THE FLYER'S GUIDE

CAPTAIN N. J. GILL

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AN ELEMENTARY HANDBOOK FOR AVIATORS

BY

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CHAPTER I

ON TAKING A TICKET

AEROPLANE pilots only become proficient by constant and untiring practice. The beginner has a long uphill fight before him, and the sooner he realizes it the better he will get on.

The first question that arises in the mind of the would-be pilot is "on what machine shall I begin?"

At first the question appears rather formidable, but on more mature consideration we can weed out many of the irrelevancies that surround the problem. The beginner naturally wants to learn on what he calls an "easy machine."

Now what is meant by an easy machine?

Obviously a machine upon which his initial errors will have the least effect. That is, a machine which is slow on its controls, inefficient, and with considerable reserve of power.

During the early stages of tuition the pupil is apt to make exaggerated movements with the control lever; if the machine is sensitive on its controls, such movements will have instant effects such as may reasonably be expected to cause disquietude of mind. An inefficient machine may be described as being slow, with a steep, gliding angle; in consequence, the heavy-handed push given to the control lever on commencing a descent will not cause the wires to whistle.

A considerable reserve of power will afford a margin of safety to the beginner who tries to climb too steeply.

Every beginner is bound to meet the same difficulty—namely, inexperience.

It is the novelty of a sensation, hitherto untried, a certain feeling of elation and uneasiness, and, in most cases, sheer ignorance that are responsible for the learner's erratic movements.

Total ignorance as to the whole theory of dynamic flight and its limitations can to a large measure be overcome by reading. This I would strongly recommend. However, the novelty and its effect on the mind can only be overcome by actually going up, while knowledge gained on the ground will require to be amplified by practice.

It is almost a natural instinct to move the controls the right way, given normal circumstances. The beginner's chief mistake is that he moves them too much and, where landing is concerned, generally at not quite the correct moment. It is thus of the utmost importance that the pupil should essay his first landings on a slow machine, because the ill effects of his inaccurately timed movements will be minimised.

The novelty of being in the air entails a certain loss of the sense of feel, and beginners experience considerable difficulty in knowing whether the machine is level, especially in a fore and aft direction. The result is an undoubted tendency to climb too steeply, which is often accompanied by an attempt to turn. A little reserve of power may then save disaster.

The conclusion may now be drawn that the pupil should commence his career on a slow but fairly powerful pusher biplane, although more than one tractor machine fulfils the above conditions. However, the tractor machine never allows of the same good view being obtained, and creates a slip stream which may disconcert the novice.

Until recently the box kite has been the favourite school machine. A 50 Gnome box kite, while undoubtedly possessing many virtues, does not possess any reserve of power; for that reason I am inclined to the opinion that they are more dangerous than a learner's machine need be.

No one will deny that many of our finest pilots started on a box kite, but such men would be equally good flyers on whatever they had learnt. Further, no one will deny that the box kite has played a very important rôle in the development of aviation.

In the pre-war days there was not the same hurry and recognised need for pilots, so that tuition was perhaps more thorough; the would-be pilot was given plenty of time behind his instructor to learn the vicissitudes of the animal before making his first solo. Nowadays a man is expected to get his "ticket" in three or four days, so it would seem inevitable for the old school box kite to be replaced by a somewhat more powerful machine.

Without mentioning any type by name, the learner should have no great difficulty in selecting a machine to fulfil the above conditions.

We will now come a step further and consider the actual methods of instruction.

"Dual Control" is almost universally considered to be the quickest and most satisfactory way of learning—that is to say, on a machine fitted with two control levers and two rudder bars, the instructor, however, having sole control over the engine.

The pupil is then taken up and at once allowed to control the machine in the air, any erratic movements being corrected by the instructor. In this connection I may say that the controls of an aeroplane are very light, any correcting movement by the instructor being easily felt.

When the pupil begins to "find his feet" in the air, he is allowed to try landings, the pilot always having sole control of the engine.

Pupils must try and remember at all times to hold the control lightly. With an absolute beginner on dual control this is essential, as it is a bad thing to wear out the pilot's strength, especially in the early hours of the morning! In addition it may, of course, prove really dangerous if the pilot's control is hampered.

The pupil must have engraved on his mind the fact that a machine only flies by virtue of the speed with which it is passing through the air. If he allows that speed to be lost it will cease to fly.

The aviator of to-day is usually assisted by various instruments, but opinion differs as to the wisdom of allowing the learner to use them. The instruments more generally fitted are:

(1) Some form of air-speed indicator, such as a Pitot tube;
(2) Aneroid barometer;
(3) Revolution counter;
(4) Inclinometer;
(5) Watch;
(6) Compass.

(1) Air-speed indicators are recognised as not being dead accurate, but they should give a constant reading for any one machine. They are then manifestly a great help to the beginner. He is told that if the indicator registers x miles an hour the machine will necessarily be in the correct flying attitude. He is also told at what speed he should glide and land.

It is argued, probably with a certain amount of truth, that such methods of tuition tend to glue the beginner's eyes too much on his indicator, with the result that he does not acquire that great sense of feel, which is the mark of the really first-class pilot.

On the other hand, it does undoubtedly prove a check to the erratic notions of a heavy-handed beginner. In that way it probably tends to hasten a man's tuition.

(2) The aneroid barometer is, I think, without doubt, a very useful accessory. It is harmless, as it is not a direct help to the flying of a machine. Furthermore, there is in every pilot's mind, especially in the beginner's, an unexplainable desire, one might even say craving, to know how high he is. The satisfying of this desire is a source of great encouragement to the novice.

(3) A revolution counter is a great safeguard, and if used in moderation may prove of real assistance in learning how one's engine is running.

The true habits of an engine cannot be acquired in a day, or even a month, and a judicious use of the revolution counter should prove a fruitful source of knowledge.

Before making a flight the engine should always be run on the ground, and the revolution counter will say whether it is going well enough to attempt a flight or not.

Such an instrument should, I think, be fitted to all school machines.

(4) The inclinometer is a spirit level marked in degrees to show at what angle the machine is to the horizon in a lateral sense. As a rule they are rather inclined to stick, and are of little value to the beginner.

(5) A watch is a decided source of comfort.

(6) Compass. Not necessary for aerodrome tuition.

To sum up, my opinion is that a school machine should be fitted with:

(1) Aneroid barometer;
(2) Revolution counter;
(3) Watch.

All instruments are liable to go wrong, and it is a bad principle to allow the pupil to put his entire faith in them.

To go back to our beginner. He continues his practice from the passenger's seat until his instructor considers that he is competent to control the machine in calm air and land himself. During the instructional flights it is of the utmost importance that a great number of landings be made, and the instructor must be satisfied of the pupil's ability to land before allowing him to go solo.

The first solo flight will be short, and the beginner should continue such practice for some hours over the aerodrome, in order to make certain of his ability to effect a tolerably good landing under normal conditions. During these flights the pupil must be careful to keep within reach of the aerodrome. He will then combine landing practice with elementary air experience, such as making wide turns, etc.

Instructors must be very careful to ascertain that each pupil is thoroughly acquainted with the details of the controls before allowing the latter to start off on a solo.

In all aerodromes there are rules as to which way machines should go around and land according to the wind. These must be thoroughly explained to the pupil before sending him up. He should also be acquainted with the Royal Aero Club's rules on aerial navigation.

The beginner should be disabused of the old fallacy as to the colossal difficulty of a right-hand turn.

It is admitted that with ill-balanced, badly trued box kites a right-hand turn was "some" undertaking. In the type of school machine now under discussion the beginner should be clearly told that there is no difference between a left and right-handed turn.

Having learnt how to put the machine on the ground without breaking it and in a reasonable manner, our novice must next practice landing on a mark.

To land reasonably near any mark from an appreciable height requires practice, which must be given with a generous hand. It should not, however, take very long for our budding aviator to make certain that he can land within 50 yards of a given mark from some 300 feet. He should then be made to do a series of vol-planes from 400 or 500 feet with his engine completely shut off.

He is then ready to take his Royal Aero Club's brevet.

The tests for this brevet are two series of five figures of eight each round two given marks. At the end of each series a landing has to be made withing 50 yards of a given mark. In addition, a third flight has to be made to a height of not less than about 400 feet and a descent effected with the engine completely cut off.

Many people only take about three or four hours' actual flying before they take their tickets. That is certainly quick, but I think a good ticket should be taken after six or seven hours in the air.

It must be clear then that a so-called certified pilot and no more has but very little experience. All beginners will do well to realise this and appreciate that they have only just begun.

A boy who has just taken his ticket is naturally very pleased with himself, and thinks there is nothing about aviation that he does not know. It is a great mistake and sometimes, alas, a fatal one. Always remember in aviation that you learnt to walk before you could run.

Under existing conditions the pressing need for pilots has led to the suspension of the formality of military pilots having to take the Royal Aero Club's brevet. Elementary instructions, corresponding to the standard required to pass the above tests, is, however, imparted to all pupils before they are sent on to learn machines whose performances more nearly approximate those of present-day service machines.

It may be appropriate to add a few words with regard to clothing. There are such a large number of disguises on the market that the intending aviator may experience some difficulty in making his choice.

Unless the pilot is comfortable in his machine, he will become fidgety, and his attention will be slightly disturbed. To be comfortable then is a necessity. Comfort can only be attained by being properly clothed. Even in summer and at a few hundred feet only it is rather cold work sitting still in an aeroplane, while in winter the cold becomes really acute.

A warm coat should always be worn. Not necessarily leather, but something in which one's movements are free and easy. Leather, of course, is a special advantage in certain tractor machines where oil is flowing freely.

The hands and feet are perhaps the easiest target for the cold, so that particular care should be devoted to obtaining a really comfortable warm pair of gloves.

Leather gauntlet gloves, with some form of woollen lining, would appear the most satisfactory; but the leather should be sufficiently soft to allow the fingers and wrists to move freely. Whatever the pattern selected it is essential that gloves shall be sufficiently large without being clumsy.

Warm socks or stockings are essential to keep the feet warm. A great many pilots like to fly in gun boots. But here again the same principle applies. Something warm, sufficiently large to be comfortable, without being too large to fit on the rudder bar.

The head and ears require protection, which is best afforded by a woollen or leather (wool lined) cap.

If no wind screen is provided, goggles must be worn. This is important. At first you may find that your eyes get used to the rush of air and do not water. However, the perpetual strain on the eyes is bound to tell, and trouble will ensue. If you are lucky enough to have strong eyes and a good sight, remember they were given to you to use and not to abuse.

If flying a tractor machine whose engine throws back much oil, take a small piece of chamois leather with which to wipe your goggles. It is no use smearing the glass with gloves or a handkerchief; it only makes matters worse. In most machines of to-day efficient wind screens are provided which do away with the necessity of goggles.

When in the machine, get settled comfortably in the seat and use a deep safety-belt with quick release. See that the belt is correctly adjusted for your particular rotundity; it should be tight enough to prevent your falling forward in the unhappy event of an abrupt landing.

With regard to the actual flying of a machine there is little to be said, as it can only be acquired by practice. I am, however, tempted into writing a few paragraphs for the benefit of those quite uninitiated.

It is necessary before attempting a solo flight to learn to control the machine on the ground. An aeroplane is steered by means of a rudder, which is connected to a rudder bar worked by the pilot's feet. Now the rudder is designed to steer the machine in normal flight—that is to say, when the machine is passing through the air at a high speed; therefore, when the machine is travelling slowly on the ground, there will be very little wind pressure and the rudder will not have very much effect. In consequence, until the machine has nearly attained flying speed, it will be found difficult to steer. Once the tail is in the air, flying speed being almost reached, it will be found to answer the rudder very quickly.

When "taxying" with the tail down, big movements of the rudder will be found necessary; but, when flying, a small movement is sufficient to commence a turn.

Care must be taken not to turn the machine quickly on the ground when travelling fast, because the sudden change of direction will probably remove the undercarriage. A machine can be turned when travelling very slowly on the ground by opening the engine out for a moment or two and then cutting it off again. This momentary acceleration of the propeller will not be sufficient to start the machine travelling fast, but the resultant slip stream will create a large pressure on the rudder if held well over.

The fore and aft control is effected by means of a hinged elevator flap, which is worked from the pilot's seat by means of a lever. As the lever is pushed forward the elevator is depressed, thus offering a surface to the wind stream. The pressure on this surface causes the tail to rise. When the elevator is straight out behind—*i.e.*, horizontal—there is no pressure on it, and, when pulled up above the horizontal, the pressure on it causes the tail to drop.

To revert to our pupil, let us imagine him starting off for a flight. In a good aerodrome he will always be able to start dead into the wind and be able to keep over possible landing-ground until high enough to turn with safety. As a matter of fact, a beginner should only be allowed out in calm weather; but, however light the wind, he should be made to start dead into it.

We assume then that he starts from the sheds dead into the wind. He will push the control lever forward until the tail gets well in the air and the machine assumes a horizontal or flying position. As the speed increases the control lever will have to be pulled gently back until the machine attains its flying speed. The control lever will then be held steady, and, after running along the ground for some distance (varying from about 70 to 300 yards according to the machine), the machine will gradually lift. Most machines will climb while in the horizontal flying position when the engine is full on, so that our pupil will not require to pull the lever back at all. Great care must be taken not to let the machine get at a steep angle.

When about 200 feet a wide turn may be attempted. Press the rudder gently, and at the same time push the control lever slightly forward to ensure that the machine is not climbing. Some machines, however, tend to dive themselves on a right-hand turn and climb on a left-hand one, and vice versa.

However, on an ordinary slow pusher with fixed engine (that is, non-rotary) the beginner will not be worried with any antics of that kind. He will just have to take care that he does not lose flying speed, while being equally careful not to get into a nose dive. The machine should, in fact, be flying almost horizontally (if anything very slightly downwards).

The method of lateral control is explained in a later chapter, but, briefly, the principle is this. The incidence of the plane (or planes) on one side is increased while that on the other is decreased, and vice versa.

By increasing the incidence on one side, the lift is increased on that side and decreased on the other. So to bank a machine for a left-hand turn the control lever is held over to the left, which has the effect of decreasing the incidence on the left plane while increasing that on the right. The left-hand plane then tends to drop and the right-hand one to rise.

Similarly, if a gust of wind causes an increased lift on the left-hand plane it is corrected by moving the control lever to the left.

The actual methods of effecting this lateral control are:

(1) By means of flaps (called ailerons) hinged to the rear spar of the planes; *or*

(2) By warping the rear spar of the planes.

These two methods are described in greater detail in Chapter III.

Many machines bank themselves quite appreciably on a turn, so that the beginner will only have to assist very slightly with the warp on his first wide turns. He should, however, get into the way at once of turning with a slight bank. If no bank is applied, the machine will slip outwards, which is very ungraceful and may even prove a source of danger.

The first descents should always be straight glides. The pupil must get his machine facing direct into the wind (that is the way he will land) before shutting off the engine.

Whatever the machine, it should be glided at a speed just lower than its normal flying speed. Great care must of course be exercised not to stall it, but the happy mean should become a second nature with practice. The actual landing must be made at a greatly reduced speed. To this effect the control lever should be pulled very slowly back when about 10 feet off the ground. A perfect landing would be such that the wheels and tail skid, touch the ground together, but the beginner should not attempt such an ideal at first. He would be almost certain to misjudge his height, "pancake," rather severely, with probable damage to the undercarriage.

Landing is an operation that requires great care and attention, it being necessary, especially in the vicinity of aerodromes, to keep a sharp lookout for the movements of other machines. It is never advisable to purposely lose one's engine when gliding, as it may suddenly be required to avoid a collision, or even to neutralise the effects of an ill-judged landing.

CHAPTER II

PRACTICAL FLYING

Aeronautics being at present entirely subservient to military requirements, it may not be amiss to consider the practical side of flying from a purely military point of view.

The object of military aviation is two-fold:

(*a*) To gain intelligence;

(*b*) Offensive action, such as bomb-dropping.

To carry out these missions, fighting machines are a necessary adjunct; so without going further into the subject it is obvious that the practical pilot must be an experienced cross-country flyer.

It is with the object of giving a few hints about cross-country flying that these paragraphs are written.

Considerable aerodrome practice is necessary after taking a ticket before making a cross-country flight. The limited scope of elementary training was clearly indicated in the foregoing chapter. On an average the newly certified aviator has not been higher than some 500 feet, and then only in the calmest weather. It is then essential that he should put in several hours on the same or a similar type of machine in short flights over the aerodrome. Each time he should go a little higher, until he gets quite used to being at 2000 or 3000 feet. Once he is used to that height, he will not find that greater altitudes in any way worry him.

Every flight should be terminated by a practice landing on some particular mark. As the pilot becomes more proficient and self-confident, he should practise turning while vol-planing. At first the turns should be very wide and not through more than 180 degrees (that is half a turn). Keep the machine at its normal gliding angle throughout the turn. At first the tendency of the beginner will probably be towards rather a steep descent.

This malpractice must be overcome before attempting a complete turn. By degrees the turns can be made smaller until a neat spiral of about $2\frac{1}{2}$ turns be accomplished in 1000 feet.

By dint of constant practice the art of turning sharply and effecting steeply banked spirals is gradually acquired, but care must be taken not to attempt aerial acrobatics at an height of less than about 1000 feet above the ground.

Some eight or ten hours of such aerodrome practice should render the average pupil sufficiently skilled to undertake a short cross-country flight.

His first expedition across country should be round some well-defined objectives in the vicinity of the aerodrome, and should not last more than half an hour or forty minutes. A few short flights of this nature will tend to create confidence and inspire enthusiasm, whilst affording the pupil occasion to accustom himself to beholding mother earth from above. From a gradual "air-seasoning" of this kind the pupil will eventually learn to anticipate the country that lies before him by a careful study of the map.

Before making long flights in any weather, experience must be obtained over short courses on selected days.

Similarly, before taking a new machine across country, considerable practice must be obtained over an aerodrome. A few landings in adjoining fields, where practicable, should prove of real value.

In the previous chapter the use of the following instruments was advocated on behalf of the beginner in his initial struggles:

(1) Aneroid barometer;
(2) Revolution counter;
(3) Watch.

For cross-country work the following should be added:

(4) Compass;
(5) Air-speed indicator;
(6) Inclinometer.

Although few pilots rely on the compass to find their way, it is of the greatest use under certain circumstances.

It is always advisable to look up one's course on a map before starting off and to note down the compass bearing from point to point. These bearings should be marked on the map or a separate piece of paper so that they are clearly visible from the pilot's seat.

The compass bearing then forms a check if the pilot is following a railway, canal, etc., on the ground. Many pilots have lost their way through following the wrong railway, etc. Such errors might be avoided by a judicious use of the compass. A still stronger *raison d'être* exists for the compass when flying over the sea or in clouds. In either of these cases a compass is essential, as it then forms the sole means of finding one's way.

There are two sources of error peculiar to the compass. They are:

(1) Variation;
(2) Deviation.

By variation is meant the angle between true north and magnetic north. The variation is different for every place, and changes from year to year. At present the variation in London is about 16° W. That is to say, the compass points 16° W. of true north. It is important to remember this when taking a course from a map, because maps are made in relation to true north. To take an example. Suppose a course on the map is due east, that is to say 90° over an area where the variation is about 17° West. The compass course would then be 90°+17°, that is, 107°.

Deviation is an error caused by the proximity of metal to the compass. The large amount of metal work in an aeroplane will thus cause a big deviation. It is quite impossible to lay down any rules about deviation. It is different in every machine, and even varies for every position of the compass in any one machine.

It is corrected, as far as possible, by placing small magnets under the compass approximately at right angles to the north and south line. When this adjustment is being carried out, the areoplane should be placed in the middle of a field as far from any metal (such as iron palings, etc.) as possible. It is even advisable to do it with the engine running, as the magneto being then in action may materially affect the deviation.

It is not intended to describe this adjustment (or compass swinging, as it is called) in detail, as it hardly comes within the scope of this work.

The air-speed indicator was discussed in the previous chapter, and I ventured the opinion that it should not be used by beginners in the first stage. For long-distance flights in any weather it is, however, a great asset. The cross-country pilot will be continually flying in or through clouds. It is in such circumstances that an air-speed indicator becomes an urgent need. Imagine a pilot in a cloud. He cannot see the ground; he can see nothing but the damp obscurity that surrounds him. He inevitably loses all sense of speed and direction, unconsciously allowing the machine to assume the most alarming attitudes. How many pilots, on emerging from a cloud, have been horrified to find themselves in a steep nose dive!

Such incidents can be avoided by the use of certain instruments.

The compass, as already explained, provides the necessary assurance with regard to direction. By means of an air-speed indicator the pilot can keep his machine in the normal position fore and aft. Similarly an inclinometer will prevent him allowing the machine to stand on a wing tip.

All instruments should be arranged carefully in front of the pilot, so that he can read them in comfort.

For night flying the above instruments are more than ever necessary, and they must be well illuminated.

Before starting off across country, it is as well to make certain that you have enough petrol and oil in your tanks. In addition, a certain number of tools, a sparking plug or two, some wire, etc., should be carried. Your map, with route clearly marked, must be placed so that you can read it in comfort. The engine must be run on the ground to your entire satisfaction. It is never worth while commencing a flight with an engine that is not doing its best. Get to a reasonable height over the aerodrome before leaving its vicinity.

It is difficult to say anything very definite about the height at which cross-country flights should be made. It depends on the circumstances of each case. On service, for instance, reconnaissances are made at an average height of about 14,000 feet, at which height one may expect to enjoy comparative immunity from rifle fire. "Archie," however, is not so easy to outclimb, and has frequently been known to burst above this height.

At home I would recommend 3000 feet as being a comfortable kind of average for cross-country flying. In many parts of the country, where there is an abundance of good landing ground, it is perfectly safe to come down considerably lower, perhaps to 1500 feet. Again, where the country is particularly bad, it may be advisable to fly higher, perhaps at 5000 feet or thereabouts.

The point is that you want to be sufficiently high to reach good ground in the event of engine failure. Such a height should then give time to consider how the selected field is to be approached, having due regard to the wind.

The height at which you select to fly should also be considerably dependent on the wind and clouds. Both the direction and velocity of the wind vary with the height above sea-level. The direction, as a rule, veers clockwise from sea-level up to some 3000 feet, after which it appears to be fairly constant. The velocity increases from sea-level, becoming a maximum at about 4000 feet, above which it would seem to remain fairly steady.

As an example: a ground wind of 15 m.p.h. from S.W. would probably be about 30 m.p.h. from W. at 4000 feet.

So if flying westwards on such a day, the higher you flew the more would you be impeded by the wind. If flying eastwards, on the other hand, the wind will be of more assistance the greater the altitude.

If the clouds are thick and numerous, one of two courses must be adopted. Either fly below them if they are sufficiently high to allow of this, or, if they are very low, it will be necessary to get above them and fly entirely by compass bearing. In the latter event I would recommend a descent being made at regular intervals (every 20 miles or so) until the earth becomes visible in order to verify one's position.

A few words now with regard to finding one's way.

It is most necessary to have a good map of the whole course. I personally think $\frac{1}{4}''$ Ordnance Survey is the most suitable map for ordinary cross-country work. The course should be clearly marked and the map arranged in its case. Owing to limitations of space and weight you will find very few map-cases more than about 9 inches long. This then allows of about 36 miles on the map being visible at any one time. The roller map-case overcomes this difficulty, as a long length of map can be put on the rollers. As the pilot advances along his course he can keep pace on the map by turning one of the rollers.

Provided that the ground is visible, the whole course should be followed on the map. Certain objects stand out very clearly, and these should always be looked for. Water is perhaps the best guide to the aviator. Canals, rivers, and reservoirs prove of the greatest assistance. Railways too stand out very clearly in open country. Even in enclosed country they are usually to be found from the smoke of a passing train. Roads are apt to be rather deceptive, especially in England, where there are so few straight stretches; furthermore, there are many miles of roads concealed by trees; also unimportant roads in existence that are not marked on the map. Main roads, if they are covered with tarmac, are not nearly so visible as the second-class macadamed road.

In any flight that you are likely to undertake you are almost sure to find either a river, canal, or railway along a greater part of it. If you do not happen to have one of them to follow, you will be continually cutting them, when you can check your exact position on the map. Towns and large forests, being visible from a long distance, are also of great assistance.

In addition, the course should throughout be checked by compass bearing. It is most necessary to make allowance for a side (or partially side) wind when using the compass. For example, an aeroplane travelling from A to B (B being west of A), in a northerly wind has to steer considerably north of west to counteract the effect of the wind.

If the exact strength and direction of the wind were known for the height at which a flight is to be made, the necessary allowance could easily be calculated from an ordinary parallelogram of forces. As the wind is such a variable quantity, this is not a very practical method. The best way to make the necessary allowance is as under:

Climb to the height at which you intend to fly, over the aerodrome; start exactly over the aerodrome in a direction along your course. There is almost certain to be some prominent object within view along this course; about 5 miles would be a suitable distance. Steer direct at this point and note the compass reading, which will be the correct one for that course. On changing course the procedure should be repeated.

Such a method is, of course, only wholly possible when flying below the clouds. If a flight is to be made entirely above the clouds, the necessary allowance for wind must be calculated. Meteorological reports should be available at any aerodrome, giving the strength and direction of the wind at various heights. Failing this, the strength and direction of the wind at the ground level can be read from an anemometer and deduced for any other height. Under such circumstances it is essential to have the compass accurately adjusted to counteract deviation, and to make proper allowance for variation.

Although not advocating this method of finding a compass course, it should be possible to get within 5 or 10 degrees of the required direction. As already explained, the accuracy of the calculation should be tested by a regular descent below the clouds.

I now come on to the rather thorny question of forced landings. To land a machine where one wants and in an orderly manner is by far the most difficult part of flying. When forced to descend across country, there is the further difficulty of determining where one does not want to land. As soon as the engine stops it becomes necessary to choose a landing-place.

Provided one has a sufficient margin of height, there is time to look around and make a careful selection. There is of necessity a great element of uncertainty when choosing a ground from above.

It must be borne in mind that an aeroplane will only land on certain surfaces. The ordinary aerodrome is grass covered, and short grass does perhaps form the most suitable surface possible. However, when forced to descend in strange country, if you decide on a grass field, make certain it is grass. Roots and unripe corn are also green, and at any height are very difficult to distinguish from grass.

Then there is grass and grass. Uncut hay presents the same disadvantages to the aviator as corn does. It is almost impossible to land a machine in corn or long grass, because the wheels and skids (if any) will catch in it and cause the machine to turn over its nose on to its back. It might be possible for a very skilful pilot to land certain machines in corn without turning over, but the landing would have to be so slow that the machine had practically lost all forward way. It would, in fact, be a "pancake" landing, which would very likely break the undercarriage.

If you do find yourself about to settle in corn, you must of course pancake, the possibility of a broken undercarriage being a far lesser evil than a cartwheel over the nose of the machine.

Then again, suppose one did effect a successful landing in crops, it would be impossible to get out of them without beating down a track for the machine to run along. Material damage of that kind should always be avoided. So from every point of view avoid landing in crops.

On a windy day it should be possible to spot long grass or corn, as the wind sets up a wavy motion.

In the fall of the year, when the corn has been cut, stubble forms an excellent surface. Ordinary plough is quite possible, but great care must be taken to settle very slowly. Where the furrows are more than usually deep it should be avoided.

As the surface of an unknown ground is such an uncertain quantity, it is of the first importance to see that its surroundings make a descent feasible. For instance, a ground surrounded by trees should be avoided unless, of course, the available landing surface is particularly large; it is always most difficult to alight successfully over trees.

An efficient machine dived steeply on such an occasion will have acquired an enormous speed by the time it is flattened out. The result will be a collision with whatever there happens to be at the other end of the field. A normal glide over trees will bring a machine a long way across the field before it touches the ground at all. The result will be similar in either case.

For the same reason, fields surrounded by houses or other buildings should be avoided. Whenever possible then, make for open country.

Then again, the shape of the field selected is of the utmost importance. Some fields are long and narrow; such a field is quite all right provided the wind is blowing approximately up or down it. It is, however, a mistake to try and land in the length of a long field if a strong side wind is blowing.

It is always essential to land as nearly into the wind as possible. Try then and select a field whose lengthways happens to be against the wind. The direction of the wind is best indicated by smoke; this should always be looked for.

The next consideration is the slope of the ground. Gentle slopes are not easily discernible from a height, but they should be carefully watched for. A steepish slope should be detected without much difficulty. River valleys will help to give a general indication of the lie of the land. Flat ground should always be tried for. If only sloping ground is available, select a patch which can be approached uphill and against the wind.

In the same way, if plough is the only ground within reach, select a place where the plough is cut up and down the particular direction of the wind—that is to say, land along the plough provided it is also against the wind.

On all occasions select a place where misjudgment will have the least evil consequences. For example, do not select the edge of a precipice or even the sides of a railway cutting.

It is of course more convenient to land near a road if help is required. Such a consideration, however, should be taken into account after all others. Do not risk a smash in order to get near a road. When landing over a road or a railway, bear in mind that there are almost certain to be telegraph wires to land over. Now, telegraph wires are invisible from above, but the poles are not. Always keep a sharp lookout for the latter when making a descent near a road or railway.

A few general hints may prove of value to the uninitiated.

Firstly always take a little money when flying across country. It will be found very useful if forced to descend in strange parts.

A smoke and a match may prove of some comfort to the smoker who has to survey the remains of his erstwhile flying machine!

Even nowadays the sight of an aeroplane still attracts a large crowd of inquisitive yokels. Try and prevent them from breaking up the machine, or even its remains, if you do have to land in the country. If possible a local policeman should be put in charge of it while you go and telephone for help.

If the machine has to be left out all night, it should be wheeled to the most sheltered corner of the field, placed head to wind, and pegged down. Screw pickets are the best things to use as pegs. The machine should then be picketed down at both wheels and at each wing tip. In addition the tail should be secured to the ground. The propeller, engine, and seating accommodation should be covered over if covers can possibly be procured.

The above paragraphs only refer to flying as such, and contain no mention of the training required to apply same to the exigencies of modern warfare. Such references are included in the scope of many other publications, this work being entirely confined to an elementary treatise on the practice of aviation alone.

CHAPTER III

THE CONSTRUCTION OF AEROPLANES. THEIR CARE AND MAINTENANCE

An aeroplane is, or should be, constructed in such a manner as to get a maximum of strength with a minimum of weight. Roughly speaking, the planes, which form the lifting surface of a machine, are built about a body or fuselage in which the engine, fuel, and pilot are accommodated. Underneath a landing-carriage has to be provided. A stabilising plane at a distance from the main planes is also essential. In modern machines this is always behind, and is known as the tail plane.

The construction of a main plane will, therefore, be now briefly described. In flight the planes are subject to a constant reaction. It is this reaction which provides the lift. In horizontal flight this reaction must be equal to the total weight lifted. Therefore the total weight lifted divided by the area of the plane surface gives the normal loading per unit area. The loading per square foot of course varies with different machines, but 6 lbs. per square foot may be taken as a fair average. As the speed of the aeroplane increases (*e.g.* in a steep nose dive), the reaction on the planes also increases, the reaction varying as the square of the velocity.

With this consideration before you, and also the fact that a considerable factor of safety has to be provided, you will appreciate that a plane has to be of very sound construction.

The design of a plane then is governed by the following principles:

(1) The attainment of requisite strength;
(2) The saving of every ounce of weight;
(3) The choice of such a section as will conduce to efficiency.

All planes are cambered in section, the top surface being of a very pronounced camber while the lower surface is usually almost flat (in some machines it is quite flat). About two-thirds of the lift is derived from the vacuum created above the top surface. A pronounced camber on the lower surface tends to increase the head resistance while not materially affecting the lift.

The centre of pressure on a plane varies with the angle of incidence, but in normal flight on an average it may be assumed to be about one-third of the chord from the leading edge. As the speed increases the centre of pressure moves back, possibly in practice up to a limit of about two-thirds of the chord from the leading edge.

In practice the whole work thrown on the plane is borne by two spars. These are usually situated approximately as in diagram B below, but in many cases the front spar is coincident with the leading edge. The external bracing of the spars varies in different types of machines, which will be dealt with later; but, however supported, they are subjected to a bending moment which is a maximum at the centre point between two supports and vanishes to zero when actually at the point of support. They are also subjected to a shearing force, which is a maximum at the points of support (always assuming the structure to be rigid) and vanishes to zero at the centre point between two supports. Assuming the structure to be rigid, the breaking strain of a spar will then vary as its breadth to the power of one and as the square of its depth. The necessary strength consistent with lightness can therefore be best obtained by making the spar deep and thin. This method of obtaining strength is, however, strictly limited by the shape of the wing curve, which it is desired to employ. In order to obtain the best stream lines the plane section should be fairly deep in front, tapering to a point at the trailing edge. This enables one to have a fairly deep front spar, the depth of the back one, however, being considerably curtailed. To make up for the loss of depth the back spar has to be of considerable breadth. In flight there is a tendency for the planes to fold backwards, due to pressure of the air stream on them.

This tendency is resisted in all planes by compression stays and internal bracing wires.

In some machines there are also external bracing wires to prevent the wings folding backwards. These are known as drift wires. Diagram A shows the internal construction of a plane in plan. This is not a scale drawing and does not represent any particular plane. It is only shown as an example.

The leading and trailing edges are not shown in the diagram.

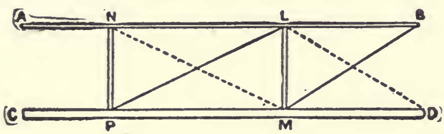


Diagram A.

A B is the front spar. C D is the rear spar. L M and N P are compression stays. B M and L P are internal drift wires. N M and L D are internal anti-drift wires.

The spars are fixed to the fuselage or body of the machine at B and D. A and C are the outside ends of the spars. As the wind pressure tends to force the plane to fold backwards, the wire B M tightens up and prevents the rear spar from folding backwards. The tendency is also, of course, to push the front spar back so that the compression stay L M is at once put in a state of compression, thus preventing the front spar from folding back. Exactly similar work is done by the wire L P and the compression stay P N. Thus the whole wing is kept rigid in a fore and aft sense. One might have three or four or more compression stays in a plane, but two is, I think, the commonest number. As I have already pointed out, reduction of unnecessary weight throughout the machine is essential.

When in flight, the drift wires B M and L P being taut, the anti-drift wires L D and N M become slack and do no work.

If, however, the machine is subject to a sudden loss of forward way (*i.e.* on a heavy land or taxying over rough ground) the planes then tend to go on. The anti-drift wires immediately become taut and keep the structure rigid in the same manner as the drift wires do in flight.

Spars are usually made of either ash or silver spruce. Given two spars of the same section, one ash and the other silver spruce, the ash would give the higher breaking strain. Owing to the fact that ash is heavier than spruce, this advantage is more or less counterbalanced, because a thicker spruce spar can be employed for the same weight. Ash for practical purposes has another disadvantage. It has to be thoroughly seasoned for about a year before use, and seasoned ash is rare. The majority of spars on present-day machines are therefore made of silver spruce.

Compression stays usually consist of either hollow box ribs or steel tube. They fit into sockets, generally steel, which are clipped round the spar. Spars should not be drilled to take fittings, as they will thereby be slightly weakened. The drift (and anti-drift) wires are attached to steel clips, and made adjustable by turn-buckles.

In most planes you will find the positions of the spars, leading and trailing edges, approximately as in diagram B (as noted above, the front spar and leading edge are sometimes coincident). The leading edge is not meant to take any appreciable load, and consists of some light wood rounded off in front. The trailing edge has no thickness, and may consist of a piece of string, stretched from rib to rib, to support the fabric. Ribs run from the leading to the trailing edges

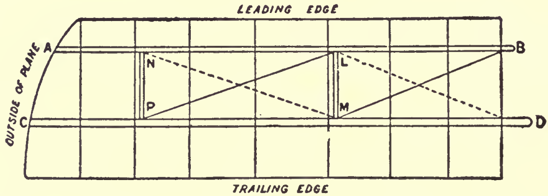


Diagram B.—Showing Uncovered Plane in Plan.

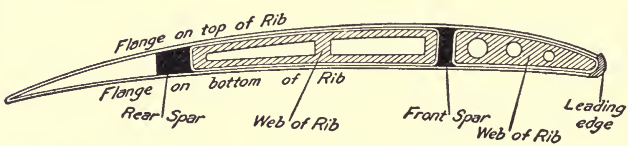


Diagram C.—Showing Approximate Section of a Plane through a Rib.

at intervals of about 18 inches. These are only to support the fabric, and are usually made of three-ply. Holes are generally bored in the ribs to lighten them.

A rib consists of a web with a flange on top and bottom (width of flanges about 1 inch). The fabric is tacked on through the centre of the flanges, so that the tack passes down the web of the rib.

In flight the resultant reaction on a plane is at right angles to it. This resultant can be resolved into two forces at right angles to each other, the one horizontal, the other vertical. The former is called drift, the latter lift. Having briefly considered the construction of a plane in so far as the withstanding of drift is concerned, it would now appear appropriate to add a few notes on lift and anti-lift bracings.

There are, of course, many variations in bracings, but the two main types are:

(1) Monoplanes;
(2) Biplanes.

(1) The ordinary type of monoplane consists of a fuselage, in the front of which the engine is mounted, with the pilot and passenger behind the engine. One set of planes is mounted on each side of the fuselage. The spars of the wings are either pinned to

a fitting on the fuselage, or else pass through steel guides into the fuselage, being pinned together (that is the two front ones together and the two back ones together) in the centre inside.

Some monoplanes, of the parasol type, have the planes mounted above the fuselage, thus affording the pilot a clear field of vision directly below him. The general principles of bracing are, however, identical with those of an ordinary monoplane.

The planes are kept in place by high tensile steel wire or cables from above and below the fuselage. (Cables are used more than wires for this purpose.)

Now, in flight the tendency is to lift the planes, therefore the bracings from below do all the work, the top bracings being slack. The former are called flying wires, the latter landing wires. When on the ground the planes, being subject only to the force of gravity, tend to drop. Therefore the landing wires do all the work on the ground, the flying wires becoming slack. These bracing wires or cables are attached to a fitting on the spar. In most monoplanes there are three wires to each spar; in some small-span machines, however, there may be only two. The top support for the bracing wires is furnished by a cabane, usually composed of four steel tubes (two from each side of the fuselage) which meet at the top. In a similar manner a lower cabane is provided below the fuselage to take the flying wires. In many machines a cabane is only provided to take the rear spar flying wires, the front ones being attached to some part of the landing chassis.

(2) A tractor biplane consists of a fuselage with engine and propeller in front, with two sets of planes, one above the other. The lower planes are attached to the sides of the fuselage in a similar manner to those of a monoplane, but lower down. The method of attaching the top planes varies, but one method is as under.

Two struts project upward from each side of the fuselage, and to these is attached a small centre top plane kept in position by cross-bracing wires. The total length of this plane will then be equal to the breadth of the fuselage. The outside top planes are then pinned to this centre section and kept in position by bracing as under.

L M is top left-hand plane. A B is bottom left-hand plane. P K and M B are the interplane struts.

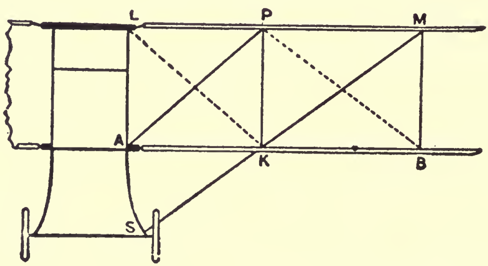


Diagram D.—Showing Bracing of Tractor Biplane (from Front).

There are of course two similar struts behind P K and M B (being exactly behind, they do not appear in the diagram). These struts fit into sockets on the spars.

A P and K M are the flying wires (there are, of course, two similar wires behind these bracing the rear spars). L K and P B are the landing wires, there being two similar ones for the back spars.

In flight A P and K M become in tension (the landing wires being slack), thus putting the inter-plane struts in compression. The top spars are thus put in a state of compression and bottom spars in one of tension. The inter-plane struts are kept in position fore and aft by incidence wires (ordinary cross bracing). The whole structure then becomes a rigid Warren girder.

S K is shown as an additional flying wire. This should not be necessary, but forms a standby if one of the other flying wires break. If S is on the front of the landing chassis, and is in front of K, S K also becomes an external drift wire. On the ground the landing wires L K and P B do all the work of supporting the weight of the planes.

The bracing of pusher biplanes is identical to the above, but in some machines of the pusher type the lower plane is in one piece, with the nacelle bolted down on the spars thereof.

The duplication of all flying wires is very necessary, especially in these times when it is no uncommon thing to have them cut by bullets during an aerial fight.

The correct rigging and tracing up of planes is greatly facilitated by fitting adjustable turn-buckles to all wires and cables.

Now practically every tractor machine, monoplane or biplane (there may be a few exceptions, such as the Caudron), has an enclosed, or partially enclosed, fuselage.

A fuselage is composed four longerons, usually of ash, (two on each side, one top and one bottom), supported at frequent intervals by vertical and horizontal struts cross-braced with high-tensile steel wire. It is seldom possible to get pieces of ash long enough to make the longeron in one piece, therefore two pieces spliced together have to be used. No strength is lost in a good splice.

In pusher machines tail booms are made of either steel tube or wood (usually silver spruce). These are also kept in a rigid position by means of struts and cross bracing. Engine bearers for stationary engines should be either of ash or steel tube.

Rotary engines are supported by steel plates through which the crankshaft passes. The latter is prevented from turning by means of a key and kept in position by locking nuts. Two such plates are always employed. In pushers the two plates are on the same side of the engine (in front of it). The engine is then said to be overhung.

In many rotary engined tractors both plates are also on the same side of the engine (behind it), the engine in such a case also being overhung. In that case the crankshaft (a non-revolving part) transmits the whole weight of the engine to the engine bearers.

In cases of other tractors, however, a front engine bearer is employed between the cambox and the propeller (only one back plate is then necessary). In such cases the nose piece (a revolving part) transmits part of the weight of the engine to the engine bearers, the nose piece revolving round a ball-bearing mounted in the front bearer. Alignment in such cases is more difficult to obtain. Any inaccuracy of alignment will strain the nose piece and may cause a fracture.

It is, of course, essential that the utmost care should be given to every detail of aeroplane construction. Many small defects, such as the breaking of oil and petrol pipes, often lead to considerable trouble. Petrol and oil pipes usually break at or just below a nipple, where they are attached to a tank (or carburettor, etc.).

The vibration in an aeroplane is very great, and, unless nipples, etc., are made sufficiently strong, such breakages are to be expected. Vibration is more evenly distributed by fitting pipes with a curl  just below the points of support.

Flexible pipes are unlikely to break, but most of them suffer from the great disadvantage of not being able to withstand petrol. They also kink very readily.

Tail planes vary, but most machines have a fixed stabilising plane and a hinged elevator. The latter is necessary so that the pilot can change his flight-path. Some machines have a single movable surface for a tail, which performs the function of both a stabilising plane and of an elevator. Some tail planes are cambered in section, others are flat. Their shape (in plan) also varies from rectangular to semi-circular. The principles of their construction are similar to those of a main plane, having usually one spar to take the load and a series of ribs to which the fabric is attached.

Tail planes are, in the case of machines with fuselages, either attached to the top of the fuselage by means of clips or else they are made in two pieces on either side of the fuselage, the latter being reinforced at the points of attachment by a strong compression piece. They are also stayed from above or below (or both) by steel tubes.

Undercarriages also vary considerably. Some are wooden, others are made of steel tubes. Whatever the particular form, an undercarriage must be designed so as to give the necessary propeller-clearance and to form a strong support on which to mount the wheels. The wheels must be considerably in front of the centre of gravity, so as to obviate any possibility of the machine turning on its nose. In order to distribute the shock of landing and of taxying over rough ground, the wheels are not attached rigidly to the undercarriage, but are attached through the media of shock absorbers. The commonest form of shock absorber is the rubber type, but Oleo gear are now also used to a considerable extent, especially on several of the larger weight-carrying machines. The ordinary type of rubber shock absorber consists of a number of thick elastic bands stretched tightly over the top of a skid. In such a case there would be two skids (one on each side), and the axle would pass across over the skids and under the rubbers. The wheels would be fitted outside the skids so as to revolve round the axle. The axle would be kept in its place fore and aft by means of tie rods. There are, of course, many modifications in details of various designs, but the above illustrate the main principle.

To come on to the covering of planes. The fabric most commonly used is a flax fabric, which should be fine and closely woven and left unbleached. If a sufficiently large piece of fabric is available, it may be laid over the upper surface, folded around the leading edge and along the lower surface, being sewn along the trailing edge. It should be arranged so as to lay fairly tight over the plane before being sewn. It should then be tacked (only copper tacks being employed) about every foot along the ribs on both upper and lower surfaces. A narrow tape and washers are placed along the ribs over the fabric before putting the tacks in. If the fabric is not sufficiently wide to allow of its being folded over the plane, two pieces should be sewn together, the join being made to lay along the leading edge.

When the fabric is finally in place, it will be doped, two coats of dope being necessary. The dope has the effect of tautening the fabric. When the second coat of dope is dry, the plane is then varnished. Varnish keeps the plane weather-proof to a certain extent and also makes a nice smooth surface. The smoother the surface, the less the skin friction. When doping or varnishing, it is important to keep out all dust and dirt, and also to see that the hairs are not coming out of the brush, as these would adhere to the plane and make the surface rough. Although it is very necessary to keep the surface smooth, on no account must the fabric be touched up with sand-paper, as this will cause weakness.

Lateral control is given to the pilot by one of two means.

The first method is by means of hinged flaps or ailerons, the second by warping the rear spar.

Ailerons are hinged to the rear spar, the trailing edge being cut away. They are operated by the control lever (or wheel) by means of cables, passing over pulleys and attached to a king post on the ailerons. In every modern machine ailerons, when employed, are of the balanced type—that is to say, when the aileron on one side is pulled down, that on the other side is pulled up at the same time.

In the case of warping wings, the tips of the rear spars are pulled down and up. The effect is, of course, the same as with ailerons—namely, to increase or decrease the incidence of the plane. In the case of a monoplane, where wing-warping is still the most usual form of lateral control, the lift wires to rear spar pass over pulleys in the lower cabane and are operated by the control lever so as to warp the spar. The anti-lift or landing wires to the rear spar are continuous —that is to say, they pass over pulleys on the upper cabane, the ends being attached to corresponding points of the rear spars on each side of the fuselage.

Fore and aft control is given by a hinged elevator or horizontal rudder. The elevator is fitted with king posts, two on the upper and two on the lower surface. Cables are attached to these and passed through guides to the cotrol lever, by means of which the pilot operates the elevator.

Directional control is given by a vertical rudder, actuated through the media of king posts and cables by a rudder-bar in the pilot's seat.

All control wires should be duplicated in case one breaks in the air.

Some biplanes have one plane vertically

above the other; others have the lower plane slightly in rear of the top one. In the latter case the planes are said to be staggered. Staggered planes are slightly more efficient (about 4 per cent.) than those arranged vertically above one another; also, in the case of tractor biplanes, the occupant of the front seat is enabled to get a larger field of view vertically downwards by staggering the planes.

The erection of machines forming so important a lesson for all intending aviators should be studied *ab initio.* Firstly with reference to the planes; the spars, which are cut to size by machinery, are fitted with compression stays, ribs, internal bracing wires, and such other fittings as are incidental to the design. These are all put into their correct position from the drawings, and finally trued up by the adjustment of the turnbuckles on the drift and anti-drift wires. In the case of wing-warping machines it is interesting to note that ribs should not be a dead-tight fit, as a little play is necessary when the spar is warped. Before covering the planes care must be taken to see that the turn-buckles are locked, whilst all wires and metal fittings must be painted to prevent rust. Drift wires should be duplicated.

The erection of biplanes may be considered under two categories:

(1) Those machines whose lower and top planes are each in one piece with the nacelle built on to the lower plane.

(2) Those machines whose lower and top planes are each in two pieces built on to a fuselage (or nacelle).

(1) In the former case the first thing to do is to erect the planes as under.

The positions of the inter-plane strut-sockets are marked on the upper surface of the lower plane, exactly corresponding positions being given for those of the lower surface of the upper plane by superimposing the planes.

These sockets are then very carefully bolted in position and the planes erected by inserting the inter-plane struts and bracing wires. Great care must be taken to see that the struts are placed in their correct positions. In some machines the rear sets of struts are not interchangeable, slightly increasing in length on one side from the centre in order to counter-balance the torque of the propeller. Front and rear struts are not always interchangeable. It is, therefore, of the utmost importance to see that struts are exactly as per drawings. During this time the lower plane should be supported under the spars by low trestles or some similar device.

Now, considering the front or rear sets of struts separately, a pair of inter-plane struts and the sections of upper and lower spar between them form a rectangle (that is, of course, provided the struts are of equal length). Now, the diagonals of a rectangle are equal. Therefore, provided you have fitted the strut-sockets accurately and that the struts are also accurate, that section of the planes will be true when the diagonals (*e.g.* the landing and flying wires) are equal.

If the struts are not meant to be quite the same length, the length of the diagonals (*e.g.* the landing and flying wires) for that particular section must be obtained from the drawings and adjusted accordingly. Similarly each section of the plane can be trued up, as far as is concerned by the landing and flying wires. This process of trueing up should be commenced at the centre section of the planes, the incidence wires being adjusted as far as possible to measurement simultaneously with the flying and landing wires of each section. It will be necessary and more convenient to finally check the incidence after the machine is wholly erected.

Having erected the planes, the tail booms are next put together in a similar manner by very carefully fitting the inter-tail boom struts and adjusting them with their bracing wires. The tail booms, having been correctly rigged, are then fitted to the main planes. The ends of the tail booms either fit into sockets or are pinned to clips fitted on the rear spars of the planes. When finally erected, the load is taken by the bracing wires and not by these fittings. The planes and tail booms, thus erected, are then lifted on trestles sufficiently high to allow of the undercarriage being fitted.

In most types of machines the undercarriage struts fit into sockets on the underside of the lower plane spars (or of the fuselage in the case of fuselage machines). The undercarriage must be carefully erected about a centre line. Care must also be taken to see that strut, sockets are fitted at the correct angle to take the struts.

It is not, of course, possible to give a detailed description of the erection of every type of machine, but it is considered that once the main principles are appreciated such knowledge should be applicable to any ordinary type of which drawings are available.

Finally, the nacelle, tail plane, elevator, rudder, ailerons, etc., may be fitted.

The angle of incidence of the planes is finally checked by getting the machine level laterally and chocking the tail up in the flying position. The incidence is then measured by means of a straight edge and spirit level. Incidence is given in inches (not degrees). Sometimes the chord is taken as between the two spars, sometimes as between the leading and trailing edges. These details will always be found on the drawings. The straight edge is placed on the under surface of the plane, one end being held lightly against the rear spar (or trailing edge, according to the data). The straight edge is then kept horizontal by means of the spirit level, and the difference of height between the front and leading edge of the chord in question is then measured in inches. The incidence must be checked at regular intervals along the planes. The incidence is corrected by means of the incidence wires.

(2) The erection of machines whose planes are attached to each side of a fuselage (or nacelle).

The first thing to do in this case will be to erect the fuselage. One side is erected at a time. An easy way to get the sides of the fuselage correct is to make a scale drawing on the floor. In most modern fuselages the longerons are decidedly curved. They can be kept in their correct position while the struts are being fitted by nailing little wooden blocks in the floor, the places for these blocks being shown from the drawing on the floor.

All the fittings for the fuselage struts and wire clips must be put on the longerons previous to this. The longerons being temporarily held in their proper places as described above, the struts are then fitted and the whole side of the fuselage is made to assume its permanent shape by fitting and adjusting the cross-bracing wires.

Having got the two sides of the fuselage correct, the horizontal struts and bracing wires are then fitted and the fuselage is then erected. The centre section of the top plane is then fitted to the fuselage by fitting the four inter-plane struts (two on each side of the fuselage) and their cross-bracing wires. The planes are then erected on each side of this structure in a similar manner to that described above. The erection of the remainder of the machine is also in principle as described above.

The procedure of erecting a monoplane is similar to that of a biplane with fuselage. Before fitting the planes the cabanes must be fitted.

In all cases the dihedral angle between the planes (if any; where the upper and lower planes are each only in one piece there can of course be no dihedral) is correctly adjusted by means of the landing wires.

Aeroplanes, being very fragile, require constant attention to keep them in an efficient state.

All wires must at all times be covered with a thin film of grease to keep out rust. High tensile steel wire or steel cable, when subjected only to a direct pull, lasts for a very long time providing rust is kept out. Cables that pass over pulleys or through guides, however, have only a very short life and must be constantly inspected. As soon as one strand is seen to have frayed the whole cable should be replaced by a new one. When one strand has worn, it is almost invariably the case that others have done the same, although not visible. The life of cables running over pulleys can be prolonged by ensuring that they pass over the pulleys at the correct angle (*i.e.* do not rub against the flanges). The rigger on a machine should carefully inspect all wires and controls every night. In addition, a machine should be thoroughly inspected by the officer in charge of it at least once a week. In the case of machines with enclosed fuselages, the latter should be uncovered for the weekly inspection. The greatest care must at all times be taken to ensure that all turn-buckles have locking wires. Another point with regard to turn-buckles is to see that the bolts fitting into them are sufficiently engaged.

It is of the utmost importance to ensure that aeroplanes and their sheds are kept thoroughly clean. The floors of most sheds have a strip of sheet metal inset up their centre. Care must be taken to leave machines with their engines over this metal part, so that any oil that drips down will drip on to the metal and not on to the wood flooring. If metal is not provided up the floor of the shed, small trays must be placed under the engines at night.

The floor of a shed will soon become covered with oil unless these precautions are taken, with the result that tyres will suffer and dust and dirt accumulate.

Grease and oil should be wiped off the planes as soon as a machine comes in. A dry rag will be employed for this purpose. On no account is petrol to be used, as it deteriorates the fabric.

See that tyres are kept sufficiently tight. Shock absorbers must also be carefully watched, as their life is not very long, especially when a machine is constantly landing on or taxying over rough ground.

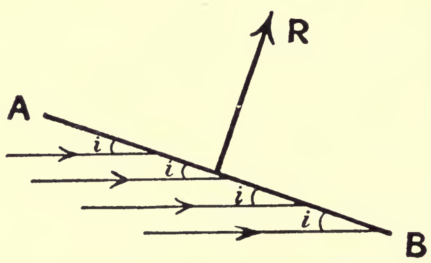
Special care must be taken in handling machines of the pusher type with tubular steel outriggers. If these outriggers are constantly being lifted they are very liable to lose shape. It is generally possible in such cases to make a little two-wheeled truck to fit under the rudder post. This saves lifting the tail booms when man-handling a machine.

When filling up with petrol or oil it is essential to use a filter.

CHAPTER IV

THE THEORY OF FLIGHT

CONSIDERING the question from the most elementary point of view it is evident that flight is only a dynamical possibility; or in plain words a flying machine is only sustained in the air by the force of air moving past it.



Now the air flowing past an aerofoil causes a reaction, whose resultant acts at right angles to it. Thus if A B is an aerofoil meeting a stream of air, the resultant reaction R is at right angles to A B.

The value of the reaction R is given as being equal to KSV^2i. It is not intended to give a quantity of formulæ or equations, but the following fundamental equation should be carefully noted, as much may be learnt from its application:

$$R = KSV^2i.$$

Where R = total reaction in kilogrammes.

K = a co-efficient (which varies with various wing curves, etc.).

S = Surface of the aerofoil in square metres.

V = Velocity (in metres per second) of the air stream.

i = Angle at which the aerofoil meets the stream of air, measured in radians.

Now, a force can be resolved into any two components at right angles to each other. Considering our aerofoil as the planes of a practical flying machine, the resultant reaction can be resolved into two components, one vertical, the other horizontal.

Furthermore, it is obvious that, if the machine is going to lift, the vertical component of the reaction must be equal to or just greater than the total weight of the machine.

It was seen from the fundamental equation that the reaction varies as the surface, the square of the velocity, and the angle at which the planes meet the air, or, as it is called, the angle of incidence, and a coefficient K, which is a constant for any one form of plane.

The vertical component of the reaction is, as a matter of fact, equal to the total reaction $\times$ cosine of the angle of incidence, and, where the latter is small, as it must be in practice, the vertical component may be taken as being equivalent to the total reaction, cosine $0°$ being unity.

Therefore for a machine to lift at all, the reaction on the planes must be a certain value, which can be expressed in terms of velocity, surface, and angle of incidence.

Thus to actually make any machine leave the ground (quite apart from all other qualities which are essential to the flying machine) it is necessary to have a certain plane area passing through the air at a given speed.

The question of the speed required to bring about a condition of flight and of the power necessary to produce that speed may now be considered in conjunction with the fundamental formula.

As already mentioned, at the small angles of incidence at which the planes of a flying machine meet the air in practice, the vertical component is almost equal to the total reaction. The smaller the angle gets, the more nearly are they equal, until, the planes being horizontal, they would become coincident, and equal to zero!

The greater the vertical component the less does the horizontal component become. (This is apparent from an ordinary parallelogram of forces.) The horizontal component of the reaction represents the resistance that the planes offer to being drawn through the air.

Besides the resistance of the planes, the resistance created by the other parts of the machine, such as struts, wires, fuselage, landing chassis, etc., must now be considered. The resistance of or reaction on these parts varies as the square of the velocity at which they are travelling. Consequently, as the speed gets higher their resistance increases very rapidly. But at high speeds the angle of incidence must necessarily be small. We can see this from the fundamental equation $R = KSV^2i$, because V varies inversely as the square root of i for any given machine.

Now, considering the resistance of the planes only (that is, leaving out of account the wires, struts, etc.), up to a limit their resistance decreases at higher speeds for any given machine, because they are at a smaller angle of incidence and therefore meet the wind at a more convenient angle.

The total resistance of the machine, that is, the resistance of the planes plus the resistance of the other parts of the machine, together form a resistance which is equal and opposite to the thrust created by the propeller.

Thus, it is obvious that to make an efficient aeroplane this total resistance must be as low as possible. Without going into formulæ, it can be assumed that the total resistance will be a minimum when the two resistances are equal. The angle of incidence at which this occurs is easily found.

Now to come on to the question of power required to sustain a machine in horizontal flight.

Power is merely the measure of the rate of doing work. If one is employing metric units, it is measured in kilogramme-metre-seconds. That is, the work done in one second is the thrust multiplied by the distance travelled in that time. But the distance travelled through in one second is the velocity. The power then required, to sustain a machine in horizontal flight, is equal to the thrust velocity. But thrust varies as the square of the velocity. Therefore power varies as the velocity cubed. Consequently very high-speed machines require enormous power (the power necessary increasing very rapidly at high speeds).

A few typical curves for any one machine should prove the best method of amplifying the ground already covered.

As has already been seen from the fundamental formulæ that for any given machine $V \propto \frac{1}{\sqrt{i}}$, a curve can therefore be plotted showing, for any one machine, how speed required for flight varies with the angle of incidence. Without professing to have worked out a curve for any particular machine, the

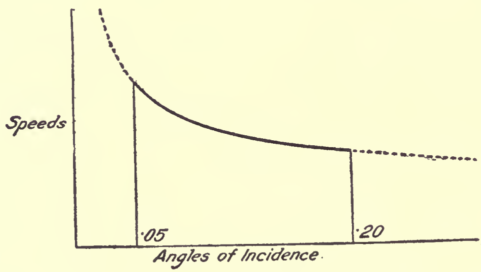


DIAGRAM E.

curve would always be somewhat after the style of diagram E.

It might be added that the practical limits for the angle of incidence of the planes of a flying machine are between about 2° and 12°; or employing circular units, which are the only true mathematical measure of an angle, as between .05 and .20 radians.

In a similar manner a curve can be plotted showing how the thrust for any one machine varies according to the angle of incidence.

Again without professing to any great accuracy, the curve will be something after the form shown in diagram F. The same two practical limits for the angle of incidence are

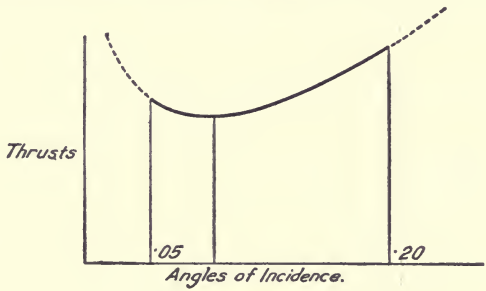


DIAGRAM F.

again shown, and it is apparent from the curve that the minimum thrust occurs between these two limits. After these two limits have been passed, the thrust decreases very rapidly, especially on the side where the angle of incidence decreases.

As already explained, power is only a measure of the rate of doing work.

Considering the case of an aeroplane, the power required to sustain it in horizontal flight in kilogrammetres per second is the thrust × distance moved through in one second—that is, the thrust × velocity.

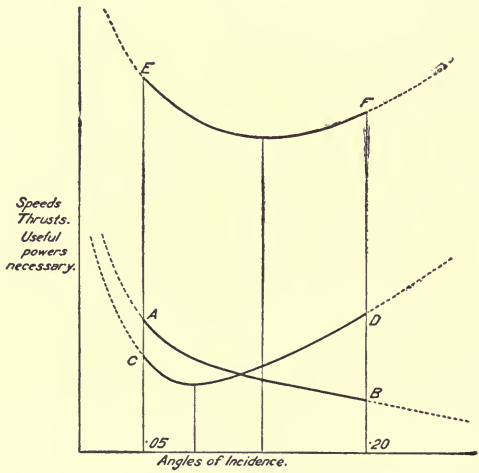


DIAGRAM G.

Diagram G shows the speed angle of incidence curve and the thrust angle of incidence curve for any one machine plotted on the same base (speeds and thrusts being plotted vertically, and angle of incidence horizontally).

A B is the speed angle of incidence curve. C D is the thrust angle of incidence curve.

Now if the two ordinates are multiplied together—that is, the speeds and the thrusts—a curve is obtained showing useful power required for any angle of incidence for this given machine.

E F represents the approximate shape of this curve (diagram G).

From this curve the angle of incidence can be found at which the power required is a minimum. It is *not* the same as the angle at which the thrust is a minimum, but is always slightly larger.

This should be fairly apparent now that the three curves are together on one base.

It is a very easy matter to convert the power angle of incidence curve into a power speed curve, since a speed angle of incidence curve has already been obtained.

It is apparent from this latter curve that, as the angle of incidence decreases, the speed increases; consequently the power speed curve is virtually the same as the power angle of incidence curve the other way round, but slightly elongated. This power speed

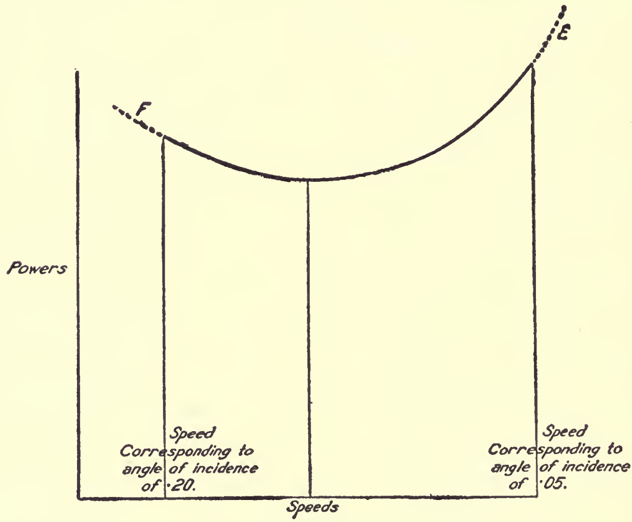


Diagram H.

curve is represented in diagram H. It is known as the "aeroplane curve."

Now, in a practical flying machine the power required, as found from that curve, means that so much power should actually be given out by the propeller.

Imagine a machine fitted with an engine of nominal 80 horse-power; that does not mean that the power given out by the propeller is 80 H.P. The inefficiency of the propeller and the drive have to be considered. The most efficient propeller is only about 75 per cent. efficient.

Consequently it is almost impossible to know what power is actually given out by a propeller of a plant of some nominal horse-power. To overcome this difficulty makers supply a curve with their plants showing the power actually given out by the propeller at various speeds.

The useful power given out by a propeller at various air speeds is characteristically of the form O P (diagram K).

This is known as the propeller curve. The aeroplane curve F E (originally found in diagrams G and H) is also plotted on the same speed base as the aeroplane curve in diagram K.

Now, if the propeller curve cuts the aeroplane curve in two places, as it does in the diagram, then the aeroplane would fly at the two speeds corresponding to the points of intersection of the curves with the engine full on.

At any intermediate speed, unless the engine is throttled down, the aeroplane will

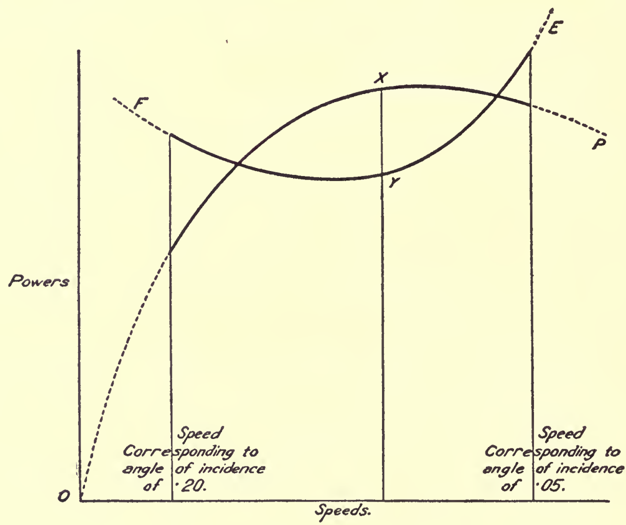


Diagram K.

tend to rise. In practice a machine is usually designed to fly at the highest of these two speeds. However, horizontal flight can be maintained at any speed between these two points by manipulation of the throttle and elevator.

Horizontal flight cannot be maintained at any speed outside these points owing to the power being insufficient. These curves therefore show the range of speed of a machine.

The greatest distance between the curves X Y shows the maximum excess of power, and the speed corresponding to that excess of power is the speed at which the aeroplane will climb fastest.

If the curves only just touch, that means that the propeller is only just giving out sufficient power to sustain the machine in horizontal flight, and therefore it will not climb. If the curves do not touch at all, it means that insufficient power is being given out by the propeller to even maintain horizontal flight.

Having disposed of a few of the elements of dynamic flight the study should now be completed by a brief reference to the question of stability.

It is common knowledge that the planes of any practical flying machine are cambered in section. In some cases the lower surface is flat, or almost flat, but the upper surface is always cambered.

Now a cambered plane meeting a stream of air at any angle of incidence less than about 15° is inherently unstable. And as we have already seen that for a practical machine the incidence must be less than that, therefore in practice a cambered plane is unstable. At the present moment fore and aft stability only is under consideration. To take an example. Imagine a machine (with cambered planes) flying horizontally so that the centre of pressure is coincident with the centre of gravity *and* that the machine is in equilibrium. Suppose now that this state of equilibrium is disturbed and that the tail drops slightly—that is to say, the angle of incidence is slightly increased; then the centre of pressure moves, but it moves *forward* and becomes in front of the CG. The result is that a couple is set up between the weight acting through the CG and the reaction acting through the CP, which causes the tail to drop still more.

Therefore, if a machine consisted of a single cambered surface only, it would be inherently unstable fore and aft.

A flat plane on the other hand would be stable in so far as the movement of the CP

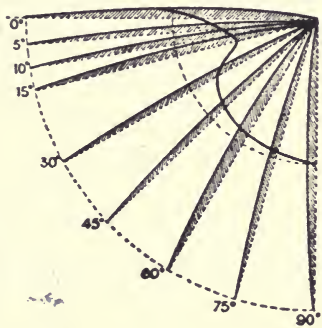


Diagram L.—Figure Showing Movements of CP with Various Angles of Incidence for Typical Cambered Plane.

was concerned. With a flat plane at 0°, of course, there would be no vertical reaction. At just more than zero the CP would be well forward and would move back until at right angles to the air stream it would be half way.

However, flat planes cannot be used as the lifting surface on a flying machine owing to their inefficiency. Therefore, a cambered

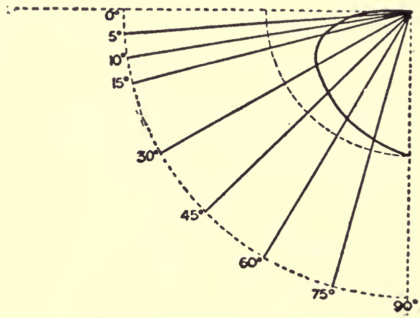


DIAGRAM M.—FIGURE SHOWING MOVEMENT OF CP WITH VARIOUS ANGLES OF INCIDENCE FOR FLAT PLANE.

plane must be used and some device employed to overcome this inherent instability.

Consider an aeroplane in horizontal flight. There are four forces acting on it, and they must be in equilibrium.

These forces are:

(1) The weight of the machine acting vertically downwards;
(2) The lift acting vertically upwards;

(3) The thrust created by the propeller acting along the line of flight;

(4) The total head resistance of the whole machine acting against the line of flight.

The designer's object is to get all these four forces to pass through the centre of gravity when the machine is in normal hori-

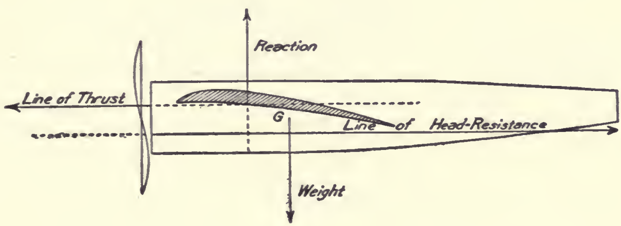


Diagram N.

zontal flight. The machine will then obviously be in equilibrium, as there will be no disturbing element. If these forces do not quite coincide through the centre of gravity, then the couple of the thrust and head resistance must be made to balance the couple of the lift and the weight. In any case these four forces must be nearly coincident through the centre of gravity.

Diagram N represents a machine under the influence of these four forces.

G is the centre of gravity. In this case the couple of the thrust and head resistance tend to turn the nose of the machine down-

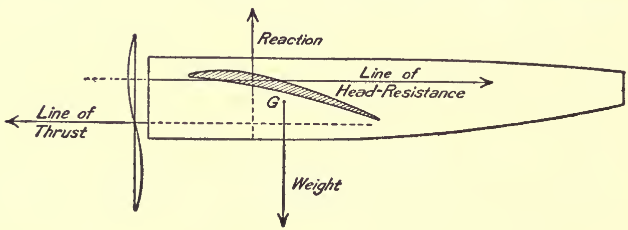


Diagram P.

wards, whereas the couple of the reaction and the weight tend to keep it up. Therefore, these couples could be made to counterbalance each other.

Diagram P represents another case where the line of head resistance is above the CG and the thrust below it, the reaction again acting in front of the CG. In this case, then, both couples tend to turn the nose upwards, and the machine could never be in equilibrium.

There are three kinds of equilibrium.

(1) Stable equilibrium.

A body in a state of stable equilibrium is in such a state that if disturbed by an outside force it will come back to its original state.

(2) Neutral equilibrium.

A body in a state of neutral equilibrium when, if disturbed, it will remain in that disturbed position.

(3) Unstable equilibrium.

A body is in unstable equilibrium when, if disturbed, it tends to go still further from its original state.

Therefore, it is desirable to keep an aeroplane in a state of stable equilibrium.

We have seen from the foregoing that an aeroplane having only one cambered surface cannot be stable. To make it stable we have to employ another surface at a distance from it. Part or the whole of this surface must be movable and in practice we know it nowadays as the tail plane and elevator.

Furthermore, it is essential that this tail plane should form a \/ or dihedral angle with the main planes.

A few words about tail planes. The tail plane must be considered as part of the whole aeroplane, and not as a separate entity.

Tail planes may be designed so as to carry a certain portion of the weight of the aeroplane. They may be designed so as to exert no pressure either way, and in some cases they are designed to exert a negative pressure in normal flight.

In practice it would appear that the middle course is found the most satisfactory, because then the tail plane has exactly the same effect whether the motor is running or not. In either of the other two cases the pressure on the tail plane is affected by the subtraction of the slip stream when the motor is shut off.

The functions of the tail plane as a stabiliser may be described as follows:

Suppose a disturbing influence tends to make the tail of the machine drop. As it drops, the angle of incidence on the tail plane increases; consequently the reaction on the tail plane increases and tends to lift the tail back to its normal position again.

On the other hand, if the nose of the machine drops, the tail plane gradually assumes a negative angle of incidence, and consequently top pressure tends to lower the tail into its normal position again.

Another point with regard to minimising the effect of disturbing influences is to keep the main weights concentrated, as far as practicable, around the centre of gravity.

So much for fore and aft stability.

The question of stability from a directional point of view is the next consideration.

An aeroplane is steered by means of a vertical rudder.

A practical aeroplane consists of a quantity of material, such as struts, wires, and in many cases an enclosed fuselage, which form a side area, or, as we may call it for convenience, fin area.

It is obvious that it is not possible to make a machine without a certain amount of fin area, but this fin area is of the utmost importance from the point of view of directional and lateral stability.

It would be found impossible to steer a machine with a rudder and no fixed fin area. Imagine such a machine (which is only a theoretical possibility) in the act of turning. As soon as the rudder is put over it presents a certain surface to the wind, thus causing the whole machine to turn about its centre of gravity, until the rudder again comes into the eye of the wind, but the machine will continue in the same flight path, flying partially sideways.

Therefore, to steer a machine it is essential to have a fixed side surface in addition to the rudder.

The above statement is only strictly true as far as gliding flight is concerned. If the engine were running it would turn owing to the effect of the thrust.

Now consider a machine turning which has a fixed side surface and a rudder. As soon as the rudder is put over it presents a surface to the air stream and a moment is created about the centre of gravity. Therefore, the machine tends to turn about its centre of gravity. Directly the machine starts to turn, the fixed surface presents a surface to the air stream. The pressure on this also creates a moment about the centre of gravity. As soon as these two moments about the centre of gravity are equal the machine ceases to turn about its CG.

When, however, the moment of these two forces about the CG are equal, the forces themselves must be unequal, since their distances from the CG are unequal.

The greater of the two forces will be that on the fixed fin area (as it is acting nearer to the CG) and the lesser on the rudder.

The resultant of these two forces will be approximately equal to their difference (it would be exactly so if they were parallel) and will act through the CG in a direction approximately parallel to the greater—that is, it will be centripetal (*i.e.* tending to pull inwards). Consequently the flight path becomes curved as the axis of the machine is drawn inwards by this resultant centripetal force.

The effect of this turn is to produce a centrifugal force which balances the centripetal force. The balance is, of course, only exact when the machine is correctly banked for the turn it is making.

A further reference to the question of fin area is necessary before the problems bearing on a turn can be satisfactorily mastered.

Now, the arrangement of the fin area is one of the most important of the many considerations in aeroplane design.

An aeroplane to be directionally stable must fly with its head direct to the relative wind stream. To bring about this condition, the moment of pressure on the fin area behind the CG must be greater than the moment of the pressure on the fin area in front of the CG. In other words, the centre of effect of the whole fin area must be behind the centre of gravity. It is just this condition that makes a good weather-cock always turn into the wind.

Considering our flying machine again, if the centre of effect of the fin area lay in front of the CG it would always tend to turn away from the relative wind stream; it would in fact spin, and this has actually happened in more than one case.

Well, the centre of effect of the fin area must be behind the CG. That is one important axiom with regard to fin area.

The next thing to consider is whether the centre of pressure or effect of the fin area should be above or below the CG. Usually speaking, it will be somewhere very near the CG, and in almost every case slightly above it.

If you consider an aeroplane, there are a host of parts which constitute fin area, and a lot of these parts, such as landing chassis struts and disc wheels, are much below the CG.

The most usual way to counteract this low fin area is by means of a dihedral angle between the planes. The planes thus turned up form a considerable side or fin area.

To consider once more the question of turning.

Everybody knows that when turning a corner on a bicycle it is necessary to lean inwards. This is because there is a centrifugal force trying to pull the machine outwards. Exactly similarly with the aeroplane. Unless the machine is sufficiently banked it will slip outwards. If it is too much banked it will fall inwards. The exact bank for any turn at any speed is easily found. It depends on the speed and the radius of the turn.

As soon as an aeroplane commences to turn, through the effect of forces already described, the outside wing is of necessity going faster than the inside one, therefore the lift on the outside wing is increased over that of the inside one. This is known from the fundamental formula, because the lift varies as the square of the velocity—that is, the machine tends to bank. Also, when a machine first starts to turn, until sufficiently banked it will slip outwards.

Now, the fact of the machine slipping outwards will create a pressure on the fin area. If the centre of pressure of the fin area is above the CG, the tendency of this pressure will be to bank the machine correctly for the turn. If the centre of pressure of the fin area is below the CG, the tendency of this pressure will be to bank the machine incorrectly for the turn, which is a tendency to instability. Similarly, if the machine is overbanked and side slips, the tendency of the high fin area is to correct it, whereas that of the low one is to make it worse.

Imagine next a machine under the influence of some lateral disturbing force, such as a gust.

A gust striking side area creates a pressure on it. If the centre of pressure of the fin area is above the CG, the gust will tip the machine up so that it tends to turn out of the gust, which is undesirable, while another gust coming quickly after will make it worse. On the other hand, a low fin area will tend to turn the machine into the gust and to minimise the disturbing influence.

It is, therefore, this consideration of outside disturbing influences which keeps the CP of the fin area somewhere near the CG and not too far above it. But, on the other hand, a gust, or most gusts, must be considered as taking the machine bodily with it, besides being considered just as a passing disturbing element. So from that point of view one would again be inclined to argue for the higher position of the CP of the fin area. Also a gust, as it passes along, hits the tail of the machine. This also has the effect of turning the machine into the gust.

CHAPTER V

INTERNAL COMBUSTION ENGINES

PRACTICAL flying really owes its birth to the development of the internal combustion engine. Gliders were experimented with for many years before the flying machine, as we know it to-day, took shape. However, power-driven aeroplanes could not then be made, as all engines existing at the time were far too heavy.

It is only intended to deal with the general principles of the petrol engine in this chapter, as excellent text-books are provided describing the various engines in detail.

An internal combustion engine in its simplest form consists of a cylinder which is bolted to some form of crank case. A piston works up and down in the cylinder, and is connected to a crank by means of a connecting rod. The latter has a bearing at each end. A pin, called the gudgeon pin, passes through this bearing at the piston end. The gudgeon pin is mounted rigidly in the piston. Similarly the crank pin passes through the other end of the connecting rod. As the piston moves up and down in the cylinder, a rotary motion is thus conveyed to the crank. The cylinder is fitted with two valves, one being the induction and the other the exhaust valve. A pipe is fitted over the induction valve, through which gas or oil vapour is drawn. The port of the exhaust valve merely leads into the open.

The commonest principle upon which such engines work is the Otto or four-cycle system, which I will now briefly describe.

Imagine the piston at the top of its stroke commencing to move downwards. As it moves downwards, gas or vapour is drawn into the cylinder through the induction pipe. When the piston gets to the bottom of its stroke, the induction valve closes. The cylinder is then full of gas. As the piston comes up it compresses this gas, there being no outlet. When it gets almost to the top of its stroke again, the gas is exploded (usually by an electric spark).

The explosion causes the gas to expand very rapidly, which forces the piston down again. When the piston is near the bottom, the exhaust valve is mechanically opened and the gases commence to rush out. During the whole of the upward stroke the piston forces the gases out of the cylinder. The cylinder is then devoid of gas and the same cycle of operations recurs. The first stroke is called the induction stroke, the second the compression, the third the working, and the fourth the exhaust.

Thus only one stroke in every four (or in two revolutions of the crank) does any work. The crankshaft must therefore be fitted with a sufficiently large flywheel to store up the necessary energy to carry it over the other three strokes in a smooth manner.

The construction of a petrol engine is briefly as follows:

The cylinder (or cylinders) are usually made of cast iron (sometimes steel). The inside, or bore of the cylinder is cast slightly smaller than the required dimension. This allows for it to be machined to size. As cast iron leaves a rough surface, the inside of a cylinder has to be bored smooth and true. The outside wall of the cylinder varies according to whether it is to be air or water cooled. In the former case the outside of the cylinder is cast in fins, which radiate off the heat. If a system of water cooling is to be adopted, the cylinder has to be cast with a jacket round it, in which the water can circulate. In neither case does the outside of the cylinder require machining. Cylinder walls have to be of sufficient thickness, both to ensure of their standing up against the internal pressure and of avoiding blow-holes (blow-holes are very common in iron castings). Cylinders have to be provided with valve seatings, which may either be accommodated in the cylinder head or in special valve pockets. In any case valve seatings have to be very carefully machined. Cylinders may either be cast in one or two pieces. In the latter event, the cylinder head is bolted on to the cylinder itself. The cylinder is attached (usually by bolts or studs) to a crank case. The latter will generally be cast aluminium.

In some aeronautical engines steel is used for both cylinders and crank case.

A crankshaft (usually a steel forging) revolves about bearings in the ends of the crank case.

Pistons are almost invariably made of cast iron. Connecting rods, which are usually steel forgings, are fitted with bearings (such as phosphor-bronze) at each end. The small end bearing works about the gudgeon pin and the big end about the crank pin. Many big ends are now fitted with ball-bearings in order to reduce friction, and thus obtain a maximum efficiency. Pistons are fitted with cast iron split rings (usually three or four) to prevent the gas leaking past into the crank case.

Induction valves may be either automatic or mechanical. In the former case a short stem valve, free to work up and down in its guide, is kept on its seating by a spring (comparatively light spring). As the piston goes down, the partial vacuum created overcomes the spring (if light enough) and the valve opens. The oil vapour from the carburettor then rushes into the cylinder head above the piston. As the piston comes up on the compression stroke the pressure forces the valve to shut. The pressure in the cylinder is sufficient to keep the valve closed until the induction stroke comes round again. Mechanically operated induction valves are fitted with stronger springs which would not allow of the valve being opened by suction. As their name suggests, they are dependent for their opening on a device worked by the engine. As already explained, the induction valve is only required to be open during one stroke of every four—that is, in two revolutions of the crankshaft.

The simplest form of mechanical valve is worked as follows. The valve works in a seating in a valve pocket and has a stem about 7 inches long. The valve pocket, which is part of the cylinder casting, projects over one side of the cylinder. The valve stem passes through a guide in the pocket and assumes an upright position parallel to the cylinder walls. The valve head is kept on its seating by means of a strong spring passed over this guide. The spring is kept in compression by means of a washer pin and passed through the stem. A push rod is mounted underneath the valve stem and is actuated by a cam. A cam is a circular steel disc (case hardened) with a lump on it and is mounted on a camshaft, which revolves at half the speed of the crankshaft. The lower end of the push rod, which is usually fitted with a roller (case-hardened steel), rests on the circumference of the cam. The push rod, of course, is mounted in a guide so that it can only travel up and down. As the lump on the cam comes round under the push rod the latter is forced up. The push rod in its turn forces the valve open. The fact of the cam revolving only half the speed of the crankshaft makes the valve open only once in two revolutions of the latter. As soon as the lump on the cam has passed from underneath the push rod the valve is forced shut again by its spring.

There are many modifications of this system in practice, some valves being overhead, in which case they are operated by tappet rods and rockers, or by rockers only from an overhead camshaft. The operation of exhaust valves is exactly similar to that of mechanical induction valves.

The exact setting of valves varies on different engines, but a rough guide is as under.

The induction valve should open very soon after the piston is past its top dead centre (about 6 degrees) and remain open during the whole of the suction stroke. As soon as the piston has passed the bottom dead centre and commenced to come up to compress the charge, the induction valve should close. In practice it will usually close about 6 degrees after the piston has passed bottom dead centre. Both valves remain closed during the compression stroke and during the commencement of the firing stroke. It is, however, advantageous for the exhaust valve to be timed to open well before the piston reaches the bottom dead centre (probably about 50 degrees). The expansion of gas during the firing stroke is so rapid that, providing the spark is sufficiently advanced, most of the useful work has been done on the piston by the time it has got half way down its stroke. An early opening of the exhaust valve then ensures an effective escape of the burnt gases and consequent absence of pressure against the piston on its return stroke. The exhaust valve should be timed to close when the piston reaches top dead centre again.

The spark must be timed so as to occur well before the piston reaches the top of its compression stroke. It must be borne in mind that the explosion of the charge is not instantaneous. By firing the charge before the piston reaches the top of its stroke the full force of the explosion is felt by the time the piston begins to go down again. If the spark were timed to occur at the moment the piston was at the top, the full force of the explosion would not be felt until the piston was well on its way down, and a great deal of efficiency would be lost. When fully advanced, the spark should occur about

25 degrees before the piston reaches top dead centre.

The next consideration is the requisite supply of petrol vapour to the engine. Petrol is vapourised in a carburettor, which in its simplest form consists of two parts: (1) float chamber, (2) jet or vapourising chamber.

Petrol flows from the tank into the bottom of the float chamber either by gravity or by pressure. The supply is regulated by means of a float. As the latter rises with the incoming petrol, it forces a needle valve down, which checks the flow. As the petrol is drawn through the jet from the float chamber, the float falls, thus releasing the needle valve. A small pipe leads from the bottom of the float chamber, making a free passage for the petrol up the centre of the jet. The top of the jet should be the same level as the petrol in the float chamber when the latter is full. As explained, the jet is situated in the vapourising chamber, to the top of which the induction pipe is attached. Holes are fitted in the jet chamber below the jet through which air is drawn. Extra air holes or an air valve (or both) may be fitted on the induction pipe above the jet.

As the piston comes down on the induction stroke, a partial vacuum is created in the induction pipe. This causes petrol to be drawn through the jet from the float chamber. The orifice in the jet being very small (it varies according to the size of the engine), the petrol when drawn through squirts out in very fine columns. Air is at the same time drawn through the holes in the bottom of the jet chamber. The petrol, being very volatile, evaporates and forms an explosive mixture with the air. The correct proportion of petrol vapour to air by volumes is about 1 to 16.

Diagram Q is a rough sketch of a simple carburettor. It does not represent any particular design. It is a section taken through the centre of the carburettor.

It must be remembered that the working parts of an engine are revolving (or moving) at very high speeds, consequently the friction between such parts is great, which necessitates a very efficient system of lubrication.

Bearings are lubricated by a thin film of oil being formed between the bearing and the moving surface. It is essential that all bear-

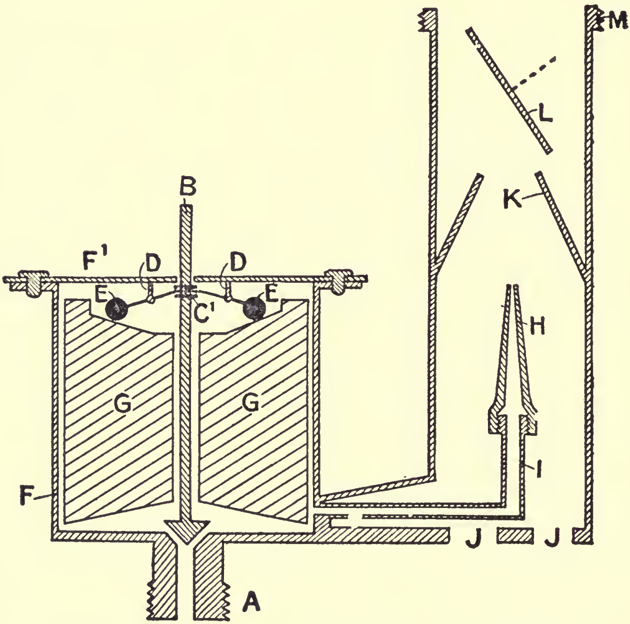


Diagram Q.

A, Screw thread to take petrol pipe union; B, Needle valve; C, Collar actuated by balance weights; D, Fulcrum; E, Balance weights; F, Float chamber; F¹, Top of Float chamber; G, Float; H, Jet screwed on to (I) pipe leading from Float chamber; J, Air hole; K, Choke tube; L, Throttle actuated by outside lever; M, Screw thread to take induction pipe union.

ings should be truly aligned and worked to a smooth surface for lubrication to be effective. The film of oil is formed by the relative motion of the two surfaces, and the higher the relative velocity and the more viscous the oil, the more stable will the film become.

At low speeds, especially under heavy loads, the oil film is liable to be squashed from between the bearing surfaces, and the lubrication will then entirely depend on the greasiness of the oily surfaces; for this reason slow moving toothed wheels are better lubricated by a thick grease than any sort of oil.

At high speeds the film of oil will form between the moving surfaces even if the oil is fairly thin, and, as far as friction and consequent heating are concerned, the thinner the oil the better.

Animal and vegetable oils are more greasy than mineral oils, but, on the other hand, they soon become acid and gummy and carbonise very quickly when in contact with hot cylinder walls; therefore mineral oils are almost invariably used for lubricating internal combustion engines. Rotary aero engines form an exception, as castor oil is always used. In most cases it should, however, be borne in mind that fresh oil is always being employed, the oil being pumped right out of the engine through the exhaust valves, whereas stationary engines, which use mineral oil, have a very much lower oil consumption, the same oil, after being pumped through the bearings, etc., being filtered in the crank case and used again and again.

In practically every aeroplane engine the oil is forced through to the bearings, etc., by means of a force pump. In many cases, however, the centrifugal force created by the crank (or connecting rods in the case of rotary engines) is utilised to distribute the oil to cylinder walls, small end bearings, etc.

From the foregoing it should be realized that four essential conditions have to be fulfilled in order that a petrol motor may start and keep running. They are:

(1) An explosive mixture of the correct strength has to be drawn into the cylinder.

(2) This mixture must be sufficiently compressed to ensure efficient explosion.

(3) Some method of igniting the charge at the right time must be provided.

(4) All working parts must be properly lubricated.

The peculiarities and more common troubles associated with the above axioms may be set out as follows:

(1) This depends on:

(*a*) The petrol supply to the carburettor working properly. A kinked, leaky, or dirty petrol pipe will interrupt the even flow of the petrol.

(*b*) The correct carburettor and jet for the engine must be used. All parts of the carburettor must be thoroughly clean and free from grit and dirt.

(*c*) The induction valve must be working properly (and correctly timed in the case of mechanically operated valves).

(*d*) In the case of a multi-cylinder engine a suitable arrangement of induction pipes is most necessary. In the case of a four-cylinder engine, for example, it is inadvisable to have the carburettor at one end feeding all four cylinders from a single pipe. In that event the cylinders nearest to the carburettor are inclined to starve the others. It would be better in such a case to have the carburettor between the two centre cylinders with the induction pipes leading from it (one for each pair of cylinders).

(2) Sufficient compression can only be ensured by guarding against the leakage of gas either past the pistons or through the valves.

As already mentioned, piston rings are fitted to prevent leakage past the piston. Piston rings, which are of cast iron, are turned just a shade larger diameter than that of the cylinder. A section is then cut out to enable the ring to be inserted in the cylinder. Each ring fits in a groove in the piston, and its natural spring tends to keep it pressed out against the cylinder wall. Each ring is fitted so as to leave a small clearance, thus allowing for the expansion of the ring under heat. When fitting the rings to a piston, the cuts in the former must not be superimposed, because the clearance allows of a slight leakage.

Valves constantly cause a loss of compression owing to the high temperatures to which they are exposed, either the valve head or its seating becoming pitted through dirt (little pieces of carbon) getting between them.

To keep a good seating, valves have to be constantly reground. It is not uncommon for valves to stick open. To avoid this trouble valve stems must be kept clean and free from any gumminess. Valve springs must also be carefully watched, as in time they either break or lose their strength.

In the case of all mechanical valves (either induction or exhaust) it is essential that there should be a small clearance between the valve stem and push rod (or rocking bar) when the valve is shut and the engine cold. If no such clearance is fitted, both the push rod and valve stem expanding under heat will prevent the valve from shutting properly. A great loss of compression would ensue thereform.

(3) It has already been briefly explained why the ignition has to be timed so that the spark may occur before the piston gets to top dead centre. Some of the chief points to look to with regard to ignition are:

(*a*) See that the platinum points on the make and break are properly adjusted and that they are not burnt. If burnt at all, the surfaces would be rough.

Platinum points can be trued up with a very fine file so as to ensure good smooth surfaces of contact.

(*b*) The distributor of an aeroplane engine will require constantly cleaning with petrol, as in almost every engine considerable quantities of oil are thrown out on to it. Oil on the distributor prevents the brush making good contact.

(*c*) Sparking plugs are a considerable source of trouble. They require constant cleaning and not infrequently renewing. Oil between the points becomes burnt and makes a direct path for the current, and consequently no spark is produced. Porcelains are occasionally fractured by vibration, in which case a new plug must be substituted for the broken one.

(*d*) Care must be taken to see that there is no short circuit in the wiring. A wire passing very near an exhaust pipe will very likely short-circuit owing to the insulation being burnt off.

(4) Lubrication troubles are usually caused by:

(*a*) Lack of oil. Great care must be taken to see that all machines are filled with sufficient oil to outlast the petrol.

Some engines (such as the Gnome) are fitted with an external oil tank and pump. In such cases the oil pipes must receive constant attention. The vibration constantly causes oil pipes to fracture. Particular care must be taken to see that the tap is always turned open. It is a very good plan to keep oil taps permanently fixed in the open position.

In engines (such as the Renault) where the oil is poured straight into the sump, attention must be given to the regular draining of the latter.

(*b*) The quality of oil as recommended for the particular engine must only be used.

(*c*) The cold weather causes oil to become very thick. In winter castor oil may be mixed with a little methylated spirits to thin it out (about one part of methylated spirits to eight of castor oil by volume). Similarly the thick air-cooled mineral oils may be mixed with a small quantity of a thinner quality.

Before proceeding further it may be as well to explain two terms which are frequently confused—namely, backfiring and pre-ignition.

Backfiring occurs when the charge explodes on entering the cylinder through the open induction valve and back into the carburettor, which is then liable to catch fire.

The causes of backfiring are:

(*a*) Through the mixture being too weak. The immediate cause of this is probably due to the very slow explosion of the previous charge keeping the piston head at a high temperature, thus setting the new charge alight immediately it enters the cylinder head.

(*b*) Carbon deposits being formed on the piston head and cylinder walls becoming heated to incandescence, thus igniting the incoming charge immediately on contact.

(*c*) A leaky exhaust valve will allow the hot exhaust gases to be sucked back from the exhaust pipe and so explode the incoming charge.

(*d*) An inlet valve, which becomes broken or hung up, will, of course, allow the charge on being exploded in the cylinder head to blow back into the carburettor.

Backfiring is very dangerous, as, once the carburettor has caught alight, the fire will spread very rapidly, especially in an aeroplane where it is fanned by a constant flow of air.

Wire gauze is now usually fitted to induction pipes. This has the effect of preventing a blow back (backfire) reaching the carburettor.

Preignition occurs when the charge is fired too early on the compression stroke, thereby tending to make the engine run backwards. This may be caused by:

(*a*) The spark being too far advanced, thus causing the expansion of the gas to be too rapid in comparison with the position of the piston. Great care should be taken when starting an engine by hand to have the spark retarded, as the rapid backward motion caused by preignition is sufficient to break a wrist (or worse).

(*b*) Overheating, which may be caused by a defective water circulation, by insufficient lubrication, or by the spark being too far retarded. If the spark is too far retarded, the full force of the explosion is not felt until the piston is well on its way down its stroke. Thus a large area of the cylinder wall becomes exposed to the maximum heat of explosion.

Carbon deposits on the piston head and cylinder walls (caused by too rich a mixture) also cause overheating (as explained above).

A few notes on indicator diagrams may be of assistance in mastering the principles of the internal combustion engine.

An indicator diagram is a graph showing the pressure in the cylinder at all points in the stroke of the piston during the whole cycle of operations (that is four strokes). The pressures are actually taken in practice by means of an indicator.

Diagram R represents a typical curve during the four strokes of one piston of an engine. The ordinate erected at A represents the top of the stroke, and that at B the bottom.

Consider first the induction stroke, which is represented by $a_1 b_1$. Now the charge enters the cylinder, where the pressure is slightly below atmosperhic (owing to the partial vacuum created by the descending piston), with a rush and does work on the piston.

Now the work done (either on or against the piston) during any stroke is represented on the graph by the area bounded by (1) the pressure curve for that stroke, (2) the ordinate through A, (3) the ordinate through B, (4) the base line of no pressure—that is, the work done on the piston during the induction stroke is represented by the area $a_1 b_1$, B A.

As soon as the piston turns to come up on compression the pressure rises very quickly.

The portion of the curve b_1 a_2 represents the pressures throughout the compression stroke. The work done against the piston is therefore represented by the figure A a_2 b_1 B.

In this diagram it is assumed that the spark takes place when the piston is just at the top of the stroke. The diagram shows clearly that the spark is then too far retarded, as the maximum pressure does not occur until the piston is well on its way down.

The firing stroke is then represented by the portion of the curve a_2 b_2. As the piston gets towards the bottom of its stroke the pressure falls rapidly. This is accentuated by an early opening of the exhaust valve. The useful work done on the piston during the firing stroke then is represented by the figure A a_2 b_2 B.

During the exhaust stroke the pressure in the cylinder will be working against the piston. If the exhaust valve is properly timed and is sufficiently large, this pressure should only be very slight until when the piston reaches the top it becomes equal to zero. The work done against the piston during this stroke is then represented by the figure A a^1 b^2 B.

The total useful work done during the four strokes can then be found by subtracting the work done against the piston from the work done on the piston.

Considering the diagram again. The portions of the curve representing the exhaust stroke and the induction stroke are very near together. The difference between the areas A a^1 b^2 B and A a^1 b^1 B (that is, the small area enclosed by the curves) gives the net work done against the piston during these two strokes. As can be seen from the diagram, this area is very small.

In a similar way it is clear that the figure bounded by the curves of the compression and firing strokes gives the net useful work done on the piston during these two strokes. Therefore, it is clear that the net useful work done on the piston during the whole four strokes is equal to the area bounded by the compression-firing stroke curves minus the area bounded by the exhaust-induction stroke curves. The latter being almost negligible, the total useful work done on the piston may be assumed to be represented by the figure between the compression-firing stroke curves.

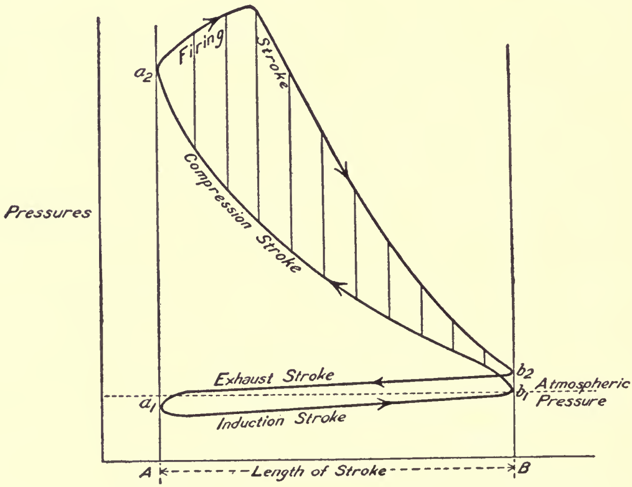


DIAGRAM R.

(This Diagram is not to Scale)

If a number of ordinates (not less than about 10) are erected between these two portions of the curve, the mean of them may be taken as the mean pressure in the cylinder during the four strokes (that is, in one complete cycle of operations) and is expressed in lbs. per square inch (if using British units).

A formula giving indicated horse-power may now be deduced from the above diagram.

Assuming that the engine in question has only one cylinder, and that the area of the piston is A square inches. The mean pressure per unit area already found from the diagram will be called P lbs. per square inch. The total pressure on the piston then $= P \times A$ lbs. per cycle.

If L be the length of the piston's stroke in feet, the work done per cycle = PAL foot-lbs.

If N be the number of revolutions per minute, there will be $\frac{N}{2}$ explosions per minute. Then the work done per minute (that is, the power) will be:

$$\frac{PLAN}{2} \text{ foot-lbs. per minute.}$$

Since 1 horse-power = 33,000 foot-lbs. per minute, then the indicated horse-power

$$= \frac{PLAN}{2 \times 33{,}000} = \frac{PLAN}{66{,}000}.$$

Now, the petrol engine is simply a heat engine. The source of the heat supplied is the fuel, each pound of which gives out a certain definite amount of heat when burnt.

This heat is dissipated in four ways:

(1) Part does useful work on the piston;
(2) Part escapes with the exhaust gases at the end of the stroke;
(3) Part goes into the cooling system;
(4) Part, but only a very small part, is lost by radiation, and may be neglected.

Considering the loss under heading (2). The only way to lessen this loss is by reducing the temperature of the gases before they leave the cylinders.

Now, at the end of the explosion there is always a certain definite amount of heat present in the burnt gases. During expansion these gases do work, and lose an amount of heat corresponding to the amount of work done by them on the pistons. Hence by making them do the maximum amount of work on the piston, these gases will be reduced to a minimum temperature. To make them do work they must be expanded; and to get the maximum amount of work out of them, they must be expanded as much as possible. The travel of the piston is the same on the compression as on the working stroke, and so the maximum ratio of expansion is practically the same as the ratio of compression. If the latter be made too great, however, the heat generated in the unexploded mixture during compression will be so great that it will cause preignition, and loss of power will ensue. Therefore, the degree of compression and hence the ratio of expansion of the gases is limited.

To obtain the maximum benefit of the ratio of expansion the gases should be just, and only just, completely burnt at the instant the piston starts on its working stroke. As already explained, the spark must be advanced so as to occur while the piston is still going up on the compression stroke. When the engine is running fast the spark requires to be more advanced than when running slow, because the speed of the piston is greater in the former case while the time occupied by combustion remains approximately the same.

Considering the losses under heading (3), the amount of heat passing out to the cooling system will depend on:

(*a*) The temperature of the burnt gases;
(*b*) The area of cylinder walls exposed to these gases;
(*c*) The time these gases are in contact with these walls.

(*a*) The temperature of the gases cannot be lowered without impairing the efficiency of the engine, as explained above.

(*b*) The loss of heat can be reduced to a minimum by arranging that the explosion is just completed when the area of cylinder walls exposed is a minimum—that is, when the piston is at the top of its stroke. This is also the condition, already explained, to obtain the maximum ratio of expansion.

(*c*) The time the gases are in contact with the cylinder walls is dependent on the rate of explosion. To reduce the time taken to complete combustion the mixture must be of the correct strength and undiluted with burnt gases remaining over from the previous cycle. To prevent burnt gases remaining in the cylinder, the exhaust valve must be

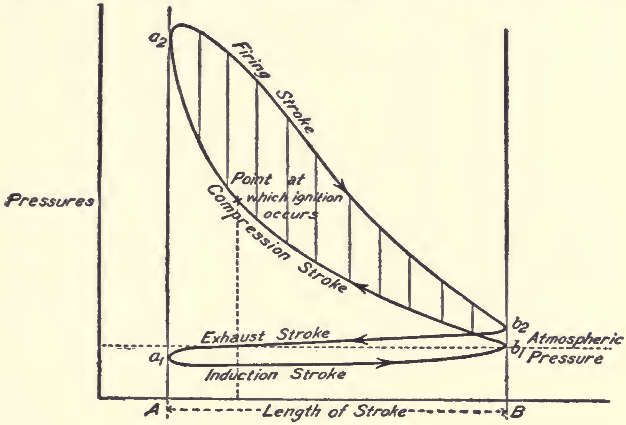


DIAGRAM S.

(This Diagram is not to Scale.)

sufficiently large, must have sufficient lift, and must be correctly timed.

Diagram S is an indicator diagram, similar to diagram R, except that the spark is correctly advanced, so that the explosion is complete by the time the piston gets to the top of the compression stroke. The diagram should be self-explanatory, the extra amount of work done on the piston being apparent from the figures.

When working on petrol engines it must be borne in mind that all the parts are very light and delicate (this particularly applies to aeroplane engines, where every ounce of weight has to be saved). Particular care must be taken in handling all parts and the correct kind of tools must be invariably used. Most engines are supplied with special tools, and these must always be used. Cleanliness and absence of dust and grit are essential when doing any work on an engine.

CHAPTER VI

IGNITION DEVICES

It would appear fitting to commence this chapter with a few notes on electro-magnetic induction. Consider an electric current passing through any conductor (*e.g.* a piece of wire); as soon as the current commences to flow, a magnetic field is created about that conductor from which the lines of force move out radially. Assuming one conductor to be a coil of insulated wire forming part of a closed circuit. Now wind another length of insulated wire around the original conductor. As soon as the current is switched on to pass through the latter, the lines of force thus created in radiating outwards cut the former and set up a momentary DP (difference of potential) in it, which is easily detected by means of a galvanometer. The current thus created is called an induced current, and only lasts for the instant that the lines of force from the original conductor actually cut it. In future, reference will be made to the original conductor as the primary circuit or winding and to the outside coil as the secondary. As soon as the current is switched off in the primary circuit, the magnetic field is discharged and the lines of force radiate inwards and so again cut the secondary winding in which a DP is again created. In this case, however, the direction of the induced current will be opposite to that created by switching on the current in the primary circuit.

The foregoing then briefly explains the origin of an induced current.

The voltage produced in the secondary circuit is dependent on the rate at which it is cut by the lines of force—that is, the number of lines of force divided by the time they take to cut it. If this rate is sufficiently high, a very high voltage can be produced in the secondary circuit. To bring about such a result the following arrangements are adopted:

(1) The primary circuit is wound in the

form of a hollow cylinder, the length of conductor emitting lines of force being thereby increased.

(2) An iron core is placed inside this hollow cylinder, thereby becoming magnetised as soon as the current is switched on in the primary circuit, and thus creating a field of force of its own.

(3) The secondary is made of great length (being wound around the primary many thousands of times) and of very high resistance.

(4) The magnetic field created by the current passing through the primary winding is rapidly destroyed and remade. This is done by closing and reopening the primary circuit.

It must be borne in mind that the current induced in the secondary circuit will produce a detrimental effect on that flowing through the primary. It does, in fact, tend to stop the primary voltage rising instantaneously to its full pressure when the current is switched on. This check to the instantaneous rise in voltage on the primary winding reacts again on the secondary.

Similarly, when the current in the primary circuit is switched off, that set up in the secondary will still tend to keep it moving on in the same direction.

To overcome this effect of reinduction from the secondary back to the primary circuit, a condenser is fitted to the latter. A condenser is formed of a number of sheets of tin foil insulated from each other by oiled paper, and has the effect of rapidly reversing the current in its circuit (primary).

The simplest form of electric ignition is worked by an accumulator and trembler coil. Diagram T is a diagrammatic representation of this form for a single cylinder engine, and should be studied in conjunction with the following explanation.

One terminal of the accumulator (it does not make the slightest difference whether this is the positive or negative terminal) is led to earth (the bedplate of the engine for convenience). The other terminal is led to the adjustable screw on the trembler. The trembler blade when in its normal position is so adjusted as to make contact with the adjustable screw. Both the point of the screw

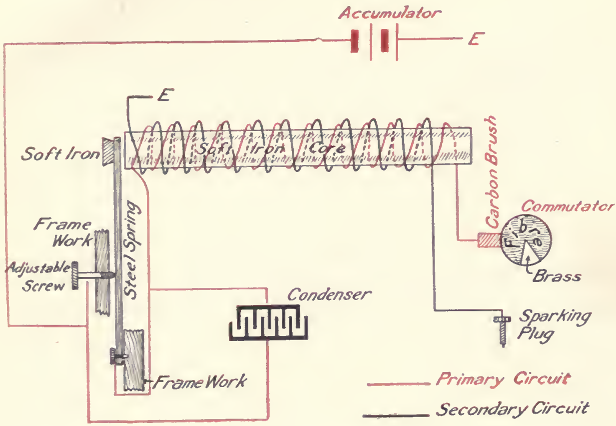


DIAGRAM T.—IGNITING ARRANGEMENT FOR SINGLE-CYLINDER ENGINE (ACCUMULATOR AND TREMBLER COIL).

and the point of contact of the blade should be platinum (other metals are burnt away by the spark produced on contact being broken).

The trembler blade is connected at one end of the primary winding of the induction coil (otherwise the blade is insulated). This blade is made of spring steel, and is kept in position at only one end by a single screw. The other end, to which a piece of soft iron is fixed, covers the core of the induction coil. In its normal position the end of the trembler blade does not touch the core of the coil, but is about $\frac{1}{16}$ inch from it. The core consists of a bundle of soft iron wires around which the primary coil is wound. The latter consists of about twenty feet of thick insulated wire, the other end of which is connected to the brush of a wipe contact. This brush (carbon) bears on the perimeter of a fibre (or any non-conducting) disc which is revolving at half the speed of the crankshaft (it is usually mounted on the camshaft). This disc has let into it a brass (or any good conducting metal) segment, which is earthed through the spindle of the shaft. The disc has to be so timed that the segment and brush are in contact when it is required to fire the charge in the cylinder. The secondary winding is made up of about one and a half miles of wire of very thin diameter coiled round over the primary. One end of the secondary winding is earthed, the other being led to the central electrode of the sparking plug. As soon as the brush comes into contact with the metal segment of the wipe contact the primary circuit becomes closed.

There are two instantaneous effects of this closing of the primary circuit.

(*a*) An induced current is set up in the secondary winding.

(*b*) The soft iron core becomes magnetised. The effect of this is to draw the trembler blade down on to the core. As soon as this happens the adjustable screw ceases to touch the blade, and the circuit is therefore broken —that is, the primary circuit is no longer closed and the core of the coil becomes demagnetised, thus releasing the trembler blade which springs back into its normal position and again makes contact with the adjustable screw.

This making and breaking of the primary circuit is instantaneous, and occurs during the whole time the brush on the commutator is in contact with the metal segment.

Every time the primary circuit is thus made and broken an induced current of very high voltage is created in the secondary winding. As already explained, one end of the secondary winding is earthed, while the other is led to the central electrode of the sparking plug and so insulated. The only path available for the secondary current is across the points of the sparking plug, which distance is jumped and a spark created thereby.

The necessity for a condenser to ensure the rapid reversal of the primary current on contact being broken has already been alluded to. The condenser is connected in parallel with the make and break (that is, the trembler blade and screw), and performs the function of Leyden jar or storage battery.

The condenser accommodates the current so rapidly that it becomes overcharged and discharges its current again, causing a flow in the opposite direction.

The same principle is of course applicable to a multi-cylinder engine. For example, take a four-cylinder engine.

There are two ways of doing it:

(*a*) By using four separate induction coils;
(*b*) By using only one coil and a distributor.

(*a*) The general principle is identical to the above. As four coils are being employed there would, of course, have to be four brushes on the commutator (or else four earth segments on the disc and one brush). One end of the secondary winding on each coil would lead to its respective sparking plug, the other being earthed as before.

(*b*) This case is represented in diagram U.

The commutator has four earthed segments, and is timed so that one segment is in contact with the brush when each cylinder should be firing. The primary circuit is identical to that illustrated in diagram T.

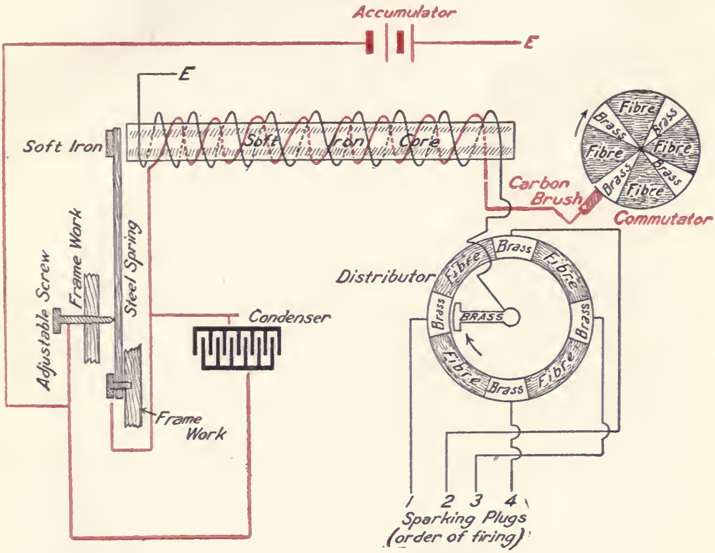


Diagram U.—Ignition Arrangements for Four-Cylinder Engine, Accumulator, and One Trembler Coil.

One end of the secondary circuit is earthed, the other being led to the revolving arm of the distributor. In practice both the distributor and commutator would be mounted on one shaft (usually the camshaft—anyway, it must be a half-time shaft), although this cannot be represented diagrammatically. The revolving part of the distributor is insulated, and, as it goes round, it rubs against the inside of a fibre (or vulcanite) ring. Four metal strips are let into this ring, from which four high tension wires lead to the sparking plug. As the revolving parts of the distributor touch the metal strip, the secondary circuit becomes closed so that its current can pass from the coil to the sparking plug. The distributor must, of course, be accurately timed.

In all the above cases a considerable variation can be given to the time at which the spark occurs by moving the position of the brush on the commutator. Arrangements are usually made for this to be done from the driver's or pilot's seat. In the last case it can also be done by giving a slight movement to the nonrevolving part of the distributor.

In all the above cases an ordinary switch can be fitted to the primary circuit. When the switch is off (*i.e.* open) there is no path for the primary circuit; consequently there can be no induced current in the secondary.

In practice, of course, magnetos are almost exclusively used so as to avoid carrying accumulators or dry cells, which always run down after a certain amount of use.

The magneto works on the same principles as the above, except that the primary current is generated by a dynamo; the make and break being mechanical.

The principle of the magneto is briefly as under:

A powerful steel horse-shoe magneto is fitted with soft iron pole-shoes. (Diagram V shows this in elevation.) An armature, mounted on a steel spindle, and composed of a laminated shuttle-core of soft iron, about which the primary wiring is wound, revolves inside the pole-shoes.

As before, the primary winding consists of about twenty feet of thick (low-resistance) insulated wire, one end of which is anchored to the armature and so earthed, whilst the

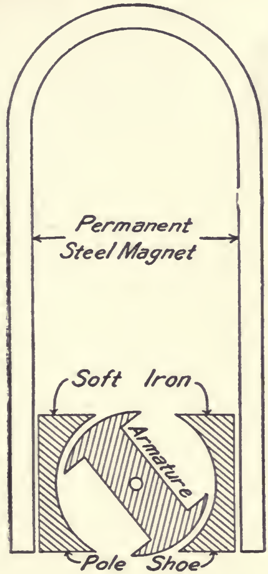


Diagram V.—Section Showing Permanent Magnet, Armature and Pole-Shoes.

other is connected to the fixed end of the contact breaker, through a long fastening screw, which is insulated from the armature.

The contact breaker is mounted on a disc of non-conducting material (usually fibre), which is mounted on and revolves with the spindle. A brass lug is mounted on this insulated disc and kept in place by the fastening screw, which passes through the centre of each. A platinum-tipped screw passing through this lug forms the fixed part of the contact breaker, the moving portion of which is provided by a bell crank lever also mounted on the fibre disc. One end of this lever has a platinum-tipped screw passing through it, while the other is fitted with a small roller. This bell crank lever is pivoted about its elbow, as shown in diagram W, and is kept in position by a light spring, so that its platinum-tipped screw is in contact with that on the fixed portion of the make and break.

The pivoting point is earthed by means of a flat spring, which also serves to keep the whole lever in place. One end of this spring presses down on the pivoting point; the other is connected to a carbon brush, which is let into the inside face of insulated disc, and

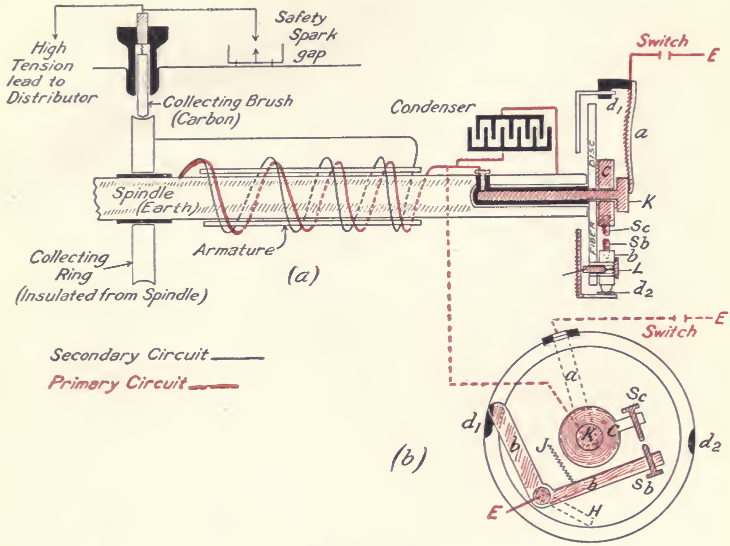


DIAGRAM W.

a = steel spring: bears on fastening screw K; makes earth when switch is closed. b = bell crank lever of make and break. c = fixed part of make and break. d_1 and d_2 = projections on fixed part of machine. H = spring keeping bell crank lever down. K = fastening screw. J = small spiral spring keeping bell crank lever in such position that the points of make and break (Sc and Sc) are touching (except when displaced by the projections d_1 and d_2). L = screw at fulcrum of bell crank lever. x = carbon brush earthing bell crank lever.

presses against the framework of the magneto throughout its circular track.

When the magneto is being turned, the roller on one end of the bell crank lever (described above) travels in a circular path. Two projections are fitted in this path. As the end of the bell crank lever hits these projections, the lever is bound to turn around its own pivot, thus forcing the two portions of the contact breaker apart. As soon as the projection is passed, the spring on the lever pulls the latter back into its normal position, thus remaking contact. (This explanation should be read in conjunction with diagram W.)

A condenser, mounted on the spindle, is wired in parallel with the contact breaker (exactly as with the accumulator and coil ignition).

The secondary winding, as in the case of the ordinary induction coil, consists of about one and a half miles of wire of very small diameter wound over the primary. One end of this is earthed (in practice it is anchored to the spindle with the earthed end of the primary winding), the other end being connected to a slip ring, which is mounted on, but insulated from, the spindle.

A carbon brush bearing on the slip ring (or collecting ring) conveys the secondary current to the distributor, whence it is led to the sparking plugs as described above.

The lead from the carbon brush to the distributor is in parallel with a safety spark gap. The safety spark gap is similar to a sparking plug, but with an appreciably larger gap. The gap must be sufficiently large to ensure that the resistance offered to jumping the spark gap (which is only under atmospheric pressure) is greater than that offered by jumping the gap of the sparking plug (which is under high pressure). The spark gap will not therefore normally come unto use. Should the high tension leads come undone or be broken (or sparking plug break, etc.), the high tension current would then have a path to earth across the safety gap.

If this outlet to earth were not available, the current, being of so high a voltage. would probably burn out the insulation.

To sum up, then, the action is as follows:

A spindle carrying soft iron armature, primary winding and secondary winding revolves in a magnetic field. As the lines of force are broken, a low tension current is set up in the primary winding. This current is instantaneously broken by the mechanical make and break.

The making and breaking of this primary circuit, intensified by the action of the condenser, induces a very high voltage current in the secondary circuit.

The secondary circuit is led off from the collecting ring through a carbon brush to the distributor, thence across the plugs to earth.

The moment when the highest current is set up in the primary circuit is that at which the armature just breaks the lines of force of the permanent magnetic field (position shown in diagram X). Such a position then occurs twice in one revolution of the armature.

The actual break of the primary circuit must then be timed to occur when the armature is in such a position.

Now a single-cylinder engine only requires one spark in every two revolutions of the crankshaft—that is to say, the magneto could be mounted on the camshaft, provided there was only one break per revolution of the armature (in the foregoing description of a

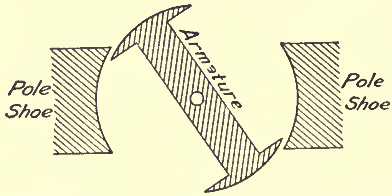


DIAGRAM X.

make and break it was assumed to break twice per armature revolution; it can just as easily be made to break only once per revolution). The break would have to be correctly timed so as to occur about 25° before top dead centre of the crank. The high tension lead could then be led direct from the brush of the collecting ring to the sparking plug without passing through a distributor.

In the case of a two-cylinder engine the magneto (with two breaks per revolution of the armature as originally described) should be mounted on the camshaft. Two sparks are then obtained per one revolution of the camshaft. That is equivalent to one per revolution of the crankshaft, which is what is required for a two-cylinder engine. In this case the high tension circuit would have to be led through a distributor to each plug.

In the case of a four-cylinder engine the armature would have to be revolving at the same speed as the crankshaft.

In a seven-cylinder engine (*e.g.* Gnome) it would have to be geared as 7 to 4 with reference to the crankshaft and so on.

In each case, of course, the distributor must be timed correctly in conjunction with the make and break.

Owing to the fact that the whole of the primary winding is revolving, it cannot be provided with a switch (as in the case of accumulator ignition). Therefore, another means of switching off has to be devised.

As already explained, the high voltage current induced in the secondary winding is dependent on the make and break of the primary circuit. If, therefore, the make and break is cut out, no high voltage current will be set up in the secondary circuit.

This is done by providing a direct path to earth for the primary current, so that when the make and break opens, the circuit is not really broken.

In practice a flat steel spring bears on the top of the fastening screw (see diagram W). The other end of the spring is fixed to, but insulated from, the fixed part of the magneto. A lead from this spring is then connected to one terminal of a tumbler switch, the other terminal of which is connected to earth.

When the switch is open, the current has no path to earth, and the make and break is therefore not short-circuited. Consequently, a secondary current is produced and led to the plugs. That is the position known as "Contact."

On the other hand, when the switch is closed, the make and break is short-circuited and no secondary current is produced. That is the position known as "Switch off."

As these positions of the switch are contrary to the ordinary acceptance of the terms "switch off" and "contact," great care must be taken to see that switches are marked correctly.

One cannot emphasise this point too strongly, especially where inexperienced mechanics are concerned. A switch incorrectly marked may have fatal results where propeller swinging is involved.