SECTION 2

OPERATION

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Note.—*This section applies to Avon Mk. 10701, 10901, 11301, 11501 and 12101 Engine Change Units*

LIST OF CONTENTS

LIST OF ILLUSTRATIONS

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

2. Control of the engine depends upon the correct use of the throttle and on the right interpretation of the engine speed and jet pipe temperature indicator readings; the latter are related to the mechanical and thermal stresses within the engine. The engine speed, of course, also provides an indication of engine thrust.

FUNDAMENTAL OPERATION AND CONTROL

3. All aircraft are propelled by the reaction to acceleration of part of the air through which they fly. 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.

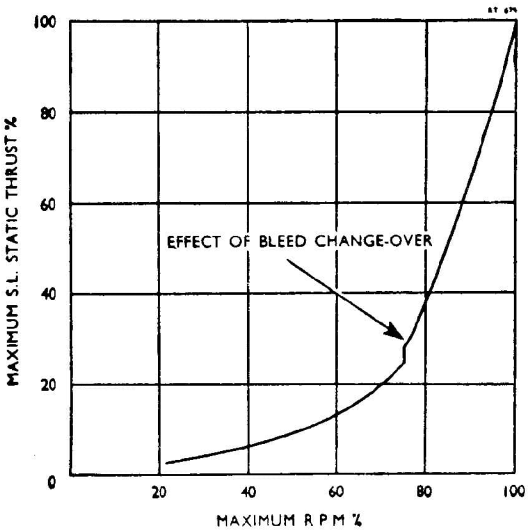

Fig. 1. Thrust v. r.p.m.

(Static, sea-level, International Standard atmospheric conditions)

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.

5. It can be seen from fig. 1 and 2 that, as the engine speed increases the thrust and fuel consumption also increase, but that the rate of increase in both cases is greater in the higher range of engine speeds.

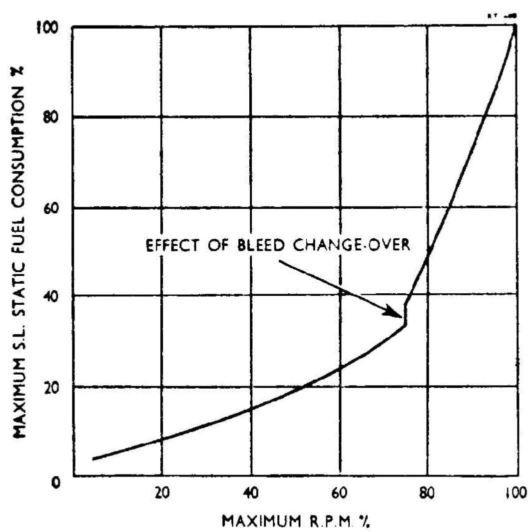

Fig. 2. Fuel consumption v. r.p.m.

(Static, sea-level, International Standard atmospheric conditions)

6. When a higher thrust is required, the throttle valve is opened to permit a greater fuel flow. This has the effect of increasing the gas temperature which in turn increases the acceleration of 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 varies the amount of air consumed at any particular engine speed. The effect of ram in the forward facing intake also raises both air pressure and temperature by an amount depending upon the aircraft speed.

8. To maintain stable burning conditions a change in airflow 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 in relation to the airflow, the object being to maintain the selected engine r.p.m. and jet pipe temperature. Fig. 3 shows how air consumption at constant r.p.m. decreases with altitude; two fixed values of aircraft speed are shown and it will be noted that more air is consumed at the higher aircraft speed. Fig. 4 shows that fuel consumption changes with altitude in exactly the same way as does air consumption.

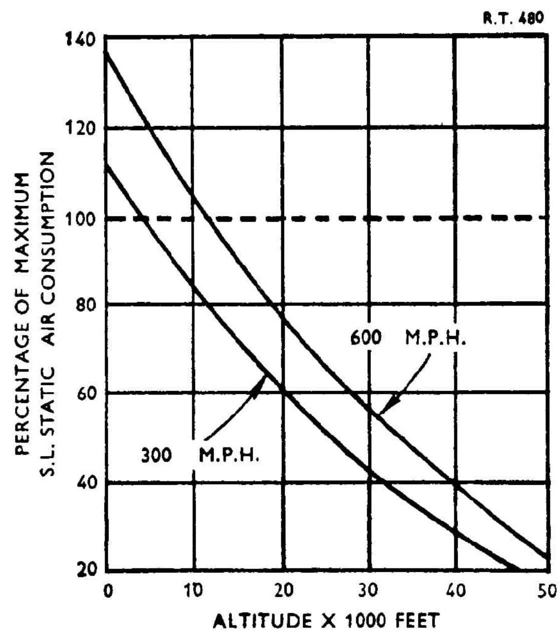

Fig. 3. Air consumption changing with altitude

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

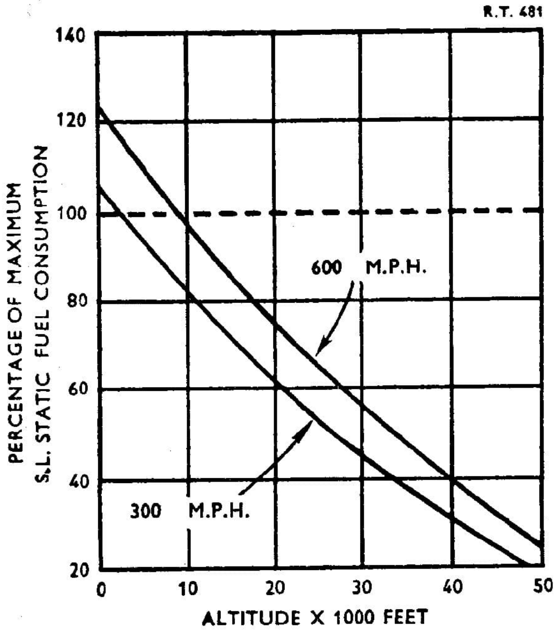

Fig. 4. Fuel consumption changing with altitude

10. The maximum r.p.m. of the engine is governed automatically, thus relieving the operator of responsibility for preventing overspeeding of the engine with the consequent danger of over-stressing the rotating parts. The over-speed governor controls the maximum r.p.m. through the fuel servo system, as described in Sect. 1, Chap. 2. Maximum r.p.m. may vary slightly with altitude and, therefore, manual control may be necessary to prevent the Operating Limitations from being exceeded under these conditions.

11. Mk. 115 and 121 engines incorporate a top temperature control to relieve the pilot of the responsibility of preventing maximum jet pipe temperature from being exceeded. Under certain conditions the controller may begin to operate before maximum r.p.m. is reached and thus prevent maximum thrust from being obtained ; in these circumstances the pilot can regain maximum thrust by operating an over-ride switch, which isolates the controller. A micro switch automatically isolates the controller when the undercarriage is DOWN.

12. As described in para. 6 extra fuel is essential to produce acceleration, but as the rate of acceleration is governed by the inertia of the rotating parts, if the throttle is opened very rapidly the fuel supply will become excessive and cause high temperatures with the possibility of compressor surge (*para.* 30). To avoid this condition during acceleration periods an acceleration control unit (A.C.U.) is included in the fuel system to retard the rate of increase of fuel flow.

13. The compressor stages are matched to give the optimum airflow at high engine speed and would be subject to surge at the lower r.p.m. if the airflow was not reduced over the critical range from idling to 7,000 r.p.m. This reduction in airflow is effected by automatically-controlled intake guide-vanes and compressor bleed valves, as described in Sect. 1, Chap. 1.

14. The effect on performance when the bleed valves close is a small decrease in r.p.m. and a slight increase in thrust due to the extra weight of air passed through the compressor. Conversely, when closing the throttle the bleed valves will open and the r.p.m. will increase slightly due to release of air from the compressor. These changes in r.p.m. are momentary and cannot normally be observed.

15. The action of the intake guide-vanes has no noticeable effect on engine running, but it is pointed out that until the guide-vanes reach their maximum open position, at approximately 7,000 r.p.m., the compressor is not operating at optimum efficiency ; a lower specific fuel consumption will be obtained by operating above this figure (*fig.* 5).

Jet pipe temperature (j.p.t.)

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

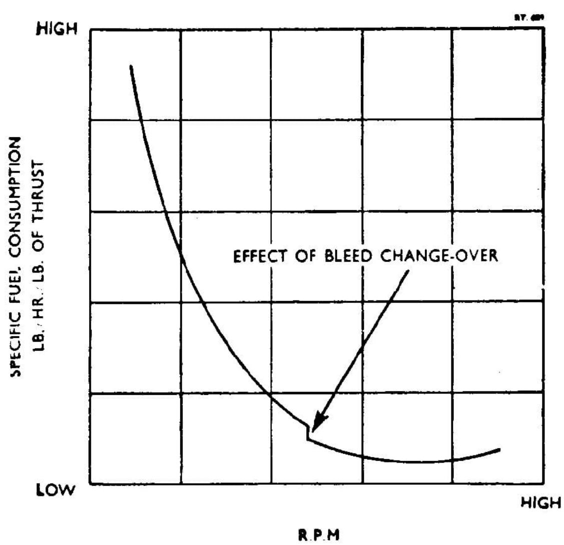

Fig. 5. Typical graph of specific fuel consumption and r.p.m.

17. Generally speaking, the amount of air passing through the engine is approximately four or five times that required for complete combustion of the fuel. The extra air serves to cool 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.

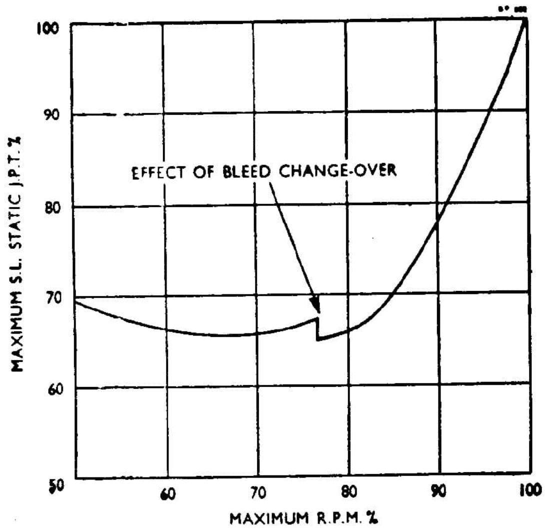

Fig. 6. Jet pipe temperature v. r.p.m. *(Static, sea-level, International Standard atmospheric conditions)*

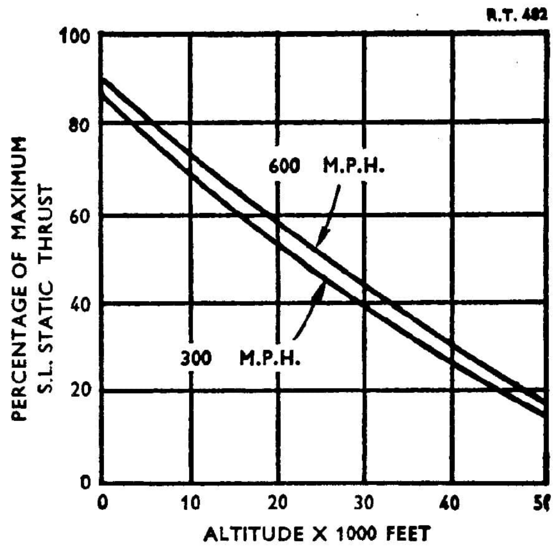

Fig. 7. Thrust at maximum r.p.m.

18. The j.p.t. at constant r.p.m. shows little variation with altitude, but may be found to alter slightly with abnormal climatic conditions and to a certain extent with variations of aircraft speed. As a general rule the j.p.t. will increase slightly with an increase of aircraft speed but will remain unchanged by the effect of altitude up to approximately 35,000 ft.; above this altitude the temperature may begin to increase slightly.

19. Unduly high temperatures and sudden temperature changes should be avoided by careful use of the throttle due to their harmful effect upon the engine turbine and combustion equipment. Conditions less than the maximum limitations should be adopted for climbing and cruising whenever operational requirements permit.

Performance

20. The net effect of air and fuel flows diminishing with altitude is a reduction in thrust, as shown in fig. 7. Actually the thrust falls at approximately the same rate as the air density. The effect of aircraft speed on thrust is not so readily apparent. Forward speed increases the air-intake pressure (ram effect) and the thrust but at the same time it increases the intake drag; with increasing aircraft speed the effect of this drag is offset by the increasing effect of 'ram,' until a point is reached when the net result is an increase in thrust. Fig. 8

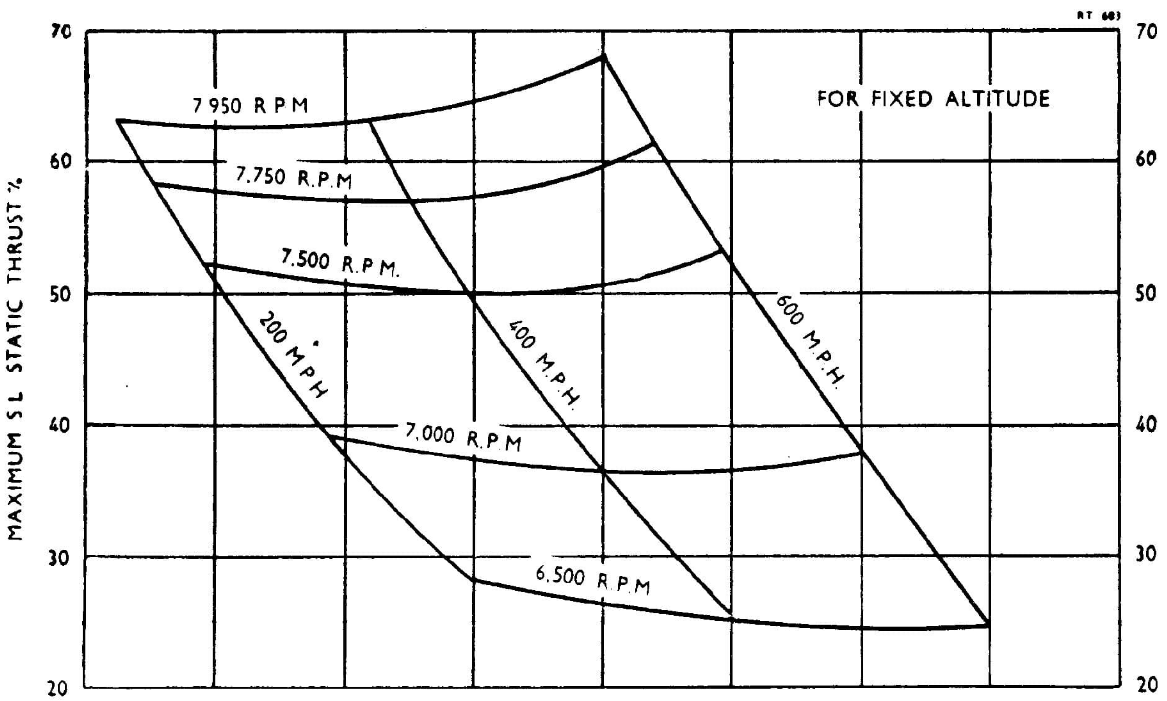

Fig. 8. Variation of thrust with r.p.m. and forward speed

shows typical graphs of thrust, r.p.m. and aircraft speed for a fixed altitude. Fig. 9 is a companion graph for the same 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 maxima which are allowed to be used in flight and are not necessarily those which will be used for normal routine duties. Greater reliability and longer life will be obtained at ratings lower than the quoted maxima.

The isolating valve

22. An isolating valve, fully described in Sect 1, Chap. 2, is used on the Avon Mk. 107, 113, 115 and 121 as a protection against a loss of thrust due to a fault in the fuel pump servo system. It ensures that maximum fuel demands can be restored if such a fault occurs.

23. The isolating valve must only be used in an extreme emergency because, while in the isolated state, the servo mechanism of the upper fuel pump cannot be controlled by either the B.P.C. or the A.C.U. Thus it will move towards the maximum stroke position.

24. Due to the change in pumping stroke with isolation it is apparent that by isolating above a certain altitude, where the fuel requirements are smaller, there would be an abrupt increase in fuel flow. This would result in extremely rapid accelerations with abnormally high j.p.t. which could produce surge (*para.* 30). The detailed drill for isolating is given in the Pilot's Notes.

25. When isolated the greatest possible care is necessary when approaching to land, since the A.C.U. will be ineffective. The throttle movements must therefore be made slowly and smoothly to avoid the possibility of surge.

Thrust response

26. The thrust response of the gas turbine engine is not so rapid as that of the piston engine and this 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 ; the lower thrust response of the turbine

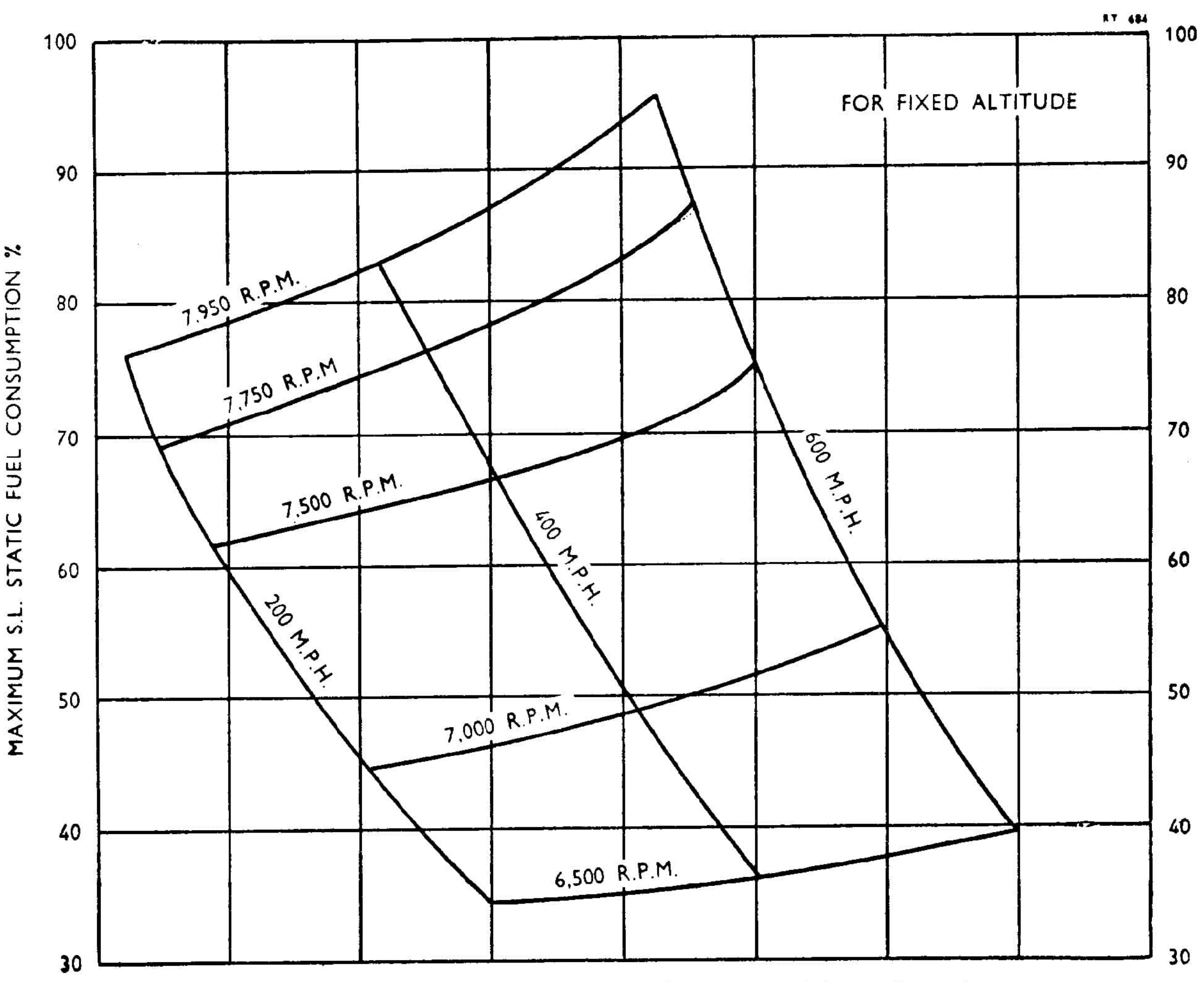

Fig. 9. Variation of fuel consumption with r.p.m. and forward speed

engine is due to the large rotating mass to be accelerated. The major increase in thrust is obtained over a narrow speed range as maximum speed is approached. The best compromise between the requirement of low thrust and maximum acceleration when approaching to land is obtained at approximately 4,500 r.p.m.

Fuel economy

27. An increase in aircraft speed produces a higher intake pressure and temperature, and although the increase in temperature reduces the compressor efficiency slightly the increase in pressure improves the power output ; the combined effect is an increase in thrust and a decrease in specific fuel consumption.

28. The gain in economy due to flying at high speed may be further enhanced by flying the aircraft near to 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 fraction of maximum engine thrust and the engine must run at low r.p.m. where the specific fuel consumption is high. Maximum economy and best range are therefore obtained at high altitude where the engine can operate at a more economical r.p.m.

29. 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

30. 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.

31. Surge is possible with all axial flow compressors on account 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.

32. As previously mentioned in para. 13, the compressor stages on the Avon are matched to give the optimum airflow at high r.p.m. and the tendency to surge at low r.p.m. has been overcome by the use of automatically-controlled intake guide-vanes and bleed valves.

33. 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.

34. 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 of blade speed (r.p.m.) causes the air to approach the compressor blades at a different angle and eventually causes blade stall.

35. Compressor surge can also be caused on early 'Hunter' aircraft if the guns are fired at high altitude. This is due to instability at the air intake arising from shock waves created by the bullets and to a lesser extent from gases entering the engine. Mk. 121 engines fitted to later aircraft incorporate a fuel and air "dip-system" which operates when the gun firing button is pressed. The system reduces the fuel flow and increases the airflow through the compressor and thus re-establishes a safe margin between the compressor working line and surge line.

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. The train of events takes place with great rapidity and the j.p.t. will rapidly become excessive unless dealt with by closing the throttle immediately.

Relighting in flight

37. Provision is made for relighting the Avon in flight, although flame extinction should not normally occur. Should it arise, however, the fuel 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 15,000 ft. and 200 knots respectively. Low altitudes give higher burner pressure with improved atomization and higher combustion chamber air pressures 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 button 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.

Anti-icing

40. 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 and thereby reduce thrust and increase the jet pipe temperature and, in extreme cases could completely seal the air-intake, or the ice could break off in large pieces and damage the compressor.

41. 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

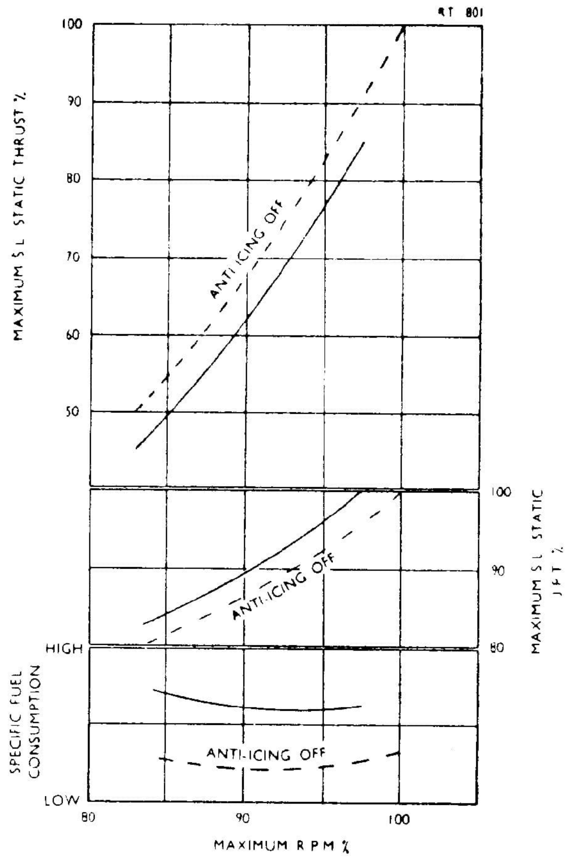

Fig. 10. Effect of anti-icing airflow

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.

42. The aircraft anti-icing system may also use air from the delivery end of the compressor. The effect on performance will be as outlined in the preceding paragraphs but to a greater extent as the air used will be lost to the engine instead of being returned to the air-intake.

43. 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

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

45. An engine which fails to respond to the isolating procedure and fails to relight after obtaining 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 prevent a possible leakage of fuel into and around a damaged engine.

Engine on fire in flight

46. An engine on fire in flight must be shut down by closing H.P. and L.P. cocks. Before pressing the fire extinguishing switch, 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 cockpit warning lamp which is electrically connected to flame detector switches in the engine bay. These switches 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

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

48. 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.

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

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

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

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

50. 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 over-fuelling on a subsequent start.

51. 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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