

CARBURATION, SUPERCHARGING, AND FUEL INJECTION

CARBURATION

Fuels

1. Aero-engine fuels consist of roughly 85 per cent. carbon and 14 per cent. hydrogen, the atoms of which are linked together in a manner characteristic of certain substances known as hydrocarbons.

2. When mixed with air (which is about 21 per cent. oxygen and 79 per cent. nitrogen) and burned in an engine, the hydrogen and carbon combine with the oxygen to form carbon dioxide and water vapour; the nitrogen, being an inert gas, remains chemically unchanged, but its presence is valuable in that it acts as a buffer, slowing down what would otherwise be an explosive combustion, and helping to maintain reasonable temperatures.

3. The most important qualities of engine fuels are:—

(a) *Calorific Value.* This is a measure of the amount of heat that can be obtained from the fuel, and is measured in British Thermal Units per pound. It varies according to the composition of the fuel, those with a high hydrogen content being superior in this respect. However, in small high-performance aircraft with limited tankage, the heat energy in a given volume of fuel is more important than that per unit weight.

(b) *Volatility.* This is the tendency of a liquid to evaporate. High volatility is desirable in aero-engine fuels for easy starting, but if it is too high, vapour locks tend to form, particularly in the fuel pump, and the tendency for carburettor ice to form under certain conditions is enhanced.

(c) *Anti-Knock Properties.* The higher the pressure to which the air/fuel mixture can be raised before combustion the higher will be the pressure (and the temperature) of the burning gases; consequently the greater will be the power output and the thermal efficiency. This compression pressure is governed by the compression ratio of the engine and, where applicable, by the degree of supercharging. It is limited by the tendency of the fuel to detonate.

Detonation

4. After ignition the flame normally travels smoothly through the combustion chamber until the charge is all burned. The rate of burning may be as high as 60 ft. per second, which may seem very fast in view of the size of the cylinder but, nevertheless, it is steady. Combustion is comparatively quiet, with a regular pressure rise and a steady push on the piston. When the detonation occurs, combustion begins normally, but at an early stage the temperature of the unburned part of the mixture is raised so high that it ignites spontaneously, with a flame velocity in the neighbourhood of 1,000 ft. per second. The cylinder walls and piston receive a hammer-like blow (knocking) giving rise to the characteristic pinking noise, familiar to motorists though not audible in the air because of propeller and other noises. The rate of pressure rise (Fig. 1) is too great to be accommodated by movement of the piston, so that much of the chemical energy released is wasted as heat, instead of being transformed into mechanical power.

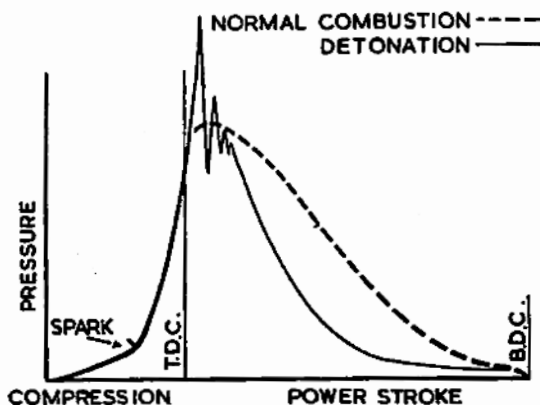


Fig. 1. Detonation—Combustion Pressures.

Effects of Detonation

5. The loss of power consequent upon the reduced thermal efficiency is accompanied by a rise in cylinder temperatures, which may become

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excessive at certain positions. Burning of the piston crown (Fig. 2) and exhaust valves will result from prolonged or severe detonation, the high maximum combustion pressures possibly leading to the collapse of the former and loosening of the valve seats. Also to be expected are carbonizing of the oil in piston-ring grooves, with consequent burning of the piston walls, and vaporization of oil owing to the hot gases forcing their way past gummed-up rings into the crankcase.

Causes of Detonation

6. Apart from certain engine design features over which the pilot has no control, detonation may be caused by one or a combination of the following:—

(a) Incorrect mixture strength. The greater the amount of fuel for a given amount of air the greater the power that can be obtained without detonation. If boost and r.p.m., and therefore the power output, are high the mixture must be rich.

(b) Anything that raises unduly the temperature or pressure of the mixture before it is burned, e.g. the use of warm air (against carburettor icing) at high powers, overheated cylinders or hot spots within them, and high boost with unusually low r.p.m. This last condition is likely to cause detonation because, at the reduced induction velocity, the resistance to

flow is less and consequently the volumetric efficiency is greater. Therefore, at a given boost a greater weight of charge is admitted per stroke and higher cylinder pressures are obtained.

(c) Fuel of low anti-knock value.

Knock Rating of Fuels

7. Depending on their composition, fuels differ considerably in their resistance to detonation, highly rated fuels permitting:—

(a) An increase in compression ratio and hence in thermal efficiency, with a resultant gain in economy and at the same time slightly increased power.

(b) An increase in permissible boost pressure, and therefore greatly increased power. (The power output of an engine is almost directly proportional to the weight of air consumed in a given time; higher boost pressure increases this weight.)

8. It should be understood that these improvements apply only if the engine is designed or modified to take advantage of the higher grade fuel. Such a fuel used in a low-performance engine will not give more power or greater economy but may, on the other hand, cause fouling of the cylinders and eventual mechanical failure.



Fig. 2. Effects of Detonation on an Aero-Engine Piston.

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(A.L. 2, Jan. '55)

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Anti-Detonation Measures

9. The anti-knock value of fuels can be raised by the addition of substances such as tetra-ethyl-lead, or by changing the composition of the fuel itself. For various reasons the use of such measures is impracticable beyond a certain point, and to enable the use of very high boosts, other methods are used. The temperature of the fuel/air charge can be reduced by more efficient cooling of the cylinders, and by the use of inter-coolers which reduce the charge temperature on engines fitted with two-stage superchargers; an over-rich mixture at high boosts will also help to keep the charge temperature down. In addition to the foregoing, a further method is available to enable very high boost pressures to be used. This is to inject into the induction system, at high boosts, a fluid with a high latent heat of vaporization which, in the process of vaporizing, cools the fuel and air with which it mixes. Water is the best known substance for this purpose, but since its freezing point is not low enough for general service use it is mixed with methanol to reduce the freezing level. A mixture of 60 per cent. methanol to 40 per cent. water by volume has been found satisfactory under widely varying conditions. The injection of such a mixture, even at boosts somewhat below those at which its use is essential, gives a small increase in power at a given boost due to an improvement in volumetric efficiency resulting from the reduction in charge temperature.

Use of Water Injection

10. With water-methanol injection installed, a pump, supplying water-methanol to the induction system, is switched on when maximum boost is required; an interconnection with the boost regulator then permits the throttle valve to open further to give an increased boost. When the water-methanol pump is switched off, or the supply becomes exhausted, the boost regulator again automatically adjusts the throttle opening, and so the boost, to the maximum permissible without the use of the anti-detonant.

Octane Numbering and Fuel Grading

11. Before the advent of the more highly supercharged engines, the resistance to detonation of an aviation fuel was expressed by its octane number. This rating system was based on the widely different knock resistance of two pure spirits, iso-octane (excellent) and heptane (very poor). By degrading iso-octane with heptane until the blend detonated in a variable compression engine under the same standard conditions as the fuel under test, it was possible to classify that

fuel by a number representing the percentage of iso-octane in the test blend. Thus 87-octane fuel corresponded to a mixture of 87 per cent. iso-octane and 13 per cent. heptane.

12. This system, however, took no account of the increase in knock resistance at rich mixture strengths (see para. 6 (a)), and for a very good reason. Although engines are supplied with a much weaker mixture under cruising conditions than when developing high-power outputs (for reasons to be discussed later), those using lower grade fuels do not have to cope with markedly increased combustion pressures at a maximum output. Consequently the margin between the operating power of such engines, and the power as limited by detonation, is smallest at weak mixtures and increases as the mixture is richened. The octane system, therefore, specified weak mixture knock ratings only. With highly supercharged engines, however, combustion pressures at maximum output are well above those at cruising powers, and it has become necessary to specify knock ratings for both weak and rich mixture conditions. Furthermore, as fuels with knock ratings superior to iso-octane are now available, the rating of these fuels has become more involved, necessitating the addition of tetra-ethyl-lead to the reference fuels.

13. The system now adopted categorizes piston-engine fuels (Avgas) by a grade name consisting of two numbers, the first being the knock rating for weak mixture conditions and the second that for rich mixture, e.g. Avgas Grade 91/98 and Grade 100/130. For reasons given earlier, the lower grades usually have only one number, e.g. Grade 73.

14. Whilst weak mixture ratings are still measured in the same way as octane numbers (in fact they are octane numbers), rich mixture ratings are related to the maximum boost that can be applied without detonation. The precise difference is of no direct concern to pilots, but those interested will find the information in A.P. 3160, Volume 1, Section 2, Chapter 1, "Gasolines—Design and Performance Requirements".

Pre-Ignition

15. Detonation should not be confused with pre-ignition; although the latter may follow it. If an engine is allowed to become overheated the temperature of some projection in the combustion chamber, such as the sparking plug points or a piece of carbon, may rise so much that the mixture is prematurely ignited during the compression

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stroke, and the engine will continue to fire with the ignition system switched off, though probably not on all its cylinders. With pre-ignition there is a loss of power, rough running, and further overheating, and the higher the engine speed the worse it becomes, whereas detonation almost always diminishes with an increase in r.p.m.

Mixture Requirements

16. Carburation, as applied to the internal combustion engine, is the process by which air and fuel vapour are mixed in suitable proportions, and the supply of this mixture regulated according to the requirements of any given operating condition.

17. Although air and fuel vapour will burn when mixed in proportions ranging between roughly 8 to 1 and 20 to 1 (by weight), complete combustion occurs only at an air/fuel ratio of about 15 to 1. With this, the chemically correct mixture, all the hydrogen and carbon in the fuel combine with all the oxygen in the air to form carbon dioxide and water vapour. The atmospheric nitrogen, as previously explained, takes no active part in the combustion process beyond moderating the rate of burning.

18. The chemically correct mixture, however, does not give the best results because the temperature of combustion is so high that power is lost through a phenomenon known as *dissociation*. Some degree of detonation also occurs at such temperatures, and the loss of power is thereby aggravated. Dissociation is a momentary splitting-up of the products of combustion into their separate elements, during which heat is absorbed which would otherwise have helped to raise the combustion pressure; although these elements re-combine later in the power stroke and the lost heat is regained, it is too late to be of much value.

19. With a mixture about 10 per cent. richer than the chemically correct one the excess petrol absorbs sufficient latent heat during vaporization to obviate dissociation and detonation at moderate power outputs. But, as there is a tendency for some cylinders in an engine to receive a weaker mixture than others, owing to the difference in inertia between air and petrol droplets, it is the practice to err on the safe side by supplying a mixture about 15 per cent. richer at normal cruising powers.

20. Since engine power is a product of engine speed and the average pressure in the cylinders

during one cycle (the mean effective pressure (M.E.P.)), higher power outputs involve increases in either or both of these factors. Such increases, however, involve an increase in mixture temperature, and therefore in the tendency to detonate. Therefore when higher power is required, as for climbing, the mixture is further enriched to about 20 per cent. above chemically correct, to obtain the necessary cooling, and for take-off, when maximum power is employed, the figure rises to 30 per cent. or more.

21. Apart from its cooling function the excess petrol necessary at high powers is wasted, for there is no oxygen available to burn it. (Higher power results from the supply of a greater weight of charge in a given time and not because of mixture enrichment.) In practice, excess petrol vapour is not exhausted as such; the oxygen is shared out to some extent, so that carbon monoxide is produced as well as carbon dioxide. With very rich mixtures, however, some carbon particles fail to unite with oxygen at all, and are exhausted as black smoke.

22. Cooler burning is also obtained with mixtures weaker than the chemically correct, partly because less petrol is burnt per power stroke, and also because the rate of burning slows down (owing to the greater proportion of inert gas in the cylinder). With extremely weak mixtures, in fact, the flame rate may be so slow that combustion is still taking place when the inlet valve next opens, and "popping back" tends to occur in the inlet manifold.

23. For these reasons power tends to decrease as the mixture is weakened from chemically correct. With moderate weakening (about 80 per cent.), however, this decrease is partly compensated by the improved efficiency resulting from cooler burning and the fall in power is relatively less than the saving in fuel, *i.e.* the *specific fuel consumption* is reduced (galls. per horse-power/hour). Provided, then, that only a modest power output is required, such a mixture will give the most economical operation, the maximum power obtainable being limited by the rise in mixture temperature with increased r.p.m. or boost.

24. It will be recalled that the exhaust valve is given a certain amount of lag so that advantage may be taken of the considerable inertia of the escaping gases at normal and high engine speeds, to obtain thorough scavenging and to give impetus to the incoming charge. As engine speed is reduced; however, the exhaust gas velocity falls

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and more combustion products are left behind in the cylinder, whilst at still lower speeds there is even a tendency for gas to be sucked back by the descending piston through the exhaust valve before it closes. The consequent dilution of the fresh charge is such that, to maintain smooth running, a progressively richer mixture must be supplied as idling speed is approached.

Float-Chamber Carburettor

25. A carburettor is a device attached to the inlet manifold of an engine for the purpose of providing a well atomized and correctly proportioned mixture of fuel and air. It includes a valve for limiting the flow of mixture, by means of which the pilot can control power output. The simplest kind of carburettor is shown in Fig. 3.

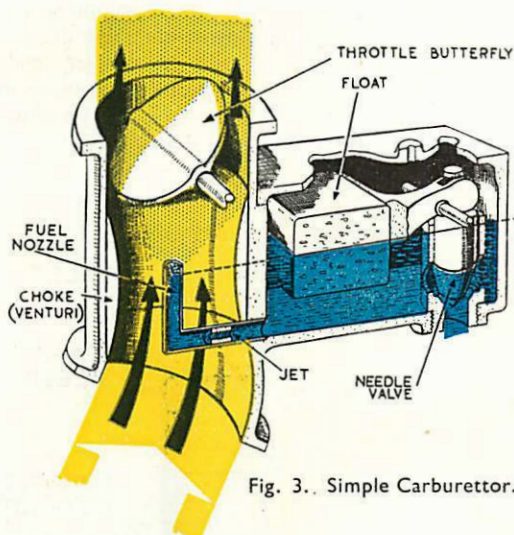


Fig. 3. Simple Carburettor.

26. The induction stroke in each cylinder reduces the pressure in the inlet manifold and thereby causes air to flow through the choke tube from the carburettor air inlet. Projecting into the choke tube is a fuel nozzle from which petrol is

sprayed into the air stream as droplets of various sizes. These in turn divide as they are swept along, during which time vaporization takes place at the surface of each droplet, causing the disappearance of the smallest and a reduction in size of the others. Not all of the petrol is vaporized by the time it reaches the cylinders—indeed, as has been pointed out, the cooling due to evaporation during the compression stroke is necessary under high-power conditions to prevent detonation—consequently, inequalities arise in the composition of the mixture in different cylinders. Fig. 4 gives an example of what may occur; the inertia of the fuel particles being greater than that of the vaporized mixture in which they are carried along, the tendency is for them to overshoot the earlier inlet branch pipes and accumulate in the most distant cylinders, thus providing a richer mixture in the latter.

27. Control of power output is the function of the throttle-valve, or throttle-butterfly, as it is more usually termed. According to the attitude of the butterfly, the flow of mixture from the choke tube is more or less impeded and the power of the engine thereby varied. In supercharged engines the throttle is directly controlled by the pilot's throttle lever, but, as will be seen later, where an automatic boost control is fitted, this also has influence in the matter.

28. To obtain a required fuel/air ratio a certain weight of fuel must be mixed with a given weight of air, consequently the rate of flow of fuel from the nozzle must be related to that of the air through the choke tube. In this type of carburettor the desired result is achieved by creating a region of substantially reduced pressure at the fuel nozzle by means of a venturi, and so causing fuel to be sucked from the float chamber through a jet—the purpose of which is to cut down the flow to the required rate.

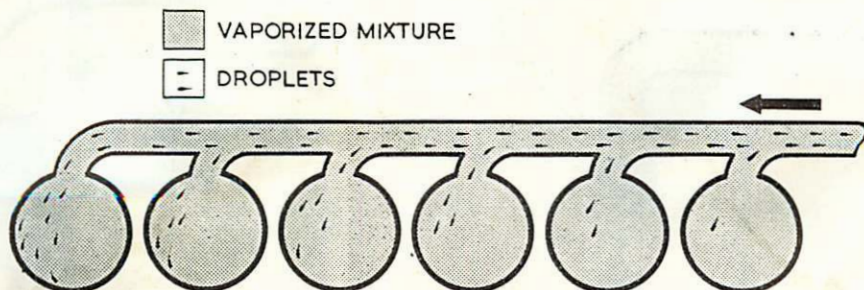


Fig. 4. Inequality in Distribution.

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29. As will be seen in Fig. 3, the venturi is a streamlined restriction in the choke tube, the effect of which is temporarily to speed up the flow of air. Now, in accordance with Bernoulli's theorem, as the air accelerates, its pressure falls, the lowest pressure and highest velocity being reached at the throat of the venturi, where the fuel nozzle outlet is located.

30. The purpose of the float chamber is to provide a supply of fuel to the nozzle at atmospheric pressure, so that the rate of flow will depend entirely on the suction at the venturi throat. Fuel is admitted to the float chamber through a float-controlled needle valve so that as the fuel level rises the valve progressively closes until, when the level is a little below that of the nozzle outlet, the supply is cut off. With the engine running, the fuel level in the float chamber falls until the needle valve is sufficiently open to balance demand and supply. The air space in the chamber is connected to the atmosphere, usually by a pipe known as the pressure balance tube, leading to the carburettor air inlet.

31. The first drawback that arises with the simple arrangement so far described is that the flow characteristics of fuel and air differ, so that as the throttle is opened, and the air demand of the engine accordingly increased, the proportion of fuel to air rises. This tendency is corrected by *air bleeding* through a diffuser (Fig. 5). Beneath

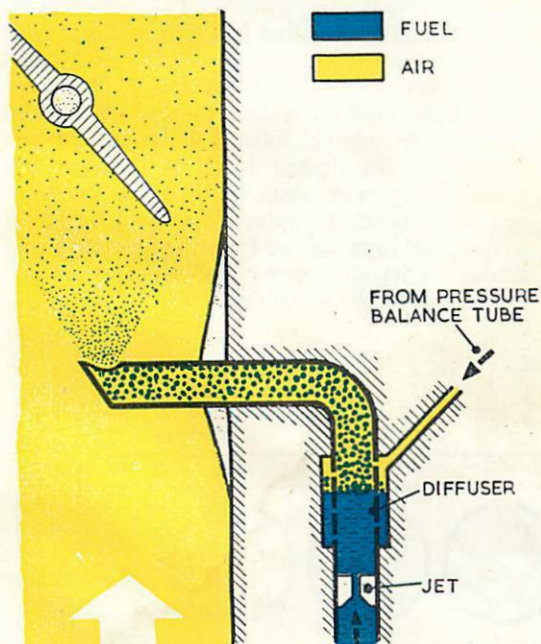


Fig. 5. Action of Diffuser.

the static fuel level is a series of small holes communicating with the pressure balance tube. When the engine is running the fuel level falls by an amount depending on the velocity of the air in the choke tube; consequently, as the throttle is opened, the holes in the diffuser passage are progressively uncovered and the depression over the fuel is reduced sufficiently to maintain a constant fuel/air ratio. In addition, the air entering through the diffuser holes mixes with the fuel and helps to break it up into small drops.

32. A further shortcoming becomes apparent at low engine speeds, for, with the butterfly nearly closed, the volume of air passing into the engine is so small that the pressure drop in the choke is insufficient to draw fuel past the jet. Above the butterfly, however, a considerable suction still exists, and this is utilized to effect a second source of fuel supply solely for slow-running conditions. A separate fuel passage, with its own jet, leads from the float chamber to an outlet above or in line with the butterfly, when it is in the slow-running position (Fig. 6), the size of the jet being

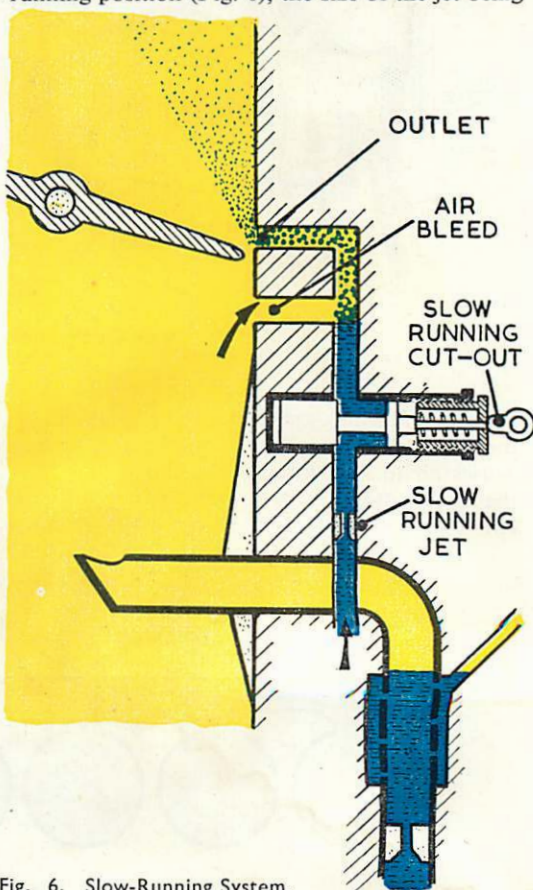


Fig. 6. Slow-Running System.

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such that the rich mixture necessary under these conditions is obtained. An air bleed, opening into the choke tube below the butterfly, assists atomization. A cut-out valve is also usually incorporated for shutting down the engine, its use being particularly necessary when the engine is so hot that it would continue to fire with the ignition switched off.

33. To supply the rich mixture required at high powers, extra jets, controlled by cam-operated valves, are fitted. Their output supplements that from the main jet (Fig. 7). The power jet comes into operation when the throttle lever is advanced beyond the maximum position and so gives sufficient enrichment for climbing conditions, this being augmented by the enrichment jet, operated by the boost control mechanism,

for take-off power. The method of delivery of this extra fuel into the choke varies between carburetors. Some employ an extra fuel nozzle for each jet, others a single nozzle supplied by both, while a third delivers fuel from the power jet into the main jet passage, and from the enrichment jet through holes in the choke tube.

34. When the throttle is opened other than very slowly the mixture becomes temporarily weakened; the engine tends to gulp too much air for the fuel immediately available. Some relief during this off-balance period is afforded by the reserve of fuel above the jet in the diffuser, but it is insufficient to enable the engine to pick up quickly. An accelerator pump is therefore provided to squirt extra fuel into the choke tube while the throttle is being opened, and for a

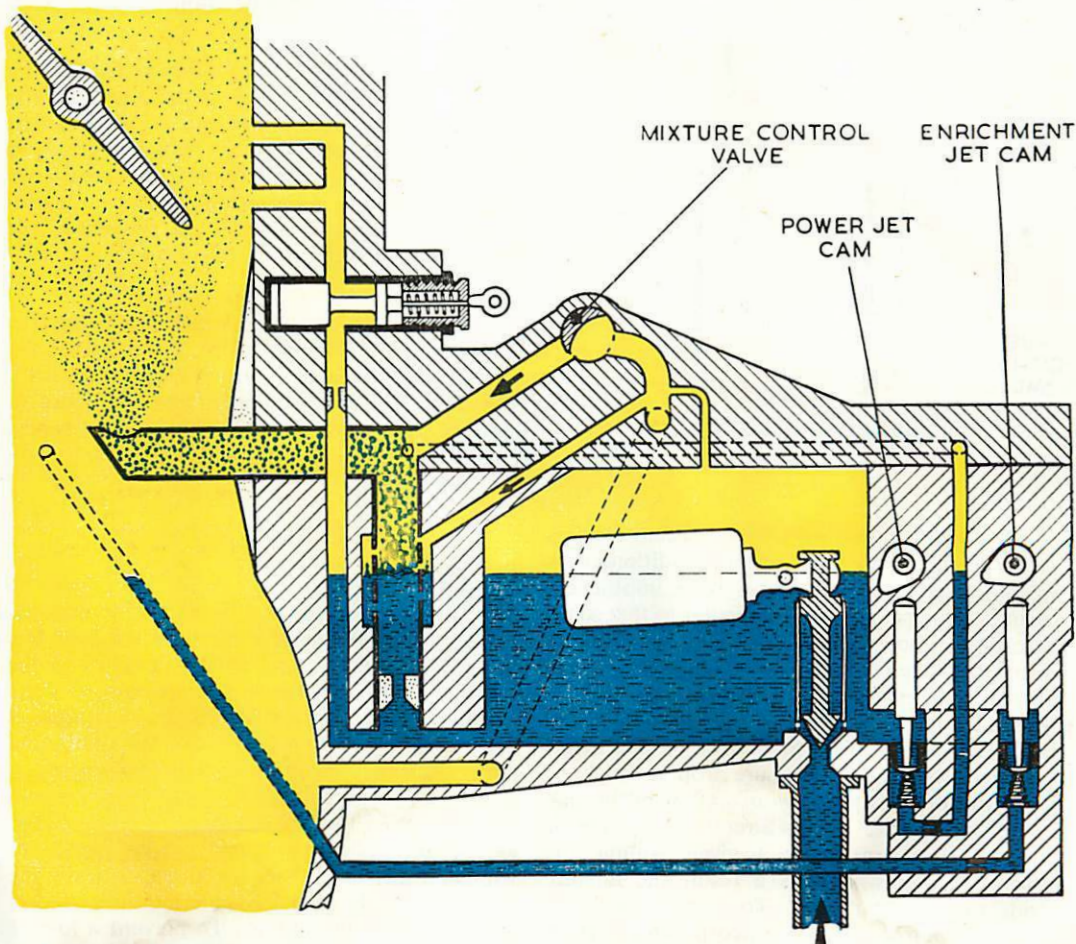


Fig. 7. Carburetor, Showing Power and Enrichment Jets and Mixture Control.

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second or two afterwards. The principle of one type of pump is shown diagrammatically in Fig. 8, which is self-explanatory.

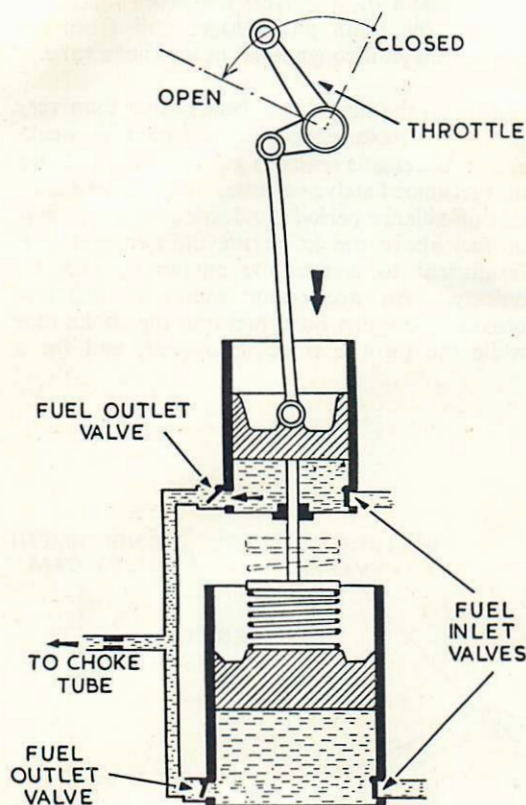


Fig. 8. Accelerator Pump.

35. Up to this point, with the exception of take-off enrichment, the carburation conditions considered apply generally, and some motor car carburetors are, in fact, very similar to that so far described. But aero-engines are required to operate through a wide range of altitudes, and this introduces another problem. It will be recalled that a given mixture strength consists of so many parts of fuel to so many parts of air *by weight* and that the pressure drop in the choke is proportional to the *volume* of air flowing through it in a given time. As an aircraft climbs, the air becomes less dense—for a given volume the weight decreases—and as a result the mixture *tends* to become richer. To counteract this a **mixture control valve** is incorporated, which admits a controlled flow of air from the pressure balance tube to the fuel passage above the diffuser

(Fig. 7). This partially breaks down the suction causing the fuel-flow, and so enables the flow to be sufficiently reduced to maintain the correct mixture strength at increased altitude.

36. In low-powered engines the mixture control valve is connected to a lever on the pilot's throttle quadrant, by means of which the pilot can adjust the mixture strength both for altitude and for economic cruising. With larger engines, however, it is usual for altitude compensation to be automatic, this being achieved by coupling the valve to an aneroid unit sensitive to atmospheric pressure. As the pressure decreases with altitude the aneroid capsules expand, causing a servo piston to open the mixture control valve progressively, maintaining a constant mixture strength. For economical cruising the aneroid unit can be reset by a lever in the cockpit with the valve in a more open position.

37. Not all carburetors conform to the pattern outlined in the foregoing paragraphs; Rolls Royce types omit the power and enrichment jets, using instead a tapered needle which is arranged to move in and out of the main jet in accordance with the different mixture and altitude requirements. The basic principles are the same, but the method of application differs.

38. As all aero-engines, except those fitted to light aircraft, are supercharged, it is usual for the carburettor to include an automatic boost control. Description of this component and fuel injection systems will be left until the principles of supercharging have been explained.

SUPERCHARGING

Purpose

39. The power developed by an engine depends on the weight of mixture burnt in the cylinders in a given time. As each piston descends on the induction stroke it creates a depression, and the weight of charge that enters the cylinder is dependent on the pressure in the induction manifold, which, in an unsupercharged engine, is governed by the pressure of the atmosphere and the amount of throttle opening. Consequently, as the atmospheric pressure steadily decreases with altitude, the higher an aircraft climbs the less is the weight of charge entering the cylinders at a given throttle setting. To prevent a loss of power as altitude is gained it is necessary to maintain the manifold pressure by supercharging.

Supercharger Construction

40. A supercharger (Fig. 9) is basically an engine-driven fan which is interposed between the carburettor and the induction manifold, although it may be fitted between the carburettor and the air intake. The fan, or impeller, as it is called, is driven from the crankshaft through a train of gears which impart to it a high rotational speed, which causes the particles of fuel and air between the impeller blades to be thrown radially outwards at a high velocity by centrifugal force. The resulting suction at the centre, or eye, of the impeller, induces a steady flow of mixture from the carburettor.

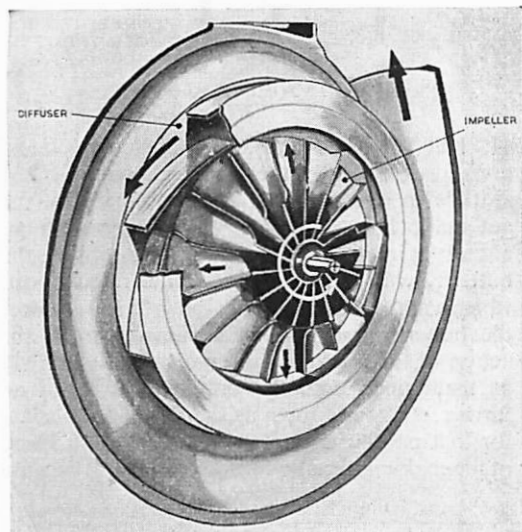


Fig. 9. Supercharger.

41. Surrounding the impeller is a system of divergent passages, known collectively as a diffuser, the function of which is just the opposite to that of the carburettor choke; for in the latter the flow of air is smoothly accelerated so that its pressure will fall, whereas in the diffuser the high-velocity flow of mixture from the impeller is smoothly decelerated to give an increase in pressure. This manifold, or boost pressure, is indicated by a gauge in the cockpit, the dial being graduated usually in pounds per square inch above and below standard sea-level atmospheric pressure which is marked as zero.

Automatic Boost Control

42. Since the supercharger is designed to produce a high manifold pressure at altitude, at low altitudes it will tend to overboost the engine and so, to avoid severe detonation and mechanical

strain due to excessive combustion pressures, it is necessary to restrict the opening of the throttle butterfly. With some American engines this is the responsibility of the pilot who must not exceed the maximum permitted boost when at low altitudes, and to maintain a given boost during a climb or descent, must be continually adjusting the throttle setting. In British engines this is done automatically by a boost control unit attached to the carburettor (Fig. 10). An aneroid unit, exposed only to the pressure in the induction system, is coupled to the throttle linkage through an oil-operated servo piston in such a way that when the capsules compress, the butterfly valve is partly closed, and *vice versa*. When the engine is started the induction pressure falls to a low value and the aneroid expands, causing oil to be directed below the servo piston, which is moved to the top of its stroke. Subsequent throttle opening is accompanied by an increase in the induction pressure, causing the aneroid unit to compress and the valve to rise until the supply of oil to the underside of the servo piston is cut off. Any further throttle opening will now cause oil to be directed above the piston, which will descend and close the butterfly until the induction pressure falls sufficiently to cut off the servo oil supply.

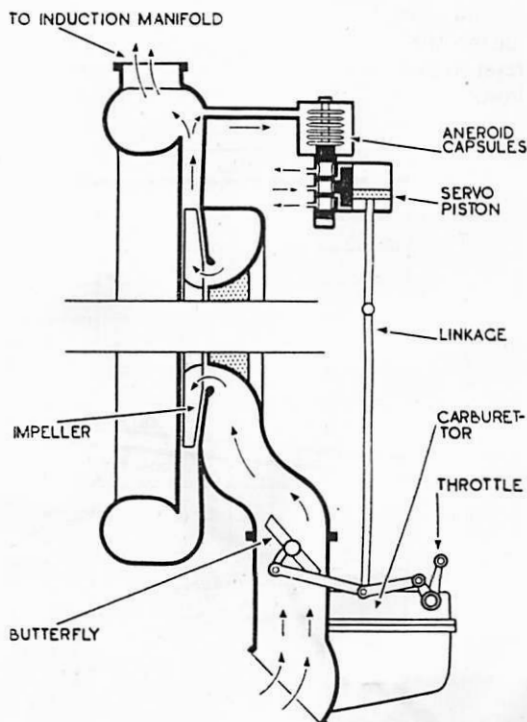


Fig. 10. Automatic Boost Control.

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Thus, whatever the position of the throttle lever, the induction pressure cannot rise above a certain value known as the *rated boost*. With the valve in the equilibrium position, any tendency for the induction pressure to fall off as height is gained will be counteracted by a progressive opening of the butterfly through the admission of more oil beneath the servo piston, until the height is reached where, with the throttle lever fully advanced, the butterfly is wide open. Above this, the *rated altitude*, the induction pressure will fall as in an unsupercharged engine.

43. **Variable Datum Cam.** At low altitudes the action of the boost control, as so far described, would be such that rated boost would be reached with the throttle lever partly open, beyond which there would be lost motion. Furthermore, although the aneroid unit would prevent a fall in boost pressure during a climb at full throttle, it would not be able to do so at pressures lower than the rated boost, and it would be necessary for the pilot to be continually advancing the throttle. These disadvantages are overcome by the addition of a variable datum cam (Fig. 11) fitted to the top of the aneroid chamber and interconnected with the throttle lever. This cam permits the aneroid unit to rise as the throttle is closed. Thus, with the aneroid unit adjusted to give the rated pressure with the throttle lever fully advanced, as the throttle is closed the valve will be progressively reset so that its equilibrium position will occur at lower boost pressures, and for a given position of

the throttle lever a corresponding degree of boost will be obtained.

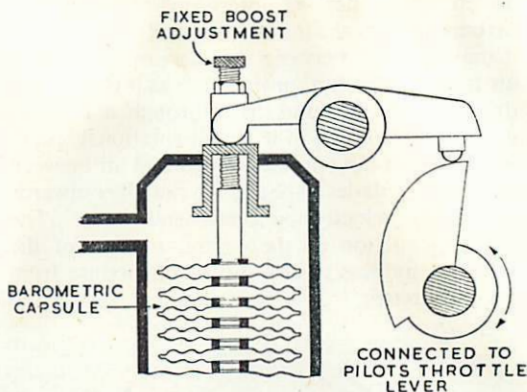


Fig. 11. Variable Datum Cam.

44. **Full-Throttle Height.** The lower the boost pressure selected by the pilot the greater is the altitude to which it can be maintained by the automatic boost control. For example, in an aircraft at its rated altitude and still climbing, the butterfly will be fully open at the rated boost, which will then begin to fall; but at a lower boost the butterfly will still be opening through the action of the aneroid unit, and the pressure will be maintained until the butterfly can open no further. This is known as the *full-throttle height* for that particular boost and r.p.m. The speed of the engine is a qualifying factor (Fig. 12) because

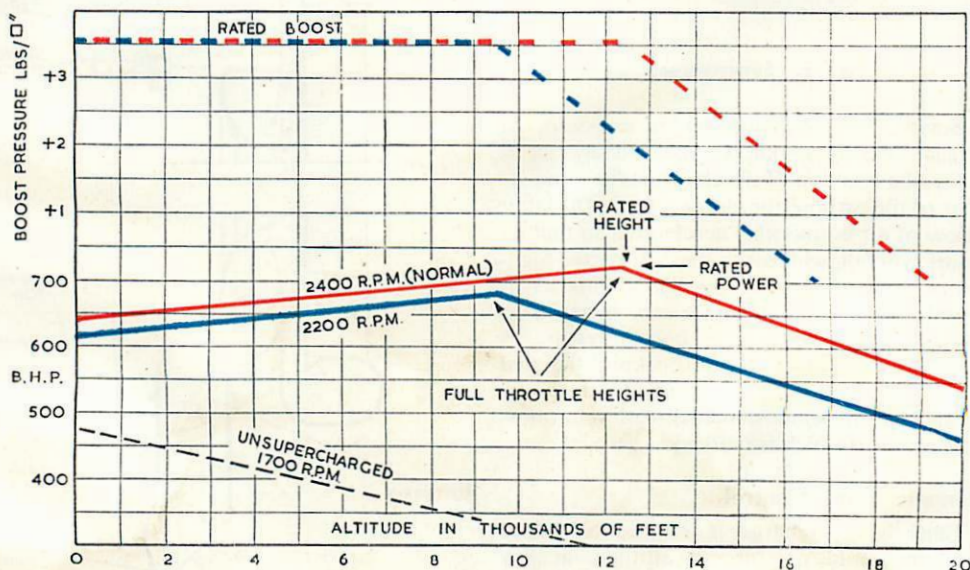


Fig. 12. Power Curves—Supercharged Engine.

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it controls the speed of the supercharger impeller ; at higher than normal r.p.m. the full-throttle height for a particular boost will be raised, and conversely. (Note : The *rated altitude* is the full-throttle height at rated boost and *normal* r.p.m. for that boost.)

45. **Automatic Boost Control—Override.** Before leaving the automatic boost control there is one other feature to be explained. So that the maximum possible power is available for take-off and emergencies, provision is made for the rated boost to be exceeded under these circumstances. This may be done either by arranging for the pressure in the aneroid chamber to be reduced through a controlled leak, or by lowering the aneroid unit beyond the rated boost position. In one installation, when the throttle lever is advanced beyond a gated position on the quadrant, an extension to the variable datum cam gives the required depression and at the same time brings the enrichment jet into operation.

Supercharger Losses

46. From Fig. 12 it will be seen that, for a constant boost and r.p.m. setting, engine power increases up to the full-throttle height. As an aircraft climbs, the fall in temperature of the air is accompanied by a corresponding drop in the charge temperature. Consequently the density of the mixture increases and a greater weight of charge is burnt per power stroke. Furthermore, the decreasing atmospheric pressure offers less resistance to the expulsion of the exhaust gases and to the downward movement of the pistons, in the former case improving the volumetric efficiency and in the latter raising the mean effective pressure.

47. Of the total power absorbed by the supercharger a proportion is wasted in overcoming friction and in heating the mixture adiabatically. The rise in mixture (charge) temperature, unavoidable though it is, must be kept as low as possible, because the higher the temperature the greater is the loss in engine power due to reduced charge density, and the greater the risk of detonation. Both friction losses and supercharger heating increase with impeller r.p.m. ; consequently, for efficient operation the engine speed should be as low as possible.

48. It is clear that a supercharged engine is comparatively inefficient at or near sea-level ;

much of the power absorbed by the supercharger goes in restoring the drop in induction pressure necessarily created by the butterfly to prevent over-boosting ; the power developed at a given boost and r.p.m. setting is lower than at altitude because of the higher air temperature and pressure ; and, although considerable power can be obtained by using high boost pressures and r.p.m., it involves the supply of a very rich mixture to counteract the combined effects of high air temperature and adiabatic heating.

Control Settings for Maximum Efficiency

49. On the other hand, maximum efficiency (minimum specific fuel consumption) is obtained when the butterfly is fully open and the r.p.m. as low as can be obtained without detonation ; in practice, this is at the full-throttle height for the power setting in use. The power is obtained by using the highest possible weak mixture boost in conjunction with the lowest practicable r.p.m. to give the required air speed. This subject is discussed more fully in the chapters in Vol. 2, Range and Endurance.

Two-Speed Superchargers

50. When a high rated altitude is desired, it is necessary to step up the supercharger gear ratio so that the impeller can be driven at a sufficiently high speed. With such an arrangement, however, the power losses at low altitudes are considerable for the reasons already given. To avoid such losses, superchargers with two impeller gear ratios are used, the change from one to the other being made either manually or automatically at a certain height. In Fig. 13, which shows how the power output varies with altitude at rated boost and normal r.p.m., the loss of power at low altitudes in high (S) gear is immediately evident. Furthermore, it can be seen that it is pointless to change from low (M) gear to S gear at the M gear rated altitude for, although the rated boost pressure would be maintained, the power output would immediately fall, in this case by about 190 B.H.P. The change should be delayed until the boost pressure has fallen by about 2 lbs./sq. in., when the altitude is reached at which the M and S power curves intersect. The rated power in S gear, obtained at 13,000 feet, is well below that in M gear because of the extra power needed to drive the supercharger at the higher speed.

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51. On some two-speed installations the selection of high gear is automatic. On fighter-type aircraft the automatic gear change is usually set for combat climb power conditions; if economical climbing power conditions are used the automatic change-over will occur too soon. The pilot can delay the change by selecting "MOD" until the boost pressure selected has dropped by at least 2 lbs./sq. in. and then selecting "AUTO". Full instructions are contained in Pilots' Notes for the type.

Two-Stage Superchargers

52. In aircraft that are required to operate at altitudes much in excess of 30,000 feet, a higher degree of supercharging than can be obtained with a two-speed impeller is needed, and it is necessary to provide an additional stage of compression. In two-stage superchargers (which are also two-speed) separate impeller units, mounted on a common shaft, are arranged, so that the outlet of the first is fed to the inlet of the second. The considerable adiabatic temperature rise through the two stages is counteracted by passing the mixture through an intercooler before it enters the induction manifold, the excess heat

being transferred to coolant which is circulated through a radiator exposed to the outside flow. There is no connection between the intercooler and the engine coolant systems on liquid-cooled engines.

Supercharger Accessories

53. Because of the high rotational speed of the impeller unit—it may be up to ten times engine r.p.m.—the inertia forces developed are considerable, and to avoid large stresses in the transmission it is necessary for the drive to be as smooth as possible and for sudden changes of r.p.m. to be avoided. To damp out pulsations from the crankshaft the initial drive is through a spring-loaded gear, the springs absorbing crankshaft torque irregularities and so protecting the gear teeth. To allow for sudden alterations in engine r.p.m. a clutch is included in the gear train the inner member carrying blocks or segments which are pressed against the rim of the outer member by centrifugal force. At any steady r.p.m. the centrifugal force is sufficient to keep the clutch solid, but when engine speed is changed quickly a certain amount of slip takes place and so limits the stress on the transmission.

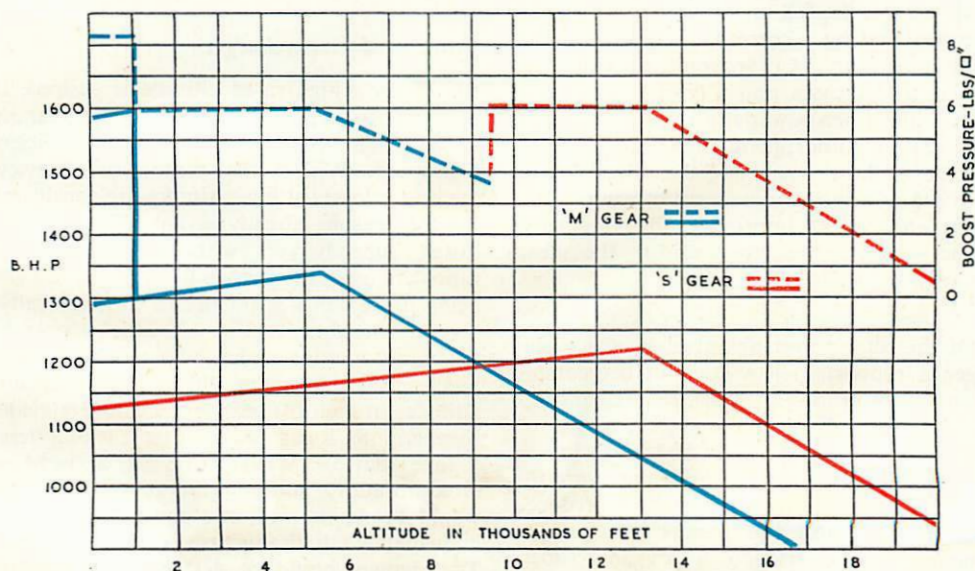


Fig. 13. Power Curves—Engine Fitted with Two-Speed Supercharger.

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CARBURATION, SUPERCHARGING, AND FUEL INJECTION

54. In superchargers of the two-speed type the change from one gear to the other is made through a hydraulically-operated clutch unit (Fig. 14). The two clutch plates, which are free to travel along their respective splined shafts, are rotated at different speeds by the crankshaft driving gear. The chamber behind each clutch plate is connected to the lubrication system through a valve, so that when oil under pressure is admitted to one chamber the other chamber is opened to the oil return system. Thus, when low gear is selected, pressure oil forces the right clutch plate against the centre plate, causing the intermediate gear (which is integral with the clutch unit casing) to rotate the impeller pinion at the lower speed. In high gear the left clutch plate becomes the driving member, the right clutch plate withdrawing slightly under the influence of its return spring.

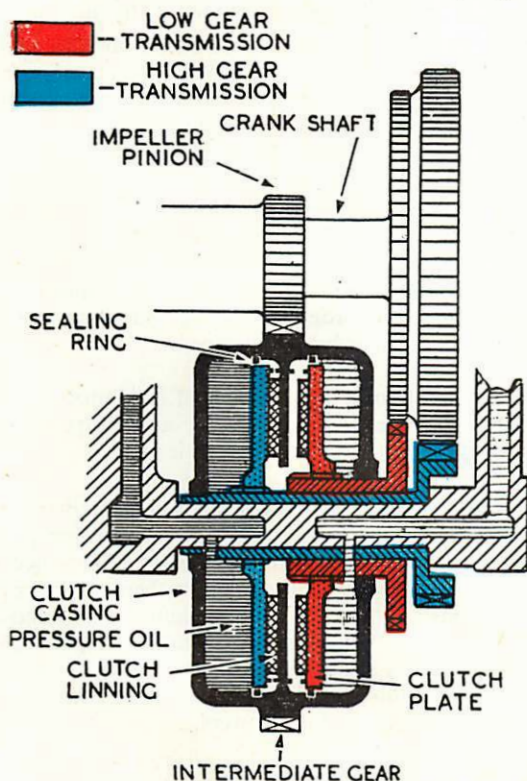


Fig. 14. Supercharger Gear-Change Unit.

55. It is essential that the clutch operating oil be clean, for, owing to the high speed of rotation, any solid impurities are thrown out of suspension by centrifugal force and deposited on the chamber walls. If this sludge were to accumulate, the response to the change-over lever would be retarded or prevented, resulting in over-heated or burnt plates. For this reason the oil is cleaned

in a centrifuger before reaching the control valve. A centrifuger (Fig. 15) is a cylindrical container rotated at a high speed by the intermediate gear. Oil pumped through it consequently deposits any impurities on the walls of its two chambers before discharging through the hollow central bearing.

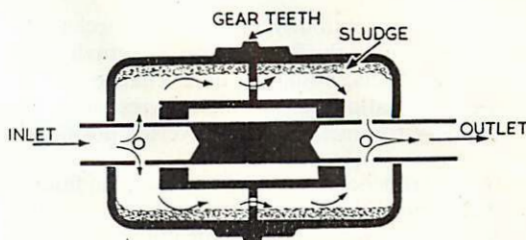


Fig. 15. Centrifuger.

Supercharger Controls

56. There are three controls that affect the pressure developed by the supercharger :—

- (a) The throttle lever.
- (b) The r.p.m. control lever.
- (c) The supercharger gear selector.

The throttle lever position, within the limits imposed by the full-throttle height, determines the boost pressure that is delivered by the supercharger. It is a boost selection lever and, together with the r.p.m. control lever, determines the power output of the engine. The r.p.m. control lever is in effect an engine-speed control and, since the supercharger is geared to the engine crankshaft, changes in engine speed will be reproduced in the supercharger. Changes in the supercharger gear ratio will affect its output, but as seen in para. 50 an increase in supercharger speed does not always mean an increase in engine power output.

Handling Considerations

57. The following points of practical significance should be known :—

- (a) It is unnecessary and uneconomical to use high gear if the required boost pressure can be obtained in low gear.
- (b) The use of high gear reduces the gross brake horse-power at a given power setting, owing to the high temperature of the charge.
- (c) At any given power setting, high gear reduces the power transmitted to the propeller by absorbing more power to drive the supercharger.
- (d) High gear should never be used until the boost in low gear has fallen by at least 2 lbs./sq. in.

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FUEL INJECTION

Advantages

58. The float-type carburettor, in spite of its many refinements, possesses certain inherent disadvantages, among which may be noted :—

(a) The susceptibility of the float mechanism and the fuel in the float chamber to gravity and inertia effects, resulting in a change in the mixture ratio during manœuvres and an inability to function in the inverted position.

(b) A proneness to icing in certain conditions, which, notwithstanding preventive and remedial measures, remains a fundamental weakness of this type.

(c) The adverse effect on volumetric efficiency caused by the choke and the fuel nozzles, which impede to some degree the free flow of air to the engine.

59. As a result, the float-chamber carburettor has largely given way, particularly in high-power engines, to systems in which the fuel is injected under pressure directly into the supercharger and in which the choke is either eliminated or, if retained, is used for a different purpose. Those types which retain the venturi or choke are termed *injection carburettors* and those without a choke are known as *injectors*. The principle of the injection carburettor is outlined below, followed by the working of a typical injector.

Injection Carburettors

60. In injection carburettors the choke passage is retained purely as a means for measuring the airflow. Fuel is not sucked through jets opening into the choke and there is no float chamber. Fuel is supplied, at a higher pressure than is required for float-type carburettors, from a normal engine-driven fuel pump; it passes through a pressure equalizing device, a number of measuring (metering) passages or jets and a manually controlled fuel cut-off valve, to an atomizing nozzle in the eye of the supercharger inlet. These carburettors are complicated, but the following is a brief outline of the essential features and principles of operation. Control of airflow is by means of a throttle butterfly, as in float-type carburettors.

61. Regulation of the quantity of fuel supplied, and of mixture strength, is effected thus :—

(a) In response to the throttle butterfly setting, and so to the boost, by interconnecting a valve with the throttle linkage, controlling the flow through the main jet.

(b) In response to changes in altitude or temperature, by connecting the needle of the appropriate metering jet to a pressure-differential control unit. This consists of two chambers separated by a diaphragm, one side of which is connected to the pressure in the throat of the carburettor choke and the other to the pressure in the carburettor air intake.

(c) At high power and when idling, by opening enrichment jets similarly controlled by a diaphragm unit, in response to the difference in fuel pressure on opposite sides of the main jet.

(d) To ensure that adequate fuel is supplied in response to rapid throttle opening, an accelerator pump is also provided on this type.

62. As with float-type carburettors, the boost is set by means of the throttle lever, a boost regulator controlling the position of the throttle butterfly. On some versions of this carburettor the lever controls only the butterfly; there is no boost regulator and it is necessary to advance the throttle lever progressively to maintain the required boost as height is gained.

63. Operation of the fuel cut-off lever stops the flow of all fuel to the atomizing nozzle, irrespective of the setting of the throttle lever.

64. No manual mixture control is fitted to British versions of this carburettor, but on American versions a manual enrichment control is combined with the fuel cut-off lever which then has three positions: "idle cut-off", "auto-lean", and "rich". In "auto-lean", mixture is regulated automatically as described in para. 61 (a) and (b); the rich position opening an additional enrichment jet for use at high powers.

Fuel Injectors

65. Fuel injectors differ fundamentally from float-type and injection carburettors in that the airflow to the engine is not measured by a venturi. They are thus, strictly speaking, not carburettors but engine-driven pumps which supply fuel direct to the cylinders via the supercharger in accordance with engine requirements. Below follows a description of the working of a typical fuel injector.

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66. Fig. 16 is a diagram of a fuel injector which is fitted in place of the standard engine-driven fuel pump, and which also performs all the functions of a normal aircraft carburettor. The air supply to the engine is controlled in the usual way by a throttle valve in conjunction with a boost control unit (not shown). Fuel is forced into the governor chamber by the vane-type feed pump, which is designed to supply an excess, so that surplus fuel escapes through the relief valve and the pressure in the governor chamber remains constant. Rotation of the governor causes the needle valve to be opened and fuel to flow, first into the governed fuel chamber, and then through the two variable jets into the metered fuel chamber. The difference in pressure between the governed and metered fuel chambers acting on the diaphragm tends to close the needle valve in opposition to the action of the governor. Now, as the thrust exerted by a centrifugal governor is proportional to the square of the r.p.m., and as the diaphragm always balances that thrust, it will be realized that the pressure difference across the diaphragm is also proportional to the square of the r.p.m.

Consequently, as the flow of fuel through a jet is proportional to the square root of the pressure difference across it, for a given opening of the jets the fuel-flow through them will vary directly with the engine speed.

67. The pressure in the governor chamber being higher than that in the governed fuel chamber, there is a small residual pressure on the needle valve tending to close it. This is balanced out by the "idle" spring fitted against the outer surface of the diaphragm. The spring load is adjustable, providing a means of varying the fuel-flow at idling conditions, when the thrust from the governor is very small.

68. The flow of fuel through the main jet (at a given r.p.m.) is governed by the boost pressure and the exhaust back pressure. Ignoring the latter, for the moment, the effect of an increase in boost is to compress the evacuated boost-pressure capsules, this causing the main metering needle to withdraw and the flow of fuel through the jet to

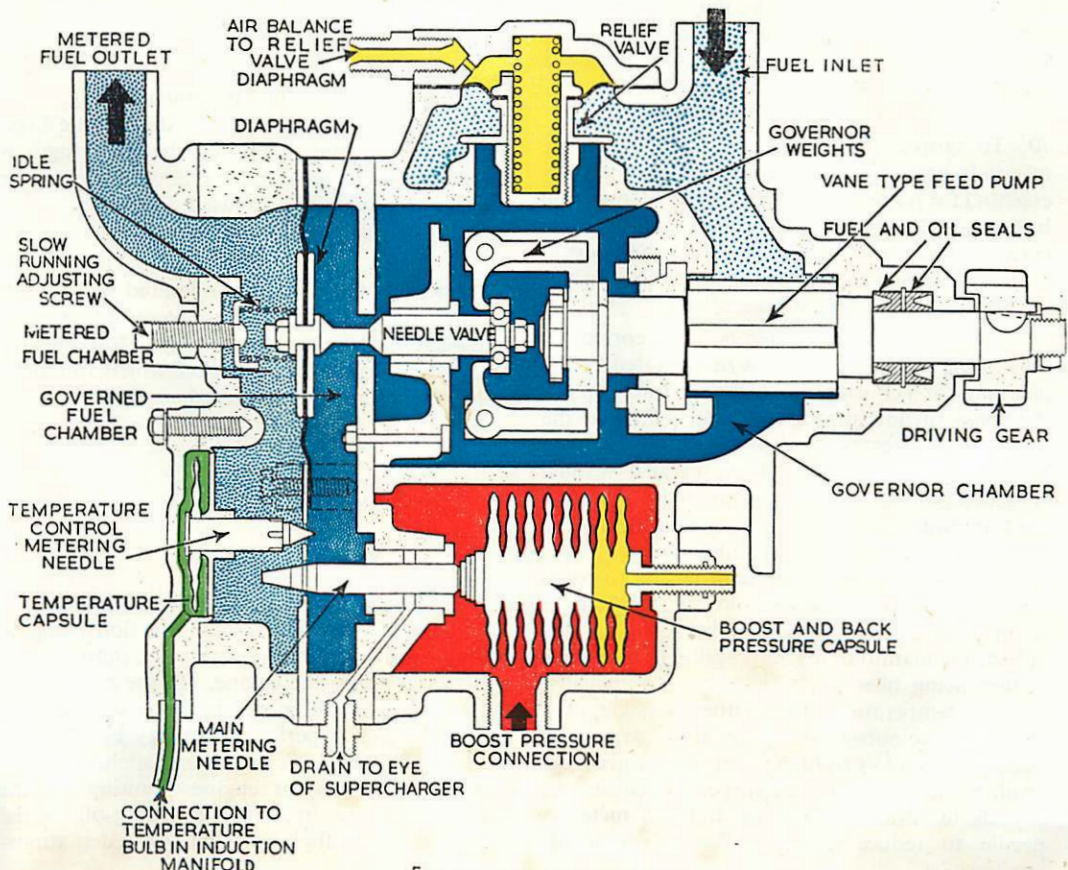


Fig. 16. Fuel Injection Pump.

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increase. Control of mixture strength to suit all operating conditions is effected by variation in the taper of the main metering needle, so that the rich-weak-rich characteristic is automatically provided over the whole range of boost pressures from idling to take-off. As the flow of fuel is governed by boost and r.p.m., no altitude control of the kind fitted to float-type carburetors is required.

69. It will be recalled that the fall in air pressure with altitude, results in less exhaust gas remaining in the cylinders at the end of each exhaust stroke and, consequently, the volumetric efficiency improves, *i.e.* more mixture goes into each cylinder at a given induction pressure. In the float-type carburettor the extra fuel is automatically drawn off by the increased depression in the choke, but in a fuel injector, compensation is necessary to avoid a weakening of the mixture. Here compensation is provided by the back-pressure capsule, which although integral with the boost-pressure capsule, is sealed from it and subjected internally to atmospheric pressure. Thus, as height is gained, the back-pressure capsule is compressed and the main metering needle is withdrawn sufficiently to maintain a constant mixture strength.

70. To ensure that the main metering needle responds accurately to capsule movement, it is essential for it not to be a tight fit in its supporting bushes. Consequently, to prevent leakage between the boost and governed fuel chambers, a drainage channel is provided between the bushes.

71. The introduction of a temperature correction unit to the metering system is necessitated by the fact that, for a constant boost pressure and r.p.m., the mass airflow through an engine falls as the temperature rises, because of the reduced density of warmer air. As any decrease in airflow must be accompanied by a proportional drop in fuel consumption to maintain a constant mixture strength, a temperature-controlled auxiliary jet is added in parallel with the main jet. Control is effected by the single-capsule unit, which is coupled to a thermometer bulb located in the induction manifold by a capillary tube, the system being filled with turpentine. When the mixture temperature rises, either because of a change in the outside air temperature or through a change from low to high supercharger gear, the resulting expansion of the turpentine causes the capsule to compress and the attached metering needle to reduce the fuel-flow through the auxiliary jet.

72. From the injector the metered fuel is delivered to the injection nozzle at the supercharger inlet via the accelerator pump and flexible hose (Fig. 17). To maintain a constant discharge pressure, irrespective of the rate of fuel-flow, a needle valve, controlled by a spring-loaded diaphragm, is included in the nozzle assembly. When the metered fuel pressure rises to approximately 6 lbs./sq. in. the valve diaphragm is forced outwards, thereby opening the valve against the action of the spring. The greater the fuel-flow the more will the diaphragm be deflected and the valve opened.

73. The diaphragm-spring chamber is connected by a tube to the air intake via a slow-running cut-off device which, when operated, cuts off the air balance connection and admits fuel at pump pressure to the rear of the diaphragm. As soon as the diaphragm-spring chamber is filled, the diaphragm is forced inwards and the needle valve thereby closed. When the cut-off control is released the air balance connection is restored and fuel from the chamber drains to the air intake.

74. The accelerator pump shown in Fig. 17 is simply a diaphragm operated by the throttle lever. When the throttle is opened the diaphragm is forced in (to the left) and the flow of fuel to the nozzle is temporarily increased.

75. **Fuel Cut-Off.** A pilot-operated fuel cut-off is fitted on most injectors: it cuts off all fuel irrespective of the throttle setting. However, the S.U. type injector has a cut-off which functions only when the throttle is closed.

AIR INTAKE FILTERS

Purpose

76. Engine air filters are fitted to all service aircraft except flying-boats, their function being to prevent undue engine wear through induction of dust or sand into the engine. In the majority of installations the filter can be bypassed so that maximum engine performance may be obtained in normal flight. Air filters are intended to be used at all times for engines running on the ground, starting up, taxiing, taking-off, initial climbing, and in flight through dust-laden atmosphere.

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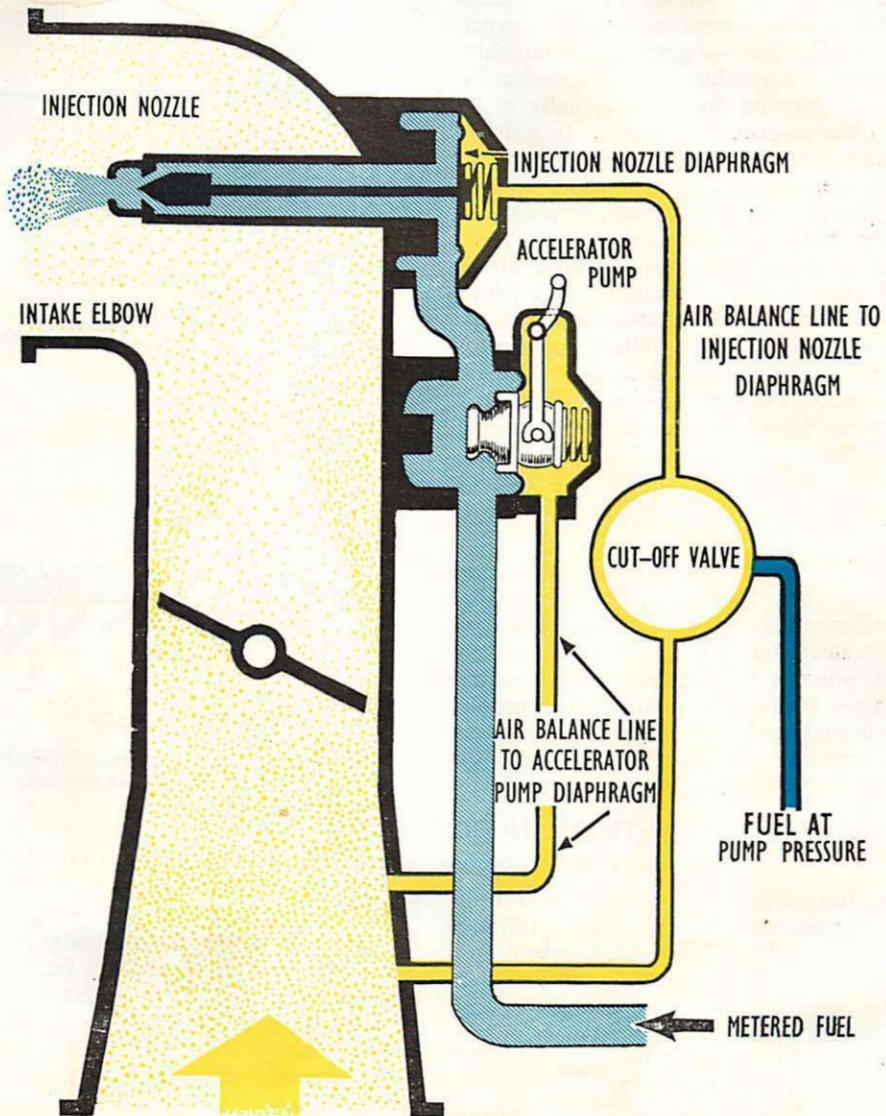


Fig. 17.
Fuel Injection Nozzle, Accelerator Pump, and Cut-Out.

Filter Control

77. The control system for the engine air filter installation varies in different aircraft, and reference should be made to Pilots' Notes for the type. Some aircraft have separate controls for the filter and for the hot-air intake, whereas others have a three-position lever or switch marked "filter"—"hot"—"cold, ram, or normal", at the appropriate positions. The mechanism for the selection may be operated manually or by electric or electro-pneumatic means. In addition to the pilot's control, some aircraft embody an automatic inter-lock with the undercarriage which ensures that the filtered-air intake is always in circuit when the aircraft is on the ground. Thus, with the undercarriage down, filtered air is obtained regardless of the position of the pilot's control. On this type of installation, the pilot's control should be set in the "filter" position for take-off as, if this control is in the "normal" position, raising the undercarriage will cause a change from "filter" to "normal" and at high power this may result in a weak mixture cut.

Types of Filter

78. Filter installations are of two main types, ram and non-ram. Non-ram installations (Fig. 18) are preferable as very high filtration efficiencies can be obtained, but only at the expense of an increased pressure drop which affects engine performance. Non-ram installations are generally confined to engines having a large reserve of boost above normal take-off boost (Fig. 18).

Effect of the Filter on Full-Throttle Height and Take-Off

79. The pressure drop reduces the full-throttle height of the aircraft to a degree varying with the particular installation, but which should not exceed 2,000 to 3,000 feet. This consideration should be borne in mind when taking off from airfields having a high elevation, particularly when the engine concerned has a low full-throttle height.

80. **Bypassing of Filter.** With engines having little or no reserve of boost, take-off from airfields at a high altitude, or under tropical conditions, may necessitate bypassing the filter in order that full take-off boost may be obtained. Similarly, if a take-off is required to be made from a restricted runway, from an aircraft carrier, or with a heavily-loaded aircraft, it may be necessary to use a boost rating in excess of that normally used for take-off, and bypassing of the filter may then be essential. In such cases, the Pilots' Notes for the type may

recommend that the filter should be bypassed for take-off. On certain aircraft, particularly naval types, means are provided which enable the undercarriage interconnection to be cut out of circuit, thereby permitting the pilot to select "normal" air intake for take-off. On other types the undercarriage interconnection is replaced by a simple pilot's control.

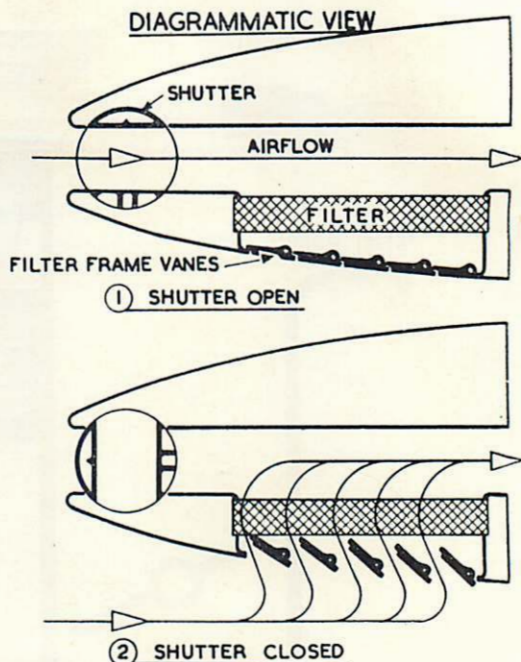


Fig. 18. Non-Ram Air-Intake Filter of the Type Fitted to Hornet Aircraft.

AIR INTAKE HEAT CONTROLS

Purpose

81. When flying in certain conditions of humidity and temperature, ice will quickly build up on the throttle butterflies and in the induction system. To obviate this most aircraft are fitted with a shutter system to blank off the entry of the cold air and obtain warm or hot air from inside the engine cowling.

Operation

82. The intake shutters may be operated from the cockpit, either manually by means of control rods and cables, or electro-pneumatically by a selector switch which may have a third position for selecting filtered air. On some installations fitted with gapless ice-guards, air is automatically drawn through the hot-air intake when the ice-guard becomes blocked.

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83. The effects of warm air can be summarized as follows :—

(a) The use of warm air causes a loss of power at given r.p.m. and boost, by reducing the weight of charge drawn in. Cold air should therefore be used for maximum power, although when a take-off or landing is made in severe icing conditions or in cold humid weather, it may be advisable to use warm air to prevent carburettor icing. When taking off, however, the all-up weight and available run should be considered in conjunction with the slight loss of power owing to the reduced weight of cylinder charge. Warm air should not be used at boosts in excess of +18 lbs./sq. in. or at take-off power if the outside air temperature exceeds +10°C. (+50°F.), as the resulting temperature rise may cause detonation.

(b) If warm air is used, a change back to cold air must not be made during take-off, when

going round again, or during a mislanding, until power has been reduced.

(c) When warm air is used the ram effect is lost, the full-throttle height is lowered, and the power obtainable above full-throttle height is reduced.

(d) If the carburettor is fully compensated for varying charge temperatures, the use of warm air may have no adverse effect on range ; it may even increase range by improving the charge distribution at low power, especially in cold weather. If the carburettor is not temperature compensated, warm air will decrease range. The adverse effect may not be serious, but should be borne in mind.

84. **Use of Cold Air.** Cold air must always be used for starting as, if warm air is used with an up-draught carburettor, a backfire may ignite any priming fuel which may have reached the engine bay, and the intake shutters may be damaged by backfiring.

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