SECTION 2

OPERATION

Section 2

OPERATION

Note.—*This section applies to Avon Mk. 10801 and 11401 Engine Change Units*

LIST OF CONTENTS

LIST OF ILLUSTRATIONS

1. This chapter describes briefly the reasons underlying the instructions for operating and handling given in Part 2, Section 2 of this publication and in the Pilot's Notes.

2. Successful engine operation depends upon correct interpretation of the tachometer and jet pipe temperature indicator readings, which are also indications of the mechanical and thermal stresses within the engine. Engine control is maintained through intelligent use of the throttle.

FUNDAMENTAL OPERATION AND CONTROL

3. An aircraft is propelled by the reaction to acceleration of part of the air through which it flies. The turbo-jet engine produces this reaction by taking in air, heating it by adding and burning fuel and then discharging it rearwards at a greatly increased velocity. Part of the energy imparted to the air in this manner is used in driving the air compressor; the remainder produces the reaction which acts upon the airframe structure to thrust the aircraft through the air. This reaction force or thrust is equal to the increase in momentum of the gases passing through the engine.

Manual control of thrust and engine speed

4. The thrust developed by the engine is dependent upon the mass and temperature of the gas flow under stable conditions of air-intake pressure and temperature. Changes in mass flow are effected by varying the amount of fuel introduced into the engine. This is accomplished manually, by use of the throttle control.

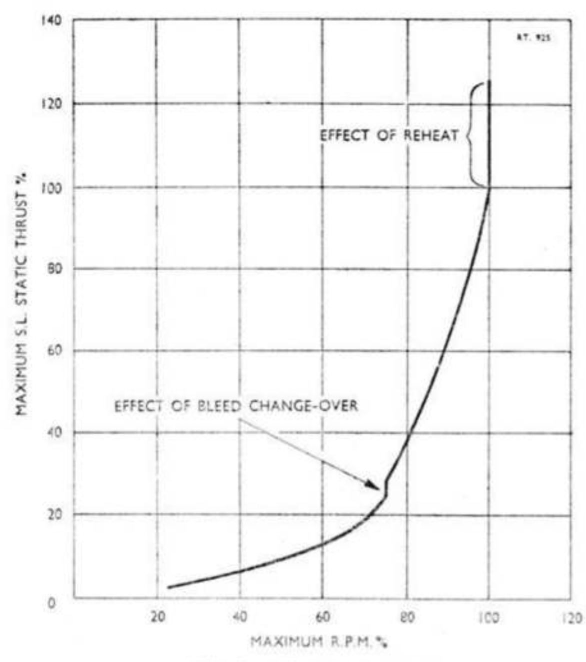

Fig. 1. Thrust v r.p.m.

5. It can be seen from fig. 1 and 2 that as the engine speed increases the thrust and fuel consumption also increases but that the rate of increase in both cases is greater in the higher range of engine speeds. The increases shown without a

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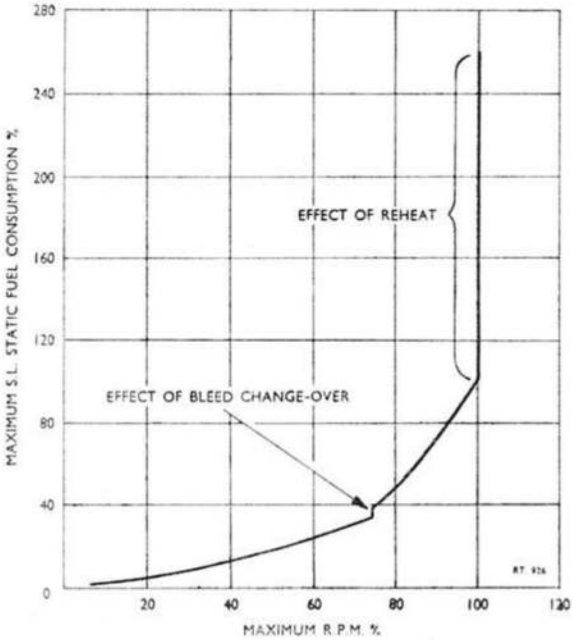

Fig. 2. Fuel consumption v r.p.m.

corresponding increase in engine speed are a result of the operation of the reheat system, details of which are given in para. 40.

6. When more thrust is required, the throttle valve is opened to permit a greater fuel flow. This increases the gas temperature which accelerates the gases through the turbine to produce a higher engine speed and greater airflow. The increased airflow restores the gas temperature approximately to its former level and at the same time produces an increase in engine thrust.

Automatic controls

7. Changes in the pressure and temperature of the surrounding atmosphere have a marked effect on engine thrust, since a change in their values due to variation of altitude and climate alters the air density and therefore the mass of air consumed at any particular engine speed. The ram effect of the forward facing intake also raises both air pressure and temperature by an amount depending upon the aircraft speed.

8. To maintain steady running conditions a change in airflow, as a result of a change in altitude or forward speed, must be accompanied by a corresponding change in the amount of fuel burnt. This change is effected by automatic devices in the fuel system which regulate the fuel flow, the object being to maintain the engine r.p.m. and jet pipe temperature approximately constant for a given throttle setting. Fig. 3 shows how air consumption at constant r.p.m. decreases with altitude; two fixed values of aircraft speed are shown and it can be seen that more air is consumed at the higher speed. Fig. 4 shows that fuel consumption changes with altitude in the same way as does air consumption. In each case separate values are shown for the engine running with the reheat system in operation.

9. The idling speed of the engine (*throttle closed*) is made to increase automatically as atmospheric pressure is reduced, to ensure satisfactory combustion at altitude. At intermediate throttle settings an upward creep of r.p.m. will be experienced during a climb and adjustment of the throttle may be necessary to avoid exceeding the Operating Limitations.

10. The maximum r.p.m. of the engine is restricted automatically, thus relieving the operator of responsibility for preventing accidental overspeeding of the engine with consequent danger of overstressing the rotating parts. The overspeed governor controls the maximum r.p.m. through the fuel servo system, as described in Section 1, Chapter 2. The maximum r.p.m. setting may vary slightly with altitude and, therefore, manual control may be necessary to prevent the Operating Limitations from being exceeded.

11. As described in para. 6 extra fuel is essential to produce acceleration, but because the rate of acceleration is governed by the inertia of the rotating parts, too-rapid opening of the throttle would cause an excessive fuel supply resulting in high temperatures and the possibility of compressor surge (*para.* 31). To prevent this condition during acceleration an acceleration control unit (A.C.U.) is included in the fuel system to retard the rate of increase of fuel flow.

12. The compressor stages are matched for operation at high r.p.m., which results in a tendency for the front stages to be stalled at low engine speeds, with the risk of compressor surge. This stalled condition is relieved by the operation of automatically-controlled intake guide-vanes and bleed valves, reducing the possibility of surge throughout the r.p.m. range.

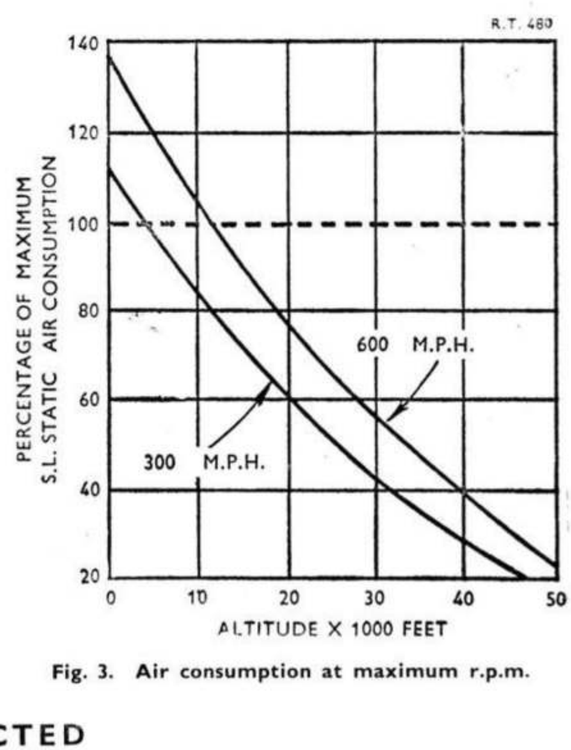

Fig. 3. Air consumption at maximum r.p.m.

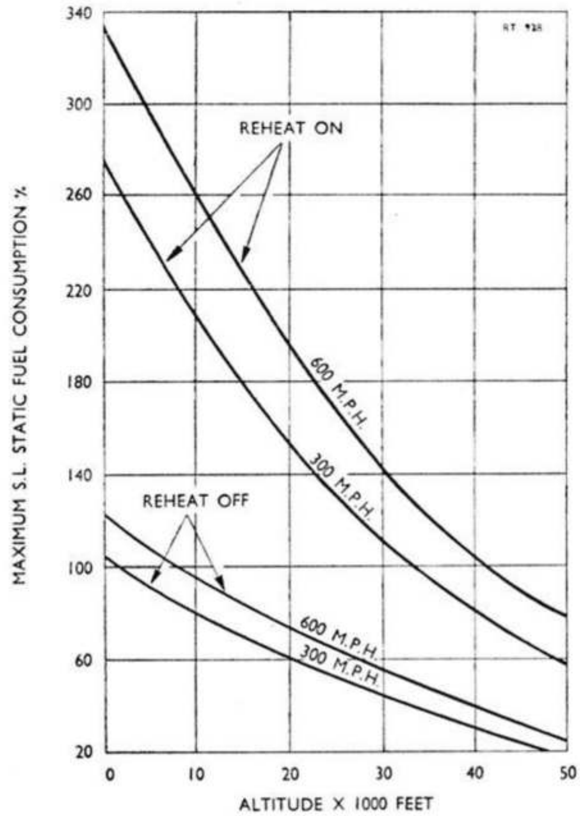

Fig. 4. Fuel consumption at maximum r.p.m.

13. The effect on performance when the bleed valves close is a small decrease in r.p.m. and a slight increase in thrust; conversely, when closing the throttle the bleed valves will open and the r.p.m. will increase slightly. These variations in r.p.m. are momentary and cannot normally be observed.

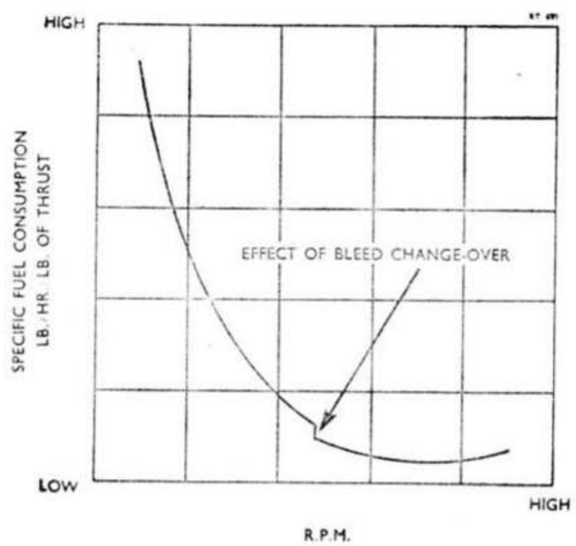

Fig. 5. Typical graph of specific fuel consumption and r.p.m.

14. Until the bleed valves are fully-closed at approximately 6,000 r.p.m., the compressor is not operating at maximum efficiency. A lower specific fuel consumption will be obtained by operating above this engine speed (*fig.* 5), although the addition of reheat at maximum r.p.m. increases the fuel consumption considerably.

Jet pipe temperature

15. The jet pipe temperature (j.p.t.) is very important as it is directly related to temperatures within the engine, particularly at the inlet to the turbine. It is the only engine temperature indicated and is normally measured by thermo-couples in the jet pipe; due allowance has been made in the Operating Limitations for the temperature drop between the turbine and the thermocouples. Different installations may therefore have different values of Maximum Permissible j.p.t. quoted, although the maximum engine operating temperatures will not be effected.

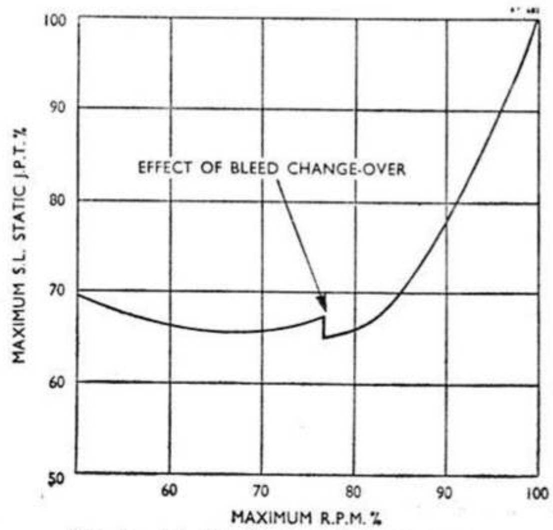

Fig. 6. Jet pipe temperature v r.p.m.

16. The amount of air passing through the engine is approximately four or five times that required for complete combustion of the fuel; the surplus air cools the products of combustion to a safe temperature for the turbine materials. If the ratio of air to fuel is reduced for any reason, the j.p.t. will be increased. As the reheat burners are placed behind the j.p.t. thermocouples in the jet pipe, the increased temperature of the gases caused by burning the extra fuel will thus not be recorded on the j.p.t. indicator.

17. Up to approximately 35,000 feet the j.p.t. at constant r.p.m. will be unaffected by changes in altitude but may rise slightly thereafter. The j.p.t. will increase slightly as the aircraft speed increases and may also be affected by abnormal climatic conditions.

18. Extreme temperatures and sudden temperature changes should be avoided by careful use of the throttle because of their harmful effect upon

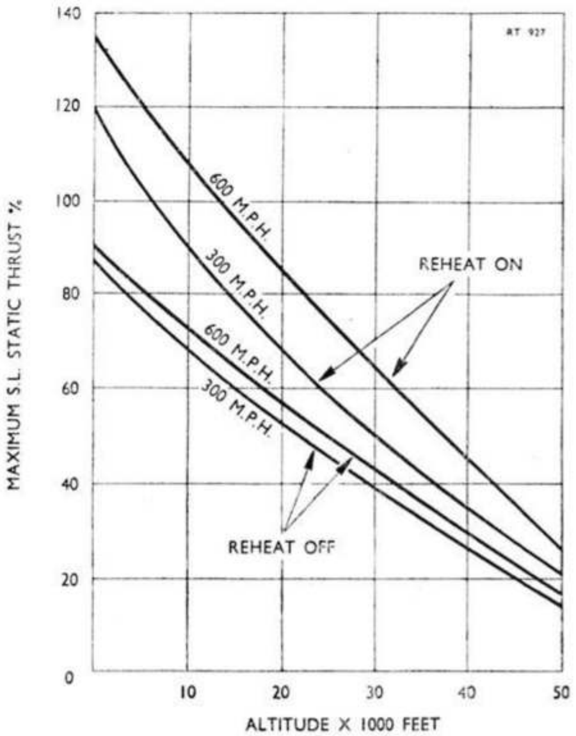

Fig. 7. Thrust at maximum r.p.m.

the engine turbine and combustion equipment.

Performance

19. Due to the reduction in air density the engine thrust decreases with increasing altitude at approximately the same rate as the air density (*fig.* 7).

20. The effect of aircraft speed on thrust is not so obvious. Increasing forward speed produces greater thrust due to a higher intake pressure (*ram effect*) but it also increases the intake drag.

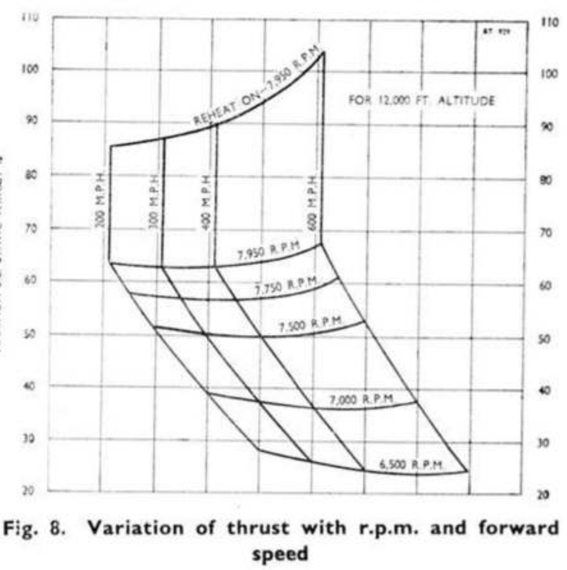

Fig. 8. Variation of thrust with r.p.m. and forward speed

As the aircraft speed increases further, the effect of this drag is progressively offset by the greater ram effect, until a point is reached where the net result is an increase in thrust. Fig. 8 shows typical values of thrust, r.p.m. and aircraft speed for a fixed altitude. Fig. 9 is a companion graph for a similar range of conditions, but deals with fuel consumption instead of thrust.

NORMAL HANDLING

Operating limitations

21. In addition to adopting a correct engine handling technique, the operator must observe the official table of operating limitations. The engine has been tested to establish these figures but they represent the maximum conditions allowed in flight.

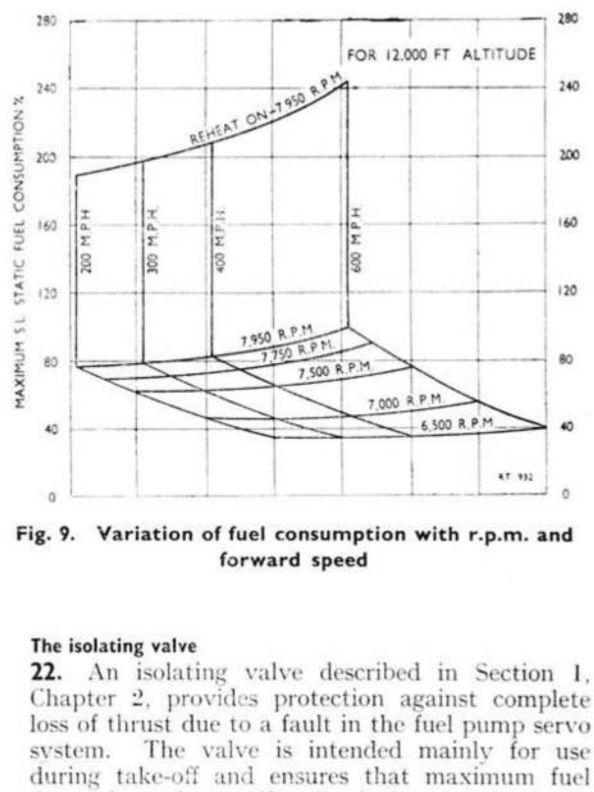

Fig. 9. Variation of fuel consumption with r.p.m. and forward speed

The isolating valve

22. An isolating valve described in Section 1, Chapter 2, provides protection against complete loss of thrust due to a fault in the fuel pump servo system. The valve is intended mainly for use during take-off and ensures that maximum fuel demands can be met if such a fault occurs.

23. Whilst in the isolated state, the upper pump mechanism cannot be controlled by either the B.P.C. or the A.C.U. To minimise the risk of surge therefore, the isolating valve should be operated only after critical r.p.m. have been reached during engine acceleration at take-off.

24. After take-off is completed safely the isolating valve should be returned to the normal position so that the B.P.C. can resume full control of the fuel system. If this is not done and a climb is commenced, the fuel supply can be reduced only by B.P.C. action on the non-isolated pump. The isolated pump would continue to work at maximum stroke and an altitude might be reached, depending on the throttle position, when total fuel flow to the burners would become excessive and cause the r.p.m. and j.p.t. to increase.

25. The isolating valve may be operated in flight if a servo system fault is suspected, but the throttle must be operated slowly and evenly during the landing approach, otherwise surge may occur. Unless a fault exists, the isolating valve should not be used during landing.

Thrust response

26. The thrust response of the gas turbine engine is not so rapid as that of the piston engine, due to the large rotating mass to be accelerated. This fact must be considered on the landing approach, since a longer interval must elapse before full climbing power becomes available in the event of a baulked landing.

27. The greatest increase in thrust occurs over a narrow speed range close to the maximum engine speed. The best compromise between the requirements of low thrust and maximum acceleration during the landing approach is obtained at approximately 4,500 r.p.m.

Fuel economy

28. An increase in aircraft speed produces a higher intake pressure and temperature. Although the increase in temperature has a negligible effect, the increase in pressure improves the power output, resulting in increased aircraft range.

29. The improvement in range due to flying at high speed may be further enhanced by flying the aircraft at or near its minimum drag speed; a speed which is found to increase with altitude. To fly near to the minimum drag speed at low altitude requires only a small fraction of maximum engine thrust and the engine must run at low r.p.m. with a consequent reduction in range. Maximum economy and range are therefore obtained at high altitudes where the engine can operate at a more economical r.p.m.

30. The high specific fuel consumption at low r.p.m. is of importance when idling prior to take-off. Idling fuel consumption is approximately 2 gallons per minute and fuel will be wasted by delaying the take-off.

Compressor surge

31. In the preceding paragraphs occasional reference has been made to surge and, although this condition is unlikely to occur during normal operation, a few remarks on its cause may be helpful.

32. Surge is possible with all axial flow compressors because of the large number of stages, each of which has its own individual operating characteristics, which must be matched over the range of engine operation.

33. As stated in para. 12, the compressor stages on the Avon are matched for operation at high r.p.m. and the tendency to surge at low r.p.m. has been reduced by the use of automatically-controlled intake guide-vanes and bleed valves.

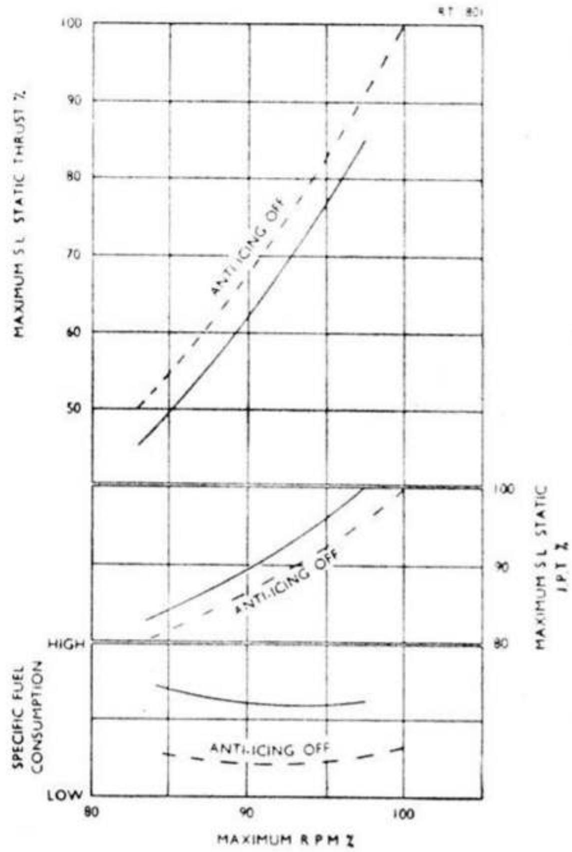

Fig. 10. Effect of anti-icing airflow

34. The immediate cause of surge is compressor blade stall which occurs when the air in one or more stages of the compressor is not flowing at the correct angle in relation to the compressor blades. This condition arises when the amount of air which can be expanded through the turbine and final nozzle becomes less than the stable delivery of the compressor.

35. The effect of overfuelling is readily apparent; the excess fuel causes unduly high temperatures and the resulting excessive expansion of the gas within the combustion chambers slows down the rate of mass flow. This means that less air can be accepted from the compressor and the axial velocity of flow must diminish. Such a change in air velocity without a corresponding reduction in compressor speed causes the air to approach the compressor blades at a different angle and eventually causes blade stall.

36. A condition of surge, once begun, is regenerative unless the cause is removed. Once the compressor blades have stalled, air turbulence and eddying reduce the effective flow path between the blades which in turn further reduces the airflow and increases the gas temperature. This train of events takes place with great rapidity and the j.p.t. will become excessive unless dealt with by closing the throttle immediately.

Relighting in flight

37. Provision is made for relighting the engine in flight, although flame extinction should not normally occur. If combustion ceases, the fuel supply should be cut off immediately by closing the H.P. cock, to prevent an accumulation of fuel in the engine.

38. The chances of relighting are better at low altitude and low aircraft speed and the recommended maximum values are 25,000 ft. and 0·8 Mach No. respectively. Low altitudes ensure higher burner pressure with improved atomization and higher combustion chamber air pressure which support combustion more readily. Low aircraft speeds reduce the windmilling r.p.m. and moderate the combustion chamber air velocity.

39. The relight is accomplished with the throttle closed, by pressing the relight buttons to operate the high energy igniters, opening the H.P. cock, releasing the relight button when r.p.m. begins to rise and then opening-up slowly to the required r.p.m. Relighting imposes considerable thermal shock on the engine, particularly on the turbine nozzle guide-vanes.

Reheat

40. The reheat system provides a considerable increase in thrust for use during special conditions such as take-off, climb or combat. The amount of increase will depend on the actual conditions when reheat is used, but at high speeds it may be as much as 65 per cent. Operation of reheat should be kept to a minimum, as fuel consumption is high, although this is partly offset by the improvement in performance.

41. As explained in para. 16 the bulk of the compressor delivery passes through the engine to cool the products of combustion to a safe limit. When reheat is selected, by pushing the throttle lever into the reheat segment, fuel is sprayed into the jet pipe to be burnt with some of this air, thereby raising the temperature of the exhaust gases.

42. To maintain the relationship between conditions on either side of the turbine the adjustable jet-pipe nozzle is opened when reheat is in operation. This permits the expanding gases to escape more rapidly and produce the additional thrust reaction. The immediate increase in thrust is the most definite indication that the system is operating. If for any reason the nozzle is open when the reheat system is out of operation, a considerable amount of thrust will be lost; therefore if the reheat flame is extinguished the throttle lever should be moved immediately out of the reheat segment.

43. At very high altitudes slight 'burbling' caused by uneven combustion may occur and in extreme conditions the reheat flame may be extinguished. As the system functions most satisfactorily when the mass air flow through the engine is greatest, a reduction in altitude and an increase in aircraft speed may be necessary before relighting is successful.

Anti-icing

44. The anti-icing system is provided to prevent the formation of ice in the engine intake during operation in low temperature conditions. Accretion of ice in the intake would restrict the engine airflow, reducing the thrust and increasing the jet pipe temperature and in extreme cases could completely seal the air-intake, or the ice could break off and damage the compressor.

45. Ice is prevented from forming in and around the air-intake by controlled distribution of heated air transferred from the delivery end of the compressor. The effect on performance of this transfer of air is twofold. In the first place the airflow through the engine is reduced, thereby decreasing the thrust and increasing the jet pipe temperature and secondly the air entering the intake is heated slightly causing a decrease in air density and a further decrease in thrust. The net result is, therefore, a decrease in thrust and an increase in specific fuel consumption and consequently, an increase in jet pipe temperature.

46. Air from the delivery end of the compressor may also be used to supply the aircraft anti-icing system. The effect on engine performance will be as described in the preceding paragraphs, but to a lesser extent, as the heated air used will be discharged to atmosphere instead of being returned to the air-intake.

47. It will be seen, therefore, that to maintain engine thrust the airflow must be restored by opening the throttle, which in turn will further increase the fuel consumption and jet pipe temperature, bearing in mind that the operating limitations must not be exceeded.

EMERGENCIES

Engine trouble in flight

48. The nature of any engine trouble should be indicated by the r.p.m. and j.p.t. indicator readings, the previous action by the pilot and by symptoms generally. A sudden inexplicable drop in r.p.m. with or without flame extinction,could be due to a fuel system defect which would almost certainly be overcome by operating the isolating valve. The act of isolating at high altitude with the engine still lit might result in a sudden acceleration consequent surge or flame extinction; the throttle should therefore be closed before isolating and subsequent acceleration and should be made very carefully.

49. An engine which does not respond to the isolating procedure and fails to relight under favourable conditions (*para.* 37, 38 *and* 39) should be closed down completely by turning off the H.P. and L.P. cocks. An engine which exhibits extreme roughness and vibration and which is therefore considered to have suffered a mechanical failure should be shut down immediately and the fuel supply cut off to reduce the possibility of fire

Engine fire in flight

50. An engine fire in flight calls for immediate closing of the H.P. and L.P. cocks. Before the fire extinguisher switch is operated the aircraft speed should be reduced to a minimum to obtain relatively stagnant air conditions in the engine and nacelle. An engine fire will be indicated by illumination of a warning lamp in the cockpit, electrically connected to flame detector switches in the engine bay. These switches are automatically reset when the temperature falls after the fire has been extinguished. Fire-fighting resources are sufficient for one outbreak only and the engine should not be restarted.

STARTING AND STOPPING

51. The engine is started by a cartridge-driven impulse turbine mounted on the front of the compressor. The starter rapidly accelerates the engine up to a speed at which it is self-sustaining and able to accelerate under its own power to idling speed.

52. The starting sequence, including firing of the cartridge and operation of the high energy ignition system to light the main fuel sprays, is controlled automatically by a system of relays and time switches after pressing the starter button.

53. The starter electrical system is provided with suitable switching arrangements so that the following combinations of operations may be selected.

(1) Turbo-starter and ignition, for a normal start.

(2) Turbo-starter only, for motoring over.

(3) Ignition only, for a relight in flight.

54. The engine should be stopped by closing the throttle and then the H.P. cock, and drainage of fuel from the drain valves should be confirmed as the engine runs down. Failure to drain an accumulation of fuel in the engine will cause overfuelling on a subsequent start. The L.P. cock should be closed when the engine stops turning.

55. If flames issue from the jet pipe of a stopped engine the liquid fuel may be blown out by performing a motoring cycle with the fuel cocks closed and the ignition switched off.

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