PREFACE

Thousands of mechanics of various kinds are going to be needed to inspect, adjust and repair the large air fleet which is now being prepared in this country and as this is a new industry it has been deemed advisable to compile such facts regarding aircraft as may help to make these available in the shortest time. Except for a considerable amount of actual personal observation in both factory and flying field, no originality is claimed for this handbook; instead, it represents what is believed to be the best practice known at this time and contains many suggestions which cannot fail to be of value to any aircraft mechanic.

It is in the hope of aiding work of this kind, in helping to make our aircraft more efficient, that the work has been undertaken.

NEW YORK,
March, 1918.

THE AUTHOR.

INTRODUCTION

The first requirement of an airplane mechanic is reliability—there must be no guesswork about anything that goes to make up an airplane—everything should be right before a machine goes into the air. No good pilot starts a flight until he has tested his motor up to speed and knows that it will give him the necessary power. But the details of the plane, the wire rope and its connections, the eyes, the splicing or other fastenings, the pulleys over which the ropes run, the condition of the rudder and wing hinges and connections, must be taken care of by the mechanics. The failure to know that everything is right may not only mean the life of the pilot but, in military matters, the loss of valuable information and the death of hundreds of troops.

There are usually two mechanics assigned to each machine, one for the engine and propellor, or power plant, the other for the plane and all its connections. The English call the first the fitter and the latter the rigger; we substitute machinist for fitter and retain rigger or plane man for the other.

The machinist or fitter should thoroughly understand internal combustion motor construction and repair, and of as many types of motor as possible. Each has its peculiarities and should be studied so as to best know how to handle it. This is particularly true of the rotary type such as the Gnome and Rhone. We have comparatively few of these in this country but their peculiarities should be known, as well as how to take them down for examination and repair and to reassemble them, for this is quite an intricate task on some of the motors of this type. The parts must go together in a certain sequence or they will not go at all, as in a Japanese puzzle.

CONTENTS

THE AIRCRAFT MECHANICS HANDBOOK

SECTION I

THE GENERAL CONSTRUCTION

Although the modern airplane framework is apparently a simple arrangement of wood and wire, it will be found to contain many lessons in mechanical structures and is well worth considerable study. The combination of wooden spars and struts, secured against movement by suitable fittings and held in their proper positions by steel cables, forms an interesting engineering structure and one which the airplane rigger or mechanic must be familiar with if he is to do good work. The general construction is shown in Fig. 1 with the principal parts named.

The struts, as in all built-up structures, serve to hold the framework apart and in the proper position. They are always in compression and must be held firmly but not so tight as to spring the struts out of line as they can resist very little after they are bent, but continue to bend and break under a comparatively light load. Wood is very strong in direct compression but its resistance to bending is not great, particularly in the wood generally used for struts, which is spruce.

This should be straight-grained and free from defects of all kinds as the work of the strut is very important. Some of the rules of inspection call for spruce which has at least six rings, marking the yearly growth, to the inch. A few insist on eight rings to the inch, but this is almost impossible to secure. The distance between the rings shows the growth of the tree during

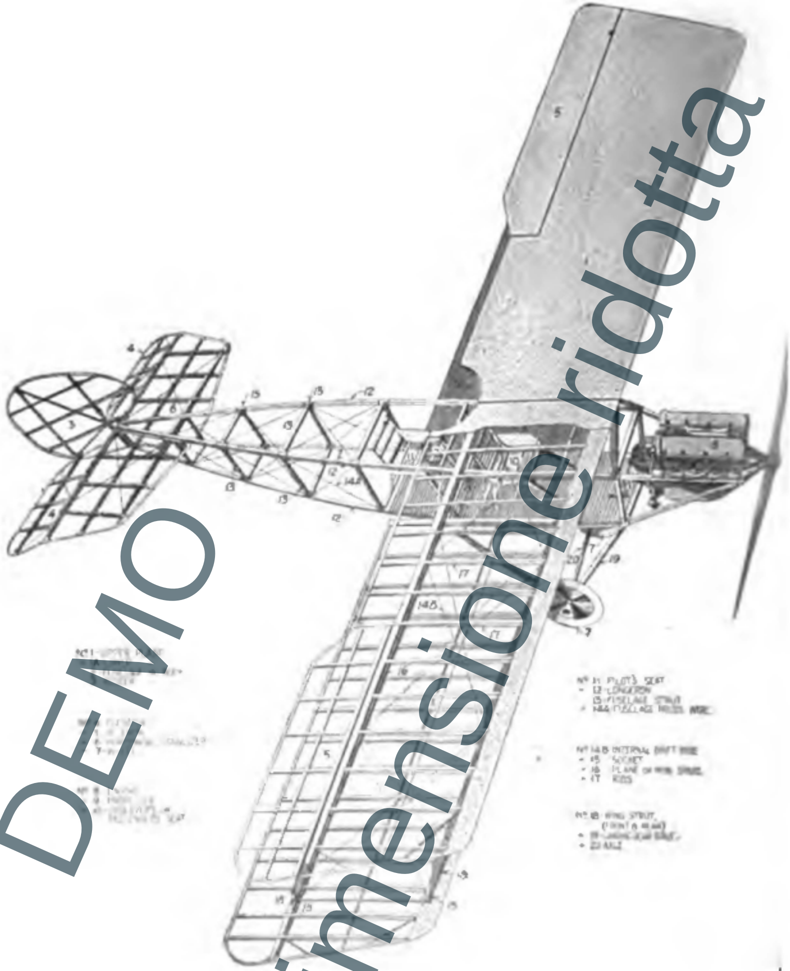

No 1 UPPER PLANE
No 11 PILOT'S SEAT
12 LONGERON
13 FUSELAGE STRUT
No 14 B INTERNAL DRIFT WIRE
15 SOCKET
17 RIBS
No 18 WING STRUT,
(FRONT & REAR)
20 AXLE

FIG. 1.

a single year and as a tree in good soil will grow much faster than a tree in poor soil, there will be fewer rings per inch even though the wood be equally sound and strong. Foresters say that a rapidly growing tree is more subject to disease and this is the basis for the demand for finely spaced rings. But excellent spars have been made from spruce having only two rings per inch, so that the exact number of rings per inch is not an infallible guide in choosing suitable wood for spars and struts.

The mechanic who would be a rigger has much to learn about the various parts of the framework and wings, for these must receive the most scrupulous care in every way. The center line of the body or fuselage must be straight and true, the planes at the rear which act as a stabilizer or balancer for the front of the machine must be in correct alignment, the wings or planes must be square with the fuselage and also at the correct angles when the whole machine is resting on a level floor. In other words, they must be in their proper position from every point of view, lengthwise, sidewise and frontwise, as a slight variation makes considerable difference in the handling of the machine and affects its stability and safety to a considerable degree. Some of these alignments can be checked up with the eye by a trained man but there are some which should be carefully measured if there is any reason to believe that the machine has been subject to undue stresses which may have twisted it somewhat out of shape.

The fuselage is a square-sectioned framework, in most cases, with the members separated by short struts, held in steel fittings, No. 15, and tied together by steel wires, No. 14*A*, running diagonally from strut to strut, No. 13, Fig. 1. The tension of these wires is very important not only as to amount but as to uniformity, and this is one of the fine points in the rigger's part of the work. With these wires too tight an undue stress is put on the strut and also on the wire itself, reducing the factor of safety in both cases. With unequal tension, unequal stresses are imposed on various parts of the frame and accidents are apt to occur from some part giving way. For even if the strut does not break but is bent out of shape this throws undue stresses on certain parts, shortens the distance between the surface it separates and otherwise disturbs the general layout of the machine. All these things interfere with the efficiency of the airplane and every drop in efficiency is serious in the case of a military machine, more so than in any other case. For efficiency is the one thing that enables the pilot to do his best work, and may easily mean the difference between victory and death.

The struts must be carefully watched to see that they are not damaged in any way, as if the outside fibers of the wood become splintered or bruised it makes a tendency to bend at this point and may lead to rupture just as a defect in the wood itself. The ends of the struts are also very important, particularly where they fit into the sockets and also the sockets themselves. These sockets should fit snugly and require pushing into place but should never be driven on with a heavy hammer owing to injury to the fibers of the wood. The strut should fit the socket well on its end so as to distribute the load evenly and avoid all tendency to split from bearing on a single point. One good plan is to paint the end of the strut and then note how it beds itself on the bottom of the socket after it is put into place.

In these days when it is not possible to get thoroughly seasoned woods, it is particularly necessary to watch against distortion due to uneven shrinking. This again tends to throw undue stresses on certain parts as when the strut is bent from uneven tension on the strut wires. By keeping the woodwork carefully varnished and never letting the bare wood be exposed to the atmosphere, this warping can be reduced to a minimum.

A good rule in all woodwork, which includes struts as well as the other parts, is to bore as few holes as possible for any purpose whatever. Every hole weakens the piece and the fact that the hole is filled makes no difference as to the strength of the piece as many seem to think. This makes it essential that the location of every hole be verified before it is bored so as to avoid unnecessary drilling and consequent weakening of the piece. Where holes are drilled, the size should be carefully determined, as the bolt or screw should be a good fit and not require driving in as this has a tendency to split the wood. A light tapping is not objectionable but the fit should not be tighter than this. On the other hand, the hole should not be large enough to let the bolt move in the wood. Either too tight or too loose may split the wood, the latter by working sideways and enlarging the hole to the danger point.

A careful study should be made of the methods used by the best builders in holding the various pieces of the framework together, both as to the fittings and the way in which they fit the wood and how the wires are connected to them. Sheet-metal stampings and drop forgings are being largely used with good results and care should be taken to note how they are designed to resist the various stresses and how they are used to enable quick assembly and rigid construction. Some fuselage fittings, for example, must be slipped over the whole length of the longeron while others can be put on at any point without disturbing any other fittings which may already be in place. Some require the ears which take the strut wires to be bent to the proper angle while others are so designed that the eye which receives the wire, swivels, and so adjusts itself to whatever angle the wire may assume under tension.

Where bolt heads and nuts fit against woodwork large washers must be used to prevent the metal, either nut or washer, being pulled into the wood and destroying the fibers. A large washer distributes the stresses over a large area and prevents this destructive pressure.

SECTION II

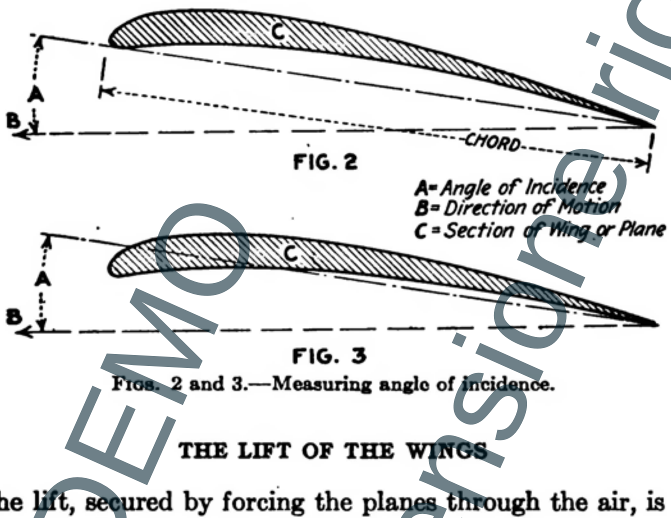
THEORY OF THE PLANES

In order for the rigger to be thoroughly efficient he must understand considerable theory of the construction of airplane wings and the essential features necessary for satisfactory flight. The importance of care and accuracy in this connection can hardly be overstated, for the pilot's life depends on the condition of the machine itself, for even should the engine fail with him high in the air he can usually land safely with the planes in good condition.

The rigger must know why a machine flies and what makes it stable. To insure this we shall take up a few of the points regarding modern airplanes.

A machine is supported in the air by driving it so that the air is forced under its inclined surfaces. These force the air down and the reaction of the air supports the planes. The inclination of these surfaces is called the angle of incidence and is measured when the plane is level or in its normal flying position, which is parallel with the shaft of the engine. In the side view of the surface shown the angle of incidence is that formed between the horizontal or line of motion and the chord, or straight line from one side of the wing to the other. This chord is the effective width of the wing. A more correct definition of the angle of incidence is the angle formed between the direction of motion and the neutral lift line, which starts at the trailing edge of the plane and runs along its main lifting surface, neglecting the downward curve of the front edge. The two methods are shown in Figs. 2 and 3. From a practical viewpoint the former is sufficient and enables the rigger to measure the angle more accurately than the other way.

The angle of incidence varies considerably in different machines: the Curtiss triplane scout has 3½ degrees; the twin-motored military tractor only 2 degrees; the training machine J N 4 B. 2 degrees; a hydro-airplane 4 degrees; and the flying boat 6½ degrees. On the other hand, the Standard Airplane Corporation use 2½ degrees on the training machine, 1¾ degrees on a training hydro, 5 degrees on a twin-motored military hydro and only 2 degrees on a military reconnaissance machine.



FIGS. 2 and 3.—Measuring angle of incidence.

THE LIFT OF THE WINGS

The lift, secured by forcing the planes through the air, is due both to the direct reaction of the air against the lower planes and to the partial vacuum formed over the top of the wing, as at *A*, behind its leading edge as shown in Fig. 4. This is found to be over half the lifting force, in fact is usually considered as about three-fifths or 60 per cent., due to the upper surface of the plane. This makes it essential to keep the upper surface of the wing in good condition, especially as it is more apt to strip off the top than the bottom.

The resistance of the machine, or drift as it is often called, is made up of the resistance of the lifting surfaces, the passive resistance of the struts, propeller hub, wires, landing gear, etc., and the skin friction produced by the roughness of surface.

The efficiency of the machine itself, without regard to the engine which drives it, is due to the relation between the lift and

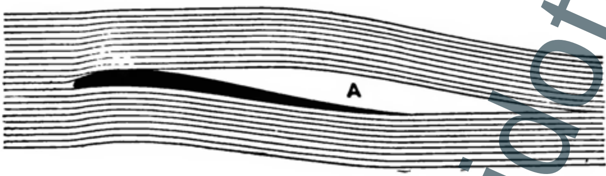


FIG. 4.—Action of air on wing.

the resistance or drift, this being known as the lift-drift ratio. The less the resistance the greater the efficiency of the machine so that every effort is made to decrease the resistance by stream-lining all parts which are exposed. This stream-lining is making the piece pointed not so much where it enters the air as where the air leaves it, as the passing air acts in the same way over the

FIG. 5.—How air forms around struts.

top of the wing and creates a partial vacuum which holds back the piece and adds to the resistance. This is decreased by making the shape of the piece as shown in Fig. 5 which shows the effect of both round and stream-lined shapes. The space *A* shows the difference in vacuum created. It is for this reason that the landing wheels are covered and even the exposed wires are now being stream-lined on the highest-speed machines.

The camber of the wings is the curved surfaces at the top and bottom, the top being convex and the bottom concave. This camber varies greatly with the machine and the rigger can only assume that this, as with the angle of incidence, is rightly proportioned, and keep it in the condition in which he finds it. This is also true of the stagger of the planes, the rigger's work being to see that the proportions of the designer are maintained. The amount of stagger is sometimes given in inches, while other makers state it in degrees.

DIHEDRAL ANGLE

The dihedral angle, or the angle which the wings make with the horizontal, is to secure an inherent stability or self-righting

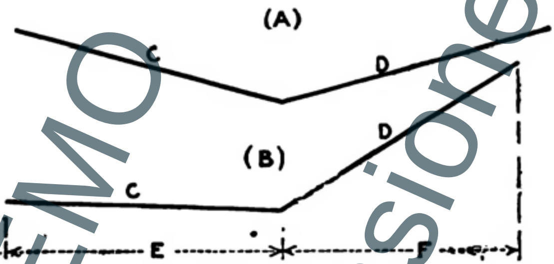


Fig. 6.—Action of dihedral wings.

quality to the machine. An exaggerated example of this is shown in Fig. 6 which shows the machine level at *A*, and tipping at *B*. As soon as the plane starts to tip the wing *C*, which goes down, immediately presents more surface to the air while the other wing *D* decreases its surface and the machine at once starts to right itself. The supporting area of each is represented by *E* and *F*.

The measuring of this dihedral angle can be done in two or more ways, the first or string method being the more satisfactory.

A cord or fine wire is stretched over the top of the wing as in Fig. 7 and held in several ways. A tripod may be used at one end and a weight at the other to keep it taut, or one end may be tied over the edge to a strut, or both ends may be secured in this way. Then, with the cord bearing on top of the wing at each end, measure the distance between the chord and the plane at definite points, taking equal points each side of the center panel of the machine. This should be done at both the front and back edges of the plane or, more properly, over the two main spars of the wing. This is done just as much to measure the angle on

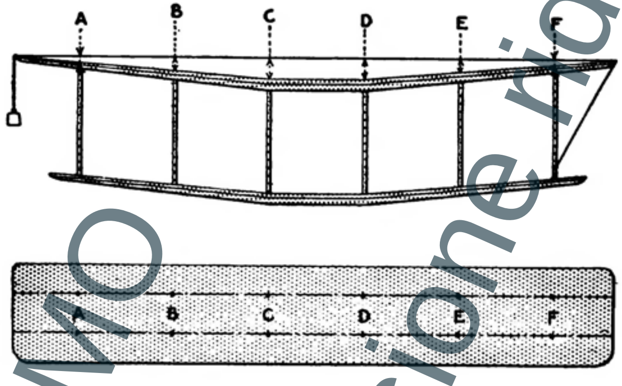


Fig. 7.—Measuring dihedral angle.

incidence as to check up the two sides of the machine and see that the angle is alike. By keeping notes of these measurements the rigger can easily detect any change which may occur.

Two strings should be used, one over each spar, and drawn very tight. The points measured should be just inside the four center section struts, in other words as far as possible from the center of the center section. Diagonal measurements are also taken, from similar points on each side of the machine. These measurements should be taken from fixed points, such as certain distances from the ends of the spars. Many take these measurements from the bottom socket of one strut to the top socket of another strut, but this is not good practice as this seldom gives accurate measurements. By measuring the distance between top and bottom planes it can readily be seen whether they are both set at the same angle.

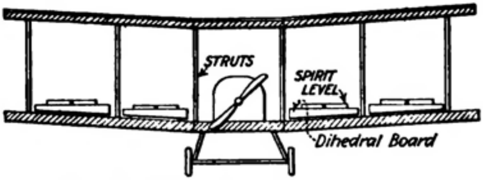


Fig. 8.—Use of dihedral angle board.

Another method and one which is easier to use although not usually as accurate is by the use of the dihedral board as shown in Fig. 8. This is simply a board cut with the proper angle for the dihedral on one side. These boards should be tested before

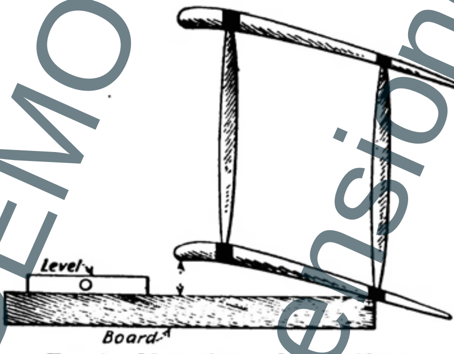


Fig. 9.—Measuring angle of incidence.

using and care must be taken that the spar is not warped or "set" at the points where they are used. For, as these must be used on the spars between the struts, slight inaccuracies often creep in from this source. The bays or sections between struts must be carefully measured diagonally as a check to the use of the boards. This same type of board is used to measure angle of incidence as shown in Fig. 9, but the level goes on the long, straight board. In all cases be sure the level is accurate.

MEASURING THE STAGGER

The amount of stagger is measured by dropping a plumb line from the leading edge of the upper plane and measuring back, as shown in Fig. 10. This can be measured either horizontally or along the

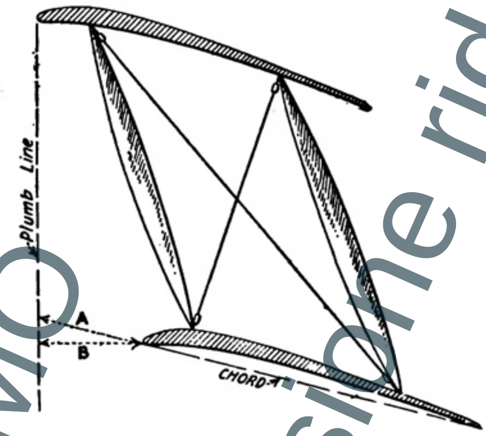


Fig. 10.—Measuring the stagger of planes.

line of the chord. Some makers measure one way and some another but the correct way should be shown on the diagram which should accompany every plane. This is the only way in which a rigger can check up his work as he goes along. The two measurements may be as much as a quarter of an inch difference, and while this may seem but a trifle, it may be enough to make the machine nose-heavy or tail-heavy as the case may be.

If any adjustments are found necessary, and they usually are, they should be very carefully made, taking great care not to spring any of the important parts such as the wing spars. It is also well to run over all adjustments after the last one is made to be sure that this has not thrown some of the others out of place.

After all other measurements have been taken and adjustments made the overall measurements will tell whether the machine as a whole is in good shape or not. These are taken in as Fig. 11. The points *A* and *B* are marked on the main spar, each the same distance from the butt or end next the fuselage.

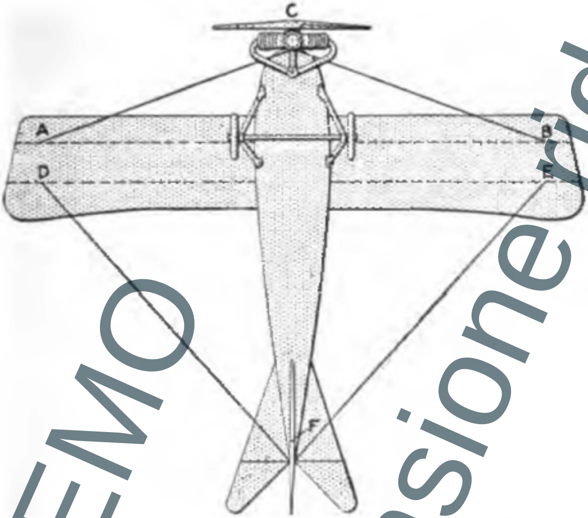


Fig. 11.—Measuring trueness of whole machine.

In a tractor machine the point *C* is the center of the propeller shaft, in a pusher, the center of the front end of the machine. From *A* to *C* and from *B* to *C* must of course be the same, these measurements being taken from both the top and bottom wing of the machine, making two measurements on each side of the machine.

In the same way mark two points D and E. on the rear spars of each wing and measure back to a point *F* in the center of the fuselage or rudder post. Here again two measurements are necessary on each side.

Should these measurements not check up as they should, it is possibly because some of the resistance or drift wires are not

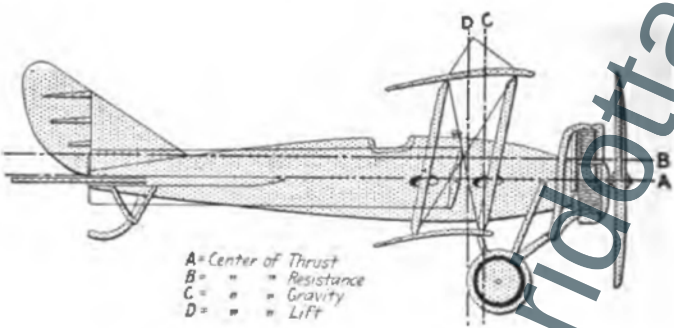


FIG. 12.—Location of thrust, resistance, gravity and lift.

tightened evenly, or the fuselage may possibly be out of true. This should, however, have been tested before the rest of the measurements were taken. The fault must be found and corrected before the machine is in condition to fly.

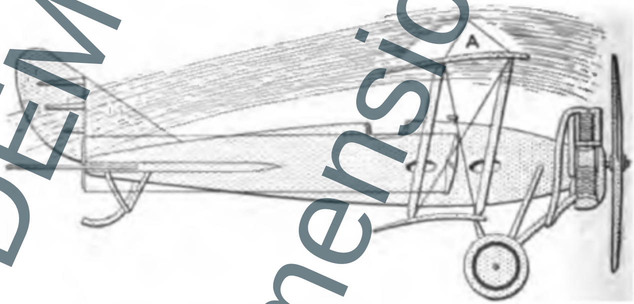


FIG. 13.—How air stream affects the tail planes.

A little study of Fig. 12 will enable the rigger to keep in mind some of the main points of the machine. It will be seen that the center of resistance or drift is above the center of thrust, or the center of the engine shaft, and parallel to it. The center of gravity is a little forward of the center of lift so that, with the power shut off, the machine will naturally assume its proper gliding angle, which should give the same speed as when flying.

As the air comes through the main planes it is deflected downward as shown in Fig. 13. This affects the angle of the tail plane, which may either be in line with this downward stream of air or at a lesser angle than the main wings. This stream of air affects the fore and aft stability of the machine.

THE STABILITY OF AIRPLANES

The following notes on stability and stresses from the Manual of the Royal Flying Corps give many useful suggestions.

Stability

By the stability of the airplane is meant the tendency of the airplane to remain upon an even keel and to keep its course; that is to say; not to fly one wing down, tail down, or nose down, or to try and turn off its course.

Directional Stability.—By directional stability is meant the natural tendency of the airplane to remain upon its course. If this did not exist it would be continually trying to turn to the right or to the left, and the pilot would not be able to control it.

For the airplane to have directional stability it is necessary for it to have, in effect, more keel surface behind its turning axis than there is in front of it.

By keel surface is meant everything you can see when you look at the airplane from the side of it—the sides of the body, under carriage, wires, struts, etc. Directional stability is sometimes known as "weather cock" stability.

You know what would happen if, in the case of the weathercock there was too much keel surface in front of its turning axis, which is the point upon which it is pivoted. It would turn round the wrong way. That is just how it is with an airplane.

Directional stability will be badly effected if there is more drift (*i.e.*, resistance) on one side of the airplane than there is on the other side. This may be caused as follows:

1. The angle of incidence of the main planes or the tail plane may be

wrong. If the angle of incidence on one side of the machine is not what it should be, that will cause a difference in the drift between the two sides of the airplane, with the result that it will turn off its course.

2. If the alignment of the fuselage, the fin in front of the rudder, or with a machine having the front elevator and outriggers, these must be absolutely correct. For, if they are turned a little to the left or to the right, instead of being in line with the center of the machine and dead on in the direction of flight, they will act as an enormous rudder and cause the machine to turn off its course.

3. If the dihedral angle is wrong, that may have a bad effect. It may result in the propeller not thrusting from the center of the resistance, in which case it will pull the machine a little sideways, and out of its course.

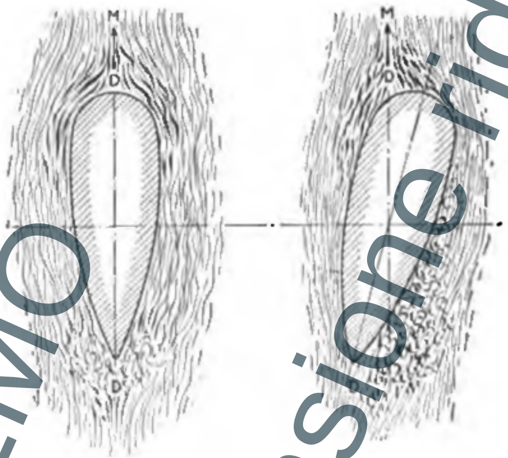


FIG. 14.—Air currents around struts.

4. If the struts and stream-line wires are not adjusted to be dead on in the line of flight, then they will produce additional drift on their side the airplane, with the result that it will turn off its course.

5. There is still one other reason why the airplane may be directionally bad, and that is *distorted surfaces*. The planes are "cambered," or curved to go through the air with the least possible resistance. If, perhaps owing to the leading edge, spars or trailing edge getting bent, the curvature is spoiled, that will change the amount of drift on one side of the airplane which will then have a tendency to turn off its course. See the struts in Fig. 14.

Lateral Stability.—By lateral stability is meant the sideways balance of the machine. The only possible thing that can make the machine fly one wing down is that there is more lift on one side than on the other. That may be due to the following reasons:

1. The angle of incidence may be wrong. If the angle of incidence is too great, then it will produce more lift than on the other side of the machine, and if the angle of incidence is too small, then it will produce less lift than on the other side, the result being that in either case the machine will try to fly one wing down.

2. *Distorted Surfaces.*—If the planes are distorted, then their camber or curvature is spoiled and the lift will not be the same on both sides of the airplane, and that, of course, will cause it to fly one wing down.

Longitudinal Stability.—Longitudinal stability means the fore and aft balance. If that is not perfectly right then the machine will try to fly nose down or tail down. This may be due to the following reasons:

1. *The Stagger May Be Wrong.*—The top plane may have drifted back a little and this will probably be due to some of the wires having elongated their loops or having pulled the fittings into the wood. If the top plane is not staggered forward to the correct degree then that means that the whole of its lift is moved backwards and it will then have a tendency to lift up the tail of the machine too much. In such a case the machine would be said to be "nose-heavy."

A ¼-inch error in the stagger will make a very considerable difference to the longitudinal stability.

2. Incorrect angle of incidence of the main planes will have a bad effect. If the angle is too great it will produce an excess of lift, which will lift up the nose of the machine and result in it trying to fly tail down. If the angle is too small there will be a decreased lift and the machine will try to fly nose down.

3. When the machine is longitudinally out of balance the usual thing is for the rigger to rush to the tail plane, thinking that its adjustment relative to the fuselage must be wrong. This is, indeed, sometimes the case, but it is the least likely reason. It is much more likely to be one of the first two reasons given, or the following:

The fuselage may have got warped upwards or downwards, thus giving the tail plane an incorrect angle of incidence. If the tail plane has too much angle of incidence it will make it lift too much and the machine will be "nose-heavy."

If the tail plane has too little angle of incidence then it will not lift enough, and the machine will be "tail-heavy."

4. If the above three points are all correct, then there is a possibility of the tail plane itself having assumed a wrong angle of incidence, in which

case it must be corrected. In such event, if the machine is nose-heavy, the tail plane should be given a smaller angle of incidence. If the machine is tail-heavy then the tail plane must be given a larger angle of incidence, *but* be careful not to give the tail plane too great an angle of incidence, because the longitudinal stability of the airplane entirely depends on the tail plane being set at a *much smaller angle of incidence* than the main plane, and if you cut the difference down too much the machine will become uncontrollable longitudinally. Sometimes the tail plane is set on the machine at the same angle of incidence as the main plane, but it actually engages the air at a lesser angle owing to the air being deflected downwards by the main planes.

Stresses and Strains

In order to rig a machine intelligently it is necessary to have a correct idea of the work every wire and every part of the airplane is doing.

The work the part is doing is known as *stress*. If, owing to undue stress, the material becomes distorted, then such distortion is known as *strain*.

Compression.—The simple stress of *compression* produces a crushing strain. As an example, the interplane and fuselage struts.

Tension.—The simple stress of *tension* results in the strain of elongation. As an example, all the wires.

Bending.—The compound stress of *bending* is composed of both tension and compression, one side is stretched, the other compressed.

Shear.—Shear stress is such that when the material breaks under it, one part slides over the other. As an example, the locking pins. Some of the bolts are in a state of shear stress also because, in some cases, there are lugs underneath the boltheads from which wires are taken. Owing to the tension of the wire the lug is exerting a sideways pull on the bolt and trying to break it in such a way as to make one part of it slide over the other.

Torsion.—This is a twisting stress composed of compression, tension, and shear stress. The propeller shaft and crankshaft of the engine is a good example.

Nature of Wood under Stress.—Wood, for its weight, takes the stress of compression the best of all. For instance, a walking stick of about half a pound in weight, will, *if* kept perfectly straight, probably stand up to a compression stress of a ton or more before crushing, whereas if the same stick is put under a bending load it will probably collapse to a stress of not more than about 50 pounds. That is a very great difference and since weight is of the greatest importance in an airplane, the wood, must, as far as possible, be kept in a state of *direct compression*. This it will do safely as long as the following conditions are carefully observed.

Conditions to be Observed.—1. All the spars and struts must be *perfectly straight.*

Fig. 15 shows a section through an interplane strut. If it is to be prevented from bending, the stress of compression must be equally disposed around the center of strength. If it is not straight, there will be more compression on one side of the center of strength than on the other side. That

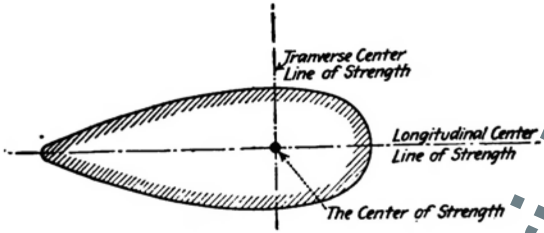


FIG. 15.—Section of strut.

is a step toward getting compression on one side and tension on the other side, in which case it will be forced to take a bending stress for which it is not designed.

Even if it does not break it will, in effect, become shorter, and thus throw out of adjustment all the wires attached to the top and bottom of it, with the result that the flight efficiency of the airplane will be spoiled,

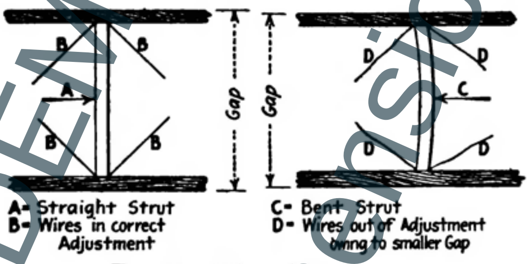


FIG. 16.—Effect of bent struts.

besides an undue and dangerous stress being thrown upon other wires, as in Fig. 16.

Where spars are concerned there is an exception known as *the arch.* For instance, in the case of the Maurice Farman, the spars of the center section plane, which have to take the weight of the nacelle, are arched upward. If this was not done it is possible that rough landings might result in the weight of the nacelle causing the spars to bend down a little. That would produce a dangerous bending stress, but as long as the wood is arched, or, at any rate, kept from bending downward it will remain in direct compression and no danger can result.

2. Struts and spars must be *symmetrical*. By that is meant that the cross-sectional dimensions must be correct, as otherwise there will be bulging places on the outside, with the result that the stress will not be evenly disposed around the center of strength, and a bending stress will be produced.

3. Struts, spars, etc., must be *undamaged*. Remember that, from what has been said about bending stresses, the outside fibers of the wood are doing by far the most work. If these get bruised or scored, then the strut or spar suffers in strength much more than one might think at first sight, and if it ever gets a tendency to bend it is likely to go at that point.

4. The wood must have a *good clear grain with no cross grain, knots or shakes*. Such blemishes mean that the wood is in some places weaker than in other places, and, if it has a tendency to bend, then it will go at those weak points.

5. The struts, spars, etc., must be *properly bedded* into their sockets or fittings. To begin with, they must be a good pushing or gentle tapping fit. They must never be driven with a heavy hammer. Then, again, they must bed well down, all over their cross-sectional area; otherwise the stress of compression will be taken on one part of the cross-sectional area with the result that it will not be evenly disposed around the center of strength, and that will produce a bending stress. The bottom of the strut or spar should be covered with some sort of paint, bedded into the socket or fitting, and then withdrawn to see if the paint has stuck all over the bottom of the fitting.

6. The atmosphere is sometimes much damper than at other times and this causes the wood to expand and contract appreciably. This would not matter but for the fact that it does not expand and contract uniformly, but becomes unsymmetrical, *i.e.*, *distorted*. This should be minimized by varnishing the wood well to keep the moisture out of it.

Function of Interplane Struts.—These struts have to keep the planes apart, but this is only part of their work. They must also keep the planes in their *correct attitude*. That is only so when the spars of the bottom plane are parallel with those of the top plane. The chord of the top plane must also be parwallel ith the chord of the bottom plane. If that is not so then one plane will not have the same angle of incidence as the other one.

It would only seem necessary to cut all struts the same length, but that is not the case. Sometimes, as illustrated in Fig. 17, the rear spar is not as thick as the main spar, and it is then necessary to make up for that lack of thickness by making the rear struts correspondingly longer. If that is not done, then the top and bottom chords will not be parallel, and the top and bottom planes will have different angles of incidence. Also, the sockets or fittings or even the spars upon which they are placed sometimes vary in thickness, and this must be offset by altering the length of the struts. The proper way to proceed in order to make sure that everything is right is to measure the distance between the top and bottom spars by the side of each strut and, if that distance, or "*gap*" as it is called, is not as specified in the rigging diagram, make it correct by changing the length of the strut.

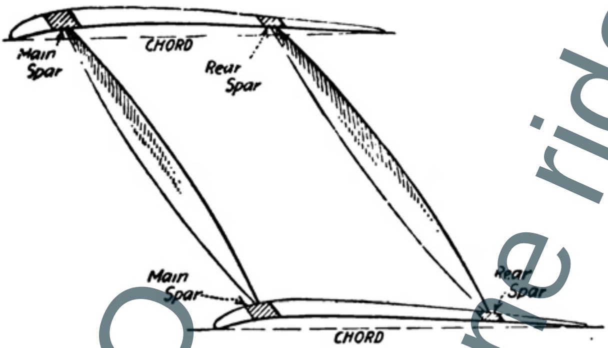


Fig. 17.—Length of struts.

When measuring the gap between the top and bottom spars *always be careful* to measure from *the center* of the spar, as it may be set at an angle, and the rear of the spar may be considerably lower than its front.

Adjustments and Inspection

Control Surfaces.—The greatest care must be exercised in properly rigging the aileron, rudder and elevator, for the pilot entirely depends upon them in managing the airplane.

The ailerons and elevator should be rigged so that *when the machine is in flight* they are in a fair line with the surface in front and to which they are hinged, as in Fig. 18.

If the surface to which they are hinged is *not a lifting surface, then rig* the controlling surface to be in a fair true line with the surface in front.

If the controlling surface is hinged to the back of a *lifting surface*, then it is necessary for it to be rigged a little below what it would be if it was in a fair true line with the surface in front. This is because in such a case it is set at an angle of incidence. This angle will, when the machine is flying, produce lift and cause it to lift a little above the point at which it has been rigged on the ground. It is able to lift owing to a certain amount of slack in the control wire holding it—and you can't adjust the control wire to have no slack, because that would cause it to bind against the pulleys and make the operation of it too hard for the pilot. It is, therefore, necessary to rig it a little below what it would be if it was rigged in a fair true line with the surface in front. Remember that this applies only when it is hinged to a lifting surface. The greater the angle of incidence of the lifting surface in front, the more the controlling surface will have to be rigged down. As a general rule you will be safe in rigging it down so that the trailing edge of the controlling surface is ½ to ¾ inch below where it would be if it was in a fair true line with the surface front—or ½ inch down for every 18 inches of chord of the controlling surface.

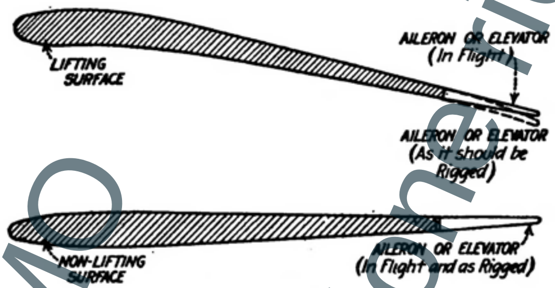


Fig. 18.—Rigging ailerons.

When adjusting the controlling surfaces the pilot's control levers must be in their neutral position. It is not sufficient to lash them in that position. They should be blocked into position with wood packing.

Remember that controlling surfaces must never be adjusted with a view to altering the stability of the machine. Nothing can be accomplished in that way. The only result will be that the control of the airplane will be spoiled.

Control Cables.—The adjustment of the control cables is quite an art, and upon it will depend to a large degree the quick and easy control of the airplane by the pilot. The method is as follows:

After having rigged the controlling surfaces remove the packing which has kept the control levers rigid. Then, sitting in the pilot's seat, move the control levers *smartly*.

up to form the propeller have been laid out, they are cut out on the band-saw, as shown. One of the long pieces is here shown being sawed into shape before gluing and building up.

In some places the propeller blades are roughed out on a sort of routing machine, using a form to guide the routing tools, but in most cases they are still worked out by hand from the rough built-up propeller blank. Great care must be taken in building up the layers that form the propeller, as it is absolutely necessary that there be a perfect union at all points of the surface.

Fig. 20.—Laying out and sawing propeller laminations.

The parts to be glued must be thoroughly covered with a thin layer and then firmly held in position until absolutely dry. After this, the propeller is ready to be worked out by whichever method may be employed in the shop. In this case, nearly all the work is done by hand, Fig. 21 showing one end of a propeller cut almost to its proper shape and being tested by carefully made templets.

As can be seen from the tools on the workman's bench, the planes and draw-knives of various shapes are the main tools required. In addition to these a steel straight-edge, a level and a surface plate are necessary in testing the various parts of the propeller at frequent intervals. As shown, the propeller is supported on a central shaft, or peg, about which it can be turned so as to bring either end in position for measuring. This is an extremely interesting job and one requiring the utmost patience, as there can be very little variation allowed from the standard shape, length or width, and the matter of balance is of the utmost importance.

Fig. 21.—Testing shape of blade.

Fig. 22.—Testing balance of propeller.

Fig. 22 shows, in its final balancing stages, a propeller built of black walnut and spruce. This is a case of static balance, the propeller being very carefully mounted on knife-edges that actually can be leveled by special screws at each end. The propeller must stay in any position in which it is placed. The final balancing is secured by applying a light coat of varnish near the outer end, in many cases a mere touch of the varnish brush serving to supply all the extra weight that is necessary to put the propeller in perfect static balance. This is one of the points that is very strictly watched, as an unbalanced propeller can do much damage to the whole machine, as well as be a source of danger to the aviator.

Another design for securing greater efficiency of the propeller is that of Dr. Olmstead and shown in Fig. 23. This reverses the usual design of having the widest part of the blade near to outer end and makes the propeller widest at the hub. The pitch angle at the hub is very sharp and the blade tapers very rapidly from the hub to the outer end, the shape resembling a bird's wing in many ways. These propellers, as with all propellers in fact, have to be designed for the particular type of machine they are propel, the resistance and speed being the prime factors. In some cases these propellers are 24 inches thick at the hub and only 4 inches wide at the tip, making them very distinctive in every way. Tests show them to give very

Fig. 23.—Olmstead propeller.

good results but they are so radical that they have not been widely used as yet.

Having the design of the propeller for the given type of machine the drafting room makes templates of the proper shape and curve and shape of the blade at various points along its length. These gaging or contour points vary with different designs from 3 to 6 inches apart, 4½ inches being a good average. In this way the propeller maker is enabled to get the two blades almost absolutely alike, which is very essential for best results and in order to have the two blades balance when the propeller is finished.

The various boards or laminations which go to make up the propeller are cut to shape on the band saw, each being cut to pattern to use the minimum amount of material. Black walnut is considered one of the best woods for this purpose but spruce, maple and birch are also used. Black walnut and spruce are often used in alternate layers. These boards are then heated to prevent the glue drying too quickly, put together in the proper order and clamped in a heavy press until thoroughly dry. When the rough propeller comes out it looks about as in Fig. 24 and is then ready to be roughed out. This is usually done by hand with different forms of draw knives but is done with a routing machine in some of the larger shops. This leaves it in approximately the correct shape and it is then finished, usually by hand, to the templates already mentioned.

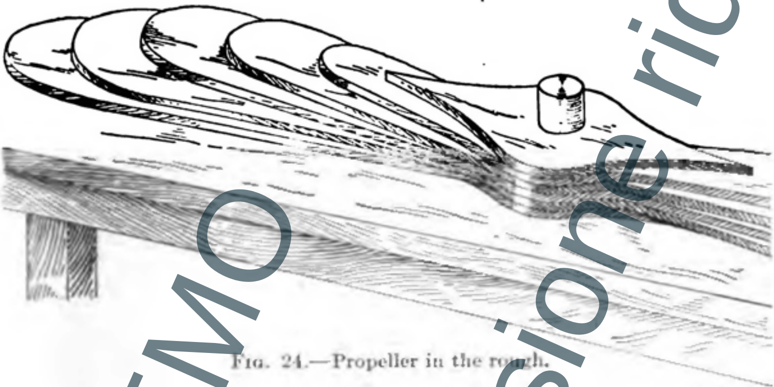


Fig. 24.—Propeller in the rough.

TESTING THE SHAPE OF BLADES

In testing the various points the propeller is laid on an iron block having a central stud at right angles to it and which represents the propeller shaft. This allows the templates to be placed on the blades at the desired intervals, these intervals being marked on the iron plate itself. The angle of the flat or nearly flat surface can also be readily measured. A surface gage is also used very carefully to test the height of various portions of the blade from the testing plate on which it rests. The pitch of a propeller can be measured by reversing this process, *i.e.*, measuring the pitch angle at various points and laying these off on a chart. Such a chart should show a uniform change of pitch from the hub out. If it fails to do this, it indicates that the propeller has not been carefully measured and that it will not be efficient.

Some allow 1/8 inch out of straight for a propeller when it is mounted on a shaft and revolved past a given point, but most makers and users expect them to be nearer straight than this. The blade length should be correct and uniform within 7/16 inch and some do better than this, as balancing is a very important feature in propeller making. Horizontal ways are generally

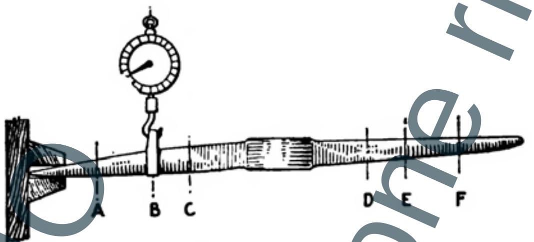


Fig. 25.—Testing uniformity of weight.

used although some mount the propeller on a shaft with a special ball bearing. This is done after the end is coppered, if it is to be so protected. The final balancing is done by putting a little more varnish on the light end of the propeller, which indicates how carefully shaped they must be.

A method of testing the propeller for uniformity of weight along its length is shown in Fig. 25. Here one end of the propeller is held loosely in an opening and the whole propeller suspended with a spring balance at different given points along its length. The propeller is then reversed and suspended in the same way from corresponding points on the other end. If the weights balance on both ends of the propeller, the centrifugal stresses should be practically equal and the propeller run satisfactorily.

It is also quite important that the surface areas of both ends of the propeller should be equal. This can be easily tested by measuring the width of the blades at given points on each end seeing how they compare. The joints are frequently tested by revolving the propeller at from 5 to 10 per cent. higher speed than that at which it will be run and then examining the joints carefully to be sure that none of them have started. These joints should not show glue as the wooden layers should be solid together.

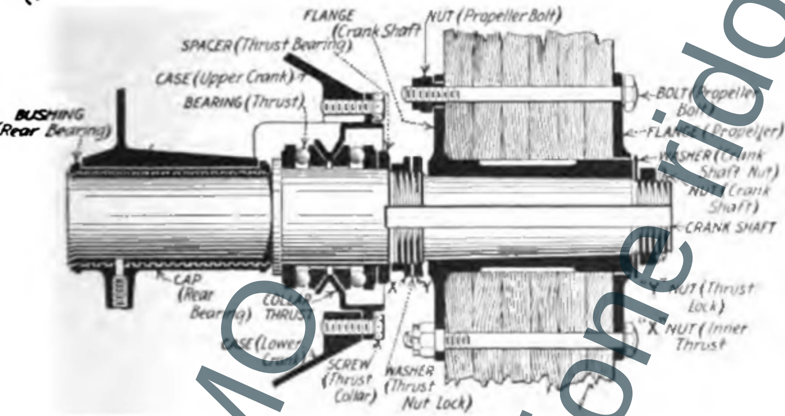


Fig. 26.—A typical propeller mounting.

The propeller surface should be very smooth particularly near the outer end where the speed is the greatest. When it is considered that the tips sometimes have a speed of 30,000 feet per minute, it can readily be seen how the surface affects the skin friction.

There are a great variety of propeller hub mountings, one of which is shown herewith in Fig. 26. This requires no explanation, as the methods of holding the propellers are clearly shown. It is very necessary that the propeller be mounted square and straight on the shaft and that it is securely fastened. This squareness can be tested in a similar manner to that alpin is held in position by a wire running through its head and around the hub, a groove being provided for this purpose. The ends are twisted together in the usual way.

The bolts have a taper head to insure a perfect fit in the inner flange, and the nut on the outer end has a projecting sleeve that goes through the outer flange, so that the thread of the bolt does not come in contact with the flange at any point. It will be noticed that the engine shaft is hollow and that the bolt is drilled for nearly its entire length. It will also be seen that the key has a tapped hole at the front end through which a screw can be used as a jack in lifting the key out of place, should it become jammed in any way.

Figs. 27*a* to 28*c* show the details of the standard hub for engines of from 170 to 250 horsepower.

TESTS OF PROPELLERS

To test the pitch angle the propeller is mounted on a shaft which is mounted at right angles to a beam which is straight

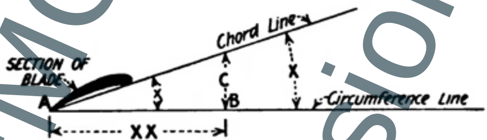


FIG. 29.—Laying out curve of propellers.

and true. Pick out some point on the propeller at any given distance from the center of the hub and find the angle the propeller makes with the beam at this point, by means of a protractor. Lay out this angle on a large sheet of paper as in Fig. 29, this being the chord of the pitch angle. The straight or base line must represent the circumference of the propeller at the face of the beam.

If this point is taken at 2 feet from the center we have a circle 4 feet in diameter or (4×3.1416) 12.5668 feet. Bring this down to any scale which is convenient, say 2 inches to the foot, and lay off the horizontal line 25.132 inches. Then the distance from this point on the circumference line to the chord line is the pitch at this point. This should agree with the specified pitch of the propeller, unless the propeller blade is distorted, due to faulty manufacture or the hole being in the wrong place. An error of a half degree is permissible but more than this should be reported. This test should be made at several points and the results carefully checked up. The length should also be tested by revolving past a given point; a difference of not over 7/16 inch is permissible. Balance is also essential and is tested by mounting on ball bearings on a carefully leveled runway or balancing way. It should remain in any position.

FIG. 30.—Testing curve of blade.

If it is out of balance appreciably it must be corrected as an unbalanced propeller will do a lot of damage to an engine and may wreck a plane. The test for weight at different points has already been given, as in Fig. 22. During this test the propeller must be kept horizontal, care being taken to have the different points the same distance apart on each side of the hub. The surface area can be easily calculated by measuring the width at several given points; these measurements should not vary over 1/8 inch at any point.

The camber or curve of the blade can also be tested quite easily on the concave side by passing a straight-edge along the blade as in Fig. 30 and noting the space at different points. On the convex side this requires a set of templates which can be readily made from the drawings of the propeller and may be worth while if there are enough of one kind to be tested occasionally.

The following suggestions for riggers is from the Royal Flying Corps manual.

NOTES ON RIGGING FOR AIR MECHANICS

Importance of Good Rigging.—It is impossible to exaggerate the importance of *care* and *accuracy* in rigging. The pilot's life, the speed and climb of the airplane, its control and general efficiency in flight, and its duration as a useful machine all depend upon the rigger. Consider that while the engine may fail the pilot may still glide safely to earth *but* if the airplane fails, then all is lost. The responsibility of the rigger is, therefore, very great, and he should strive to become a sound and reliable expert on all matters relating to his art—for an art it is, and one bound to become increasingly important as time passes.

Flight.—First of all he must have a sound idea of flight and stability.

Flight is secured by driving through the air a surface or surfaces inclined to the direction of motion. Such inclination is called the "angle of incidence.

Lift.—In this way the surfaces, that is the lifting planes, secure a lift from the air, and, when the speed through the air is sufficient, the lift will become greater than the weight of the airplane, which must then rise into the air.

Bear in mind that the drift is always trying to collapse the planes backward.

Thus you will see that there are four forces to consider. The *lift* which is opposed to the *weight*, and the *thrust* which is opposed to the *drift*. The lift is useful—the drift is the reverse of useful. The proportion of lift to drift is known as the *lift-drift ratio*. This is of paramount importance for upon it depends the efficiency of the airplane. In rigging an airplane the greatest care must be taken to *preserve the lift-drift ratio*. Always keep that in mind.

Angle of Incidence.—The angle of incidence is the inclination of the lifting surfaces. If the angle of incidence is increased over the angle specified in your rigging instructions then both the lift and the drift are increased also—and the drift is increased in greater proportion than the lift. If, however, the angle of incidence is decreased, then the lift and the drift are decreased and the lift decreases in greater proportion than does the drift. You see then that in each case the efficiency is spoiled, because the proportion of lift to drift is not so good as would otherwise be the case.

Balance.—The whole weight of the airplane is balanced upon, or slightly forward of, the center of the lift.

If the weight is too far forward then the machine is nose-heavy.

If the weight is too fa- behind the center of the lift then the airplane is tail-heavy.

Get a good understanding of the above before going any further.

ABOUT THE ENGINE

Although care of the engine is primarily the machinist's or engineman's job it is well for the rigger to know something about it as it often helps out in emergencies, and these are always arising in unexpected quarters.

As a rule, when the propeller is fitted to the crankshaft, it revolves in an anti-clockwise direction when viewing it from the position you stand in to swing it, or in front of the machine.

When it is fitted to another shaft (which is geared to the crankshaft) as in the case of the Renault and R.A.F. engines, then, as a rule, it revolves in a clockwise direction.

Following are some examples, and you will do well to add new engines to the list as they come into use:

Type		Name	No. of cylinders	Rotation of propeller
Stationary engines	120 hp.	Beardmore	8	Anti-clockwise
	100 hp.	R.A.F.	8	Clockwise
	100 hp.	Curtiss	8	Anti-clockwise
	80 hp.	Renault	8	Clockwise
	70 hp.	Renault	8	Clockwise
Gnome rotary engines	100 hp.	Monosoupape	9	Anti-clockwise
	80 hp.	Gnome	7	Anti-clockwise
	50 hp.	Gnome	7	Anti-clockwise
Rotary engines	100 hp.	Clerget	9	Anti-clockwise
	80 hp.	Le Rhone	9	Anti-clockwise

Starting the Engine

Sound Footing.—First of all make sure that the ground just in front of the propeller affords you a good sound footing. Should your foot slip when swinging the propeller it may result in serious injury for yourself.

Now place the blocks in front of the wheels, and lay out their cords toward the wing tips.

One air mechanic at each wing tip and grasping the bottom of the outer strut to steady the airplane when the engine is running. These air mechanics will pull the blocks away when the pilots signal for such action.

Not less than 2 air mechanics at the tail end of the fuselage in order to keep it *down* when the engine is running.

Rotary Engines.—In the case of rotary engines it is often necessary, *after ascertaining that the switch is off*, to dope the cylinders with petrol. This is done by squirting petrol through each exhaust valve. Great care should be exercised to make sure the squirt can is clean. Never lay it on the ground. The top of the petrol tin is a good and convenient place.

Switch Off.—Before attempting to rotate the propeller *always* make sure that the ignition switch is "off," *i.e.*, in its downward position. Otherwise the engine and propeller may start unexpectedly with disastrous results to yourself. There has been more than one fatal accident due to carelessness in overlooking this point.

Petrol on and Air Closed.—Now ascertain that the petrol is on and the air closed. The air is not really quite closed, but it is partly cut off so that the mixture may be rich in petrol in order to facilitate the first few explosions.

Rotate Propeller.—Now swing the propeller round. This will turn the engine, and the effect of the descending pistons will be to suck the mixture into the cylinders.

Contact.—Now sing out "contact" to the pilot. He will put the ignition "on" replying to you "contact."

Swing Propeller.—Now one good downward swing of the propeller blade and *stand clear*. If the engine fails to start ask the pilot to *switch off* and go through the same operation again.

"Danger of Backfire."—When swinging the propeller *be careful* to stand clear of it. There is often a possibility of the engine "backfiring" and suddenly turning the propeller the wrong way round. This is usually due to the ignition occurring early, *i.e.*, before the piston arrives at the top of the cylinder, and if the engine is revolving slowly the momentum of the moving parts (crankshaft, propeller, flywheel, etc.) may not be sufficient to carry it round in the right direction—the result being that the piston never gets to the top of its stroke but descends again driving the crankshaft back and round in the wrong direction. Any engine fitter will show you exactly how this works by means of turning round the crankshaft of a partly dismantled engine.

Signals.—1. The pilot, when ready to start, will wave his hand from side to side. This is the signal for the chocks under the wheels to be smartly pulled away by means of the cords attached to them.

2. Now the pilot waves his hand in a fore and aft direction. This is the signal for *everyone to stand clear without a moment's delay*, and is especially meant for the air mechanics at the tail of the fuselage.

The order of standing is as follows:

Pilot to Rigger...........	"Everything all right?"
Rigger....................	"All correct, sir." (Remember that "all correct" covers a lot, and that it is the rigger's duty to report anything not in *perfect* condition.)
Pilot to Machinist........	"Everything all right?"
Machinist.................	"All correct, sir."
Machinist.................	"Switch off?"
Pilot.....................	"Switch off."
Machinist.................	"Gasoline on—air closed?"
Pilot.....................	"Gasoline on—air closed." The machinist, now rotates the propeller. (In the case of a rotary engine it must first be doped with gasoline as explained above.)
Machinist.................	"Contact?"
Pilot.....................	"Contact." The machinist now swings the propeller and *stands clear*.
Pilot.....................	Waves hand sideways.
Air Mechanic..............	Pulls blocks away from wheels.
Pilot.....................	Looks at Senior Non-Commissioned Officer or Mechanic.
Senior Non-Commissioned Officer or Mechanic......	Looks to see if all is clear for ascent and no other airplane descending. If all clear he salutes.
Pilot.....................	Waves hand in a fore and aft direction.
Air Mechanic..............	*Stand clear*.

The Engine.—Although you are a rigger, and not supposed to have a close knowledge of engines, it is highly desirable that you should have some idea of the way in which they work, the rotation of propellers, and the *precautions* and *rules* in respect of swinging the propeller.

Firstly, the engine. In each cylinder is a piston which is connected to the crankshaft (see examples in your squadron engine shop) so that, as the piston travels up and down the cylinder, the shaft is made to rotate.

As the piston travels down the cylinder the inlet valve opens and the piston sucks in a mixture of petrol and air, in much the same way as a syringe sucks in water. The petrol is vaporized and mixed with the proper proportion of air in the carbureter which is connected with the inlet ports of the cylinders by means of the inlet pipe.

The piston then rising, and the inlet valve having closed, it compresses the mixture, which is much more explosive when compressed.

The explosion takes place when the piston is at about the top of the cylinder, and it is caused by an electric spark between the points of the sparking plug. The electric current is generated by the magneto which is connected to the sparking plug by wires.

The force of the explosion drives the piston down and causes the crankshaft to rotate.

As the piston rises again the exhaust valve opens and the burnt gases are forced out.

The working of the engine may then be divided into four strokes of the piston, thus:

First revolution of crankshaft.....	1. Piston descends, sucking in mixture. 2. Piston rises, compressing mixture.
Second revolution of crankshaft	3. Explosion takes place, forcing the piston to descend. 4. Piston rises, forcing burnt gases out of exhaust valve.

Thus, an explosion takes place for every two revolutions of the crankshaft.

From this it can be seen that an engine with two cylinders can have them arranged so that an explosion takes place for every revolution of the crankshaft, and, in this way, more even running of the engine is secured.

As a matter of fact this idea is carried still further and engines are constructed as a rule with four cylinders, or even six, eight, or twelve cylinders, the result being as follows:

1 cylinder	1 explosion to	2	revolutions	of shaft.
2 cylinders	1 explosion to	1	revolution	of shaft.
4 cylinders	1 explosion to	½	revolution	of shaft.
8 cylinders	1 explosion to	¼	revolution	of shaft.
12 cylinders	1 explosion to	⅙	revolution	of shaft.

Similarly inlet, compression, exhaust and explosion take place every two, one, one-half, one-fourth or one-sixth revolution of the shaft, according to the number of cylinders.

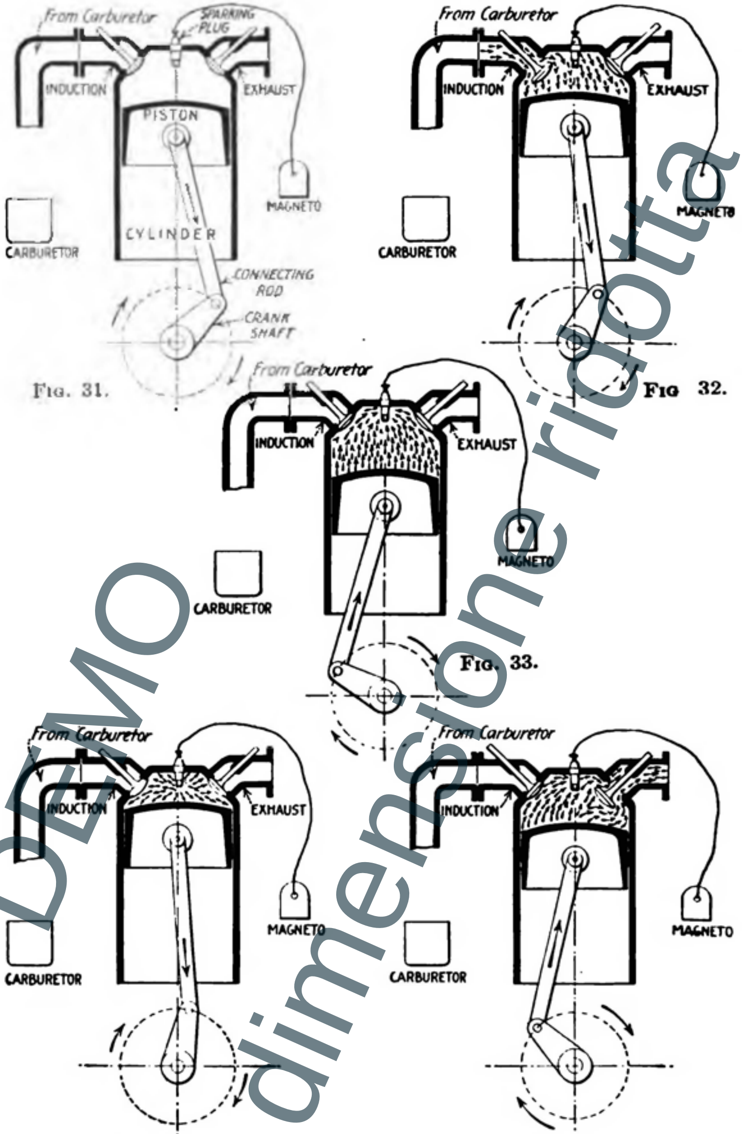


Fig. 31. Fig. 32. Fig. 33. Fig. 34. Fig. 53.

Figs. 31 to 35.—Diagrams of internal combustion engines.

The compression can be readily felt by turning the engine by means of the propeller, but *care must* be taken to see that the ignition is off or an unexpected explosion may take place.

The diagrams, Figs. 31 to 35, are simply made to show how the engine works and actual examples can be seen in the squadron workshops. The parts are named in Fig. 31, to make this clear in every respect. As the piston travels down the cylinder, Fig. 32, the inlet valve opens and the piston sucks in a mixture of gasoline and air. The gasoline is vaporized and mixed with the right proportion of air by the carbureter through which it passes. When the piston comes up, Fig. 33, the inlet valve is closed and the charge is compressed, making it much more explosive. In fact if it is compressed enough it will explode of itself.

When the piston is almost at the top of its stroke, Fig. 34, the magneto sends an electric spark through the spark plug and ignites this explosive

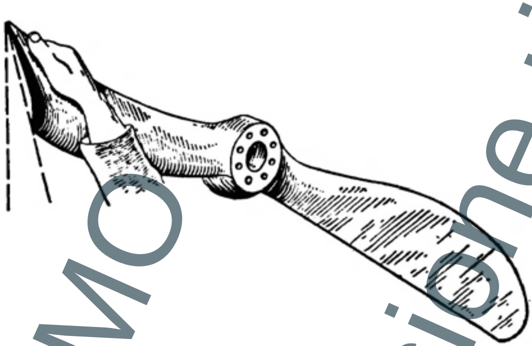


FIG. 36.—How to swing propeller.

charge which drives the piston down and rotates the crankshaft. On the next rise of the piston, Fig. 35, the exhaust valve opens and the burnt gases are forced out of the exhaust. This may be divided into the cycles of the two revolutions necessary to secure a power impulse, as follows:

First Revolution.—Downstroke piston draws in explosive mixture.

Upstroke, compresses mixture, ready for firing.

Second Revolution.—Piston forced down by explosion. Upstroke forces out burnt gases. This gives one explosion in each cylinder for each two revolutions, or four power strokes per revolution for an eight-cylinder engine. The more cylinders the more explosions or power impulses per revolution.

Care should be taken in swinging the propeller to always stand clear of an unexpected explosion or starting of the engine. The compression can be felt as it is turned by hand, but it is safer to have the ignition switch off unless it is desired to start the engine.

The shape of the propeller will readily show which way the engine is to be run as the propeller always screws into the air, no matter whether it is a tractor or a pusher. Then too, the trailing or back edge is always the thin edge as with a wing. Grasp the thin or trailing edge of the propeller and move it slightly to feel the compression. Fig. 36 shows how to take hold of the blade.

Propeller.—Before swinging the propeller (*i.e.*, rotating it to start the engine) it is necessary to know in which *direction it should be turned.*

Unless the propeller has been fitted to the engine incorrectly, it is quite easy to see in which way to turn it.

You must grasp the trailing edge of the blade and you will know it for the trailing edge because it is always much thinner than the leading edge. Move the propeller slightly so that you may "feel" the compression. The rotation of the propeller will now be in such a direction that the flattest side of the blade will engage the air and press against it thus:

Pitch.—The pitch is the distance the propeller will screw through the air in one revolution, supposing the air to be solid. As a matter of fact the air is not solid, and gives back to the thrust of the propeller blades so that the propeller does not travel its full pitch. Such "give-back" is known as *slip.* For instance, the pitch of the propeller may be perhaps 10 feet, and the propeller may have a slip of 2 feet. The propeller would then be said to have 20 per cent. slip.

To test the pitch angle the propeller is mounted on a shaft, the latter being mounted upon and at right angles to a beam. The face of the beam must be perfectly straight and true.

Now select a spot some distance (say about 2 feet) from the center of the propeller and, by means of a protractor, find the angle the chord of the blade makes with the beam. Then lay out the angle on paper thus:

The line marked *chord* represents the chord of the propeller. The line marked *circumference* represents the face of the beam. The angle the two lines make is the angle you have found by means of the protractor.

We will suppose, for the sake of example, that the point at which you have taken the angle is 2 feet from the center of the propeller. Find the circumference at that point by doubling the 2 feet (which is the radius) and then multiplying the result by 3.1417, thus:

$(2 \times 2) \times 3.1417 = 12.5668$ feet, *i.e.*, the circumference at that part of the propeller. Bring it down in scale, and mark it off from the point *A* and along the circumference line. Now draw the line marked pitch from *B* (the end of the circumference measurement of 12.5668 feet) and at right angles to the circumference line (see Fig. 29).

The distance from the base line to the chord line is the pitch of the propeller at that point (see Fig. 37).

It must agree with the specified pitch of the propeller which should be marked on the hub. If it does not do so then the pitch angle is wrong. This may be due: (1) to the propeller blade being distorted; (2) to faulty manufacture; or (3) to the hole through the boss of the propeller being out of place.

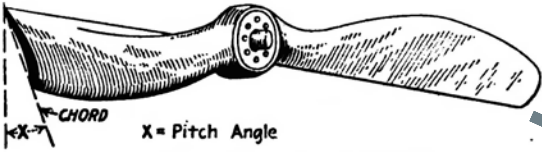


Fig. 37.—Pitch angle of propeller.

Degree of Error Allowed.—You may allow an error up to half a degree more or less of the correct angle, but if it is greater than that you must report the matter.

The propeller should be tested as explained above at points along the blades, the first point about 2 feet from the center of the boss and the others about a foot apart.

Length.—The propeller should be carefully tested to make sure the blades are of equal length. There should not be a difference of more than $\frac{1}{16}$ inch.

Fig. 38.—Testing balance of propeller.

Balance.—The prevailing method of testing for balance is as follows. Mount it upon a shaft. The shaft must be on ball bearings. Place the propeller in a horizontal position, and it should remain in that position.

If a weight of a trifle over an ounce placed in a bolt hole on one side of the boss fails to disturb the balance, then the propeller is unfit for use, as in Fig. 38.

The above method does not, however, test for the balance of centrifugal force, which comes into play as soon as the propeller revolves.

The test for centrifugal balance is as follows:

The propeller must be kept horizontal, and while in that position, weighed at any fixed points, such as *A*, *B*, *C*, *D*, *E*, and *F*, and the weights noted.

Now reverse the propeller and weight at each point again. Note the results. The first series of weights should correspond to the second series, thus:

Weight *A* should equal weight *F*.
Weight *B* should equal weight *E*.
Weight *C* should equal weight *D*.

There is no official ruling as to the degree of error allowed, but if there is any appreciable difference the propeller is unfit for use. The points *A*, *B* and *C* must, of course, be exactly the same distance from the center of the propeller as the points *D*, *E* and *F* (see Fig. 25).

Surface Area.—The surface area of the blades should be equal. Test with calipers, as in Fig. 39.

There is no official ruling as to the degree of error allowed. If, however, there is an error of over ⅛ inch, the propeller is really unfit for use. The points *A*, *B*, *C*, *D*, *E* and *F* must, of course, be exactly the same distance from the center of the propeller as the points *G*, *H*, *I*, *J*, *K* and *L*.

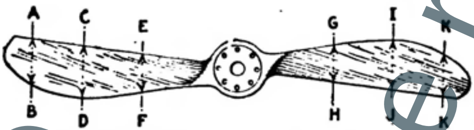


Fig. 39.—Measuring propeller surface.

Camber, i.e. (Curvature).—The camber of the blades should: (1) be equal; (2) it should decrease evenly toward the tips of the blades; and (3) its greatest depth should, at any point of the blade, be at about the same proportion of the chord from the leading edge, as at other points.

It is difficult to test the top camber without a set of templates, but a fairly accurate idea of the concave camber underneath the blade can be secured by slowly passing a straight-edge along the blade—the straight-edge (a steel rule will do) being held at right angles to the length of the blade and touching both leading and trailing edges, thus:

The concave curvature can now be easily seen, and, as you pass the straight-edge along the blade, you should look out for any irregularities of the curvature which should gradually and evenly decrease toward the tip of the blade.

Straightness.—To test for straightness mount the propeller upon a shaft. Now bring the tip of one blade around to graze some fixed object. Mark the point it grazes. Now bring the other tip round and it should come within ⅛ inch of the mark. If it does not do so it is due: (1) to the propeller being distorted; or (2) to the hole through the boss being out of place. In either case it is unfit for use.

Clip Ends.—The general proportions and dimensions for clip ends are shown in Fig. 49. The dimension *A*, which is the width of the arm, depends on the material to which the clip is welded.

Shackles.—The shackle shown in Fig. 50 is formed from a steel forging and the main dimensions are given on page 72.

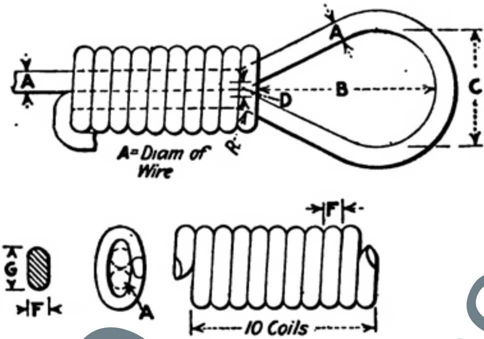


Fig. 44.—Fastenings for hard wire.

Loops

Size of wire *A*	Large loop 0.128	Small loop 0.128	0.102	0.081	0.064
B	9/16	7/16	15/32	13/32	13/32
C	23/64	17/64	9/32	17/64	17/64
D	5/64	1/16	1/32	1/32	1/32
R	13/64	9/64	9/64	9/64	9/64

Ferrules

[illegible]	0.114	0.114	0.091	0.072	0.057

Gages

[illegible]	0.130	0.130	0.104	0.083	0.066
[illegible]	0.260	0.260	0.208	0.166	0.132

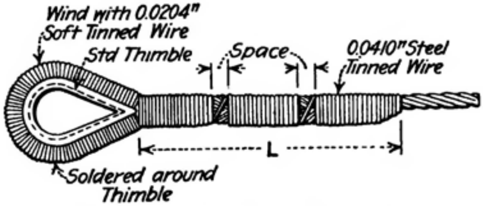


Fig. 45.—Non-flexible cable ends.

Diameter of cable, inches	Number of strands	No. wires per strand	*L*	Space	Wind	Full strength of cable, pounds
1/16	1	19	1½	⅛	1	500
3/32	1	19	2	⅛	1¼	1,100
⅛	1	19	2½	⅛	1½	2,100
5/32	1	19	2¾	⅛	2	3,200
3/16	1	19	3	3/16	2¼	4,600
7/32	1	19	3½	3/16	2¼	6,100
¼	1	19	4	¼	2½	8,000

Note.—Solder without drawing temper of wire. Loop portion served with 0.0204-inch soft-steel tinned wire before thimble is inserted.

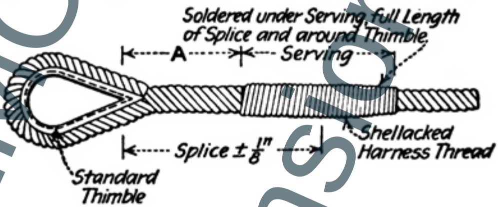


Fig. 46.—Flexible cable ends.

Diameter of cable, inches	Number of strands	No. wires per strand	Length of splice	Length of serving	*A*	Full strength of cable, pounds
3/32	7	14	1¼	1	½	800
⅛	7	19	1½	1	½	2,000
5/32	7	19	1¾	1¼	½	2,800
3/16	7	19	1⅞	1¼	¾	4,200
7/32	7	19	2⅝	1¼	¾	5,600

Note.—Solder full length of splice without drawing temper of wire.

Rod End Pins.—The general appearance of the rod end pins as well as the dimensions suggested are shown in Fig. 51.

Bolts and Nuts.—Fig. 52 shows a type of bolt recommended for general airplane work but not for engine work. These have ball heads and the table gives general dimensions. These are of 3½ per cent. nickel steel. Fig. 53 gives similar dimensions for a plain head bolt while Fig 54 shows both plain and castle nuts with a ball on the under side. Fig 55 shows a plain bottom castle nut and gives its dimensions.

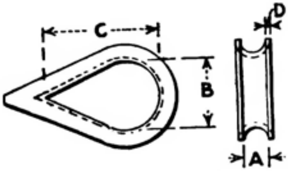


FIG. 47.—Thimble for wire ends.

Size of cable		Thickness of thimble *A*	Width of eye *B*	Length of eye *C*	Thickness of Metal *D*
1/16	0.062	0.09	0.35	0.70	0.032
3/32	0.094	0.09	0.35	0.70	0.032
1/8	0.125	0.13	0.35	0.70	0.032
5/32	0.156	0.17	0.40	0.80	0.032
3/16	0.187	0.21	0.50	1.00	0.032
7/32	0.219	0.24	0.60	1.20	0.032
1/4	0.250	0.25	0.70	1.40	0.032
9/32	0.281	0.30	0.80	1.60	0.032
5/16	0.312	0.33	0.90	1.80	0.040
3/8	0.375	0.39	1.00	2.00	0.040

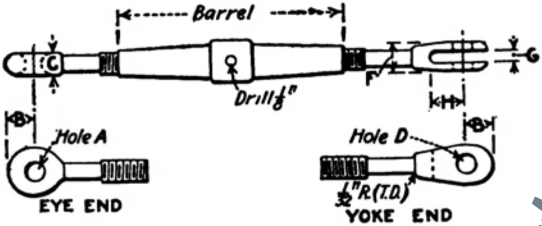


FIG. 48.—Turnbuckles.

No.	Strength in pounds	Eye ends, inches			Yoke ends, inches				
		A	*B*	*C*	*D*	*B*	*F*	*G*	*H*
1	500	5/32	9/32	1/8	3/16	9/32	3/16	5/64	3/8
2	1,000	5/32	9/32	1/8	3/16	9/32	3/16	5/64	3/8
3	1,500	3/16	11/32	3/16	3/16	11/32	1/4	5/64	3/8
4	2,000	13/64	11/32	3/16	3/16	11/32	5/16	7/64	7/16
5	2,500	19/64	13/32	7/32	1/4	13/32	11/32	7/64	7/16
6	3,000	19/64	13/32	7/32	1/4	13/32	11/32	7/64	1/2
7	3,500	19/64	7/16	1/4	1/4	7/16	7/16	13/64	1/2
8	4,000	19/64	7/16	1/4	9/32	7/16	7/16	13/16	9/16
9	4,500	21/64	7/16	9/32	9/32	7/16	1/2	13/64	9/16
10	5,000	21/64	15/32	9/32	9/32	15/32	9/16	17/64	9/16
11	6,000	23/64	15/32	5/16	5/16	15/32	9/16	17/64	9/16
12	7,000	23/64	15/32	5/16	5/16	15/32	5/8	17/64	5/8
13	8,000	25/64	1/2	11/32	5/16	1/2	5/8	21/64	11/16
14	9,000	25/64	1/2	11/32	3/8	1/2	11/16	21/64	11/16
15	10,000	29/64	9/16	3/8	3/8	9/16	11/16	21/64	11/16

Type of turnbuckle....................	Short	Long
Length of barrel......................	2 inches	4 inches
Made in numbers......................	1 to 7 incl.	1 to 15 incl.
Length between centers of eyes with:		
Threads flush with ends of barrel......	4 inches	8 inches
Ends extended a maximum..............	4 3/16	8 3/16
Ends extended a minimum...............	3 1/4	5 1/2

With two eye ends, thread one left-hand and the other right-hand.
With one eye end and one yoke end, thread eye end left-hand.

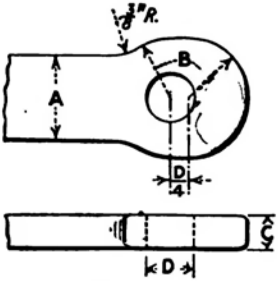


FIG. 49.—Clip ends.

CLIP ENDS

Turnbuckle		A	B	C	D
Number	Strength, pounds				
1	500	....	1/4	1/16	3/16
2	1,000	....	1/4	1/16	3/16
3	1,500	....	1/4	1/16	3/16
4	2,000	....	5/16	3/32	3/16
5	2,500	....	5/16	3/32	1/4
6	3,000	....	3/8	3/32	1/4
7	3,500	....	5/16	3/16	1/4
8	4,000	....	3/8	3/16	9/32
9	4,500	....	3/8	3/16	9/32
10	5,000	....	3/8	1/4	9/32
11	6,000	....	3/8	1/4	5/16
12	7,000	....	7/16	1/4	5/16
13	8,000	....	7/16	5/16	5/16
14	9,000	....	15/32	5/16	3/8
15	10,000	....	15/32	5/16	3/8

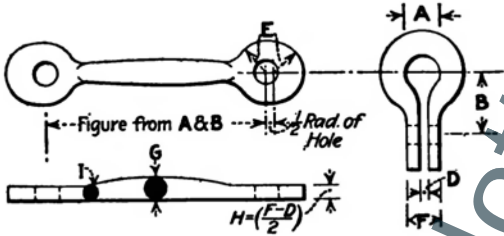


FIG. 50.—Shackles.

Turnbuckle Number	Turnbuckle Strength, pounds	Width of clip lug *D*	Hole size *C*	Radius *E*	Diameter *A*	Length *B*	Diameter *G*	Diameter *I*	Diameter *F*
1	500	5/64	3/16	1/4	1/4	9/16	3/16	5/32	3/16
2	1,000	5/64	3/16	1/4	1/4	9/16	3/16	5/32	3/16
3	1,500	5/64	3/16	1/4	1/4	9/16	3/16	5/32	1/4
4	2,000	7/64	3/16	1/4	1/4	9/16	3/16	5/32	5/16
5	2,500	7/64	1/4	5/16	5/16	5/8	1/4	3/16	11/32
6	3,000	7/64	1/4	5/16	5/16	5/8	1/4	3/16	11/32
7	3,500	13/64	1/4	5/16	5/16	5/8	1/4	3/16	7/16
8	4,000	13/64	9/32	11/32	3/8	11/16	3/8	9/32	7/16
9	4,500	13/64	9/32	11/32	3/8	11/16	3/8	9/32	1/2
10	5,000	17/64	9/32	11/32	3/8	11/16	3/8	9/32	9/16
11	6,000	17/64	5/16	3/8	7/16	3/4	7/16	5/16	9/16
12	7,000	17/64	5/16	3/8	7/16	3/4	7/16	5/16	5/8
13	8,000	21/64	5/16	3/8	7/16	3/4	7/16	5/16	5/8

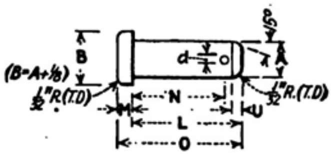


FIG. 51.—Rod end pin.

d = edges chamfered not to exceed 0.01 inch. T.D. = tooling dimension.

Size *A*	1/8	5/32*	3/16	7/32*	1/4	9/32	5/16	3/8	7/16*	1/2*
Limits *A*	−0.002 −0.004	−0.002 −0.004	−0.002 −0.004	−0.002 −0.004	−0.002 −0.004	−0.002 −0.004	−0.002 −0.004	−0.002 −0.004	−0.002 −0.004	−0.004 −0.007
B......	1/4	9/32	5/16	11/32	3/8	13/32	7/16	1/2	9/16	5/8
M.....	3/64	3/64	3/64	3/64	1/16	1/16	1/16	1/16	3/32	3/32
L-N....	3/32	3/32	3/32	3/32	7/64	7/64	9/64	9/64	9/64	9/64
U......	3/64	3/64	3/64	3/64	1/16	1/16	1/16	5/64	5/64	5/64
d......	50	50	48	48	48	48	36	36	36	36
Cotter .	1/16	1/16	1/16	1/16	1/16	1/16	3/32	3/32	3/32	3/32
Length *L*										

* Future sizes.

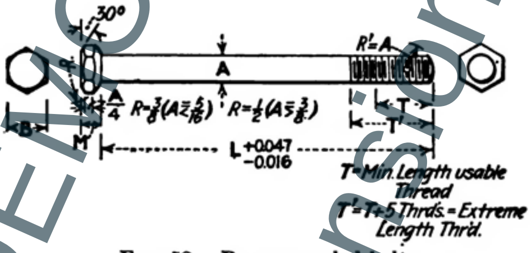


FIG. 52.—Recommended bolt.

All threads U. S. F. *R* = 3/8, [*A* = > 5/16] *R* = 1/2, [*A* = > 3/8]

Size—*A*..............	No. 8*	No. 10*	No. 12*	1/4*	5/16	3/8	7/16	1/2*	9/16*	5/8*
Threads per inch.......	32	32	32	28	24	24	20	20	18	18
Limits—*A*...........	0.160 0.164	0.186 0.190	0.212 0.216	0.246 0.250	0.308 0.312	0.371 0.375	0.433 0.437	0.496 0.500		
Head diameter.—*B*.....	5/16	3/8	3/8	7/16	1/2	9/16	11/16	3/4		
Head height.—*M*......	11/64	11/64	11/64	13/64	1/4	5/16	23/64	3/8		

* Future sizes.

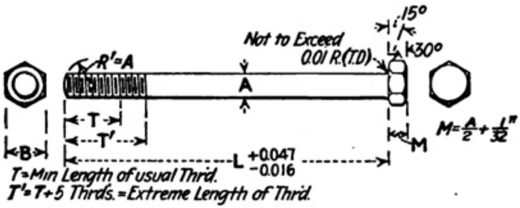


FIG. 53.—Plain head bolt.

All threads U. S. F. $M = \frac{A}{2} + \frac{1}{32}$ T.D. = tooling dimensions.

Size—*A*	No. 8	No. 10	No. 12	¼	5/16	⅜	7/16	½
Threads per inch	32	32	32	28	24	24	20	20
Limits—*A*	0.160	0.186	0.212	0.246	0.308	0.371	0.433	0.496
	0.164	0.190	0.216	0.250	0.312	0.375	0.437	0.500
Head diameter—*B*	5/16	⅜	⅜	7/16	½	9/16	11/16	¾
Head height—*M*	7/64	⅛	9/64	5/32	3/16	7/32	¼	9/32

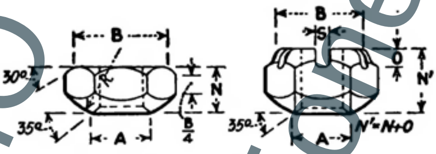


FIG. 54.—Ball seat nuts.

All threads U. S. F. N′ = $N + O$.

A	*B*	*N*	*R*	*A*	*B*	*N′*	*S*	*O*
No. 8	⅜	11/64	⅜	No. 8	⅜	¼	5/64	5/64
No. 10	⅜	11/64	⅜	No. 10	⅜	¼	5/64	5/64
No. 12	7/16	11/64	⅜	No. 12	7/16	17/64	5/64	3/32
¼	7/16	13/64	⅜	¼	7/16	19/64	5/64	3/32
5/16	½	¼	⅜	5/16	½	11/32	5/64	3/32
⅜	9/16	5/16	½	⅜	9/16	7/16	⅛	⅛
7/16	11/16	23/64	½	7/16	11/16	31/64	⅛	⅛
½	¾	⅜	½	½	¾	9/16	⅛	3/16

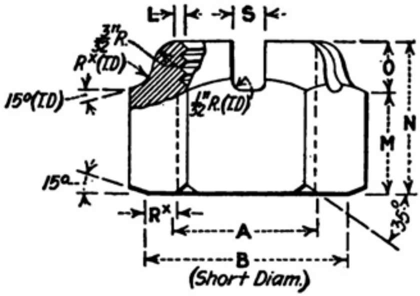


Fig. 55.—Plain castle nut.

All threads U. S. F. *O* = Also depth of slot. *T.D.* = tooling dimension.

A		*B*	*N*	*S*	*O*	*M*	*L*	*R*
No. 8	32	3/8	15/64	5/64	5/64	5/32	1/64	3/32
No. 10	32	3/8	1/4	5/64	5/64	11/64	1/64	3/32
No. 12	32	7/16	17/64	5/64	3/32	11/64	1/32	1/32
1/4	28	7/16	9/32	5/64	3/32	3/16	1/32	3/32
5/16	24	1/2	21/64	5/64	3/32	15/64	1/32	3/32
3/8	24	9/16	13/32	1/8	1/8	9/32	1/32	3/32
7/16	20	11/16	29/64	1/8	1/8	21/64	3/64	1/8
1/2	20	3/4	9/16	1/8	3/16	3/8	3/64	1/8

Magneto Base.—In order to facilitate the interchange of magnetos of different makes the dimensions shown in Fig. 56 are recommended for all magneto bases.

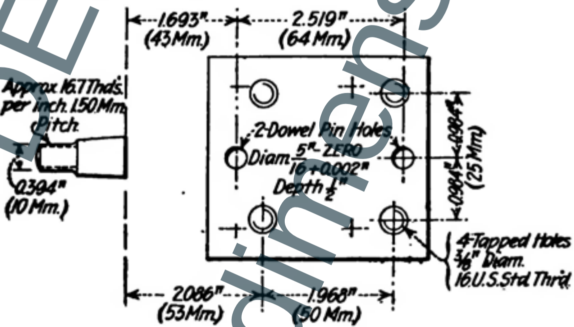


Fig. 56.—Magneto base.

Pipe-line Markings.—It is proposed to mark fuel pipe lines with red bands, lubrication pipe lines with white bands and air lines with blue bands for easily tracing all connections. These bands are recommended to be ½ inch wide and not over 24 inches apart.

Engine Supports.—The following dimensions (in inches) are recommended for standard engine supports:

Distance between timbers	12	14	16
Width of bed timbers	2	2¼	2½
Distance between centers of bolts	14	16¼	18½

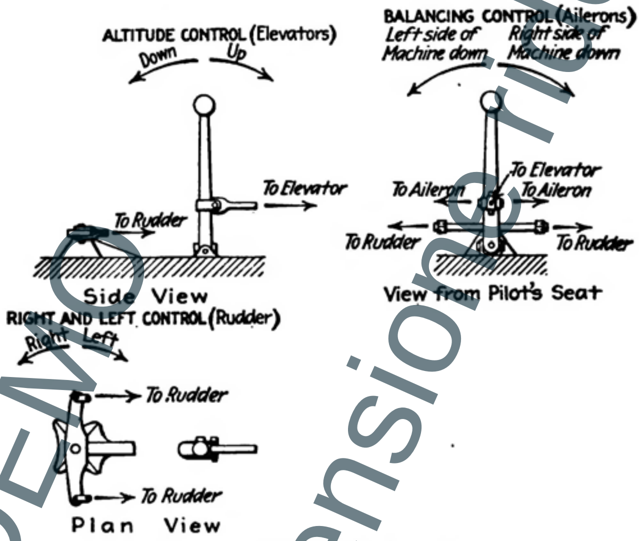


Fig. 57.—Standard stick control.

Spark-plug Dimensions.—The following dimensions for spark-plugs are recommended:

Thread: 18 millimeter, 1½-millimeter pitch.

Form of thread: international standard (same as U. S. standard only with one-half as much truncation at root of thread).

Gasket shoulder to end of shell: ⅝ inch.

Stick Control.—The illustration in Fig 57 shows the stick type of control in outline. No proportions are given but the general idea is clearly shown. This is used mostly on the small, fast airplanes.

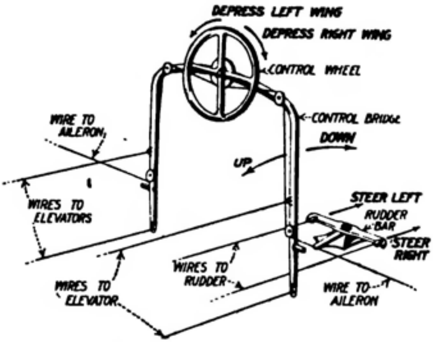


Fig. 58.—"Dep." control.

Wheel or Column Control.—This is shown in Fig. 58 and is sometimes known as the "Dep" (Deperdussin) of column control. This is more suitable for large, heavy machines with large aileron surfaces to be moved.

SECTION VI

WOODS FOR AIRPLANE CONSTRUCTION

The majority of the wood used in airplane construction is spruce and in order to secure suitable and uniform material, specifications have been drawn up as a guide in accepting material offered.

The specifications which have been proposed by the spruce men and which received the informal approval of the Government's representatives present are as follows:

Thickness.—Two to 6 inches, inclusive. At least 60 per cent. to be 3 inches and 4 inches thick. Not more than 40 per cent. 2 inches, 5 inches, and 6 inches thick.

Width.—All to be 4 inches and wider; not over 10 per cent. under 5 inches wide.

Length.—Fifty per cent. to be 18 feet and longer. Fifty per cent. to be 4 feet and longer.

Measurement.—Width and thickness fractional. Lengths in multiples of 1 foot.

Grain.—All lumber 3 inches and thicker shall be not less than 70 per cent. vertical grain of an angle of 45 to 90 degrees on each carload. All lumber 2 inches thick shall be not less than 30 per cent. vertical grain of an angle of 45 to 90 degrees on each carload.

Grades.—The grades agreed to are as follows:

GRADES AGREED UPON

The 50 per cent. of all lumber 18 feet and longer shall be clear four sides, straight grained, not less than six annular growth rings for each 1 inch, sound and well manufactured, free from shakes, spiral and curly grain.

This grade will admit of bright sap, wane, pinworm holes, slight variations in sawing, or other defects that will not impair its use for wing beams.

The 50 per cent. of all lumber 4 feet and longer shall yield clear cuttings, straight grained, not less than six annular growth rings per each 1 inch, sound and well manufactured, free from shake, spiral, and curly grain; some may contain knots, pitch pockets, wane, pinworm holes, slight variations in sawing, and other defects that will not impair its use for the purpose intended, providing, however, that each piece must produce, for buyer, clear straight grain, cuttings from 4-foot to 17-foot lengths, which shall not include over 5 per cent. of such cuttings 4 feet to 7 feet, inclusive.

The requirement regarding the number of rings per inch is the one most likely to cause trouble as the number of rings depends on whether the tree grew in good soil or poor to some extent and there is plenty of perfectly good spruce with from two to four rings per inch. This particular requirement will doubtless have to be modified according to the judgment of the inspector in order to obtain sufficient material.

Bending				Tension		
Woods	Ultimate stress, lb. sq. in.	E = Modul. of elasticity, lb.	Weight per cubic lb. foot	Woods	Ultimate stress	E
Solid square sections						
Ash	14,300	1,550,000	47	Bamboo	39,000	3,200,000
American elm	14,400	1,700,000	46	Mahogany	20,000	1,600,000
Mahogany	11,500	1,600,000	34	Yellow pine	20,000	2,070,000
Hickory	16,000	2,400,000	51	Ash	17,000	1,550,000
Pear	9,500	1,000,000	44	Spruce	12,400	1,700,000
Yellow pine	12,600	2,070,000	38			
White pine	7,900	1,390,000	24	Compression		
Spruce	11,000	1,700,000	39	Ash	9,500	1,550,000
Birch	11,500	1,650,000	45	Mahogany	8,000	1,600,000
Oak	12,500	1,600,000	56	Spruce	8,500	1,700,000
Sections round & hollow				Yellow pine	8,000	2,070,000
Bamboo	22,500	3,200,000	55			
Ash	14,300	1,550,000	47			

LOST POWER AND OVERHEATING.—(*Continued*)

Part at fault	Trouble	Effect	Remedy
35 Cylinder wall	Scored Poor lubrication causes friction	Poor compression and overheating	Replace with new Lap in cylinder Repair oiling system
36 Camshaft Drive gear	Loose on shaft Not properly meshed Worn or broken teeth	Irregular valve action	Fasten to shaft Time properly Replace with new
37 Crankshaft	Scored or rough on journals Sprung	Overheating Overheating	Smooth up Straighten
38 Crankpin Bearings and main bearings	Adjusted too tight Defective oiling	Overheating	Adjust to running clearance Clean out oil holes
39 Oil sump	Insufficient oiling Poor oil Dirty oil	Overheating and burned-out bearings	Replenish supply Use best oil—Mobile "A" recommended Wash with kerosene Replace with new oil
40 Water space and water pipes	Clogged with sediment or scale	Overheating	Dissolve and remove foreign material
41 Radiator hose	Layer of hose obstructs opening	Overheating	Refit or replace with new
42 Water pump	Impeller loose on shaft Dirty Broken	Overheating	Fasten to shaft Clean Replace with new

Noisy Operation

Part at fault	Trouble	Effect	Remedy
43 Spark plug	Leakage	Hissing	Screw down tighter Replace with new
44 Cylinder wall	Scored	Knocking	Smooth up or replace with new
45 Manifold pipe joints	Leakage Defective gaskets	Sharp hissing	Tighten bolts Replace with new
46 Combustion chamber	Carbon deposit	Knocking	Remove carbon
47 Cylinder casting	Retaining bolts loose	Sharp metallic knock	Tighten bolts
48 Cam	Worn contour	Metallic knock	Replace with new
49 Piston head	Carbon deposit	Knock	Remove carbon
50 Wristpin	Loose in piston Worn	Dull metallic knock	Replace or bush
51 Connecting rod	Worn at wristpin or crankshaft Sideplay in piston	Distinct knock	Adjust or replace Scrape and fit and oil
52 Main crankshaft bearing	Loose Defective lubrication	Metallic knock Squeak	Fit caps close to shaft Clean out oil holes and oil
53 Connecting-rod bearings	Loose Excessive play Binding	Intermittent metallic knock Knock and squeak	Refit Reline
54 Connecting-rod bolts, main-bearing bolts	Loose Stripped threads	Sharp knock	Tighten Replace bolts

NOISY OPERATION.—(*Continued*)

Part at fault	Trouble	Effect	Remedy
55 Lower half Crank-case bolts	Loose Stripped threads	Knock and rattle	Tighten New bolts
56 Water jacket	Covered with scale Clogged with dirt	Knock caused by overheating	Dissolve scale and flush out water space with water under pressure
57 Timing gears	Loose Worn or broken teeth Meshed too deeply	Metallic knock Rattle Grinding	Fasten to shaft Replace with new gear
58 Camshaft bearing	Loose or worn	Slight knock	Replace with new
59 Inlet-valve seat	Warped or pitted Dirty	Rattle Poor compression Blowback	Use reseat reamer Clean off and grind to seat
60 Inlet-valve spring	Weak or broken	Blowback in carbureter	Replace with new
61 Inlet valve	Closes late Opens early	Blowback in carbureter	Time properly
62 Valve-stem guide	Worn or loose	Rattle or click	Replace with new guide
63 Cam-follower guide	Loose	Rattle or click	Replace with new guide
64 Valve-stem clearance	Too much Too little	Click Blowback in carbureter	Set inlet gap 0.010 Set exh. gap 0.010
65 Push-rod retention stirrups	Nuts loose	Rattle Blowback in carbureter	Tighten nuts
66 Crank-case gaskets	Leak	Oil leak	Tighten bolts Replace with new
67 Cylinder or piston	No oil Poor oil	Grinding and sharp knock	Repair oil system Use best oil

Noisy Operation.—(*Continued*)

Part at fault	Trouble	Effect	Remedy
68 Piston	Binding in cylinder Worm oval causing side slap	Grind or dull squeak Dull hammer	Lap off excess metal Replace with new
69 Oil sump	Insufficient oil Poor oil	Grind and squeak in all bearings	Replenish with best oil
70 Piston rings	Defective oiling	Squeak, hiss, grind	Replace with new ring Repair oil system
71 Crankshaft	Defective oiling	Squeak	Clean out oil holes Use best oil Repair oil system
72 Engine base	Loose on frame	Dull pound	Tighten bolts
73 Water pipe	Leak Clogged Defective gaskets	Engine heats	Tighten connections Clean Replace with new

Important Dont's

1. Don't forget that "A stitch in time saves nine."
2. Don't forget to inspect the motor thoroughly before starting.
3. Don't try to start without oil, water, or gasoline; all three are vital.
4. Don't forget to see that the radiator is full of water.
5. Don't get dirt or water into the oil.
6. Don't get dirt or water into the gasoline.
7. Don't forget to oil all exposed working parts.
8. Don't try to start without retarding the magneto; a serious accident may result.
9. Don't try to start without turning on the switch.
10. Don't start the motor with throttle wide open.
11. Don't run the motor idle too long; it is not only wasteful but harmful.
12. Don't forget to watch the lubrication; it is most essential.
13. Don't forget that the propeller is the business end of the motor; treat it with profound respect—especially when it is in motion.
14. Don't cut off the ignition suddenly when the motor is hot; allow it to idle for a few minutes at low speed before turning off the switch. This

insures the forced circulation of the water till the cylinder walls have cooled considerably and also allows the valves to cool, preventing possible warping.

15. Don't fail to study the trouble charts in this book before you molest a thing about the motor, if you have trouble.

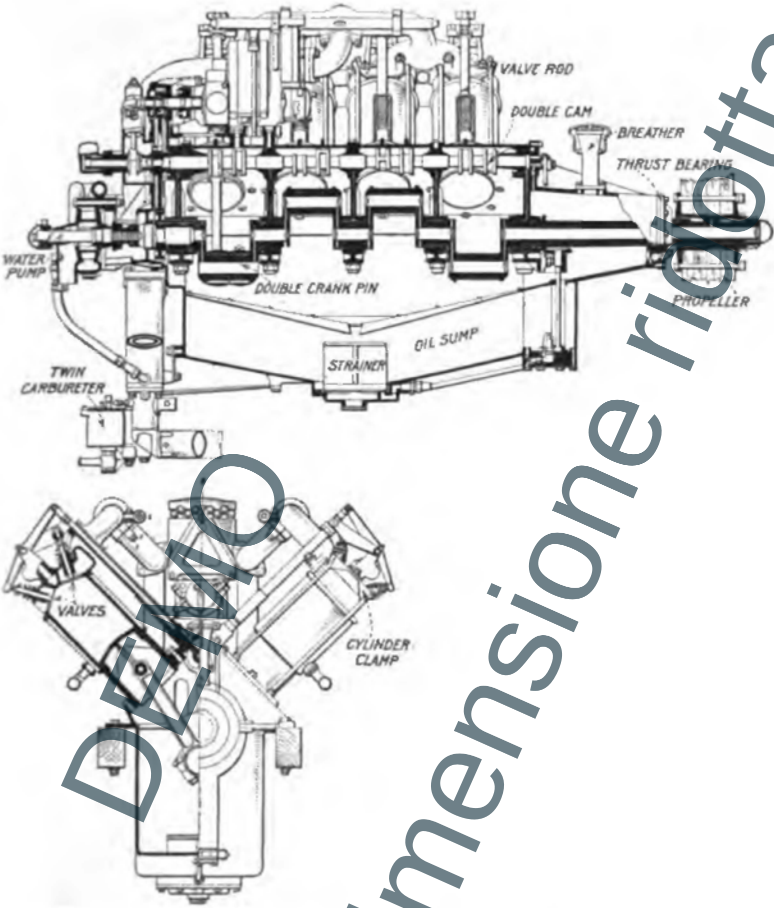


FIG. 60.—Section view of Curtiss engine.

16. Don't develop that destructive disease known as tinkeritis; when the motor is working all right, let it alone.

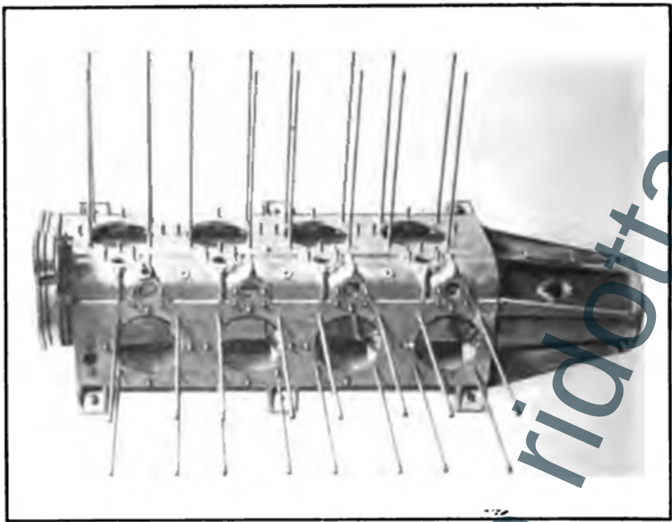


Fig. 61.—Engine base with studs.

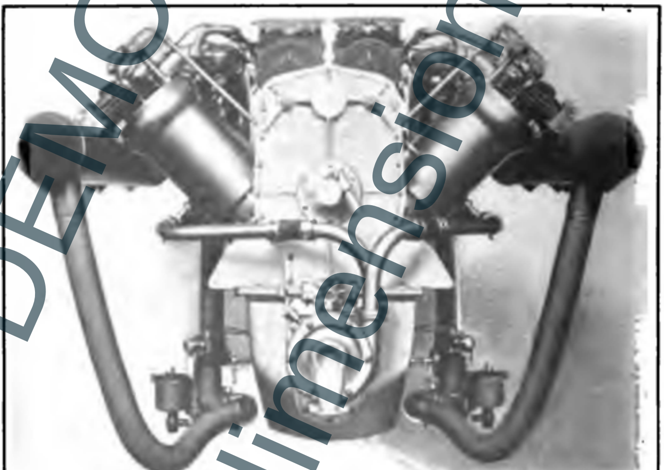


Fig. 62.—End view of Curtiss engine.

17. Don't forget a daily inspection of all bolts and nuts. Keep them well tightened.

18. Don't fail to stop your motor instantly upon detecting a knock, a grind, or other noise foreign to perfect operation. It may mean the difference between saving or ruining the motor.

19. Don't fail to study these instructions thoroughly.

A sectional view of the Curtiss engine is shown in Fig. 60 and the cylinder base with all the studs in position is shown in

FIG. 63.—Fitting piston pin.

Fig. 61. The short studs simply project through the cylinder flange while the long studs go through a cross-tie at the top of the cylinder. An end view is shown in Fig. 62.

The piston pin bears in the aluminum piston itself and as the piston expands more than the pin, it is necessary to make the pin a tight fit when the parts are cold. In order to secure uniformity in this the fit is "weighed" as shown in Fig. 63. Here the piston is held in suitable jaws to prevent marring or springing and the fit tested by using a spring balance as shown. This,

Fig. 64.—Straightening connecting rods.

when hooked into the upper end of the rod, must move the pin with a pull of 12 pounds.

When connecting rods are bent or twisted out of line they can be straightened as shown in Fig. 64. This is a substantial fixture on which the large end is held as shown. Then a rod is put through the piston-pin hole and any slight correction made. The rod is then swung over so the rod comes into con-

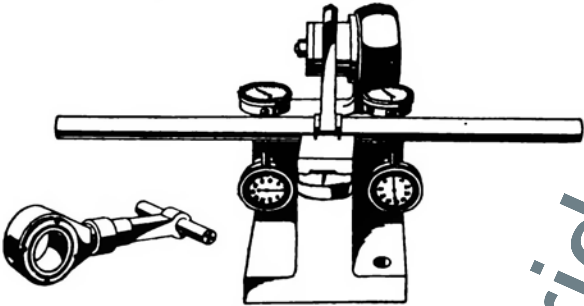


Fig. 65.

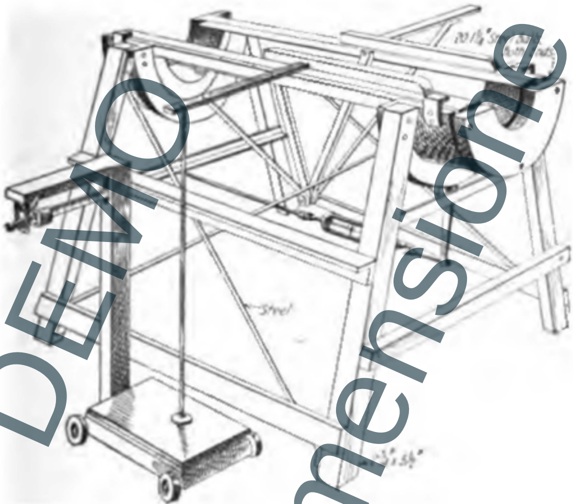


Fig. 66.—Curtiss testing stand.

tact with the four Ames dial gages and shows when the rod is straight as in Fig. 65. Standard rods used for testing are shown in both cases.

After the engine is assembled it is tested on the stand shown in Fig. 66, which can show both torque and thrust. The engine sets in a cradle mounted on ball bearings and free to turn or move forward a limited amount. The turning effort or torque, is measured by the platform scale and the thrust by the spring balance shown in Fig. 66.

SECTION IX

CARE AND OPERATION HALL-SCOTT AIRPLANE ENGINES

The Hall-Scott engine is a six-cylinder vertical type and is being largely used in training machines. Those in charge of the engine should observe the following suggestions.

To Insure Maximum Service.—The following instructions should be carried out after every long flight. If used for schooling purposes, daily care should be taken, as follows:

While engine is still warm remove all spark plugs.

Clean each plug with gasoline and a stiff brush, and space each plug with proper 0.015-inch gage.

Remove lower crank-case sump plug, and drain oil into a clean measure, cover same and allow to stand until morning.

Clean out lower crank case thoroughly with gasoline or kerosene.

Squirt gun full of kerosene into each cylinder through spark-plug opening.

Remove front portion magneto distributor cover and wipe out distributor block with soft cloth, moistened in alcohol if necessary.

In replacing distributor block be sure to wipe off all excess oil on magnetos and covers before replacing.

Cover engine for night with canvas or heavy cloth.

To Prepare Engine for Service.—Turn engine over a few times and note that all working parts are perfectly free

Replace lower oil sump.

Pour off top of oil left to stand over night, into a clean measure, making sure that the heavier portion of oil and carbon deposit is left in first measure. Add to the second measure enough new oil to make 2½ to 3 gallons.

Pour oil into sump through breather pipe lead.

Replace spark plugs and connect lead wires.

The engine is now ready to start. Run slowly with engine throttled for at least 10 minutes while the plane is on the ground, before starting on flight, so that the lubricating oil will have a chance to work up on the cylinders and pistons.

Standard Adjustments

Spark plugs should have 0.015-inch clearance between points across which the spark jumps.

Magneto Breaker Points.—Gap between breaker points in *Dixie Magnetos* when full open should be 0.020. Use gage furnished with each magneto screw-driver. It might be possible to obtain better results if the breaker gap is closed to 0.018. We recommend trying the gap with a 0.020 adjustment; if the motor misses at high speeds readjust to 0.018, which possibly will give better results.

Oil Pressure.—Oil pressure will vary according to weather conditions and gravity of oil used. In normal weather with engine properly warmed up, the pressure will register upon the oil gage from **5 to 10 pounds** when engine is turning from 1275 to 1300 r.p.m.

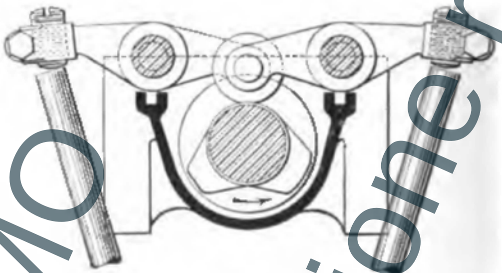


Fig. 67.—Valve clearances.

Air Pressure.—Air-pressure gage should not register under 3 pounds.

Valve Clearances.—Inlet and exhaust valves should be set with a full 0.020-inch clearance *when engine is cold* (see Fig. 67). This should be checked by a Hall-Scott timing disc.

Gear Clearances.—With the exception of the lower pinion shaft gear meshing with the crankshaft, which has a 0.010-inch clearance, all other gears have a 0.020-inch clearance.

Bearing Clearances.—Crankshaft bearings should have a 0.001-inch clearance.

Connecting rods should be set up snug, allowing enough clearance, however, so that the rod may be slid laterally on the crankskaft bearing without binding.

Lubrication System.—The proper lubrication of all airplane engines is of vital importance.

Oils best adapted for Hall-Scott engines have the following properties: A flash test of not less than 400°F.; viscosity of not less than 75 to 85 taken at 212°F. with Saybolts Universal Viscosimeter. The makers suggest:

Zeroline heavy-duty oil, manufactured by the Standard Oil Co. of California, or

Gargoyle mobile B oil, manufactured by the Vacuum Oil Co. Both fulfill the above specifications. One or the other of these oils can be obtained all over the world.

Monogram extra heavy is also recommended.

Do not experiment with other oils without first obtaining the approval of the makers.

Engine Oiling System.—Crankshaft, connecting rods and all other parts within the crank case and cylinders are lubricated directly or indirectly by a force-feed oiling system. The cylinder walls and wristpins are lubricated by oil spray thrown from the lower end of connecting-rod bearings. Fig. 68 shows engine partially in section.

This system is used only upon A-5 engines. Upon A-7a and A-5a engines a small tube supplies oil from connecting-rod bearing directly upon wristpin.

Engine Oiling Circulation.—The oil is drawn from the strainer located at the lowest portion of the lower crank case, forced around the main intake manifold oil jacket. From here it is circulated to the main distributing pipe located along the lower left-hand side of upper crank case. The oil is then forced directly to the lower side of crankshaft through holes drilled in each main bearing cap. Leakage from these main bearings is caught in scuppers placed upon the checks of the crankshafts furnishing oil under pressure to the connecting-rod bearings. A-7a and A-5a engines have small tubes leading from these bearings which conveys the oil under pressure to the wristpins.

Bypass.—A bypass located at the front end of the distributing oil pipe can be regulated to lessen or raise the pressure. By screwing the valve in, the pressure will raise and more oil will be forced to the bearings. By unscrewing, pressure is reduced and less oil is fed.

A-7a and A-5a engines have oil relief valves located just off of the main oil pump in the lower crank case. This regulates the pressure at all times so that in cold weather there will be no danger of bursting oil pipes due to excessive pressure. If it is found that the oil pressure is not maintained at a high enough level inspect this valve. A stronger spring will not allow the oil to bypass so freely and consequently the pressure will be raised, a weaker spring will bypass more oil and reduce the oil pressure materially.

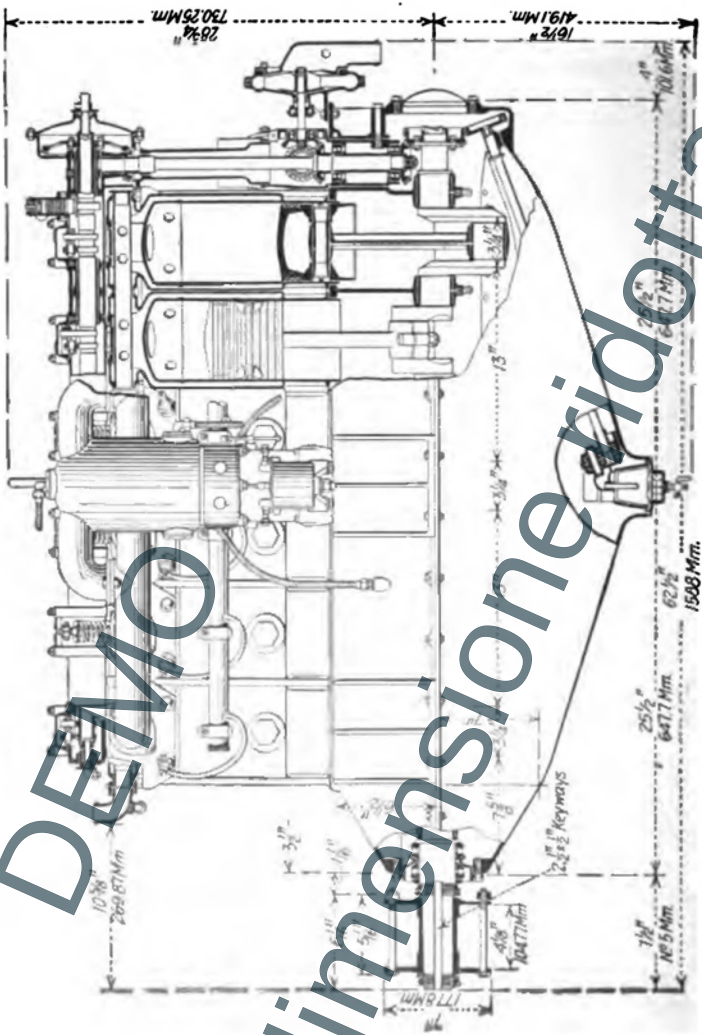


FIG. 68.—Hall-Scott engine.

so as to hold them firmly in position during the welding operation. In this connection it is interesting to note that a large heating furnace has been provided into which the crank case, already bolted on its heavy cast-iron form, can be heated as hot as may be necessary, before the welding is attempted. This, in some instances, is about 200 degrees below Fahrenheit, the melting point of the alloy, as this temperature has been found to assist the welding to a large degree and also to prevent warping after the piece is removed from the cast-iron form.

There is also considerable repair work on the engine radiators, which means sheet-metal work, soldering and brazing to a considerable extent. In all the repair departments it is necessary to exercise extreme care, particularly when green men are being broken in.

SECTION XXIII

INSTRUMENTS FOR AIRPLANES

The aviator requires a number of instruments to insure proper handling of the machine. Some of these are necessary because the aviator has no means of knowing his exact position without

Fig. 182.

them. High in air, or in the clouds with no sight of land, he cannot tell when he is flying level, climbing too steeply or banked to a dangerous degree, without some instruments to tell him his position.

These instruments are: tachometer or engine speed indicator, which sometimes includes a counter to give total engine revolutions; compass; clinometer; banking indicator; incidence indicator; altimeter; radiator thermometer; air speed indicator; drift indicator; stabilizer; clock; map board; engine controls; fuel and lubricating gages; ignition switches, bomb sighting and dropping mechanism; camera and machine gun.

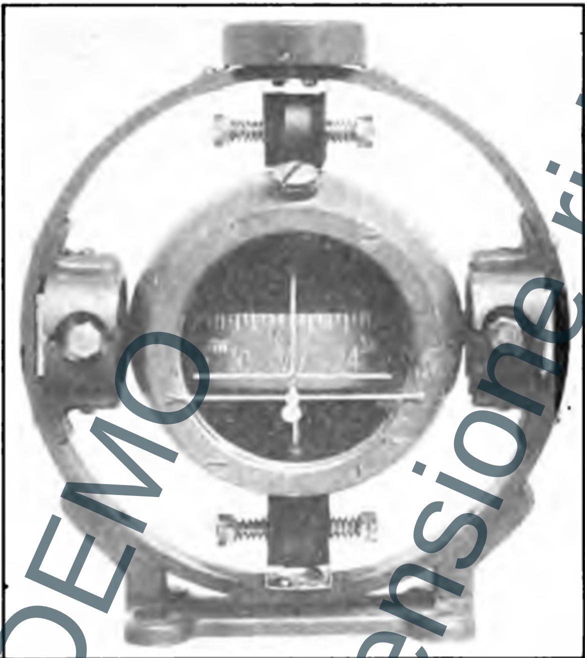


Fig. 183.

The tachometer is practically a speedometer similar to those used in automobiles.

The compass aids in navigation as at sea, two types being shown in Figs. 182 and 183. These are Creagh-Osborne liquid compasses, Fig. 182, being of the usual horizontal type. The inner bowl is filled with a mixture of alcohol and distilled water, the compass card floating in the liquid. The inner bowl rests on horse hair which acts as a spring to absorb vibration.

The mixture of liquid for air compasses varies from 45 per cent. alcohol and 55 per cent. of water to almost pure alcohol. The high percentage of alcohol is to prevent freezing at high altitudes.

In shipping liquid compasses, the jar due to transit almost invariably causes bubbles to appear in the liquid. This can be readily remedied by carefully removing the inner bowl, taking out the filling plug and adding a few drops of either alcohol or distilled water with a medicine dropper or fountain pen filler. This applies to both types of compass.

In the second compass shown, the graduations are on the outside rim of a ring which is mounted on the float. This float is centered on a suitable jeweled pivot in both cases.

This compass is held in the outer ring by means of the four spring mountings shown. These also contain soft iron cores with which to correct certain compass errors, while the small round compartment on top holds permanent magnets when necessary, to correct other errors. The correction of these errors can hardly be taken up here, as it requires long experience to insure success.

The small arrow on the wire across the face of the compass can be set to allow for the drifting of the plane. The vertical white line is a wire from which the readings are taken. The horizontal line acts to some extent as a banking indicator by showing when the machine is out of the horizontal. The indicating wires and the figures and graduations on both compasses are painted with radium material so as to show at night with no outside illumination.

The Sperry Clinometer is shown in Fig. 184. This is mounted on the back side of the dash with the small round portion projecting through. This shows the angle of the plane with the horizontal and shows the aviator whether the angle is safe for his plane. The scale is on the rim of a wheel which is weighted and the case turns around the wheel.

A very neat instrument is the Sperry banking indicator in Fig. 185. The outline of the airplane is set level with the machine and the white bar is connected to a pendulum inside the case. When the plane is banked for, a turn the pendulum flies to the outer side of the circle and swings the white line out of the horizontal just in proportion to the radius and speed of the turn.

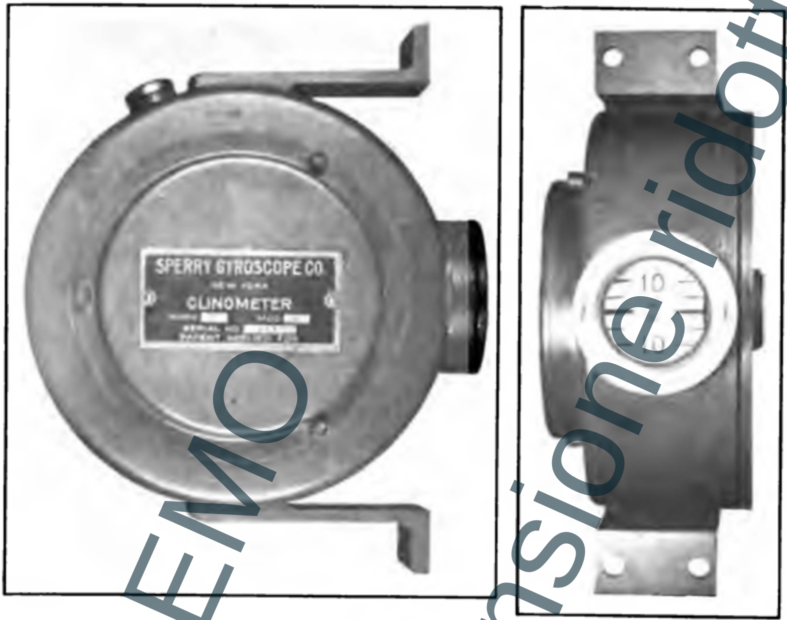


Fig. 184.

If the airplane is banked the proper amount, the white line and the outline of the plane will be parallel the same as when the machine is level.

If the plane is not properly banked for the turn, the lines will show which way the machine should be tipped and how much. It is a very simple device and very efficient. The two screws allow adjusting to the plane without requiring too careful work in mounting.

Fig. 185.

Fig. 186.

A very necessary instrument is the Clark angle of incidence indicator in Fig. 186. This fastens to one of the struts between the wings, preferably so that the pointer and scale can be seen by the pilot. The vane is so proportioned that it remains level when the plane is in motion.

Electrical connections run to the round indicator shown, this being located on the dash, and containing three lamps, green, red, and white. The indicating valve is so adjusted that when flying level no light burns. When climbing the *green* light shows when the proper climbing angle for best efficiency is reached.

Fig. 187.

If this climbing angle is increased to the stalling point—which is the danger point, the *red* light signals the aviator to decrease his angle.

Should he volplane (or glide) at too steep an angle and attain a dangerous speed, the *white* light is shown.

The three lights give a positive tell-tale as to flying conditions and make this a particularly valuable instrument.

THE CLOCK

A high grade, jeweled clock is also an important part of the equipment of a modern airplane as correct timing is very necessary for nearly all military operations.

ALTIMETER OR ALTITUDE BAROMETER

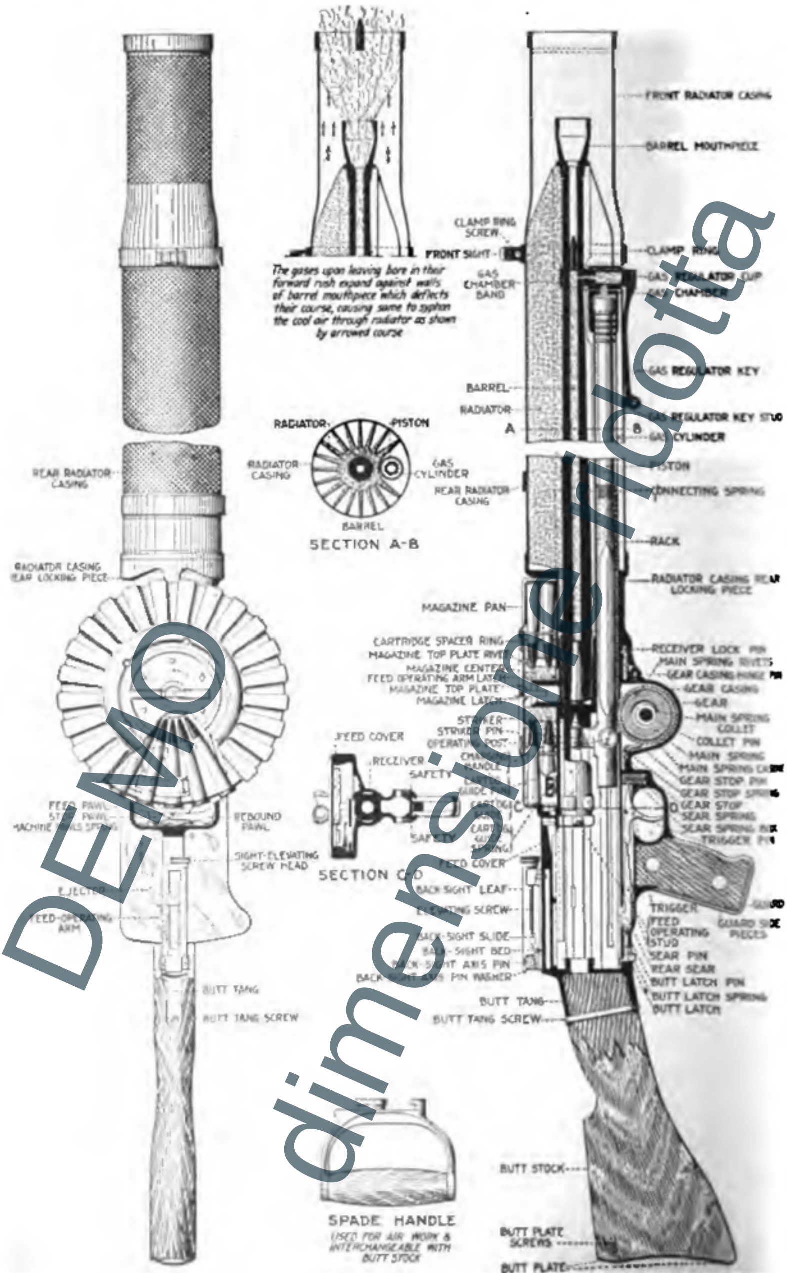
This instrument, Fig. 187, shows the height of the airplane above the earth. It contains a metal vacuum box or chamber which is acted on by the varying density of the atmosphere. This actuates a hand and shows the height on the dial. The dial is adjusted to zero on the ground so as to show the flying height at that altitude. The lock shown holds the dial in the position set. The dial diameter is about 4 inches and both dial and hand are made luminous in the dark by radium material.

SECTION XXIV

THE LEWIS MACHINE GUN

The Lewis machine gun is used very largely in airplane work and has proved very successful. It is a gas-operated gun and has a positive air-cooling device somewhat along the lines of the Franklin method of cooling gas-engine cylinders. It has a rotating drum magazine which holds 47 cartridges and double drums are also used holding 50 more than this number. The gun alone weighs 26 pounds 12 ounces and with the army tripod and magazine in place it weighs 30 pounds 2½ ounces. For airplane use it has a special gun mounting which allows it to be easily swivelled into almost any position. See Fig. 188.

The barrel is surrounded by, and throughout its length is in direct metallic contact with, an aluminum radiator. The radiator has high longitudinal radial fins, and it is inclosed in a steel radiator casing that is open at both ends and extends forward beyond the muzzle of the barrel. The barrel mouthpiece, secured to the barrel by a left-handed thread, contains a cup-shaped aperture designed to direct the muzzle blast into the forward extension of the radiator casing so as to induce suction of air from breech to muzzle inside the radiator casing and along the surfaces of the fins. Near the barrel muzzle and in its under side is a port through which powder gas at barrel pressure is admitted during the time required for the bullet to pass from the port to the muzzle. The powder gas passes into a gas chamber and thence into a gas cylinder beneath the barrel and parallel with it, in which it drives a piston rearward. The piston is pinned securely to the rack, which is provided with teeth on its lower surface meshing with teeth in the periphery of the gear.


The gases upon leaving bore in their forward rush expand against walls of barrel mouthpiece which deflects their course, causing same to syphon the cool air through radiator as shown by arrowed course
REAR RADIATOR CASING
RADIATOR CASING REAR LOCKING PIECE
FEED PAWL
STOP PAWL
REBOUND PAWL
SIGHT-ELEVATING SCREW HEAD
EJECTOR
FEED-OPERATING ARM
BUTT TANG
BUTT TANG SCREW
RADIATOR
PISTON
RADIATOR CASING
GAS CYLINDER
BARREL
SECTION A-B
FEED COVER
RECEIVER
SAFETY
SECTION C-D
SPADE HANDLE
USED FOR AIR WORK & INTERCHANGEABLE WITH BUTT STOCK
FRONT RADIATOR CASING
BARREL MOUTHPIECE
CLAMP RING SCREW
FRONT SIGHT
CLAMP RING
GAS CHAMBER BAND
GAS REGULATOR CUP
GAS CHAMBER
GAS REGULATOR KEY
GAS REGULATOR KEY STUD
GAS CYLINDER
PISTON
CONNECTING SPRING
REAR RADIATOR CASING
RACK
RADIATOR CASING REAR LOCKING PIECE
MAGAZINE PAN
CARTRIDGE SPACER RING
MAGAZINE TOP PLATE RIVET
MAGAZINE CENTER
FEED OPERATING ARM LATCH
MAGAZINE TOP PLATE
MAGAZINE LATCH
RECEIVER LOCK PIN
MAIN SPRING RIVETS
GEAR CASING HINGE PIN
GEAR CASING
GEAR
STRIKER
STRIKER PIN
OPERATING POST
MAIN SPRING COLLET
COLLET PIN
MAIN SPRING
GEAR STOP PIN
GEAR STOP SPRING
GEAR STOP
SEAR SPRING
TRIGGER PIN
FEED COVER
BACK SIGHT LEAF
ELEVATING SCREW
BACK-SIGHT SLIDE
BACK-SIGHT BED
BACK-SIGHT AXIS PIN
TRIGGER
GUARD
FEED OPERATING STUD
GUARD SIDE PIECES
SEAR PIN
REAR SEAR
BUTT LATCH PIN
BUTT LATCH SPRING
BUTT LATCH
BUTT TANG
BUTT TANG SCREW
BUTT STOCK
BUTT PLATE SCREWS
BUTT PLATE

Snaking.—Wire (soft) wound spirally or tied around another wire and attached at each end to the framework. Used to prevent the wire around which it is "snaked" from being entangled in propeller in case of breakage.

Yaw.—To swing off the course about the vertical axis, owing to gusts or lack of directional stability.

Angle of.—The temporary angular deviation of the fore-and-aft axis from the course.

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