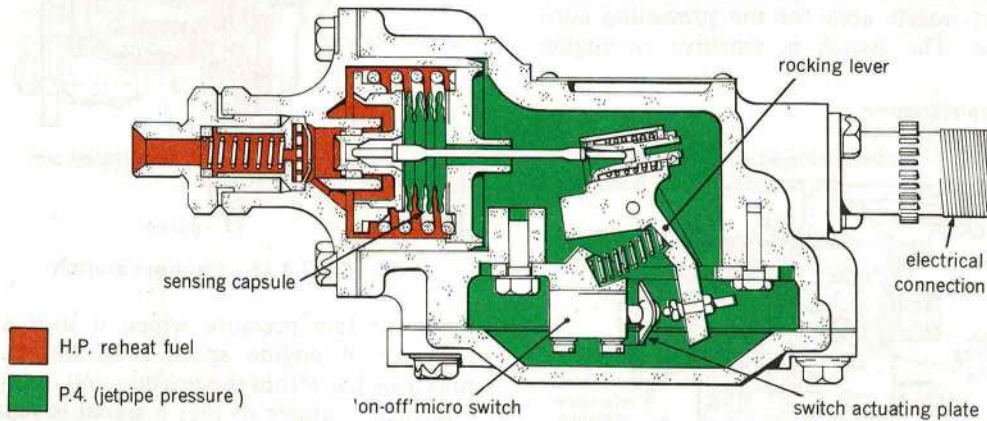


Fig 2.8.16 Pressure differential light up switch

44. **Light up switch.** Briefly, this switch consists of a pressure sensing capsule with re-heat fuel pressure on the outside and P4 (exhaust) pressure inside. A push rod relays capsule movement to one end of a rocking lever, and the other end of the lever contacts the actuating plate of an 'ON-OFF' micro switch (Fig 2.8.16). On selecting re-heat, the fuel pressure acts upon the outside of the pressure sensitive capsule and the P4 pressure is insufficient to resist the higher pressure of the re-heat fuel. When the fuel pressure reaches a value approximately 5 bars (75 psi) greater than P4 pressure, the capsule collapses and moves the push rod to close the switch contacts. Closing the switch contacts energizes the solenoid in the hot streak valve (Fig 2.8.17).

45. **Hot streak valve.** The hot streak valve consists of a fuel accumulator with a spring loaded recuperating piston, a servo piston and outlet valve, and a solenoid controlled spill valve which returns the spill fuel into the LP side of the system. High pressure fuel from the compressor bleed valve ram is fed into the accumulator which re-charges when the solenoid is de-energized, with both the spill valve and the servo valve closed. When a voltage from the

'light up' switch energizes the solenoid, the accumulator discharges its fuel into number one combustion chamber and initiates the hot streak flame; this flame is backed up by fuel from the hot streak relay injector (Fig 2.8.17).

46. **Hot streak relay injector.** This unit is a 'shut-off' cock positioned in the fuel line between the re-heat throttle and the jet pipe downstream of the turbines. It consists of a spring loaded servo piston shut-off valve and a solenoid operated servo spill valve. When the solenoid is de-energized, the servo fuel pressure plus the spring will keep the cock closed but, when the solenoid is energized, the servo pressure bleeds away so that the high pressure re-heat fuel can open the piston valve and feed fuel into the jet pipe to continue the hot streak flame rearwards to ignite the re-heat fuel.

47. The solenoid of the hot streak relay injector is energized by contacts in the time delay switch unit. At the appropriate point in the cycle after light up the time delay switch will de-energize the solenoids of the hot streak valve and the relay injector.

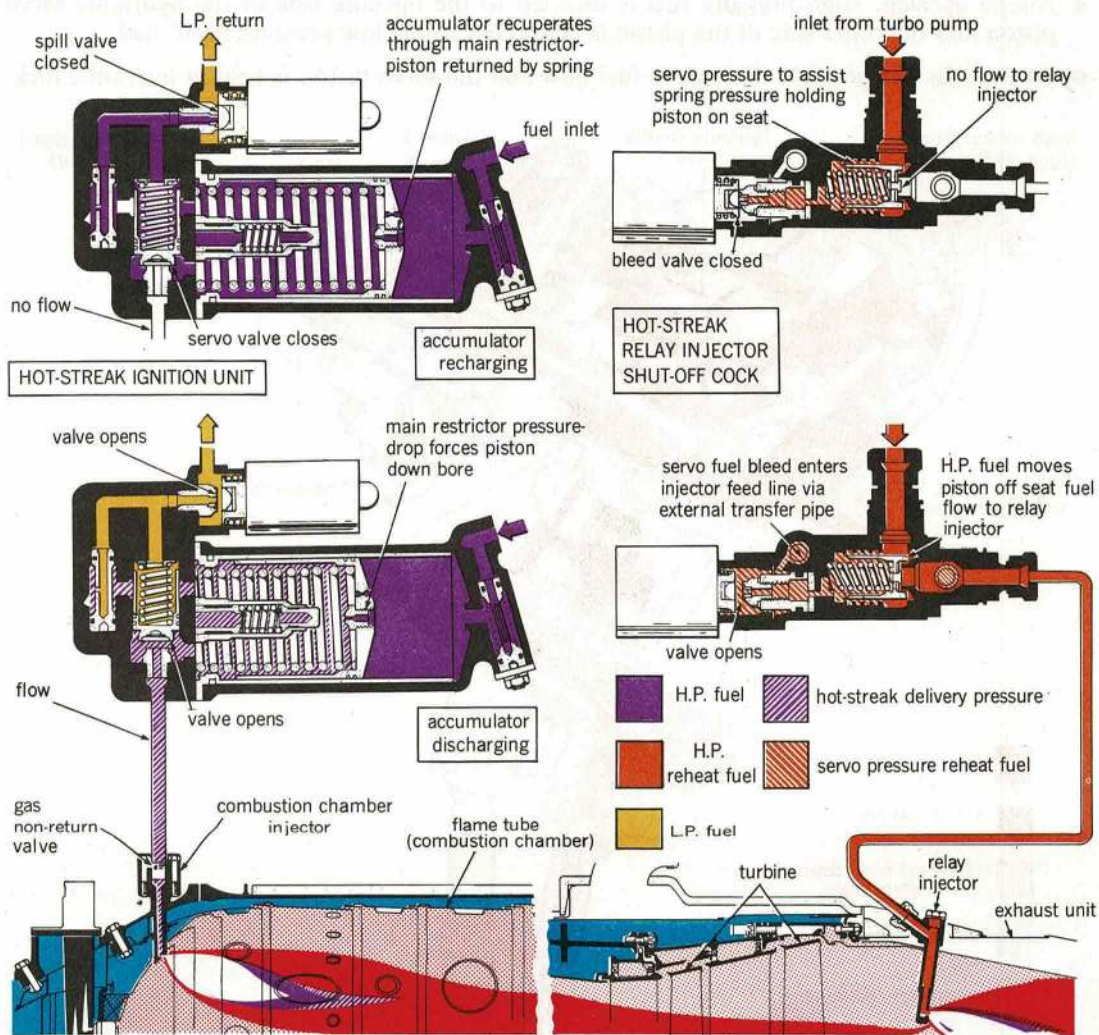


Fig 2.8.17 Hot streak ignition system

## Air Motor Control Unit

48. The air motor control unit (AMCU) is mounted on the left hand side of the re-heat jet pipe and mechanically connected to the air motor. The AMCU relays the re-heat selections to the air motor so that the appropriate nozzle area is provided. The control signal from the AMCU to the air motor is made mechanically by a pneumatically operated ram and rods (Fig 2.8.18). The AMCU consists mainly of a pneumatic ram moved by P2 air pressure, the hydraulic stop rod and servo piston to position the ram, the hydraulic shuttle valve to position the stop, a control input lever, a valve control lever and sundry spill valves, solenoid valves, ducts, ports and passages to feed or bleed fuel and air as necessary.

49. **Operation.** The waisted shuttle valve moves in a ported sleeve and is connected to the valve control lever so that it can be repositioned by movement of the input lever, or by movement of the hydraulic stop servo piston. High pressure re-heat fuel is fed to the waist of shuttle valve so that the ported sleeve provides three positions only. These are:

- **Nozzle opening.** High pressure fuel is directed to the opening side of the hydraulic servo piston and the other side of the piston is connected to the low pressure bleed fuel.
- **Neutral.** In this position there is no fuel flow and the servo piston is held in hydraulic lock.

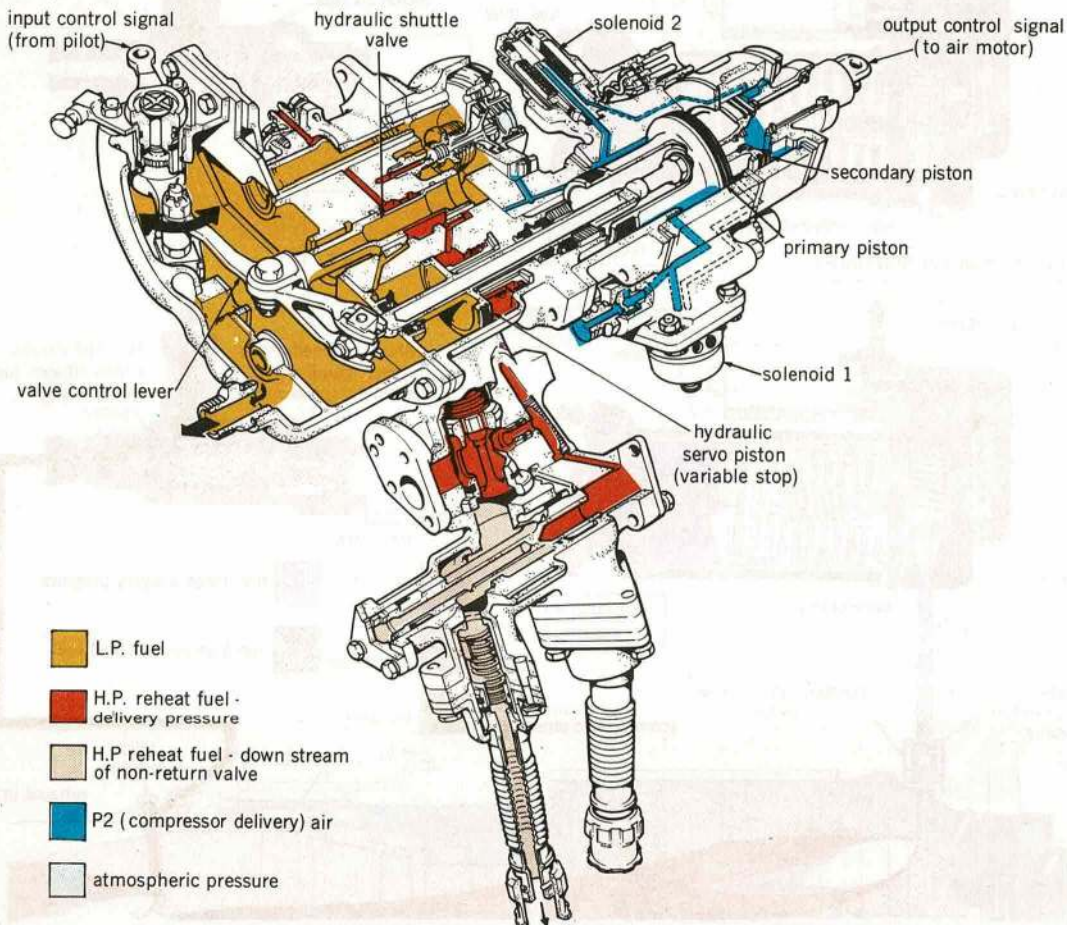


Fig 2.8.18 Air motor control unit

This situation indicates that the selected position has been achieved. The mechanism always moves into this position.

- **Nozzle closing.** This is opposite from opening and the shuttle valve has reversed the fuel flow.

The pneumatic ram is positioned by the hydraulic stop to control the air motor and hence, the area of the propelling nozzles.

50. An input signal from the throttle lever will cause the control lever to pivot about the servo piston rod and move the shuttle valve away from the neutral position. When the shuttle valve is moved from its neutral position, pressure fuel is fed to one side of the servo piston and the other side of the piston is connected to spill. The servo piston and hydraulic stop will move in the direction necessary to provide the nozzle area signalled by the input lever.

### The Air Motor

51. The air motor is mounted on the nozzle part of the jet pipe and drives the nozzle operating mechanism through a reduction gearbox. The air motor is a reversible unit consisting of two 3-lobe rotors which are meshed together and rotate in opposite directions when driven by the high pressure (P2) air supply. The air supply to the rotors is controlled by a rotary valve that is operated by the control linkage connected to the pneumatic ram in the AMCU. Depending upon the movement given to the rotary air control valve by the AMCU, the motor can be stopped, reversed or accelerated (Fig 2.8.19). The output shaft from the motor carries a worm gear which meshes with an epicyclic resetting mechanism that shuts off the air supply when the nozzle area matches the re-heat selected.

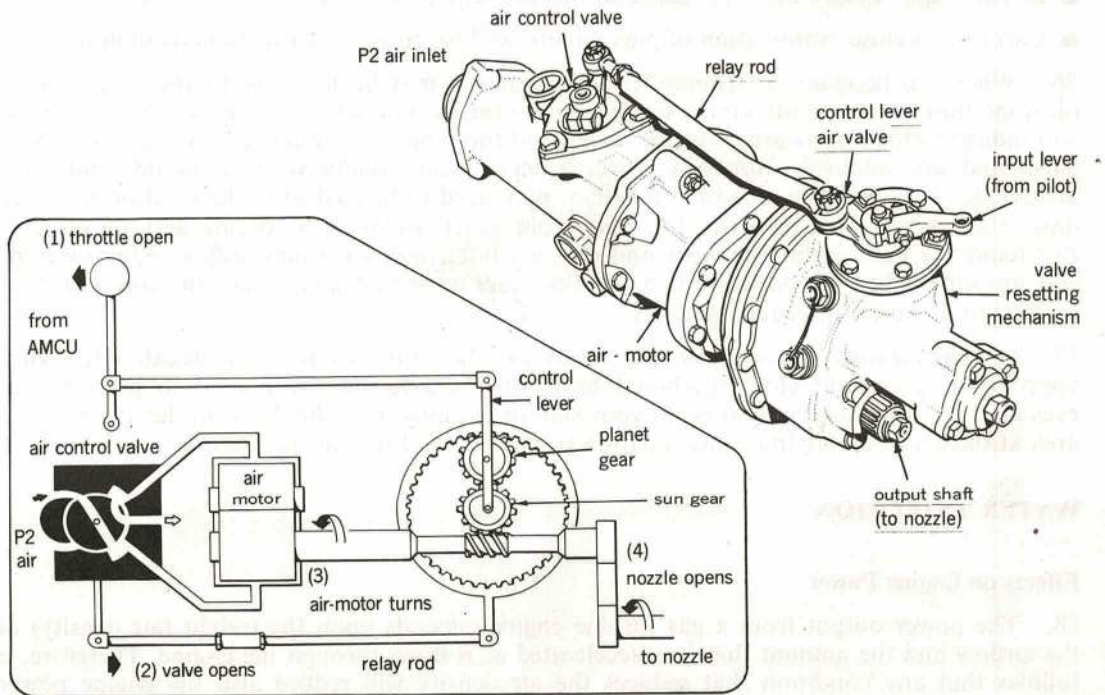


Fig 2.8.19 The air motor assembly

## SERVICING OF RE-HEAT SYSTEMS

52. **The re-heat jet pipe.** A re-heat jet pipe is a much more complicated piece of equipment to service than the normal jet pipe and more examinations and checks are necessary—eg the nozzle area of a re-heat jet pipe is set by the makers during test bed runs; the measurements are critical and they are recorded on the engine's log cards. Therefore, it is important that, during repair, you refer to the log cards and also to the engine Air Publications. Variable re-heat propelling nozzles will require nozzle area tests to ensure that they stay within the log card limits.

53. **Safety in servicing.** Before commencing work, always read the Safety and Servicing Notes along with relevant local orders. Do not rely upon memory—orders do get changed and amended. Pay particular attention to the orders regarding entering air intakes and jet pipes.

54. **Servicing.** Never attempt to carry out unauthorized work. Methods and schedules are updated only after extensive research. However, if you consider that you have a useful contribution to make, do not experiment, but consult your SNCO or officer.

55. The information given in this STTN does not constitute an authority for carrying out maintenance tasks on any given engine or its re-heat system. For this refer to the appropriate AP. However, the following points apply in a general sense to all engine re-heat systems:

- Examine the re-heat jet pipe and its associated equipment for:
  - Oil, fuel and air leaks.
  - Scoring of active sealing segments.
  - Security of attachment.
  - Burns, cracks and dents.
- In particular, ensure that fire seals and thermal expansion joints are fit for use.
- Carry out a close examination of pins, pivots, and bearings for wear, fit and condition.

56. When it is necessary to dismantle re-heat parts, it may be advisable to apply penetrating oil some time before an attempt is made to undo the nuts or set bolts. The servicing schedule will indicate which parts are to be discarded and the type of cleaning most suitable for those parts that are retained. Normally, carbon deposits are removed by a liquid containing Stripolene 704. For heavy deposits, the items may need to be soaked in the solution for some time; they should then be washed in clean cold water, followed by drying with an airblast. For removing light carbon deposits and dirt, a white spirit wash may suffice. After cleaning and servicing, when the parts are re-assembled, care must be taken to give the correct torque loading to the screw threaded members.

57. **Health hazards.** Certain cleaning fluids can be injurious to your health and, when appropriate, protective clothing should be worn. Goggles may be needed to protect your eyes and, if a toxic fluid is spilt on to your skin or clothing, you should wash the affected skin area at once and report the contamination to your SNCO for further suitable action.

## WATER INJECTION

### Effects on Engine Power

58. The power output from a gas turbine engine depends upon the weight (air density) of the airflow and the amount that it is accelerated as it flows through the engine. Therefore, it follows that any condition that reduces the air density will reduce also the engine power output. The two main natural causes of reduced air pressure are:

- Increased altitude.
- Increased temperature.

When these two causes of reduced air density are combined at a high altitude tropical airfield, there is a possibility that aero engines may not produce sufficient power for a safe take-off and climb out. However, in these circumstances, the engine power can be restored, and in some instances increased, by cooling the airflow, to increase its density. To date, the addition of water or a water/methanol mixture has proved to be the cheapest practical means of restoring or increasing the power of an engine for lengthy periods. Methanol has anti-freezing properties and it is also a fuel; therefore water/methanol increases the density of the airflow and provides the extra fuel necessary to match the increased weight of air. Adjustments to the engine fuel system are, therefore, unnecessary. The addition of water has two effects upon the performance of the engine: the cooling effect of water increases the density of the airflow to increase the thrust and, when the water is converted into steam, it provides a high volumetric expansion which increases the thrust even further.

### Methods of Applying Water/Methanol

59. The following notes describe two methods of using water/methanol as a means of restoring lost engine power, or as a means of increasing the total useful power obtainable from an aero gas turbine engine. The water/methanol mixture can be applied by:

- Injecting as a spray into the compressor air intake.
- Injecting direct into the combustion chamber.

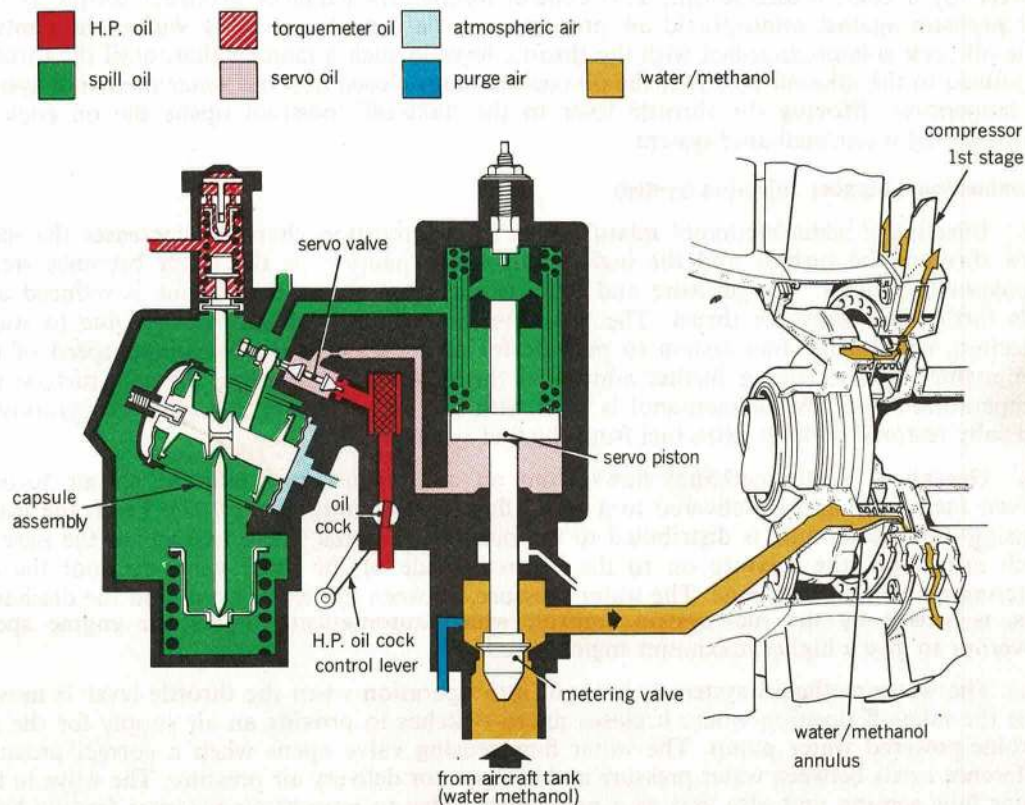


Fig 2.8.20 Water/methanol (Intake injection system)

60. Spraying the mixture into the air intake is more effective for engines with centrifugal compressors than it is for axial compressors. With centrifugal compressors, an even distribution of the mixture is obtained whereas, with an axial flow compressor, even distribution is uncertain. (Turbo propeller engines use intake injection regardless of the type of engine in use). For gas turbine engines with axial flow compressors, better results are obtained when the water/methanol is injected into the combustion chambers. There is then no distribution problem and this permits the use of larger quantities of water/methanol. Normally, in this method of injection, the mixture is delivered into the upstream side of the swirl vanes.

#### **Compressor Intake Injection (Turbo-Prop)**

61. When water or water/methanol mixes with the air at the compressor intakes the temperature of the air is reduced and, as a result, the air density, mass air flow, and thrust are increased. If water alone were to be injected, it would reduce the turbine inlet temperature and permit an increased fuel flow to be used. When methanol is added, the turbine inlet temperature is partially restored by burning the methanol in the combustion chamber; this restores the engine power without adjusting the fuel flow.

62. **Operation.** When the system is switched ON, a water/methanol mixture is pumped from the aircraft-mounted tank to a control unit which meters the flow of mixture fed to the air intakes (Fig 2.8.20). The flow of water/methanol is controlled by a single metering valve and a servo piston that is powered by engine oil. The flow of the engine oil to the servo piston is controlled both by a shut-off cock and the position of a servo valve which, in turn, is moved by a control mechanism. This control mechanism balances propeller torque system oil pressure against atmospheric air pressure upon a capsule assembly within the control. The oil cock is interconnected with the throttle lever in such a manner that, until the throttle is moved to the take-off position, the oil cock remains closed and the water/methanol system is inoperative. Moving the throttle lever to the 'take-off' position opens the oil cock to motivate the water/methanol system.

#### **Combustion Chamber Injection System**

63. Injecting a water/methanol mixture into the combustion chambers increases the mass flow through the turbine and the high volumetric expansion as the water becomes steam increases the thrust. The pressure and temperature drop across the turbine is reduced and this further increases the thrust. The reduction in turbine inlet temperature due to water injection, enables the fuel system to provide for an increase in the maximum speed of the engine, thus providing further additional thrust without exceeding the safe turbine gas temperature limits. When methanol is used with the water the turbine inlet temperature is partially restored without extra fuel from the fuel system.

64. **Operation.** Water/methanol flows from an aircraft-mounted tank to an air turbine driven fuel pump and is delivered to a water flow sensing unit (Fig 2.8.21). From the water sensing unit the mixture is distributed to the burner feed arms where two jets at the base of each arm spray the mixture on to the upstream side of the swirl vanes to cool the air entering the combustion zone. The water pressure, between the sensing unit and the discharge jets, is sensed by the fuel system control, which automatically resets the engine speed governor to give a higher maximum engine speed.

65. The water/methanol system is brought into operation when the throttle lever is moved into the take-off position where it closes micro-switches to provide an air supply for the air turbine-powered water pump. The water flow sensing valve opens when a correct pressure difference exists between water pressure and compressor delivery air pressure. The valve in the water flow sensing unit also acts as a non-return valve to prevent air pressure feeding back from the water discharge jets, and provides for the operation of an indicator to show when water/methanol is flowing.

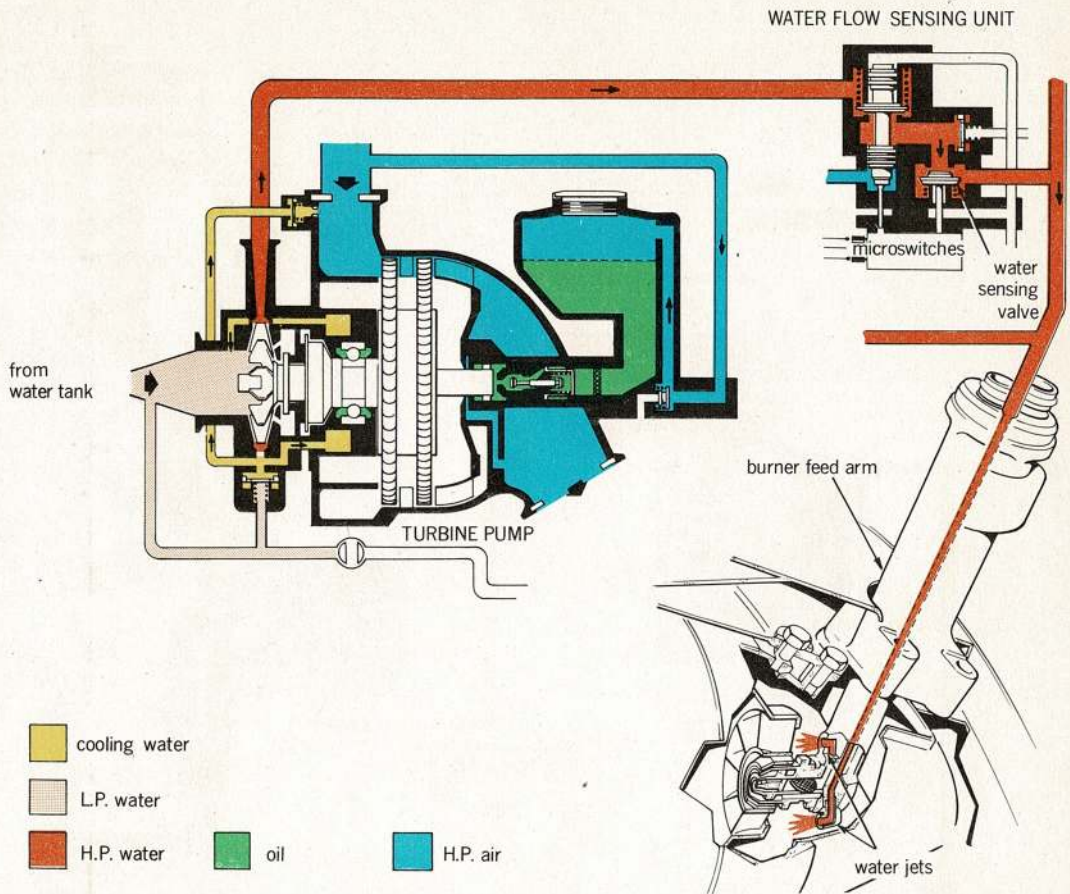


Fig 2.8.21 Water/methanol (Combustion injection system)

### Conclusions

66. After a study of this Chapter you should be able to state why re-heat is fitted to a gas-turbine engine and explain how an engine fitted with re-heat differs from a similar engine that is not so fitted.

You should also know how a re-heat system operates and its automatic safety devices; its advantages, limitations, and the servicing required to ensure its serviceability.

67. You should further understand why water/methanol is used and what effect it has upon the thrust output of a gas-turbine engine. You should know the principle and be able to explain why the mixture is injected into the air intakes of some engines, but directly into the combustion chambers of others.

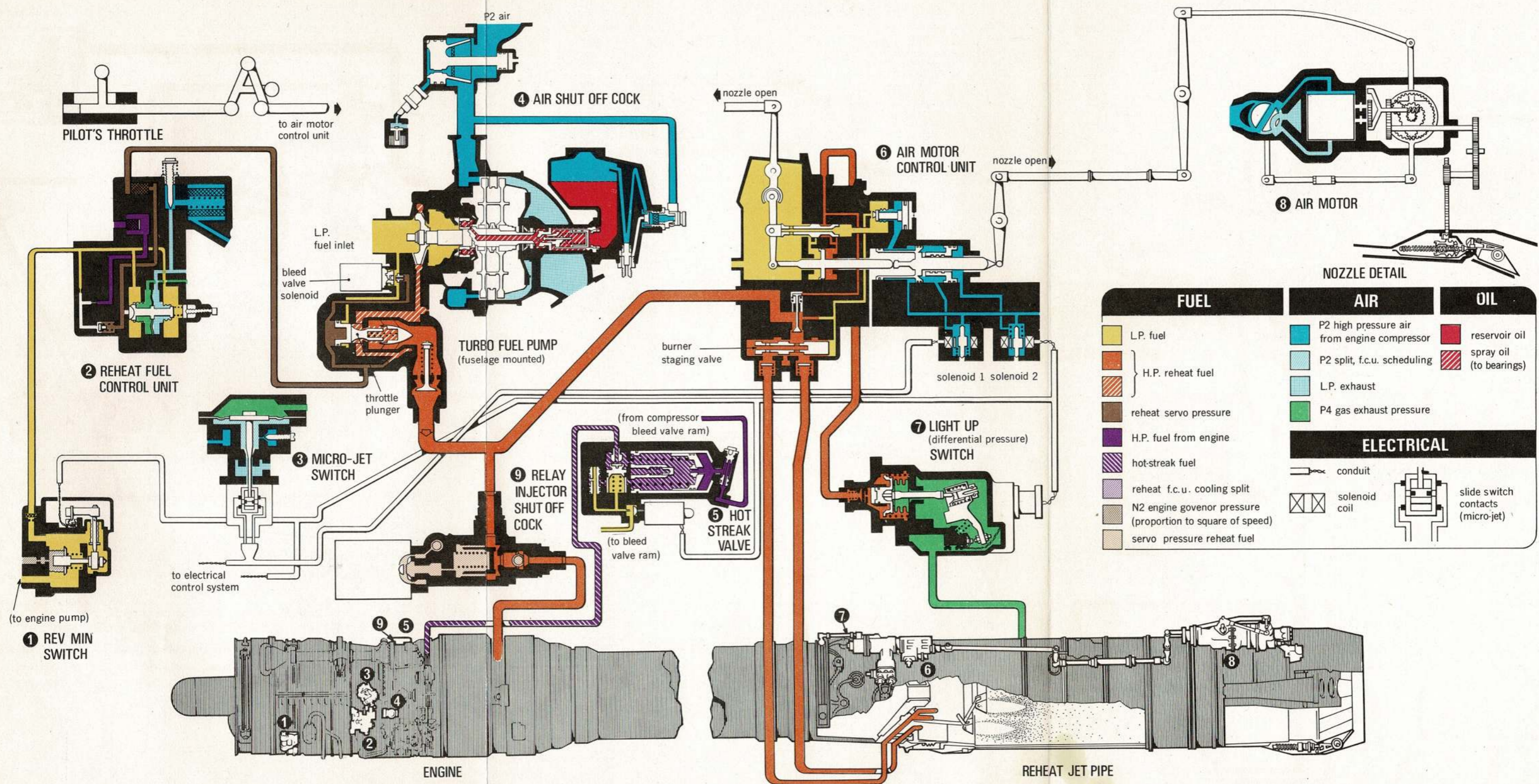


Fig 2.8.8 A Re-heat system

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