SECTION 2

OPERATION

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Section 2

OPERATION

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LIST OF ILLUSTRATIONS

General

1. This chapter briefly describes the reasons underlying the operating and handling instructions detailed in Part 2, Sect. 2, and in the Pilot's Notes and Ground Handling Notes.

2. Intelligent handling and correct interpretation of engine rev/min and jet pipe temperature (j.p.t.) indications contribute largely to efficient engine operation.

FUNDAMENTAL OPERATION AND CONTROL

3. The turbo-jet engine operates by ingesting and compressing air, then heating it by adding and burning fuel. The resultant expansion accelerates the gases rearwards through the turbine, exhaust system and propelling nozzle, where its issuing momentum produces the reaction which acts upon the engine mountings to propel the aircraft forward.

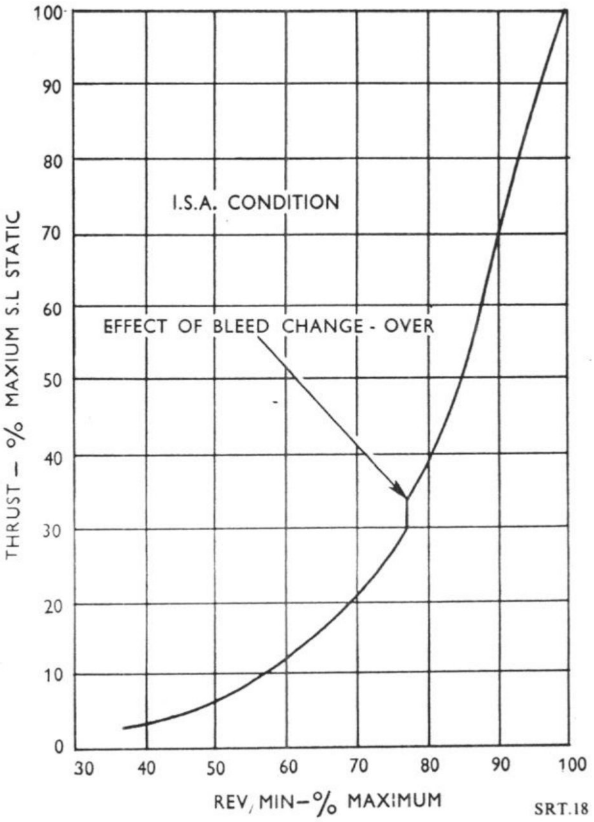

Fig. 1 Thrust v. rev/min

Manual control of thrust and engine rev/min

4. The thrust developed by the engine is dependent upon the mass and temperature of the gas flow under stable conditions of intake air pressure and temperature. Changes in mass flow are effected by manual operation of the throttle, thus varying the amount of fuel introduced into the engine (para. 6).

5. As engine rev/min increase, thrust and fuel consumption also increase (fig. 1 and 2) but the rate of increase in both cases is greater in the higher range of engine rev/min. The 'steps' in the graphs are caused by the operation of the compressor air bleed valve (para. 14).

6. When a greater 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 velocity of the gases through the turbine and final nozzle to produce higher engine rev/min and greater mass air flow, resulting in an increase in thrust.

AUTOMATIC CONTROLS

7. Atmospheric changes caused by variation of altitude and climatic conditions alter the intake air density and, therefore, the mass air flow at any particular engine rev/min condition. The ram effect in the forward facing intake also varies air pressure and temperature by an amount dependent upon the aircraft speed; the use of the engine anti-icing system can, by heating the intake air, also affect the intake air density (para. 35).

8. To maintain the correct air/fuel ratio, a change in airflow must be accompanied by a corresponding change in the amount of fuel delivered to the burners. This is effected by automatic devices in the fuel system; fig. 3 and 4, respectively, show how at constant rev/min conditions, airflow and fuel consumption decrease with altitude.

9. The idling rev/min of the engine (throttle fully closed) increases as atmospheric pressure decreases. At intermediate throttle settings, negative or positive rev/min 'creep' (i.e., rev/min decrease or increase respectively) may be

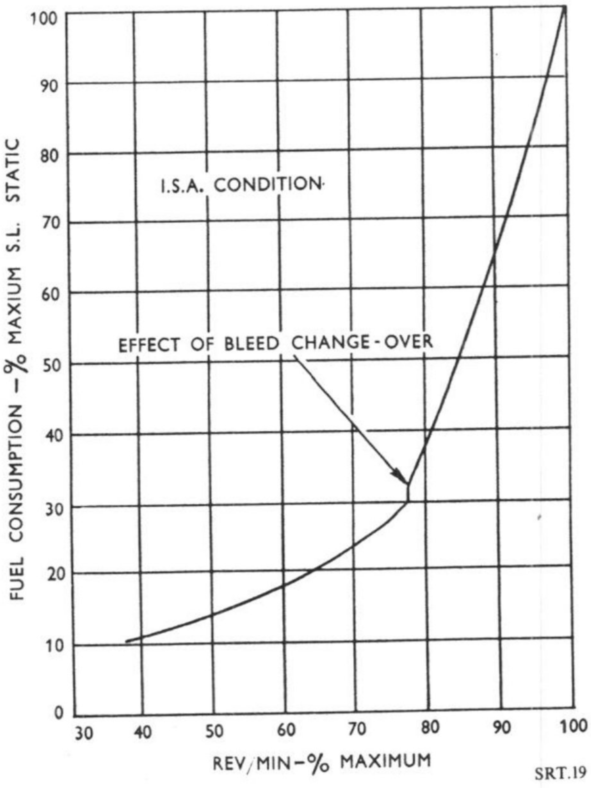

Fig. 2 Fuel consumption v. rev/min

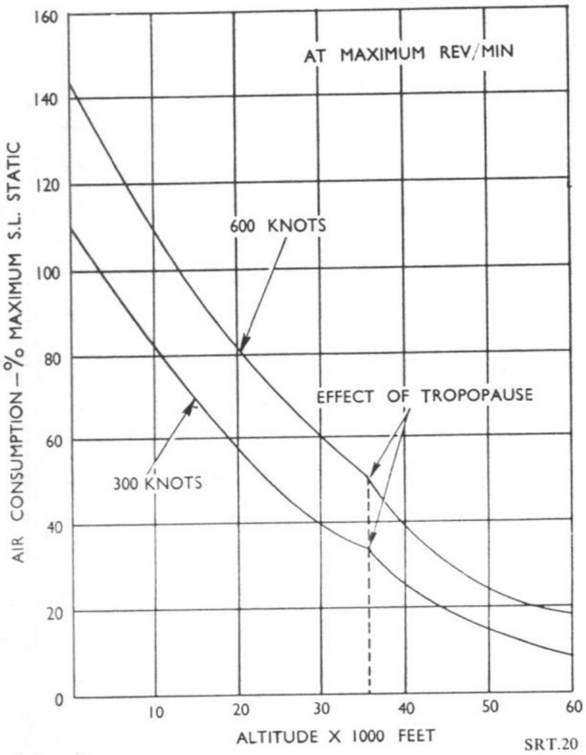

Fig. 3 Air consumption changing with altitude

experienced during a fixed-throttle climb, and manual adjustment of the throttle may be necessary to maintain a desired condition.

Maximum rev/min governor

10. The maximum rev/min of the engine is governed automatically, thus preventing overspeeding of the engine with the consequent danger of overstressing the rotating parts. Governed rev/min 'creep', which is positive, may be experienced at altitude and a degree of manual control may be necessary to prevent the Operating Limitations being exceeded under these conditions. Under normal circumstances, the governor controls the maximum rev/min as described in Sect. 1, Chap. 2.

Acceleration control

11. As described in para. 6, extra fuel is required to produce acceleration, the rate of which is governed largely by the inertia of the rotating parts and the amount of fuel delivered to the burners. If the throttle was opened rapidly without some form of automatic control, the fuel supply would become excessive and cause high temperatures with the possibility of compressor surge (para. 27). To avoid this, an acceleration control unit (a.c.u.) in the fuel system controls the rate of increase in fuel flow.

Air flow control

12. Each stage of the compressor possesses certain airflow characteristics which are carefully matched to give optimum airflow at high rev/min conditions. If, however, the airflow was not reduced a predetermined amount in the lower rev/min range, the air would approach some of the compressor stages at an unsuitable angle, causing the blades to stall. This reduction in airflow is effected by progressively-variable intake guide vanes and a compressor air bleed valve as described in Sect. 1, Chap. 1.

13. The intake guide vanes direct the flow of air on to the initial stage of the compressor at an angle appropriate to the rotational speed of the engine, the flow angle becoming progressively reduced until optimum airflow is obtained.

14. The air bleed valve is open at low rev/min conditions, permitting compressor air to bleed to atmosphere; the valve closes as the

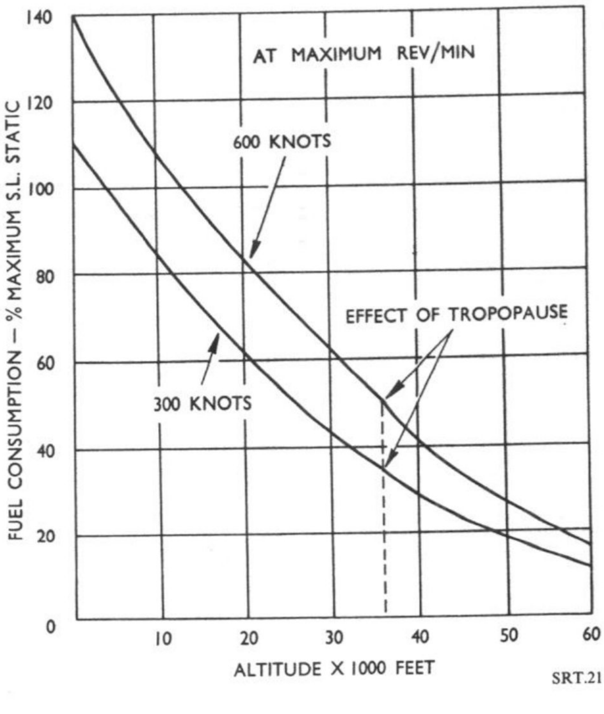

Fig. 4 Fuel consumption changing with altitude

intake guide vanes move towards the full flow angle. Compressor efficiency improves as the bleed valve closes and a lower specific fuel consumption is obtained (fig. 5).

Jet pipe temperature control

15. To prevent overheating of the turbine, the maximum jet pipe temperature (j.p.t.) is limited by an automatic controller. This device trims the fuel flow if the maximum j.p.t. is exceeded, reducing the rev/min until the temperature is lowered to the correct operating value. Excessive temperatures are most likely to occur when the mass air flow to the turbine is reduced other than by throttle control, e.g., when the anti-icing system is switched on (para. 35).

JET PIPE TEMPERATURE

16. The jet pipe temperature (j.p.t.) is directly related to the temperature at the inlet to the turbine; it is the only temperature indicated and is measured by thermocouples in the jet pipe. Allowance has been made in the Operating Limitations for the temperature drop between the turbine and the thermocouples. Fig. 6 shows the variation of j.p.t. with rev/min in a typical installation.

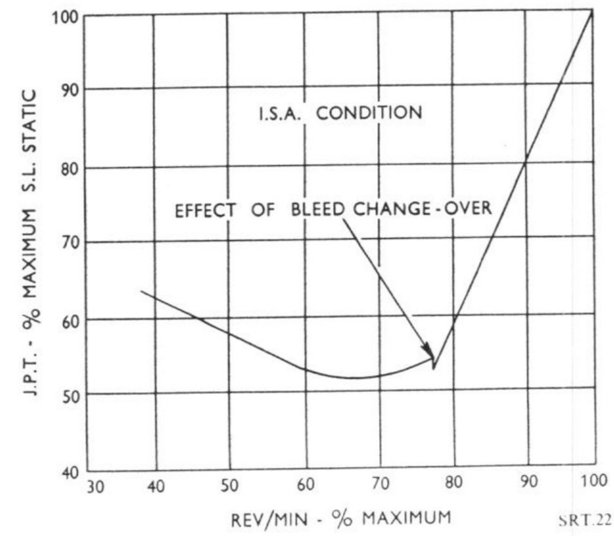

Fig. 6 Jet pipe temperature v. rev/min

17. Since the amount of air passing through the engine is approximately four times the amount required for complete fuel combustion, the surplus air cools the products of combustion to a temperature acceptable to the turbine materials. If, for any reason, the ratio of air to fuel is reduced, the j.p.t. will be increased.

18. At constant rev/min conditions the j.p.t. shows little variation with altitude, but may 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 in aircraft speed, but will remain unchanged by the effect of altitude up to approximately 36000 ft.; above this altitude the j.p.t. may begin to increase slightly.

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

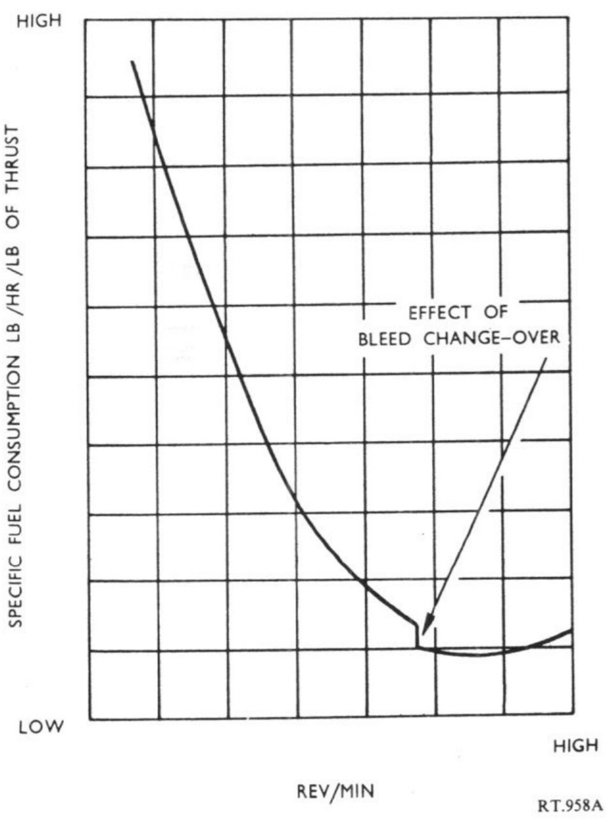

Fig. 5 Typical graph of specific fuel consumption and rev/min

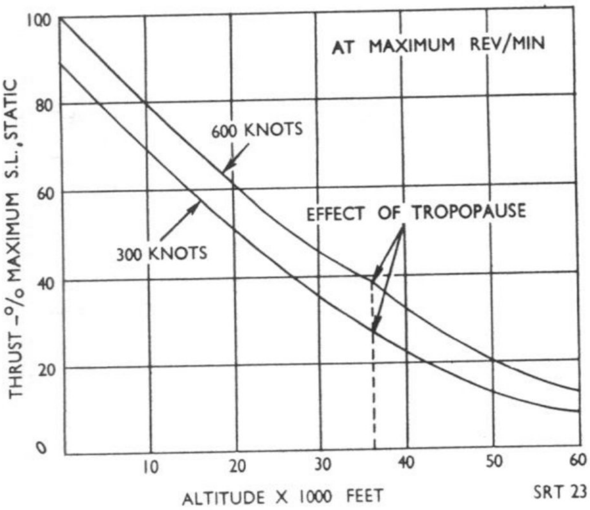

Fig. 7 Effect of altitude on engine thrust

PERFORMANCE

20. With increasing altitude, the ambient air pressure and temperature are reduced and affect the engine in two inter-related ways:—

(1) The fall in pressure reduces the air density and, hence, the mass air flow into the engine for a given rev/min, causing a reduction in thrust (fig. 7).

(2) The fall in temperature increases the air density and, to some extent, compensates for the reduction in thrust caused by the fall in pressure. At altitudes above 36000 ft. (tropopause), the temperature remains nominally constant at minus 56·5°C. and the thrust is affected by pressure only.

21. The effect of aircraft speed on thrust is not so apparent. Forward speed increases the air intake pressure (ram effect) and the thrust, simultaneously increasing the air intake 'drag'. However, with increasing aircraft speed, the effect of this drag is offset by the increasing ram effect until a point is reached when the result is an increase in thrust. Fig. 8 shows typical graphs of thrust, rev/min and aircraft speed for a fixed altitude.

HANDLING

Operating limitations

22. 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 and they are the permitted maxima.

Thrust response

23. The thrust response of the gas turbine engine is retarded because of the large rotating mass to be accelerated. The major increase in thrust is obtained over a narrow rev/min range as the maximum rev/min condition is approached. The best compromise between the requirement of low thrust and maximum acceleration when approaching to land is obtained at approximately 4500 rev/min (approach idling).

Fuel economy

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

25. The gain in economy due to flying at high speed may be further enhanced by flying the aircraft near its minimum drag speed, which increases with altitude. To fly near the minimum drag speed at low altitude requires only a fraction of engine maximum thrust and the engine must run at a low rev/min condition where the specific fuel consumption is high. Maximum economy and optimum range are, therefore, obtained at high altitude where the

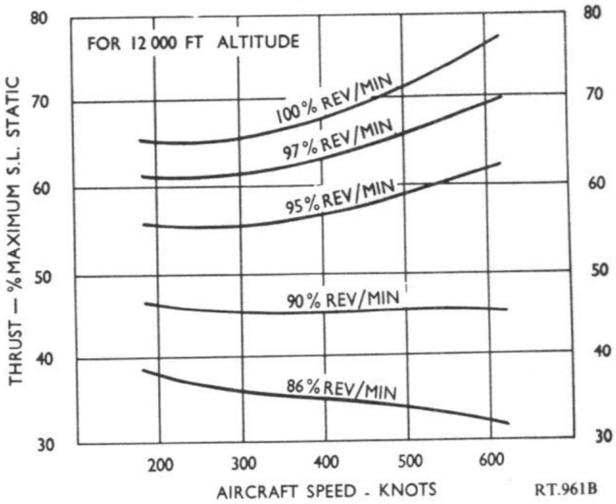

Fig. 8 Variation of thrust with forward speed and rev/min

engine can operate at a more economical rev/min condition.

26. At low rev/min conditions the specific fuel consumption is high; fuel consumption at ground idling rev/min is approximately two gallons per minute and fuel will be wasted by delaying take-off.

Compressor surge

27. In the preceding paragraphs, occasional reference has been made to compressor surge, although this condition is unlikely to occur during normal operation.

28. Surge is possible with all axial-flow compressors because of the large number of stages, each of which has characteristics which must be matched over the entire range of engine operation.

29. As mentioned in para. 12, the compressor stages are matched to give optimum airflow at high rev/min conditions and the tendency to surge at low rev/min has been overcome by the use of automatically controlled intake guide vanes and a compressor air bleed valve.

30. 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 jet pipe final nozzle becomes less than the stable delivery of the compressor.

31. 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, therefore, the axial velocity of flow must diminish. Such a change in air velocity, without a corresponding reduction of rev/min, causes the air to approach the compressor blades at an unsuitable angle and eventually causes blade stall.

32. 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 the throttle is closed immediately.

Relighting in flight

33. Provision is made for relighting the engine in flight although flame extinction should not normally occur. If, however, the flame extinguishes, the h.p. cock must be closed immediately to prevent an accumulation of fuel in the engine.

34. Relighting can be successfully achieved up to 36000 ft. and Mach No. 0·8, but becomes progressively more certain as altitude and air speed are reduced. Low altitudes ensure higher burner pressures with improved atomization and high combustion chamber air pressures which support combustion more readily. Lower aircraft speeds reduce the windmilling rev/min and moderate the combustion chamber air velocity. The relighting technique is detailed in the Pilot's Notes.

Engine anti-icing

35. The anti-icing system prevents the formation of ice on the engine air intake during operation in low temperature conditions. Ice accretion would restrict the airflow into the engine, reducing the thrust and increasing the jet pipe temperature with possible damage to the engine.

36. Ice is prevented from forming in and around the air intake by controlled distribution of warm air from the delivery end of the compressor; this affects the engine in two interrelated ways. Firstly, the airflow through the turbine is reduced, thus reducing the thrust and increasing the jet pipe temperature; secondly, the air entering the intake is heated slightly, causing a decrease in air density and a further decrease in thrust. Therefore, to maintain the required thrust the airflow must be restored by use of the throttle which, in turn, increases the fuel consumption and jet pipe temperature, but the Operating Limitations must not be exceeded. Fig. 9 shows how anti-icing affects the thrust, specific fuel consumption and the jet pipe temperature.

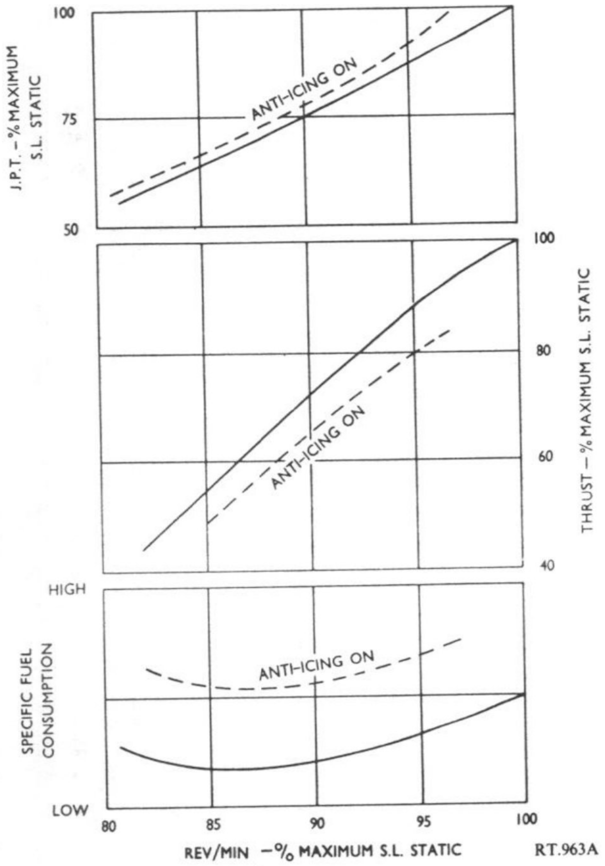

Fig. 9 Effect of anti-icing airflow

Fuel filter de-icing

37. At high altitudes or low temperature conditions, the water content in the fuel may form ice particles which would block the engine filter. If icing occurs, the increased pressure drop across the filter is sensed by a switch (integral with the filter assembly) which energizes an aircraft-mounted pump to supply de-icing fluid to the filter. When the pressure drop returns to normal, the pump is automatically switched off.

STARTING AND STOPPING

38. The engine is started by a turbine-powered starter motor mounted on the front bearing housing. The starter, which derives its energy from the combustion of iso-propyl-nitrate fuel, rotates the engine to a rev/min at which it could become self-sustaining and able to accelerate under its own power. The starting drill is described in A.P.43473J. G. H. N.

39. Because of the need for accurate timing of the starter-assisted period and the ignition (light-up) process, the starting cycle is fully automatic. The controls should be set, the starting button pressed, and the jet pipe temperature observed.

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

(1) Starter and ignition, for a normal start.

(2) Starter only, for motoring over.

(3) Ignition only, for relighting in flight.

41. If 'light-up' is delayed and does not occur until towards the end of the starter-assisted period, the engine may not have reached a self-sustaining speed before the starting cycle terminates; in this case, the engine rev/min will fall and the start fail. On the other hand, 'light-up' may not occur at all and the engine rev/min will fall with that of the starter motor. This is known as a 'false start'.

42. A more serious form of faulty start, i.e. 'hot-start' or 'torching', may occur if the accumulation of fuel resulting from the 'false-start' is not given sufficient time to drain from the combustion chambers before attempting another start. The surplus fuel gives a rich overall mixture which, on starting, may produce excessively high jet pipe temperatures with possible damage to the engine. Excess fuel may be removed by motoring the engine as described in Vol. 1, Part 2, Sect. 2, Chap. 2. The starting and stopping drill is given in A.P.4347J. G. H. N.

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