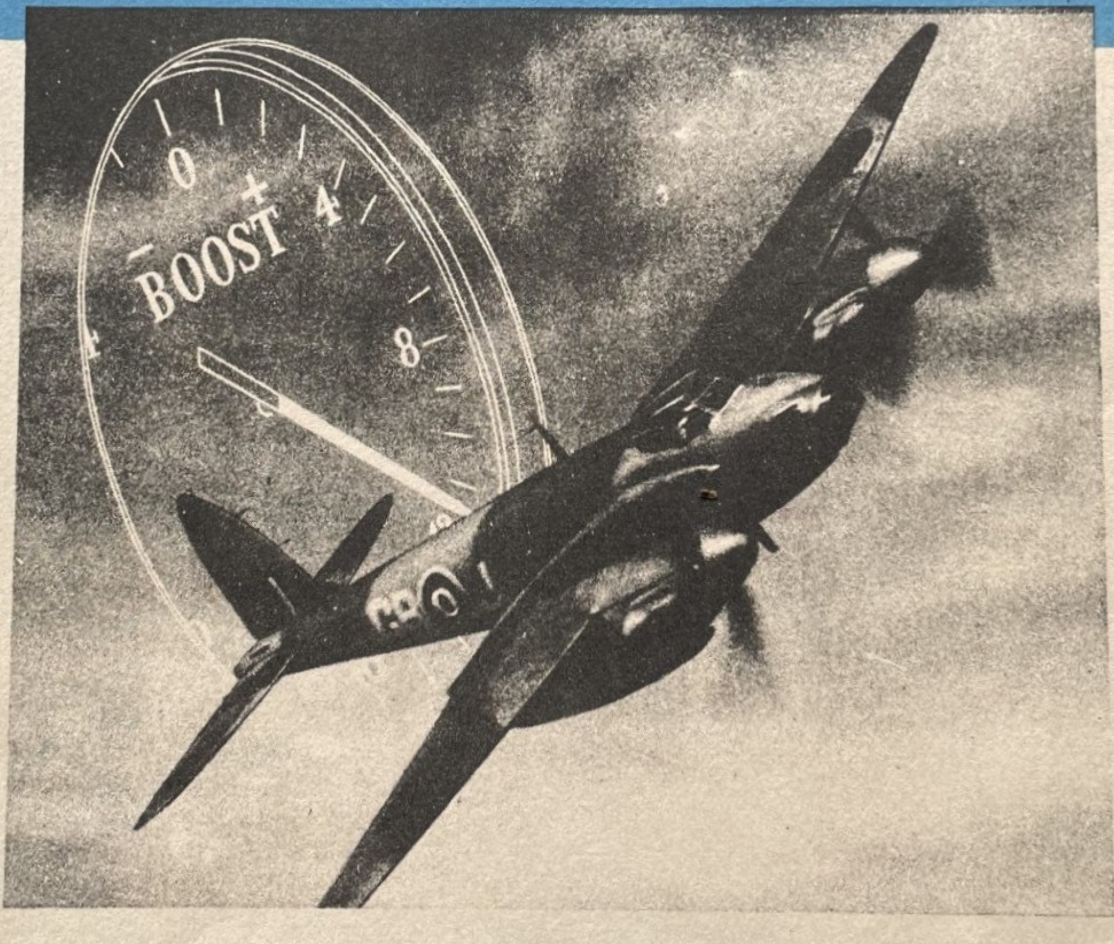
SUPERCHARGER SENSE



A.M. PAMPHLET 172

A.M.T. 15

Supercharger Sense

FOR PILOTS OF ADVANCED TRAINERS
AND OPERATIONAL-TYPE AIRCRAFT

ISSUED BY THE AIR MINISTRY
AIR MEMBER FOR TRAINING

A.M. PAMPHLET 172
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INTRODUCTION

In *Engine Sense* we told you a good deal of what you, as a pilot, ought to know about engines. In *Propeller Sense* we told you more about your power plant in general and your propeller in particular. In this and another pamphlet, we are going to discuss in some detail the *induction system* of your engine. By induction system we mean that part of the engine that is concerned with providing the cylinders with adequate quantities of the right quality of combustible charge. First we shall discuss all that happens between the air intake and the cylinders; and then we shall add some consideration of what effect this has on the engine as a whole.

This subject has been divided into two parts, Supercharging and Carburation. This pamphlet only discusses Supercharging; another pamphlet, to follow shortly, will deal with Carburation. We emphasize the dividing line because each subject can be understood more easily if it is considered with as little reference as possible to the other, and we want to make the distinction clear from the start. If the induction system is looked at from the viewpoint of the cylinders to which the combustible charge is being supplied, matters of quantity are the concern of the supercharger, and matters of quality the concern of the carburettor.

Petrol is burned in the cylinders in the form of a mixture of petrol and air, which is about one to fourteen by weight. The exact proportion varies as certain factors, such as economy and cylinder temperature, require a weaker or richer mixture. This is controlled almost entirely by the carburettor. It is a complicated subject, but supercharging need not enter into it.

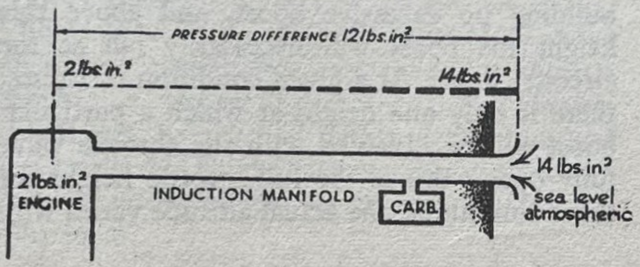
The supercharger was added to provide the engine with more of this combustible charge, not to alter its composition. This proportion has just been described as about 14 of air to 1 of petrol by weight. When we try to provide more charge, the difficult thing is to provide enough air; it is a simple matter to provide more petrol, the supercharger's real work is to get more air, which can then be mixed with a proportion of petrol as it passes through the carburettor. Power becomes a matter of the amount of air that can be provided.

This pamphlet on supercharging will be found to deal almost entirely with the search for more air, on the presumption that the carburettor is ideal and will deal with whatever comes. The later pamphlet on Carburation will deal with all the problems connected with adding the correct amount of petrol to this air, describing the considerations that influence the choice of a particular mixture, and the means of maintaining it.

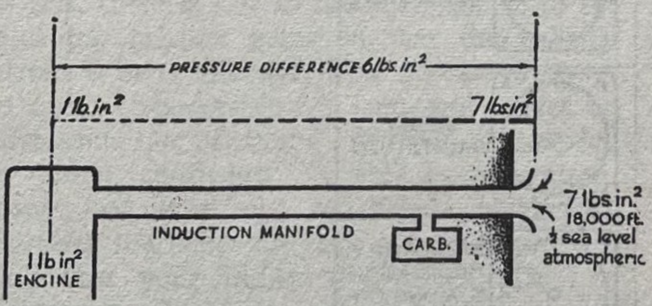
CONTENTS

I. THE NORMALLY-ASPIRATED ENGINE

You were probably taught the four-stroke cycle some time ago, but you will still have some idea that when the piston descends on the induction stroke, the inlet valve opens and the charge is drawn into the cylinder. This is true as far as it goes, but it isn't quite enough for our purpose. As the piston goes down on the induction stroke it reduces the pressure in the cylinder; outside there is an atmospheric pressure which at sea level is something over 14 lbs. per sq. in. Suppose the pressure in the cylinders is reduced to 2 lbs. per sq. in.; when the inlet valve is open there will be a pressure difference of 12 lbs. per sq. in., and this is what induces the charge to enter the cylinder. It is therefore more accurate to think of the charge entering the cylinders as the result of a difference in pressure, and to get out of your head any picture of the charge being sucked in.



The pressure difference in the example above is worked out at 12 lbs. per sq. in. at sea level. Atmospheric pressure decreases with altitude; at 18,000 feet it will probably be only half sea-level pressure, let us suppose it to be 7 lbs. per sq. in. Pressure in the cylinders will have decreased in roughly the same proportion, and we will suppose it has fallen from 2 lbs. per sq. in. to 1. The pressure difference between 7 and 1 is only six; this is half the sea-level

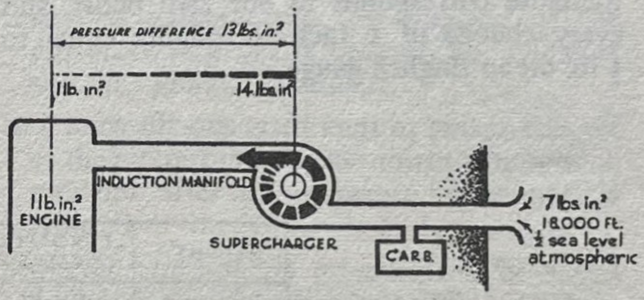


pressure difference so that the means of inducing the charge to enter the cylinders is only half as powerful as it was. Power is governed by the quantity of charge usefully burned in the cylinders; if at 18,000 feet only half as much charge gets into the cylinders for each stroke, we shall expect only half the power we developed at sea-level. This is almost exactly what does happen.

An engine in which the charge is induced into the cylinders in this way is called *normally aspirated*. The outstanding characteristic of a normally-aspirated engine is that the power it develops falls off steadily as the aircraft climbs, and a rough figure for the extent of this decline is obtained by knowing that the power will be reduced by half by the time 18,000 feet is reached.

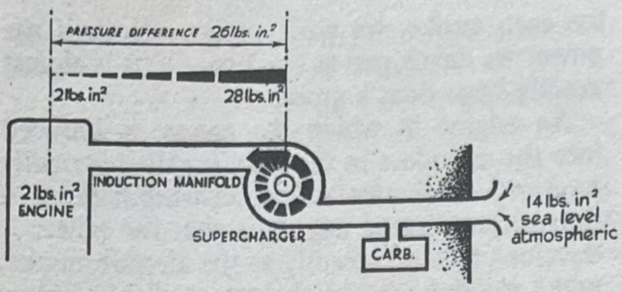
The elementary supercharger

Supercharging was first thought of as a means of counteracting the drop in power that occurs when an aircraft climbs. The supercharger, which is just a big fan, would be used to maintain sea-level pressure in the induction manifold up to the greatest practicable, or to a certain desired height. Let us include this in our example at 18,000 feet:



Atmospheric pressure is down to 7 lbs. per sq. in. By means of our fan this is increased to 14 lbs. per sq. in. in the induction manifold. The pressure difference is now actually 13 lbs. per sq. in., so that there will be a slight increase in the power produced by the engine. Later on we shall consider what power we have had to use up in driving the fan, and give you an idea of the eventual profit.

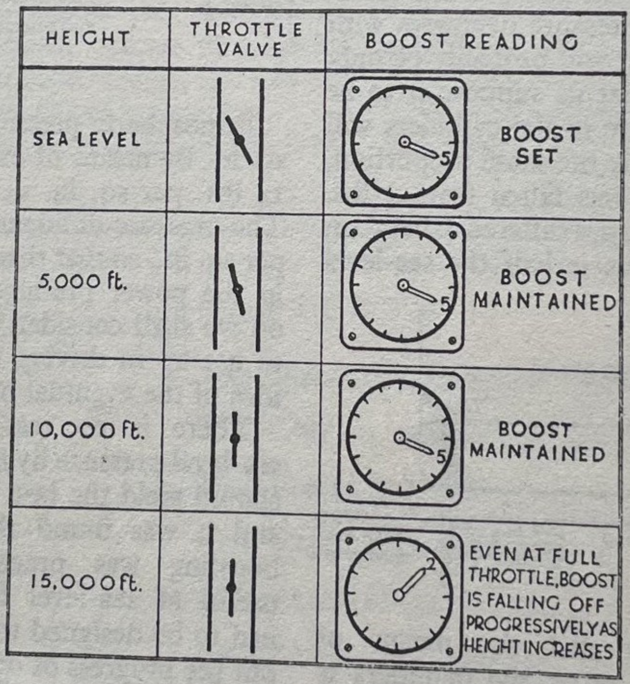
There is no reason why producing just sea-level pressure by means of the supercharger should yield the best that the engine can give, and it was found that a certain amount of boosting was practicable, and particularly useful at sea-level for take-off. The engine had to be designed to stand the extra stresses; but the progress of design has made higher and higher boosting possible, and in the later marks of Merlin the pressure maintained by the supercharger for take-off and combat is twice sea-level atmospheric.



The pressure in the induction manifold is called the *boost pressure*. Pressure is recorded on the instrument panel by the *boost gauge*: English boost gauges record the difference between the pressure in the inlet manifold and standard atmospheric pressure (14·7 lbs. per sq. in.); they read + or − and are calibrated in lbs. per sq. in. (Your boost gauges read about zero when the engine is stopped.) American gauges show the manifold pressure measured from zero, and are calibrated in inches of mercury. The height of the mercury barometer at standard atmospheric pressure is 30 inches; 30 in. Hg. manifold pressure therefore corresponds to our zero boost, and every change of 1 inch is roughly equal to ½ lb. on an English gauge.

Full-throttle height

We have seen that supercharging was introduced as a means of providing sea-level performance at altitude and was developed to provide positive boosts at sea level and upwards. Nowadays the maximum boost we can get at sea level is fixed by what the engine will stand on the fuel used, not by problems of supercharger design. This figure is given to us as 'maximum permissible'; almost every engine is so designed that maximum permissible boost can be obtained at sea level with the throttle partially closed, so that it is possible to maintain maximum permissible up to some pre-determined height by opening the throttle as the aircraft climbs. We call this pre-determined height the *full-throttle height*, because below this height we have to throttle down the indrawn air to prevent the supercharger building up excessive boost, and above this height the boost will necessarily fall as the aircraft climbs. At a given condition of r.p.m., there is only one height at which a particular boost will be obtained with the throttle valve fully open; this is the full-throttle height for those conditions, the actual altitude varies with



the revs. and boost in question. Let us say suppose we intend to fly at +5, and full-throttle height is 10,000 feet. This is what will happen as the aircraft climbs :

The usual supercharger is gear-driven by the engine, and its effect is roughly to multiply the intake pressure by a constant factor: at climbing revs. this factor is commonly about 2. Applying this to our example, it would be possible for the sea-level atmospheric pressure of 14·7 lbs. per sq. in. to be doubled in the induction manifold making 29·4 lbs., which of course is recorded as a boost of +14·7, being 14·7 above normal atmospheric. The throttle must therefore be partially closed to reduce boost to maximum permissible of +5. But at 10,000 feet atmospheric pressure has fallen to about 10 lbs. per sq. in. ; the supercharger multiplies this by 2 so that the pressure in the induction manifold is 20 lbs. per sq. in. ; normal atmospheric is 14·7, so this represents a boost of +5·3 lbs. This is only slightly above maximum permissible, so that the throttle should be almost fully open. Full-throttle height will be reached within a few hundred feet ; after this height has been passed the boost will fall progressively, even with the throttle fully open.

How power varies with height

Maintaining a constant boost up to full-throttle height does not mean maintaining a constant power. In fact the power will rise, for two reasons : first because as the air gets colder it gets denser, so that if we are able to maintain a constant pressure in the induction manifold there will be in fact a greater weight of air getting into the cylinders ; second because at greater heights where atmospheric pressure is less, there is not so much resistance to the escaping exhaust gases so that the exhaust stroke is more effective. The increase of power is quite considerable ; it commonly gives an increasing rate of climb. The effect on airspeed is rather confusing ; if you keep constant boost and level out at various heights to discover the effect on your airspeed, you will find that your indicated airspeed (IAS) is falling off, which does not seem to agree with an increase in power. But this is really a disguise of the true state of affairs, for if the true airspeed (TAS) is calculated in each case, it will be found to have risen at successive heights (but not sufficiently to offset the normal decrease in indicated airspeed).

How boost varies with r.p.m.

One more thing about the supercharger. The superchargers universally used are centrifugal pumps, and they compress the charge in a ratio depending on the r.p.m. at which they are run. Thus the pressure added by the supercharger is greater as the supercharger is run faster. Increasing the r.p.m., therefore, because it increases the compression ratio of the supercharger, will raise the full-throttle height for a given boost. It also follows that at any height at which the throttle valve is fully opened, it is only possible to increase power by increasing the r.p.m.

Summary

Charge is induced into the cylinders by the difference in pressure between the cylinders and the induction manifold.

In a normally-aspirated engine, power falls off as the aircraft climbs into lower atmospheric pressure and the pressure difference is reduced.

Sea-level atmospheric pressure can be maintained in the induction manifold to a predetermined height by the use of a supercharger.

Superchargers have been developed to provide positive boost pressures at sea level and upwards.

The limit of boost is a matter of what the engine will stand: this is called maximum permissible. If necessary the throttle must be partially closed to reduce boost to this limit.

The height at which maximum permissible is obtained with the throttle butterfly fully open is the full-throttle height.

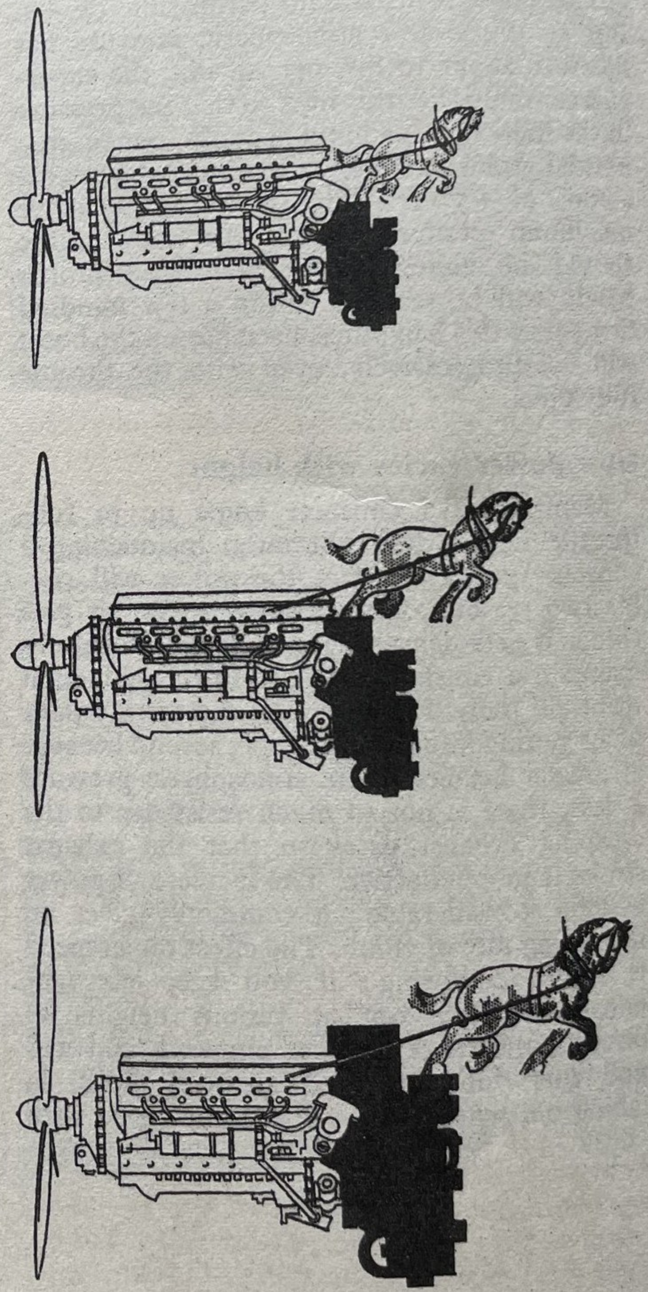
This is the height at which most power is developed.

II. THE COST OF SUPERCHARGING

In the last chapter, we considered only the boost that could be produced and maintained. We did not consider what power must be taken from the engine to provide this boost; but you should always remember that the supercharging unit uses up a great deal of power, and that it weighs quite a lot, although it so happens that designers are able to make a profit on the deal. The bigger the supercharger, the more power it absorbs. Suppose an engine is fitted with a supercharger capable of maintaining maximum permissible boost up to 15,000 feet. It is quite wrong to assume that an engine so supercharged is able to deliver as much power to the propeller *at that boost* as a similar engine fitted with a smaller supercharger that produces a full-throttle height of only 5,000 feet. This is often overlooked; with the large supercharger you will certainly get more power at 15,000 feet than you can get in any other way, but it won't be as much as your smaller supercharger will give you at its full-throttle height of 5,000 feet. Full boost can only be obtained at 15,000 feet by using a big impeller going very fast; the power needed to drive this fan must be subtracted from the total the engine produces, only what remains being available to the propeller. And even when this engine is flown below that height, the power available to the propeller is still less than it would be with a smaller supercharger running at its full-throttle height. At 5,000 feet the power available with the big supercharger would possibly be 15 per cent. less than with a small supercharger at the same height, which would be the latter's full-throttle height.

What is the cause of the losses? The first cause is straightforward: the bigger the supercharger, the more power is needed to drive it. The second cause is the increase in temperature of the charge as a result of the supercharging; as the temperature is raised the charge becomes less dense, so there is less charge per unit of volume at any given boost. The higher the ratio of compression, the greater the rise in temperature, and the more serious the loss in power. Both these losses can be considerable; so bear in mind that a really big supercharger, brought down to sea level still goes on absorbing a great deal of power.

Let us examine in greater detail what happens. The engine is at maximum boost and revs. at 15,000 feet; when it is brought down to sea level these maximum permissible limits cannot be exceeded. Left to itself, this powerful supercharger would be capable of producing, say, +30 at sea level; because it cannot be allowed to, the pressure entering the supercharger must be reduced by closing the throttle until the pressure produced in the manifold is reduced to maximum permissible limits. Cutting down the effects of a really powerful supercharger by choking the intake with the throttle in this way has been described as exactly comparable to driving a car with the brakes on. But besides the waste of effort in driving the impeller very fast,



THE BIGGER THE SUPERCHARGER THE MORE POWER IT ABSORBS ; AND IT WEIGHS QUITE A LOT its power and speed are causing another unwelcome effect by overheating the charge, which we agreed lost us power at any given boost by reducing density. The existence of these losses is straightforward enough once they are pointed out; it is not perhaps so widely known how serious are their effects. To take an extreme example; it has been estimated that if a supercharger were fitted to a Hercules which could give +40 boost at sea level, and the engine were then throttled down to a permissible figure of +8¼, the power necessary to drive such a supercharger and the loss through overheating the charge would just be met by the engine, *leaving nothing for the propeller*.

III. TWO-SPEED SUPERCHARGERS

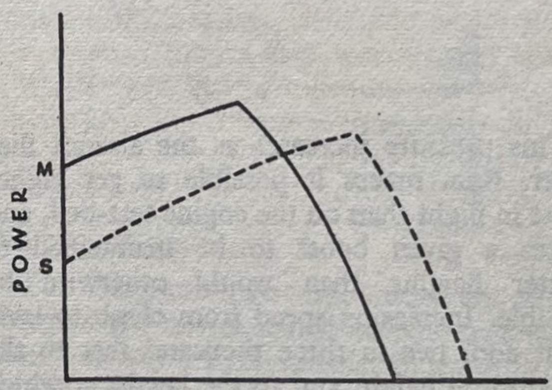
We should now agree that by fitting an engine with a really powerful supercharging unit, we reduce the power available within the limitations of maximum boost and revs., but obtain this reduced output at a higher altitude than would otherwise be possible.

Operational requirements demand high performance at great heights. How can this be obtained without crippling the performance lower down? Everyone knows the answer: 2-speed superchargers. A change-speed device is fitted to the supercharger drive so that a high-speed gear (S gear) can be used at heights where it can better the failing medium-speed performance (M gear). Lower down the medium gear will drive the impeller slower, using less power, will heat the mixture less, and deliver more power to the propeller. Get out of your head any suggestion that S gear is really a super-booster, which could give you something terrific low down if you were allowed to use it; the smallest supercharger that can produce the boost delivers most power to the propeller, which is where you want it. M gear is introduced for the purpose of making more power available at lower altitudes.

When to change speed

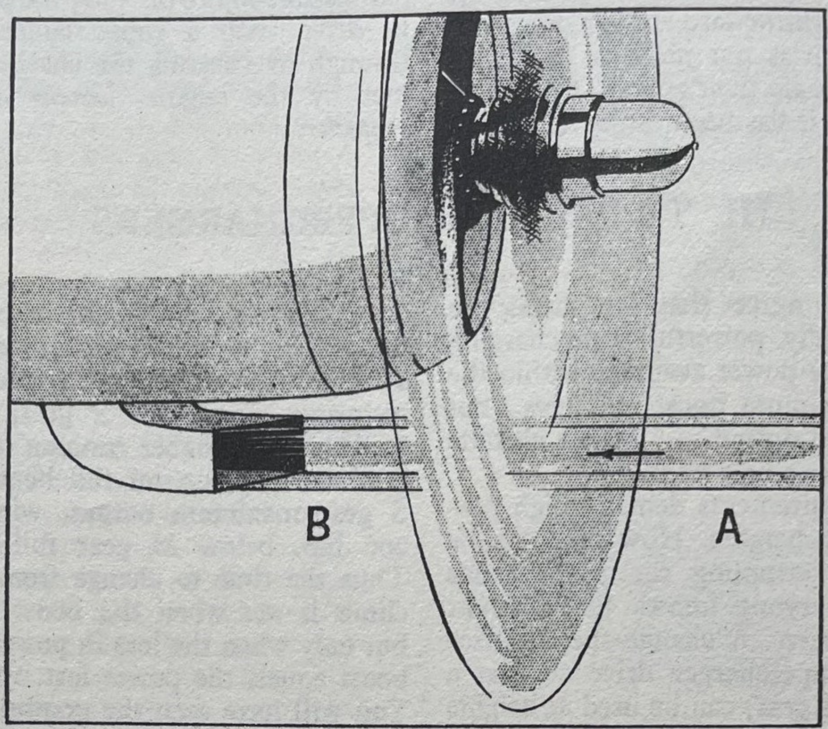
The two-speed supercharger is not the complete solution; if a suitable design could be evolved, we would get best performance with an infinitely variable supercharger, so that every height could be a full-throttle height; until this is possible, we must understand and make the best use of the speed change.

Once again remember that even when S gear is producing full boost, it doesn't deliver as much power to the propeller as M gear at the same boost. Suppose then that we are climbing in M gear; we reach and pass its full-throttle height, and boost begins to fall. If we still regard S gear as a super-gear, we shall change at once. But what would this mean? In M gear the falling boost has perhaps cost us 50 h.p. of the total available at full-throttle height. By restoring boost with S gear, we incur immediately the higher running expenses of this gear and pay for our full boost by accepting S gear maximum output, which is possibly 200 h.p. below M gear full-throttle figure; Thus the time to change from M to S on a climb is *not* when the boost begins to fall, but only when the loss in power due to falling boost equals the power lost by using S ratio. You will have seen the graphs that show this happening, they look like this:



But the pilot isn't expected to do more than understand the reasoning and study Pilot's Notes; there he will be told how far he should let the boost drop before changing. The right height will not be the same under all circumstances; it depends on the boost limits you are working to—continuous cruising, climbing or combat limit—and on the r.p.m. of the engine and the consequent compression ratio of the supercharger. There is another factor that must be mentioned here, that is *ram*. The speed of the aircraft through the air creates at the air intake a certain pressure, which helps the supercharger.

RAM



Note : Ram effect is actually increased if the intake lies behind a propeller

This pressure increases as the aircraft flies faster. Ram makes it possible to get higher boost in flight than on the engine test-bed, and causes a given boost to be maintained to greater heights than would otherwise be possible. Increasing speed from climb to level flight adds two to three thousand feet to the full-throttle height and to the height at which you should change to S ratio for maximum power. Running on WARM air, which is taken from some sheltered spot, loses you the beneficial effects of ram; and drawing air through an air filter has the same effect.

Speed-changing and range flying

The correct use of the two speeds in range flying is a less simple problem. You know that when you want to get the maximum range out of your aircraft it pays to run your engine at high boost and to reduce your r.p.m. until you get down to the best IAS for maximum air miles per gallon. (Given in Pilot's Notes.) So long as you can get high boost with comparatively low revs. there can be no question of changing to S ratio. But generally, when cruising at the higher levels, the boost obtainable will be well down on the maximum permissible, while the revs. will be high. If you change to S ratio you can get the boost up and drop the revs., but not without cost. You will appreciate how inadvisable it is to make a general ruling on when to change. All we can definitely say is that when you reach nearly the maximum r.p.m. for economical cruising, it will make very little difference whether you change or not. Of course, if you want to fly higher, you must change, and you will get much the same air miles per gallon as in M.

A note on making the change

When you change the gear, you must always do it smartly and firmly. It is a very high-speed change and the mechanism is carefully designed to take the strain ; but it does not like a faltering hand. If you have not got controlled boost (Chapter 4) you must have your throttle lever set so that you won't overboost when you change from M to S. Some operational duties may not call for high supercharge very often; it is important then to remember to exercise the gear regularly to clear out any oil sludge that may accumulate and so make sure that it will work if and when it is needed.

Summary

Powerful superchargers consume a great deal of the power the engine is producing.

At any particular boost and height, more power is always available to the propeller with a less powerful supercharger. The best performance follows the rule:—maximum throttle, minimum supercharging.

For range flying, the advantages, at critical heights, of maintaining high boost and low revs. by using a more powerful supercharger must be weighed against the known disadvantages of using the more powerful supercharger.

You are not expected to work out for yourselves when to change speed. You are expected to know enough to make intelligent use of the information provided in Pilot's Notes.

Only when the less powerful supercharger is unable to maintain a particular boost can the big supercharger give you more power.

But the right time to change is not when boost first begins to fall. The choice must strike a balance between power lost through falling boost, and power lost through engaging a more powerful supercharger.

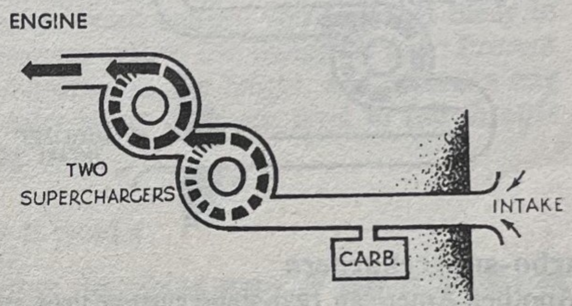
IV. TWO-STAGE SUPERCHARGERS

You should be careful not to confuse *two-stage* and *two-speed* supercharging. Two-speed supercharging, which we considered in the last chapter, provides a choice of speeds at which the supercharging unit (one impeller of a fixed size) can be driven; two-stage supercharging is a particular sort of supercharging unit in which the charge is compressed by two impellers one after the other, one taking up where the other leaves off.

A single-stage centrifugal supercharger can be designed to give up to about $3\frac{1}{2}$ to 1 compression; this could give about +14 boost at 15,000 feet, and a falling boost above that height. If we want to better this—and we do—we must compress the compressed charge a second time; another impeller is fitted and the supercharging is thus done in two stages. Two-stage superchargers are fitted to British and American engines; there are certain differences between English and American designs which you should understand.

Rolls-Royce system

In the Rolls-Royce two-stage supercharger, the two impellers are geared to the same shaft and run as one unit; the whole unit can be run in either M or S gear. The result is, in effect, a more powerful two-speed supercharger, without any complications in handling. Diagrammatically it can be represented like this:



American system

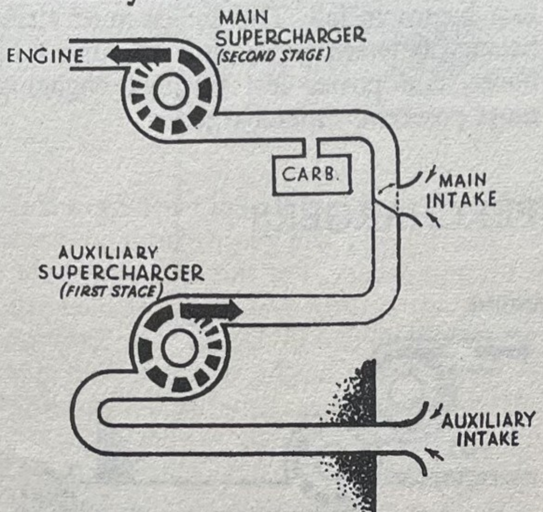
The American two-stage two-speed superchargers are not designed as one unit in the same way as the Rolls-Royce. In the American system, the second stage, called the *main* supercharger, is one-speed and constantly in action. It is quite outside the pilot's control just like any other one-speed supercharger; but the first stage, the auxiliary supercharger, is brought into or put out of action at the will of the pilot and this supercharger may be used in low or high speed as required. There are, therefore, three degrees of supercharging available:

1 Main supercharger only; straightforward single impeller, no speed change available

2 Main supercharger + auxiliary added in low gear

3 Main supercharger + auxiliary added in high gear

Not only are these two impellers independently driven, in contrast to the Rolls-Royce system, they are not even working side by side. The main supercharger is fitted in the usual position between the carburettor and the engine (where the complete Rolls-Royce two-stage unit is fitted); but the auxiliary supercharger is between the air intake and the carburettor, so that it feeds compressed air to the carburettor. When only the main supercharger is in action, it draws air through its own special intake, which is shut off automatically when the auxiliary supercharger is brought into action. Here is a diagrammatical representation of this system:



Turbo-superchargers

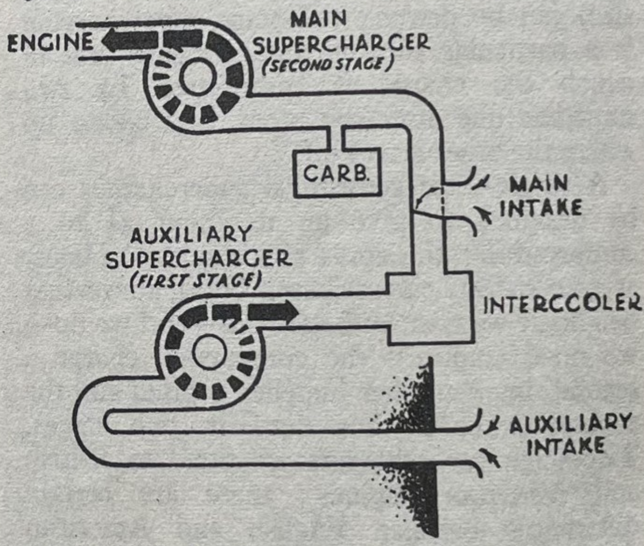
Another American two-stage system uses an exhaust-gas turbine to drive the first stage (auxiliary supercharger); this is known as a turbo-supercharger and consists of a turbine wheel on which the pressure from the exhaust acts through suitable jets or passages. This provides an infinitely variable drive, for the speed of the turbine can be regulated by allowing more or less exhaust gases to by-pass the turbine and escape direct to the atmosphere. The by-pass is known as the *waste-gate*. In practice a limit is set to the height to which we can maintain pressure on the carburettor by the highest speed at which the turbo-supercharger can safely be run. Above this height we have to work to a descending scale of boost limitations to prevent over-speeding of the supercharger. More will be said about this system in the next chapter.

Maximum throttle—minimum supercharging

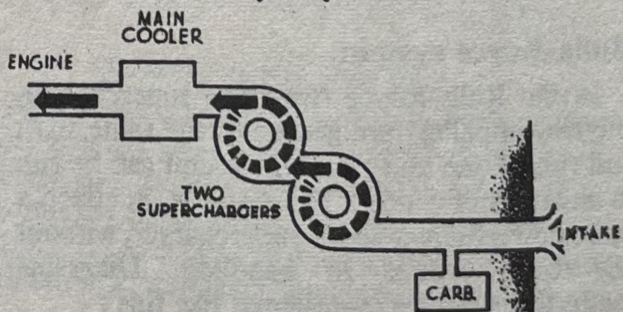
With either of these American systems, we should of course use as little first stage (auxiliary) supercharging as we can do with; this follows the old rule of maximum throttle—minimum supercharging; we should not work the auxiliary or the turbo-supercharger against the throttle unnecessarily, which is just following up the rule of not using S when M will do the job. In the case of the turbo-supercharger, the impeller keeps running gently, although you aren't really using it, because this ensures lubrication. When you do need it, the throttle is usually kept fully open, and power is regulated on the waste-gate. (Chapter 4.)

Intercoolers

The high degree of supercharging that the two-stage systems provide, involves a considerable rise in temperature of the charge, which may have serious consequences by causing detonation, and anyhow means that the mixture is less dense. Therefore special coolers are fitted to cool the charge before it enters the cylinders. In the Rolls-Royce system the main cooler is between the supercharger and the engine. In the American system the cooler is fitted between the first stage and the carburettor; these coolers are known as intercoolers. Therefore our diagram of the American system should now be drawn like this:



and the Rolls-Royce system like this:



Incidentally, having a blower on the intake side of the American carburettor provides a means of running on warm air to prevent icing without losing ram, as happens with the usual warm intake which takes air from the engine bay.

Summary

Two-stage superchargers consist of two impellers compressing the charge one after the other.

In the Rolls-Royce system the two impellers are coupled together and are run as one two-speed unit; the pilot has no more problems than with a single-stage two-speed supercharger.

In the American systems, the impellers are separated and run independently. Usually the main supercharger is single-speed and the pilot regulates the degree of supercharge with his use of the auxiliary.

Two-stage supercharging tends to overheat the charge, therefore intercoolers are fitted.

V. AUTOMATIC BOOST CONTROLS

Their purpose

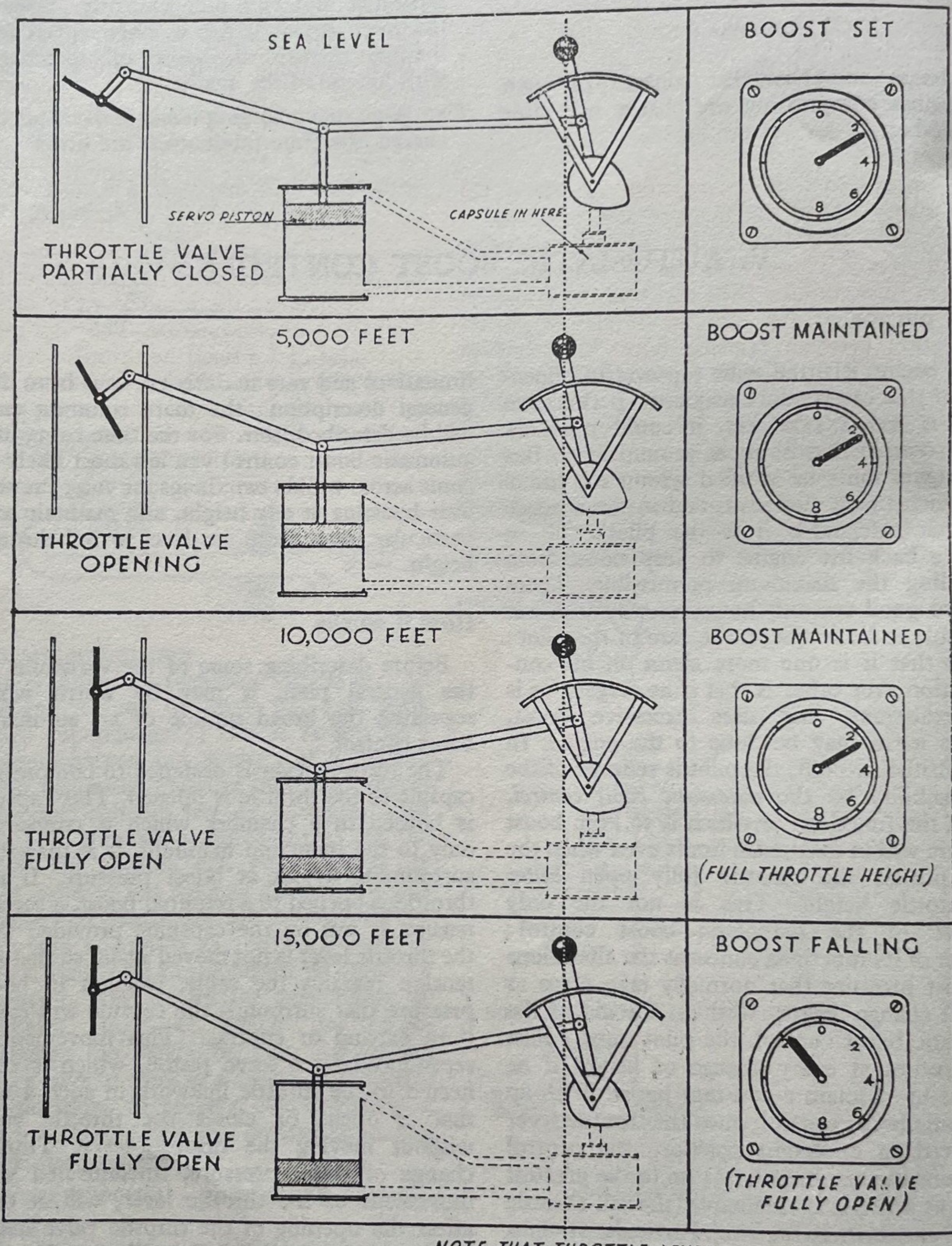
If an engine is fitted with a powerful supercharger that can produce maximum permissible boost at say 15,000 feet, it could probably nearly double that boost at ground level. But the engine must be worked within the limits for which it was designed, and in the absence of other safeguards it is the pilot's job to throttle back the engine to keep boost from exceeding the maximum permissible. There are two good reasons, however, why it is not advisable to leave this in the care of the pilot: one is that it is one more claim on his concentration; the other is that if he forgets, or is over-exuberant, and uses excessive boost, serious harm may be done to the engine. In most British aircraft, the pilot is relieved of the responsibility by the *automatic boost control*, one of the functions of which is to keep boost pressure within maximum limits even when the pilot pushes the throttle fully open *below* full-throttle height. This is not the only purpose of the automatic boost control; another of its functions concerns the alterations of boost pressure that normally take place as aircraft change height. Without the aid of the automatic boost control, the pilot must adjust his throttles at every change of height if he intends to maintain a constant boost. With an automatic boost control, once the throttle lever is moved to a certain position, the control maintains the resultant boost up to the greatest height at which it is obtainable (the full-throttle height) and down to sea level. Particular systems of automatic boost control have certain limitations and vary in different ways from this general description; the more common ones will be described later. For the time being, the automatic boost control you are most likely to come across will do two things for you: Prevent over-boosting at any height, and maintain any particular boost from sea level to full-throttle height.

How it works

Before describing some of the variations to the general plan, it may be worth while repeating the broad outline of an automatic boost control.

The throttle lever is designed to compress a capsule as the throttle is opened. This capsule is housed in a chamber which is connected only to the induction manifold, it is therefore surrounded by air at boost pressure. If the throttle is opened to a required boost, a certain tension is put on the capsule; provided that the throttle lever is not moved again, so that the tension remains the same, changes in boost pressure that surrounds the capsule will cause it to expand or contract. This movement is reproduced by a servo piston, which is connected to the throttle linkwork in such a way that it opens or closes the throttle valve without moving the throttle lever. Thus a change of boost pressure, unconnected with movement of the throttle lever, will at once affect the opening of the throttle valve itself; the piston and the linkwork are designed in such a way that variations of boost pressure cause changes of throttle valve opening that reproduce the original boost pressure. In this way, any desired boost will be maintained up to full-throttle height, provided that the linkwork has sufficient freedom of movement. Above full-throttle height, all that the boost control can do is to hold the throttle valve fully open while the boost falls off. You will get the idea from the diagram below.

The capsule can also be adjusted in such a way that a particular limit cannot be exceeded.



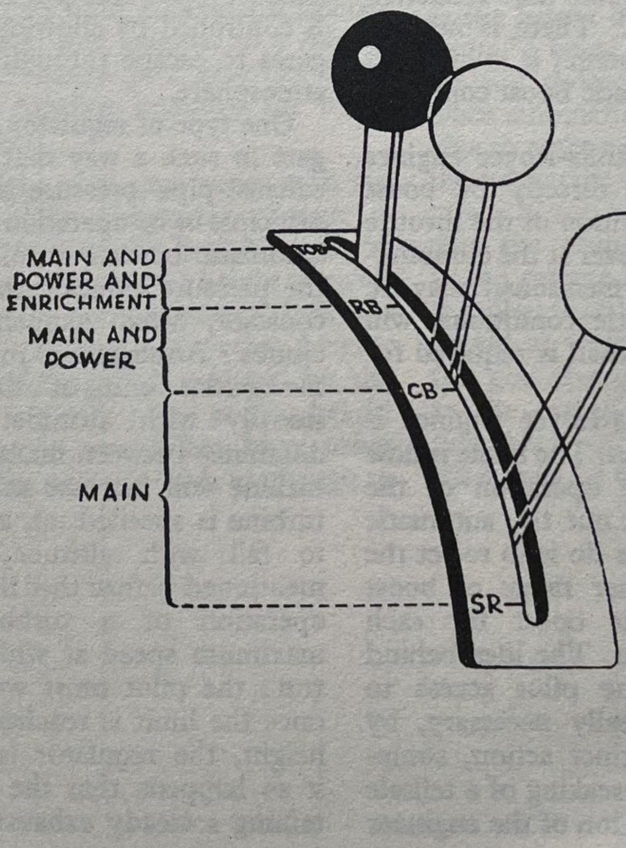
NOTE THAT THROTTLE LEVER SETTING IS UNCHANGED THROUGHOUT

A note on Bristol engines

The general description of the automatic boost control corresponds to the Hobson system, which is fitted to many British engines, including Bristols. With this system it is exactly true to say that, up to full-throttle height, the pilot's lever sets the boost, and the automatic boost control, through the servo piston, adjusts the throttle valve to maintain that boost; and above that height, the throttle can only be kept fully open. But on Bristol engines fitted with Hobsons there is a complication here.

It happens that the power and enrichment jets (which change the mixture strength) are brought into operation by the *position* of the throttle lever. Thus, with the throttle lever between slow running (SR) and cruising boost (CR) on the gantry, the main jets are in operation; between cruising boost (CB) and rated boost (RB) the main jets and the power jets are in operation, and between (RB) and take-off boost (TOB) the enrichment jets are added too. All this depends entirely on the position of the lever in the quadrant and has no connection with the automatic boost control.

Up to full-throttle height these jets richen the mixture the right amount for the boost that normally corresponds to that position on the quadrant, and the system need never concern the pilot. But above full-throttle height a slight complication arises. We have agreed that above full-throttle height the boost will fall steadily. Suppose then, that the aircraft has been climbing with the throttle lever between the CB and RB on the quadrant. The power jet will be in operation, which is correct for the corresponding boost of, shall we say, +1. But above full-throttle height the boost will fall and will eventually come within the range properly covered by the main jet alone, say, $-\frac{1}{2}$. Yet the power jet will remain in operation merely because of the position of the lever in the gantry; the result is an incorrect and probably wasteful mixture. The pilot must watch for this and retract the throttle lever to the CB position when the boost falls to this value. You must not think that this has anything to do with the automatic boost control (which after all is keeping the throttle valve fully open and can do no better); it just so happens that other things are controlled by the throttle



lever. Remember then that if you are above full-throttle height with the throttle lever engaging extra jets, and you are no longer getting the boosts for which these jets are intended, you must bring the lever back into the sector that does correspond. This is usually described in your handling notes as following the boost back with the throttle lever.

A note on Rolls-Royce engines

The Rolls-Royce system is not quite so comprehensive in operation as the Hobson. We said of the Hobson system that up to full-throttle height, the pilot's lever sets the boost, and the automatic boost control adjusts the throttle valve to maintain that boost. The Rolls-Royce system is similar in principle, but the servo piston and the throttle linkwork do not have so wide a range of action; as a result, the automatic boost control is not able to open the throttle valve fully unless the throttle lever is at least as far open as the climbing boost position. When the lever is behind the climbing position, and the automatic boost control cannot open the throttle valve fully, boost begins to fall earlier than it need. To prevent this happening, the throttle lever must be advanced to the climbing-boost position before it is presumed that full-throttle height has been reached, and that reduction of boost must be accepted. There is nothing new or different in this system; it is just that the operation of the automatic boost control is limited.

On the other hand, in Rolls-Royce engines the mixture is controlled directly by boost pressure and not by the position of the throttle lever. Leaving the throttle lever at the climbing-boost position, which we mentioned may be necessary to get full-throttle conditions, will not cause a richer mixture than is required for the boost being used.

Another feature of Rolls-Royce engines is known as *boost-control cut-out*. The name is now rather misleading, because operation of the cut-out does not really cut out the automatic boost control. What it does do is to re-set the control to work to a higher range of boost pressures, giving a higher boost for each position of the throttle lever. The idea behind the cut-out is to give the pilot access to emergency power when really necessary, by means of a deliberate, distinct action, sometimes accompanied by the breaking of a telltale sealing wire for the information of the engineer officers; but the cut-out is also used regularly in taking off heavily-laden bombers.

Gated take-off

In some Merlin installations the throttle lever, moving through a gate to the take-off position, does override the automatic boost control and sets the throttle valve to a definite opening. The boost so obtained will fall with increasing altitude; it will also vary somewhat with atmospheric conditions.

American boost-control

The Americans have been slow to introduce boost controls. The automatic controls fitted to some American aircraft for our use do not provide the full control of the British systems; they are the best that could be done in the circumstances.

Turbo-supercharger regulator

Turbo-superchargers are fitted with a boost control (or regulator) that is rather different in design, though more or less comparable in effect, to the automatic boost control we have been considering.

The regulator is designed to govern the boost produced by the auxiliary supercharger.

You will remember that the first (auxiliary) supercharger is driven by a turbine in the exhaust pipe; and that the speed of the turbine is controlled by allowing more or less exhaust gases to escape through a waste-gate into the atmosphere.

One type of regulator operates on the waste-gate in such a way that it keeps constant any exhaust-pipe pressure set by the pilot; the principle of its operation is not unlike that of an automatic boost control. Presuming then that the pressure entering the turbine can be kept constant, what happens when the aircraft climbs? Atmospheric pressure (the pressure at the outlet end of the turbine) decreases steadily with altitude. Thus the pressure difference between intake and outlet across the turbine will increase as height is gained; the turbine is speeded up, and boost, which tends to fall with altitude, is maintained. We mentioned before that the practical limit to the operation of a turbo-supercharger is the maximum speed at which the turbine can be run; the pilot must work to reduced figures once the limit is reached. But even below this height, the regulator is not fully automatic: it so happens that the arrangement of maintaining a steady exhaust pipe pressure gives a slightly rising boost, and an adjustment every one or two thousand feet is necessary to keep the boost constant.

There is now a second type of turbo regulator, which is electrically operated, and controlled from turbo-boost pressure, not exhaust pressure. This type therefore does not need re-adjustment for height; it also, incidentally, has another automatic device that prevents the turbo overspeeding.

Summary

The automatic boost control will usually do two things for you; it will prevent over-boosting at any height, and it will maintain any particular boost from sea level to full-throttle height.

There are peculiarities in various installations. With Bristols the position of the throttle lever also introduces extra jets. Therefore you are told that above full-throttle height you must follow the boost back with the throttle. This is *not* a shortcoming of the automatic boost control.

The control fitted to Rolls-Royce will only maintain boost up to full-throttle height if the throttle lever is at least as far advanced as the climbing boost position. On Rolls-Royce engines you may also find a *boost-control cut-out*, which sets the automatic boost control to work at a higher range of boost pressures, and a *gated take-off* which overrides the automatic control and sets the throttle valve to a definite opening.

American engines available in this country will probably have less effective boost controls.

American turbo-superchargers are fitted with a regulator which governs the auxiliary super-charger and is able to maintain an almost constant boost.

VI. AUTOMATIC GEAR-CHANGE

We have seen that the use of S gear at low heights gives us less power; and we have agreed that under certain conditions it may overheat the charge to such an extent that it will damage the engine. Engineers want a safeguard against the use of S ratio at low heights, so a *height-operated automatic change-speed gear* has come into use in later Merlins intended for high-altitude performance.

The correct height to change varies with the power required; the automatic change is designed to take place at the lowest height at which it can be of use, which is the height at which to change when using combat power. It is not possible to engage S gear below that height. However, if 'auto-change' is selected by the pilot, the change will take place at that height regardless of boost or revs. When he is using less power, the pilot will not wish to change to S gear so low; for he is provided with an overriding switch with which he is able to retain M gear as long as he wishes. If, then, he is climbing at economical settings, he will switch to 'override' early in the climb, and at the height he normally changes to S, select 'auto'; being above the change-speed height for full power, the change will at once take place automatically. The pilot therefore is still able to make a change at any height he wishes; the advantage is that if he is flying at combat power he can leave the switch on auto and know that the change will be made automatically at the correct height. And the engineer knows that S gear cannot be engaged below the lowest height at which it can be of any use. Clearly this gear change is by no means fully automatic to the extent that it takes the responsibility completely off the pilot's shoulders; possibly there may be developments to come.

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