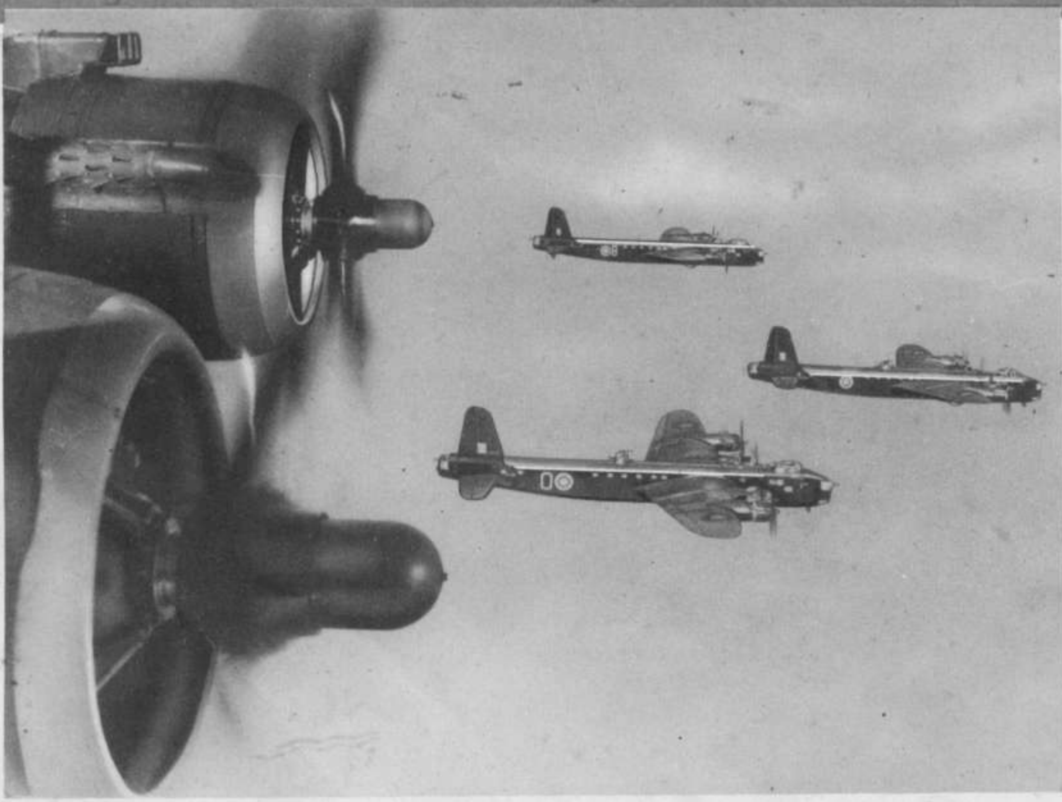
ENGINE SENSE



A.M. PAMPHLET 136 A.M.T. 2

Engine Sense

SOME THOUGHTS
FOR PILOTS AT THE
S.F.T.S., A.F.U. and O.T.U.

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CONTENTS

I: WHAT THIS PAMPHLET HAS TO TELL YOU

Nowhere but in an aeroplane would you be entrusted with the operation of an engine (or several engines) of a thousand horse-power (or more) without years of technical training and service in a subordinate position. Yet it is possible to fly without knowing more about the internal combustion engine than the average motorist, and such is the need for judgment, physical fitness and other qualities which are not necessarily accompanied by technical knowledge, that the engine-designer has reduced the handling of his very complicated engine to a few simple rules. If you stick to the rules you won't go far wrong, and we know you have plenty of other things to learn before you go on operations. But you are completely dependent on your engine, and it is part of your job as a pilot to handle the engine as well as you know how.

Your training will include what is thought to be the bare minimum of engine-handling instruction. Anything more than that is up to you; there is a lot more that you can learn, and everything you learn about your engine will help you to handle it better, to get a better performance out of it, or to lengthen its life. We need not harp on the advantage of getting more out of the engine, except to remind you that fuel economy may some day be just as important to you as climb or speed; as it may save you from an unpleasant sea voyage in a dinghy. But we are going to harp on the importance of lengthening the engine's life. About a quarter of the labour expended in the building of the average aeroplane goes into the engine or engines, and you should not be deceived, by the comparative ease with which engines are changed, into thinking that a wrecked engine is a small matter. It is only a small matter if the alternative was a wrecked aeroplane or the loss of a trained man; if you wreck an engine through carelessness or ignorance it is not by any means a small matter.

How are you to learn about your engine? There is no difficulty about this; engineer officers and instructors know more about it than you do, and if you want details, every engine has a handbook written about it. The difficulty is rather to find out what you should try to learn and what you can leave to look after itself. This pamphlet is intended to give you some idea of the sort of things you want to know. It is written mainly about up-to-date British types. Don't stop here; there will be more to learn about the engines of future years, which will probably develop three-speed superchargers and contra-rotating propellers, if indeed there are not more radical changes.

Engine limitations

In your aeroplane there ought to be a little plate or card telling you the limitations of the engine. We agree that it is usually very difficult to find, if you don't know where to look, so if you can't find it, look up the limitations in the Pilot's Notes. You ought to do this anyway, as the plates are not always up to date, and are sometimes covered over by bits of paper with the private limitations of some previous 'owner' of the aeroplane who knew better than the engine experts.

An engine cannot be made to last for ever, even by the gentlest treatment. But it can be made unserviceable very quickly by being worked too hard. The engine limitations are fixed to guide you in your job of saving the engine as far as possible. Roughly speaking, they represent the limits to which you may work on operational flights. For training they represent the absolute limits which you should never exceed, and below which you should keep for most of the time.

The modern engine and propeller are designed for maintaining power to greater heights and over a wider speed range. Consequently, operation is now subject to many restrictions which were unnecessary with the earlier engines, which were supercharged only for low heights (if at all), and whose propellers were capable of keeping the r.p.m. down under almost any conditions. As engines grow more versatile, and more powerful for their weight, restrictions multiply. Meanwhile the engine-designer, who wants the restrictions observed, is doing his best to develop automatic devices which simplify the restrictions into the observance of a few rules.

The main limitations are on power, to avoid general overheating; on boost, to avoid detonation and consequent damage to pistons, connecting rods and big ends; and on r.p.m. to avoid damage to bearings generally from excessive inertia loads and wear. The limitation of power is looked after by the r.p.m. and boost limits, and as a safeguard maximum temperatures are specified as well. The modern type is not yet foolproof, but it is getting more so as time goes on, and it is not far wrong to say that the development of automatic controls has now reached a stage where you have to do something really silly to wreck an engine in five minutes.

But it can be done, and here are some of the obvious things to avoid:

> *Don't* overprime; overpriming will only make it more difficult for someone else to start the engine if you give it up as a bad job; and reckless overpriming can do real damage without the engine ever firing at all.
>
> *Don't* run up or take-off without warming up to at least the minimum specified temperatures.
>
> *Don't* test the propeller at take-off boost; if you pull the control right back, you will get r.p.m. far below those at which the engine can run at take-off boost without damage.
>
> *Don't* overheat by unnecessary running on the ground. Cooling systems are designed for conditions in flight, and engines overheat very easily on the ground.
>
> *Don't* leave the throttle open if the engine cuts out in the air. Quite apart from the fact that closing the throttle may inspire the engine to run again, if you leave it open and the power comes back, the r.p.m. will go screaming up until the propeller has had time to coarsen its pitch.

You will notice that, with the exception of the last, these don'ts refer to errors you may commit on the ground. This is because the various automatics are primarily designed to look after you in the air, and not on the ground. It is not necessary for you to know the details of their insides, but a general idea of how they work will improve your handling of the engine, so we will try to describe what happens in the average British engine, and why, without too much detail.

II: THE PRINCIPAL ENGINE CONTROLS AND WHAT THEY DO

Throttle

MOST OF THE AEROPLANES YOU WILL BE FLYING will have an automatic boost-control. The boost (pressure in the inlet manifold of the engine) depends on the height, the speed of the supercharger (and, therefore, on the engine r.p.m.) and the setting of the throttle valve in the carburettor. The boost desired does not depend on any of these factors directly, and it would be very inconvenient for the pilot always to be fiddling with the throttle lever merely to keep the boost constant. So the engine-designer has introduced the automatic boost-control, and instead of having a throttle valve worked directly, your throttle lever sets the boost on the automatic boost-control. This unit operates the throttle valve in the carburettor, opening it or closing it as required to keep the boost at that set on the pilot's throttle lever. This makes it possible to have *cruising* and *climbing* gates on the quadrant, although the throttle valve settings for cruising or climbing boost vary widely with height and r.p.m.

At great heights (how great depending on the supercharger design) you cannot get even cruising boost with the throttle valve fully open. For each engine speed and boost there is a 'full-throttle height'. With the throttle lever set to the boost you want, you get it up to the full-throttle height, and above that you get less. Full-throttle height for any boost is, of course, higher at high r.p.m., and at a fixed r.p.m. the lower the boost the higher the full-throttle height.

Mixture control

There are still a few aircraft on which a control has to be adjusted to keep the mixture strength constant as height is gained, but this is a complication that will not last much longer.

Mixture strength has still to be varied with varying boost. On most aircraft this variation with boost is partly automatic; the enrichment above 'normal' which is required to keep the engine cool and suppress detonation at take-off power is automatic, while the full weakening which is required for most economical cruising is left for the pilot. His lever has two positions only, and is usually interlocked with the throttle lever to prevent him using 'weak' except within the range of boost for which weak can be used without harm to the engine.

This control is disappearing from modern aircraft. Since 'weak' is permissible only at low powers and 'rich' is not necessary at these powers, it is an obvious step to make the weakening at cruising boost automatic, just as the enrichment at take-off boost is automatic.

Constant-speed propeller

The pitch setting suitable for take-off is not suitable for high speeds or for cruising at low power, still less for diving. The propeller is therefore built with a means of pitch variation, from that suitable at the start of the take-off run to that suitable in a dive. On earlier propellers the pitch range was limited, but it is now sufficient to cover all conditions and is extended to provide feathering when necessary.

The pitch is controlled by a centrifugal governor, which regulates the hydraulic or electric supply to the propeller itself. If the r.p.m. are too high, the governor causes the pitch to coarsen ; if too low, the pitch is fined. In fact, the governor regulates the pitch to keep the r.p.m. at a given value. The pilot's lever merely determines what this value shall be. The quadrant could be, and occasionally is, graduated in r.p.m. In flight, the r.p.m. will be held to the setting of the lever, unless the propeller reaches its limits of pitch. This occurs at low speeds with the engine throttled back, when the r.p.m. will very often fall below the lever setting. If the r.p.m. rise above the lever setting in a dive it is because the coarse pitch limit of the propeller is not coarse enough to cope with the speed.

On an earlier type, the de Havilland or Hamilton Standard 20° propeller, the movement to fine pitch is effected by oil pressure and that to coarse pitch by springs, and centrifugal force which moves the counterweights at the blade roots, as soon as the oil pressure is cut off. With these types, it is usual for the fully-back position of the pilot's lever to cut off the oil regardless of the r.p.m., so that this position gives coarse pitch at any r.p.m., and is therefore called *positive-coarse pitch*. This may give lower r.p.m. and more economical cruising than any governor setting. It is also the position in which this type of propeller should be stopped, unless the engine is to be restarted before it is cold.

The Hydromatic (de Havilland or Hamilton) and Rotol hydraulic propellers use oil pressure for both movements and some of them have no 'positive-coarse pitch'. The Curtiss and Rotol electric propellers use an electric motor in the hub to change the pitch, the direction of movement being controlled by contacts on the governor. These electric propellers have a further refinement in their control : with the selector switch in the 'automatic' position the lever controls the speed in the normal way, but with the selector switch in the central position the pitch-changing circuits are broken and the pitch remains fixed. You can also change the pitch 'manually' (instead of through the speed control) by pressing the selector switch into positions marked *increase (or decrease) r.p.m.* If you want to find out just how much the governor is doing for you (on any type of propeller) try flying with an electric propeller, if you can borrow an aeroplane with one, and see if you can manage the r.p.m. by using the 'manual' positions. But be careful ; don't start this experiment until you are in the air ; and if you are increasing speed, either by opening up or by putting the nose down, do it gently and watch the r.p.m. until you have discovered how they behave. You will be surprised, if you do get a chance to try it, at the amount of pitch changing you have to do, and you will appreciate better what the constant-speed unit normally does for you.

For further instruction on the handling of propellers, see the recently-produced Air Ministry pamphlet 153, *Propeller Sense*.

Supercharger

This may have two gear ratios ; but only on types which are designed to operate fairly high, but cannot afford any sacrifice of take-off power. Newer types are using automatic gear-change mechanisms (aneroid-operated), but the more common pilot-operated control has only two positions. Your movement of the lever does, in fact, set some complicated machinery in motion, starting with an oil pressure-operated servo piston and going on to friction clutches for each gear. Incidentally, you will notice on some engines that oil pressure drops momentarily when you change gear. This is a useful indication that the change has happened, but not to be relied on with all engines, as some use scavenge oil-pressure to do the job and this is not shown on the gauge. Anyway, you should never be changing gear in the air (we will explain why later) except at a height at which high gear will give a considerable increase in boost, and so you can always tell from the boost gauge whether the servo mechanism has worked correctly in the air.

Air intake heat control

The air intake for normal use is external and faces forwards, in order that the forward speed of the aeroplane may assist the supercharger as far as possible. The result is that any foreign matter (ice and snow are not required in the engine) finds its way straight into the normal intake. Hence the existence of this control, which cuts off the normal intake and opens an alternative inside the engine cowling, where the snow and ice are excluded and the air is warm. The use of the warm intake involves some loss of boost at altitude, and at all heights some loss of power and increased liability to detonation, and a loss of economy which varies from one engine to another, but may be serious. Installations vary widely; some have simply hot and cold intakes selected manually, some have an automatic control with a manual override, some have a purely automatic control, some have only the one air intake with no sheltered position and some have a filter in the cold intake, with the sheltered intake as an alternative in case the filter gets choked. Snow and ice guards are often fitted on the intake, and these, with oil and coolant heating of carburettors, reduce the need for the use of the hot intake on modern engines.

For a closer consideration of icing, see Air Ministry Pamphlet 138, *Aircraft Icing*.

Gills or radiator

The radiator of a liquid-cooled engine is by-passed by a thermostatic valve to assist warming up and keeping warm on a glide, but in flight the engine is normally so hot that the by-pass is closed and, at a given airspeed, the radiator shutters alone control the temperature. But the variation of cooling with speed is very great; radiator shutters need to be open and gills partly open on a climb at full power, but can usually be shut in level flight, even at the same power. If you find the temperatures getting too high on the climb, quite a moderate increase in speed will often correct them. This is often a better way of keeping the temperature down, as even a slight extra opening of the gills causes a considerable increase in drag.

On a few aircraft, radiator shutters are now automatic, and the number is likely to increase. The action depends on a thermostat which opens and shuts the shutters as required, and the pilot is relieved of the shutter controls, but must still watch temperatures, especially on the climb.

Oil coolers

The oil cooler is invariably provided with a by-pass, usually with a valve controlled by oil viscosity and so indirectly by oil temperature. In flight, the oil is normally so hot that the by-pass is out of use and the temperature varies with power and speed. A few aircraft have, in addition, a manual control of oil-cooler shutters. This does not require so much attention as a radiator-shutter control, but should be used to keep the oil temperature at a reasonable figure in flight.

A few aircraft are subject to a trouble known as *coring*. The full explanation is complicated; but, briefly, coring may be described as over-cooling and partial congealing in the cooler, which reduces the cooling, so that the oil that remains in circulation actually gets hotter. The symptoms are an excessive oil temperature, generally rising very rapidly. As this symptom may equally well indicate such disasters as shortage of oil or mechanical failure, it should not be taken as an indication of coring unless it happens in cold air conditions and after a spell of low power; and even then, you should not be too certain of it unless you know that the aeroplane type suffers from this trouble. The first move is to increase r.p.m. and so speed up the flow of oil through the cooler. If you have oil-cooler shutters, you should close them (in spite of the high oil temperature). If the trouble persists, the only cure is to descend into warmer air. Coring only occurs on certain types, and on these it is being cured by modifications to the oil cooler, so we hope it will soon be a thing of the past.

III: ENGINE SENSE

THE MINORITY OF ENGINE OPERATORS, WHETHER they operate motor cars, steam engines, trams or aero-engines, have an underlying knowledge of what is happening inside which makes them do the right thing without thinking, both when the engine runs as it should and when it begins to go wrong. If you can add yourself to their number you will get better service from your engine, and you may one day bring an aeroplane home under conditions in which a non-engine-minded pilot would lose the aircraft and perhaps himself and his crew.

There is no end to talking about engine sense, and we cannot do more than give some of the more obvious examples, with reasons.

Instrument failures

Any engine instrument may go wrong, but you are very unlucky if several go wrong at the same moment. If your r.p.m. counter suddenly drops to zero, you wouldn't land and report that the engine has stopped (unless it really had). This is an extreme case, but any single instrument cannot suddenly give an absurdly abnormal reading without some other indication of trouble ; if your oil pressure gauge reads zero but the oil temperature is normal and the engine is still running, it is the gauge that is wrong. If your boost gauge or r.p.m. indicator have clearly failed, use the control settings that *ought* to give the right boost or r.p.m. If your temperature gauges read too low, don't try to bring them up to normal by a spell of hard climbing with the gills closed. Generally, if one gauge reads queerly with normal handling of the engine and all other readings normal, assume it is the one gauge that is wrong.

Oil pressure

The entire lubricating system depends on correct oil pressure, and the gauge is provided in the hope that you will look at it frequently. The main thing to look for is falling oil pressure in flight, and all you can do if it begins to fall is to reduce power as much as you can and get down as soon as you can. There is a specified minimum oil pressure ; this does not mean that a lower oil pressure will instantly destroy the engine, but is intended to give you an idea of when to regard low oil pressure as a danger signal. Low oil pressure is commonly the result of excessive oil temperature after a spell of high power, and the way to get the temperature down is to reduce power, especially r.p.m. (unless the rise happens after a spell of low power in cold-air conditions, when you may reasonably suspect coring). Obviously, your next action must depend on circumstances ; it does no one any good if you land in enemy territory because your oil pressure is low, but it does no one any harm and may save the engine if you land at a friendly airfield to investigate. On engines which use pressure oil (as opposed to scavenge oil) to operate the two-speed supercharger clutches, low oil pressure may indicate that the gear-change mechanism is not fully engaged in either gear, and a change to the other gear and back may remedy this.

Some pilots think the gauge is there only to tell you that the engine is just going to seize up. Of course, if the oil pressure drops suddenly to zero there is not much you can do about it, but quite often it will give you plenty of warning by dropping gradually ; and if the drop is merely the result of excessive temperature you should soon be back to normal again if you give the engine a chance.

Remember also that the oil pressure can be raised by getting the oil colder than normal. If the oil pressure is dangerously low, you may be able to save a failing engine by running it lightly, when it will cool off a bit and perhaps keep the pressure up, and also will survive longer.

Starting

Don't skip this bit just because you usually have your engine started for you, or even because your ground crew usually tell you how to do it. You cannot be sure that you are going to spend your time operating from home stations where these luxuries are sometimes provided. As soon as you get to a place where there is fighting on the ground as well as in the air, it is almost certain that you will find yourself having to operate from downs, fields, deserts, steppes, prairies, or whatever the local country is called. You may have to start your engine yourself with no one to help you, and maybe knowing that the alternative is to be taken prisoner. So don't think we are wasting your time in trying to persuade you to think about starting. And because engines seem to start so easily, don't think we are exaggerating the difficulties. Starting looks easy because an engine that will start at all will start as soon as you have done the necessary turning and priming, and the difficulties begin only when you fail to start it according to plan.

Obviously, there are conditions of cold in which no engine can be expected to start. You may, for operational reasons, have to try when you don't know whether you can expect success. But the first essential for successful starting is to give the engine a reasonable chance, by diluting the oil when it was stopped, or keeping it warm by occasional runs.

Assuming the engine is in proper order and that the job is not ruled out as hopeless by the cold, it *must* start as soon as, with the starting magneto or ignition and booster coil on, you get the right mixture in the cylinders ; so concentrate your mind on this. All the details are directed to this one end ; you turn on the fuel (and prime the carburettor if the aeroplane is one which needs it) in order to supply the petrol-part of the mixture. You turn on the priming cocks and work the primer, because on large engines the carburettor won't supply the right mixture at starter turning speeds. You open the throttle slightly because it is *mixture* you want, not just petrol, and you don't open it too far because if you admit more air than you need, you will have to use more priming than you need.

How far do you open the throttle ? Enough to enable the engine to pick up on the slow-running system of the carburettor when it has burnt the priming. How far is this ? You must learn by experience, preferably by experience begun in warm weather and continued by degrees into arctic conditions. Slightly more throttle is required in cold weather. Pilot's Notes give you an average from which to develop your knowledge. Before we leave the throttle, remember that pumping the throttle lever injects fuel into the carburettor. Whether it then goes into the engine and causes damage, or merely runs down the air intake and creates a fire risk, depends on the type of carburettor. This is *not* the way to prime the engine ; the priming pump is fitted for use and not ornament.

How much do you prime ? The answer depends on four factors ; how cold it is, how far open the throttle is, with what fuel you are priming and how much turning you have done. Pilot's Notes tell you how much priming you should give, for normal fuel and high volatility fuel, and for various temperatures, on the assumption that you have the throttle open no more than is necessary and that you give all the priming quickly at the beginning of the turning (if you do it quickly, the amount needed for priming while turning is so nearly the same as for priming before turning that the same figure can be used for each).

Why should you prime while turning ? Because it mixes the priming better with the air if you squirt it into moving air, and because, as you keep on pumping, there *must* come a moment when you have got the *right* mixture, and if the engine is turning at a reasonable speed when this happens, it *must* start. (Why then is any pilot debarred from this foolproof method by being provided with a cartridge starter ? That is easy ; cartridges are portable, ground-starter batteries less so.)

Of course the engine will not always start when you expect it to, and this is when your engine sense is required. You have got a mixture of air and priming in the cylinders ; either it is too rich or too weak. You have got to guess which. If in doubt, plump for too rich ; not that this is any more likely than the other, but if you decide *wrongly* that it is too weak, you will richen it up excessively and will be in a worse mess than if you decide *wrongly* that it is too rich and clear out some of what you have got in.

The reason for this advice is that it is easier to put more priming in than to get rid of what you have already got in. To put it in, you have only got to pump a bit more ; to get it out you have to rely on blowing it out through the exhaust ports, and only the vaporized part goes out. When the inlet manifold is cold, liquid fuel condenses in it and only vaporizes slowly even when the space is cleared of vapour and filled with air. Consequently if you have badly overprimed the engine, a lot of turning is required before the over-richness is corrected.

There are, of course, other and more powerful objections to overpriming ; the fire risk, and the damage that can be done, especially to a sleeve valve engine, by liquid fuel in the cylinders.

If you have to make several attempts to start, you must keep a mental record of the state of priming, bearing in mind how much you have put in and how much you think has been blown out by turning. If you have ' engine-sense ' you will be doing this instinctively, possibly without realizing you are doing it. It is often said that the only way to learn to start engines is by practical experience. We agree, but we think that what we have told you may help you to avoid the more serious errors, and that you will learn more quickly from your practical experience if you realize that the main problem is to get the right mixture into the engine.

Warming up and testing

Engines and their lubricating systems are designed to run warm, and running at more than a fast tick-over before reaching the proper temperature is a quick way of wearing the engine out. We hope no more need be said on this subject.

The object of running up on the ground is not to accelerate warming up, but to ensure as far as you can that the engine is giving full power before you try to take-off with it.

Cooling systems are not designed to deal with ground running, and the temperatures will rise steadily whenever the engine is opened up appreciably. So don't run the engine up more than is necessary, and don't open it up without knowing what you are going to look for ; the test will take twice as long if you try to do any thinking in the middle of it.

You want to ensure that the propeller and two-speed supercharger control (if you have it) are working correctly, that the engine will develop its normal full power, and that the ignition is in order.

The supercharger test we shall leave till later, as many aircraft have no control. The propeller can be tested at any of a wide variety of boosts. At very high boost you will probably cause detonation if you pull the control right back. At very low boost you will get no result, as the control lever will only reduce the r.p.m. if they are not already below the minimum governor setting. Engines vary, but as a general rule the maximum weak-mixture cruising boost is about right (but do the test in rich mixture). On most engines this boost is high enough to allow an appreciable drop of r.p.m. as the lever is pulled back, but not so high that detonation is likely.

Testing ignition on a modern, high-performance engine is a very different thing to the same test on a training type. The purpose of the test is the same ; to make sure that all the plugs are firing under all conditions from cruising up to take-off power. You will have learnt to test switches at full take-off power on training types, but you should not test a modern operational type in the same way.

Why not ? First, because of the extremely rough running which may result if a plug is not firing. When you switch off the other magneto, the cylinder with the faulty plug is left without any spark at all. The engine is then running at nearly its maximum r.p.m. on all the cylinders but one. This will give rough and unbalanced running on any engine, but the ill-effects are not appreciable except on an engine which has been developed (as have modern operational types) to the limit of its power. For the same reason you should not open up to full power if the engine runs roughly or gives less than normal r.p.m. at cruising boost. Secondly, take-off boost has been raised on modern engines to the point at which the engine is only saved from detonation by a considerable enrichment of the mixture. With this over-rich mixture there is a large drop of power on single ignition and a strong tendency to rough running, both of which make the single ignition test at take-off boost valueless, because they suggest faults even when the engine is in perfect order.

There are thus two arguments against testing switches at take-off boost, and the force of these arguments varies with the particular engine under consideration. Fortunately, it so happens that the stronger the argument against testing switches at full power, the easier it is to detect ignition faults without this test. The fitting of two plugs per cylinder may once have been a precaution against ignition failure, but in the search for increased power, conditions inside the cylinder have been developed to a pitch at which double ignition in every cylinder is essential for full power. Consequently the failure of a plug to fire at take-off boost will be shown up by failure of the engine to develop full power, and this can be detected without switching off either magneto. After running up to full power, the switches should be tested at a moderate boost, such as the maximum for continuous cruising, in order to see that all plugs are firing at this moderate power.

It is most important to do the full-power test accurately, as it is part of the ignition check as well as a general running check. There are two cases to consider ; the only difference is the setting of the fine-pitch stop on the propeller. This may be set so that at take-off boost the take-off r.p.m. are not attained with the aeroplane stationary. In this case there are two things to look for ; with the throttle at take-off the boost should be right and the r.p.m. should be normal (usually 100 to 300 below the take-off r.p.m.). But with 35° propellers the fine-pitch setting is usually fine enough to allow the engine to reach take-off r.p.m. below the take-off boost. In this case the governor will come into action and keep the r.p.m. at the take-off maximum. You then want to check that with the throttle at the take-off position the boost is right, and that the boost at which the r.p.m. begin to drop below the take-off figure as you throttle back is normal (usually about 2 lb./sq. in. below take-off boost).

Take-off

The regrettable thing about an aeroplane is that it needs maximum power right at the start of the flight. It is better for engines to be worked up to maximum power by degrees ; but there is no help for it, except that, if you are flying a high performance aeroplane off a large airfield, there is every reason why you should let the engine off lightly; it will lengthen its life. And the sooner you reduce power to climbing conditions, the better for the engine; but don't take any flying risks by being in too much of a hurry to reduce from take-off power.

Flight

Having now at long last got into the air, we can leave you to be looked after by the automatic boost control and the constant-speed propeller. You have still got your part to play in observing time limits and temperature limitations, watching oil pressure, refraining from using climbing or combat boost at less than climbing or combat r.p.m., and avoiding opening the throttle suddenly when the engine is wind-milling, or leaving it open if it cuts out momentarily. But as we have already said, the automatics are designed to help you in the air, and on the whole they do their job very well.

IV: CONCLUSION

WE HAVE PICKED OUT A FEW TIT-BITS OF information about engines, choosing the ones we think will be most useful to you in your job of getting the best out of the engine and keeping it in good condition. There is a lot more you can learn if you feel inclined, and the more you know about the working of the engine the better you will handle it. The engine handbooks tell you all about the inside of the engine; we don't recommend a pilot to read them through from cover to cover unless he is mechanically minded, but we do suggest that whenever you come across some point you don't understand about the way your engine works, you should look it up and work it out for yourself. Don't just ask your neighbour in the mess unless you have good reason to think he knows. Even engineer officers have been known to talk nonsense about engine handling. Don't take things on trust; find out how they work and think out for yourself the reason behind the various operating instructions. Having now come to the end of our first discourse, we are going to disregard the heading of this paragraph and start again on some advice to the pilot of a more advanced aeroplane.

V: FOR MORE AMBITIOUS STUDENTS

The two-speed supercharger

THE NORMAL, SINGLE-SPEED SUPERCHARGER IS capable of providing climbing boost up to a certain height, and not merely at sea level. What this height is depends on the boost aimed at, the engine r.p.m., the supercharger diameter and the supercharger gear-ratio. The height in question is called the full-throttle height, because as the aeroplane climbs to this height the automatic boost-control moves the throttle valve to fully open. Above the full-throttle height the throttle valve remains fully open, but the boost falls off because the supercharger cannot provide enough air to maintain it. To simplify our discussion, we will for the moment confine ourselves to climbing conditions at the maximum boost and r.p.m. permitted by the engine limitations. Under these conditions the full-throttle height depends on the design of the engine, and can be raised, in order to improve high altitude performance, only by a change in supercharger design, either an increase in diameter or an increase in gear ratio. If either of these things is done, the low-altitude performance, and particularly the take-off, becomes worse. The reason for this is that the supercharger takes a lot of power to drive it; in some cases as much as a fifth of the total engine power. At the full-throttle height this power is usefully employed in forcing air into the engine, but at sea level the power required to drive a high altitude supercharger merely reduces the net output without any corresponding gain. The increased charge temperature also results in a further loss of power.

Thus the raising of the supercharger gear-ratio, to improve high-altitude performance, results in considerable loss of power low down. To avoid this loss, which is commonly over 10 per cent., and approaches 20 per cent. on the latest high-altitude engines, the supercharger is provided with a change speed mechanism, and the power the engine will develop at a given height, boost and r.p.m. is always greater in low gear than in high. The only reason for *ever* using high gear is to give a boost which cannot be obtained in low gear at the same height and engine r.p.m.; therefore, it should never be used if the desired boost can be obtained in low gear. It follows that high gear should never be used for take-off; one might conclude that it should never be used on the ground at all, but it is desirable to see that the gear does change when running up, and to exercise it in order to clear sludge from the gear-change mechanism. One change for testing purposes before and one after each flight is sufficient exercise.

Unless there are special instructions for the particular engine, the test should be done (in rich mixture) at maximum weak mixture boost. It is convenient to do it immediately before testing the propeller. The purpose of the test is to see that the gear does change. The change of gear on the ground results in a momentary rise of boost immediately corrected by the automatic boost-control. The signs that it changes are a momentary rise in boost, followed by a small drop of r.p.m. as the boost settles down. These effects are reversed when you change down again, and you should see that both changes have the expected result. On Hercules engines a momentary drop in oil pressure is a sign that the change has taken place, and this is fortunate, as on these engines the test may not be done above 1,500 r.p.m., and it would be difficult to see the fluctuations in boost and drop in r.p.m.

Maximum performance

To climb at the maximum rate, you leave the throttle lever and propeller controls at the positions which give maximum climbing boost and r.p.m. As you go up, the automatic boost-control opens the throttle valve to maintain the boost until the full-throttle height is reached. (On Merlin engines the throttle valve cannot open fully unless the lever is at the position for maximum climbing boost, and this has to be remembered when climbing at reduced power.) As you continue to climb, the boost begins to fall off, but if you used high gear it would be maintained to a greater height. Why not then change at the full-throttle height? The answer is seen by looking at the rate of climb curves for the two gears. (See Fig. 1.) High gear, at any given height, boost and r.p.m.

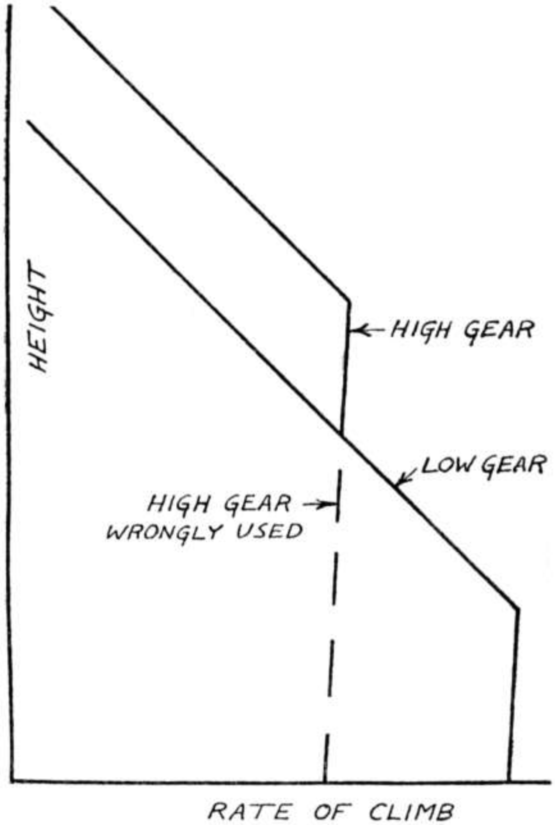

FIG. 1. *Typical curves of rate of climb at various heights.*

will give you less power, because of the extra power needed to drive the supercharger faster, and because it results in a higher charge temperature. The correct height for changing gear is that at which the power in high gear (still rising) catches up and equals the power in low gear (which has been falling since the full throttle height). It is difficult to find this height for yourself in the air; Pilot's Notes will usually tell you exactly how far you should let the boost fall before changing, but if they don't or if you have forgotten to look it up, allow the boost to fall about 3 lb./sq. in. below the climbing figure before changing gear.

Some engines have a 'combat' rating in their limitations, allowing the use of higher boost and r.p.m. for combat than for climbing. Above full-throttle height you cannot raise the boost by opening the throttle, but it still pays to increase the r.p.m. The reason for this is that, when the throttle valve is fully open, raising the r.p.m. raises the boost. So the use for climbing of r.p.m. up to the combat maximum gives you an increase of power above the climbing full-throttle height as well as below it. (See Fig. 2.)

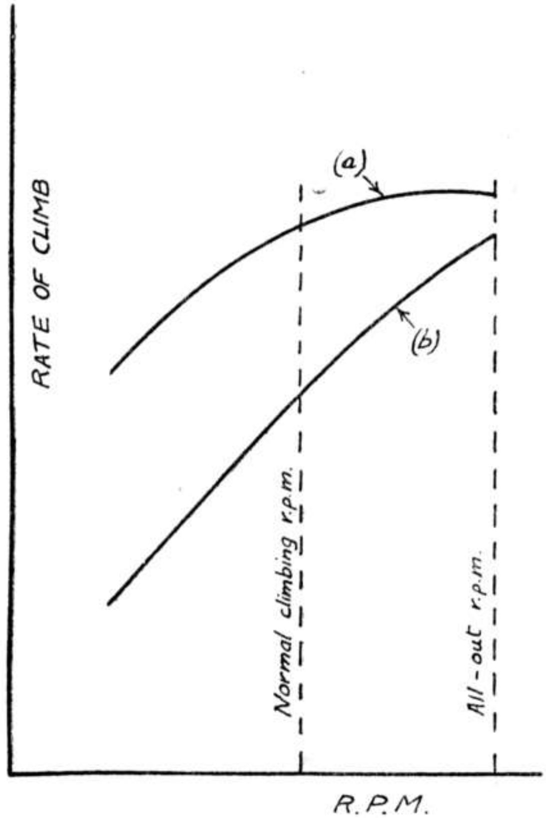

FIG. 2. *Typical curves of rate of climb at various r.p.m. each curve for a fixed height*

(a) *At constant boost, below full-throttle height.*

(b) *Above full-throttle height, at full throttle, boost rising with r.p.m.*

For maximum speed at combat boost and r.p.m. at any given height the only question which arises is which gear ratio to use. Exactly as for climbing, it pays to use low gear up to somewhat above full-throttle height (remember that the full-throttle height will not be the same as for climbing, on account of the different boost and r.p.m. and increased value of the forward-facing air intake in maintaining boost. This alone may raise the full-throttle height by as much as 3,000 feet). (See Fig. 3.)

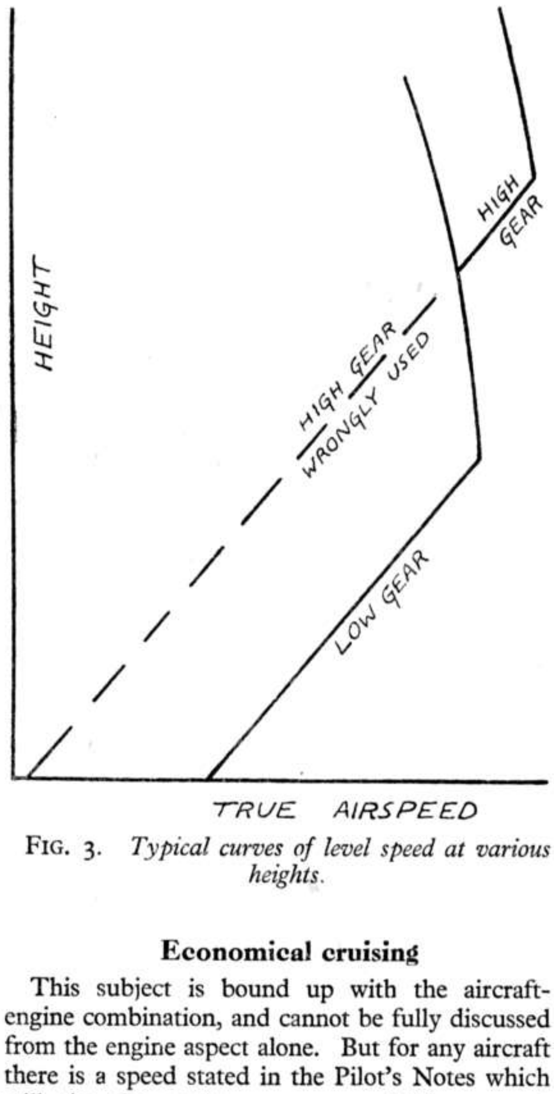

FIG. 3. *Typical curves of level speed at various heights.*

Economical cruising

This subject is bound up with the aircraft-engine combination, and cannot be fully discussed from the engine aspect alone. But for any aircraft there is a speed stated in the Pilot's Notes which will give the maximum range, and if we accept this without discussion (it is based on fuel consumption tests), there is still a lot to be said about the handling of the engine to obtain any given speed in the most economical manner. The necessary advice may be summed up briefly as follows :—

(1) Always use weak mixture

(2) Use low gear if you can

(3) Use the lowest r.p.m. you can.

To get the most economical mixture-strength under all conditions requires a little knowledge of the way the carburettor varies the mixture with changes of boost. The mixture required is richer at climbing boost than at cruising boost and richer still at take-off boost; this is necessary to save the engine from overheating and detonation. With the S.U. carburettor (as on most Merlins) this variation is controlled by the boost (not the throttle-lever position, but the actual pressure in the inlet manifold). The mixture lever does not affect the mixture at all at any boost appreciably above that permitted for economical cruising, and so no interlock with the throttle lever at the forward end of the throttle lever travel is necessary.

At economical-cruising boost the mixture lever should be in the weak position; the only object of having it in the rich position is to give a better pick-up when the throttle is opened. (On the later types of this carburettor the pick-up difficulty is overcome and the mixture lever may be found wired in the weak position or even removed altogether from the cockpit.) Even if, as may occur, it is necessary at altitude to set the throttle lever forward to the climbing position in order to maintain economical cruising boost, it is not necessary to return the mixture lever to rich. But economical-cruising boost cannot be exceeded, even with the mixture lever in the weak position or removed, without spoiling your economy.

In the C.H. carburettor (as on most Bristol engines) the variation of mixture strength is controlled by the throttle lever and the mixture lever. An interlock is, therefore, fitted which prevents the mixture lever being in the weak position with the throttle lever set for more than economical-cruising boost, and this makes it impossible for you to run the engine on a weaker mixture than is good for it. But it does not prevent you using a richer mixture than you need, and to achieve economy, you must use the weak setting of the mixture control, not only for its direct effect on the carburettor, but also because it prevents you having the throttle lever forward of the economical-cruising position and so bringing the power jet into operation. Incidentally, with this type of carburettor you can spoil your full-power performance as well as your economy if you have the throttle lever further forward than corresponds to the boost you are getting. On later types of engine this carburettor also may be found without a mixture lever.

The interrelation of boost, r.p.m. and supercharger ratio at a fixed I.A.S. is most easily followed by starting low down, and imagining a gradual gain of height. Boost should be as high and r.p.m. as low as possible within limits set by rough running, cutting out of generators, and maximum weak-mixture limits. (This has been proved over and over again by fuel consumption tests.) Low down, therefore, in low gear, you will try maximum weak-mixture boost and reduce r.p.m. to get the recommended I.A.S. If you cannot go slow enough without rough running or cutting out of generators, or because the minimum controlled r.p.m. are too

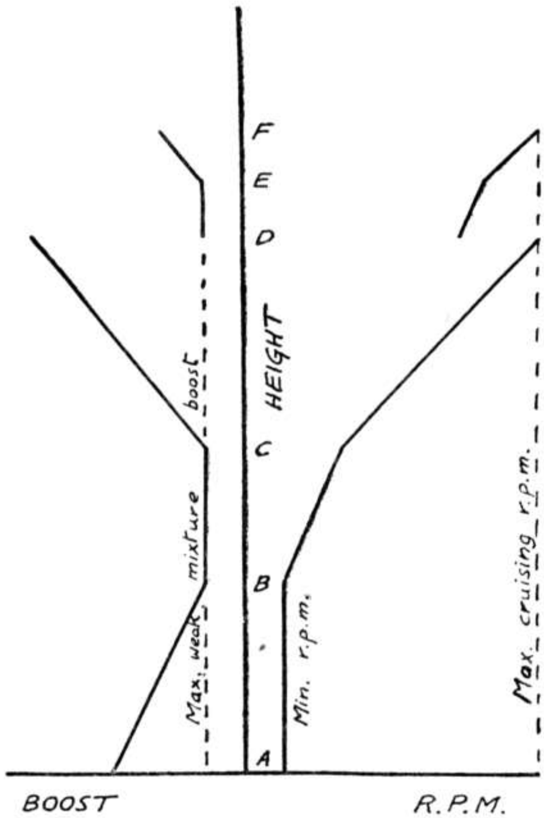

FIG. 4. *Variation of boost and r.p.m. with height when cruising at fixed I.A.S. in weak mixture.*
A—*Sea level.*
B—*Height up to which minimum r.p.m. can be used.*
C—*Full-throttle height in low gear*
D—*Maximum height in low gear and weak mixture.*
E—*Full-throttle height in high gear.*
F—*Maximum height in high gear and weak mixture.*

high, you will have to reduce boost. As height increases, you will have to increase power to maintain I.A.S. You increase boost until it reaches the weak-mixture maximum. Then you increase r.p.m. During this stage the boost will begin to fall, requiring a quicker increase of r.p.m. to maintain power. If you continue this process, you eventually reach the limiting height in low gear, at the maximum r.p.m. permitted in weak mixture and some boost below the weak-mixture maximum. You now have to change gear to maintain the same I.A.S. to a greater height.

Having changed to high gear you will get maximum weak-mixture boost again and can, therefore, reduce r.p.m. again. As you gain further height, using maximum weak-mixture boost or as near it as you can get, you will have to increase r.p.m. until you reach the maximum, when you are as high as you can fly at that particular I.A.S. in weak mixture. (See Fig. 4.)

All this is written as though you found the best conditions by going up to the desired height on an infinitely gentle climb. In fact, you will more often find yourself reaching a certain height with excess power for cruising economically at that height. It is quite easy to find on the spot what are the best conditions for cruising at your recommended I.A.S. ; try low gear first, maximum weak-mixture boost and low r.p.m. ; increase the r.p.m. if necessary to maintain height and, only if you then find it essential, change to high gear.

The foregoing description applies to a normal bomber. Fighters usually require a much smaller fraction of the total engine power to maintain economical speeds, and on the average fighter the behaviour of r.p.m. and boost will be rather different. But these variations make no difference to the principles you work on ; you still use weak mixture, low gear if you can and the lowest r.p.m. you can.

But there is one important variation to be noted ; a very heavily-loaded bomber may require maximum weak-mixture power for level flight at a height at which the boost, even in low gear, has not begun to fall. In this case high gear won't give you more power in weak mixture (it will give you less). If you must fly higher, you can only do so in rich mixture.

We said just now that for any given aircraft there is an I.A.S. stated for maximum range. This varies, as the Pilot's Notes tell you, with the total weight of the aeroplane, for reasons which have nothing to do with engines. Does it also vary with height ? The answer is that usually it does not, but when it does, the cause is the engine. The best I.A.S. would be the same at all heights if the engine's fuel consumption *per horse-power* per hour was the same at all powers. This figure is known to the experts as the specific fuel consumption. Its variation upsets the simple rule that the same I.A.S. is best at all heights in two ways. First, the specific fuel consumption rises at very low powers. Consequently, an aircraft flying low down may cover more air miles per gallon by flying at an I.A.S. higher than that which is best for range at normal operating heights. Secondly, the specific fuel consumption on certain engines rises *considerably* (on all engines it rises a little) when the r.p.m. are raised, or when high gear is used. The effect is that at great heights the best I.A.S. is somewhat lower, as the rise in r.p.m. with height is thereby reduced, and that it pays at certain heights to reduce I.A.S. rather than to change into high gear. But these are exceptions, and as a general rule you may take it that if nothing is said in the Pilot's Notes about these variations in best I.A.S., then it is not known to vary appreciably ; though on all aircraft it tends to get lower if the ceiling is near.

Finally, we will tell you quite frankly that all is not yet known about the subject of flying for maximum range. As fuel-consumption tests are done on each new aircraft a little more is learnt. If you take an interest in the subject, and do a lot of flying on one particular type, you may learn how to get it farther on a gallon of petrol than it can be got by the methods recommended in the Pilot's Notes. You cannot do fuel-consumption tests without accurate methods of measuring the amount consumed, but you may be able to find by practical experience that a certain type goes farther per gallon at a higher or lower speed than that recommended, or by being flown at some particular height or in some particular way that the experts have not thought of. But don't do your experiments over the sea or enemy territory. If you do find out anything useful, don't keep it to yourself, but send your information through the usual channels to The Under-Secretary of State for Air, Air Ministry (T.F.2). But you must send all the relevant information. The best I.A.S. for range is reduced if your aeroplane has strange excrescences all over it, and it will be merely confusing the experts if you tell them that you find it best to fly much slower than they suggest and omit to mention that your particular aircraft has things sticking out in unexpected places.

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