

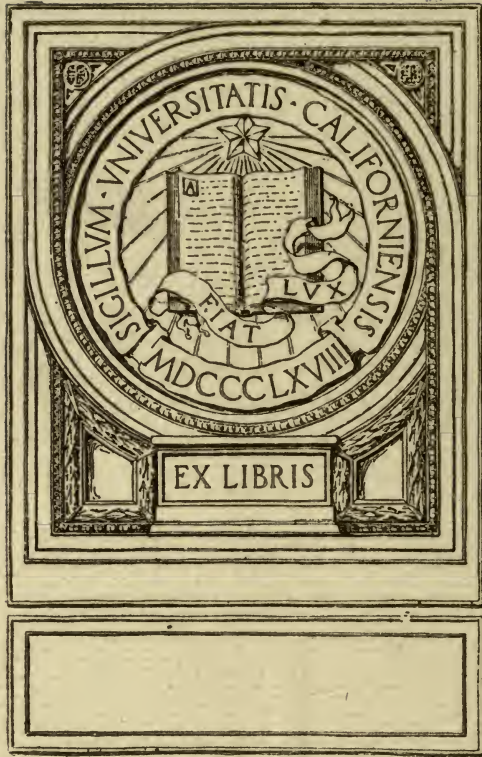
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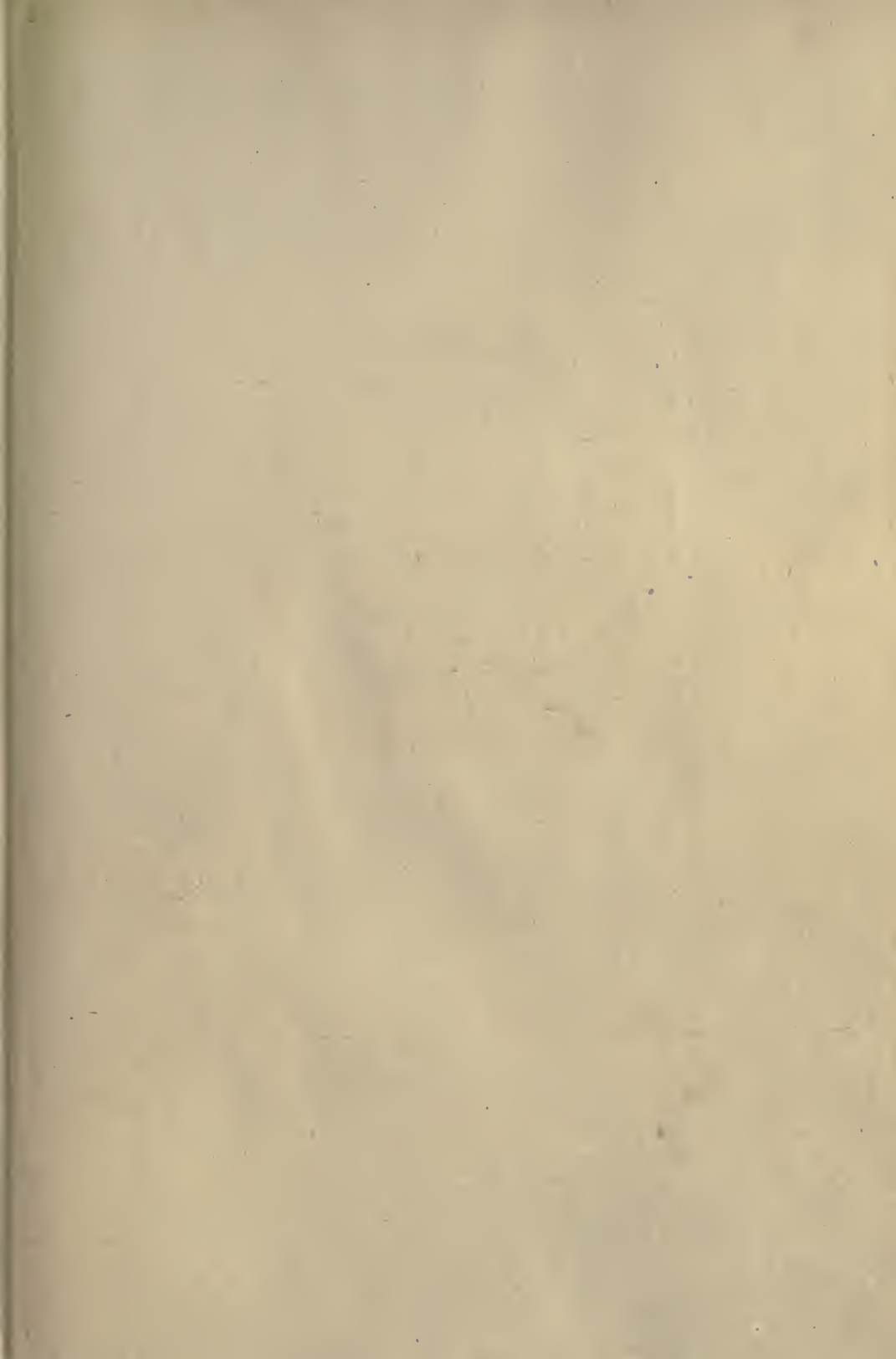


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PRACTICAL
AVIATION
INCLUDING
CONSTRUCTION AND OPERATION

J. ANDREW WHITE



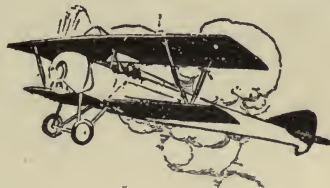




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PRACTICAL AVIATION

including
Construction and Operation



By

J. ANDREW WHITE

Author of "Signal Corps Manual"
Director of Vocational Training, Marconi Institute

A text book for intensive study by men preparing to become skilled mechanics and aviators, containing all the knowledge of fundamentals required prior to elementary and advanced flying.

Each subject is presented by illustration and described completely for the reader without turning the page.

A broad treatment of subjects never before contained in general aeronautic text books is included, comprising operation and care of aviation engines, reconnaissance, map reading, radio and its uses, machine gunnery and bombing from airplanes.

Designed particularly for individual and class study with an analysis of important factors preceding each chapter and a set of review questions following every division.

200 Illustrations

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Foreword

It seems to be generally understood that the real value of a textbook's foreword is measured by its helpfulness to the reader in explaining how the volume may be studied to best advantage. Almost without exception, what is said here in front is supplementary and of a postscript nature, for, paradoxically, the foreword is written after the manuscript has been completed.

Seeking to play the game according to the rules, I am forced to two conclusions: First, that I have little to say on the grouping of subjects and, secondly, that the typographical arrangement requires some explanation—perhaps even justification.

I will dismiss the first by noting merely that the analysis, in skeleton form, which precedes each chapter is intended as a guide, aiding dissection of the subject into easily remembered parts. These pages are in many ways comparable to the instructor's preliminary talk or a blackboard outline before the class takes up co-related subjects in detail.

To explain, or justify, if you choose, the typographical appearance of the pages, necessitates striking the personal note for a minute. The idea had its origin in an informal talk with a noncommissioned officer who was among the students of an aviation ground school class which I conducted at the outbreak of the war. By accident, his notebook came to my hands. It was amazingly comprehensive, covering by diagram and data an entire series of lectures. When I commended the student for its compilation he voiced typically youthful impatience with its limitations. "I try to jot down each important thing you say, Sir," he complained, "but I can't seem to get them verbatim. The diagrams I copy from the blackboard; that is easy. I am never satisfied with my notes, though, because it's so hard to distinguish the vital thing to remember as you go along. Now if I could get everything word for word and devise some system of marking so I could record the relative emphasis of your voice—well, I'd call that a real notebook."

That ended the episode. But in it was born the idea which forms the basis of this book. By typographical arrangement I have presented military aviation as it has been taught in the class room. The diagrams are those which have proven most valuable on the blackboard; photographs were chosen from among those projected on a screen by balopticon. Supporting text explanation of the illustrations has been arranged so the reader is never required to turn the page to apply its teachings—each page is a brief blackboard talk or illustrated lecture, so to speak. For valuation of the importance of statements I have used relative sizes and boldness of type.

Thus the volume appears as a series of condensed statements, presented in a form at variance with usual typographical arrangements, but, I hope, an exceedingly useful one. The text is not designed for those merely curious about military aviation, nor is it in any sense a treatise on aeronautical engi-

neering. The entire book has been written with the idea of possible usefulness to student aviators who, rising to a military emergency, have to prepare in the shortest possible time.

It is quite true that flying cannot be learned by reading a book. But if the "reason why" is made known by the printed word, the process of mastering actual airplane manipulation is made shorter and safer for the aviation candidate. And in acquiring this understanding of an art which is undergoing constant change, best results are attained by concentrating on fundamentals. For, once a sound knowledge of aerodynamic principles and elements of design is acquired, the constant technical changes in aircraft and their employment—even those advances which at first glance appear revolutionary—may be easily understood.

That is why, in the pages following, no particular type of airplane construction has been emphasized, no special motor featured. Where a method of control or use of an airplane has been explained, the endeavor has been to select the practice which presents the basic principle upon which modifications rest.

A Review Quiz follows each chapter. The questions are purposely not exhaustive. Each one is designed, however, to start a train of thought in the mind of the reader which will encourage him to turn back and dig into parts of the text which he may have skipped over too lightly.

It may also be noted that the decorative style of writing has been diligently repressed. More than once in preparing the manuscript the temptation arose to illustrate a point by a humorous or dramatic anecdote; but in all instances it was regretfully set aside. The method of presentation demanded concise statement, else the reading matter essential to understanding of the illustrations would have carried over the page.

Widely varied aspects of flying are treated in the fifteen chapters; in many of these the consensus of best obtainable opinion has ruled in the absence of finally established practice. In fact, all through the text the opinion of General Sir David Henderson has been borne in mind, that: "There are no experts in military aeronautics. There are experts in the various branches: in flying, in scientific research, in the design and construction of airplanes and engines, in military organization and tactics." In consequence of which many practical men have been consulted in the endeavor to place into this volume the best thought of specialists in each subject. Since aviation still remains in a transitory stage from an art to a science, further comment from readers will be cordially welcomed and carefully weighed with a view to improving future editions.

In conclusion, I should like to acknowledge the assistance of Mr. William J. Hernan and Lieut. Marius Mignot in supplying for the terms defined in the nomenclature French equivalents and their phonetic pronunciation. With generous thanks also to the many others who criticized the book in manuscript form, I send the volume on its journey to make its bid for approval on the sincerity with which it was written—solely, simply and finally for military aviators, to whom it is dedicated with the hope that it will be useful in their preliminary and supplemental study to the ultimate end of becoming qualified airmen.

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CHAPTER ANALYSIS**The Theory and Principles of Flight****TYPES OF AIRPLANES:**

- (a) Helicopter.
- (b) Ornithopter.
- (c) Tractor.
- (d) Pusher.
- (e) Monoplane.
- (f) Biplane.
- (g) Triplane.

AXES OF ROTATION:

- (a) Pitching.
- (b) Yawing.
- (c) Banking.

THE PRINCIPLE OF FLIGHT:

- (a) Air Pressure.
- (b) The Aerofoil.
- (c) Camber.
- (d) Chord and Span.
- (e) Angle of Incidence.

LIFT BY AIR PRESSURE AND SUCTION:

- (a) Lift.
- (b) Drift.
- (c) Lift-Drift Ratio.
- (d) Velocity.
- (e) Flow of Air.
- (f) Aspect Ratio.
- (g) Stagger.

CHAPTER I

The Theory and Principles of Flight

It is natural for the student aviator to be more or less impatient with the technical side of aviation. He is anxious to fly immediately, and rather disposed toward acquiring his knowledge of fundamentals at some later date. This mental attitude must be overcome; many tragic occurrences have had their origin in impatience.

The military aviator's success largely depends upon his acquaintance with the essential features of airplane design—why the machine flies and what makes it stable. Safety in maneuvering in air battles and flying efficiency is based on knowledge of the theory of dynamic flight and the limitations of his machine. The noticeably exaggerated movements of controls by students in first flights, too, are due not alone to nervousness, but to ignorance of the sensitiveness of the control surfaces, all of which function in accordance with flight laws.

Theoretical knowledge is necessary. That it can be satisfactorily acquired by textbook study has been demonstrated and it is expected that the reader will begin the study of these pages with a firm conviction that the prospective aviator must be thoroughly grounded in fundamentals.

Military airplanes will of course be given first consideration. Some aeronautical generalities are necessary, however, in dealing with design and construction, but these will be treated briefly.

The airplane is but one form of flying machine. Leaving balloons of various types entirely outside the question, there still remain three types of heavier-than-air machines. While study will be concentrated on the airplane, passing reference should be made to the other two types before proceeding. These are:

The Helicopter—a machine which employs the principle of direct lift by means of an air screw propeller operating on a vertical axis. This is not a practical type of flying machine and little has been done with it.

The Ornithopter—a machine which derives its name from the bird, its principle being the creation of flapping wings given a reciprocal motion somewhat similar to rowing, the forward push intended to exactly counterfeet that of the bird's wings. These machines are not yet successful.

The reader may be fascinated by the possibilities of research into the field represented by this latter type, but considering the present efficiency of the airplane, it is safe to assume that time will be better spent in utilizing its man-discovered principles of flight, rather than in following a new line of thought on the assumption that Nature never makes a mistake and the bird is therefore the best model.

It must be remembered that flying is but an incident in the life of a bird, just as walking is to a man. The famous aviator Santos-Dumont drew a



An airplane of the "tractor" type, so called because the propeller is attached to the front, pulling the machine through the air

parallel which disclosed the folly of blindly following Nature, when he pointed out that such a procedure would have resulted in locomotives being built with huge iron legs and steamships with the flapping fins and lashing tail of the whale. Sir Hiram Maxim further blasted the bird-flight theory by noting that "in order to build a flying machine with flapping wings, to exactly imitate birds, a very complicated system of levers, cams, cranks, etc., would have to be employed, and these of themselves would weigh more than the wings would lift."

Without further comment, therefore, the study will be confined to the airplane, the most successful type of aircraft and the best developed means of navigating the air.

The airplane is sustained by the upward push of the air flowing past it; it therefore is composed of (a) lifting surfaces, (b) power for propulsion.

Propulsion through the air is effected by a propeller, identical in principle though not in appearance, to the screw on a boat. An engine drives this propeller at the required velocity. The propulsion produced by the propeller is called the *thrust*.

When the propeller is attached to the front, pulling the machine through the air, the airplane is called a *tractor*.

If the propeller is back of the wings, or main lifting surfaces, the airplane is called a *pusher*.

The tractor type, with a single propeller, is generally acknowledged the most efficient all-round machine, although pushers with two air screws have distinct values in gun-carrying machines.

An airplane with two wings, one above the other, is known as a *biplane*. One with three wings is called a *triplane*.



A "pusher" biplane with the propeller back of the wings or main lifting surfaces and the pilot's seat directly in front

The single wing type, with one lifting surface, is called a *monoplane*.

The *tractor biplane* is the type which is more nearly standardized and will be principally considered here.

The main lifting surfaces are planes, or "wings," which present their widest dimension across the line of flight and create the air compression on their surfaces which produces flight.

The body to which these planes are attached is known as the *fuselage*, the engine and seats mounted in it being enclosed to lessen the resistance of the wind.

In pusher types the body is called the *nacelle*.

Since the airplane "sails" through the free air, it has three axes of rotation.

(1) It may ascend or descend. This is known as *pitching*, and is controlled by depressing or elevating an *elevator* by means of suitable controls.

(2) It may change its direction of travel, or steer to right and left. This is called *yawing*, and is made possible by the operation of the rudder.

(3) It may tip over to either side, a movement termed *banking* or *rolling*. This lateral motion is offset by three means of control which give a difference in angle to the two sides of the wing surface, causing one side to lift more than the other. The controls are: (a) *ailerons*, small planes set at each side, between and independent of the main lifting surfaces; (b) *wing flaps*, also called ailerons, which are hinged portions of the main planes; (c) *warping*, or twisting the main lifting surfaces to simultaneously lessen and increase the angle of inclination to the wind as required on both sides.

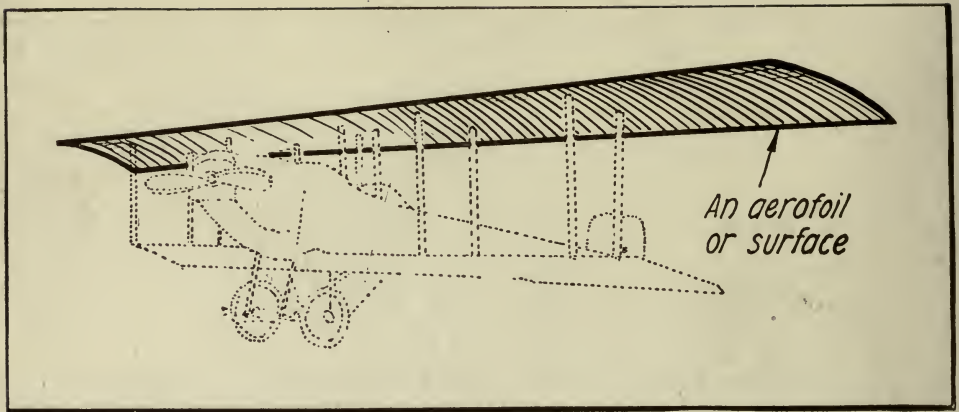


Figure 1—A lifting surface

THE PRINCIPLE OF FLIGHT

The upward air pressure against its main wing surfaces enables the airplane to fly, when these wing surfaces, or planes, are set at an angle inclined from the direction of motion, the pressure being supplied by the speed at which the planes are driven by the propeller.

AIR—Air is attracted by the mass of earth, or the gravity force, and therefore has **weight**. A cubic foot of dry air, at sea level and 32 degrees Fahrenheit temperature, weighs 0.0807 lb. Its density decreases with altitude, until at a mile above sea level it weighs 0.0619 lb., and at five miles, 0.0309 lb. per cubic foot.

Air also has **motion**, which must be taken into consideration by the aviator, and **resistance**, due to density and intensity of motion, or wind. Air resistance comprises:

Inertia—Its tendency to remain at rest, if still; in motion, if moving.

Elasticity—Its tendency to reoccupy its normal amount of space after being disturbed.

Viscosity—The tendency of particles of air to resist separation.

Inertia gives the propeller its "hold" in the air; elasticity, when air is compressed under the surface of the plane, aids the lift; viscosity creates friction, which is minimized by using polished surfaces and stream-lining airplane parts.

THE SURFACE

A wing surface is meant by this expression (see Figure 1). It has a strictly aeronautical designation, viz.:

THE AEROFOIL

This term is seldom used by aviators, but is commonly employed by aeronautical engineers to differentiate between an ordinary surface and one inclined at an angle to the direction of motion, having thickness, and curved to secure a reaction from the air for lifting.

CAMBER

This is the term which designates the curvature of the surface, or aerofoil.

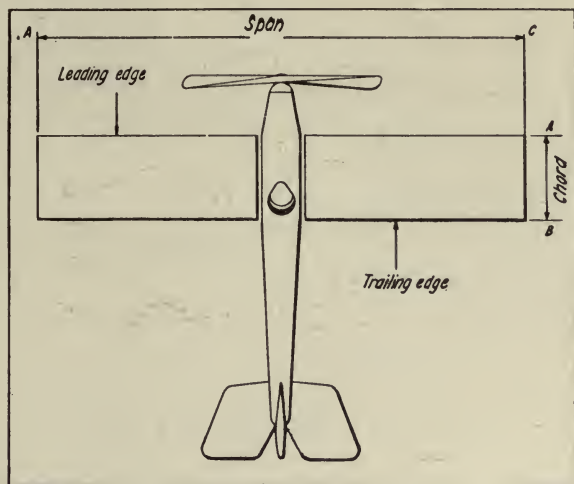


Figure 2—The chord and span of a wing surface

THE CHORD

This is the dimension of an imaginary straight line from the front edge of the aerofoil, or surface, to the rear edge, as shown by $A-B$, in Figure 2.

The front edge of the wing is known as the **leading edge**, and the rear as the **trailing edge**.

SPAN

This is the dimension of the surface across the direction of motion, indicated by $A-C$, in Figure 2.

THE ANGLE OF INCIDENCE

This is the angle of inclination of the chord to the air stream.

In practice this is the angle of inclination of the chord to the line of the propeller thrust. If the leading edge of a surface is above the trailing edge when driven through the air, the angle of incidence is **positive**. A surface with the trailing edge presented above the leading edge, or negatively to the air flow, would bring the air pressure to the top of the surface and constitute a **negative angle**.

LIFT BY AIR PRESSURE AND SUCTION

The airplane wing having been considered as a surface, its action upon the air may be described.

Air, or the atmosphere, has characteristics similar to water, the atmosphere being an ocean of definite extent and pressure at different altitudes, and flowing past an object either in stream lines, or in broken up eddies due to disturbances in its flow.

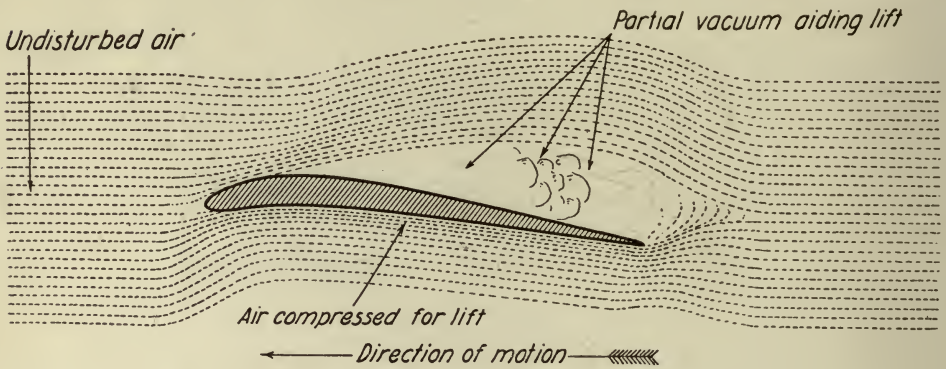


Figure 3—Action of air on the aerofoil

The nature of the air pressure when encountering the aerofoil is shown in the drawing, Figure 3.

The under face of the airplane wing compresses the air, resulting in a positive force.

At the same time a suction is caused by the air flowing past the upper face, causing a partial vacuum, tending to draw the surface upward.

The value of this suction is about three-fifths of the total pounds force of the air's action on the aerofoil. The factors of this air reaction are:

- (a) The mass of the air.
- (b) The velocity of the aerofoil.

The reaction increase is as the square of the velocity.

The air reaction has two values:

LIFT—opposed to gravity, or the airplane's weight.

DRIFT—opposed to the thrust of the propeller.

The lift is opposed by the drift, which must be overcome by the thrust supplying velocity great enough to produce an air reaction sufficient to produce flight.

Drift is of three kinds: (a) **active drift**, produced by the velocity of the lifting surfaces; (b) **passive drift**, the resistance of other parts of the airplane, such as struts, wires, tank, fuselage, hood, etc.; (c) **skin friction**, or the air resistance on roughness of surface.

LIFT AND DRIFT

It has been shown how the air pressure is created on a surface inclined at a positive angle to the direction of motion, and that this pressure exerts a lifting force.

The air pressure is inclined upward and to the rear of the direction of motion in a ratio equal to the variance of the angle of incidence of the wing plane.

The vertical action of the air pressure is a force capable of lifting weight but its horizontal component of air pressure represents resistance to motion. Thus, while

LIFT is a vertical air pressure.

DRIFT, its horizontal component, is resistance.

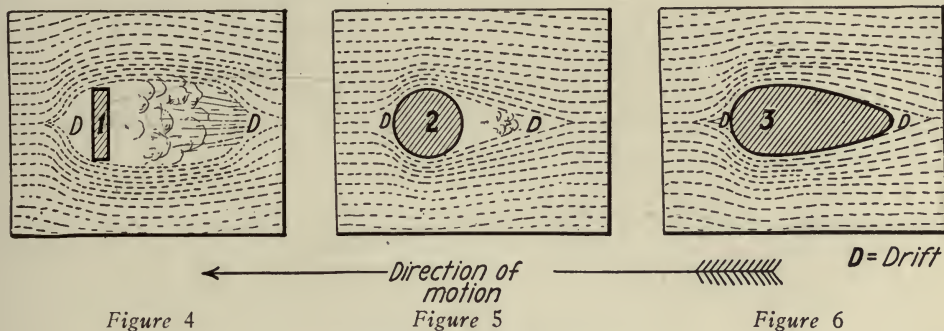


Figure 4

Figure 5

Figure 6

LIFT-DRIFT RATIO

Flight is maintained by the proportion of lift to drift being sufficiently great to overcome the force of drift. The characteristics of the wing surface are designed for the greatest lift with the smallest consequent drift, so that minimum power supplies maximum capacity for load carrying.

The factors to be considered in determining lift-drift ratio are velocity, angle of incidence, camber and aspect ratio.

VELOCITY

Drift increases to lift proportionately with increase of velocity.

Active drift, formed by the wing surfaces, is a component part of the air reaction which creates the lift, and therefore increases as the square of the velocity. At all speeds the efficiency of the airplane would remain the same, but for the

Passive drift, or the resistance of the airplane parts other than the lifting surfaces, which also increases as the square of the velocity, yet adds nothing to the lift. Thus by adding its resistance to the active lift, it prevents the airplane's ratio of lift to drift from increasing proportionately with the increase of the thrust. In other words, the efficiency of the airplane would not decrease with added velocity, if it were not for the passive drift. This factor prevents, so to speak, doubling the speed or lift by doubling the thrust.

To diminish the passive drift all parts of the airplane are given **stream lines**, or a form offering least resistance as they pass through the air.

Head resistance is a term formerly employed to described passive drift. It has been largely discarded, however, for its inaccuracy of description of the effect of the action of parts in air reaction. Passive drift is due more to the action on the rarefied area behind the object than to the head or forward part of hood, struts, wires, etc.

FLOW OF AIR

Figures 4, 5, 6 illustrate the flow of air around three objects of varying form.

In Figure 4 the rarefied area, or drift, is represented by $D-D$, and is of marked extent.

In Figure 5, this area, indicated by the same symbol, has decreased, the air flowing closer to the spherical body.

Figure 6 shows the rarefied area still further diminished, the shape of the body being conducive to closer air flow.

These three figures illustrate the importance of stream-lining parts on the line of flight.

As the head resistance is increased by the rarefied area in the rear of the object, the thrust required increases proportionately.

The action of air on objects of different shapes and propelled at varying velocities is determined by visualizing the air in laboratory research with wind tunnels.

ANGLE OF INCIDENCE

This is the angle of inclination of the chord to the air stream. Its efficiency varies and is determined by what is desired in thrust, weight-carrying capacity, and ratio of climb to velocity.

It may be accepted as a general premise that the greater the velocity the smaller should be the angle of incidence, so that the rarefied area may be kept to stream-lines and the eddies of air reduced to a minimum. These eddies represent drift, since they have no lift, and when produced by too great an angle of incidence, the power required to produce them is wasted, with consequent loss in efficiency of the airplane.

Wind tunnel research largely determines the best angles of incidence.

CAMBER

The purpose of the camber, or curve, in a lifting surface is to decrease the active drift, horizontal component of the lift.

Camber of lower face—The horizontal air reaction from a flat surface would be considerable and increase the drift. Curving the wing surface compresses and accelerates the air from the leading edge to the trailing edge. If this air action is not uniform the drift will be increased.

With a fixed upper face, an increase in the camber of the lower face does not greatly vary the relation of lift to drift, but lift increases with camber increase. Most of the lift is furnished by the upper face, however, and the camber increase of the lower does not produce sufficient effect on the upper to compensate for the lessened depth of spar allowed when a rather flat surface is used. Decreased depth of spar permits a weight reduction in the framework of the wing without sacrifice of strength. It is for this reason that lessened camber for the under side is allowed.

Camber of upper face—The top surface is curved to produce the least possible eddies of air resistance behind the trailing edges, the rarefied area produced being given the best obtainable stream line to lessen the drift in the lift-drift ratio.

Velocity, angle of incidence and thickness of aerofoil, or surface, determines the camber of the upper face. In general, the camber and angle of incidence should decrease proportionately with velocity increase.

On an aerofoil with a *flat* under face the maximum lift increases with the upper face cambered up to $1/15$, beyond which it decreases. Improvement of the lift-drift ratio is steady up to $1/20$ camber, thereafter showing decrease in value with deeper cambers.

With the under face *cambered* the increase of upper face camber above $1/15$ shows little variation in lift, but steady increase of drift.

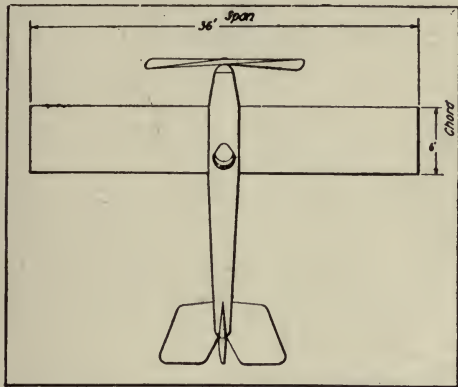


Figure 7—High aspect ratio

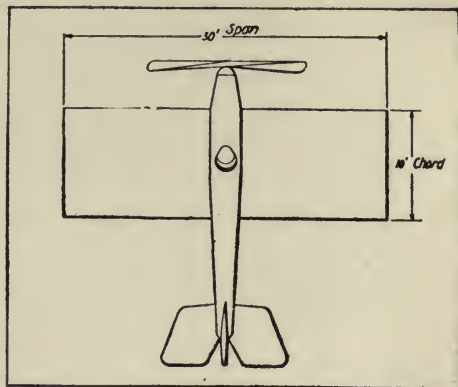


Figure 8—Low aspect ratio

ASPECT RATIO

The proportion of span to chord is the aspect ratio. The total span divided by the chord of the wings is the "aspect" of an airplane.

In Figure 7 the span is 36 feet, the chord is 6 feet, the aspect ratio is therefore 6 to 1.

Figure 8 shows a span of 30 feet and a chord of 10 feet, an aspect of 3.

At a given velocity and given wing area, the reaction increases with increase in aspect ratio. The reason for this is that a greater mass of air is engaged with a wider span, the reaction of air being partly the result of the mass of air engaged.

An average aspect for an airplane is 6, but in deep cambered planes an aspect of 9 is considered practicable by designers.

The usual limits are 2 to 8. High speed airplanes of the pursuit type seldom exceed an aspect ratio of 5.

In a general way it may be said that the higher the aspect ratio, the better is the lift-drift ratio. But with decrease of chord the deepening of the camber requires added thickness of aerofoil, or surface, and in practice the reduction of chord required for an extremely high aspect ratio makes prohibitive the use of the thickness of surface which would give the best camber.

The "spill" of the air from under the tips of the wings also has some bearing on aspect ratio, since with wings of small span this loss in lift is material, whereas in wings of wide span the percentage is small and the loss inconsequential. It is because of the slight lift gained in proportion to the air disturbance that wing tips are rounded off in many airplanes.

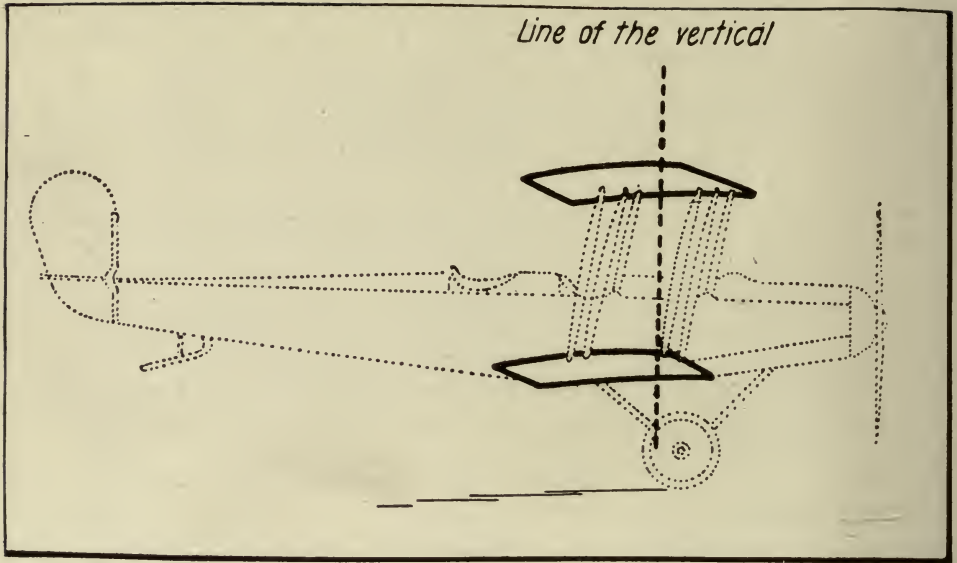


Figure 9—The upper plane placed in advance of the lower, or staggered

STAGGER

When the top surface of a biplane is placed in advance of the vertical with relation to the lower wing surface, the term stagger is used.

See Figure 9.

By staggering the upper plane ahead of the lower plane it is removed from the area of action of the lower aerofoil and engages undisturbed air.

Without stagger, the confusion of air reaction could be obviated by increasing the gap between upper and lower planes a dimension equal to $1\frac{1}{2}$ times the chord. But the length of struts and wires required for this opening increases the drift, making it impracticable to have a gap much greater than the chord.

Minor considerations of construction and balance, and visibility for pilot and observer, govern the proportion of stagger, although, theoretically, the upper plane should be advanced a distance about equal to 30 per cent. of the chord, small variations being further governed by velocity and angle of incidence.

REVIEW QUIZ

Theory and Principles of Flight

1. Describe three types of heavier-than-air machines and state their practicability.
2. Define three main divisions in the uses of military airplanes which govern types.
3. State the fundamental principle which makes flight possible.
4. What is meant by the inertia of air?
5. What is the aeronautical term for a wing surface, and how does it differ from an ordinary surface?
6. Define camber.
7. How is the dimension of the chord of an airplane taken? The span?
8. Give a full definition of the angle of incidence.
9. In what way does atmosphere resemble water?
10. What is the action on air when it encounters the under face of the aerofoil?
11. State what proportion of lift is represented in the partial vacuum above the upper face.
12. What are the two values of air reaction?
13. Define three kinds of drift.
14. What is lift-drift ratio and how are the characteristics of the wing surface governed by it?
15. State the four factors to be considered in determining lift-drift ratio.
16. Define two kinds of drift created by velocity and state how these affect flight efficiency.
17. Show by a simple diagram why head resistance requires proportionate thrust increase.
18. In what way does increased velocity affect the angle of incidence?
19. What is the purpose of the camber and why should upper and lower faces differ?
20. What is meant by an airplane's aspect ratio?

CHAPTER ANALYSIS

Elements of Airplane Design

FACTORS OF SUPERIORITY IN DESIGN:

- (a) Climbing Rate.
- (b) Greatest Speed.
- (c) Horizontal Equivalent.
- (d) Design for Maximum Climb.
- (e) Design for Maximum Velocity.

ANGLES OF INCIDENCE IN FLIGHT:

- (a) Minimum.
- (b) Optimum.
- (c) Best Climb.
- (d) Maximum.

CHAPTER II

Elements of Airplane Design

The military aviator can insure proficiency only through acquisition of a sound knowledge of the characteristics of design which govern the construction of an airplane. Air tactics in warfare, while a subject for military experts, are insolubly a part of the mechanics of aeronautics. While the manner of conducting air battles is subject to daily changes, it must be remembered that the effective observer or air fighter who creates new evolutions is logically one whose knowledge of engineering features of design is sound. Skill in manipulation of controls is essential of course, but it can readily be recognized that attempted creation of new tactics might well be fatal unless an aviator has an intelligent understanding of the limitations of his machine and what it can accomplish within the safety factor.

In this chapter some consideration will be given to the factors upon which a military airplane must base its superiority.

In the preceding chapter fundamental principles of flight have been given; it now devolves upon the student to recognize that in military use of flying machines two important features are encountered:

- (a) Superiority in climbing rate.
- (b) Greatest speed.

It is obvious that the machine which excels in speed and ability for fast climb will be most effective against the enemy. An airplane which attains speed at the sacrifice of climbing ability can be out-maneuvered by fast-climbing enemy aircraft in air battles, and the same is true of reverse qualities of climb versus speed. The combination of great speed with maximum climb is the ideal striven for in military airplane design.

As in all mechanical devices, however, the ideal must be subjected to compromise, and it is now purposed to apply the knowledge of fundamentals previously gained to consideration of the engineering factors which govern the design of machines for maximum climb and greatest velocity.

Thus far the reader should bear in mind that the airplane is being studied in two distinct divisions; viz., the **lifting surfaces** and the **propelling mechanism**, or (a) the airplane structure, (b) engine and propeller.

In the preceding chapter the factors of lift-drift ratio were outlined and commented upon. As a thorough knowledge of the proportion of lift to drift is essential to an aviator, further considerations of design will be mentioned.



Airplanes of various types are here illustrated; from left to right, a large triplane, a pusher biplane, a monoplane, and a tractor biplane. For size comparison note the man standing at the extreme left of each of the airplanes

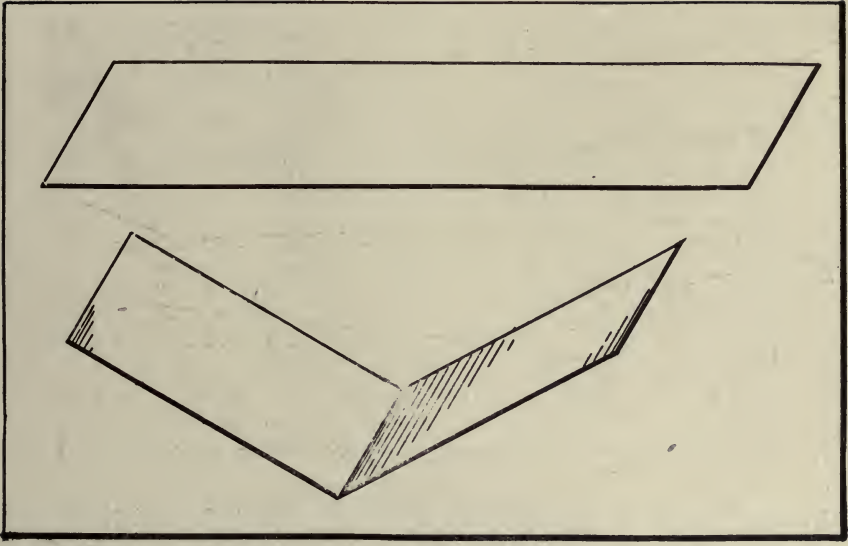


Figure 10—Lifting surfaces of same area but different horizontal equivalent

The efficiency of the airplane structure is determined by the lift-drift ratio, and an additional item in relation to lifting surfaces which must be considered is:

HORIZONTAL EQUIVALENT

This is determined by the arrangement of lifting surfaces and is important because lift (vertical component of the reaction) varies as the horizontal equivalent of the surface, but drift remains the same. That is, with reduction in horizontal equivalent (H. E.) of aerofoil the ratio of lift to drift is lessened.

Figure 10 gives front views of two lifting surfaces.

Both have the same surface area, but the upper, having its full horizontal equivalent, has the best lift-drift ratio.

The lower surface, being inclined from its center, has lessened H. E. and in consequence less lift.

Therefore, as the lower surface containing the same area as the upper surface, produces the same amount of drift, but less vertical lift, its lift-drift ratio is less than the upper's.

Sacrifice of efficiency in lift-drift ratio is often made to gain lateral stability; such employment of surfaces tilted from the center will be considered later.

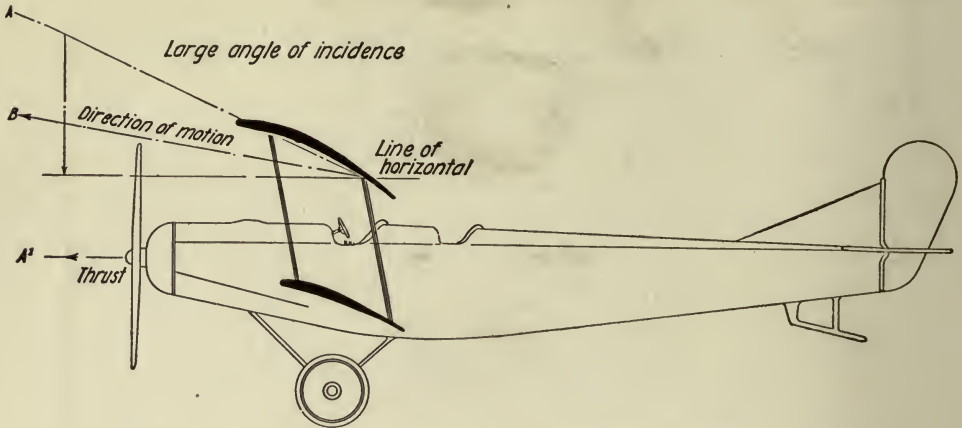


Figure 11—Airplane designed for maximum climb

Airplane design is restricted by opposing essentials which require the aerofoil (lifting surface) characteristics and velocity to produce either Maximum Climb or Maximum Velocity. A compromise between the two is represented in all airplanes.

DESIGN FOR MAXIMUM CLIMB

The factors in an airplane designed for maximum climb are:

- (a) Large aerofoil.
- (b) Low velocity.
- (c) Large angle of incidence to propeller thrust.
- (d) Large angle relative to direction of motion.
- (e) Large camber.

(a) *LARGE AEROFOIL*—A large area of lifting surface is required to engage the mass of air necessary for flight with a low velocity.

(b) *LOW VELOCITY*—Speed must be sacrificed to secure the best lift-drift ratio.

(c) *LARGE ANGLE OF INCIDENCE TO PROPELLER THRUST*—The most efficient airplane is one with inclined lifting surfaces propelled by horizontal thrust, therefore a flying machine for maximum climb to be driven along an upward sloping path with propeller thrust horizontal has its aerofoil at a large angle to the direction of the thrust.

See A—A¹ Figure 11.

In the preceding chapter it was shown that the lift-drift ratio falls with increased velocity where the angle of incidence is great, because with a large-angled aerofoil increased speed creates more eddies in the air reaction. These air reactions require power to produce them, yet they have no lift value; they therefore represent drift and lower the lift-drift ratio.

(d) *LARGE ANGLE OF INCIDENCE TO DIRECTION OF MOTION*—With low velocity the angle's relation to the direction of motion should be large.

See A—B, Figure 11.

(e) *LARGE CAMBER*—With low velocity and large angle of incidence the camber of the aerofoil should be large.

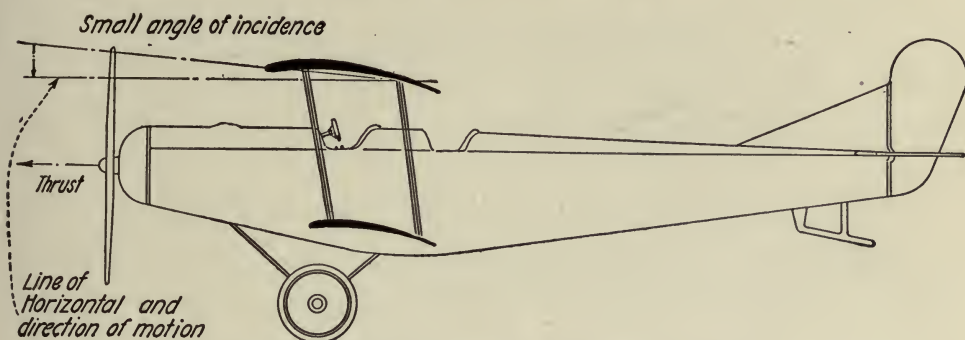


Figure 12—Airplane designed for maximum velocity

The airplane designed mainly for speed has a small margin of lift at low altitudes when its propeller thrust is horizontal. In the rarefied atmosphere of higher altitudes engine efficiency is lowered and the margin of lift disappears. Then only horizontal flight is possible. Flying thus with its thrust horizontal it is at maximum efficiency, if loss of engine and propeller efficiency is not considered.

DESIGN FOR MAXIMUM VELOCITY

The factors in an airplane designed for maximum speed with given surface and power are exactly opposite the requirements for maximum climb. Thus:

- (a) Small aerofoil.
- (b) High velocity.
- (c) Small angle of incidence to propeller thrust.
- (d) Small angle relative to direction of motion.
- (e) Small camber.

(a) *SMALL AEROFOIL*—By its increased velocity the speedier propelled surface engages a greater mass of air in a given time and the required lift is secured with smaller surface.

(b) *HIGH VELOCITY*—Lessened aerofoil angle produces less drift, and velocity may be increased without loss in lift-drift ratio.

(c) *SMALL ANGLE OF INCIDENCE TO PROPELLER THRUST*—As both propeller thrust and direction of motion are horizontal, a small angle of incidence is most efficient for speed.

(d) *SMALL ANGLE OF INCIDENCE TO DIRECTION OF MOTION*—Where velocity is a consideration paramount to lift, a small angle of incidence is most efficient.

(e) *SMALL CAMBER*—Lessened camber at high velocity produces the best lift-drift ratio.

The airplane built in accordance with the above is intended to possess only sufficient lift to get off the ground. The types illustrated on this and the preceding page are extremes, but the compromise, an airplane with climb and velocity made equal considerations, i.e., a practical all-around type, is designed by consideration of the factors disclosed in these examples.

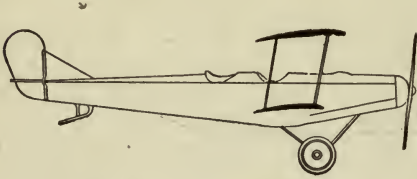


Figure 13a—Minimum angle

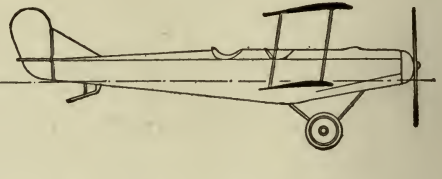


Figure 13b—Optimum angle

In the illustrations on this page an airplane of practical utility is shown at varying angles of incidence while in flight.

At low altitudes the aircraft shown has slight margin of lift when the thrust is horizontal.

The fighting machine usually flies at an altitude where maximum velocity is gained at sacrifice of maximum lift. It is obvious that with slight margin of lift at low altitudes, the margin of lift disappears with the rise of the airplane, because of loss of engine power in the rarefied air. But when the machine arrives at the altitude where horizontal flight is just possible, it is given its maximum velocity because, even though engine and propeller efficiency is lowered, the margin of lift has disappeared and the surfaces are at their best flying efficiency for horizontal flight.

ANGLES OF INCIDENCE IN FLIGHT

Minimum—(See Figure 13a). The angle of the aerofoil is the smallest at which, with amount of power and area of surface fixed, the machine can maintain greatest velocity in horizontal flight at low altitudes.

An airplane having less camber and smaller angle of incidence, i.e., so designed that the margin of lift is negligible, or just sufficient to maintain horizontal flight, would attain greater velocity with the same surface area and power.

Optimum—(See Figure 13b). Here the axis of the propeller is horizontal and the angle of incidence that which is required for best lift-drift ratio. Velocity is lessened at this angle, at which slight climb is developed at low altitudes.

Best Climb—(See Figure 13c). This angle is about midway between maximum and optimum angles of incidence. Here the increased angle has added to the drift and thereby decreased the velocity.

With the angle fixed, a decrease in velocity lessens the drift, but where the angle has been increased the lift thereby gained in a measure offsets the loss in lift through lessened velocity.

Beginners should never exceed the angle of best climb.

Maximum—(See Figure 13d). Horizontal flight is just possible at this angle, because drift has been greatly increased and velocity materially lessened in consequence.

If the angle were further increased the lift-drift ratio would be so lowered that the lift would be less than the weight and the airplane would fall. This fall is known as the "pancake."

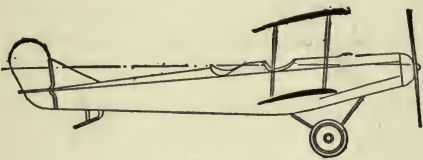


Figure 13c—Angle of best climb

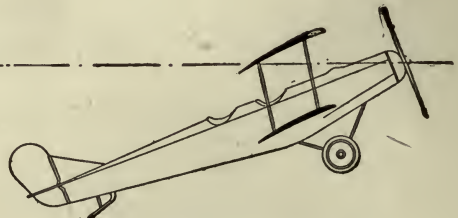


Figure 13d—Maximum angle

REVIEW QUIZ

Elements of Airplane Design

1. Why is a knowledge of design valuable to the military aviator?
2. State the combination of qualities which represents the ideal in military airplanes.
3. Define horizontal equivalent.
4. What change is effected in the lift-drift ratio when horizontal equivalent is reduced?
5. For what reason is a sacrifice of efficiency in lift-drift ratio often made?
6. Name the factors of design which produce an airplane for maximum climb.
7. Why is a large aerofoil required with low velocity?
8. Should the aerofoil's angle of incidence be great or small for climbing?
9. What should be its relation to the direction of motion when climbing?
10. State when an airplane designed mainly for speed is at maximum efficiency with given motive power efficiency.
11. Name the requirements of airplane design for maximum velocity.
12. State the reason why, with engine efficiency lowered, certain airplane surfaces are at their best flying efficiency at high altitudes.
13. What is meant by the minimum angle of incidence in flight?
14. What flight quality is developed at low altitudes with optimum angle of incidence?
15. State the effect on velocity at the angle of incidence for best climb. What will happen if the maximum angle is exceeded?

CHAPTER ANALYSIS**Flight Stability and Control****AIRPLANE EQUILIBRIUM:**

- (a) Stability.
- (b) Longitudinal Stability.
- (c) Lateral Stability.
- (d) Directional Stability.
- (e) Center of Gravity.

LONGITUDINAL STABILITY:

- (a) Lifting Surfaces.
- (b) Stabilizing Surfaces.
- (c) Longitudinal Dihedral.
- (d) Canard Principle.
- (e) Main Surface Dihedral.

LATERAL STABILITY:

- (a) Washout and Washin.
- (b) Ailerons.
- (c) Banking.

CONTROLS:

- (a) Wheel and Column.
- (b) Joystick.

CHAPTER III

Flight Stability and Control

Maintenance of airplane equilibrium is secured by (a) features of design, (b) controls operated by the pilot.

The following factors of stability and control are to be considered:

(1) **Stability**—The natural tendency of a body disturbed to return to normal position.

(2) **Longitudinal Stability**—The tendency of an airplane to maintain stability along the direction of normal horizontal flight and overcome pitching and tossing.

(3) **Lateral Stability**—The tendency to oppose rolling sideways.

(4) **Directional Stability**—The tendency to oppose swerving to the right or left of its proper course.

In dealing with these factors, one must dispose of the popular misconception that stability is fixed "steadiness" in flight, attained through skillful design. While not easily capsized, an inherently stable airplane does not respond readily to its controls; it is sensitive to all air disturbances and will roll and sway in response to air billows, whereas one of neutral stability answers its mechanical and automatic controls handily, and because it has no inherent tendency to hold a fixed position relative to the air, adjusts itself easily so that its position relative to the ground is not changed by air disturbances.

It is well to remember that the air is at times treacherous and the airplane should be so designed that it will sail through the medium on an even keel more or less of its own accord, yet not be too sensitive to air disturbances. Through actual participation in flight the aviator learns manipulation of controls according to the "feel" of the air, and this constitutes a large part of his training; it is at once seen, however, that this instinctive handling limits his usefulness unless with it goes an understanding of the principles of stability and control which govern flight.

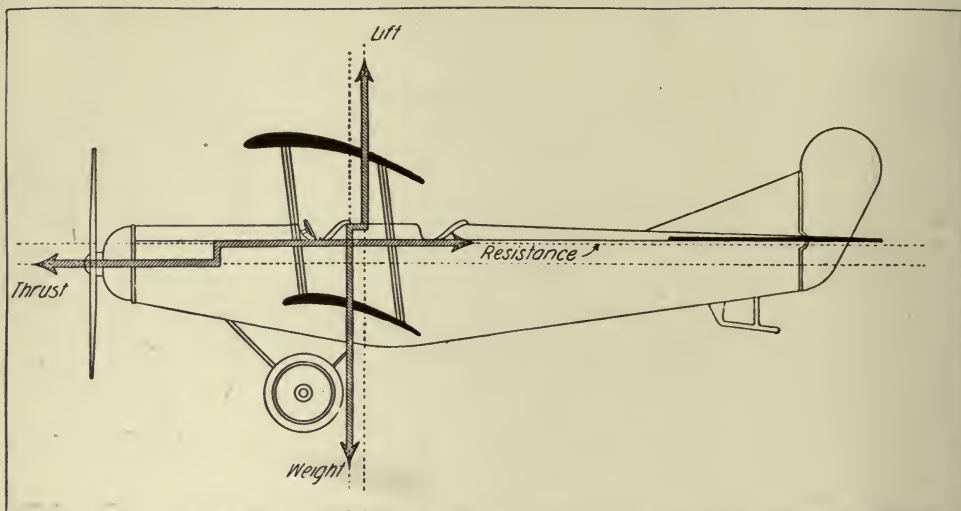


Figure 14—Balance of forces for airplane equilibrium

CENTER OF GRAVITY

The first consideration of airplane stability and general flying efficiency is the center of gravity, for the craft is suspended in the air and rotates about this point. The proper place for its location is where the forces of thrust, resistance, lift and weight act.

Ordinarily, the airplane is so designed that the thrust line passes nearly through the center of resistance, and the center of gravity is made in line with the weight and lift.

See Figure 14.

The center of thrust is often placed below the center of resistance, for convenience. In pusher types the thrust is sometimes above the line of resistance. The tendency to nose down thus produced is overcome by having the center of lift back of the center of gravity. The principle of coincident centers is the factor of proper balance, but with variations in the position and strength of these forces produced in flight, the balance is restored by small forces, such as the tail of the airplane.

If the center of gravity is too low it produces a pendulum effect and causes a sideway roll of the airplane. When too high, if disturbed it seeks a position as far as possible from the original, tending to tip over the airplane.

METHODS OF DETERMINING THE C. G.

- (a) Point of balance may be determined by placing a roller under the airplane.
- (b) The airplane swung from a point overhead and a plumb line dropped from this point.
- (c) With the machine supported at front and rear, the weight at each point determined and the distance between the two points measured. This is known as the method of moments.

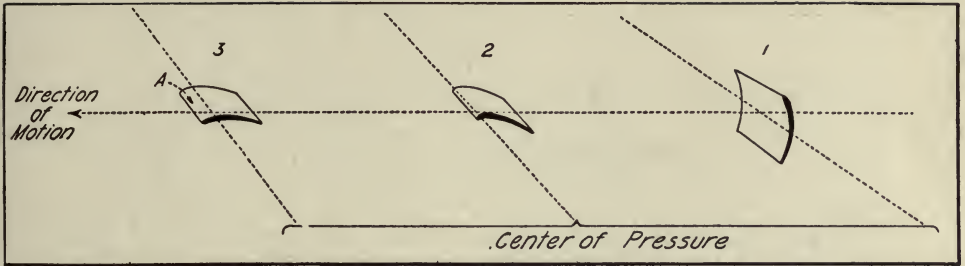


Figure 15—Instability of cambered surfaces

LONGITUDINAL STABILITY

LIFTING SURFACES

Cambered wing surfaces are longitudinally unstable at angles of incidence below 12 degrees, at which angles fair lift-drift ratio is produced.

In Figure 15, the centers of pressure of surfaces 1, 2 and 3 are indicated. The C. P. is the point at which all the air forces about balance.

Surface 1 is cambered and in a position approximately vertical, moving in a direction from right to left. Its center of pressure is along the exact center of the surface.

With decrease in angle to one of about 30 degrees, the center of pressure moves forward to the position shown in Surface 2.

In Surface 3 the angle of incidence has so decreased that there is a downward pressure at point A. Corresponding depressions in such negative angles increase proportionately the pressure A. The center of pressure being the resultant of all air forces, it is affected by the downward pressure at A and moves backward. This pushes up the rear of the surface and increases the tendency to dive. But as the surface's angle of incidence is increased the pressure at point A decreases, whereupon the center of pressure moves forward and pushes up the front. If the angle is thus greatly increased the result is a "tail slide."

STABILIZING SURFACE

Since the cambered wing surface is inherently unstable, a stabilizing surface at some distance in the rear, or at the tail, is added. This tail surface has less angle of incidence.

Figures 16a, 16b and 16c illustrate the effect of the tail surfaces, the upper portions of the drawing showing main lifting surfaces at varying angles, and with tail attached in lower view.

In Figure 16a, the lift force is in rear of the center of gravity, which tends to make the wing dive; in the lower view it is shown how the downward pressure on the tail counteracts this tendency.

Figure 16b shows a surface with lift passing through the center of gravity. The wing is therefore balanced and tail pressure is not needed unless a sudden change in angle is effected.

In Figure 16c the line of lift force is ahead of the center of gravity. The tendency of the wing to rear up is offset by upward pressure on the tail; note lower view.

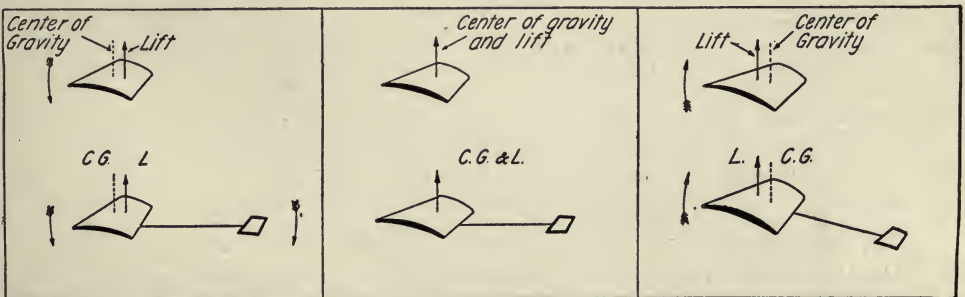


Figure 16a

Figure 16b
Balance of lifting surfaces by tail stabilizer

Figure 16c

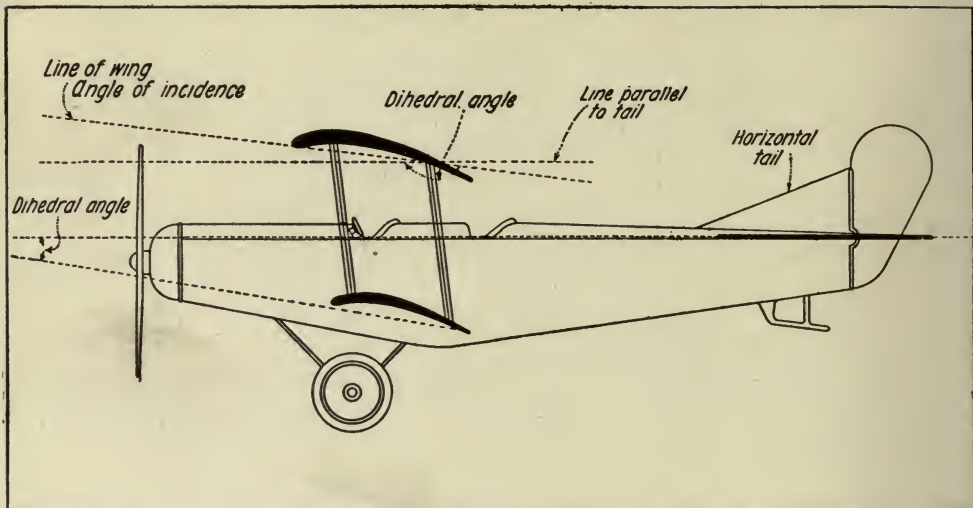


Figure 17—Dihedral angle formed by lifting surfaces and stabilizer

LONGITUDINAL DIHEDRAL ANGLE

The tail must have an angle of incidence smaller than that of the wings. The angle of incidence of the tail stabilizing surface is ordinarily about one-third of the aerofoil angle. The neutral lift lines of each, when projected to meet, make a dihedral angle.

See Figure 17.

Occasionally, the tail-plane's angle is the same as that of the main lifting surfaces, the lessened angle of incidence required of the former being secured by the downward deflection of air from the upper aerofoil.

To illustrate the effect of stability secured by the longitudinal dihedral, we may consider an airplane traveling a horizontal course; in this position the thrust and direction of motion are identical. The nose of the machine then being suddenly deflected by some air disturbance, the angle of incidence is changed with the downward position. Assume that on the horizontal course the aerofoil angle was 12 degrees and with the deflection the thrust line is lowered, say, 3 degrees. The angle of incidence is not changed in the same proportion, because the momentum of the former (horizontal) course pulls it off the direction of thrust.

The net change of angle of incidence will be assumed to be 2 degrees. Both main lifting surfaces and tail stabilizer are affected by the change because both are fixed to the airplane structure. Both have decreased, proportionately. The main lifting surfaces, with former angle of incidence at 12 degrees, have decreased to 10 degrees. The tail stabilizer, with former angle 0 degrees, has now a minus angle or negative of 2 degrees. Therefore, since the main surfaces have lost 12 deg.—2 deg, or 1/6 of their lift, and the tail stabilizer is now at an entirely negative angle, the tail will fall faster than the main planes. The airplane in consequence rights itself, or readjusts to the former horizontal.

The reverse happens when the nose of the machine is tilted up by a gust of wind. While both main lifting surfaces and tail surface increase angles of incidence in the same amount, the angle (which determines the lift) increases in greater proportion with the tail than with the main surfaces, which lifts the tail faster. The airplane then assumes its first position at a slightly greater altitude.

The variation of angle of incidence is not as great as the variation of the airplane's angle to the horizontal.

Stability produced by the effect of the longitudinal dihedral exists only when there is momentum in the original direction.

The stability adjustments described are taking place almost continuously in flight, although not always perceptible to the aviator.

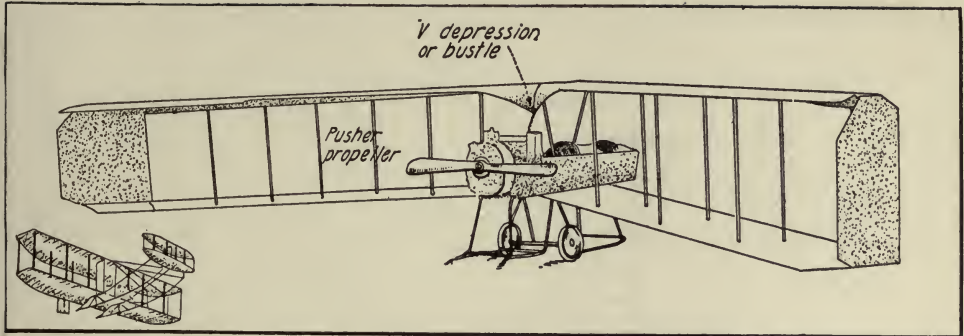


Figure 18

Figure 19—Airplane of the Dunne type, with longitudinal dihedral surfaces

CANARD PRINCIPLE

In early types, such as shown in the lower left of the drawing on this page, Figure 18, it was customary to place the stabilizing surface in front. The tail-first principle possessed obvious disadvantages, notably that sufficient longitudinal stability could be had only by giving this a greater angle of incidence than the main lifting surfaces. Thus if the wings had an angle of 5 degrees, the forward stabilizer was set at an angle of incidence of 15 degrees, which gave poor lift-drift ratio at high speeds.

Low velocities were the rule in the early days and the defect in design was not appreciated until increased speeds were required. The principle of the forward stabilizer, known as the canard, is now obsolete.

MAIN SURFACE DIHEDRAL

Figure 19 shows a view of the Dunne airplane, from the right rear. This type has no stabilizing tail surface, longitudinal dihedral being given by the main surface having a decreasing angle of incidence toward the wing tips and corresponding camber. The theory is that the wing tips act as longitudinal stabilizers.

This design has the following disadvantages:

(a) Departure from the usual form of lifting surfaces, in plan a parallelogram, is a mechanical inferiority, requiring additional strength of construction. This increases weight.

(b) Aspect ratio is lowered because the leading edge of the aerofoil is not at a right angle to the direction of motion. Lift is lessened on account of lowered aspect.

(c) Drift is increased by the action of the air on the V-shaped depression in the center of the aerofoil. This dip is pointed in the direction of motion and when the airplane is turned off its course to a direction which is the resultant of thrust and momentum, or a sideways motion, the air pressure on the corresponding side of the V depression turns the machine back on its course. It is obvious that the air reaction set up by this depression increases drift.

(d) The necessity for decreasing the angle and camber toward wing tips increases time and cost of construction.

Vertical surfaces at the wing tips, as shown in the drawing, are sometimes added, set at an angle producing the same stabilizing effect. Drift is increased by this arrangement, and efficiency lowered.

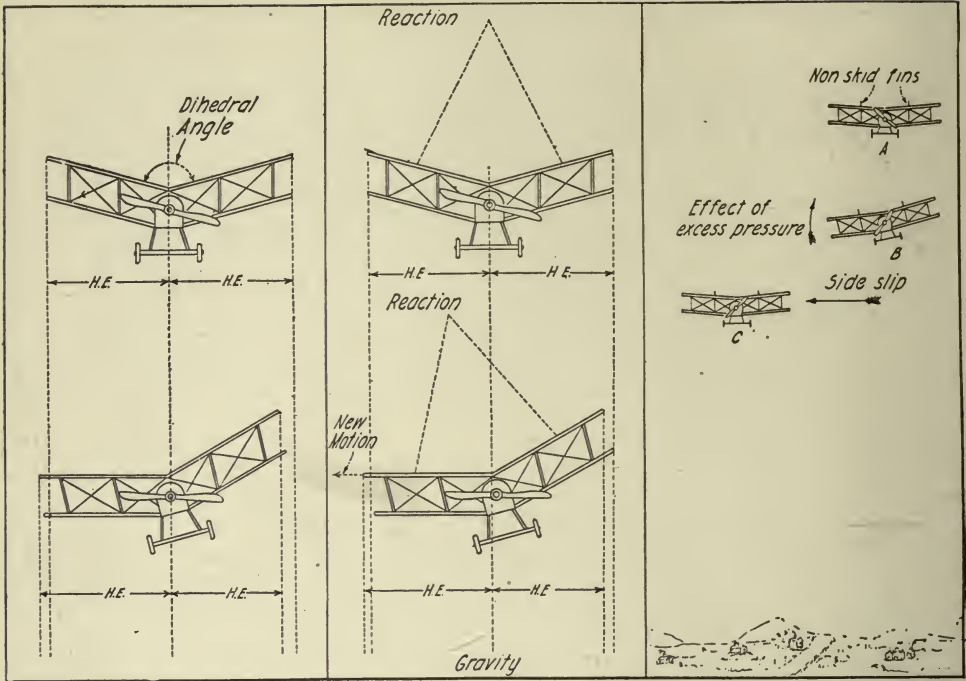


Figure 20

Figure 21

Figure 22

Lateral stabilizing effect of upwardly inclined wings

LATERAL STABILITY

Upward inclination of the lifting surfaces gives a degree of lateral stability, the wings forming a dihedral angle. The tendency to a sideways roll through air disturbance is thus corrected by the lower wing gaining greater pressure or lift and the consequent side slip restoring the machine to level position.

In the upper portion of Figure 20 is a representation of a front view of an airplane in flight, lifting surfaces having equal horizontal equivalent. When the machine is tilted sideways, as shown in the lower view, the horizontal equivalent (H. E.) of the left wing, now horizontal, has increased; a decrease is seen in the right hand wing, the lower wing in consequence rising through its added lift. The airplane is thus restored to its first, or normal, position.

The righting effect is not, however, proportional to the horizontal equivalents of both wings. In the upper portion of Figure 21 it is indicated that the reaction, when the airplane is at normal position, has a direction opposed to the gravity force, or weight, the two forces being evenly balanced, or equilibrium maintained. In the lower half of Figure 21, with the airplane tilted sideways the force of reaction is at an angle or not directly opposed to gravity force. The direction of motion is therefore no longer directly forward, the resultant of the thrust and momentum giving the added direction of motion indicated in the drawing. The airplane is thus moving sideways while flying forward.

To be effective, the angle of the lateral dihedral must be great enough to force the airplane back to equilibrium, and overcome the tendency to turning caused by the increased air pressure exerted on the keel surface, greatest in effect toward the tail.

The theory is advanced, and with some justification, that the lifting force is derived from the side-slip in the direction of the lower wing. Some designers therefore advocate for tractor biplanes a dihedral angle for the lower wing only. An increasing tendency toward this construction is noticeable.

Figure 22 shows the side slip, with non-skid fins added where excessive dihedral is needed to balance large keel surface.

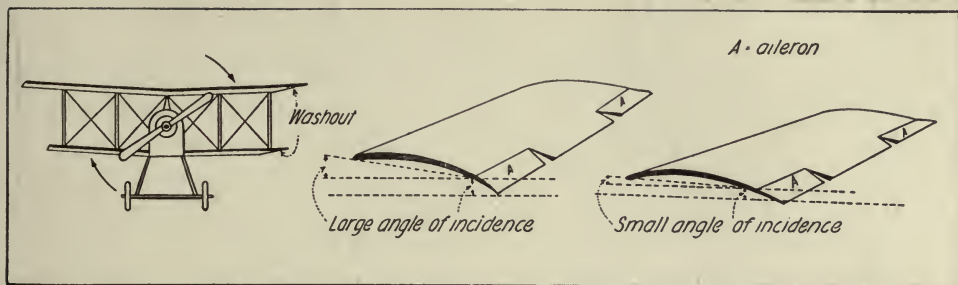


Figure 23—Washout

Figure 24—Ailerons attached to lifting surfaces

WASHOUT

An airplane tends to turn over sideways in a direction opposite to that in which the propeller revolves. The adverse effect of propeller torque (drift) is neutralized by giving the wing tip on the side not affected a smaller angle of incidence.

The washout is shown in Figure 23.

Where practicable, the angle of incidence is also *increased* on the side tending to fall, its lift thereby being increased. **Washin** is the term used to describe the increased angle.

Washing out the angle of incidence on both sides increases the drift, making possible lessened angle for the ailerons (the lateral controlling surfaces shown in Figure 24) which gives them better lift-drift ratio.

AILERONS (WING FLAPS)

In Figure 24, the drawing to the extreme right shows the smaller angle of incidence of the aerofoil (lifting surface) given by washout. In comparing it with the other aerofoil (top center of page) it is noted that the ailerons attached to both have the same inclination, although the ailerons of the aerofoil with washout have considerably less angle of incidence, therefore greater efficiency.

BANKING

When an airplane is turned off its course it does not instantly proceed along its new course. This is due to the momentum of the original course. The new direction is therefore the resultant of this momentum and the thrust, and the sideways skid caused by the centrifugal force turns the lifting surfaces away from their proper horizontal position, causing lessened lift. Neutralization of this effect is created by "banking," or tilting the airplane sideways.

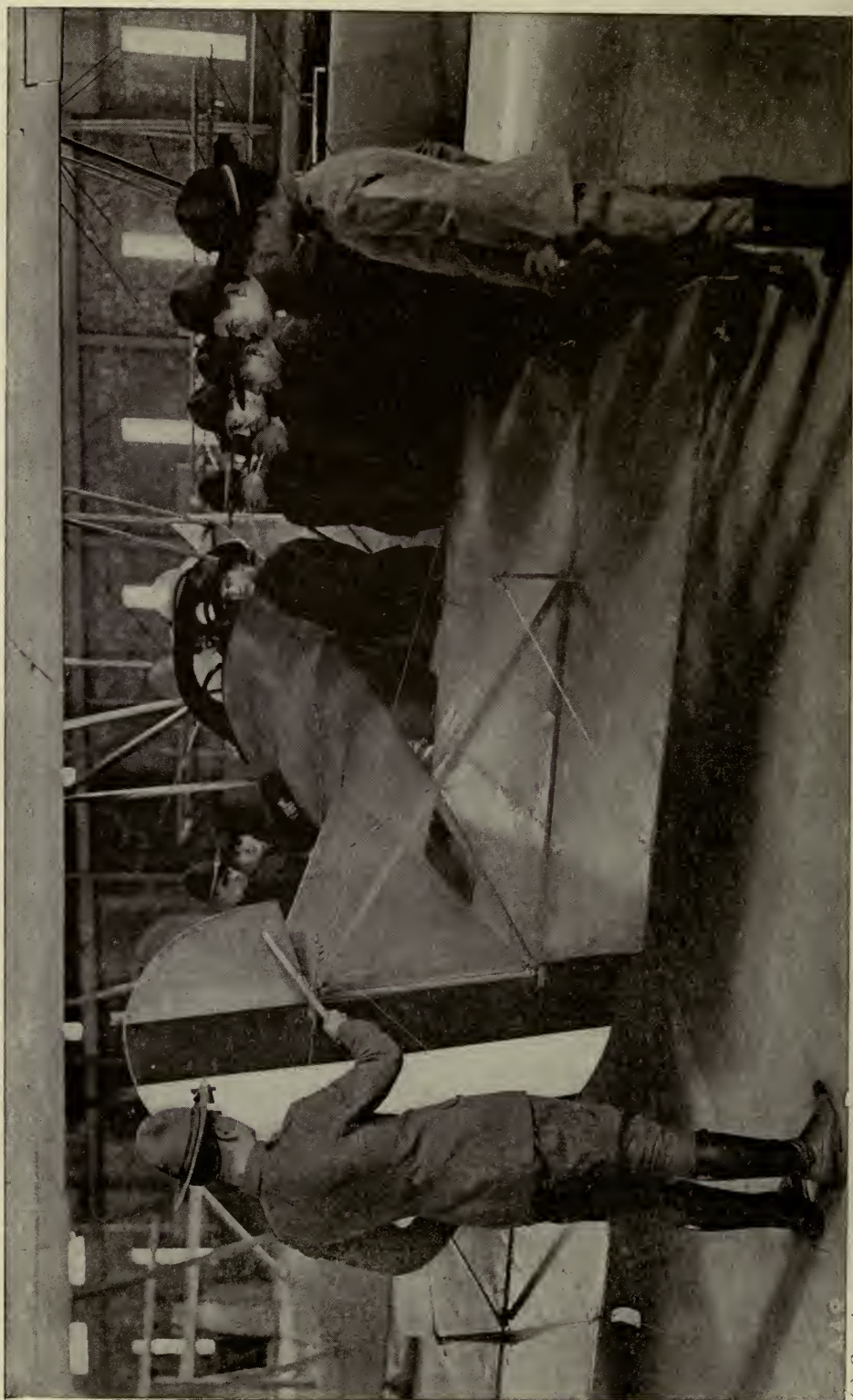
With the angle of the lifting surface changed by banking, the inclination of bottom of the lifting surface makes the pressure or lift force a horizontal component of the centrifugal force. The velocity of the skid is that required to secure an air pressure or lift opposite and equal to the centrifugal force of the turn. The steepness of the bank is governed by the sharpness of the turn, increasing as the strength of the centrifugal force.

It is obvious that when banking the entire lift force is no longer vertical, and it is important that it be sufficient to support the weight of the airplane, or it will fall. Speed is a requirement to offset this.

Pilots must not try to climb while banking.

Slight banking results in skidding, which is easily corrected.

Too steep banking, however, may result in a side slip inward, which is likely to be followed by a nose dive.



(c) Committee on Public Information
Instructor at an Army aviation ground school explaining the operation of controls

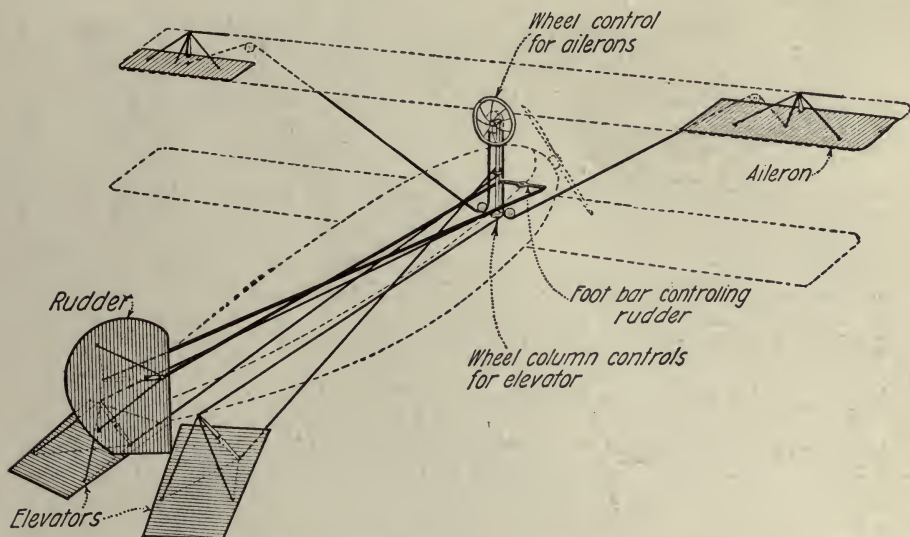


Figure 25—Mechanical means of directional and lateral control

DEP CONTROL

The illustration above shows the airplane's mechanical means of directional and lateral control. These comprise operation of the elevators, ailerons (sometimes called "wing flaps," when attached to main lifting surfaces as shown in drawing), and the rudder.

All operate on the principle of air force derived from an inclined plane.

The elevators are controlled, in U. S. training machines, from the column which supports the wheel, as shown.

The ailerons, or wing flaps, for lateral control are moved by the wheel in the cockpit.

The rudder is controlled by a foot bar.

The elevators are inclined up or down to depress or lift the tail of the airplane.

The ailerons supply the difference in angle to the two tips of the wings, as needed, causing one to lift more than the other.

The rudder's action in turning the machine is due to the varying wind pressure exerted on the sides when moved to one side or the other.

JOY STICK

Figure 25b, at the bottom of the page, shows the stick control usually preferred for speed work, and widely known to aviators as the "joy stick." Pushing the stick sideways toward a wing tip raises its aileron (wing flap) and deflects the aileron on the opposite end. When the stick is pulled back the elevators at the tail are raised, and when pushed forward they are dropped.

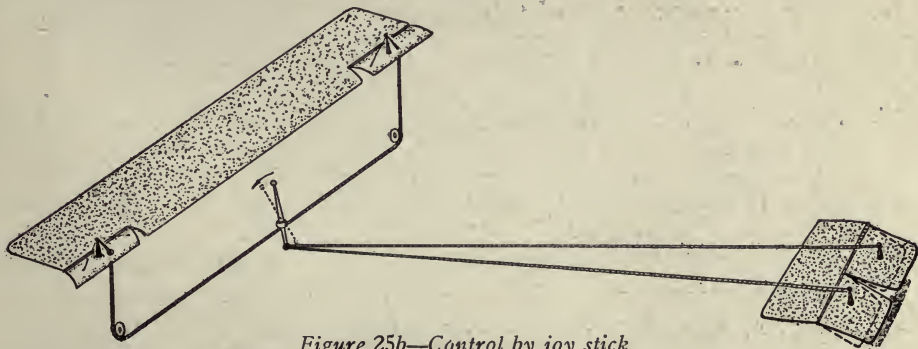
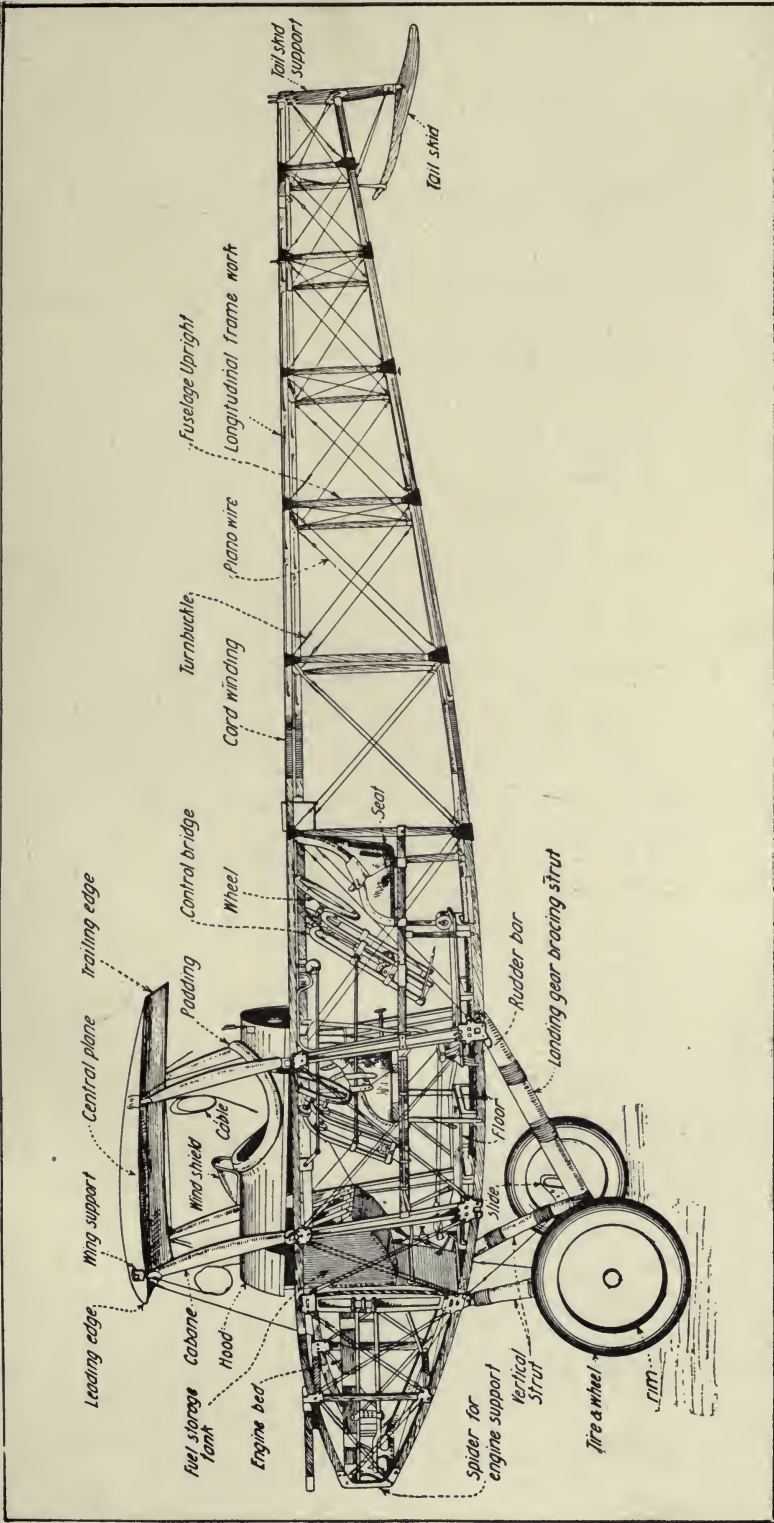


Figure 25b—Control by joy stick

REVIEW QUIZ

Flight Stability and Control

1. Classify and define stability as it applies to airplane equilibrium.
2. What undesirable qualities has an inherently stable airplane?
3. State the proper location for an airplane's center of gravity.
4. What is the effect if the center of gravity is too high? If too low?
5. How is the point of balance determined?
6. Below what angle are cambered surfaces longitudinally unstable?
7. Why is the tail stabilizer necessary?
8. Explain the action of the tail surfaces.
9. What is the relation of the tail's angle of incidence to that of the wing?
10. When is the stability produced by longitudinal dihedral effective?
11. By example, illustrate the effect of stability secured by the longitudinal dihedral.
12. Why was the canard, or tail-first construction, discarded?
13. Explain how the Dunne machine omitted the tail stabilizer and state the disadvantages of this type of construction.
14. Explain the stabilizing action of a lateral dihedral.
15. Why is washout applied to wing tips?
16. Is the angle of incidence of ailerons affected by washout?
17. State the reason why the airplane is "banked" when turned off its course.
18. Why is steep banking dangerous?
19. Define in detail the mechanical means for operating directional and lateral control surfaces by foot bar, wheel and column.
20. What is the operation of the "joy stick"?



General view of an airplane with fuselage covering removed, showing details of body construction

CHAPTER ANALYSIS**Materials, Stresses and Strains****ACTION ON MATERIALS:**

- (a) Stress.
- (b) Strain.
- (c) Factor of Safety.

STRESS AND STRAIN FORCES:

- (a) Compression.
- (b) Tension.
- (c) Bending.
- (d) Shearing.
- (e) Torsion.

STRENGTH OF WOOD UNDER STRESS:

- (a) Straightness.
- (b) Fit.
- (c) Condition.

WOOD FOR AIRPLANES:

- (a) Spruce.
- (b) Ash.
- (c) Maple.
- (d) Hard Pine.
- (e) Walnut and Mahogany.
- (f) Cedar.
- (g) Hickory.

WING COVERING:

- (a) Fabric.
- (b) Dope.

METAL FITTINGS AND WIRE:

- (a) Steel.
- (b) Other Metals.
- (c) Wire.

CHAPTER IV

Materials, Stresses and Strains

The student having now mastered the theory of flight and the fundamentals of design of airplane lifting surfaces and controls, knowledge of rigging is next in order.

As an infantryman's first care is for his feet, and a cavalryman for his mount, so must the military aviator know his means of locomotion, his airplane. The army does not require the dismounted soldier to be a chiropodist, or the cavalryman a veterinarian, no more than the aviator is expected to be an expert mechanic. But he must know whether or not his machine is in condition, and what he may expect of it, without recourse to another's judgment. With the engine out of order a safe landing can be made, but when something goes wrong with the rigging there is trouble ahead. Should the rigging be wrong, even though nothing breaks, speed is lessened and stability and control made less effective.

Rigging an airplane properly presupposes knowledge of the stresses it is subjected to and the strains which may appear. Airplane materials are of the size and weight which combine greatest strength and least weight. A knowledge of them is important.

Stress is the load which a body bears. It is generally expressed thus: $L \div A = S$, where L is the load, A the square inches contained in the cross-sectional area, and S the resultant stress. For example, with an object measuring in cross-section $3'' \times 2''$ (an area of 6 sq. in.) and required to support a total load of 12 tons, the stress would be $12 \div 6 = 2$ tons.

Strain is deformation produced by stress.

If a spar is known to collapse under a maximum stress of 1200 lbs., in a training machine it would be subjected to no greater stress than 100 lbs.; thus where known stress of an object is 1200 lbs., and the maximum stress it is called upon to endure is 100 lbs., then $1200 \text{ lbs.} \div 100 \text{ lbs.} = 12$, representing:

The Factor of Safety, which is ordinarily expressed by the resultant of known collapsing strength divided by maximum stress the object is called upon to endure.

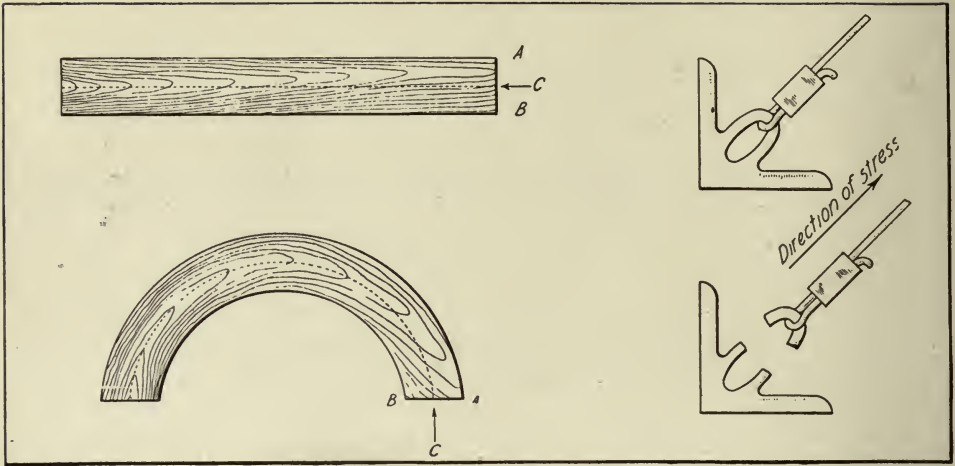


Figure 26—Compression and tension stresses produced by wood bending

Figure 27—An illustration of shearing

STRESS AND STRAIN FORCES

Strength of materials must be understood from the viewpoint of strength in compression, tension, bending, torsion and shearing. For example, wire is designed to take tension but not compression, wood takes compression but not shearing, bolts are liable to shearing, etc.

Compression—The stress of pressure produces a crushing strain, best exemplified by the stress on interplane struts.

Tension—The stress of pull, tending to elongation, exemplified by all wires.

Bending—A combination of tension and compression exemplified by the bending of wood, the outside fibres tending to pull apart, the inside to go together.

Shearing—A cutting off sideways by a pull such as is exerted on an eyebolt or pin.

Torsion—A twisting stress, a combination of the forces of compression, tension and shearing, such as is received by the propeller shaft.

Bending—Figure 26 illustrates how the combination of compression and tension stresses are produced by bending. The upper view shows a straight piece of wood, the top line (A), the center line, or “neutral axis” (C) and the bottom line (B) being all of equal length. In the lower view the same piece of wood is bent. Then center line (C) is still the same length, but the top line (A) is further from the center and therefore longer. This is due to the stress of tension producing the strain of elongation; the upper portion is therefore in tension, which increases with its distance from the center. Meanwhile, the bottom line, under the strain of crushing produced by the stress of compression, has become shorter than the center line. At the center line, therefore, there is neither tension nor compression and the wood nearest the center is under considerably less stress than that near the top and bottom lines. Thus the center may be hollowed out without appreciably weakening the wood, which makes it possible to save about 25 per cent. of the weight of the wood used in the construction of an airplane.

Shearing—In Figure 27, a wire exerting pull on an eyebolt is shown. The lower view illustrates how the stress may shear an eyebolt.

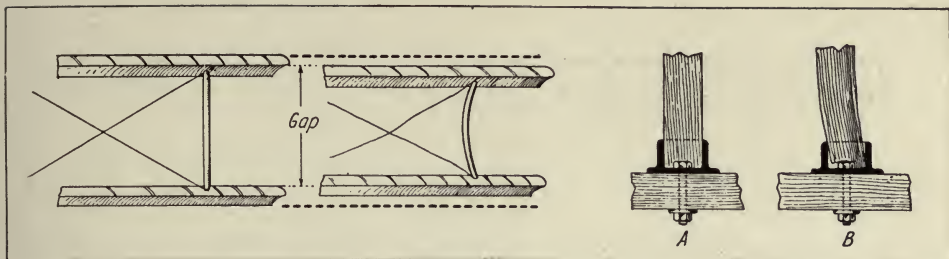


Figure 28-a

Effect of strut bending under stress

Figure 28-b

Figure 29
Strut properly and improperly bedded

STRENGTH OF WOOD UNDER STRESS

Upon the care exercised to have struts kept perfectly straight and evenly bedded into sockets rests the strength of wood under compression. A stick 1 inch in diameter and 36 inches long, if kept perfectly straight can perhaps bear a ton weight without breaking, but if it were not straight, or had started to bend, a compression of 50 pounds would break it. Weight being of the greatest importance in airplane design, the wooden parts are kept as far as possible in direct compression. To save weight is the aim of all designers and in consequence an airplane's factor of safety is ordinarily low. The required stresses for parts in direct compression may be safely taken, however, if they meet the requirements which follow:

Straightness—Spars and struts must be perfectly straight. Viewed in cross-section, these supporting members are elliptical in shape (stream lined); the center of strength is therefore midway between the points of greatest transverse width. If the stress of compression is not equally distributed about this point the strut will bend, because tension will be created on one side and compression on the other. The effect of a strut bending is shown in Figures 28-a and 28-b. In the former the wire stays are taut and the proper gap between wings maintained. With the strut bent, as in Figure 28-b, the gap is lessened and the wires have become slack, efficiency in flight being thereby lessened.

Fit—Struts and spars must fit their sockets accurately and be bedded correctly. While snugness is essential, the wooden portions of the structure must slide into their sockets or fittings by pushing; a hammer is never required. The bottom should fit the socket exactly. In Figure 29, strut A is correctly bedded; strut B is not snug at the bottom, in consequence of which the compression stress is not evenly distributed about the center of strength and a bending stress is produced.

In assembly, the customary test consists of painting the bottom of struts before they are fitted to sockets; the paint must be distributed over the entire bed when strut is withdrawn.

Condition—Struts and spars must be undamaged. If the wood is scored or dented, and the strut or spar should be subjected to a bending stress, the outside fibres receive the greatest strain (as explained on the preceding page) and the collapse will come at the imperfect point. Cross grain, knots and similar blemishes are prohibited for the same reason.

The wood must also be well varnished to keep the moisture out. Variation in the dampness of the atmosphere causes wood to expand and contract, the danger in this variation being that this expansion and contraction is not evenly distributed and the symmetry of the spar or strut is lost.

WOOD FOR AIRPLANES

Practically all of the airplane's framing is constructed of wood, one reason for this being that flaws can easily be detected; consequently, wooden parts are seldom painted, preservation being secured by the use of varnish which brings out clearly any defects. Lightness, strength and rigidity are the prime requirements for flying machine construction. Certain woods best fulfill these, better in fact than any metal. This may be illustrated by a comparison of spruce with aluminum, lightest of the metals.

A cubic foot of spruce weighs 27 pounds.

A cubic foot of aluminum weighs 162 pounds.

Tensile strength of spruce per square inch is 7,900 pounds.

Tensile strength of aluminum per square inch is 15,000 pounds.

Compression strength of spruce per square inch is 4,300 pounds.

Compression strength of aluminum per square inch is 12,000 pounds.

On the cubic foot basis, the weight of spruce has a decided advantage over metal. Aluminum's weight is 6 times greater; brass about 19 times greater; nickel and steel about 18 times; copper about 20 times.

While wood is not as strong as steel of the same size, the construction of struts requires a certain thickness in proportion to their unsupported length, so the use of spruce, although it offers by its size more head resistance, is to be preferred because strength against bending is secured with less weight.

Preferential woods for airplane work are Spruce, Ash, Pine, Maple, Walnut, Mahogany, Cedar and Hickory. The selection of the right kind of lumber is largely a matter of experience, but the fundamentals are soon acquired with application to the subject.

Spruce—The strongest and most generally satisfactory material when clear grained, straight, smooth and free of knot holes and sap pockets. Combining flexibility, lightness and strength, it is used for struts and spars.

Ash—A straight-grained wood, strong in tension, springy, but heavier than spruce. It is used for main spars, longerons, engine supports, rudder post, etc.

Maple—A strong wood suitable for small parts such as the blocks to connect rib pieces across a spar.

Hard Pine—A tough and uniform wood adapted for the long braces in the wings.

Walnut and Mahogany—Uniformity, hardness and finishing qualities are the reasons for extensive use of these woods for propellers.

Cedar—Lightness, uniformity and easy working qualities recommend this wood for occasional use in fuselage covering. Three-ply wood, or veneers, are sometimes used.

Hickory—Tough, hard and springy, this is the favored material for skids and landing chassis struts.

**Condensed Table of Weight and Strength
U. S. Government Specifications**

Wood	Weight per cubic foot (15% moisture)	Modulus of rupture, pounds per square inch	Compression strength, pounds per square inch
Hickory	50	16,300	7,300
Ash	40	12,700	6,000
Walnut	38	11,900	6,100
Spruce	27	7,900	4,300

Linen and cord are used for wrapping wooden members to increase strength against splitting; the winding is made very tight and treated with "dope" or glue for waterproofing and also to increase the tightness. Wooden parts are ordinarily ferruled at the ends, usually with copper or tin, to prevent the bolt pulling out with the grain, to prevent splitting and to supply a uniform base,

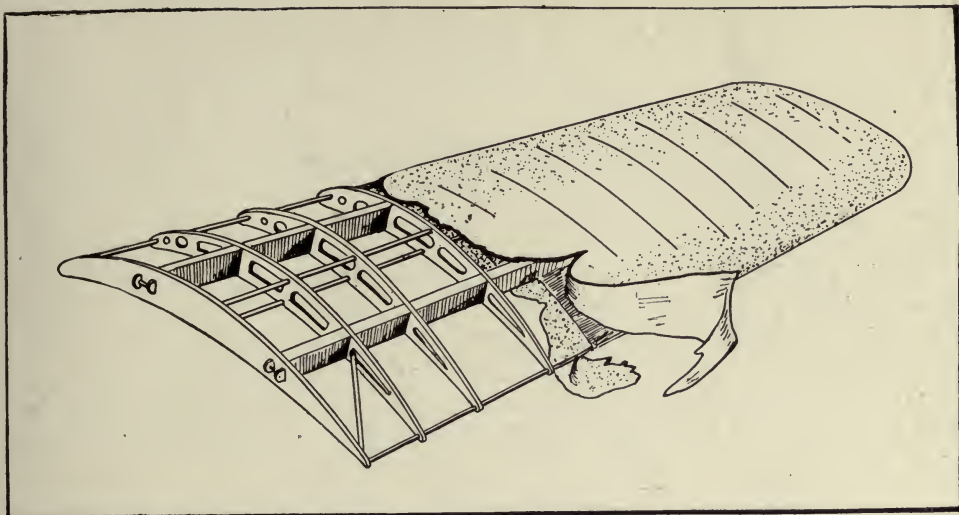


Figure 30—View of wing surface and method of applying covering

WING COVERING

Unbleached Irish linen, stretched rather loosely on the frame of the wing and then treated with "dope," is the almost universal covering for airplane lifting surfaces.

This fabric is woven with the "warp" of the yarn lengthwise and the "weft" across the cloth. It tests to a 60-pound tension on an inch-wide strip, and when doped shows a strength of at least 70 pounds per inch. It ordinarily weighs $3\frac{3}{4}$ to $4\frac{3}{4}$ ounces per square yard. Doped and finished, airplane linen weighs about 0.10 pound per square foot, inclusive of tape and varnish for both top and bottom faces of the surface.

Rubberized fabrics, formerly used, were discarded because of the necessity for stretching them tightly by hand on the frame, and because they tightened in dampness and sagged in dry weather.

The strips of the linen wing covering are sewed together by machine, forming a bag which slips easily over the framework, seams running diagonally across the wing. Figure 30 illustrates a partial covering on the wing framework.

A cotton fabric, the new way of spinning which is a closely guarded military secret, has been added to the materials for wing covering. Under the most rigid tests it surpassed in strength the stoutest linen.

DOPE

Dopes for coating linen wing coverings are of several kinds, but all are some compound of cellulose acetate or nitrate, soluble in ether or in acetone. Through doping, the linen is tightened up on the frame and given a smooth, weather-resisting finish.

The United States Army requires four coats of nitrate dope, this covering being varnished with two coats of spar varnish after the dope has set; this acts as waterproofing and protects the dope from peeling. Doped fabrics are best cleaned by soap and water.

Trade names of commercial dopes include: Cellon, Novavia, Emaillite, Cavaro and Titanine.

METAL FITTINGS AND WIRE

STEEL

Chrome nickel or vanadium steel, specially heat-treated, is often used for bolts, turnbuckles and pins. When parts are to be bent, special care must be taken that the heating is not done unequally. Serious weakening may result.

Cold rolled steel, used largely for ferrules, clips and fittings in airplane construction, is harder than mild annealed steel, works easily and wears well. Its grain is well marked and it should be remembered that it is weakest across the grain. Sharp bends should never be made and, unless one is familiar with annealing, any required bend should be made slowly in a vise. The jaws of the vise should be protected by thick copper pads to prevent nicking the plate.

OTHER METALS

Copper and tin are used for tanks and ferrules of wire joints.

Where rust resisting qualities are essential on metal fittings, "monel" metal is extensively used. It is composed of 60 per cent nickel, 35 per cent copper and 5 per cent iron.

Aluminum is unreliable and is never used in important fittings.

CRYSTALLIZATION AND FATIGUE

Metal is subject to crystallization and fatigue.

Crystallization—Constant vibration and jarring which causes easy breakage at a particular point.

Fatigue—Repeated strains of bending and twisting result in loss of "springiness" of metal, lessening its strength. This is known as fatigue.

WIRE

Two types of wire are used on airplanes: solid-drawn, for all minor bracing purposes; flexible cable, for control, flying and landing wires.

Aviation wire—This is a single wire, piano grade. While it is the strongest for its weight, it forms kinks easily when coiled and may be seriously injured by a blow. Its main use, therefore, is for braces in the protected fuselage and wings.

Aviator strand—This is 7 or 19 wires stranded together and used for tension wires because of its elasticity, permitting it to be bent around parts of small diameter.

Tinned aviator cord—This is a cord or rope stay, composed of seven strands of 7 or 19 wires twisted into a rope. The wires are galvanized as a protection against rust, but where the heat required for galvanizing will injure hard or small wires, they are tinned. It is in general use for controls, and although less strong as the same size in single wire, has the advantage of not being seriously injured by a single weak spot.

REVIEW QUIZ

Materials, Stresses and Strains

1. Why is a knowledge of strength of materials valuable to the aviator?
2. Define stress and give an example with an object of definite area supporting a given weight.
3. What is strain?
4. By an example, explain the factor of safety.
5. Briefly state the difference between the forces of compression, tension, bending, shearing and torsion.
6. How is it possible to hollow out wooden parts without appreciable weakening?
7. State the value of direct compression upon struts.
8. Give the reason for the care exercised in keeping struts straight.
9. How should a strut be bedded?
10. Why is it important that struts or spars should not be scored or dented?
11. Of what value is varnish?
12. In what respects is spruce superior to aluminum for airplane framing?
13. Explain how wooden members are given increased strength against splitting.
14. What material is generally used for wing covering?
15. How is the covering made and placed on the framework?
16. What is the purpose of dope and what is its composition?
17. Give some commercial names of dope.
18. In bending chrome nickel or vanadium steel what caution should be exercised? Cold rolled steel?
19. Define crystallization and fatigue.
20. State the composition and uses of aviation wire, aviator strand, tinned aviator cord.

CHAPTER ANALYSIS**Rigging the Airplane****ERECTION AND ASSEMBLY:**

- (a) Landing Gear.
- (b) Horizontal Stabilizer.
- (c) Vertical Stabilizer.
- (d) Rudder.
- (e) Elevators.

ASSEMBLY OF LIFTING SURFACES:

- (a) Center Section.
- (b) Main Wing Section.
- (c) Assembly.

ALIGNMENT:

- (a) Landing Gear.
- (b) Wings Without Stagger.
- (c) Staggered Wings.
- (d) Main Wing Sections.
- (e) Dihedral Angle.
- (f) Angle of Incidence.
- (g) Droop.
- (h) Controlling Surfaces.
- (i) Over-All Adjustments.

CONTROL CABLES AND WIRES:

- (a) Adjustment of Controls.
- (b) Turnbuckles.
- (c) Cables.
- (d) Wire Loops.
- (e) Tightening Wires.

EFFECT OF ALIGNMENT ERRORS:

- (a) Directional Stability.
- (b) Lateral Instability.
- (c) Longitudinal Instability.

FLIGHT DEFECTS:

- (a) Poor Climb.
- (b) Lessened Speed.
- (c) Poor Control.
- (d) Uncontrollable on Ground.

CHAPTER V

Rigging the Airplane

With a thorough understanding of the fundamental factors that make for flight efficiency, practical rigging of the machine may be turned to in full confidence of doing a good job. Reasonable familiarity with the use of simple tools remains to be acquired; but this is a short process of practice in their handling, the keystone of success being the exercise of care. If the preliminary study has been conscientious up to this point, the reason for each step in assembly will be clear without explanation and the requisite exactness will follow as a matter of course.

Golden Rules of Rigging

Don't hurry. If the job is a rush one, make haste slowly.

Never lay tools on the planes.

Pliers or wrenches are not for use on airplane bolts; a burred thread, or one damaged in any way, should be discarded.

Turnbuckles are to be started from both ends.

There should be a cotter pin for every nut and safety wires should lock all pins and turnbuckles.

Wire with a kink in it should be brought to the attention of some one in authority.

Don't hammer or pound bolts and pins into position; they must go into place by pushing or gentle tapping.



(c) Committee on Public Information

Figure 31—Assembling and rigging U. S. Army airplanes at a flying field

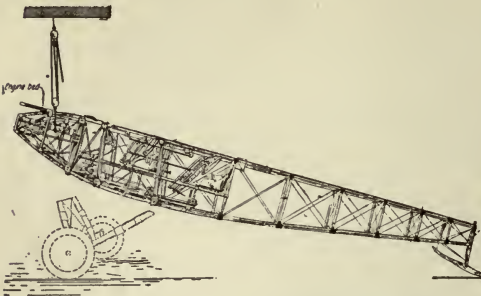


Figure 32a—Method of attaching landing gear



Figure 32b—Method of attaching horizontal stabilizer

ERECTION AND ASSEMBLY

An assembled airplane is a trim and fairly hardy machine, but before assembly the parts are fragile. When received, the greatest care should be exercised in unpacking boxes and crates.

The order of assembly and directions follow:

Landing Gear—Mount the wheels on the axle and bolt them into place. Connect up the tail skid by pinning the front end to the spring fitting and the other end to the socket of the tail post. Now raise the fuselage to receive the landing gear. This may be accomplished by blocking, or by tackle as shown in Figure 32a, where a line is passed under the sills of the engine bed—nowhere else—and caught by the hook of the hoisting block. Raise the front end of the fuselage until the lower clips of the longeron line up with the clips on the ends of the landing gear struts. The bolts are then passed through the aligned holes and the nuts drawn up tight. Cotter-pins are inserted in the holes drilled through the bolt, which then appear just beyond the castle of the nut. The leaves of the cotter-pins are turned backward, locking the nuts in place. The gear should then be aligned in accordance with instructions on page 44.

Horizontal Stabilizer—With the landing gear attached to the fuselage, elevate the tail of the machine, supporting it on a horse of proper height, or block until the upper longeron is level, verifying the arrangement by use of a spirit level placed on the upper longeron at the tail. See Figure 32b. Bolt the horizontal stabilizer to the top longeron and tail post and draw all nuts tight and secure them with cotter-pins.

Vertical Stabilizer—Fasten the vertical stabilizer by bolting it through the forward part of the horizontal stabilizer and the clip at the front of the vertical stabilizer; tighten nuts and lock with cotter-pins. A double clip in the rear passes over the two bolts which fasten the horizontal stabilizer to the tail post. Attach the flexible wire cables and tighten by the turnbuckles.

Rudder—Attach the control braces so that the upper tips point toward the line of the hinge. Mount the rudder on the tail post and vertical stabilizer and insert the pins in the hinges, securing them with cotter-pins.

Elevators—Attach the control braces in the same manner as with the rudder and mount the elevators on the horizontal stabilizer by means of the hinges and pins, the latter being secured by insertion of cotter-pins in the holes drilled for that purpose.

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Figure 33—Assembly of center section

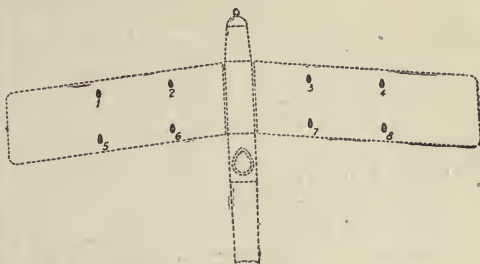
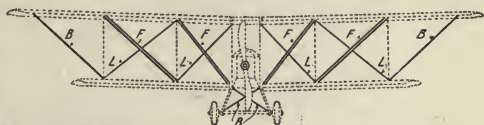


Figure 34—Curtiss strut numbering



B - bracing wires
 F - flying wires
 L - landing wires

Figure 35—Method of wiring

ASSEMBLY OF LIFTING SURFACES

Center Section—The section of wing surface first attached is that which is directly over the fuselage and known as the engine section panel. With the struts fitted into the proper sockets of the wing surface, the entire section with bracing wires attached, is lifted and set into the sockets on the upper longeron. Bracing wires are then attached and the section aligned.

The method is clearly shown in the photograph, Figure 33.

Main Wing Sections—While the upper lifting surfaces may be first assembled to the engine section and the lower wing then attached, it is preferable to complete assembly of the sections, or panels, before attaching them to the fuselage. The advantage of the latter method is that less adjustment is required and the correct stagger and dihedral is secured.

Figure 34 shows the numbering of struts on the Curtiss JN-4. These may be quickly committed to memory by noting that the four struts of the center, or engine section panel, are not designated, and that beginning at the left from the pilot's seat, the eight remaining struts are numbered from 1 to 8.

The main struts bear a number and can easily be read from the pilot's seat; it is therefore at once evident if, through error, a strut is inverted.

Assembly—The upper wing of the left lifting surface receives struts Nos. 1 and 2 in the proper sockets. The wires are then connected to right and left by clips and adjusted by turnbuckle until the spars are straight. The wing is then set on a cushioned block, leading edge down. See Figure 31.

The lower left wing is then brought, leading edge resting on cushioned block, to a space equal to the length of the struts. Diagonal wires are loosely connected and spars inserted in sockets, 5 and 6, and bolted into place.

The "landing," or single, wires and the "flying," or double, wires of struts 1 and 5 are then connected closely, so the wings may be held together while being attached to the fuselage.

Figure 35 clearly indicates the wiring of the assembled airplane wings.

The erection of the wing must be done with special care. Lifting by the struts or edges of the wings may result in a serious strain. Boards placed under the beams of the wing framework should be used for carrying.

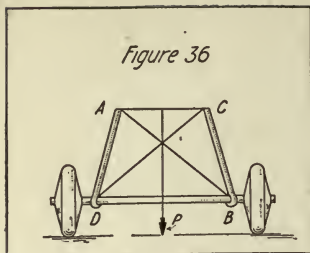


Figure 36

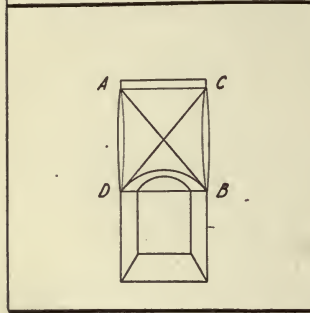


Figure 37a

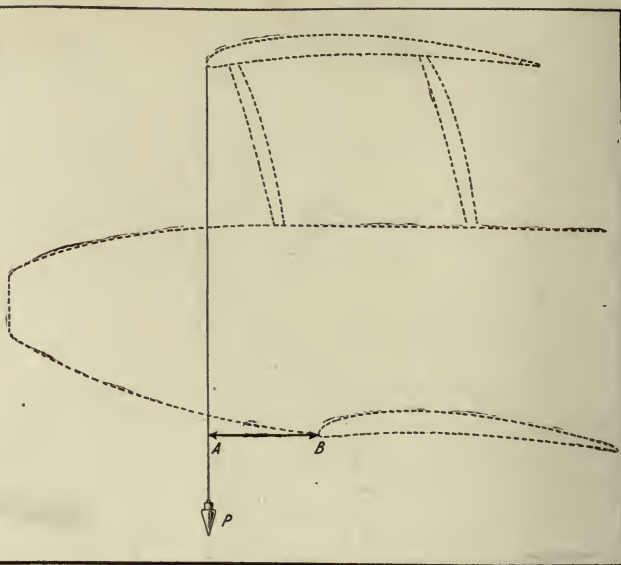


Figure 37b—Stagger alignment

ALIGNING THE AIRPLANE

Correct alignment of an airplane is of tremendous importance. Its flying efficiency depends largely upon exactness in truing up all controls and wires and securing proper angle of incidence and dihedral. The parts should be aligned in regular order as follows:

Landing Gear—To be aligned before wings are attached to fuselage. The axle should be parallel with the lateral axis of the fuselage. Ascertain the exact center of the fuselage and the axle; with spirit level align the cross width of the fuselage. Drop a plumb line from the center of the fuselage and adjust the cross wires until it is in the exact center of the axle.

Or, if plumb bob and line are not available, adjust the cross wires so that the measurement *A-B* is exactly equal to the measurement *C-D* in Figure 36. The adjustment is made on both front and rear supports of the under carriage.

The landing gear and fuselage are aligned in the factory, but their correctness should be determined by the method just given. Before aligning, it is well to verify that the tail support still holds the fuselage horizontal.

Center Section—The bracing wires (*A-B*, *C-D*, Figure 37a) are left sufficiently tightened to keep the struts straight, while the wings are being aligned.

Without Stagger—The upper longerons of the fuselage being horizontal, the struts are properly placed when they form a right angle. Adjust the sides first and then the front. Check the perpendicular alignment by measuring off an equal distance on the upper longeron back and forward of some point on the bottom of the strut; the strut will be exactly perpendicular when the distance from these two points to the top of the strut measures exactly the same. Tighten bracing wires evenly until sides and front are correctly aligned; i. e., until the measurement of corresponding points on cross wires are identical.

Staggered—The angle of strut fittings and sockets serves as a guide to the degree of stagger. The airplane's specifications state the stagger; for example in the Curtiss JN-4 it is $10\frac{1}{8}$ inches. This is checked by a plumb line suspended from the leading edge of the top surface, as in Figure 37b, and the measurement is taken between points *A-B*; that is, the plumb line should be $10\frac{1}{8}$ inches in advance of the leading edge of the lower wing.

In all types of airplanes the specifications state how the measurements should be taken (a) along the line of the chord, or (b) horizontally.

When the stagger is verified, the wires should be tightened and the cross distances measured until one side corresponds exactly with the other. Side wires should be adjusted first, and then the front, and cross distances measured until they correspond exactly.

Main Wing Sections—The first point to determine is whether leading edges of the upper and lower wing surfaces are exactly in line with the center section. Standing on a step ladder, 15 feet to one side, a sight by eye is taken along the leading edge of the upper plane. If not straight, the adjustment for warp or bow is made by tightening or loosening the front landing wires. The same should then be done for the lower plane and the opposite wing aligned in the same manner. When the cross wire adjustments have been completed, a sight taken from both ends of the wings should show all struts in line and parallel with the center section struts.

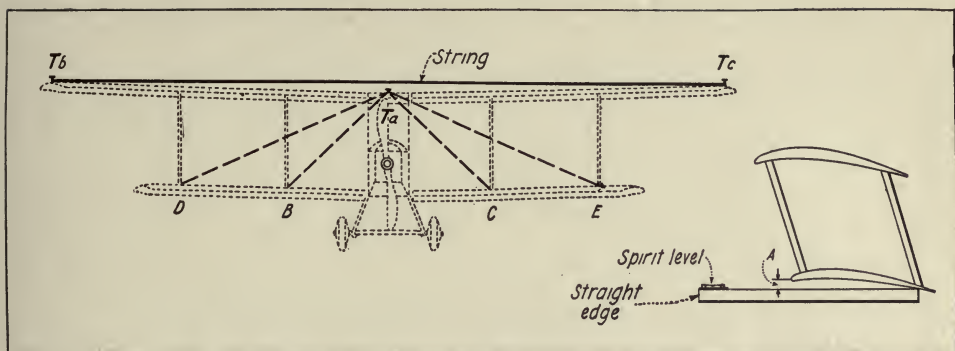


Figure 38—Dihedral angle measurements

Figure 39—Angle of incidence

DIHEDRAL ANGLE

One method of securing the dihedral angle is shown in Figure 38, where Ta is a tack placed in the exact center of the center section, on the leading edge of the upper wing. The exact distance is measured off then on each side and tacks, Tb , Tc , placed in the leading edge of both upper wings, at a point near their tips. A string is stretched tightly between Tb and Tc . The specifications are then referred to and the dihedral angle checked. Assuming the dihedral angle to be 176 degrees, then each wing has been raised 2 degrees. The natural sine of 2° being 0.0349, this, multiplied by the distance between Tb and Ta (or Ta and Tc) gives the proper distance between Ta and the string directly above it.

Example:

The distance $Tb-Ta$ (or $Ta-Tc$) is 16 feet=192 inches.

$192 \text{ in.} \times 0.0349 = 6.7 \text{ in.}$, or the proper distance between Ta and the string above, if wings are set at the proper dihedral.

In making the alignment, wings should be raised equally until the correct measurement over the center section is secured, with leading edges kept straight.

All adjustments should be made by altering the wires from the inside bays; when diagonal wires are to be tightened make sure that the opposite wires in the same bay are slackened off.

Check up the alignment by measuring (Figure 38) from Ta successively to points D , B , C , E , making certain that the distance $Ta-B$ corresponds with $Ta-C$, and $Ta-D$ is the same as $Ta-E$. This will show that both wings are the same height.

ANGLE OF INCIDENCE

The specifications give a set measurement for the angle of incidence. Verify the horizontal position of the top longeron of the fuselage, i. e., make certain that the airplane is in flying position. Then place the straight-edge underneath the center of a rear strut as shown in Figure 39. With a spirit-level, adjust the straight-edge to horizontal position. Refer to the specifications and note the set measurement given; this will require measurement from

- (a)—the lowest part of the leading edge to top of the straight-edge, or
- (b)—the center of the front strut to the top of the straight-edge.

This measurement must be repeated under every strut, or the lower surface where struts occur.

The measurement should not be made between struts, because the wings may be slightly warped.

If the angle is too great:

Slacken all the wires attached to the top of the rear strut and tighten all the wires attached to the bottom.

If the angle is too small:

Slacken all wires attached to the bottom of the strut and tighten all wires attached to the top.

The correct adjustment, laid down in the specifications, should be made with no greater variation than 1-16 inch. The measurements at all struts must agree, i. e., the angle of incidence all along the wing must be the same, unless the wings have a wash-out or wash-in.

Check up the stagger with a plumb line to see that it has not been disturbed while securing the dihedral.

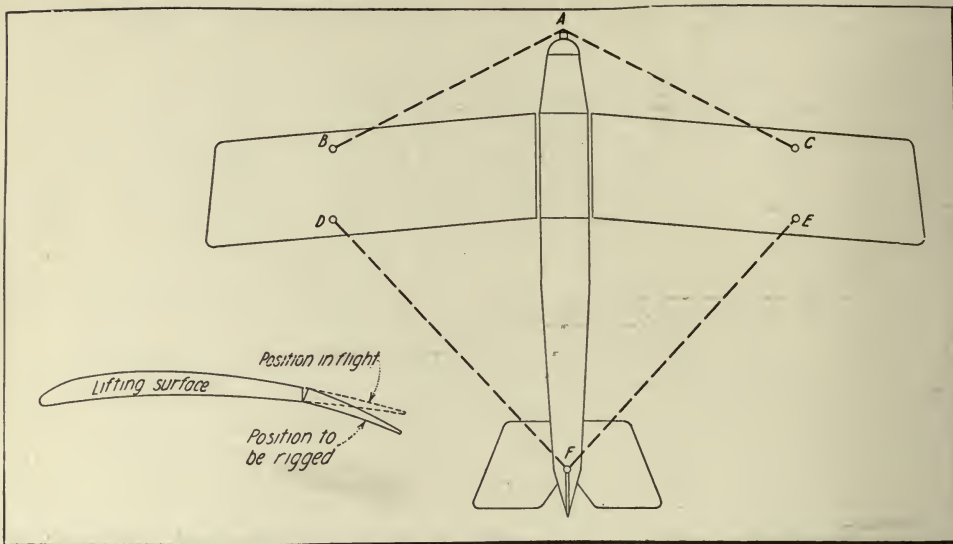


Figure 40—Aileron rigging

Figure 41—Over-all check

DROOP

When the angle of incidence and the stagger have been adjusted, one wing must be slightly drooped to correct for the torque of the propeller, where a single propeller is used in tractor airplanes.

With a propeller that turns to the right (clockwise) the left wing is drooped. If it turns to the left the right wing is drooped.

For machines up to 100 horsepower, the outer rear landing wire of the wing which is to be drooped is slackened until the trailing edge between outer and intermediate struts is about 1 inch lower than the rest of the trailing edge.

CONTROLLING SURFACES

Since the pilot depends upon the manipulation of controlling surfaces to manage his airplane, exceptional care should be taken that ailerons, elevator and rudder are properly rigged.

Ailerons, Trailing Edge (wing flaps)—With the control levers rigidly blocked into neutral position, the aileron should be rigged so its trailing edge is about $\frac{3}{4}$ inch below the trailing edge of the surface to which it is attached. In flight the angle of incidence of the surface will cause it to lift a little above the position, or to the true line. This is illustrated in Figure 40 where the dotted outline shows the position during flight.

A basis of measurement commonly used is $\frac{1}{2}$ inch depression for every 18 inches of chord of the controlling surface.

Tail Stabilizer—With the weight of the tail supported by the tail skid, align the rear edge of the stabilizer so it is straight and parallel with the lateral axis of the airplane. Take a sight from the rear to the leading edge of the upper plane, which should be in alignment with the trailing edge of the stabilizer. Tighten the wires by turnbuckles.

Elevator Flaps—With the controls in neutral position adjust the control wires by turnbuckles until the elevator flaps are in the same plane, and sufficiently tight to eliminate lost motion.

Rudder—Adjust the control wires by turnbuckle until both foot bar and rudder in neutral position show no lost motion in control.

Over-All Adjustments—Figure 41 illustrates the measurements which are taken as a final check. The measurement $A-B$ must equal $A-C$ within $\frac{1}{8}$ inch. Point A is the center of the propeller (in pusher types, the center of the nacelle) and B and C are points marked on the outer spars equally distant from the butts of the spars. The measurement should be taken from both top and bottom on each side.

$D-F$ should equal $E-F$ within $\frac{1}{8}$ inch. The rudder post is point F , and D and E are points on the rear struts marked as in the case of B and C . Two measurements, top and bottom, are also taken here.

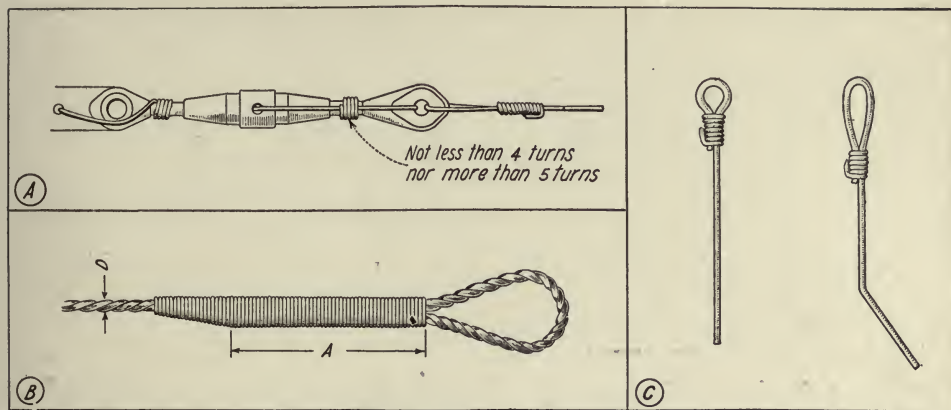


Figure 42—Turnbuckles, cables and wire loops

CONTROL CABLES AND WIRES

Adjustment of Controls—From the pilot's seat move the control levers and note if a quick movement shows lag or snatch in the movement of the control surfaces. Movement of $\frac{1}{8}$ inch to either side should produce corresponding motion of the controlling surfaces.

Turnbuckles—The turnbuckle, which is shown in Figure 42a, is a barrel with an eye-bolt screwed into each end; it is therefore hollow and should not be turned with pliers. It is best adjusted by passing a piece of wire through the hole in the center and using it as a lever. The illustration shows the proper method of using the locking wire, so the barrel may not turn and thereby throw the airplane wires out of the fine adjustments required.

Cables—Windings must be even with a stream-lined effect at the end of the winding as shown in Figure 42b. The dimensions of the winding before it tapers off (see *A*, in the illustration) must be at least 15 times as great as *D*, the diameter of the cable. Only non-acid flux should be used in soldering.

Correct Winding for Cables

Size of Cable Inches	Length of Winding Inches	Breaking Strength Pounds	Size of Cable Inches	Length of Winding Inches	Breaking Strength Pounds
1-32	$1\frac{1}{2}$	185	5-32	$2\frac{3}{8}$	3,200
1-16	$1\frac{1}{2}$	500	3-16	3	5,500*
3-32	$1\frac{1}{2}$	1,100	7-32	$3\frac{3}{8}$	6,100
7-64	$1\frac{3}{4}$	1,600	$\frac{1}{4}$	$3\frac{7}{8}$	8,000
$\frac{1}{8}$	2	2,100	5-16	$4\frac{3}{4}$	12,500

*For cable; loop strength is 5,100 pounds.

Control cables wear and fray out by friction with pulleys; careful examination should be made after each flight, and if a single strand is broken the cable should be replaced.

WIRE LOOPS

Wherever a loop is made with wire to connect with a fitting or turn-buckle it should be symmetrical in shape and reasonably small, with well defined shoulders. A loop properly made is shown at the left of Figure 42c, and one improperly made at the right. Where the shoulder is not properly made and the loop elongated the ferrule is likely to slip up and throw the wire out of adjustment.

When the loop is finished the wire should be undamaged. Wire bent to the degree shown at the lower end of Figure 42c should be discarded.

TIGHTENING WIRES

Care must be exercised that wires are not too tight or extra loads will be placed on spars and struts. Wires should never be at a tension so they "sing."

THE EFFECT IN FLIGHT OF ALIGNMENT ERRORS

DIRECTIONAL STABILITY

Wrong Angle of Incidence—The airplane will turn toward one side if the angle of incidence of one side of the wing surface or tail surface is wrong; for drift increases with greater angle and decreases with lessened angle.

Fuselage, Rudder-fin or Struts Off Line of Direction of Flight—The airplane will turn off its course, for unless these are aligned they will act as a rudder.

Distorted Surfaces—The airplane will turn off its course if there is an improper bend in leading or trailing edge or spars, for the amount of drift will be changed on one side by increased resistance.

LATERAL INSTABILITY

Wrong Angle of Incidence—If the angle of one wing is greater, more lift will be produced on that side, with corresponding decrease on the other wing. The airplane's tendency will then be to fly one wing down.

Distorted Surfaces—The same tendency to fly one wing down will be observed when the camber of the wing surfaces is spoiled by some distortion, through which the lift is made unequal.

LONGITUDINAL INSTABILITY

Wrong Angle of Incidence—If the lifting surface angle is too great the nose will rise through excess of lift and a tendency to fly tail down will result. Too small an angle may cause the airplane to fly nose down.

Occasionally, the tail plane's angle of incidence is found to be wrong; the angle should be lessened if the airplane is nosing down, and increased if tail-heavy. Adjustments of this kind must be made with care, because longitudinal stability depends entirely on the tail-plane having less angle than the main lifting surfaces.

Fuselage Warped—For the reason given above, a fuselage warped up or down, thereby giving an incorrect angle of incidence to the tail plane, may result in the airplane nosing down or being tail heavy.

Wrong Stagger—A nose-heavy airplane will result if the top wing is not staggered forward to the correct degree, because the lift will then be too far back. An error of $\frac{1}{4}$ inch will make a material difference in longitudinal stability. The cause of such error is generally due to the elongation of wire loops or if wires have pulled the fittings into the wood.

FLIGHT DEFECTS

POOR CLIMB

Excepting engine and propeller trouble, the reason for an airplane climbing badly is generally due to (1) too small angle of incidence; (2) distorted surfaces.

LESSENERD SPEED

Excepting engine and propeller trouble, poor flight speed is generally due to (1) too great angle of incidence; (2) distorted surfaces; (3) skin-friction, from dirt or mud on surfaces.

POOR CONTROL

The main causes are (1) incorrect setting of control surfaces; (2) distortion of control surfaces; (3) control cables badly tensioned.

UNCONTROLLABLE ON GROUND

When an airplane will not "taxi" straight the fault is generally due to (1) improper alignment of landing gear, wobbly wheels, or (2) unequal tension of shock absorbers.

REVIEW QUIZ

Rigging the Airplane

1. Give six important cautions about handling tools.
2. Explain the process of assembling the landing gear.
3. What control is first attached to the fuselage, and how?
4. How is the vertical stabilizer fastened?
5. Explain the assembly of rudder and elevators.
6. What section of the wing surface is first attached to the fuselage?
7. Should main wing sections be assembled complete before attaching?
8. State how struts are numbered and a reason why numbering is essential.
9. Give in detail the process of wing assembly with particular reference to the initial adjustment of wires.
10. Why is careful alignment of an airplane important?
11. What are the two methods of aligning the landing gear?
12. Describe wing alignment without stagger.
13. What is the check for staggered wings?
14. State how the alignment of main wing sections is verified.
15. Explain the method which insures correct dihedral angle.
16. Where and with what aids should the measurement be taken for the angle of incidence?
17. What adjustment is made to correct for torque of the propeller?
18. Give a rule for rigging the trailing edge ailerons.
19. From what points are final check measurements taken?
20. State seven general rules which govern adjustment of cables, wire loops and turnbuckles.

CHAPTER ANALYSIS**Fundamentals of Motive Power****THE PROPELLER:**

- (a) Balance.
- (b) Surface Area.
- (c) Length.
- (d) Straightness.
- (e) Care.

THE GASOLINE ENGINE CYLINDER:

- (a) Combustion Chamber.
- (b) Piston.
- (c) Connecting Rod.
- (d) Crank Shaft.
- (e) Revolution.

THE FOUR-CYCLE PRINCIPLE:

- (a) Intake Stroke.
- (b) Compression Stroke.
- (c) Power Stroke.
- (d) Exhaust Stroke.

MULTIPLE CYLINDER ENGINES:

- (a) 4-cylinder Operation.
- (b) 6-cylinder Operation.

CHAPTER VI

Fundamentals of Motive Power

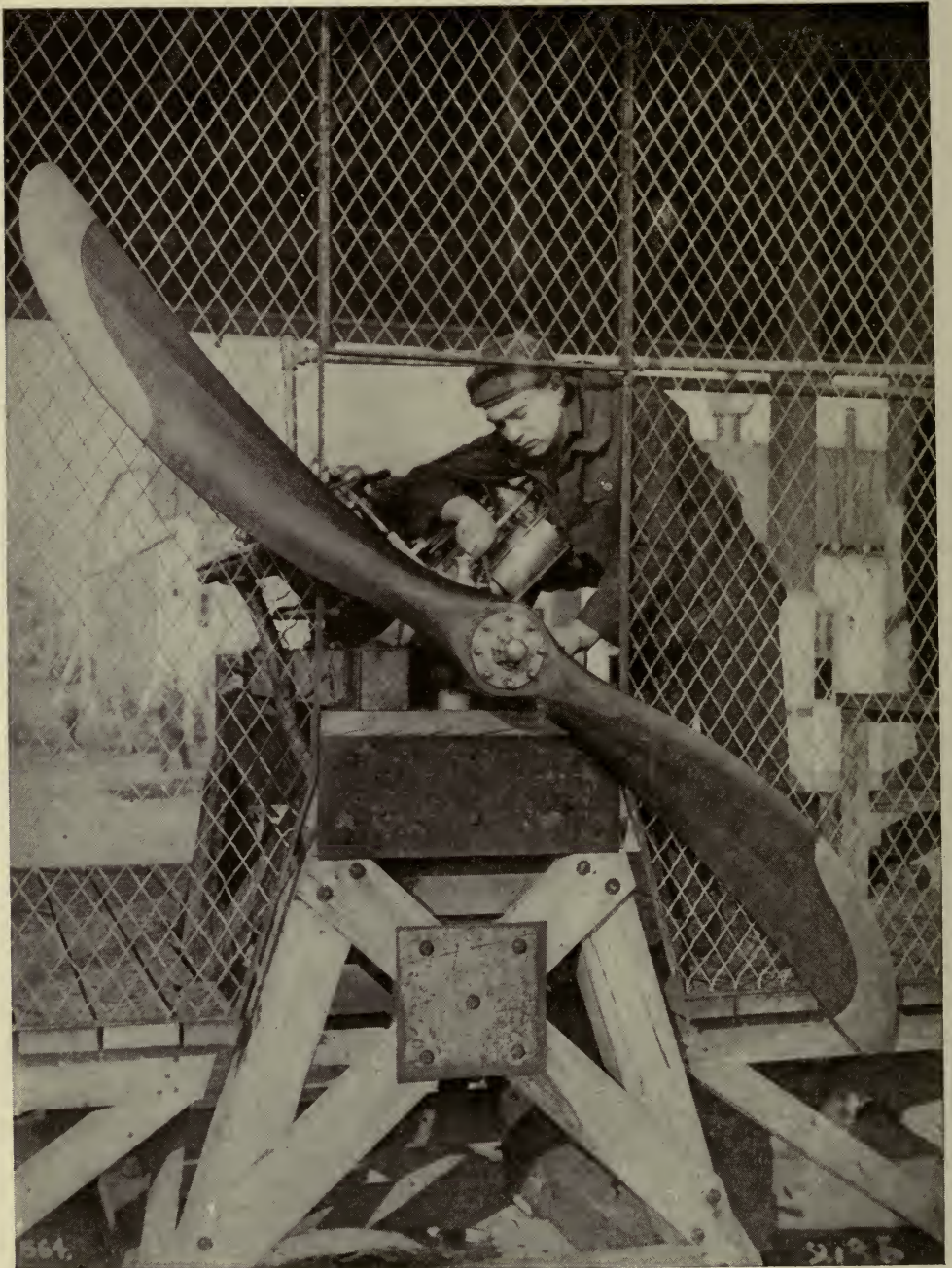
Earlier chapters have dealt entirely with the theory of flight and the function and construction of the airplane as a flight medium. The student is now ready to consider the propulsion of the machine, upon which all theory of flight obtains.

Flight is made possible, as has already been explained, by the action of the air on inclined surfaces driven through the air at high velocity. The reader is aware that the driving force is a propeller actuated by a gasoline engine. Consideration of the propeller will be brief, as the military aviator is not concerned with the details of engineering mathematics upon which propeller efficiency is based. Some knowledge of the method of checking up the balance of the air screw is all that is required of the pilot, and this is given on the page following.

The study of engines must necessarily be of a general character, as the varying types of design in internal combustion engines make a full consideration of the refinements of operation a subject of voluminous proportions. The four chapters devoted to airplane motors give all the important points of information in a brief survey of the general construction and operation principles which apply to the most familiar types of aviation engines.

The aviation engine must have small weight per horse power, minimum head resistance and reliability of operation; for these reasons some minor changes in design from familiar automobile types will be noticed. The first consideration is the stationary water-cooled motor; later, the rotary air-cooled types will be described.

The student aviator is specially cautioned to apply himself to mastery of this chapter on engine theory. A thorough working knowledge of motors is required of military airmen before flight instruction is begun. A pilot who does not understand the principles of his motor's operation can never expect to secure the best efficiency from his engine, and the ability to secure an extra ounce of motive power or speed is often the means of gaining a victory over an enemy airplane. Special emphasis is laid on the explanation of the four-cycle principle in this chapter; without a full understanding of these phases of operation the study cannot be continued intelligently.



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Block test of an airplane engine with propeller attached, showing the screen protection given to the mechanic. The necessity for this precaution is at once obvious when it is known that the propeller revolves at a speed of 1,400 revolutions per minute

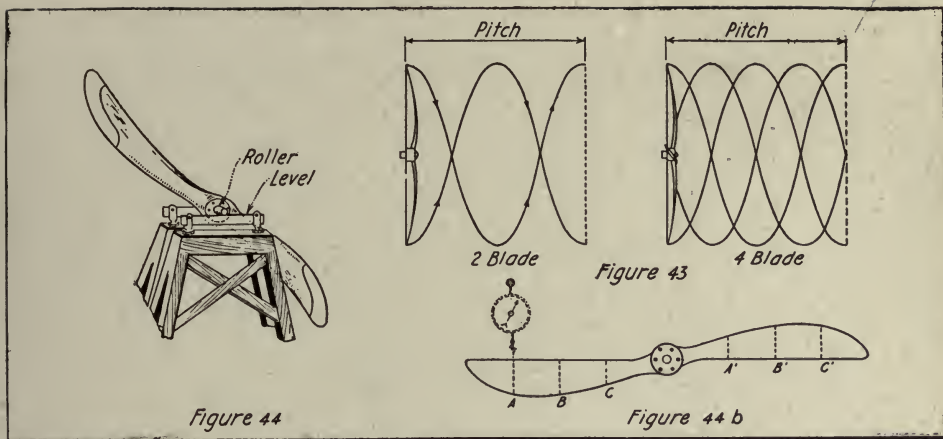


Figure 43—Action of propeller revolutions
 Figures 44, 44b—Method of propeller test for balance and area

THE PROPELLER OR "AIR SCREW"

The propeller's revolutions represent thrust, its action in screwing through the air (see Figure 43) translating the power of the engine into forward motion. The drift of the airplane, due to its resistance, is overcome by opposition of the thrust; it follows, therefore, that the power of the propeller thrust must be greater than the airplane's drift, or the velocity will decrease.

BALANCE

The propeller is mounted after the airplane is assembled. It should first be tested for balance, for if one blade is heavier than the other it will vibrate when run on the engine. The usual test is shown in Figure 44. A stand is leveled up; a roller is then inserted in the hub of the propeller, which turns freely on the roller; this roller is then allowed to roll freely on the level. Any lack of balance is thus easily detected.

Another method is indicated in Figure 44b. The propeller is placed in horizontal position and three points on the blades measured off equally distant from the center. By means of a spring balance weighing scale, the weights are taken at these points, and must correspond for each side.

Application of more varnish on the lighter side is usually sufficient to equalize a propeller out of balance.

SURFACE AREA

Measurement of three equi-distant points by callipers should show corresponding measurements to exactness of less than $\frac{1}{8}$ inch. Figure 44b illustrates this measurement, A being equal to A' , B to B' and C to C' .

LENGTH

Blades should be of equal length to 1-16 inch.

STRAIGHTNESS

With the propeller mounted on a shaft an object should be fixed in a position where the tip of one blade grazes it. With the point marked, the other blade is brought around and should come within $\frac{1}{8}$ inch or graze it.

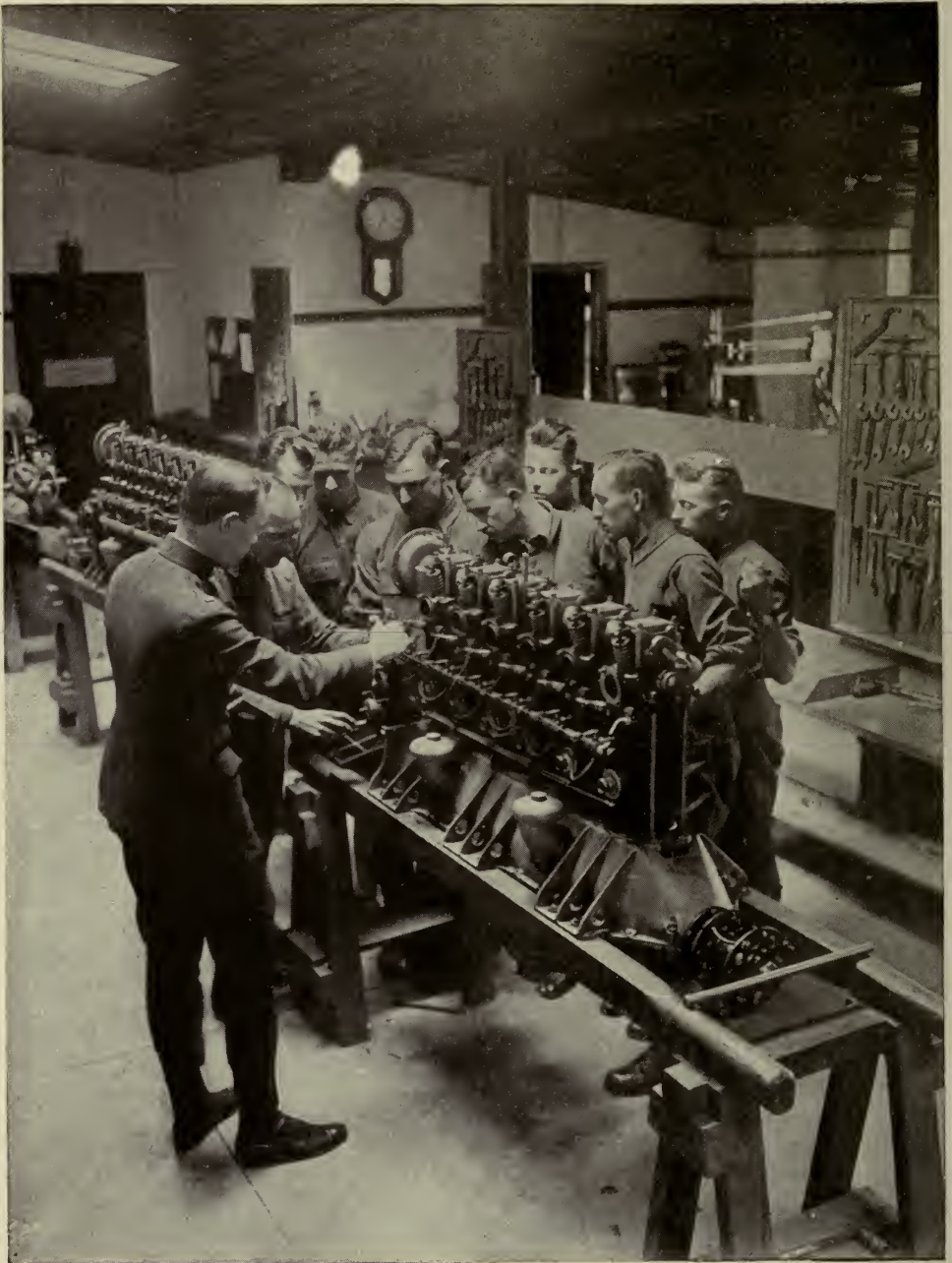
CARE OF PROPELLERS

They should never be leaned against a wall or allowed to remain long in horizontal position.

They should not be stored either in very damp, or very dry, places.

They should not be stored where the sun will shine on them.

The proper method of storage is hanging in vertical position on horizontal pegs.



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This picture, taken at one of the "Ground Schools" of the Army Signal Corps, well illustrates the earnestness and concentration of the men. The instructor is obviously having no difficulty in keeping his men at work, for these future American airmen know just as well as he how vital it is that they should understand every impulse of the engine which will soon mean so much to them in midair. A most thorough and fundamental course of training in engines is necessary for the men who carry the responsibility for America's warfare in the skies

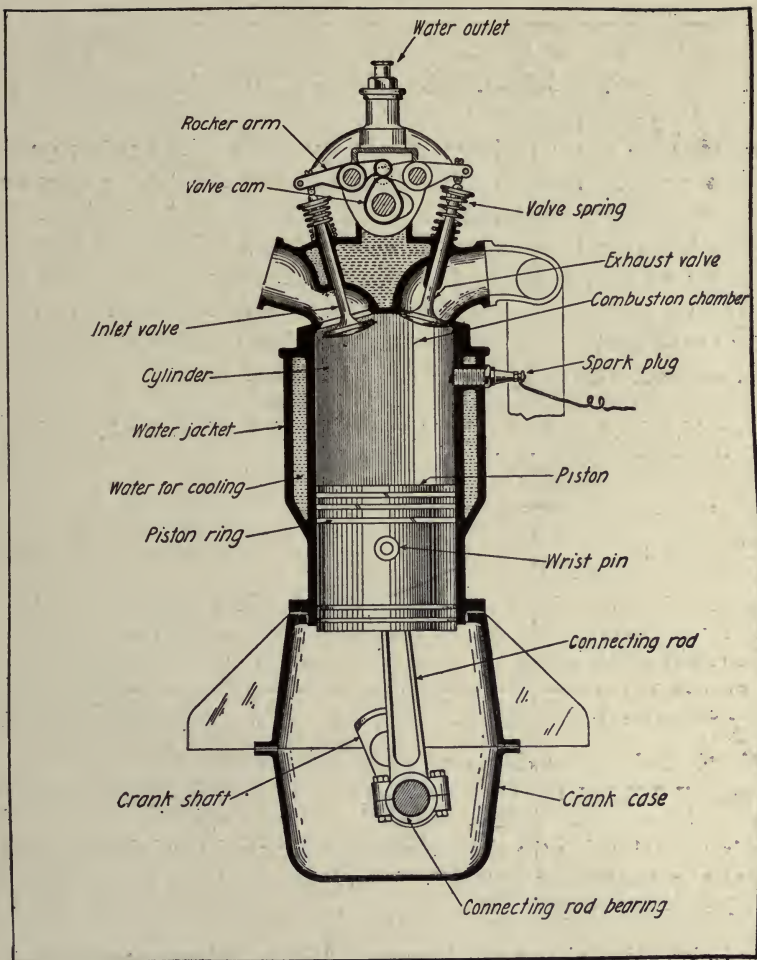


Figure 45—Single cylinder of a gasoline engine

THE GASOLINE ENGINE CYLINDER

Vaporized gasoline mixed with air and set afire by an electric spark results in combustion (explosion), the intense heat from which develops the pressure which operates the engine.

Figure 45 shows a single cylinder of a gasoline engine in sectional view. The names of the parts should be studied.

COMBUSTION CHAMBER

The closed end of the cylinder, in which the combustion takes place, is known as the cylinder head, the space between it and the piston being the combustion chamber.

PISTON

This is a cylindrical-shaped body which slides back and forth in the cylinder, the combustion (explosion) driving it downward.

CONNECTING ROD

Suspended from the piston is a connecting rod which acquires a *reciprocating motion* as the piston moves up and down.

CRANK SHAFT

The connecting rod is attached to the crank shaft, by means of which the reciprocating motion is changed to a *rotary motion* (as a wheel revolving on its axis) which turns the propeller.

REVOLUTION

A complete turn of the crank shaft, moving the piston down and back, is called a revolution.

THE FOUR-CYCLE PRINCIPLE

There are two types of internal combustion engines using gasoline for motive power; viz.: the two-cycle and the four-cycle. These may be distinguished by considering them as two-stroke and four-stroke engines. The two-cycle engine has no valves, the gas entering and exhausting through ports in the cylinder walls, covered and uncovered at proper intervals by the travel of the piston up and down. The four-cycle engine, which will be considered exclusively in the text following, as its use is almost universal in aviation, has intake and exhaust valves operated by mechanical means.

Figures 46, 47, 48 and 49 show the action of the four-cycle engine, clearly indicating the operations during the four strokes.

INTAKE STROKE

Suction caused by the piston starting downward, as the engine is "cranked," draws the explosive gasoline vapor into the combustion chamber of the cylinder. It enters through the intake valve, which is the only opening. The exhaust valve is closed, the intake valve being so adjusted that the cam opens it mechanically as the suction action of the piston commences.

COMPRESSION STROKE

Both valves are closed as the piston starts on its up-stroke and the explosive mixture in the cylinder is compressed into the small space of the combustion chamber as it reaches the top of the stroke.

The explosive value of compression may be illustrated by considering the action of gunpowder, which, ignited in the open air burns slowly but is instantly exploded if confined to a small chamber.

POWER STROKE

As the piston reaches the top the spark is timed to jump the spark gap points and ignite the explosive vapor. The piston is driven down by the expansion of the gas, making the power stroke.

EXHAUST STROKE

As the piston returns from the power stroke the exhaust valve is opened, the pressure from the explosion forcing out the burned gas. The upward move of the piston pushes out all of the burned gas that does not escape by its own pressure.

The exhaust valve closes as the piston reaches the top, and the inlet valve opens to admit a fresh charge of gas into the cylinder. The operation is then repeated as long as the engine runs.

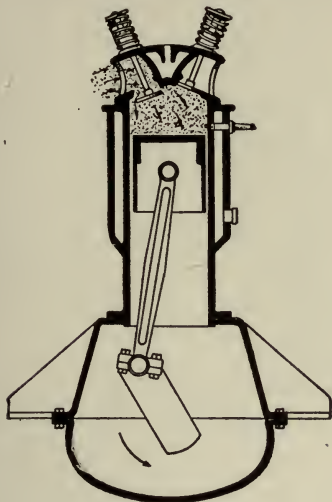


Figure 46

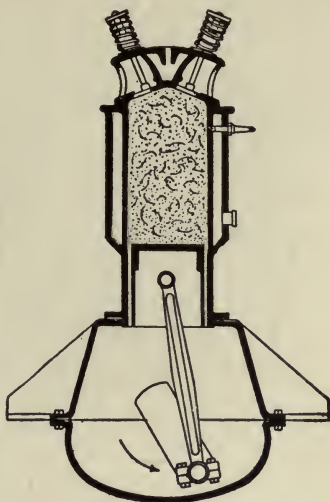


Figure 47

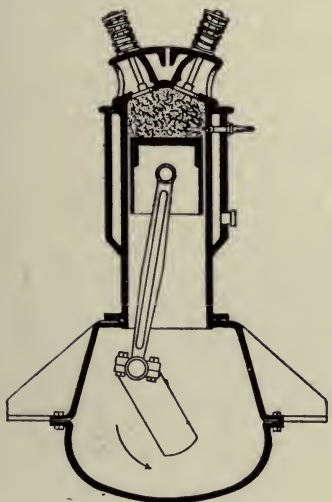


Figure 48

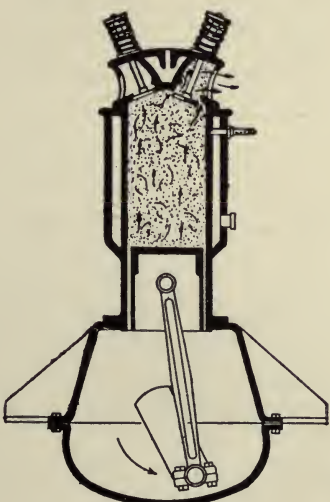


Figure 49

Figure 46—Intake stroke

Figure 47—Compression stroke

Figure 48—Power stroke

Figure 49—Exhaust stroke

THE FOUR-CYCLE PRINCIPLE

FIGURE 46

This is the intake stroke. The inlet valve is open and the gas is entering the cylinder, drawn by the suction of the piston.

FIGURE 47

This is the compression stroke. Both valves are closed and the piston is returning, the upward stroke compressing the gas.

FIGURE 48

This is the power stroke. The electrical spark from the spark plug ignites the gas. Both valves are closed as the combustion drives the cylinder downward.

FIGURE 49

This is the exhaust stroke. Only the exhaust valve is open, the upward movement of the piston forcing the burned gases out of the cylinder.

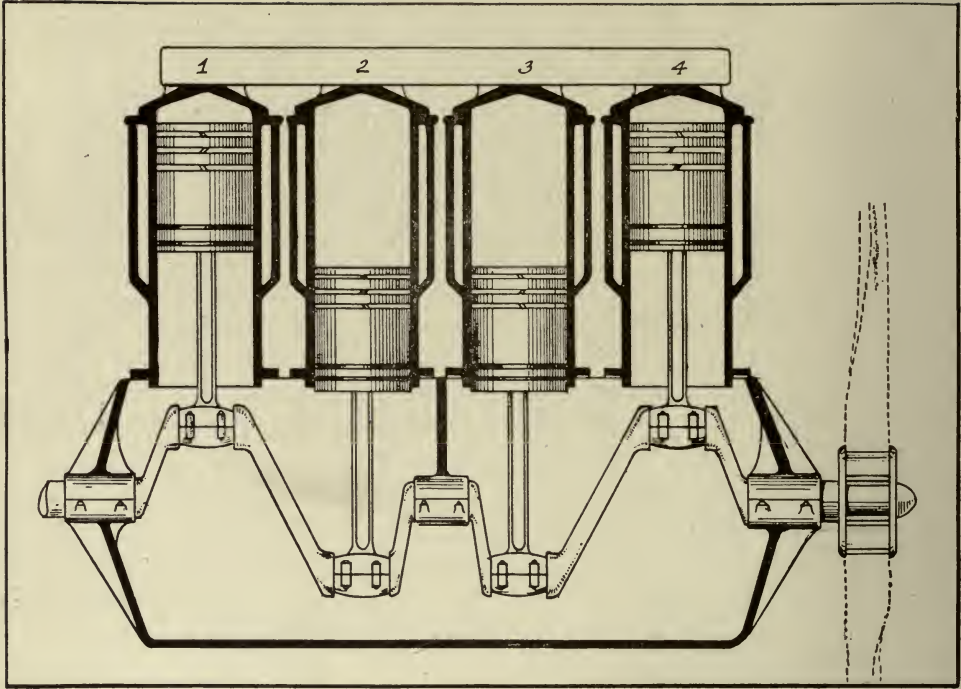


Figure 50—Cross section of a 4-cylinder engine

MULTIPLE CYLINDER ENGINES

A cycle operation requires four strokes to two revolutions. Only one of the four strokes is a power stroke; therefore, in a single cylinder engine the piston must be carried through three dead strokes. This ordinarily requires a heavy fly wheel, which when started will continue to revolve. It is obvious that the more cylinders an engine has the steadier will be the power impulses, since the successive explosions may be timed to follow so closely that one of the pistons will always be on a power stroke. Thus in aviation engines where weight is a material factor, the heavy fly-wheel is dispensed with by use of multiple cylinder engines.

4-CYLINDER OPERATION

Four-cylinder engines deliver a power impulse every stroke, or two power impulses to every revolution.

Figure 50 shows a 4-cylinder engine in cross section.

It will be noted that the crank shaft which delivers motion to the propeller is set at 180 degrees, the end pair being a half-revolution from the inside pair.

As piston No. 1 descends on the power stroke, No. 2 is coming up on exhaust; No. 3 is ascending on compression and will be fired next; No. 4 is taking in gas.

FIRING ORDER

The rotation in which the explosions take place in the cylinders is therefore 1, 3, 4, 2.

This engine could as well fire 1, 2, 4, 3, but it will be obvious that explosions in the order 1, 2, 3, 4 would require a crank shaft alternately projecting to each side, 1 and 3 being up when 2 and 4 are down. This construction has the following disadvantages:

- (a) A crank shaft weaker and more difficult to make.
- (b) A rocking motion, or vibration, from side to side.

The alternate distribution of power impulses, when cylinders are fired in the order shown in the illustration, makes for smooth running.

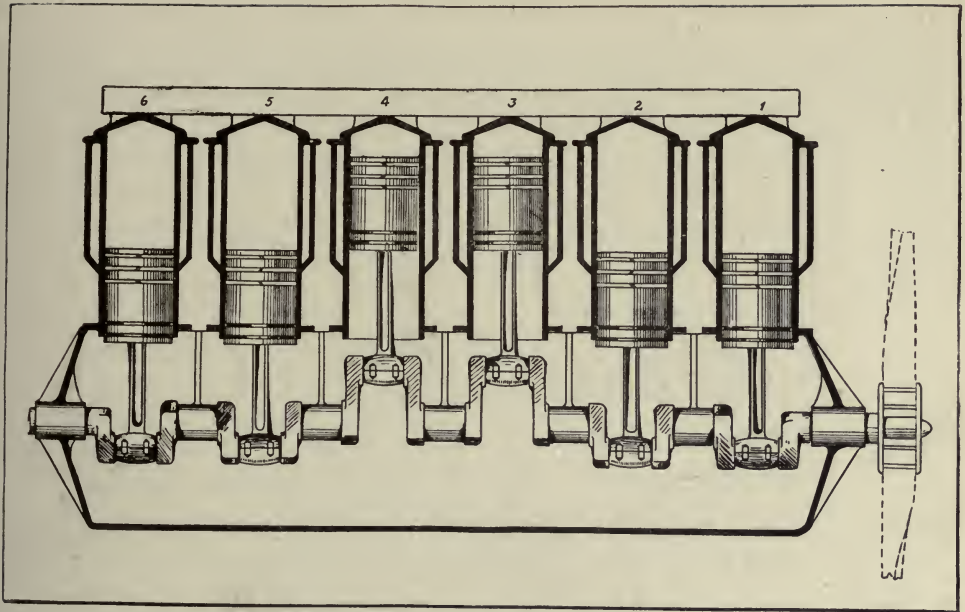


Figure 51—Cross section of a 6-cylinder engine

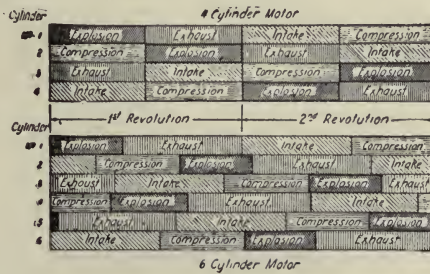


Figure 52—Graphic illustration of cylinder operation in 4- and 6-cylinder engines

6-CYLINDER OPERATION

The 6-cylinder engine is four-cycle, the same as the 4-cylinder engine. The principal differences in construction are in the addition of more cylinders and consequent change in crank shaft.

Figure 51 shows a cross section of the 6-cylinder engine.

It will be noted that the crank shaft is arranged to turn two revolutions during four strokes, as in the case of the 4-cylinder engine. The crank shaft is therefore divided into three pairs of throws, i.e., each pair is placed at 120 degrees, or $1/3$ of a circle apart. The pairs are: 1 and 6, 2 and 5, 4 and 3.

FIRING ORDER

In Figure 51, cylinder No. 5 has just fired, No. 3 will fire next, after which the order will be 6, 2, 4, 1.

With 4-cylinder engines an explosion takes place each half-revolution; the 6-cylinder engine in the same half-revolution has $1\frac{1}{2}$ explosions. That is, power impulses are continuous in 6-cylinder engines, in fact they overlap; this results in smooth running.

Figure 52 is a graphic representation of the sequence of cylinder operation in 4-cylinder and 6-cylinder types of engines, showing how power impulses overlap in the latter.



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The construction of the lower half of the crank case and the method of supporting the crank shaft are clearly shown in this photograph. An interesting feature of the illustration is the cradle in which the crank case rests; it is so constructed that the successive assembly of engine parts may be made and the engine turned around so as to be at any angle with the floor. Since the introduction of this cradle the mechanic is no longer required to lie on his back and work upwards

REVIEW QUIZ

Fundamentals of Motive Power

1. What is the aerodynamic force which the power of the propeller thrust must overcome?
2. How is a propeller tested for balance? Give two methods.
3. When a propeller is out of balance how is the lighter side usually equalized?
4. State how surface area measurement of the propeller is taken.
5. What is the test for straightness?
6. Give four rules for care of propellers.
7. Explain how the motive force is produced in the cylinder of an engine.
8. Name and define three moving parts which transmit the motion.
9. State the difference between a two-cycle engine and a four-cycle engine.
10. Describe in detail the four phases or operations of the four-cycle engine.
11. What operating advantage is gained by increasing the number of cylinders?
12. How many power impulses per revolution are delivered by a 4-cylinder engine?
13. In a 4-cylinder engine, at what degree angle are crank throws set?
14. Explain why the four cylinders are not fired in successive order.
15. In what important particular does the 6-cylinder engine differ from the 4-cylinder?
16. How are the throws of the crank shaft arranged for six cylinders?
17. Give a proper firing order for a 6-cylinder engine.
18. In a half-revolution, how many explosions take place in the six cylinders?
19. State an advantage gained when power impulses overlap.
20. Compare the sequence of operation in 4-cylinder and 6-cylinder engines.

CHAPTER ANALYSIS**Pistons, Valves and Carburetors****THE PISTON:**

- (a) Construction.
- (b) Piston Rings.
- (c) Connecting Rod.
- (d) Wrist Pin.

CRANK SHAFT:

- (a) Construction.
- (b) Attachments.

CRANK CASE:

- (a) Construction.
- (b) Mountings.

VALVES AND VALVE MECHANISM:

- (a) Camshaft.
- (b) Cams.
- (c) Exhaust Valve.
- (d) Inlet Valve.
- (e) Valve Operating Mechanism.
- (f) Valve Clearance.

CARBURETION:

- (a) Principle of the Carburetor.
- (b) Construction.
- (c) Duplex.
- (d) Manifolds.

CHAPTER VII

Pistons, Valves and Carburetors

Continuing the subject of aviation engines, a few considerations may be noted, preliminary to the study of pistons, valves and carburetors.

First is the refinement of design necessary for aeronautical work. The aviation engine, unlike those of motor cars, ordinarily uses 75 per cent. of its horsepower, as against one-quarter usage in motor cars.

A second consideration of design is the necessity for building an aviation engine as light as possible, yet the punishment of material within the engine structure is about fourteen times as severe as in the motor car. The effect is demonstrated in the respective lives of both types. A motor car engine generally runs up to a mileage of 25,000, at a maximum average speed of 25 miles per hour, or completes 1,000 hours operation before overhauling is necessary. The aviation engine, with a speed of 100 miles an hour, requires a complete overhaul in about 50 flying hours, a total of 5,000 miles, or one-fifth of the motor car's mileage.

These comparisons broadly illustrate the relative severity of the two types of engine service. But although it is required that the aviation engine be of light construction, strength must not be sacrificed in vital parts. While light weight is the aim in designing the crank shaft and crank case, main bearings, crank and piston bearings, strength is maintained by very careful selection of materials.

An airplane required to make climbs of 20,000 feet must necessarily have perfect reliability of operation. The structure of the aircraft is obviously sensitive to vibration and an engine which does not function smoothly materially impairs flight efficiency. Irregular impulses of the engine also affect its light structure and uniform explosions are a requisite. This uniformity is gained only through perfect distribution of gas to the cylinders.

The student should keep these conditions in mind as the study of vital parts of the engine is continued.

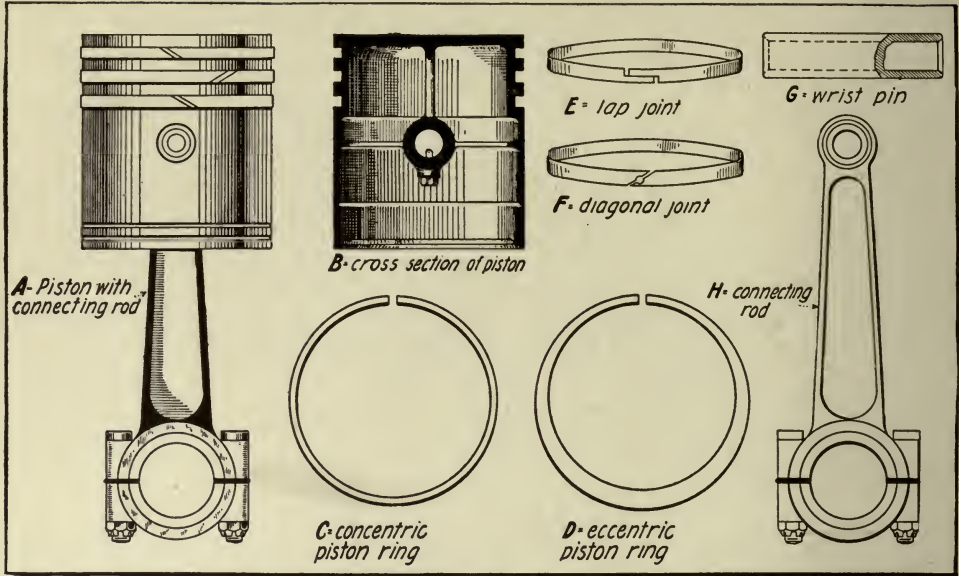


Figure 53—Details of the piston and connecting rod

PISTON

Although one of the simplest parts of the airplane motor, the piston is one of the most important, as it receives the full force of the explosion and transmits the gas combustion into power.

In construction, it shows only slight variations in the numerous types of engines; the most common form of construction is shown at *A* and *B* in Figure 53. The piston is made usually of cast iron, steel or aluminum, machined to fit the cylinder diameter with a clearance of .005 to .010 of an inch to compensate for the expansion of heat and permit lubrication between it and the cylinder walls. The clearance varies with the designed speed of the motor, increasing for the higher speed motors in which greater friction is created. Channels are cut in the outer face of the piston wall, near the top; in these the piston rings are placed.

PISTON RINGS

These are split rings of cast iron, sprung so as to bear tightly against the wall of the cylinder to prevent leakage of gas from the combustion chamber and the passage of lubricating oil into the explosion area. Two types are shown at *C* and *D* in Figure 53, and the common forms of expansion joints at *E* and *F*.

CONNECTING ROD

The connecting rod joins the piston to the crank shaft and transmits the motion to the latter as the piston travels up and down. It is usually made of drop forged steel, I-beam construction.

A typical connecting rod is shown at *H* in Figure 53, which indicates the two bearings, the upper, of bronze, connected to the wrist pin, and the lower bearing, through which the crank shaft passes, usually split and made of a bronze base with babbitt metal carefully scraped to exact clearance.

WRIST PIN

This fitting, also known as the gudgeon or piston pin, joins the piston to the connecting rod. As shown at *G* in Figure 53, it is a simple cylindrical element, usually made of steel and fitting the bosses closely.

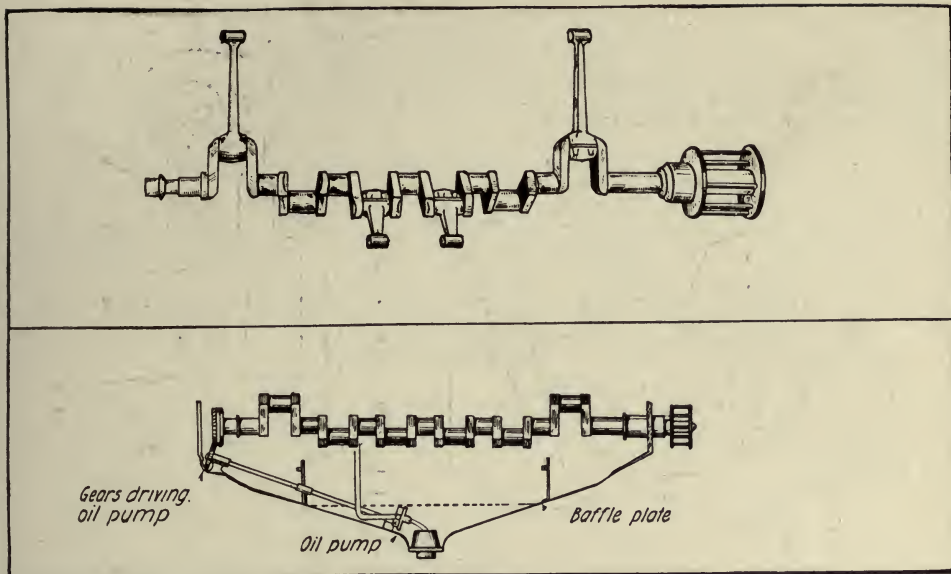


Figure 54 (upper)—Crank shaft of 6-cylinder engine
 Figure 55 (lower)—Lower section of crank case with shaft in position

CRANK SHAFT

As the main drive shaft of the motor, the crank shaft is subjected to greatest strain; it is therefore ordinarily made of high tensile steel, drop or machine forging. It is constructed as a bar having U-shaped offset arms, or crank-throws, one for each cylinder, for attachment to the connecting rods. It is usually drilled for oil ducts and hollowed to reduce weight, yet is of requisite strength to withstand the continuous shocks it sustains.

A crank shaft for a 6-cylinder engine is shown in Figure 54, with four of the connecting rods attached and the propeller hub and flange shown at the right end. The opposite end carries a gear which meshes with a system of gears to transmit motion to the camshaft, magneto, oil pump and other auxiliary parts.

In the illustration provision is made for mounting the propeller on the crank shaft for direct drive, in which case a flywheel would not ordinarily be used. Because the speed of the motor is generally considerably higher than the most efficient number of revolutions per minute of the propeller, reduction gears are commonly introduced at the propeller end of the crank shaft where the motor speed exceeds 1,400 revolutions per minute.

CRANK CASE

The crank case is usually made of aluminum alloy, in two parts, the upper, to which the cylinders are bolted, and the lower containing the crank-shaft and lubricating oil. It contains the crank shaft bearings, or seats, in which the center line of the crank shaft is supported. These mountings are usually made of babbitt or other high anti-friction metal.

Figure 55 shows the lower half of a typical crank case for a 6-cylinder engine, the shape of the case conforming to the type of the motor in each instance.

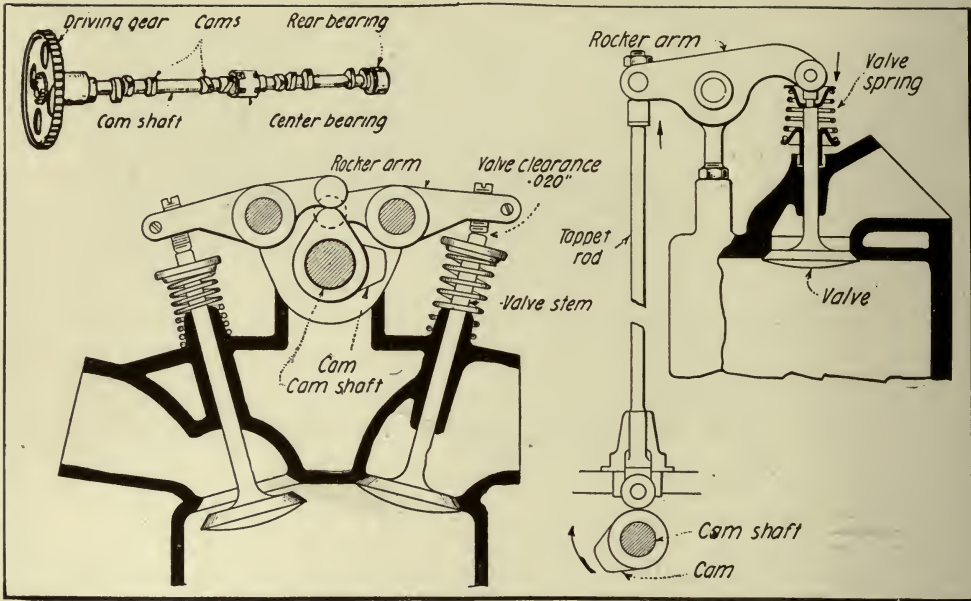


Figure 56 (upper left)—Camshaft, showing the driving gear and cams
 Figure 57a (lower left)—Valve operating mechanism for overhead valves
 Figure 57b (right)—Valve operating mechanism where camshaft is at base of motor

VALVES AND VALVE MECHANISM

CAMSHAFT

The shafts for operating the cams, irregularly curved lugs which operate the valve mechanisms, are known as camshafts. The material generally used is open hearth or drop-forged steel; the bearings are of bronze. Camshafts are drilled to reduce weight.

Two methods of driving or rotating the camshaft are employed, the most common being by means of gearing, a simple spur gear such as shown at the left of Figure 56 being employed when the camshaft is horizontal, or parallel to the crank shaft, from which it obtains its motion at half-speed.

Operation through use of a chain drive in the form of link belts over toothed pulleys, is the second method, recently come into some favor through its use in foreign engines.

CAMS

A cam is a lug cast integrally on the camshaft and machined to a form resembling a circle, with an approximately triangular projection at one point. It is this projection which acts on the valve mechanism as the shaft rotates.

Figures 57a and 57b show cams operating on overhead valves, the former acting direct on rocker arms and the latter through the medium of a tappet rod. Both inlet and exhaust valves are operated by the same camshaft in general practice, although many exceptions are made in engines which have separate camshafts for intake and exhaust valves.

VALVES

In almost every instance, aviation motors have valves placed in the head of the cylinder, or overhead valves, thereby gaining increased power. The valves are opened by the mechanism operated by the camshaft and closed by springs.

EXHAUST VALVE

Exhaust valves are generally made of tungsten steel, which has the necessary high resistance to the heat of the exploded gases which pass through the exhaust. The disk and valve seat are beveled and ground so that the valve is gas-tight when seated.

Theoretically, the exhaust valve is opened only during one of the four cycles or phases of the engine's operation, that is on the upward exhaust stroke. In practice, however, it is usually opened as soon as the piston has moved downward through about seven-eighths of its power stroke, or $\frac{1}{2}$ -inch from bottom dead center. It closes exactly at the finish of the exhaust stroke, or in some cases it is allowed to remain open until the piston has moved down about 1-20-inch on its intake stroke, so that all exhaust gas has a chance to escape.

The exhaust ports are of proper dimensions, varying with type of engine, to insure rapid and complete expulsion of the burnt gas. Exhaust manifolds are seldom used as they retard this expulsion, but short pipes are common, permitting the gas to exhaust into the open air but carrying it away from the aviator's face, and reducing the danger from fire.

INLET VALVE

High nickel steel or cast iron are the materials generally used for inlet valves. The construction of valve and seat is identical with the exhaust valves, usually beveled and always ground so as to be leak-proof when closed.

The inlet valve is timed to open when the piston has descended about $\frac{1}{8}$ -inch on its intake stroke, and remains open until the piston has traveled about $\frac{1}{8}$ -inch up on the compression stroke. This permits the cylinder to fill with gas, the downward drive of the piston creating a suction which will remain stronger than the slight upward pressure created during the 200th part of a second in which the valve remains open as the upward compression stroke begins.

VALVE OPERATING MECHANISM

Valve-in-the-head motors gain flexibility by offering no resistance to the entrance of gas into the combustion chamber, or impediment to straight exhaustion. But the valve opening mechanism is somewhat more complicated than that used in T-head or L-head cylinders. In place of the direct push rod action from the cams employed by the latter, the valve in the head motor secures its opening of valves by the system of rods and rocker arms illustrated in two forms, respectively in Figures 57a and 57b.

In Figure 57b, the camshaft is located at the base of the cylinders, or at the crank case, being rotated by bevel gears at half speed from the crank shaft. The cam pushes up the tappet rod, raising the rocker arm at one end, which pushes down the valve attached to the other.

Figure 57a shows a form of construction which places the camshaft above the cylinders, where it is driven by bevel pinion and gear drive by a vertical countershaft from the crank shaft. This form of construction is being adopted by many American aviation engine manufacturers, since it does away with the tappet rods and simplifies the engine construction.

All valves are closed by the action of the spring, as clearly indicated in the drawings.

VALVE CLEARANCE

Space must be left between the valve stem and the actuating means, the amount of clearance depending upon the design of the engine. The clearance is indicated as .020 inch in Figure 57a, where the valve stems are long; in the Curtiss OX2 engine the clearance is .010 inch, or half, the variation being due to the amount of valve area which becomes heated and expands in length when the engine is running.

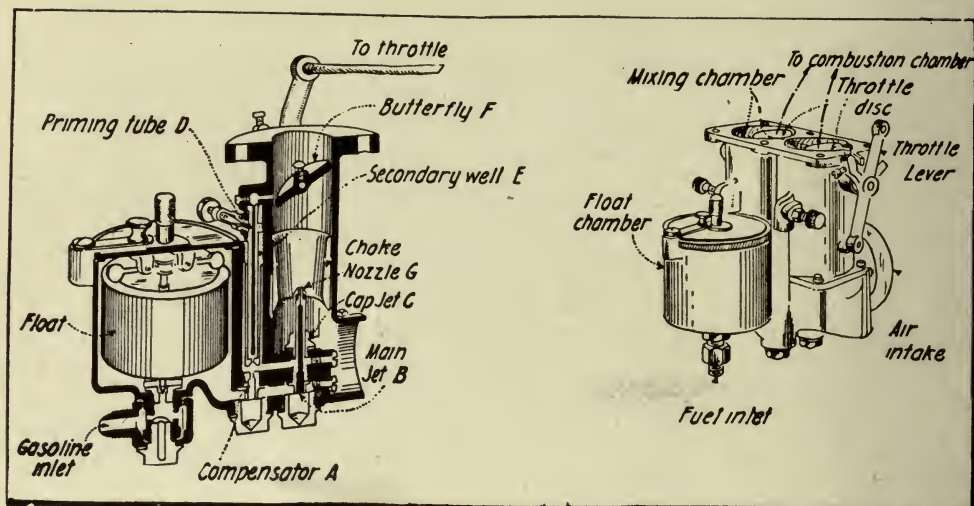


Figure 58 (left)—Sectional view of carburetor showing details of the compound nozzle and compensator

Figure 59 (right)—The duplex carburetor for multiple cylinder engines

CARBURETION

Gasoline will not burn unless it is mixed with air. To burn with great rapidity and heat, or to "explode," as required by the internal combustion engines of aviation, the air must be in correct proportion to the gasoline vapor; these proportions range from 18 to 20 parts of air to one of gasoline. The vapor is produced by exposing the liquid to the air, generally by spraying into a mixing chamber.

PRINCIPLE OF THE CARBURETOR

The device in which the vaporizing of gasoline is performed is termed a carburetor. There are numerous types used on airplanes, but the standard construction calls for: (a) a float chamber to maintain the gasoline at a constant level, (b) a mixing chamber where the gasoline is sprayed through a nozzle and mixed with incoming air. In the form of vapor it is then drawn through the inlet valve into the cylinder by the suction of the down stroke of the piston.

The throttle valve, or butterfly, generally placed above the spray nozzle in the mixing chamber, regulates the amount of gas entering the cylinder; this valve is controlled by a lever near the pilot's seat. The speed of the engine increases with the opening of this throttle and decreases accordingly as it is closed.

A float with a needle valve cuts off the flow of gasoline when the engine is not running.

CONSTRUCTION OF THE CARBURETOR

Figure 58 is a sectional view of the Zenith carburetor, selected as typical of the best construction and widely used in American aviation engines. By a compensator and compound nozzle principle, this carburetor maintains a constant ratio of air and gasoline at the most efficient combustion mixture.

The advance in design here represented is the elimination of variable air valves or moving parts. The construction is clearly indicated in Figure 58. Gasoline from the float chamber is admitted at compensator *A* into the priming tube *D*, extending into the secondary well *E*, and opening at the priming hole uncovered by the action of the butterfly valve *F*. The suction at the priming hole is powerful and with the butterfly partly open the well full of gasoline is drawn into the cylinders, effectively priming the motor.

At high speeds with the butterfly opened further, the priming well ceases to operate and the compound nozzle drains the well. It is this feature of the Zenith carburetor which counteracts the defects of the vaporization at the nozzle of the conventional carburetor when the engine is operating at low speed.

To illustrate: In the conventional single jet carburetor the gasoline enters by suction through main jet *B*, spraying from nozzle *G* in the path of air entering through the inlet at the lower right of the drawing, Figure 58. As the speed of the motor increases, the air flow increases, but the law of flow of liquid bodies makes the flow of gasoline from the jet increase faster, giving a mixture which increases the percentage of gasoline, or becomes richer. By the introduction of the secondary well *E*, the gasoline is fed through the compensator *A* and is not affected by the suction, since the well is open to atmospheric pressure. The flow of gasoline is therefore made constant at all speeds, it being obvious that as the air intake increases with greater speed, the mixture becomes poorer. The combination of the two results in a carburetor giving a constant mixture.

DUPLEX CARBURETOR

For multiple cylinder aviation engines, arranged in V form, which will be discussed later, it was found that the strong cross suction in the inlet manifold made good carburetion difficult with a single carburetor. The development of the duplex carburetor, shown in Figure 59, followed. It provides two separate mixing chambers, fed by a common float chamber and permitting each set of cylinders a separate intake.

MANIFOLDS

As the gas mixture passes upward and out of the mixing chamber it reaches the cylinders by way of pipes divided into branches built to accommodate the model of motor, and termed manifolds. The branches of the manifold are of the same dimensions, so as to obtain the same results for all cylinders and are free from sharp bends or obstructions which might retard the progress of the gas to the cylinders.



(c) Committee on Public Information

Figure 60—Student aviators of the Signal Corps closely examining the assembly of the carburetor on an aviation engine

REVIEW QUIZ

Pistons, Valves and Carburetors

1. Compare the average life of a motor car engine and an aviation engine.
2. Describe the construction of the piston.
3. What is the purpose of the piston rings?
4. Name two types of piston rings.
5. How is the connecting rod constructed?
6. Give two additional names for the wrist pin.
7. State the material of which the crank shaft is constructed and describe its features.
8. Are propellers always mounted on the crank shaft for direct drive?
9. Explain the construction of a crank case.
10. Give two methods of rotating the camshaft.
11. Describe a cam and how it operates a valve.
12. In what portion of the engine are valves usually placed and how are they closed?
13. Why is the exhaust valve generally made of tungsten steel and how is it made gas-tight?
14. Give the essential differences in valve operating mechanisms which employ tappet rods and those having rocker arms.
15. Why is valve clearance necessary?
16. State what change is necessary in gasoline before it will explode.
17. What is the principle of the carburetor?
18. Describe in detail the construction and operation of a compound nozzle carburetor.
19. How many float chambers has the duplex carburetor used for V-motors?
20. Name the engine part through which the gas passes to the combustion chamber.

CHAPTER ANALYSIS**Ignition, Cooling and Lubrication
of Engines****IGNITION:**

- (a) Magneto.
- (b) Distributor.
- (c) Condenser.
- (d) Circuit Breaker.
- (e) Spark Plug.

COOLING:

- (a) Water Cooling.
- (b) Air Cooling.

LUBRICATION:

- (a) Splash.
- (b) Force-feed.

CHAPTER VIII

Ignition, Cooling and Lubrication of Engines

Supplemental to the description and definition of function of valves contained in the previous chapter, the student will find a knowledge of valve setting and valve timing of value. Instruction in these two operations, as officially given for the Curtiss engine, follow:

Valve Setting—After grinding and cleaning, set the inlet valves at 0.010 clearance and the exhaust valves at 0.010 clearance. This setting should be done on each cylinder just after inlet valve has closed. If the stem is indented due to any cause, remove the valve and grind the stem end to a flat surface.

Valve Timing—After setting the clearance, turn the engine in the direction of rotation till the piston of No. 1 cylinder is $1/16$ inch past top center. Then turn the camshaft in its direction of rotation till the exhaust valve of No. 1 cylinder has just closed. Put on the camshaft gear, being sure that the keyway of the gear lines up with the key in the camshaft.

Thus set and timed, the inlet valves will open 12 degrees past top center and close 40 degrees past bottom center; the exhaust valves will open 45 degrees before bottom center and close on top center.

As it is now purposed to consider ignition and its relation to the efficient operation of the aviation engine, these further practical suggestions on timing may well be included.

Magneto Timing—Turn the engine in the direction of rotation till the intake valve of No. 1 cylinder has closed; then turn the engine in the same direction till the piston of No. 1 cylinder is on top dead center; then turn the motor backward till the piston of No. 1 cylinder is $1/2$ inch from top center. Turn the armature of the magneto in the direction of its rotation (it is the same as that of the crank shaft) till the distributor brush is on No. 1 segment with the breaker points just ready to open. Put on the magneto gear, using the same precaution as given for engaging the camshaft gear. This should bring the firing-time of all cylinders to 30 degrees before top center.

The spark advance lever should be in position of full advance during this whole operation. The gap between the breaker points should be 0.018 inch and that of the spark-plug points 0.023 inch.

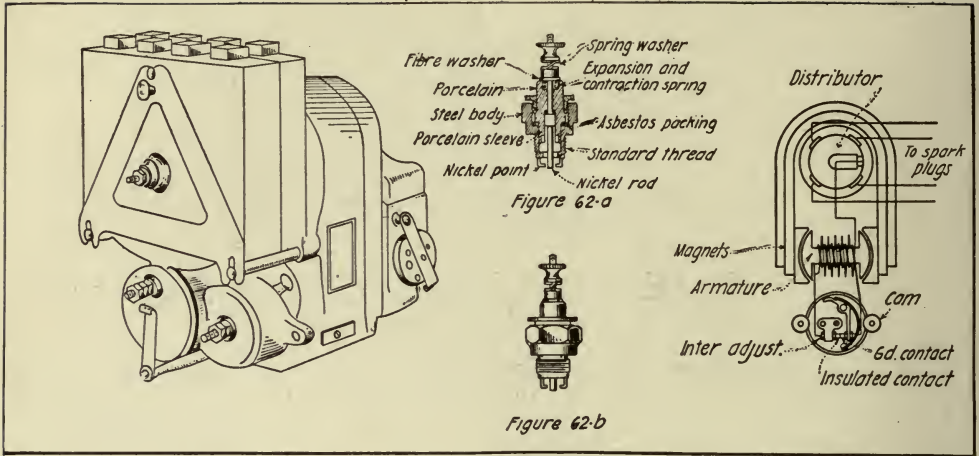


Figure 61—A high tension magneto

Figure 62a—Construction of spark plug
Figure 62b—General view of spark plug

Figure 63—Construction of the magneto

IGNITION

To set afire the compressed gas mixture in the cylinder at the proper time an electric spark is produced in the combustion chamber, through the medium of a spark plug, the points of which offer a break in the ignition circuit, causing the current to jump the gap and spark. The essentials of an ignition system for aviation engines are, (a) a method of producing the current; (b) timing apparatus to regulate the sparking at the proper instant in each cylinder, (c) wiring and auxiliary devices to carry the generated current to the spark plug in the cylinder.

MAGNETO

Aviation motors are equipped with high-tension magnetos, i.e., those with a secondary winding of fine copper wire over the primary winding, as distinguished from the low-tension type with primary coil only. In the coarse wire winding, or primary (on top of which is the secondary winding of fine wire) a low-tension current is generated as the armature revolves between the ends of the magnets. This low-tension current then flows to the circuit breaker, where it is broken by the points operated by a cam. The current then goes to a condenser for storage until the points again close. Breaking the current creates a high-tension current which flows to the distributor and spark plugs.

Figure 61 shows the Berling high-tension magneto, used on Curtiss engines and one of the best of the representative types; Figure 63 shows the construction.

DISTRIBUTOR

The distributor is the device wherein both the primary and secondary currents generated by the magneto are collected by a brush and distributed to the proper cylinder at the proper time.

CONDENSER

Absorption of the self-induced current of the primary winding, thereby preventing it opposing the rapid fall of the primary current, is the function of the condenser.

CIRCUIT BREAKER

This device keeps the circuit closed except at the time of sparking.

SPARK PLUG

This device consists of an insulating member screwed into the cylinder and carrying the terminal electrodes across which the spark for ignition jumps. The secondary wire from the coil is attached to a terminal at the top of the central electrode. Details of construction of the spark plug are shown in Figures 62a and 62b.

Spark plugs are screwed into the combustion chamber directly in the path of the incoming gases from the carburetor. On most aviation engines a double set of plugs is used, two to a cylinder, igniting the mixture at two different points and thereby gaining twenty-five per cent motor power at high speed.

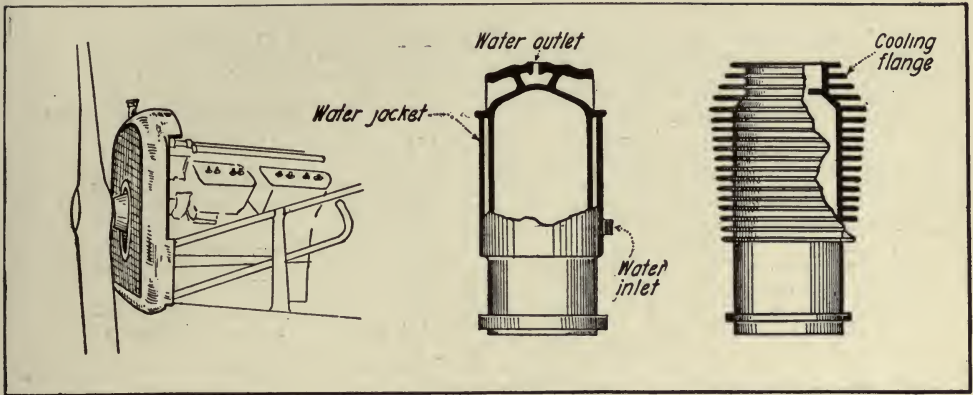


Figure 64—Radiator at front of fuselage

Figure 65a—Water-cooled cylinder

Figure 65b—Air-cooled cylinder

COOLING

The intense heat of the explosions in engine cylinders would heat the metal portions to a point where the lubricating oil would be burned and become useless and the piston rings expand and bind in the cylinder walls, if a means of cooling was not provided. There are two general systems of cooling: (a) water cooling; (b) air cooling.

WATER COOLING

This system consists of a circulation of water through jackets which surround the heated portion of the cylinder wall; a radiator, constructed of thin metal tubes with a large exposed surface area, wherein the water is cooled; and a means of keeping the water in circulation from the cylinder jackets to the radiator, and back again through the system.

Figure 64 illustrates one form of radiator, constructed at the front of the fuselage with provision for the propeller hub.

Figure 65a is a view, partly in section, of a cylinder with water jacket cast integral.

The water is circulated either by a pump which is gear-driven from the motor, or it is automatically circulated by the thermo-syphon principle, which utilizes the tendency of heated water to rise.

When the airplane is at its angle of steepest climb maximum heating of the motor occurs. For this reason, radiators are constructed so the cells are not horizontal, but parallel to a tangent of the mean trajectory of climb.

AIR COOLING

Cooling flanges, or metal fins, are radiated from the cylinder walls in the air-cooled type of engine, to absorb the heat of the explosions and diffuse it in the rush of air. The cylinders are placed directly in the path of the propeller slip stream and often a powerful fan is used to increase the rate and degree of cooling.

Figure 65b shows an air-cooled cylinder, partly in section.

The principal advantage of air cooling is reduction of weight through the elimination of the various parts of the water cooling system. Rotary radial cylinder types have proved practical with air cooling, but it is generally conceded that the water-cooled motor is best for long flights.

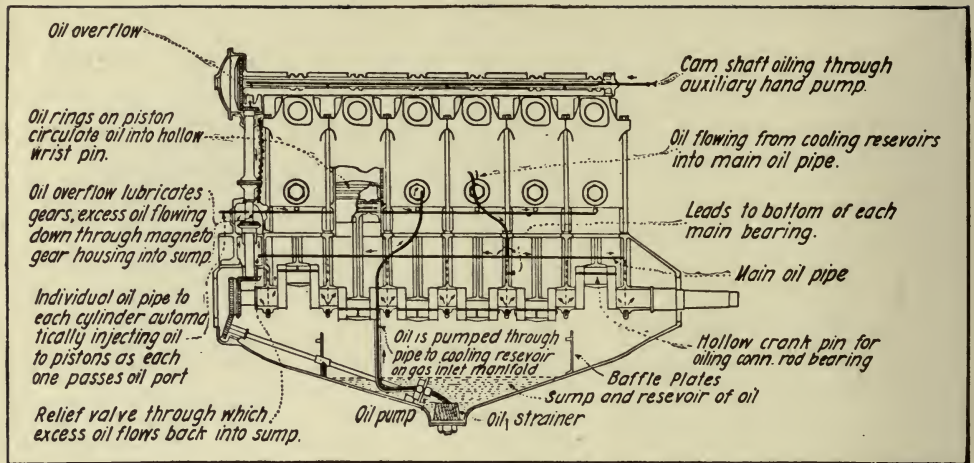


Figure 66—A modern oiling system for aviation engines

LUBRICATION

The necessity for providing some means of preventing excessive friction between swiftly moving parts is due to the heating which would result if a lubricant was not applied between them. The temperature of the aviation engine as a whole is an additional reason for insuring proper oiling of parts.

Two types of motor lubrication are in use:

(a) Splash lubrication—Oil is held in the sump, or reservoir at the bottom of the crank case, and splashed on the moving parts by the revolutions of the crank shaft.

(b) Force-feed—Positive mechanical means deliver the oil under pressure to the various working parts of the engine.

Owing to the evolutions of the airplane in flight, lubricating systems have been elaborated to deliver oil as needed to all working parts and to eliminate the possibility of flooding cylinders.

FORCE-FEED LUBRICATION

Figure 66 gives a clear illustration of a modern oiling system for aviation engines; in this instance, the Hall-Scott engine, representative of the best practice in lubrication.

The crank shaft, connecting rods and all other parts within the crank case and cylinders are lubricated directly or indirectly by a forced-feed oiling system. The cylinder walls and wrist-pins are lubricated by oil spray thrown from the lower end of the connecting rod bearings. The oil is drawn from the strainer located at the lowest portion of the crank case, forced around the main intake manifold jacket. From here it is circulated to the main distributing pipe located along the lower left hand side of the upper portion of the crank case. The oil is then forced directly to the lower side of the crank shaft, through holes drilled in each main bearing cup. Leakage from these main bearings is caught in scuppers placed upon the cheeks of the crank shaft, furnishing oil under pressure to the connecting rod bearings.

A bi-pass 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.

Independent of the above-mentioned system, a small, directly driven rotary oiler feeds oil to the base of each individual cylinder. The supply of oil is furnished by the main oil pump located in the lower half of the crank case. A small sight-feed regulator controls the supply of oil from this oiler. This instrument is placed higher than the auxiliary oil distributor itself to enable the oil to drain by gravity feed to the oiler.

The oil sump plug is located at the lowest point of the crank case. This is a trap for dirt, water and sediment and is removed by unscrewing. Oil is furnished mechanically to the camshaft housing under pressure through a small tube leading from the main distributing pipe at the propeller end of the engine directly into the end of the camshaft housing. The opposite end of this housing is amply relieved to allow the oil to rapidly flow down upon camshaft, magneto, pinion-shaft, and crank shaft gears, after which it returns to the lower crank case. An outside overflow pipe is also provided to carry away the surplus oil.

REVIEW QUIZ

Ignition, Cooling and Lubrication of Engines

1. What valve in the first cylinder should be closed as the initial step in magneto timing?
2. Explain the next steps up to the time when the magneto gear is put on.
3. What should be the position of the spark lever during the timing operation?
4. Give the dimensions of the gap between breaker points. Spark plug points.
5. Why is ignition required in aviation motors?
6. What comprises an ignition system?
7. State the principal construction difference between a high-tension magneto and a low-tension magneto.
8. Briefly explain how the high-tension magneto generates low-tension current and changes it to high-tension current.
9. What purpose is served by the distributor?
10. Define the functions of the condenser and the circuit breaker.
11. Describe the spark plug and give the reason why aviation engines usually employ a double set.
12. Why is provision for cooling an engine required?
13. Name the principal parts of a water cooling system and explain how circulation is gained.
14. What differences in construction of cylinder walls are made for air cooling?
15. State the principal advantage gained by air cooling.
16. In what way is water cooling superior?
17. Give two reasons why lubrication of engines is necessary.
18. Name the two types of motor lubrication and explain how they differ.
19. How are parts within crank case and cylinders oiled by a force-feed system?
20. How are dirt, water and sediment removed?

CHAPTER ANALYSIS

Types of Motors, Operation and Care of Engines**BORE AND STROKE RATIO:**

- (a) Long Stroke.
- (b) Short Stroke.

V-TYPE MOTORS:

- (a) 8-Cylinder.
- (b) 12-Cylinder.
- (c) The Liberty Motor.

ROTARY ENGINES:

- (a) Elements of Design.
- (b) The Gnome Engine.

STARTING THE ENGINE:

- (a) Preparatory.
- (b) Swinging the Propeller.
- (c) Signals.
- (d) Self-Starters.

FUEL CONSERVATION IN FLIGHT:

- (a) Speed.
- (b) Altitude.

CARE OF ENGINES:

- (a) General Rules.
- (b) The Trouble Chart.

CHAPTER IX

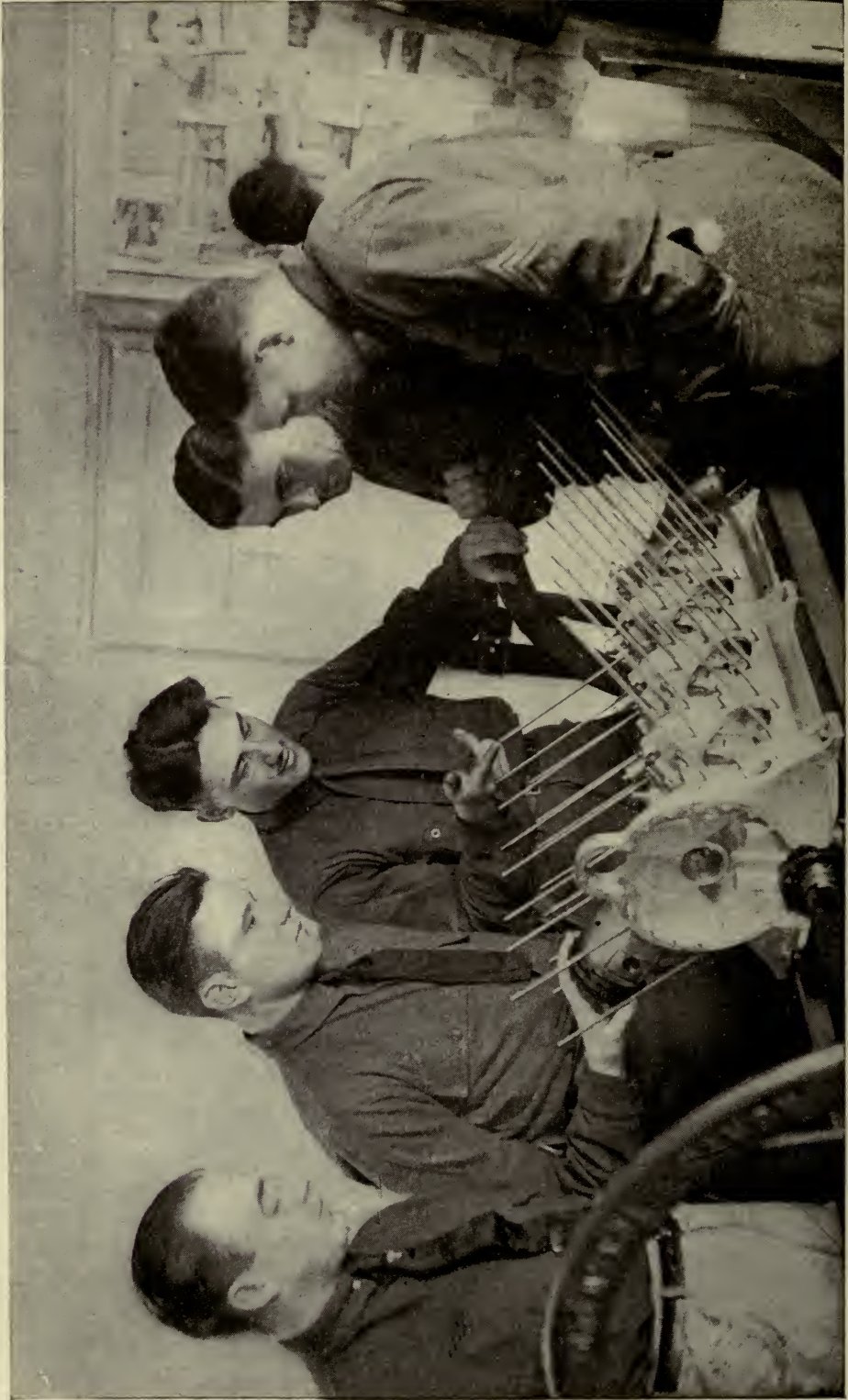
Types of Motors, Operation and Care of Engines

Fundamentals of the theory of operation and construction of aviation engine parts have been covered in sufficient detail for the student aviator in previous chapters. It but remains to consider as types, a few of the more advanced engines, and the balance of motor instruction may be safely left to shop practice, where actual assembly should be undertaken. The engineering factors which enter into the design of motors can be made a supplementary study, if desired, but the air pilot of wartime is not required to have the full mathematical knowledge of the laboratory expert, acquired only by painstaking study and entire concentration on that particular phase of aviation.

Due to the ever-changing refinements of design the aim has been to present the various parts as representative of the best practice, describing the function and operation and, in a brief manner, the construction. In this way the aviator learns the fundamentals, so that he is able to instantly comprehend the operation of any advanced design which he may later encounter.

A word may be said on bore and stroke ratio. While nothing fixed, definite and exact may be stated on the proper proportion of bore to stroke, it is clear that an engine with a short stroke will run at high speed smoothly but is of poor efficiency at low speeds. When the stroke is much longer than the diameter of the cylinder bore, the reverse is true. A bore of 5 inches and a stroke of 8 inches is considered a long stroke ratio, 4" x 5" a short stroke. Since both ratios have their disadvantages there is no agreement of opinion among designers; thus in seven representative types of aviation motors the following ratios are found: 4x5, 4x5½, 4x6, 4¼x5, 4⅝x5, 5x6½, 5x7. Among foreign motors the average is a stroke 1.2 times the bore dimension. The general trend in motor design is steadily leaning toward the short stroke, or high speed engine, and recent calculations make it appear that the practice of restraining piston speed to 1,000 feet per minute will be abandoned.

A few representative types of multi-cylinder engines will now be briefly considered.



The upper half of the crank case of an 8-cylinder, V-motor is here revealed. The student at the left is holding a piston, and the instructor, in center, is pointing to one of the tie-rods, by means of which the cylinders are bolted to the crank case

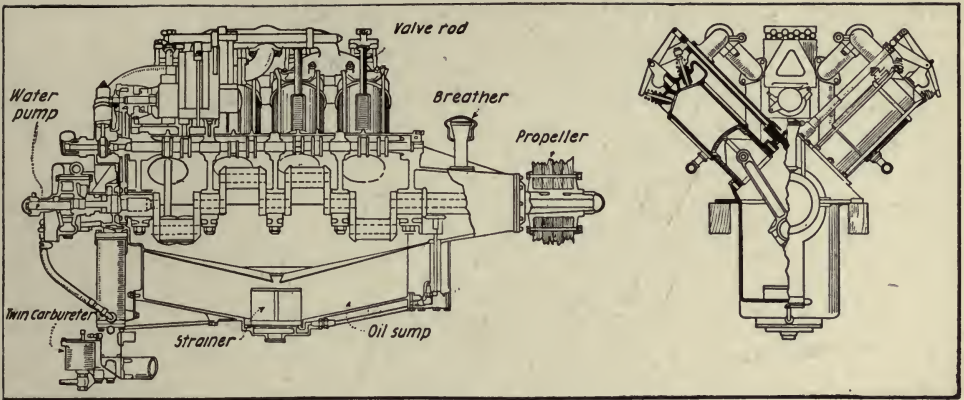


Figure 67a—Part section view of 8-cylinder V-motor

Figure 67b—Part section view of same motor from the front

V-TYPE MOTORS

The salient advantages of increasing the number of cylinders in aviation engines are, briefly, high speed with decreased vibration, flexibility and quick operation, overlapping power strokes and lighter reciprocating parts. The addition of more cylinders to the vertical type of motor is impracticable because this would require a length too great for the fuselage and a much stronger and heavier crank shaft; the best solution is therefore found in two sets of cylinders inclined inward at an angle, thus producing a motor of same length but increased power, or the V-type motor.

8-CYLINDER V-MOTOR

The standard Curtiss engine is shown in part section in Figures 67a and 67b. It will be noticed that the length of the motor and crank shaft is practically the same as in a 4-cylinder engine, and the additions are merely another set of cylinders and connecting rods.

In this engine the cylinders are set at an angle of 90 degrees, or one-half the firing distance of the 4-cylinder engine. That is, in this V-type motor the power impulses occur every 90 degrees instead of 180 degrees. In the Curtiss OX, or 90 horsepower engine, widely used in training machines, the cylinders have 4-inch bore and 5-inch stroke, is normally run at 1400 revolutions per minute (r. p. m.) and weighs 390 pounds complete.

The main difference between the 8-cylinder V-motor and the 4-cylinder vertical, is the arrangement of the connecting rod; it is common practice to have two rods attached to the same crank throw. This is accomplished, (a) by staggering the cylinders and having the connecting rods attached side by side to the same crankpin, or (b) the lower end of the connecting rod is forked just above the crank shaft-bearing, and the rod from the cylinder opposite connected to the crank shaft bushing (at a right angle) between the fork.

The firing order is generally the same as in a 4-cylinder motor, except that the explosions occur alternately in each set of cylinders.

12-CYLINDER V-MOTOR

The development of the multi-cylinder engine to 12 cylinders responded to the demand for more power. In V form, it possesses the same advantages of arrangement and lightness of weight as the 8-cylinder, and obviously reduces vibration still further. That is, where the 8-cylinder engine has four power impulses per revolution, the 12-cylinder motor gives six explosions per revolution.

The usual practice has been to set the cylinders at a 60 degree angle, but the latest design favors an angle of 45 degrees.

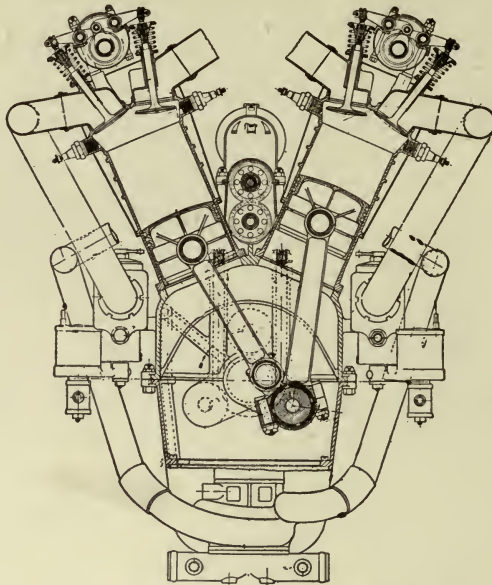


Figure 68—Cross section of a 12-cylinder engine, illustrating many features of advanced design

THE LIBERTY MOTOR

Details of the general construction of the Liberty motor have been given in an authorized statement issued by the War Department, extracts from which follow:

CYLINDERS

The cylinders follow the practice used in the German Mercedes, English Rolls Royce, French Lorraine Dietrich and Italian Isotta Fraschini. The cylinders are made of steel inner shells, surrounded by pressed steel water jackets. (This construction is clearly shown in Figure 68, a cross section of a Renault engine.) The valve cages are drop-forged, welded into the cylinder head; the principal departure from European practice is in the location of the holding down flange, which is several inches above the mouth of the cylinder.

CAMSHAFT AND VALVE MECHANISM

The design of the cam and valve mechanism is based on the Mercedes, but improved for automatic lubrication without wasting oil. Figure 68 illustrates a good example of the type, which has been described in detail on page 66. The camshaft drive is of the Hall-Scott type.

ANGLE BETWEEN CYLINDERS

The included angle between cylinders of the Liberty motor is forty-five degrees, or similar to the illustration Figure 68.

The general practice in 12-cylinder engines has been to set the cylinders at sixty degrees, but by lessening the angle each row of cylinders is brought nearer the vertical and closer together, saving width and head resistance, reducing vibration and giving greater strength to the crank case.

PISTONS AND CONNECTING RODS

Hall-Scott design has been followed for Liberty motor pistons; these are similar in type to those shown in the drawing on the opposite page. The connecting rods are of the straddle or forked type, the fork being just above the bearing at the crank shaft end.

CRANK SHAFT AND CRANK CASE

Standard 12-cylinder engine practice is followed, except as to modifications in the oiling system.

IGNITION

A specially designed Delco ignition system is used.

LUBRICATION

The first system of lubrication followed the German practice of using one pump to keep the crank case empty, delivering into an outside reservoir, and another pump to force oil under pressure to the main crank shaft bearings. This lubrication system also followed the German practice in allowing the overflow in the main bearings to travel out the face of the crank cheeks to a scupper, which collected this excess for crankpin lubrication. This is very economical in the use of oil and is still the standard German practice.

The present system is similar to the first practice, except that the oil, while under pressure, is not only fed to main bearings, but through holes inside of crank cheeks to crankpins, instead of feeding these crankpins through scuppers. The difference between the two oiling systems consists of carrying oil for the crankpins through a hole inside the crank cheek, instead of up the outside face of the crank cheek.

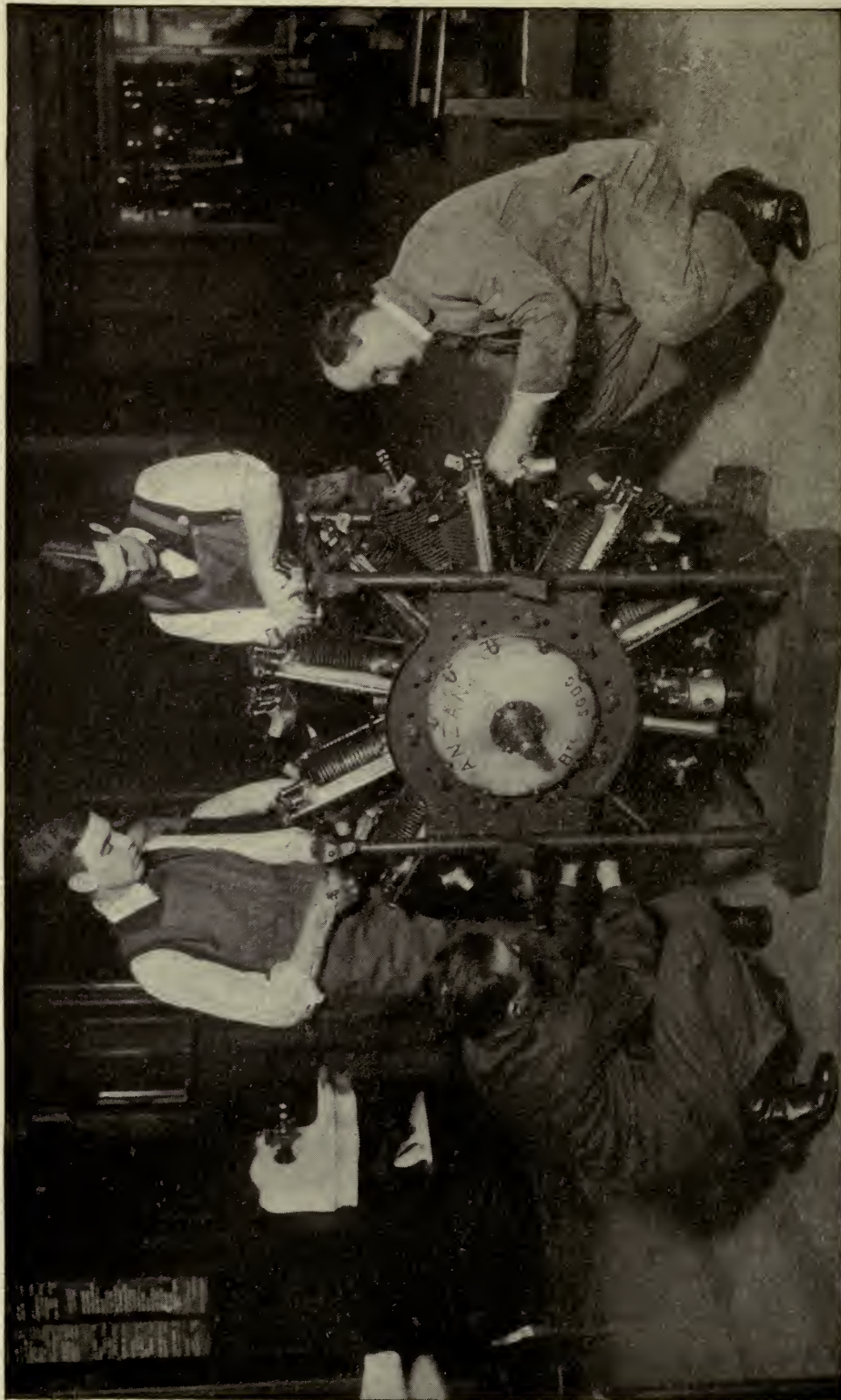
CARBURETOR

The carburetor is a Zenith development. The compound nozzle principle of the Zenith and the constructional details are described on pages 68 and 69.

BORE AND STROKE

The bore and stroke of the Liberty engine is 5x7 inches.

The first Liberty motor was an eight-cylinder model, delivered to the Bureau of Standards July 3, 1917. The eight-cylinder model, however, was never put into production, as advices from France indicated that demands for increased power would make the eight-cylinder model obsolete before it could be produced.



(c) Int. Film Service

A 20-cylinder Anzani motor, built for transatlantic flight, under examination by student mechanics

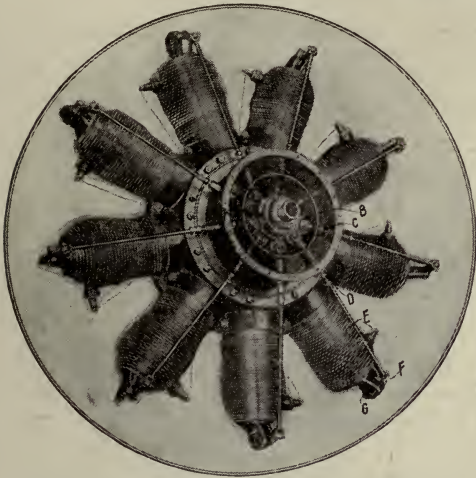


Figure 69a—General view of nine-cylinder rotary engine

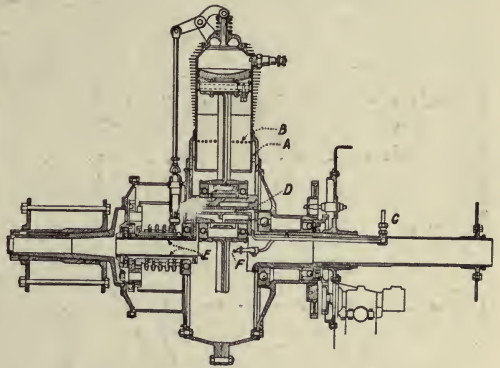


Figure 69b—Section view of rotary engine cylinder and crank case

ROTARY ENGINES

The principal claim advocated for rotary motors is that the design makes for light weight. It has been observed, however, that the rotating feature has little to do with this advantage, for the weight would not be perceptibly increased if the cylinders were stationary and the crank shaft revolved. Setting cylinders radially from a crank case of a size not much larger than that which one cylinder would require is an obvious weight saving. The absence of reciprocating parts aids smooth running and the full practicability of air cooling is an added advantage. The head resistance is a disadvantage, and the loss of power (estimated at 7 per cent) in driving the cylinders around the shaft, and the difficulty of securing high compression, further handicap this design.

GNOME ENGINE

The Figures 69a and 69b show the famous Gnome engine with nine radial cylinders. The explosions occur in each alternate cylinder as the engine revolves, the odd number thus securing a uniform period of explosion. The cylinders, the construction of which is shown in section in Figure 69b, are machined from solid 6-inch steel bars, 11 inches in length, weighing less than 100 pounds.

The operation of the engine is as follows:

Vaporized gasoline is forced into the crank case through the jet *F* (Figure 69b) entering the cylinder through the holes *A*, *B*, when the piston is at the lowest point. As the piston ascends it covers the port and the gas is compressed and fired in the usual manner. The large valve in the cylinder head is the exhaust, operated by a cam and rod. Lubricating oil enters at *C* on the stationary crank shaft, passing to the stationary crankpin *D* and flooding the bearings *E*. A portion of the oil which lubricates the crankpins is thrown by centrifugal force through the connecting rod tubes and in the same way oils the piston pins and cylinders. Additional lubrication of the cylinders is secured by oil which is thrown through crank case holes.

In Figure 69a the engine is shown with the crank case cover removed, revealing the cams and gears. One of the nine holes in the crankpin, through which oil is fed to the nine cams, is indicated at *A*. The cam rollers, one of which is shown at *B*, carry oil over the surface of the cam, surplus oil feeding through the guides *C* of the valve rods, through the ball joint *D* and hollow rod *E* to the pin *F*. A groove on the valve lever carries the lubrication to the lever bearing *G*.

Other aviation engines of the rotary type include the Anzani, Le Rhone and Clerget, constructed with varying number of cylinders up to fourteen.

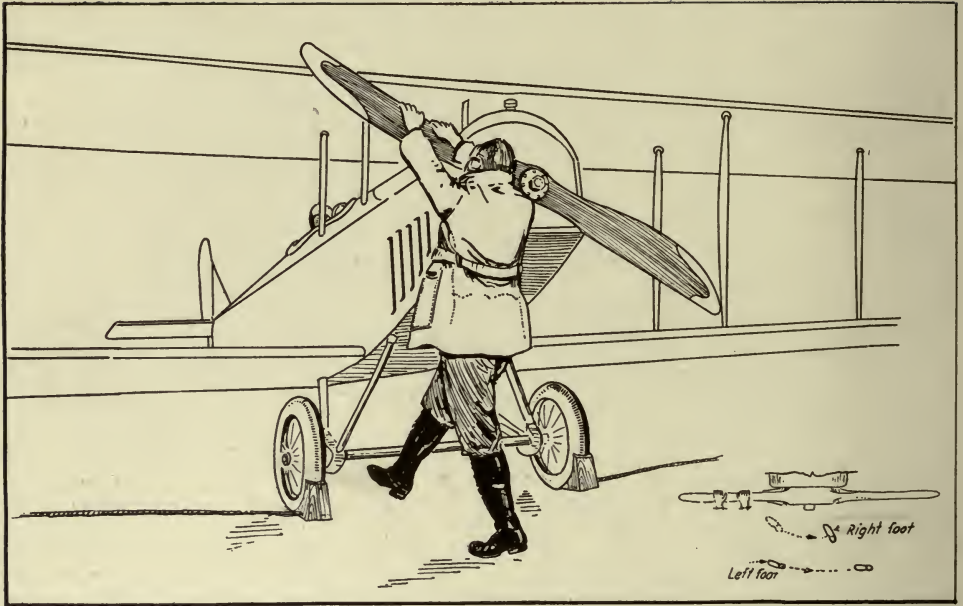


Figure 70—The proper method of swinging the propeller

STARTING THE ENGINE

PREPARATORY

The ground selected should be firm so that the foot will not slip when the propeller is swung. The blocks are then placed in front of the wheels with the cords laid toward the wing tips. A mechanic takes his place at each wing tip, grasping the bottom of the outer strut to steady the airplane when the engine is running; they pull the blocks away when the pilot signals he is ready to start. Two or more mechanics take their places at the tail end of the fuselage to hold it down while the engine is running.

SWITCH OFF

The ignition switch must be in the "off" position before any attempt is made to swing the propeller. Many fatal accidents have resulted from carelessness on this point.

With engines of the rotary type it is often necessary to prime the cylinders by squirting gasoline through each exhaust valve. Two things are to be remembered in this connection: The squirt can must be clean and the ignition switch off.

GASOLINE ON AND AIR CLOSED

The pilot ascertains that the gasoline is on and the air intake almost closed, so the mixture may be rich for the first few explosions.

ROTATION OF PROPELLER

The propeller is swung with the ignition switch off to fill the cylinders with gas.

CONTACT

The mechanic calls "contact" at this juncture, whereupon the pilot throws the ignition switch on, and replies "contact."

SWINGING PROPELLER

The propeller is swung as shown in Figure 70. Note particularly the position of the feet, shown in plain view at the lower right of the drawing. One good downward swing of the propeller is made and the mechanic immediately stands clear. If the engine fails to start the mechanic calls for "switch off" and repeats the same operation.

Once the propeller has been given its downward swing, the mechanic must stand clear immediately, as the possibility of a backfire from the engine is great and the backward swing of the propeller may result in a fatal accident. The illustration, Figure 70, should be carefully studied, with particular reference to keeping the feet apart and in a position where the body will naturally swing away with the downward pull.

SIGNALS

The following procedure is standard with the Royal Flying Corps.

1. The pilot ascertains from the rigger and the mechanic that everything is correct, immediately after entering the machine.
2. Mechanician—"Switch off?"
3. Pilot—"Switch off."
4. Mechanician—"Gas on—air closed?"
5. Pilot—"Gas on—air closed."
6. The mechanic rotates the propeller to fill the cylinders with gas.
7. Mechanician—"Contact?"
8. Pilot—"Contact."
9. The Mechanician swings the propeller and stands clear. The engine runs for a few minutes until the pilot is assured that the motor is in good working order.
10. Pilot waves hand from side to side.
11. Mechanicians pull blocks away from wheels.
12. Pilot looks at aviation mechanic or senior non-com, who ascertains if all is clear ahead and above for the ascent. He indicates all clear by saluting.
13. Pilot waves hand in fore and aft direction. This is the signal to start and all stand clear instantly, the mechanicians at the tail letting go immediately.

SELF STARTERS

There are two methods of cranking aviation engines by starting systems employing compressed air. One turns the crank shaft by means of an air motor and the other admits compressed air to the cylinders, forcing the piston down by pressure and thus turning the motor over. In the latter case, air for the system is supplied to a reservoir by an air pump driven by the engine and, when needed, enters the top of the cylinders in their proper firing order by means of check valves which open inward only and close by explosive pressure once the engine is running.

Developments of the electric starters familiar to all automobilists are also being employed on aviation engines. These are of the storage battery type with the current generated by the engine when running and stored for use until needed. The motor in this instance is turned over when electrical communication is made between the storage battery and the motor-generator unit, which then acts as a motor and turns the engine over by means of gearing to the crank shaft.

FUEL CONSERVATION IN FLIGHT

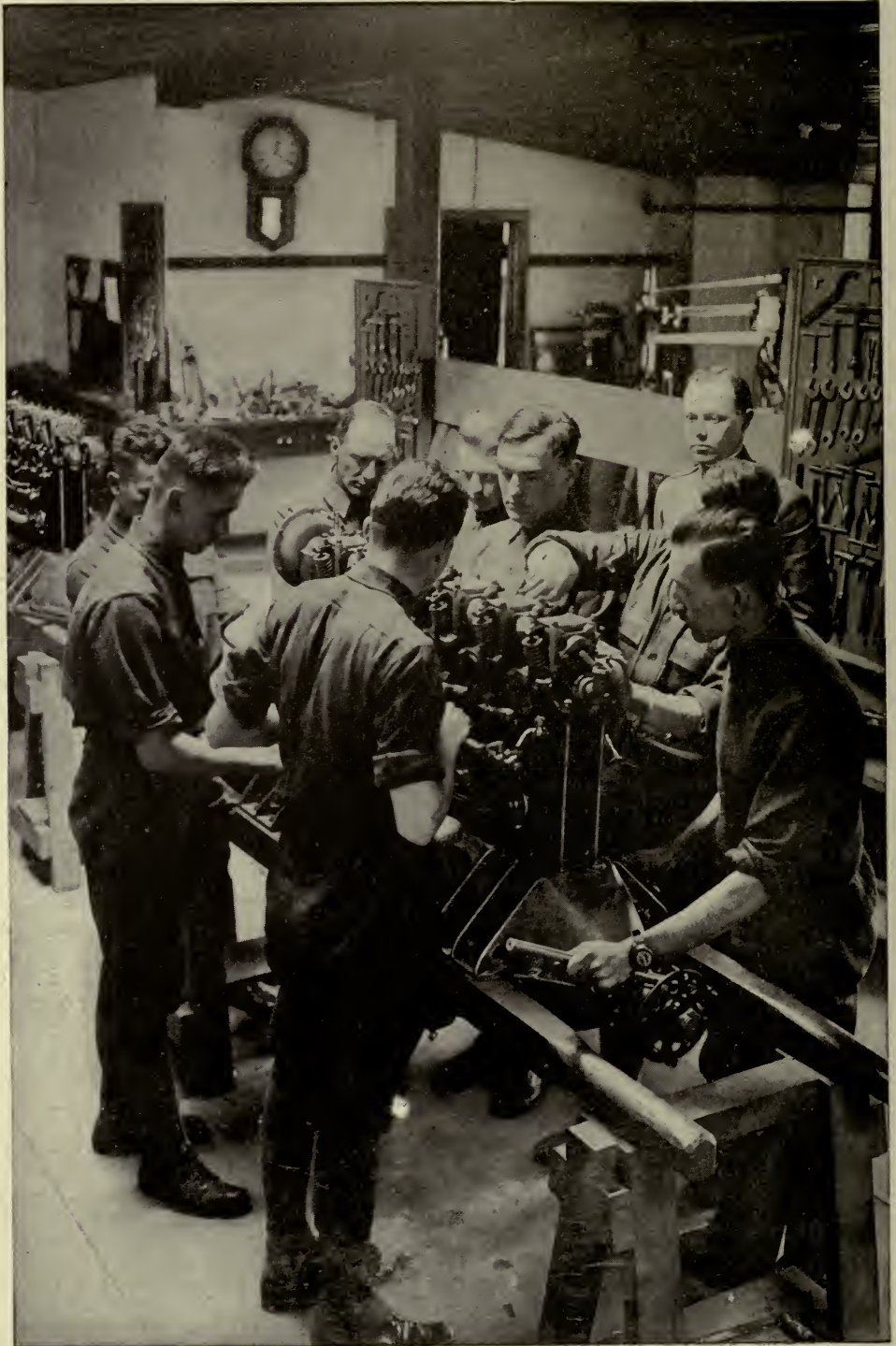
A final word may well be added before turning to the aspects of actual flight. When flying, the pilot must bear in mind that the maximum speed of the plane is not its most efficient flight speed, and driving the machine at full power must not become an habitual practice. The aviator soon learns by experience the range of speed of his machine and upon this knowledge must base his calculations for long flights, so his fuel may be properly conserved for the task in hand.

To illustrate, a given motor may be assumed to develop 90 H.P. at 1300 r.p.m. and consume 1-10 gal. of gasoline per horsepower hour, or 9 gallons per hour. If the gasoline tank holds 18 gallons and the speed at 1300 r.p.m. is 80 miles per hour, the duration of flight will be 2 hours, or 160 miles. If then, the number of revolutions is reduced to a point where the fuel consumption is one-half (at a speed, say, of 60 m.p.h.) the fuel will last twice as long, or 4 hours, and the distance covered will be

$$60 \text{ m.p.h.} \times 4 \text{ hrs.} = 240 \text{ miles}$$

as against 160 miles at the greater speed.

When flying at high altitudes, 10,000 feet or more, motor troubles increase. The explosive mixture changes in character, due to the decreased density of the air supplied to the carburetor. Lessened supply of air results in increased richness of mixture and, disregarding factors of motor design and construction, the amount of power obtained will vary with the changes in the proportions of the gasoline vapor. Increased air in the mixture means fuel economy, but lessened power. With a rich mixture, on the other hand, though the power curve rises, the motor and its parts overheat, delicate adjustments are thrown out and carbon deposits appear in the cylinders. The adjustment of the gas mixture is therefore of importance, the normal ratio for aviation engines being one part of gasoline to 9 to 20 parts of air.



(c) Committee on Public Information.
Student aviators of the Signal Corps, U. S. A., learning in the ground school how valves are adjusted and ignition timed on aeronautic motors

IMPORTANT DON'TS

- Don't forget to inspect the motor thoroughly before starting.
- Don't try to start without oil, water, or gasoline; all three are vital.
- Don't forget to see that the radiator is full of water.
- Don't get dirt or water into the oil.
- Don't get dirt or water into the gasoline.
- Don't forget to oil all exposed working parts.
- Don't try to start without retarding the magneto; a serious accident may result.
- Don't try to start without turning on the switch.
- Don't start the motor with throttle wide open.
- Don't run the motor idle too long; it is not only wasteful but harmful.
- Don't forget to watch the lubrication; it is most essential.
- Don't forget that the propeller is the business end of the motor; treat it with profound respect—especially when it is in motion.
- 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.
- Don't fail to study the trouble chart before you molest a thing about the motor, if you have trouble.
- Don't develop that destructive disease known as tinkeritis; when the motor is working all right, let it alone.
- Don't forget a daily inspection of all bolts and nuts. Keep them well tightened.
- 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.

THE TROUBLE CHART

Based on Curtiss engines, this chart has been prepared to outline in a simple manner the various troubles that interfere with the efficient action of aeronautical motors.

Defects that may develop are tabulated for ready reference, and opposite the part affected the various conditions are found under a heading that denotes the main trouble to which the others are contributing causes.

The various symptoms denoting the individual troubles outlined are given to facilitate their recognition in a positive manner. Brief note is also made of the remedies for the restoration of the defective part or condition.

It is apparent that a chart of this kind is intended merely as a guide, and it is a compilation of practically all the known troubles that may materialize in gas-engine operation. While most of the defects outlined are common enough to warrant suspicion, all will never exist in an engine at the same time; and it will be necessary to make a systematic search for such of those as do exist, and by the process of elimination locate the offending part.

To use the chart advantageously it is necessary to know and recognize easily one main trouble. For example, if the motor is skipping, look for possible troubles under the heading "Skipping." If the motor fails to develop power, the trouble will undoubtedly be found under "Lost Power and Overheating."

It is assumed in all cases that the trouble exists in the power plant or its components, and not in the auxiliary members of the ignition. In many instances, however, the seat of trouble will be traced to these latter members.

SKIPPING OR IRREGULAR OPERATION

PART AT FAULT	TROUBLE	EFFECT	REMEDY
Spark plug	Loose binding at post Leak in threads Defective gasket Cracked insulator Points too close Points too far apart Carbon deposit Plug too long	No spark Low compression Low compression Short-circuit No spark No spark No spark Pre-ignition	Tighten terminal Screw down tighter Replace with new plug Replace with new plug Set points apart Set points closer Clean off points and plug Change plug
Combustion chamber	Carbon deposit	Pre-ignition	Remove carbon
Piston head	Carbon deposit Crack or blowhole (rare)	Pre-ignition Pre-ignition	Remove carbon Replace with new
Valve head	Warped or pitted on seat	Poor mixture Low compression	True up in lathe and grind to seat Replace with new
Valve stem	Binds in guide sticks	Irregular valve action	Clean guide Straighten stem Oil
Valve spring	Weakened or broken	Irregular valve action	Replace with new
Exhaust valve seat	Scored or warped Dirty or covered with scale	Valve will not close Poor mixture Poor compression	Use reseal reamer Clean off and grind to seat
Exhaust valve-stem guide	Warped or carbonized Worn guide	Valve stem sticks Low compression Poor seating Poor mixture	Clean guide or new guide
Valve-stem clearance	Too little Too much	Valve will not shut Valve opens late and closes early	Set inlet gap 0.010 Set exh. gap 0.010
Camshaft bearing	Looseness or wear	Valves mistimed or valve lift short	Replace with new bushing
Cam	Worn contour	Valve lift short Valves mistimed	Replace with new camshaft
Timing gear	Not properly meshed Loose on shaft Worn or broken tooth	Valves mistimed Valves do not act	Time properly Fasten to shaft with key Replace with new gear
Cam-follower guide	Loose on engine base Lock pin sheared off Worn in bore	Oil leaks Poor valve action	Fasten securely New pin New guide or bushing
Cam follower	Loose in guide	Valves mistimed Oil leaks	Replace with new guide or bushing
Inlet valve	Closes late Opens early	Blowback in carburetor	Time properly
Inlet-valve seat	Warped or pitted Does not seat properly Carbon grain under seat	Blowback in carburetor Low compression	Use reseal reamer Clean off and grind to seat
Inlet-valve stem guide	Worn	Poor mixture Low compression	Bush or replace with new guide
Carburetor	Weak mixture	Blowback in carburetor	Adjust carburetor for richer mixture
Gas manifold pipe	Leak at joints Defective gasket Crack or blowhole	Poor mixture Poor mixture Poor mixture	Stop all leaks Replace with new Solder blowhole
Piston	Walls scored	Poor suction and leak of gas	Smooth up
Piston rings	Loss of spring Loose in grooves Worn or broken Slots in line	Poor suction and leak of gas Poor compression	Peen rings or replace with new Loosen rings on piston
Cylinder wall	Scored by wristpin Scored by lack of oil	Poor suction and leak of gas Poor compression	Lap in cylinder Or new cylinder
Valve-spring collar key	Broken	Release spring No valve action	Replace with new key

LOST POWER AND OVERHEATING

PART AT FAULT	TROUBLE	EFFECT	REMEDY
Manifold connections	Poor mixture in one set of cylinders with good mixture in other set	Surging or pulsating	Tighten connections; put in new gaskets
Water-pipe joint	Loose Defective gasket	Loss of water and over-heating	Tighten bolts or replace with new connection
Spark plug	Loose in threads Defective gasket	Poor compression and over-heating	(See Spark Plug under "Skipping") Screw down tight Replace with new
Combustion chamber	Crack or blowhole Roughness Carbon deposit	Poor compression Pre-ignition Pre-ignition	Fill by welding or replace with new Smooth up Remove carbon
Valve head	Warped, scored, or pitted Carbonized or covered with scale	Poor compression	True up in lathe and grind to seat Scrape off smooth with emery cloth
Valve seat	Warped or pitted Carbonized or covered with scale	Poor compression or blow-back	Use reseal reamer Clean off and grind to seat
Piston rings	Loss of spring Loose in groove Worn or broken Slots in line	Poor suction, leak of gas, and over-heating Poor compression	Peen rings or replace with new Loosen rings on piston
Piston rings	Broken because too tight Insufficient opening	Scored cylinder walls, over-heating in sump pan, and poor compression	Replace scored cylinder if groove is deep; use new rings
Wristpin	Loose Scored cylinder	Poor compression	Fasten securely Replace scored cylinder if groove is deep
Piston head	Carbon deposit Crack or blowhole (rare)	Pre-ignition Poor compression	Remove carbon Replace with new
Piston	Binds in cylinder Walls scored or worn out of round	Overheating	Lap off excess metal Replace with new
Cylinder wall	Scored Poor lubrication causes friction	Poor compression and over-heating	Replace with new Lap in cylinder Repair oiling system
Camshaft Drive gear	Loose on shaft Not properly meshed Worn or broken teeth	Irregular valve action	Fasten to shaft Time properly Replace with new
Crank shaft	Scored or rough on journals Sprung	Overheating Overheating	Smooth up Straighten
Crankpin Bearings and main bearings	Adjusted too tight Defective oiling	Overheating	Adjust to running clearance Clean out oil holes
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
Water space and water pipes	Clogged with sediment or scale	Overheating	Dissolve and remove foreign material
Radiator hose	Layer of hose obstructs opening	Overheating	Refit or replace with new
Water pump	Impeller loose on shaft Dirty Broken	Overheating	Fasten to shaft Clean Replace with new

NOISY OPERATION

PART AT FAULT	TROUBLE	EFFECT	REMEDY
Spark plug	Leakage	Hissing	Screw down tighter Replace with new
Cylinder wall	Scored	Knocking	Smooth up or replace with new
Manifold pipe joints	Leakage Defective gaskets	Sharp hissing	Tighten bolts Replace with new
Combustion chamber	Carbon deposit	Knocking	Remove carbon
Cylinder casting	Retaining bolts loose	Sharp metallic knock	Tighten bolts
Cam	Worn contour	Metallic knock	Replace with new
Piston head	Carbon deposit	Knock	Remove carbon
Wristpin	Loose in piston Worn	Dull metallic knock	Replace or bush
Connecting rod	Worn at wristpin or crank shaft Sideplay in piston	Distinct knock	Adjust or replace Scrape and fit and oil
Main crank shaft bearing	Loose Defective lubrication	Metallic knock Squeak	Fit caps close to shaft Clean out oil holes and oil
Connecting-rod bearings	Loose Excessive play Binding	Intermittent metallic knock Knock and squeak	Refit Reline
Connecting-rod bolts Main-bearing bolts	Loose Stripped threads	Sharp knock	Tighten Replace bolts
Lower half crank case bolts	Loose Stripped threads	Knock and rattle	Tighten New bolts
Water jacket	Covered with scale Clogged with dirt	Knock caused by overheat- ing	Dissolve scale and flush out water space with water under pressure
Timing gears	Loose Worn or broken teeth Meshed too deeply	Metallic knock Rattle Grinding	Fasten to shaft Replace with new gear
Camshaft bearing	Loose or worn	Slight knock	Replace with new
Inlet-valve seat	Warped or pitted Dirty	Rattle Poor compression Blowback	Use reseal reamer Clean off and grind to seat
Inlet-valve spring	Weak or broken	Blowback in carburetor	Replace with new
Inlet valve	Closes late Opens early	Blowback in carburetor	Time properly
Valve-stem guide	Worn or loose	Rattle or click	Replace with new guide
Cam-follower guide	Loose	Rattle or click	Replace with new guide
Valve-stem clearance	Too much Too little	Click Blowback in carburetor	Set inlet gap 0.010 Set exh. gap 0.010
Push-rod retention stirrups	Nuts loose	Rattle Blowback in carburetor	Tighten nuts
Crank case gaskets	Leak	Oil leak	Tighten bolts Replace with new
Cylinder or piston	No oil Poor oil	Grinding and sharp knock	Repair oil system Use best oil
Piston	Binding in cylinder Worn oval, causing side slap	Grind or dull squeak Dull hammer	Lap off excess metal Replace with new
Oil sump	Insufficient oil Poor oil	Grind and squeak in all bearings	Replenish with best oil
Piston rings	Defective oiling	Squeak, hiss, grind	Replace with new ring Repair oil system
Crank shaft	Defective oiling	Squeak	Clean out oil holes Use best oil Repair oil system
Engine base	Loose on frame	Dull pound	Tighten bolts

REVIEW QUIZ

Types of Motors, Operation and Care of Engines

1. State the relation to efficiency of an engine with a short stroke running at high speed. At low speed.
2. Name four advantages gained by increasing the number of cylinders in aviation engines.
3. Why is the V construction best for multi-cylindered engines?
4. Explain how the length of the crank shaft of an 8-cylinder V-motor is practically the same as that of a 4-cylinder vertical engine.
5. Describe two methods of attaching connecting rods in pairs to one crank throw.
6. Give the number of power impulses per revolution of a 12-cylinder motor.
7. State and weigh the respective values of the advantages and disadvantages of rotary engines.
8. Briefly describe the operations of the Gnome engine.
9. State the positions and duties assigned to five mechanics required when an airplane prepares for flight.
10. Explain how the propeller should be grasped for cranking, with particular reference to first and second positions of the feet.
11. If the engine fails to start what action is required before repeating the operation?
12. Give the full set of signals which governs the acts of pilot and mechanic during preparation for immediate flight.
13. How does a compressed air self-starter turn the motor over?
14. By an example, explain how fuel may be conserved for long flights.
15. In what way does altitude affect the amount of power secured from the engine?
16. Give twelve important precautionary acts of motor inspection before starting.
17. When the explosive charge in cylinders ignites too soon what parts should be examined? Suggest two remedies when the fault is located.
18. Name five parts which should be examined if the motor is overheating.
19. When a knock or a grind is detected what should be done instantly?
20. Describe the character of the noise which warns of a defective connecting rod bearing.

CHAPTER ANALYSIS**Instruments and Equipment for Flight****AVIATOR'S EQUIPMENT:**

- (a) Clothing.
- (b) Goggles.
- (c) Watch.
- (d) Safety Belt.

AIRPLANE INSTRUMENTS:

- (a) Scope and Usefulness.
- (b) Cockpit Arrangement.
- (c) Gauges.
- (d) Compass.
- (e) Barometer or Altimeter.
- (f) Tachometer.
- (g) Angle of Incidence Indicator.
- (h) Inclinator.
- (i) Radiator Temperature Indicator.
- (j) Drift Meter.
- (k) Air Speed Meter.
- (l) Banking Indicator.

CHAPTER X

Instruments and Equipment for Flight

Before beginning consideration of actual flight, a preliminary survey of the aviator's equipment and aids is advisable. These consist of his clothing and accessories and the instruments which aid navigation of the air. Many arguments are advanced for the method of instruction by which the pilot acquires a sense of "feel" without dependence upon mechanical devices, but while this instinctive knowledge is essential, intelligent use of the instruments undoubtedly increases the aviator's efficiency.

Clothing—A warm coat is a necessity, for even in summer it is cold at high altitudes. In winter a fur lining is advisable; in ordinary moderate weather the service uniform covered by a leather coat is sufficient. Pockets without flaps, closing by an elastic band, should be of generous size so that papers may be easily put away with one hand. Warm socks are essential and soft boots or puttees without straps should be worn with the riding breeches. Fleece-lined soft leather gauntlets, allowing easy freedom of fingers and wrists, are the proper protection for the hands. A padded helmet is a necessity. The aim in selecting clothing is to provide flexibility of movement and protection from the cold with the minimum of straps and strings to catch on the obstructions within the cockpit. Above all, clothing must be comfortable.

Goggles—As a protection from the wind, even though the airplane be provided with a wind shield, goggles should be used to take the strain off the eyes. Glass lenses should not be used; they should be made of colorless celluloid with a green shade at the top and bound by a stiff rubber rim shaped to conform to the face. A small piece of chamois should be carried to wipe off the flying oil.

Watch—An accurate timepiece with a wrist strap is essential to the military aviator.

Safety Belt—Under no circumstances should the aviator venture aloft without his safety belt adjusted. This device consists of a wide web of heavy webbing with a quick detachable locking device. The belt should be securely adjusted with the stress coming at the thighs.

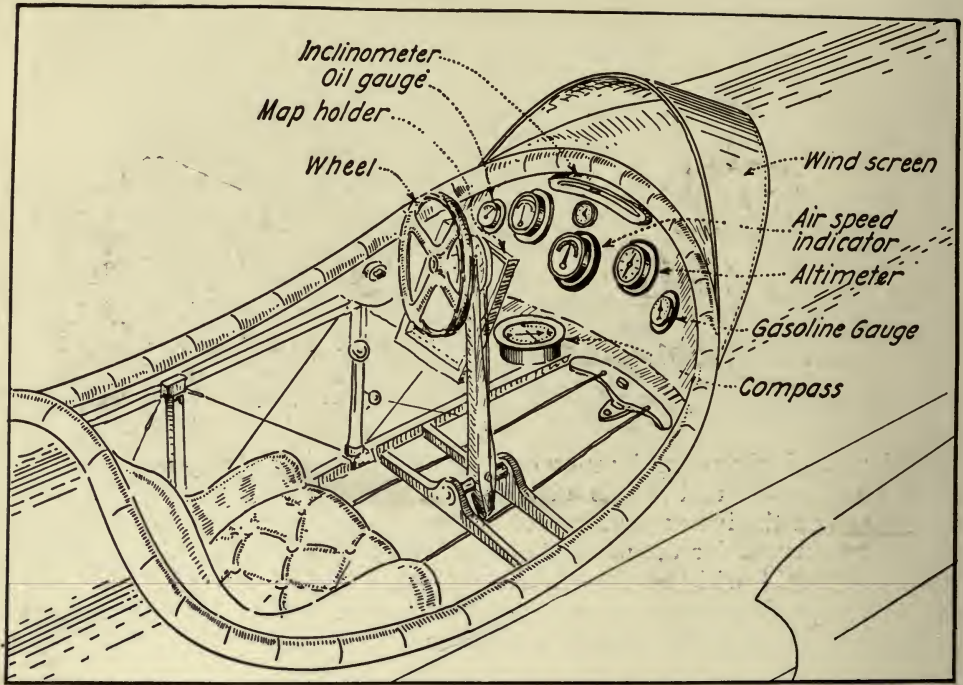


Figure 71—General view of a typical airplane cockpit

AIRPLANE INSTRUMENTS

SCOPE AND USEFULNESS

As with any class of travel, reaching the destination by air flight requires knowledge of position. The aviator obviously must also know the direction of his machine toward the horizontal. In or above the clouds, out of sight of earth, knowledge of these essentials must be gained through instruments. The devices required for air navigation must be compact and rugged, light, reliable and accurate.

GAUGES

An oil gauge definitely indicates the amount of oil in the crank case, an oil-pressure gauge accurately indicating undisturbed flow and the pressure in the oil system. The gasoline gauge registers the quantity of gasoline available in the tanks, preferably by mechanical means.

LUMINOUS DIALS

Paints and compounds which illuminate pointers and figures on instrument dials are now in general use, electric lighting having been largely done away with because of the glare and the vibration to which lights are subjected. Zinc sulphide combined with radium are the main constituents of the most reliable luminous paints.

COCKPIT ARRANGEMENT

Wherever practicable, well upholstered seats are provided for aviators and in many cases comfort is further promoted by passing heated exhaust pipes through the cockpit. Figure 71 shows a typical arrangement of the pilot's seat and dash with air navigation instruments in position of easy visibility.



Figure 72—A military airplane compass

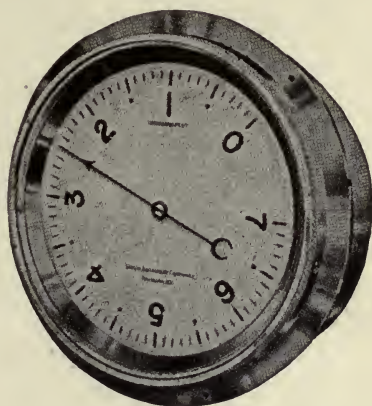


Figure 73—The barometer or altimeter

COMPASS

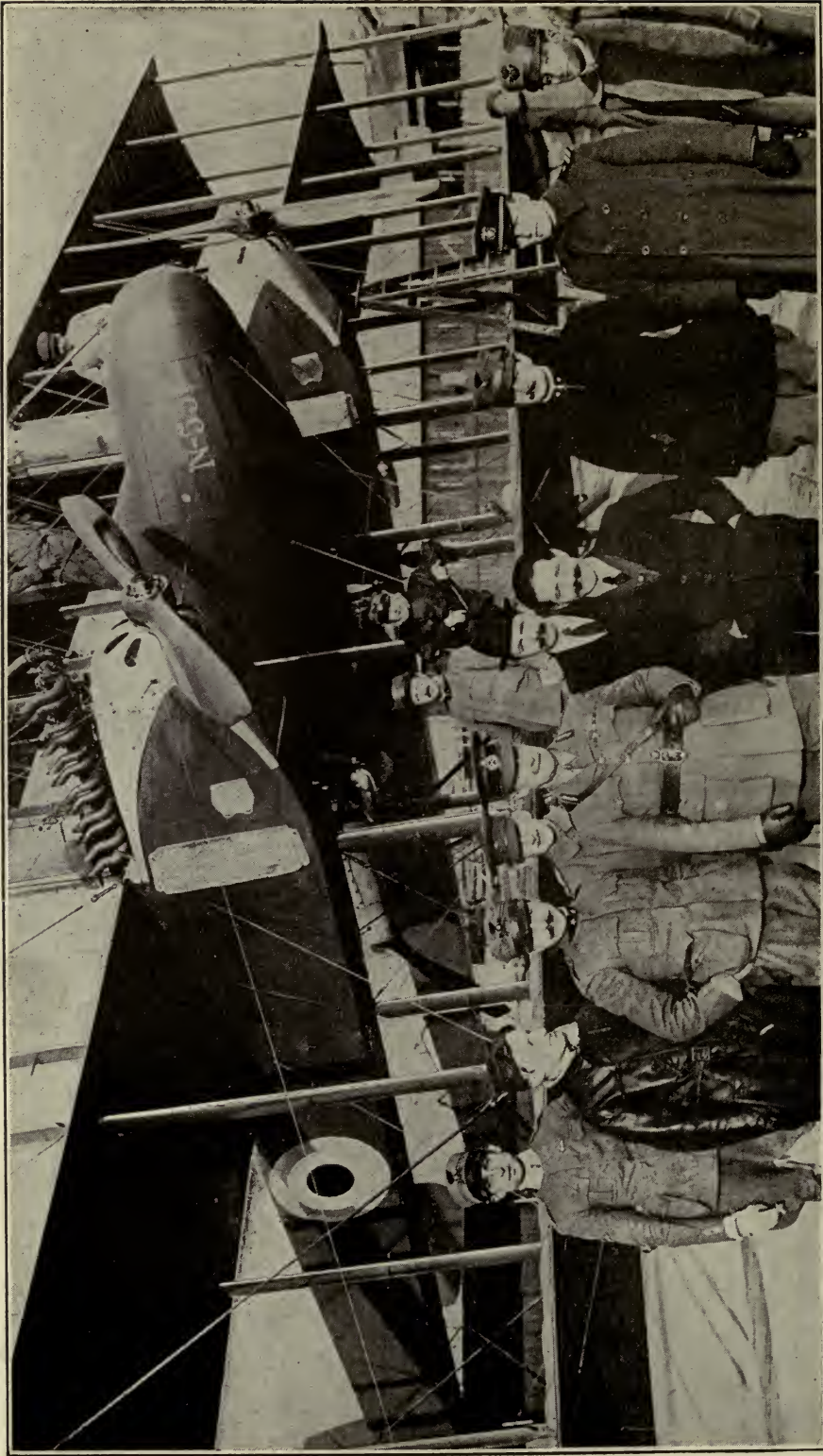
Air navigation, as well as sea, requires the aid of the compass, a device which contains a magnetic needle constantly pointing to the magnetic north. In the aviation compass illustrated in Figure 72 a compensating attachment counteracts stray magnetic influences. The card, or graduated scale, floats in a mixture of alcohol contained in the inner bowl, the latter being bedded in horsehair, which absorbs vibration. The alcohol varies in proportion to water from 45 per cent to almost pure alcohol, the high percentage being maintained to prevent freezing at high altitudes.

BAROMETER OR ALTIMETER

To indicate the height of the airplane above the earth is the function of the instrument illustrated in Figure 73. Essentially, it comprises a vacuum chamber which is acted upon by the varying density of the air. The dial is adjusted to zero on the ground. Location of the instrument on the airplane is of great importance by reason of the possibility of influence by velocity pressure.

TACHOMETER

This instrument, not illustrated, is in all essentials similar to the speedometer used for automobiles, except that it registers the number of revolutions of the motor. Its importance may be estimated by considering that the power delivered by the engine is directly related to its speed of revolution and that the speed of its turning may be used to compute the airplane's speed relative to the air. Tachometers are either magnetic or electric, the former type consisting of a magnet rotated by a flexible shaft coupled to the engine, and the latter comprising a generator, engine driven, electrically connected to an ammeter. With both types the indications are made by a needle and graduated arc on the dash.



(c) Press Ill. Svce.

The amazing development of aircraft is revealed in this photograph of the new Caproni triplane, features of which are the twin 12-cylinder motors and tractor screws with the addition of a pusher propeller behind the nacelle. The wireless generators are located on the struts just underneath the engine beds. In the center of the group are the Caproni brothers, builders of the Leviathan of the air

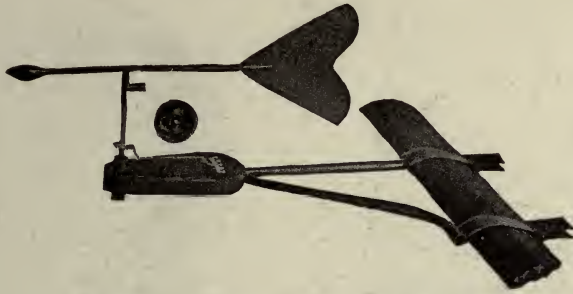


Figure 74—Angle of incidence indicator



Figure 75—An inclinometer

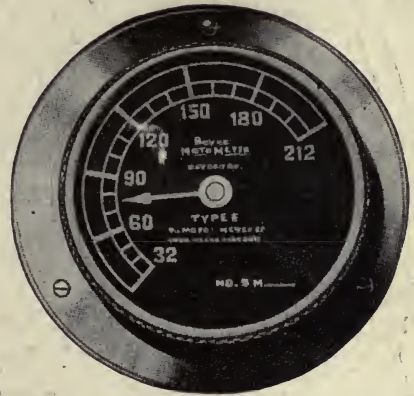


Figure 76—Engine temperature meter

ANGLE OF INCIDENCE INDICATOR

This device, illustrated in Figure 74, is mounted on a forward strut clear of the influence of the propeller and the body. The vane, which remains level when the airplane is in motion, has a pointer and indicator graduated in degrees and visible to the aviator. The instrument shows the angle between the chord of the wings and the flight path. By means of a dry battery and electrical connections the round light bank shown is attached. When the flight is level no light shows. A white lamp signals when a dive is made at too steep an angle. A red light warns of an angle close to the stalling point. A green light indicates the best climbing angle.

INCLINOMETER

Two types of inclinometers are illustrated. The spirit-level type shown mounted on the dash in Figure 71, is inaccurate in the presence of accelerations and has generally been superseded by the instrument illustrated in Figure 75. This device registers the angle of the airplane with the horizontal, the scale being on a weighted wheel which is damped by floating in liquid, which insures sensitiveness and increases accuracy. The scale tips forward or backward with the angle of the airplane, the dial being mounted on the instrument board in the cockpit.

RADIATOR TEMPERATURE INDICATOR

The value of this device, illustrated in Figure 76, is obvious when it is considered that great altitudes are attained by airplanes and the necessity of knowing whether the motor is getting cold. Equally important is knowledge of imminent overheating. The instrument is, therefore, designed to register from freezing to boiling.

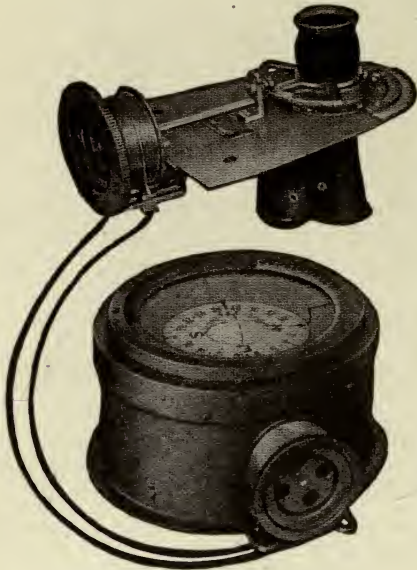


Figure 77—The drift meter



Figure 78—Air speed meter



Figure 79—Banking indicator

DRIFT METER

The purpose of this instrument, shown in Figure 77, is to enable the aviator to remain on a given course to his destination, irrespective of drift occasioned by side winds. The device comprises a telescope pointing vertically to the earth with hairs crossing the field of vision. A scale and pointer indicates the angle of drift in degrees and the compass lubber line moves automatically to correct for any existing drift. The instrument is widely used for cross-country flight.

AIR SPEED METER

This mechanism shows the airplane's rate of speed relative to the air. It serves to correct for the aviator any erroneous impressions which may be gained by his speed in relation to the ground, since that speed varies according to whether his airplane is flying with or into the wind. It is also useful to indicate excessive gliding speed, straightening out from which may stress the machine to dangerous limits. The principle of its operation is pressure of wind on a liquid contained in a tube, a lead from one end of which is open to the wind. This device is also known by the names, manometer and Pitot tube.

BANKING INDICATOR

The proper lateral attitude of flight is shown on this instrument by the airplane outline on a fixed dial, below which is a bar rotating from the center and controlled by a pendulum inside the case. When the indicator bar and the wing outline are parallel, as in the illustration, Figure 79, the machine has the proper amount of bank. The pendulum swings outward in proportion to the radius and speed of the turn, and when the pilot has not properly banked his airplane the indicator bar will be out of parallel with the wing outline on the dial. The pilot then merely operates his controls in the indicated direction until the parallel is again registered. The instrument is of special value to the aviator at night or in a cloud or fog when human sensibilities are not dependable.

REVIEW QUIZ

Instruments and Equipment for Flight

1. What type of goggles are best and why should a piece of chamois be carried?
2. Is there any occasion when an aviator should make a flight without first adjusting his safety belt?
3. What is the function of the compass?
4. Why should the altimeter be located in a position where the airplane's velocity will not affect it?
5. What are the two types of tachometers?
6. How many electric light signals are given by the angle of incidence indicator?
7. When the flight is level no light shows; which lamp, then, indicates best climbing angle?
8. If a white lamp is flashed by the action of the indicator, what does it indicate?
9. Give the essential difference between two types of inclinometers and state what these instruments register.
10. How does the drift meter indicate and correct the angle of flight in a side wind?
11. Explain how the air speed meter corrects possible erroneous impressions of the velocity of the airplane's flight.
12. How is this indicator valuable in showing gliding speed?
13. Give two other names by which the air speed meter is known.
14. What is the relative position of indicator bar and wing outline on the banking indicator when the airplane is properly banked?
15. Under what flight conditions is this instrument specially valuable?

CHAPTER ANALYSIS

Instruction in Flying

First Flights and Cross-Country Flights

INSTRUCTION IN FLYING:

- (a) The Flying Course.
- (b) Junior Military Aviator Tests.
- (c) Flying by Dual Control.
- (d) Flight Instruction by Solo Method.
- (e) Military Aviator Course.
- (f) Advanced Flying.

FIRST FLIGHTS:

- (a) Position for the Start.
- (b) Leaving the Ground.
- (c) Climbing.
- (d) Turning.
- (e) Straightening Out.
- (f) S-Turns.
- (g) Right of Way.
- (h) Meeting an Airplane.
- (i) Overtaking an Airplane.
- (j) Meeting at an Angle.
- (k) Landing Sites.
- (l) Landing.
- (m) Bad Landings.

CROSS-COUNTRY FLIGHT:

- (a) Equipment.
- (b) Physical Fitness.

USE OF THE COMPASS:

- (a) The Compass Card.
- (b) Compass Error.
- (c) Variation.
- (d) Deviation.
- (e) Adjusting the Compass.
- (f) Placing the Compass.

LAYING OFF A COURSE:

- (a) Determining the Steering Direction.

(b) Data Required.

(c) Preparing a Diagram for Wind Factor.

(d) Radius of Action.

SOME FLIGHT CONSIDERATIONS:

- (a) Proper Preparation.
- (b) Height.
- (c) Air Disturbances.
- (d) Lost Bearings.
- (e) Landmarks.
- (f) Time Checking.
- (g) Selecting Landings.
- (h) Forced Landings.
- (i) Pegging Down.
- (j) Re-Starting.

MAP READING:

- (a) Definition of Terms.
- (b) Orienting.
- (c) The Scale.
- (d) Contours.
- (e) Conventional Signs.
- (f) Map Preparation.

THE FLYING CREW:

- (a) The Navigator.
- (b) The Pilot.
- (c) The Observer.
- (d) Motor Engineer.
- (e) The Gunner.
- (f) Radio Operator.

THE REPAIR CREW:

- (a) Aviation Mechanician.
- (b) Assistant Chief of Crew.
- (c) Mechanician Helpers.

CHAPTER XI

Instruction in Flying

First Flights and Cross-Country Flights

The theory of aviation may now be said to be fully covered and the student ready for text on actual flight. If the preceding chapters have been carefully studied there is no flight evolution of the airplane which is not entirely understandable to the reader. The function and operation of the airplane as a whole, and its controlling means as separate and unified parts, will be clear without further explanation in the description of the various flight maneuvers. One point may well be repeated here, however, to fix the matter clearly in the student's mind. That is the results of operation of the stick control and rudder, which may be simplified as follows:

- To go down, push the stick control forward.
- To rise, pull it back.
- To tilt to the left, push it left.
- To tilt to the right, push it right.
- To turn left, rudder with left foot.
- To turn right, rudder with right foot.

Thus it is seen that the movements are the natural ones; for example, if the airplane is tilted sideways to the right the natural tendency is to lean left. Pulling the stick to the left rights the plane; and so on, each motion being the automatic one, so to speak.

During early stages of flight training the pupil must not hesitate to tell the instructor if at any time he feels physically or temperamentally unfit. Flying when not mentally inclined for the instruction will quickly ruin an aviator's prospects for later success, and any hesitancy about stating his condition for fear of a "cold feet" accusation is not to be tolerated. Aviation instructors and students are sympathetic, earnest men; they have no time for taunts.

Acquiring confidence in early stages is a tremendous help; until it is acquired the first solo flight should not be attempted; usually, after five hours dual-control instruction, the elementary machine may be flown solo. Some fifteen or twenty flight hours on various elementary types is generally sufficient, and the faster airplanes may then be used. Take-offs and landings should be frequent in practice, for nothing more quickly instills confidence than knowledge that the matter of alighting has been mastered.

In this chapter, the scope of the preliminary training will be considered by progressive steps, a survey of the whole subject being given by first defining the composition and duties of the flying and repair crews and the tests for grading as an aviator.

INSTRUCTION IN FLYING

Candidates for instruction in aviation in the U. S. Army are selected from the following sources:

- Officers of the line of the Army.
- Enlisted men of the Aviation Section, Signal Corps.
- Civilian aviators, employed as Instructors.
- Civilian aviators, employed to perform flying duties and given the rank of Aviator, U. S. Army.
- Officers and enlisted men of the Signal Officers and Signal Enlisted Reserve Corps.

THE FLYING COURSE

The instruction is divided into definite stages comprising a complete flying course, as follows:

- (a) Preparatory.
- (b) Preliminary.
- (c) Elementary.
- (d) Advanced.

The preparatory instruction includes all the teaching up to the point where the pupil actually takes hold of the controls while the craft is in flight through the air. Preliminary training may be defined as the instruction up to the point where the student makes a flight alone, making quarter, half or full turns. Elementary training is the stage of instruction preliminary to the completion of pilot's tests. Advanced flying is the next step up to the qualification tests as a junior military aviator.

JUNIOR MILITARY AVIATOR TESTS

- (a) Five figures-8 around pylons, keeping all parts of the machine inside of a circle with a radius of 300 feet.
- (b) Climb out of a field 1,200x900 feet and attain 500 feet altitude, keeping all parts of the machine inside of the field during climb.
- (c) Climb 3,000 feet, kill motor, spiral down, changing direction of spiral, that is from left to right, and land within 150 feet of a previously designated mark.
- (d) Land with dead motor in a field 800x100 feet, assuming the field to be surrounded by a 10-foot obstacle.
- (e) From 500 feet altitude, land within 100 feet of a previously designated point, with a dead motor.
- (f) Cross-country triangular flight of approximately 60 miles without landing.
- (g) Straightaway cross-country flight, without landing, of about 90 miles.

FLYING BY DUAL CONTROL

THE AIRPLANE

A machine of moderate power and slow speed is used, with large surfaces for slow landing speed. Dual controls are provided, so that either instructor or student can control the craft.

FIRST STAGE

The student merely observes the operations of the instructor at the beginning. He is given the "feel" of the air and taught to gauge, by the air pressure against face and body, his speed and flotation for horizontal flight, climbing and banking. The machine's response to the controls is noted and their resistance to motion observed.

SECOND STAGE

Instruction is given in the operation and management of the controls. Horizontal flights are followed by broad, flat turns, quarter, half and full circles to right and left, simple, normal landings and take-offs and balancing the airplane in the air. Flight through unfavorable, disturbed air is next performed, including banking, climbing and gliding, moderate spiral glides and straight and spiral volplanes. Landings of various kinds are then taught, including normal, slow-speed, pancake and stall landings, and landing in wind. The instructor gradually turns over the air controls to the student as the instruction progresses, and finally the power controls. Taxying, or maneuvering the machine on the ground, is also mastered before the student takes to the air alone.

FLYING ALONE

Detailed instructions as to the flight course and maneuvers to be performed are given by the instructor before the student flies alone, and the altitude is also prescribed. The first flight alone is elementary, being restricted to horizontal flight, take-offs and landings on a straight course. It is followed by adding circles to right and left, moderate climbs and straight glides. Figures eight are made with gradually decreasing radii and steeper banking; the turns are then combined with glides and advanced to spiral glides. From both straight and spiral glides, landings are then made with a dead motor. The instructor watches his pupil closely from an observation tower during these flights and corrects all faults observed at the completion of the flight.

FLIGHT INSTRUCTION BY SOLO METHOD

FIRST STAGE

The first machine used for this method, practically one of self-training by progressive use of selected airplanes, is low powered with small lifting surfaces, in fact not intended for use off the ground. The speed of propeller revolution is limited by a stop on the engine throttle. The student first learns the manipulation of controls from the pilot's seat, that is, the rudder, elevators and balancing planes, or ailerons. He is then taught to "taxi" on the ground, using a straightaway course on a broad, flat and hard path, and to acquire skill in steering the machine on the ground.

SECOND STAGE

The next machine is one of limited power but designed to lift off the ground for a height of about two feet, the lift being regulated by the throttle of the engine. The limitation of power causes the machine to sink gently back on the ground but permits the student to master the operation of the elevator. Hops up to 200 feet are made in this way and the handling of balancing planes is accurately learned. From then on the machine is regulated gradually until straightaway flight is made at heights up to 20 feet, several take-offs and landings being required with each flight.

THIRD STAGE

The next machine is of an advanced type and in it flights are made at an altitude of 50 feet, at which very slight curves are taken along the course. Increasing altitudes are attained and these curves are gradually advanced to circles, with greater angle of banking for decreased radius or increased speed; these are mastered by barely perceptible degrees. Broad figures of eight follow and straight and spiral glides under throttled power advance to glides without power, or the volplane. Accuracy in landing on a mark and coming to rest over a mark are then attained.

COMBINATION OF TRAINING METHODS

Where time permits, the best training course is a combination of solo and dual methods, the former to give the student self-reliance and the dual control instruction to correct any errors acquired in training.

MILITARY AVIATOR COURSE

Advanced flying is begun with training designed to perfect judgment in landings and the volplane. Difficult conditions are then imposed, the flyer being taught to handle his machine near buildings, fences and all classes of obstructions, first on the ground and then in the air. He is trained to rise and land over imaginary obstacles or over a specified height, indicated by a string stretched between two posts and marked by a pennant. He ascends from and descends into fields of restricted area, which for safety are marked by chalk lines.

High-powered machines and unfavorable weather are selected and sharp turns, steep banks, spiral glides and difficult landings are practiced. The instruction is mainly designed to give the pilot confidence in his abilities and to impress upon him caution and thoroughness.

The elementary observer's course consists of progressive flights at increasing altitudes and under varying conditions of visibility, from clear weather to foul. Visibility tests with naked eye and field glasses of various powers are made, followed by instruction flights in reconnaissance and navigation of the air. Short cross-country flights in preparation for junior military aviator tests are then in order.

These tests complete the training as a military pilot; further development is acquired by training on various types up to super-planes and high speed pursuit planes. Expert aviators are required to attain a minimum altitude of 12,000 feet, remain in flight for four hours and cover 200 miles, cross-country.

ADVANCED FLYING

The advanced work is classified by the Training Department of the Army Aviation Schools into special phases as follows:

- Excessive use of controls
- Reduced power flights
- Flat glides
- Steep climb
- Banking up to 90°
- Fast landings and take-offs
- Landing across wind
- Stalls, side-slips, tail-slides, loops
- Bad weather; rain
- Water flying
- Night flying
- Altitude flights; duration flights; cross-country flights
- Passenger carrying and low flying

The course of study and practical work embraces the elements of aeronautical engineering, use of meteorological and aeronautic instruments; advanced meteorology; practical reconnaissance; spotting artillery fire; bomb dropping; principles of aerial combat; wireless telegraphy; gunnery; strategic and tactical employment and administrative control of the air squadron.



Photo Com. Pub. Inf.

American beginners in France receiving solo instruction on the elementary non-flying machine



Photo Central News

The heavy bombing plane, or super-plane, here illustrated, carries as many as six men and eight machine guns

THE FLYING CREW

An airplane's flying crew is largely governed by the type of machine. Small machines of high power, designed either for strategic reconnaissance flights or pursuit at high speeds, carry but a single aviator. The two-seater, or most common airplane carries an observer or gunner. Aircraft of the super-plane class carry from 3 to 15 men, comprising additional duties of navigator, gunner, engineer and radio operator.

THE NAVIGATOR

Military control and direction of pilot, gunners, bombers, radio operator and engineers, as well as the navigation of the machine in flight, is the duty of the navigator, usually the senior officer of the crew.

THE PILOT

Management of the controls of the airplane while in flight is the duty of the pilot. He is also responsible for final inspection of the craft before the flight is begun, and for the careful completion of any repairs or alterations on the machine. Immediately upon return from a flight it is his duty to examine minutely all controls, lifting surfaces and braces and supervise all mechanical adjustments not included in shop work.

THE OBSERVER

Preparation of reconnaissance maps and reports, all observations and computations of flight navigation, is the duty of the observer. In combat he directs the fire against enemy airplanes and, if on a bombing expedition, orders the use of explosive or incendiary bombs according to the objective. He is also responsible for the efficiency of the personnel of the crew and the matériel.

MOTOR ENGINEER

Uninterrupted operation of the motor or motors in flight is the responsibility fixed on the motor engineer. At all times he performs, with the help of an assistant, any work necessary to insure the highest operating efficiency of the airplane's engines, and is responsible for all repairs other than those required to be made in the machine shop.

THE GUNNER

Expertness in the care and operation of machine guns and the construction and operation of explosive and incendiary bombs is required of the gunner. Range-finding, loading and releasing devices for bombs and telescope and air compressor must also be thoroughly mastered.

RADIO OPERATOR

Installation of apparatus, assembly and dismantling of radio equipment, thorough knowledge of all codes of army signaling, are qualifications of the radio operator. In addition, he is responsible for all communications from the airplane and must be familiar with the operation of visual signaling devices, such as the Very pistol, rockets, smoke bombs, etc.

THE REPAIR CREW

Two non-commissioned officers and three privates, first class, are generally assigned to an airplane and are responsible for its care on the ground. In the case of small airplanes the repair crew may consist of only three men, but the general practice is a crew of five.

AVIATION MECHANICIAN

The chief of the repair crew is rated first class sergeant or sergeant, and in the U. S. Army is known as Aviation Mechanician. He is responsible for the condition of the airplane and its matériel while it is in the hangar; he supervises all adjustments, alterations, installations and repairs. All property issued for maintenance and all tools and accessories are in his charge, and he is responsible for the cleaning and preservation of the craft.

ASSISTANT CHIEF OF CREW

Rated as a sergeant or a corporal, the assistant aids the chief and is required to be a qualified mechanic capable of discharging all duties of the chief of crew.

MECHANICIAN HELPERS

The three mechanician helpers, rated as privates, first class, are under the orders of the chief of crew and his assistant. They are required to assist in adjustments, alterations, removals, installations and repairs, to clean the motor and all parts of the airplane fuselage and surfaces, fittings and fixtures, wires and cables. It is their duty to keep the hangars clean at all times; to replace tools and equipment; to elevate the machine on chocks or jacks when in its stall and to cover the motor propellers and cockpit. Hauling gasoline, oil and other supplies and assisting in repair work are among their duties. When not employed about the machine they are required to be available for instruction or duty in the machine and repair shop.



Figure 80—An airplane headed into the wind, the position for the start



Figure 81—Taxying at the start with wheels on the ground and tail raised

FIRST FLIGHTS—THE START

The airplane should be turned directly against the wind, as this position aids the initial rise from the ground and makes it easier to maintain balance, a difficult matter in a cross wind.

LEAVING THE GROUND

The engine should be developing full power for the required thrust before the signal is given for the mechanics to let go. As the airplane starts forward along the ground, the tail stabilizer is depressed by moving its control forward. This causes the tail to rise from the ground and places the lifting surface more horizontal, offering less resistance as rolling speed is acquired. Figure 81 illustrates this position. When the machine is taxying at a velocity equal or greater than the airplane's low flying speed, the tail control is pulled back gently and held. The tail end of the machine then drops and the angle of incidence of the wings is increased, causing the airplane to rise.

A minimum distance of 100 yards (covered in 5 to 10 seconds, according to the wind) is allowed between the starting point and the rise from the ground.

CLIMBING

The tail control is pulled back slightly and held fixed in the new position, further increasing the lifting surface angle of incidence. The motor is then accelerated to its proper climbing speed.

The airplane should be pointed into the wind for the first 200 feet of altitude and the student flier should rise at least 100 feet. A landing made from a lesser height is valueless for instruction purposes.

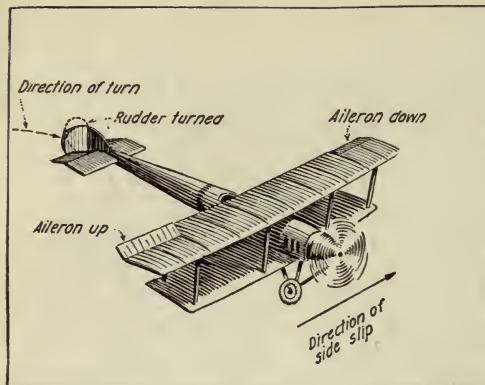


Figure 82—A turn made too flat

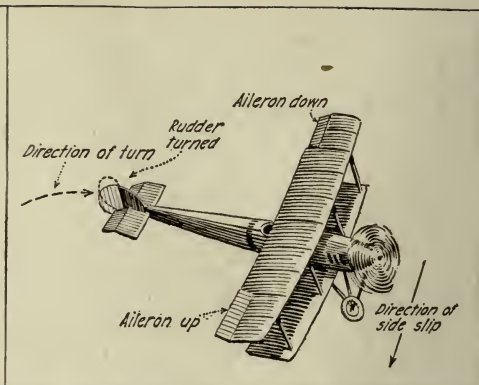


Figure 83—Too steep banking

TURNING

Turning with the novice almost invariably reveals one fault, i. e., the banking is too steep. This must be corrected before the aviator attempts the steep turns. The following general rules will prove useful in learning to turn the airplane correctly.

A good altitude margin should be allowed, so there will be at least 500 feet to correct for bumps or side-slips.

First turns should be very wide and not through more than 180 degrees, or half-turn.

While turning, speed should be kept up to at least level flying speed, and the airplane nosed down to its normal gliding angle. If flying speed is lost, the machine will side-slip or stall, getting into the cabré, or tail down, position which is dangerous to the novice.

As the natural tendency is to lose height, it is best to turn the airplane against the wind at first.

Aileron and rudder controls should be handled gently and first turns made gradual ones.

Figures 82 and 83 show turns improperly made. A turn too flat causes an outward side-slip, and too steep banking an inward side-slip. Either of these faults are perceptible to the aviator by the feel of the wind on his face. During a right turn, for instance, a noticeable wind on the opposite, or left, cheek indicates an outward side-slip. This is corrected by gently pushing the stick to the right for more bank or turning the foot bar for less rudder. When the opposite effect on the cheek is noticed, more rudder and less bank is required.

Gradually, turns may be made smaller until a $2\frac{1}{2}$ -turn spiral in 1,000 feet is accomplished. Turning while volplaning may then be tried.

In gliding turns the airplane's nose should be kept below the line of the horizon. Climbing turns require the nose of the machine above the horizon.

STRAIGHTENING OUT

A few simple rules will serve to teach how to come out of a turn properly.

Theoretically, the rudder and aileron controls are brought back to central positions. In many airplanes, however, they must be brought over to the opposite bank first and centered when the machine is level. The stick control should be moved a trifle sooner than the rudder, and brought past center, being returned to central position when the rudder is at center and the airplane at a horizontal level.

Coming out of a steep turn these control movements are made greater, the stick being given a semi-circular action. Special care should be taken that the rudder is not swung over opposite too early, for this will throw the nose of the airplane up and an inward side-slip will result.

S-TURNS

These are a series of descending Figure 8s or S-turns, useful for landing in a restricted area. Two rules should be followed. During the entire turn the aviator should keep his eye on the landing spot selected and always turn toward that point. The turns are made increasingly smaller as the ground is approached for the final glide.

Turning near the ground should be avoided; speed should be maintained by keeping the nose down.

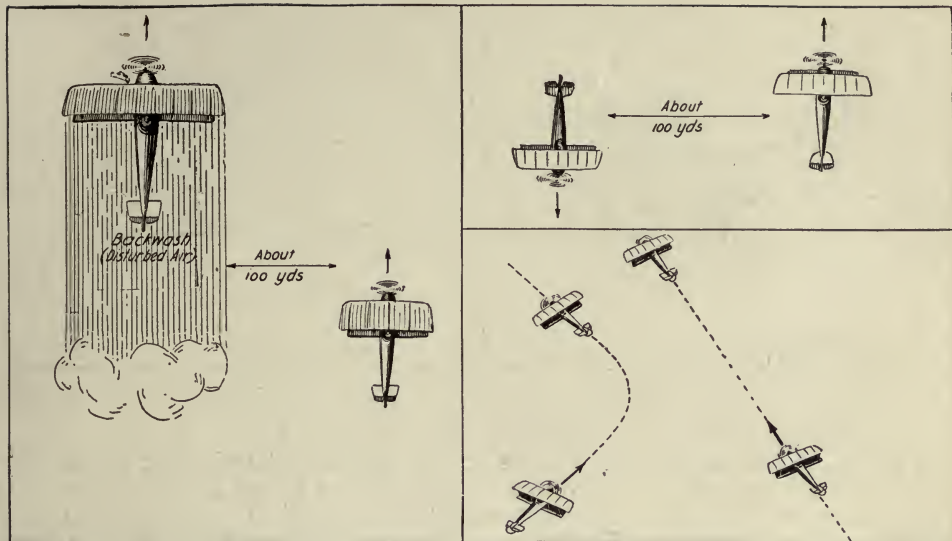


Figure 84—The overtaking airplane steers clear about 100 yards of the slower machine ahead and avoids the disturbed air of the backwash

Figure 85 (Upper)—Distance for passing in opposite directions

Figure 86 (Lower)—How an airplane gives way to one met on its right

RIGHT OF WAY IN THE AIR

The student aviator should acquaint himself with the air rules of the flying school to which he is assigned. The courses are usually prescribed and the direction of circuits and pylon markings clearly stated. While slight variations may be encountered at various flying fields, the following general rules are almost universally observed:

OVERTAKING AN AIRPLANE

The faster machine coming from the rear maintains the minimum distance, 100 yards, by steering clear, care being taken that the overtaking machine is not brought within the zone of influence of the backwash, for in the disturbed air rough going will be encountered. See Figure 84.

MEETING AN AIRPLANE

When an airplane is encountered coming in the opposite direction, both machines keep to the right and pass at a minimum distance of 100 yards. See Figure 85.

MEETING AT AN ANGLE

In a situation such as illustrated in Figure 86, where two airplanes approach at an angle, the aviator who finds the other machine on his right gives way.

LANDING SITES

The United States Army requires of a flying field for testing aviators a minimum size of 800 by 100 feet. The general area of a field is about 9 acres, 200 yards square. Area allowances are added for obstacles, proportionately based on the obstacle's height, 12 times the height being added to the area, or 12 feet of field depth added for every foot of obstacle height.

The above regulation applies only to machines of slow landing speed. When fast airplanes are used, the 200-yard depth is added to as follows; 40 m.p.h., 60 yards; 45 m.p.h., 120 yards; 50 m.p.h., 360 yards; 55-60 m.p.h., 960 yards. These dimensions are based on landing and taking off against the wind.

Plowed fields, soft ground and ditches are dangerous to the inexperienced aviator and should be avoided as landing places.

Canvas strips, 15 feet long and 3 feet wide, are usually employed to identify landing sites. These are visible to the pilot at altitudes up to 9,000 feet and indicate to the airman the direction for approach. The strips are arranged in the form of a T, the approximate outline of the airplane; a long strip is laid crosswise below the T to mark the point of contact with the ground, the machine being brought to full stop when on the T itself.

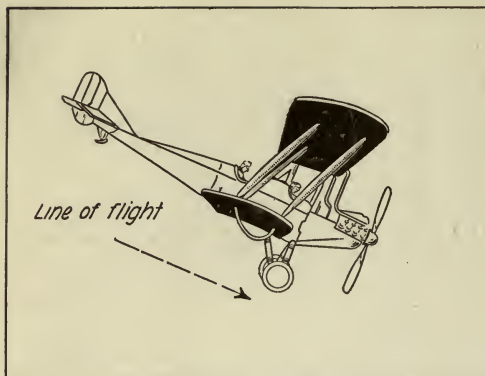


Figure 87—Airplane gliding

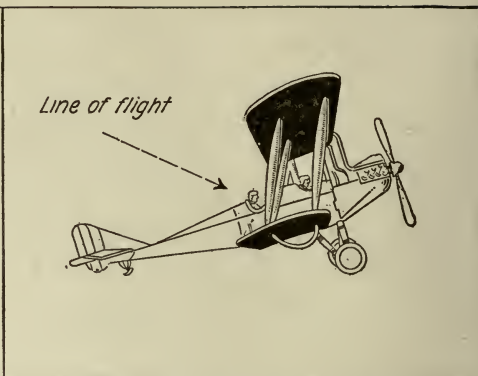


Figure 88—The pancake landing

LANDING

Making a proper landing is one of the most difficult and most important tasks that confront the student aviator. The success of the landing is largely dependent upon nosing the machine down at the proper distance from the landing field and choosing the proper gliding angle. Thus, if the angle is 1 in $6\frac{1}{2}$ and the machine is at 200 foot elevation the maximum distance allowed for the descent would be $200 \times 6\frac{1}{2} = 1300$ feet from the landing spot selected. If a greater distance is allowed, the machine is liable to fall short. A distance less than this maximum is preferred, since a spiral may be made to kill extra height and a correction of gliding angle made if the angle selected is not the best. All airplanes are designed to assume their gliding angle with power and thrust cut off.

OPERATION OF CONTROLS

When the descent is to be made the engine is throttled down to relieve strains on the airplane and insure flexibility of controls. Since the proper gliding angle is determined by the speed, the tachometer or the air speed indicator should register the determined speed within 5 miles an hour. The machine should be headed directly into the wind, the direction of which may be determined by observation of chimney smoke or flags below. When within 15 feet of the ground the tail control is gently pulled back, elevating the tail until the airplane is in its horizontal position for slow flight. This should be accomplished when 5 feet above the ground and the control then held; the airplane will thereafter descend without further assistance. The control should be held lightly, however, to correct for bumps.

When about to effect a landing a glance should be directed to the horizon or the banking indicator, and the aileron control used to keep the airplane laterally level. Swerving as the machine touches the ground is corrected by the rudder or the tail skid.

BAD LANDINGS

If, when the airplane is about to land, it assumes the position of flight shown in Figure 88 it will bounce when it strikes the ground, the running gear breaking on the second impact. Also, if brought out of gliding position when too high off the ground it will drop, due to lack of speed, and the same break follow. These landings are known as the "pancake." The remedy is to speed up the motor to regain velocity and flying position, then throttle down and land.

The most dangerous landing is caused by failure to pull the airplane from gliding to flying position, the running gear striking the ground at a forward inclined angle. The motor must be instantly opened wide after the first bounce, flying speed being regained before the rebound.

A bad landing which severely strains landing gear and causes wheels to buckle, follows contact with the ground when the rudder is turned, causing a swerve, or when the airplane is not level laterally.

PREPARATIONS FOR CROSS-COUNTRY FLIGHT

Qualifying tests for Junior Military Aviator prescribe two cross-country flights, one of approximately 60 miles and the other 90 miles. When these flights are undertaken the student aviator is expected to know all the fundamental technique of flying, turning and landing, and have reached the stage where the operation of controls is no longer a task but a matter of instruction routine, so to speak; in flying cross-country, therefore, he is enabled to give a large share of attention to following the course and selecting proper places should an emergency landing be required. Prior to the flight a few matters of importance require attention.

EQUIPMENT

The usual flying clothing is worn, the only caution being to provide for sufficient warmth. Leather suit and helmet are worn, supplemented in winter by sweaters and mufflers. Hands and feet are most sensitive to cold and should be well protected; provision of large boots with woolen socks or stockings will repay the aviator in comfort. On a long flight it is well to take two pair of goggles, in case one pair should be lost or broken, and a handkerchief to clean them is necessary. An identification card and money should be carried for emergencies; the telephone number of the airdrome should also be noted and a complete set of tools and covers for propeller and cockpit should be carried.

STANDARD EQUIPMENT—AIRPLANE TOOL CHEST

(Cover)

- | | | |
|---------------------------|--|---------------------|
| 1 Saw, hand, 26" | 1 Combination square, bevel and level, 12" | 1 Rule, folding. |
| 1 Hammer, riveting, 8 oz. | | 1 Hacksaw frame. |
| | | 1 Dividers, pair 6" |

(Top)

- | | | |
|-------------------------|-------------------------------------|----------------------------------|
| 1 Wrench, Stillson, 14" | 1 Hammer, tinsmith's, 1 pound. | 2 Center punches. |
| 1 Screwdriver, 8" | 1 Hammer, claw. | 24 Blades, Hacksaw, coarse; 12 |
| 1 Screwdriver, 7" | 1 Tape, steel, 100 feet. | blades, Hacksaw, fine; 1 chisel, |
| 1 Screwdriver, 5" | 1 Brace, 10" | cold, ¼"; 1 chisel, cold, ½". |
| 1 Nail-puller. | 1 Iron, soldering, 1½ lbs., 1 iron, | 1 Calipers, 6" |
| 1 Knife, draw 8" | soldering, jeweler's. | 1 Wrench, monkey, 6" |

(Upper Drawer)

- | | | |
|----------------------------|--------------------------------------|---------------------------------------|
| 1 Bit, expansive, ⅞ to 3" | 2 Pliers, auto, combination cutting, | 1 File holder. |
| 1 Pliers, round nose, 6" | 6 and 8" | 1 Spoke shave, 3" |
| 1 Pliers, snipe nose, 4" | 1 Nipper-cut, 7" | 1 File cleaner. |
| 1 Pliers, adjustable, 8" | 2 Pliers, diagonal, 6" | 10 Files, assorted, with canvas roll. |
| 1 Pliers, side-cutting, 8" | 1 Pliers, compound, side-cutting, | 1 Screwdriver, 4" |
| 1 Pliers, adjustable, 6" | 8" | 1 Palm, sewing; 8 needles, assorted; |
| | | 1 ball flax and 1 ball wax. |

(Lower Drawer)

- | | | |
|------------------------------|--------------------------------------|----------------------------------|
| 1 Stone, carborundum, 5" | 1 Set drills, Morse, straight shank, | 1 Wrench, 7" |
| 1 Torch, gasoline, flat. | with canvas roll. | 3 Reamers, taper, bit stock, 1¼, |
| 1 Set thin open-end wrenches | 1 Plane, block, 1½" | 1 5-16, and 1¾" |
| with canvas roll. | 1 Drill, hand. | 1 Hatchet, half (small). |
| | | 1 Snips, tinner's. |

The machine should be carefully inspected, from tires to instrument board, before the start. Wires, controls, engine and gasoline and oil reservoirs are matters to be looked into by the aviator, who must not accept the word of mechanics that everything is ready. The instruments required are a compass, wrist watch, altimeter, tachometer, inclinometer and a map board or case. The map case is highly preferable as maps pinned to a board often blow off or are torn in long fast flights.

The map is a most important part of the aviator's equipment for a cross-country flight. It should be placed in a position of easy visibility, such as on the instrument board, or, in any event, as nearly as practicable straight ahead in the line of vision. The course should be carefully mapped out and notations made, as discussed in succeeding pages. On a long journey a weather report obtained by telephone from the point of destination may save trouble should fogs or storms be prevalent there.

PHYSICAL FITNESS

The aviator should have no hesitation in informing his instructor or flight commander of any indisposition; if he does not feel well a cross country flight should not be attempted, as the correct functioning of all his faculties will be required. A long flight on an empty stomach is bad, as dizziness often results. At least a hot drink should be secured, and a good meal if possible. Food in tablet form, chocolate or biscuits may be taken along, but should be placed in a position of easy access.



Painting by Lieut. Farré

A military flight in formation; steering by compass in the clouds

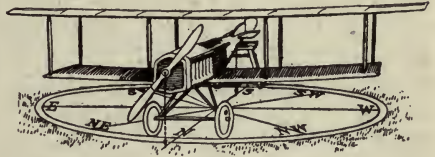
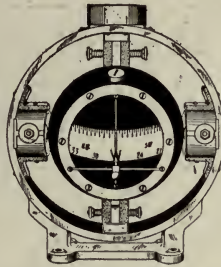
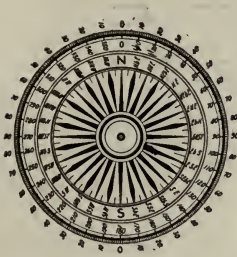


Figure 89—Compass card Figure 90—Vertical
Compass

Figure 91—Adjusting the compass

USE OF THE COMPASS AND ITS ADJUSTMENT.

The compass is an instrument for indicating the magnetic north by a magnetized needle on a pivoted card. While cross-country flight is possible with the aid of a map and identifying landmarks, at times when these are obscured the compass is a necessity to the aviator. Steering by compass accurately, reference to the map is not required in flight, providing preliminary calculations are accurately made as later outlined in this chapter.

THE COMPASS CARD

The card is illustrated in Figure 89. Marking in degrees is clockwise, the circle beginning at N (north) as zero, and comprising 360 degrees. The card is also marked in the old form of the merchant marine; north, east, south and west being represented by 90 degrees, bearings being read, for example, 20° W. of N. An aviation compass of the vertical type is illustrated in Figure 90.

COMPASS ERROR

VARIATION—The compass indicates the magnetic north from any given place; i. e., the compass magnet points to the north magnetic pole, situated on a northern Canadian island. This is not the "true" north, and it is therefore necessary on maps of the various parts of the earth to make the correction known as variation. This is the angle between the true and magnetic meridian at the point mapped.

DEVIATION—Since the compass needle is magnetic and the airplane contains much metal of magnetic attraction an error known as deviation is caused which deflects the needle some degrees to the east or west.

Adjusting the Compass—To correct the deviation error is a task seldom assigned to the aviator, but some idea of how it is accomplished will be found of value. (The process which we term adjusting, is known in England as "swinging" the compass.) The airplane is placed with its fore and aft axis exactly north and south, either by aligning it with a tripod "land" compass placed nearby, or by placing the airplane on a cement slab provided for the purpose in many flying fields. The airplane is trued up, in the latter case, by spirit level and plumb line, as illustrated in Figure 91. The compass has what is known as the "lubber's line," which is then fitted to the fore and aft line of the airplane. The compass reading is then taken, and by inserting small field magnets in slots provided for the purpose, the east or west deviation of the needle is corrected until it points north with the cement slab. When the best correction possible has been made a deviation card is generally made out and placed near the compass, for in long flights to a definite objective an error as small as 2 or 3 degrees will throw out the aviator's calculations. A specimen of these cards follows:

For Magnetic Course		Steer by Compass	For Magnetic Course		Steer by Compass
N.	0 degrees	357 degrees	S.	180 degrees	183 degrees
N. E.	45 "	47 "	S. W.	225 "	223 "
E.	90 "	90 "	W.	270 "	270 "
S. E.	135 "	137 "	N. W.	315 "	317 "

PLACING THE COMPASS

The proper location of this instrument is an important matter. It should be placed in clear view and directly in front of the pilot, preferably in the center fore and aft axis of the airplane, as far as possible from moving metal parts such as those of the engine. Metal parts such as control levers and rods, if within 2 feet of the compass, should be non-magnetic, and movable equipment such as machine guns, should be in normal flying position when the compass is adjusted. After any required change in parts is made the compass deviation should be checked and any necessary readjustment made.



Figure 92—A typical military map

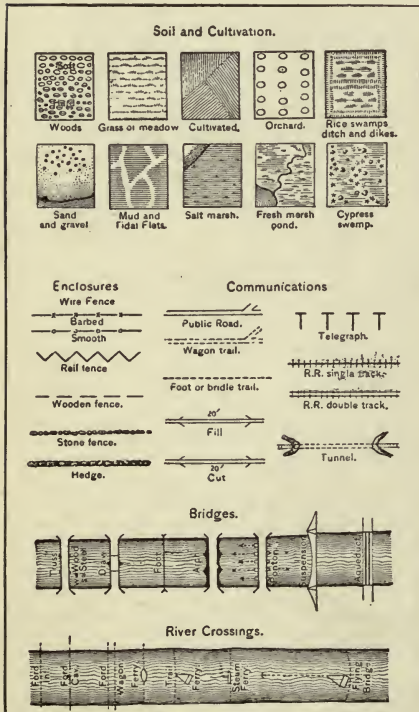


Figure 93—Conventional signs for maps

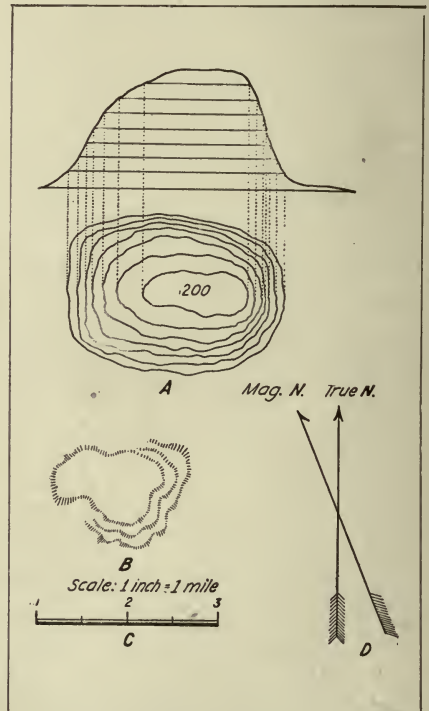


Figure 94—Height, distance and direction symbols

MAP READING

(Abstracted from Signal Corps Manual, by the same Author.)

The aviator must know how to read a map before cross-country flights can be made. An understanding of the meaning of conventional symbols and application of the scale are the main essentials, extensive knowledge not being necessary.

A typical military map is shown in Figure 92.

DEFINITIONS OF TERMS

In mapping, many terms are used, a number of which, such as basin, crest, gorge, knoll, plateau, and watershed are universally familiar. A few special terms are defined here, however, for the simplification of the subject.

Bearing—The relative position or direction with the north, or true meridian; *magnetic bearing*, the relative position or direction with the magnetic north.

Contour—A line designating the shape, outline or boundary at a fixed height of a section of ground; contours are used to indicate elevations, each contour representing a rise or fall in feet from those surrounding it. Illustrated by *A*, Figure 94.

Gradient—This indicates a slope expressed as a fraction, a gradient of 1-50 designating a rise of 1 foot in 50.

Datum—A fixed level (generally sea level) from which all heights are measured.

Hachures—A shading method of representing hills, short strokes being drawn directly down the slopes. Illustrated by *B*, Figure 94.

Meridian—A true north and south line.

ORIENTING

The first thing to be determined is: Where is the north? On a map this is usually indicated by an arrow placed in one of the corners. Some maps do not have an arrow, in which case it is a generally safe assumption that the top of the map is the north. When two arrows appear, as in *D*, Figure 94, one points the true north, the other the magnetic north. Usually they are so marked, but if not lettered, the incomplete or less elaborate arrow represents the magnetic north. The magnetic north is the north of the compass; its deviation from the true north has already been explained. When the map has been turned to its proper position, i.e., the magnetic north arrow corresponding with the compass, it is said to be oriented. This is the first step for the aviator about to lay out a cross-country flight.

THE SCALE

Having located his position on the map, the next feature for the aviator to study are the distances between points. These are shown by the scale, which appears usually on the lower end of the map; for example, two points are measured by ruler on the map and the distance is 1 inch; the scale reads: 1" = 1 mi. (as in *C*, Figure 94), then the actual distance between these points over the ground will be found to be 1 mile. Some maps state: (so many) miles to the inch; the measuring procedure is the same, allowance being made for 2 miles to the inch, or whatever the scale states. What is known as a representative fraction is sometimes used. On the map, Figure 92, this appears as $\frac{1}{21120}$. If the R.F. is $\frac{1}{100}$ it means that an inch on the map is equal to 100

inches on the ground; the fractions are usually large, such as $\frac{1}{63,360}$, which would indicate an inch to a mile, since there are 63,360 inches to a mile. On foreign maps $\frac{1}{100,000}$ is a familiar fraction, and may indicate either inches or millimetres; in all forms the principle is the same and the scale is reckoned in the same way, afterwards being calculated in inches by the aviator. Another method of showing the scale is illustrated on the map, Figure 92, where it is only necessary to copy the scale on a strip of paper and apply it directly to the map, reading off the distances between any designated points.

CONTOURS

Contours on a map show the elevations, depressions, slope and shape of the ground. Hachures, (see *B*, Figure 94), sometimes used on European maps, show elevations only and are of little value. The method of indicating features by contour lines is clearly shown in the illustration *A*, Figure 94. The irregular, curving lines which appear on the map represent the outlines of the hill at equally spaced vertical intervals. If, for example, by use of a surveying instrument a line of stakes was placed around a hill, each one exactly the same height above sea level, a line drawn on the map through all the stake positions would be a contour. Study of the diagram *A*, Figure 94, will make it clear how the steepness of hillsides is determined from the map, contour lines close together indicating a steep slope, and far apart, a gentler slope.

On some maps contours are numbered in elevation in feet above the datum plane, generally sea level. Thus, at a glance, the elevations are clearly determined.

The principal conventional signs used by the U. S. Army are given in Figure 93, and should be memorized.

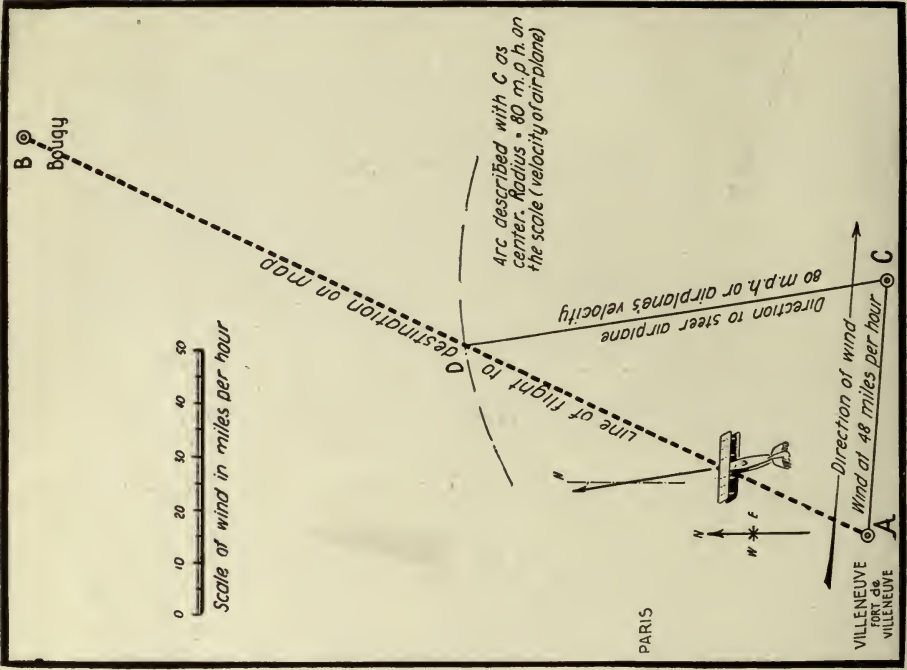


Figure 95—Diagram solution of the flight from A to B shown in Figure 94



Figure 94—How an airplane must be steered off the direct course to allow for side wind drift

LAYING OFF A COURSE

DETERMINING THE STEERING DIRECTION

It is obviously important for the aviator to know the direction to head his machine to arrive at a given destination. When flying above clouds, over water, or at night, when landmarks are not discernible, he has no means of determining how far the wind may be blowing him off his course. Calculations are therefore made in advance by the following method:

DATA REQUIRED:

- Flying speed of his airplane.
- Compass bearing of his course from point of departure to destination.
- Direction and speed of the wind.

The map of the country over which he is to fly will give him the compass bearings; the points joined by a line (see Figure 94) determine the direction and its angle to the north of the compass bearing.

Direction and speed of the wind can be found from the weather vane and anemometer of the airdrome. The anemometer is a device with four arms carrying cups on the end of each, turning about on a vertical axis at a speed varying with the wind velocity. When the wind velocity at the ground has been determined, the aviator must decide upon the height at which the flight is to be made, for as height increases the velocity and direction of the wind changes. The table below will be found useful in estimating the proper allowance:

WIND VELOCITY AND DIRECTION CHANGES WITH ALTITUDE
(Based on Wind Velocity of 25 miles per hour)

Height in feet.....	At the earth's surface	500'	1000'	2000'	3000'	4000'	5000'
Velocity change in per cent....	100%	135%	172%	188%	196%	200%	200%
Clockwise deviation in degrees..	0	5°	10°	16°	19°	20°	21°

Example: Assume that the anemometer shows a wind velocity of 25 miles per hour at the ground, and the weather vane indicates the direction of the wind 89° west of north. The aviator plans to fly his course at a height of 3000 feet. From the table he learns that the wind velocity at this altitude is 196%, greater than at the ground; then, $25 \times 1.96 = 48$ miles per hour. Likewise, from the table, it is seen that the wind direction at this altitude shows a clockwise deviation of 19°, so at 3000 feet the direction of the wind will be $89^\circ - 19^\circ = 70^\circ$ west of north.

A DIAGRAM TO DETERMINE THE WIND FACTOR

With the data in hand the aviator can lay out a simple diagram for his course. Assume that his orders call for a flight from Fort de Villeneuve to Bougy (see *A-B*, Figure 94). The route, according to the map, is 30° east of north. The speed of the aviator's airplane is 80 miles per hour. The wind, as already determined, has a velocity of 48 m.p.h. in a direction of 70° west of north at 3000 feet, at which height the flight is to be made.

Either on the map or on a separate sheet of paper, the starting point is designated *A* (see Figure 95). A line is then drawn with the proper compass bearing to the destination *B*. From point *A* a line is drawn parallel to the direction of the wind, blowing 70 degrees west of north. On this line the velocity of the wind is measured off, the aviator establishing a scale, say 1 inch = 10 miles, or any other convenient scale. Assume that the scale 1 inch = 10 miles is the one selected; then 48 m.p.h. would be measured, 4.8 inches to point *C*. With a pair of dividers opened to represent the speed of the airplane by the same scale (in this case, 80 m.p.h. = 8.0 inches) an arc is described with *C* as the center. Where it cuts the line *A-B* (see *D*, Figure 95) a line is drawn from *D* to *C*; this line gives the proper direction to steer the airplane to neutralize the drift of the airplane in one hour's flight from *A* to *B* in the cross wind. The steering is by compass bearing to the fore and aft axis of the machine.

Measurement of the line *A-D*, applied to the scale will give the actual velocity in miles per hour of the flight. In the example it is seen to be 85 m.p.h., that is, the cross wind increases the airplane's speed 5 miles per hour.

The student should reconstruct the diagram for the return flight. That it will not do to steer in exactly the opposite direction will then be made clear. In all cross-country flights a separate diagram for the return is required, unless, of course, the wind happens to be exactly parallel to the course.

RADIUS OF ACTION

To determine the distance outward the airplane can go and have sufficient gasoline to return, requires a simple calculation.

The aviator knows his gasoline capacity; i.e., how many hours of flight can be obtained before the tank is empty. With this and the other data he can figure his radius of action in miles.

Example: Assume that the flight is to be made straight into a head wind of 30 miles per hour, the speed of his airplane is 80 m.p.h., and its gasoline capacity $4\frac{1}{2}$ flight hours. (For climbing and as a general margin $\frac{1}{2}$ hour gasoline consumption is deducted, leaving 4 flight hours).

On the outward trip his speed is $80 - 30 = 50$ m.p.h.

On the return trip his speed is $80 + 30 = 110$ m.p.h.

The ratio for both trips is, then, as 50 is to 110, or 5 is to 11. The time required for the outward trip is thus $11/16$ of 4 hours, and the return trip the remaining $5/16$ of 4 hours; or, outward = $2\frac{3}{4}$ hrs.; return = $1\frac{1}{4}$ hrs. Since his outward bound speed is 50 m.p.h., then $50 \times 2\frac{3}{4} = 137\frac{1}{2}$ miles radius. Return speed being 110 m.p.h., then $110 \times 1\frac{1}{4} = 137\frac{1}{2}$ miles. This, then, is the radius of action.

A wind blowing directly along the course is a rare occurrence, however. A diagram similar to Figure 95 must therefore usually be made, both for the outward and return trips. The calculation for radius of action is then carried on as above, or by the simple formula:

$$\text{Radius of Action} = a \times \frac{b \times c}{b + c}$$

Where

a = gasoline hours.

b = outward speed.

c = return speed.

SOME FLIGHT CONSIDERATIONS

PROPER PREPARATION

Care must be observed by the aviator that his preliminary preparations are properly made. This refers particularly to a study of the course from the map.

Ordinarily the country over which he is to make the flight will be on one sheet with features and landmarks clearly indicated. Should the use of two sheets be necessary these should be pasted together before starting and cut to fit the map roll. In war flights foreign maps with the scale in fractions are often the only ones available; the aviator should immediately construct the corresponding scale at so many miles to the inch, which will facilitate rapid calculation. Distances from the starting point should also be marked at ten mile intervals or by distinctive objects to be passed. High hills should be marked as bad for landing.

HEIGHT

Where there are no high hills or mountains in friendly territory the flight is best made at heights from 1,500 to 3,000 feet. An altitude of 1,500 feet should be attained by an initial circling climb before the aviator sets off on his course. Speed and steadiness of wind increases with height, and landing or righting in case of mishap is better accomplished with a good margin; but above 2,000 feet contour of the country is not readily distinguished, so if the flight is to be at a higher altitude the poor landing places should be clearly marked on the map. It is well for beginners to keep the ground in view throughout the flight, flying under or around any clouds.

CLOUDS, FOG AND STORMS

Pupils are cautioned to avoid heavy cloud banks and not to rise above clouds when near the seacoast, for a wind off shore may carry the airplane out to sea without the pilot's knowledge. When navigation above a cloud bank is necessary, the cloud formations may be used as a basis for keeping the airplane horizontally level, for cloud formations are ordinarily sufficiently level for this purpose. Fog should be avoided; in fact, when a heavy mist is encountered a landing should be made as soon as possible. River valleys should be avoided, for they very often hold a ground fog up to a height of 700 feet. At times when the flight must be continued through clouds or fog, the instruments should be carefully watched and the stick control and rudder kept in central position as much as possible. Heavy rain, sleet and hail chip the propeller slightly and when encountered a landing should be made at the earliest favorable opportunity. A whistling sound indicates that the propeller has been chipped.

AIR DISTURBANCES

Initial cross-country flights by the student are usually made under favorable weather conditions, ordinarily in the early morning or late evening, when the atmosphere is calmest. Bumps caused by heat, as explained in a later chapter on meteorology, manifest themselves early in the day as close to the ground as 100 feet; their influence is gradually extended upward as the morning progresses until they are perceptible at noon at altitudes up to 3,000 feet. Clouds and inland waters generally predict bumps, while over the sea the air is ordinarily smooth, although of high velocity. Landings in strong, bumpy winds are best made with additional speed, caution being exercised when nearing the ground in sheltered spots as wind eddies may cause a sudden roll or a drop of 10 feet or so.

LOST BEARINGS

Should something happen to the compass and the aviator be unable to get his bearings, his wrist watch will be of assistance in locating the points of the compass. With the hour hand pointed to the sun, the point midway between the angle it makes with the numeral 12, points to the south. Thus, at 8 o'clock in the morning, with the hour hand pointed at the sun, the point midway in the angle formed by 8 and 12, i. e. 10 on the watch dial, will point to the south.

LANDMARKS

The principal landmarks of a map should be firmly fixed in the aviator's mind prior to the flight, memorized if possible. Experience has shown that the following features are the most useful:

Towns—These are the best guides and should be marked with a circle or underlined on the map. A village is sometimes difficult of identification; location of its church and its reference to the roads will aid in placing it. If flying below 2,000 feet altitude the aviator should not pass directly over the town as the heat from factory chimneys causes marked air disturbance.

Railways—Railroad tracks are of great assistance. Tunnels, bridges and cuts are marked on the map and aid in locating the line to be followed should the aviator mistake a branch line or siding for the main route. It should be remembered that the track disappears when it passes through a tunnel.

Water—Water courses and lakes are usually clearly defined and may be seen at some distance. Allowances should be made, however, for possible flooding of streams after heavy rains which may change their appearance as recorded on the map. The bearing of a river with reference to the course should be noted; following its windings may involve loss of time.

Roads—From a height all roads look very much alike and are therefore not very good guides. Main roads can occasionally be identified by the paving and the amount of traffic, and are useful because they lead into towns. Telegraph lines may be expected along them, which makes landing nearby dangerous.

Woods—Small forests serve as excellent guides.

Hills—From altitudes of 2,000 feet and over, hills are flattened out in appearance and valleys are not clearly discernible.

General Characteristics—The physical features of the country are very helpful to the aviator if his preliminary study of the map fixes in his mind their relationship to each other. How railways and streams join or intersect, how they enter and leave towns, and their relation to wooded areas, supply useful information. Dividing the course into four progressive parts also aids, if the general nature of each sector is noted for its chief distinguishing characteristics, whether water, woods, farm lands, towns or villages.

FORCED LANDINGS

Engine failure is the main cause of forced landings. As soon as it is known that the failure is complete, the engine should be switched off and the gasoline pipe closed to lessen the danger of fire. The airplane is then turned into the wind and if the ground directly beneath makes landing impossible the descent can be made in a long glide. While selection of landing ground is not practical from a recognition standpoint at altitudes greater than 1,000 feet, entirely unfavorable areas such as water, marshes or forests may be avoided by long glides. The radius of the forced landing is about five times the height at which the airplane is flying. An aviator forced to land from a height of 2,000 feet, therefore has about 10 square miles of land to choose from. At a height of 5,000 feet he has selection in an area of about 70 miles.

When a forced landing has been made the aviator's first thought should be for his machine and the immediate possibility of resuming flight. Examination of the engine is the first step; it should then be determined how much, if any, damage has been done to the airplane structure. A telephone call to his headquarters should then be made and a report given of his location and diagnosis of the trouble. If the damage requires staying where he is for the night, then the airplane should be moved to some spot sheltered from the wind and made secure.

TIME CHECKING

It is difficult to estimate time while flying, yet checking by the watch the time when successive objects are passed is an important detail often overlooked. The tendency invariably is to expect the next landmark long before it is due and confusion will arise in the aviator's mind unless time elapses are carefully checked. Knowledge of elapsed time is also valuable in steering a compass course over the clouds.

SELECTING LANDINGS

Choosing a suitable field to land in is by no means an easy task for the novice. A few primary rules governing selection will be useful.

It is better to pick out a *group of fields* as the glide may take the inexperienced aviator beyond or short of the mark.

Stubble fields, brown in color from a height, are generally smooth and, excepting sandy beaches, make the best landing ground.

Grass fields, green in appearance, often can be identified by cattle grazing. Mounds may be looked for in grass land, so they are therefore second choice.

Cultivated land is ordinarily fairly level, but landings made therein are successful only when pancaked. A ploughed field is black in appearance, vegetable and corn fields have a hue considerably darker than the green of grass lands.

A field *near a town* is the best choice, as its proximity to the source of supplies is a great convenience. The landing field selected, however, is preferably to windward of the town, so it will not be necessary to rise over the buildings when re-starting.

Telegraph wires usually border *main roads* and railways; these wires cannot be seen until the aviator is close upon them, so nearby landing places are undesirable.

When *snow* is on the ground the selection of a good landing place is practically impossible; the frozen ground, however, makes its selection of less importance.

Light variations are important. Flying into the rays of the sun, a slight haze appears which distorts objects. In the late evening, too, the light may be good at the flying altitude, but when descent is made the ground appears much darker. Before landing, therefore, a wide circle should be made until the eyes are used to the relative dullness.

PEGGING DOWN

The airplane should be placed head into the wind and the tail lifted up and supported at a height which will place the airplane's wings edgewise to the wind. The controls should be locked and the wings and fuselage near the tail pegged down, some slack being left in the rope. The propeller, engine and cockpit should then be covered. If a strong wind is blowing, trenches should be dug for the wheels to a depth of about $\frac{1}{4}$ their diameter.

RE-STARTING

A minor trouble which does not require calling a repair crew may leave the aviator without assistance for starting, although spectators willing to hold back the airplane are generally more numerous than too few. Stones or fence poles will serve as chocks under the wheels if assistance is not at hand. Any mud which may be gathered on the wheels should be cleaned off as it will be drawn to the propeller by centrifugal force and chip or break it. Before starting, the ground over which the machine is to taxi should be walked over carefully and any serious obstacles removed. The possibilities of dead wind in the lee of buildings should be estimated and allowance made to get clear of these areas as the airplane rises. Small obstacles, such as hedges, may be cleared if good taxiing speed is acquired and the control stick pulled back suddenly. Getting rid of extra weight will also aid the machine to take the air quicker, should there be doubt of getting out of the field.

REVIEW QUIZ

Instruction in Flying

First Flights and Cross-Country Flights

1. Give in simplified form the results of manipulating the stick control to its four positions and the effect of ruddering to right and left.
2. Why should the airplane be headed into the wind at the start?
3. What is the minimum taxiing distance a beginner should allow before rising from the ground?
4. State a safe altitude margin for turns, the proper turning speed for the novice, and give the cause of side-slips while turning.
5. In an S-turn how does the landing spot selected serve as a guide?
6. Give three elementary rules of the air which determine right of way.
7. Explain how landing sites are identified and on what portion of the mark should the airplane be brought to a full stop.
8. By an example, state the rule for gauging the distance allowed for descent to the landing field.
9. Name the essential equipment and the necessary inspection required of an aviator prior to cross-country flight.
10. Define compass variation and deviation and a method of adjusting the compass.
11. Lay off a course by diagram for a flight of 100 miles in a direction of 12 degrees east of north, in an airplane with speed of 75 m.p.h. and a wind blowing 48 degrees east of north with a ground velocity of 25 m.p.h.; the flight to be made at 2,000 feet altitude; determine by the diagram the proper steering direction to allow for wind drift and give the resultant compass bearing.
12. Given the following data, determine the radius of action of the airplane: Head wind blowing 41 m.p.h.; airplane's speed, 70 m.p.h.; gasoline capacity, $3\frac{1}{2}$ flight hours.
13. In what way are cloud banks useful to the aviator flying above them?
14. Explain how a wrist watch is useful in determining direction should the compass be out of commission.
15. How are towns, railways and water courses useful as landmarks?
16. Why are hills and roads poor guides?
17. Give the reason why checking the time when successive objects are passed is important.
18. What is the difference between a map contour and a gradient?
19. Explain how distances on a map are determined by the scale and describe four ways of marking the scale.
20. From memory, sketch 15 conventional map signs denoting various types of soil, communications and enclosures.

CHAPTER ANALYSIS**Advanced Flying**
Aerobatics and Night Flights**ADVANCED FLYING:**

- (a) Spiral.
- (b) Nose Dive.
- (c) Spinning Nose Dive.

AEROBATICS:

- (a) Loop the Loop.
- (b) Flying Upside Down.
- (c) Vertical Bank.
- (d) Zooming.
- (e) Roll Over.
- (f) The Stagger.
- (g) Spiral Loop.
- (h) Immelman Turn.
- (i) Flat Turn.
- (j) General Considerations.

NIGHT FLYING:

- (a) Equipment.
- (b) Preliminary Instruction.
- (c) Taking-Off and Flying.
- (d) Landing at Night.
- (e) Lighting the Field.

CHAPTER XII

Advanced Flying

Aerobatics and Night Flights

The course of training which leads to a rating as Military Aviator is known as advanced flying. It consists generally of effecting landings among obstacles and difficult turns, high altitude flights and long cross-country flights; in fact, in acquiring great skill in handling the airplane. Beyond this training lies the acrobacy of the air, termed aerobatics, stunt flying which at first appears foolhardy but has an exceptional value in war where fast machines are engaged in combat.

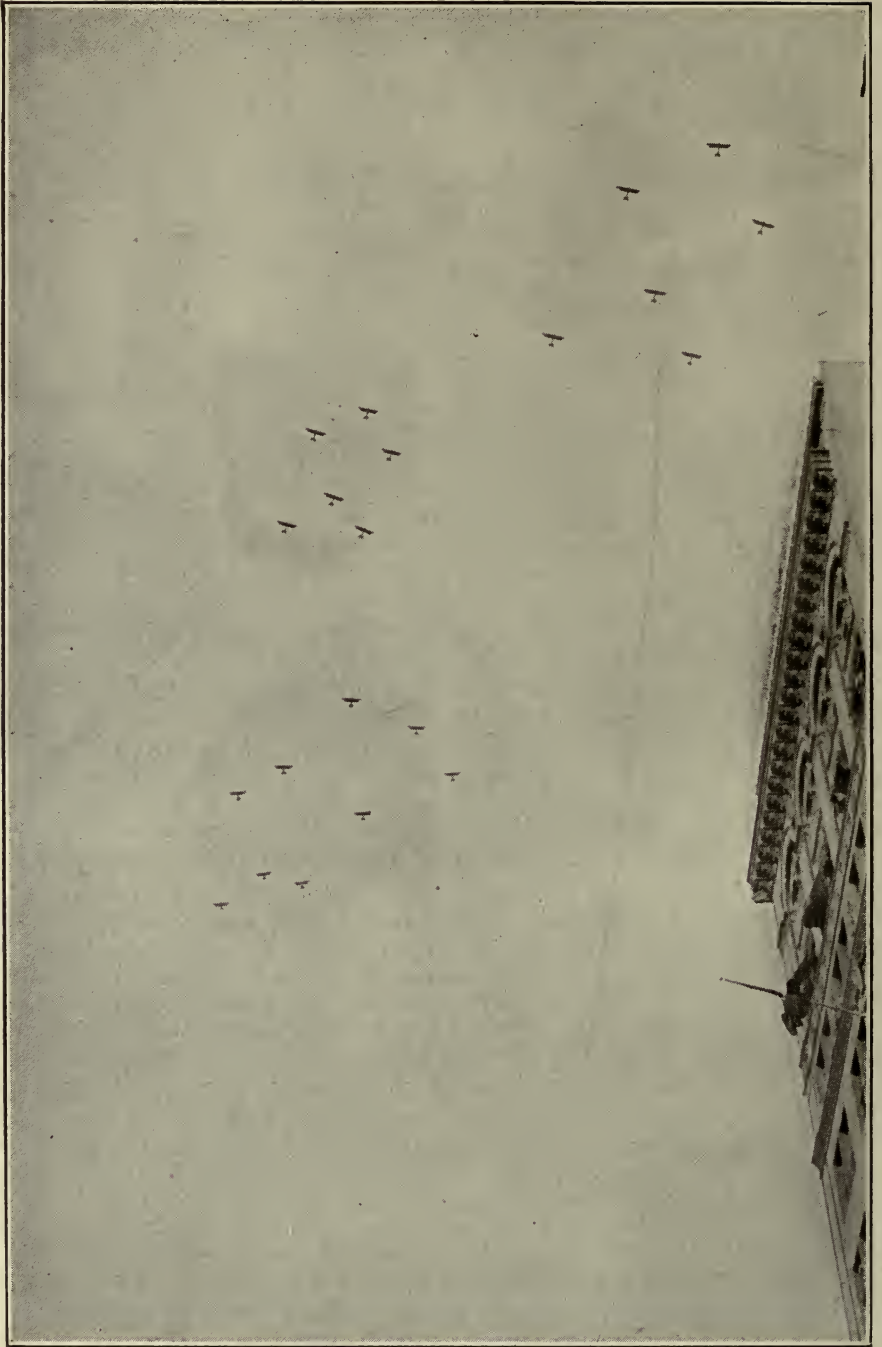
Ascents to 10,000 feet or more may be classed as advanced flying, although these climbs present few difficulties and little danger. On the assumption that all aviators are plentifully supplied with courage, climbing for the first time to high altitudes is largely a matter of patience.

A pertinent suggestion to novices in lofty climbing is not to imagine the engine is stalling as height increases; the rarefied atmosphere will require less steep climb in higher altitudes, but that is a matter for adjustment, the best angle for the particular machine being determined by the aviator's observation of altimeter and watch, and their relation to the airplane's flight efficiency.

Descent from the first 10,000-foot flight is best made slowly, so the aviator may become accustomed to variations in air pressure. Any discomfort in breathing can usually be relieved by swallowing at frequent intervals. It is advisable, too, when the airplane has come within 1,000 feet of the ground, to circle once over the flying field for the purpose of refreshing the memory on the appearance of the ground at that height.

Application of the principles of aerobatics explained in this chapter should be preceded in flight by some hours' practice in climbing turns and stalling turns at altitudes of 2,000 to 3,000 feet. Getting close upon other airplanes without being seen is also valuable maneuvering practice. Not every pilot is successful in learning aerobatics; comparatively few, in fact, are designated by the instructors to master these air evolutions; but the heady man who is physically fit takes to this form of flying readily and is fairly certain to come out with a whole skin if these two primary rules are rigidly observed:

1. Always leave a wide altitude margin between the airplane and the ground.
2. Do not effect too sudden changes of direction; straighten out gradually after diving.



(C) Int. Film Svce.

Figure 96—An American air squadron flying in formation over the City of New York to demonstrate the absolute control of the pilots in bumpy air

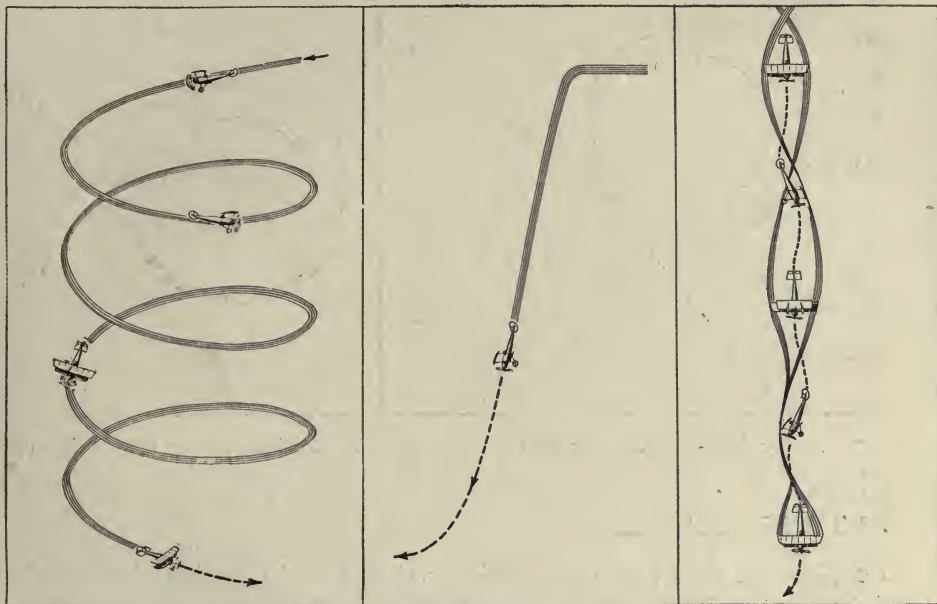


Figure 97—Descending spiral

Figure 98—Nose Dive

Figure 99—Spinning nose dive

SPIRAL

Descending spirals, illustrated in Figure 97, are made by a continuous series of banked turns in the same direction with nose slightly down. The aileron control and ruddering are governed by the steepness of the descent desired, the controls ordinarily being held steady until the descent is accomplished to the designated point. The aviator constantly looks inward and downward toward the center of the circles he describes, an occasional glance at the banking indicator serving to inform him of the accuracy of his turns. Care should be exercised that the nosing down does not become too steep, or a spinning nose dive will result; too steep and rapid descent is corrected by slightly pulling back the stick control.

NOSE DIVE

The nose dive is accomplished by shutting off the engine and pushing forward the control stick suddenly. The dive may be made with engine running, but this subjects the airplane to severe strains and should be avoided. First dives should not be as steep as that shown in Figure 98, and the novice should learn the trick far above the ground. At not less than 1,000 feet altitude the airplane should be straightened out; this is accomplished by a firm but gradual backward pull on the control stick. When the air speed indicator registers low flying speed the control should be centered and the engine switched on.

SPINNING NOSE DIVE

From the spiral it is very easy to go into a spinning nose dive, illustrated in Figure 99. While it is a recognized maneuver of air tactics, the spinning nose dive is generally the result of slowing down in the spiral, which then becomes too steep, the tail planes acting, so to speak, as a vertical rudder, and the rudder functioning as an elevator. The revolutions and fall of the machine are very fast; the aviator should avoid looking at the ground while in the spin.

To get out of a nose spin, both feet should be evenly pressed against the foot bar until it is held straightened; this evens up the rudder and stops the spinning. The control stick is then brought to center and back; then pushed forward. A steady pull back, and the airplane levels out. The engine throttle is then opened and the flight parallel to the ground continued.

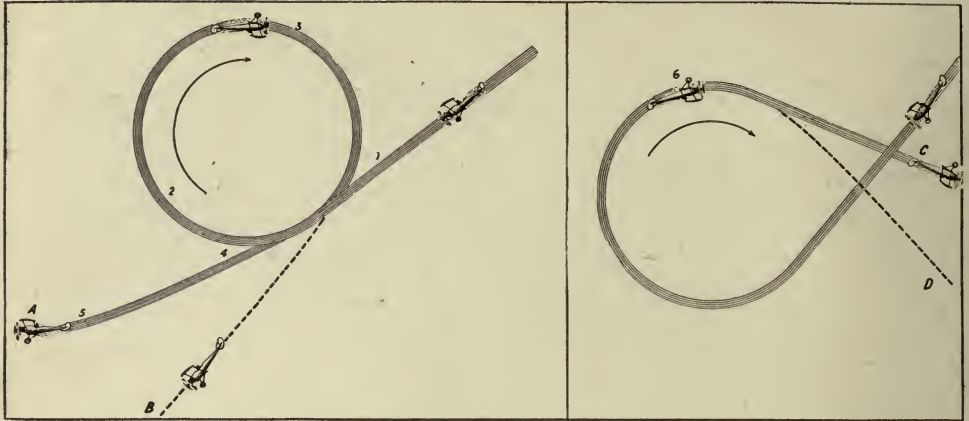


Figure 100—Looping the loop

Figure 101—Flying upside down

LOOP THE LOOP

Looping the loop is a comparatively simple and effective air evolution. A height greater than 3,000 feet should be selected and the descent begun at a more gradual angle than employed in the nose dive. When, with the aid of the motor, a speed of 75 miles per hour, or better, has been attained, a firm backward pull on the control stick causes the airplane to rise and turn over. The backward pull should begin at point 1, Figure 100, and the stick be all the way back at point 2. When the airplane is upside down and the ground visible below, the motor may be cut off (point 3, Figure 100), in which case the airplane will describe the smaller loop along course *A*. The stick is held back steady until point 4 is reached, when it is steadily moved forward to center, the motor being switched on at point 5. The loop can be made with the engine on, but the recovery will not be as quick, the airplane following the course *B*.

Special cautions—Control movements in looping should be steady and firm; jerkiness may produce dangerous stresses and lead to possible collapse.

The aviator's safety belt should be securely adjusted and seat cushions removed.

Looping is best done against the wind.

FLYING UPSIDE DOWN

This maneuver is executed the same as looping up to point 6, Figure 101. Here the engine may or may not be throttled down. If the engine speed is reduced the steeper course *D* must be taken, as there is danger of stalling at a lesser angle. With the engine on full, the stick control is pushed forward to center, at point 6, the airplane then flying upside down in the approximate course *C*.

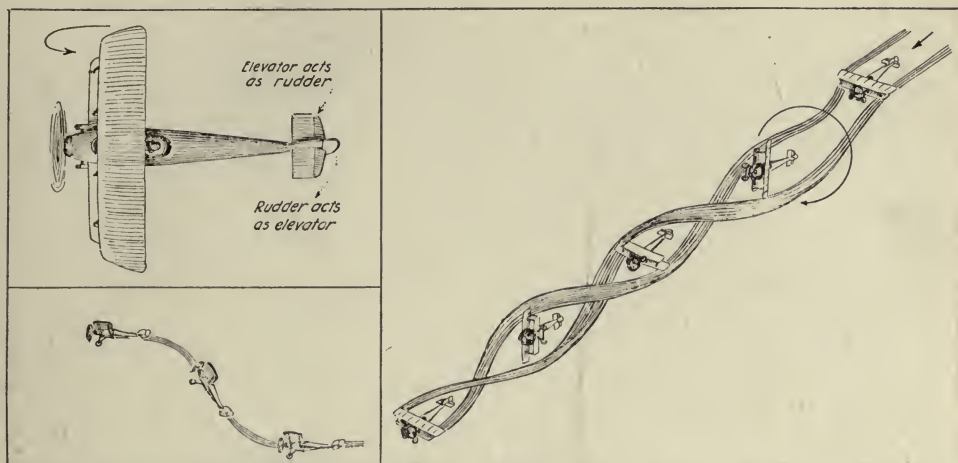


Figure 102 (Upper)—Vertical bank Figure 104—The roll over, also known as the barrel
 Figure 103 (Lower)—Zooming

VERTICAL BANK

Banking at angles greater than 45 degrees is known as vertical banking. No particular difficulties are encountered in these exaggerated turns, but the aviator must become accustomed to the reverse order of control functions while in this position. See Figure 102.

The vertical bank is accomplished by pushing both aileron and rudder controls far over in the desired direction. Once the airplane is on its side, the tail elevating planes act as a rudder and the rudder's function is that of the elevator.

The next step after banking is to level the airplane horizontally with the horizon. Pushing the rudder bar with the foot which is uppermost will raise the nose, and ruddering from the bottom will lower the nose. To turn the airplane while on its side the control stick is eased back slightly in the direction opposite its position for the original banking.

Coming out of the vertical bank, the stick control is pushed full over to the opposite side, and as the airplane reaches a position nearly horizontal, opposite ruddering is given to the degree necessary, the stick control then being centered a trifle forward. The aviator should remember that the rudder is not to be thrown over until the machine is near the horizontal, for its action has changed; it is acting as an elevator while the airplane is on its side, and raising the nose may result in a stall.

ZOOMING

This consists of a sudden upward rise or jump while flying at high speed. It is illustrated in Figure 103. The upward rise is obtained by pulling the stick control back suddenly. The machine's climb ends with the stalling point, when the control stick must be pushed forward again. The stalling point is best made known to the aviator by the sloppy feeling of the controls; the air speed indicator may also be consulted, but it is not so reliable by reason of the lag. Caution must be exercised in zooming that the control is pushed forward and speed regained before the airplane stalls, or a dangerous tail spin may result.

ROLL OVER

A very effective and comparatively easy evolution is rolling, also known as the barrel, or roll over. The airplane at high speed is made to trace an air course like a screw thread, as illustrated in Figure 104.

The roll over may be begun at a speed of about 95 miles per hour, the control stick being thrown away over to the left (or right) throwing the left aileron up and the opposite aileron down; the feet are kept still on the rudder bar.

Coming out of the roll is accomplished by bringing the control stick back to center just as the airplane levels out at the top of a turn.

THE STAGGER

A veritable see-saw may be made out of the roll over by giving the stick control a circular motion and alternately pushing right and left on the rudder bar in synchronism as the stick successively comes round right and left.

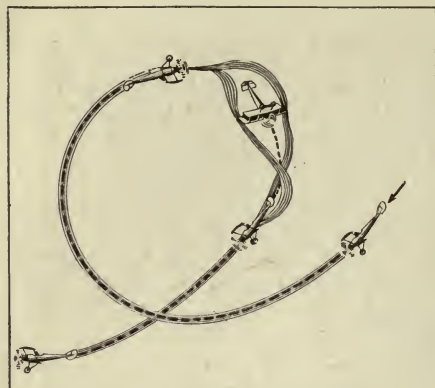


Figure 105—The spiral loop

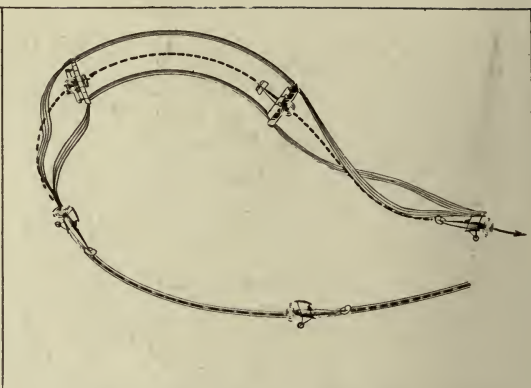


Figure 106—The Immelman turn

SPIRAL LOOP

This is a difficult evolution, but it has the special advantage of bringing the aviator back to approximately the same position from which he started and headed in the same direction. The course of the airplane is shown in Figure 105.

The beginning is the same as for looping; when the machine, upside down, reaches the top of its loop, however, the motor is cut out and the control stick pushed sharply forward, the rudder being kicked sharply left (or right). The airplane begins to fall on its back and spin slowly around; at the half-turn, the rudder is centered and the stick pulled back until the machine straightens out. The engine is then switched on and the level flight continued.

IMMELMAN TURN

The course of this famous German evolution is shown in Figure 106. It consists of turning the airplane over sideways as it begins to zoom, and righting it so it comes down in the opposite direction. It can be done with engine on or off.

The evolution is begun just like the loop, the control stick being pulled back two-thirds of the way for the steep ascent. When the machine is at the vertical position, the foot bar is pushed over left (or right) throwing the rudder and causing the airplane to describe an inverted U to the left. As it noses down the control stick is pulled back the remaining one-third and the elevating planes straighten out the airplane parallel to the ground.

FLAT TURN

A useful maneuver in air fighting is the flat turn, which enables the aviator to make a quick sweep to the side. This is accomplished by cutting off the engine for an instant, kicking the rudder bar full over, then centering it. The side sweep is through an arc of about 90 degrees; most of the flying speed is lost in the turn. Centering the rudder quickly after throwing the bar over prevents the airplane from entering into a spin.

GENERAL CONSIDERATIONS

Height—The aviator who engages in aerobatics cannot be cautioned too strongly about allowing a good altitude margin. A miscalculation of speed or distance, or engine failure, has many times resulted in a fatality when the machine was too close to the earth.

Bumps—In aerobatics it is a common experience for the aviator to encounter bumps caused by the air disturbances created by his own machine; these are not serious and should give no cause for alarm when encountered.

Lost Control—A general rule for safety when the airplane gets out of control is to throttle down or cut off the engine. If at a good altitude the nose dive should then be attempted. An unexpected spin should not cause confusion, because if the rudder is held firmly in the center position, with sufficient altitude the airplane will right itself.



From painting by Lieut. Farré

*lights and the method of lighting the landing field
Bombing airplanes returning at night from an air raid, illustrating the use of search-*

NIGHT FLYING

Nearly all bombing raids and air offensives are conducted at night; flying after dark is not particularly dangerous under instruction conditions, but considerable skill is required for a night raid over hostile territory.

EQUIPMENT

The airplanes used are generally those of marked stability, thus relieving the pilot of the mental strain of control; for this reason, also, aviators ordinarily make a night flight in machines with which they have become thoroughly familiar in daylight. The figures on instruments are treated with luminous paint and two shaded electric lights are ordinarily provided to illuminate the dashboard. Another electric light is usually placed on the floor of the cockpit. Flares for use in case of forced landing are included; these are of the parachute type and include in the equipment an electric launching tube. Navigation lights are placed on the wing tips, red on the left, green on the right, and a searchlight is generally included to light up the ground when landing. Electric current is principally used for these searchlights, a yellow metallic mirror reflector throwing a ray which best penetrates mist. The flares have the advantage of illuminating a mile or so area for about four minutes, whereas the searchlight rays are confined to a small radius; both are usually carried, however. Another lighting scheme provides a row of electric lights with reflectors, placed under the leading edge of the lower wings. The propeller and bright metal parts are painted black so as not to dazzle the aviator's eyes.

PRELIMINARY INSTRUCTION

Practice for night flying broadly includes a daylight rehearsal of exactly how the airplane will fly at night. Flying by the instruments alone, without guiding by the horizon, should be accomplished; slow glides should be practiced; small side-slips and quick recoveries should be effected; slow landings and turning with the instruments as the sole guide perfected, and the pilot should become accustomed to the sound or "sing" of wires at different speeds and varying conditions.

An aviator's fitness for night flying is generally gauged by his success in making

a half-dozen or more solo landings in the darkness; night instruction by dual control is seldom given.

An essential portion of his knowledge is thorough familiarity with the country over which he is to fly at night and full acquaintance with the airdrome in which he is to land.

TAKING-OFF AND FLYING

As the airplane is wheeled into position the aviator carefully notes the lighting and layout of the landing ground in the airdrome. The landing is usually indicated by a chain of lights in the form of an L, those at the lower end marking the point before which a full stop must be effected. The lighting is arranged so the wind blows up the long arm of the L, and the machine is faced into the wind for the start at the end, or top, of the letter. The number and spacing of the lights is fixed by the commanding officer; these should be counted by the pilot and an estimate made of the distance allowed for taking-off; obstacles should be noted, for the landing on the return is to be made on the same ground. Taking-off at night has one important difference from daylight flying; at night the airplane is allowed, so to speak, to rise from the ground itself, the instant when it becomes difficult to hold the machine down being the proper time for the take-off.

The rigging for night flying is also preferably changed, so that with the control stick neutral the airplane is in a position for slight climb; this adjustment assures medium and uniform speed, which is further provided for by adjusting the engine throttle so level flight is obtained when it is half open. The take-off is, as already explained, made into the wind.

Night pupils should remain within gliding distance of the airdrome and avoid clouds which obscure the ground lighting. Flights made on moonlight nights permit the aviator to see his landing field plainly, but it must be remembered that the airplane is quickly lost to the view of those on the ground. Railways cannot be identified easily, even under perfect conditions, but the white smoke from a train on clear moonlit nights and villages and towns are easily discerned, and roads recognized at 7,000 feet. On moonless nights only lights can be seen from 5,000 feet; rivers, railways and roads are not distinguishable, but the airdrome flares are easily recognized. If other pupils are in the air, the red and green navigation lights are lit at 2,000 feet.

LANDING AT NIGHT

The straight glide is the only type of landing to be attempted by the student aviator; the glide should begin at least a mile away with the engine turning over slowly; when within less than fifty feet of the ground the engine should be switched off and the airplane allowed to come down of itself; that is, the nose should not be put down.

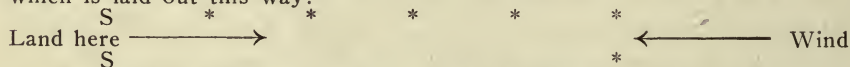
Signals for landing are arranged beforehand. By them the aviator recognizes his own airdrome, for when over his field and ready to descend he fires the prescribed colored light, which is answered from the ground by a light of the color prearranged. He then gives the landing signal and the flares are lit for his descent.

The searchlight, if the airplane is equipped with one, is sometimes switched on at about 1,500 feet and the ground searched for the landing field. A pilot flying alone will find its manipulation difficult, so at a low altitude it is switched off and a flare dropped over the field. If an observer is carried the searchlight is left to his hands.

LIGHTING THE FIELD

Proper lighting of a landing field is a matter of extreme importance. There are various types and lighting arrangements, but usually gasoline flares or flame arc lamps are used, laid out in L-form and aided by searchlights which point into the wind, or away from the eyes of the aviator who is landing. When the searchlights are used they serve to light up the strip of ground which serves as a runway for the airplane.

Twin, parallel and triangular light arrangements have been proposed and used, as well as concentric light circles. The arrangement most in favor is the L, however, which is laid out this way:



In the above diagram S. S. are the searchlights, and the asterisks the flares, placed a fixed distance apart and in the number specified by the commanding officer. The short arm, or bottom, of the L, designates the point where the airplane must be brought to a full stop. Should the airplane not reach the ground before half the length of the long arm has been traversed, the aviator should not attempt to land, but should switch on his engine and rise for another circuit.

REVIEW QUIZ

Advanced Flying

Aerobatics and Night Flights

1. Why is it advisable to make a slow descent the first time a height of 10,000 feet is attained?
2. Give two primary rules to be observed when learning aerobatics.
3. State the direction for an aviator to look while making a descending spiral.
4. How should the control stick be handled in straightening out of a nose dive?
5. Give the reason why a nose dive sometimes becomes a spinning nose dive and explain the action of the control surfaces while in the latter.
6. What are the control operations required to bring an airplane out of a nose spin?
7. In looping the loop, what is the effect on the descending flight path if the motor is cut off when the airplane is upside down?
8. What special manner of handling controls is required when looping? Give the reason.
9. Explain how the vertical bank is accomplished and how the action of controls is changed.
10. How is the airplane leveled with the horizon when in a vertical bank?
11. Describe the evolution known as zooming and state the indications which announce the end of the climb.
12. What action of controls starts the airplane on the barrel, or roll over, and how is the machine brought out of the evolution?
13. Explain the action of the controls which cause the airplane to stagger or see-saw.
14. Describe the successive movements of a spiral loop and the manipulation of the controls.
15. How does the spiral loop differ from the Immelman turn?
16. Describe the Immelman turn and how the controls are handled.
17. What control manipulations are required to make a flat turn?
18. Give a general rule for safety when an airplane gets out of control.
19. What details should be mentally noted by the aviator about to begin a night flight?
20. State in detail the nature of the glide and landing a student should make at night and the relation of the field lighting to his landing.

CHAPTER ANALYSIS**Meteorology for the Airman****CHARACTERISTICS OF THE AIR:**

- (a) Composition of the Atmosphere.
- (b) Atmospheric Pressure.
- (c) Measure of Pressure.
- (d) Pressure Areas.
- (e) Cyclone Area.
- (f) Anti-cyclone Area.
- (g) Secondary Depressions.
- (h) The Wedge.
- (i) Line Squalls.
- (j) Beaufort Scale.

WIND CONDITIONS WHICH AFFECT AVIATION:

- (a) Wind Distribution.
- (b) Aerial Fountain.
- (c) Aerial Cataract.
- (d) Aerial Cascade.
- (e) Aerial Breakers.
- (f) Vertical Wind Eddies.
- (g) Wind Layers.
- (h) Wind Billows.
- (i) Wind Gusts and Eddies.
- (j) Aerial Torrents.

CLOUDS AND THEIR SIGNIFICANCE:

- (a) Classification of Clouds.
- (b) General Observation.

CHAPTER XIII

Meteorology for the Airman

In many ways the air is comparable to the sea; in fact, in a large portion of the study of the basic principles of aerodynamics the action of the sea is used as an analogy. The professional pilot of water craft who lacks knowledge of the ocean is unheard of; and so must it be with the military aviator's knowledge of the air. Successful flying over long periods is largely due to an aviator's understanding of the air and its vagaries; in fact, where this knowledge does not exist, continued success is entirely a matter of luck. Some grasp of the elementary principles of meteorology is therefore essential. It may be gained by experience, but this method has more than once led to fatal misconceptions. Theoretical instruction, through which ability is acquired to apply the scientific laws of weather forecasting, is a safeguard well worth the time spent in acquiring it.

Flying over hostile territory in war time requires the aviator to ascend under all types of weather conditions. By thorough acquaintance with meteorological factors which bear on aviation, or aerography, as it is academically called, the pilot may know at a glance what the behavior of his machine is likely to be, and will not be surprised into falling out of control through ignorance.

The best weather for flying is obtainable on a calm, clear day, when eddies or vertical currents are not likely to be encountered. A strong gale is about the only condition that makes flight impossible to the modern airplane, although fog is a considerable handicap to military flying, by reason of the poor chances for proper observation.

A ground haze, low lying clouds, and location of the sun dead ahead, also impede useful military flight, as do detached clouds; but none of these prevent the aviator going aloft. Air eddies and ascending or descending currents, too, are seldom so violent that flying is seriously interfered with. For students engaged in first flights, the early morning and evening are the most suitable times, for it is then that the air is calmest. In the United States, winds from the east and southeast carry with them less "bumps" and are most favorable.

CHARACTERISTICS OF THE AIR

COMPOSITION OF THE ATMOSPHERE

Air is a gaseous body, which, like water, seeks the level where lowest pressure exists. It is 1,600 times lighter than water, but it is at least 50 miles deep, and since one-half of its weight is below 3 miles altitude, its weight or pressure at the earth is considerable. Its constituents are: nitrogen, 79 per cent.; hydrogen, 20 per cent.; argon, 1 per cent.

ATMOSPHERIC PRESSURE

The weight of air on a given spot is atmospheric pressure. The longer the column of air above the place, and the greater the density of the air, the greater will be the pressure at the bottom of the column.

Pressure is variable, however. The temperature of the air usually decreases with height at a rate of about one degree for every 300 feet. This rule is not an absolute one, since temperature varies with locality and season of year, but is useful as a general guide. Density of the air is affected by temperature, due to the expansion of heated air and contraction of cold; density is also affected by pressure, for the higher the air column the greater the air contained in a given space at the bottom.

Air at rest is given motion by change in temperature at the earth. For example, heat from the sun's rays is not absorbed uniformly, bare earth heating more rapidly than portions covered by trees and grass. Over the bare spot the heated column of air will rise by expansion, and as it rises the pressure there will be diminished, whereupon the cooler surrounding air will rush into the vacated space. As the operation is repeated the air motion increases. Thus elevations and depressions are formed, or, as they are termed in meteorology: **HIGH PRESSURE AREAS** and **LOW PRESSURE AREAS**.

MEASURE OF PRESSURE

The barometer is the instrument used to measure air pressure. It is measured by the height, in inches, of a column of mercury necessary to balance it. At a fixed time each day atmospheric pressures taken at various stations scattered over the country are telegraphed to the meteorological office and a weather map is made from those reports. Such a map is illustrated in Figure 107.

By joining places which register the same barometric pressure, lines are formed similar to map contour lines and known as **isobars**.

PRESSURE AREAS

All places on any line (isobar) have the same atmospheric pressure; where little difference of pressure exists at places close together, the isobars will be close together, and vice versa. The air forced from high pressure to an area of lower pressure does not follow a straight line, but takes a spiralling course in a direction more nearly parallel to the isobars than at right angles. This is due to the irregularities of the earth's surface and the revolution of the earth on its axis.

Pressure areas, which usually have a diameter of hundreds of miles, do not remain in the same position, examination of U. S. weather maps for successive days showing that they ordinarily move in a general easterly direction and occasionally north and south, but westward only in hurricanes.

An unusually small pressure area indicates a **cyclone area** and sudden violent changes in weather may be looked for. In a high pressure region, or **anti-cyclone**, the weather to be expected and the indications are almost the reverse.

Since the winds flow spirally about the pressure areas, the isobars on the weather map furnish the aviator information as to the general direction of the wind, knowledge which is extremely valuable if a cross-country flight is contemplated.

CYCLONE (LOW PRESSURE AREA)

The winds blow anti-clockwise about the center of pressure (clockwise in the southern hemisphere). The barometer falls with the approach of the cyclone, beginning to rise again after the center of the area has passed. The front of the depressed area usually holds rain or cloudiness, the rear cooler weather and clearing.

ANTI-CYCLONE (HIGH PRESSURE AREA)

An anti-cyclone has no general direction of motion, in fact it is frequently stationary for days. The winds spiral clockwise from the center and are very light. Almost any type of weather may be expected except heavy winds. Ordinarily, the weather is fine, but in cold weather fog and low lying clouds are frequent, and rain occasional.

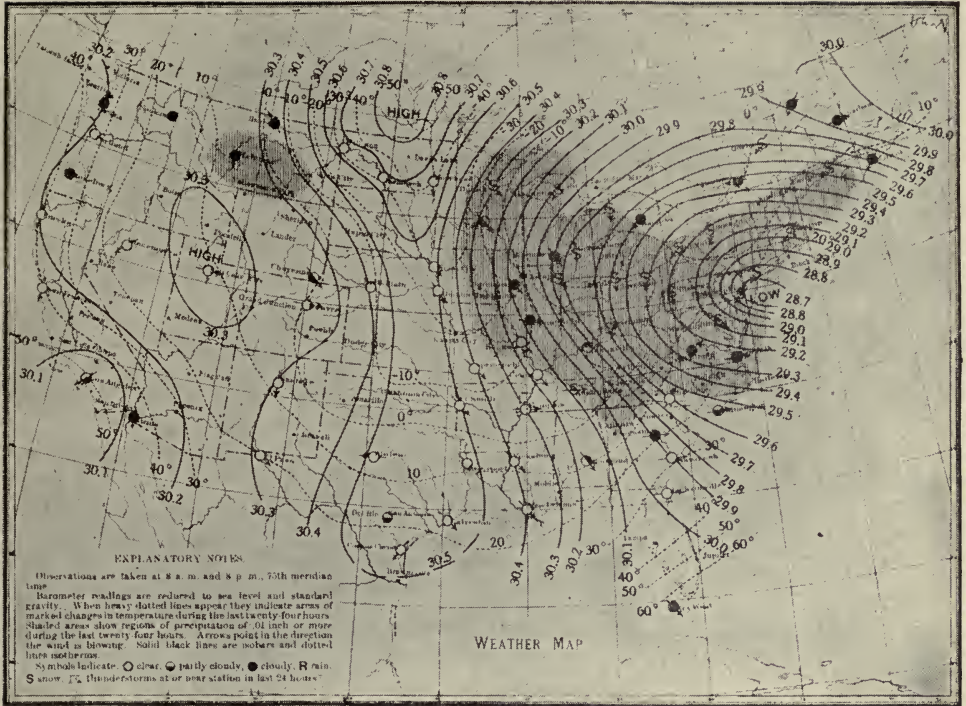


Figure 107—Meteorological map showing atmospheric pressures

SECONDARY DEPRESSIONS

Irregularities in the form of indentations in the isobars frequently appear in a cyclone area. These secondary formations may or may not be well defined; if marked, the winds may become very strong and the weather bad. In front of the secondary the weather is similar to the cyclone; between the secondary and main depression the winds are light, but very strong on the side furthest from the center of the cyclone.

THE WEDGE

When a series of cyclones pass across country in continuous succession, V-shaped isobars appear between cyclones. These indicate fine clear weather, but of short duration, as another cyclone is approaching.

LINE SQUALLS

As the center of a cyclone passes line squalls often appear. They are usually very narrow but often 500 miles in length, are very sudden and violent and, traveling approximately at a right angle to their length are very dangerous to airmen. The barometer shows a small sudden rise, and a fall in temperature is noticeable; often heavy rain and hail set in, and, occasionally, thunder. These squalls seldom give any warning and are therefore particularly dangerous.

BEAUFORT SCALE

Wind strength is generally expressed as velocity in miles per hour. For convenience winds are divided into 12 groups or classifications, a system known as the Beaufort scale.

BEAUFORT SCALE

Division Number	Nautical m. p. h.	Description of Wind	Division Number	Nautical m. p. h.	Description of Wind
0	Less than 1	Calm	7	28—33	High wind
1	1—3	Light air	8	34—40	Gales
2	4—6	Slight breezes	9	41—47	Strong gales
3	7—10	Gentle breezes	10	48—55	Whole gale
4	11—16	Moderate breezes	11	56—65	Storm
5	17—21	Fresh breezes	12	Above 65	Hurricane
6	22—27	Strong breezes			

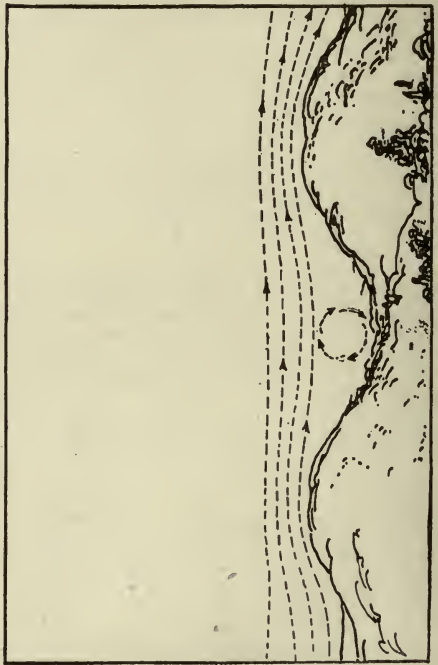
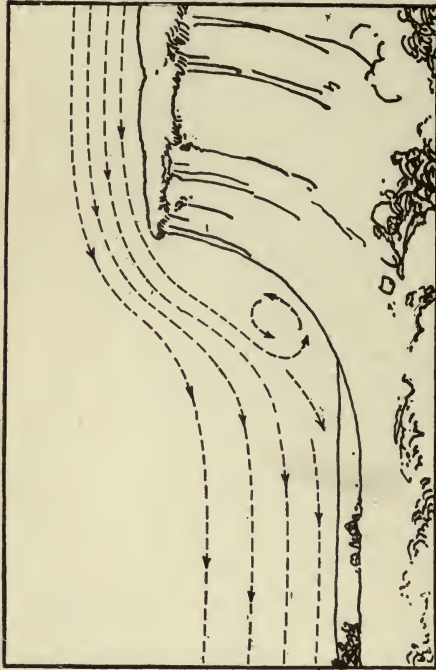


Figure 109 (Upper)—Action of the surface cataract
Figure 111 (Lower)—Eddies, or bumps, in lee of obstacles

Figure 108 (Upper)—Action of the aerial fountain
Figure 110 (Lower)—Vertical wind eddies below hill crests

WIND CONDITIONS WHICH AFFECT AVIATION

WIND DISTRIBUTION

The aviator does not need to study the cause of wind, but he should know something of its distribution. Wind is stronger by day than by night at the earth's surface; its average velocity in the United States is 11 miles per hour, normally increasing with altitude up to 1,000 feet, above which height it "veers," or goes round in a clockwise direction.

The following condensed scale is useful for calculating wind problems:

At 1,000 feet wind velocity increases $1\frac{3}{4}$ times, with 10 degree veering.

At 2,000 feet velocity nearly doubles and wind veering is 15 degrees.

Above 3,000 feet velocity is double and there is practically no further increase and veering is constant at 20 degrees.

AERIAL FOUNTAIN

A rising current of atmosphere encountered over barren land and conical hills in warm weather, the air column rising because it is heated beyond the temperature of the surrounding air. These fountains are not ordinarily dangerous but the rate of ascent has been known to reach a velocity of 25 feet per second. The airplane will rise involuntarily if caught squarely by one of these columns, dropping as it emerges. Wing tips will be tilted if the aerial fountain is grazed. See Figure 108.

AERIAL CATARACT

Descending cold air causes a current which takes two forms (a) the reverse of the aerial fountain with opposite effect on airplanes, and dangerous only in thunder storms; (b) surface cataracts developed by steep barren slopes of earth. The action of the surface cataract is shown in Figure 109. Landing should never be attempted in a surface cataract.

AERIAL CASCADE

The bounding air at the bottom of a steep fall over an earth contour is similar to the result with a water cascade. Eddies of a treacherous character are set up, and counter currents, above which the aviator must remain for safety.

AERIAL BREAKERS

Strong cross currents form choppy winds with action similar to ocean breakers. These are generally heralded by corrugated clouds and are to be noted as difficult of navigation by air pilots.

VERTICAL WIND EDDIES

Below the crests of hills wind eddies form, which describe circles in the vertical plane. See Figure 110. Should the aviator be caught in the pocket under a hill the airplane should be headed in and a landing made parallel to the side of the hill.

WIND LAYERS

Wind will very often be found blowing in different directions and velocities at different heights. Although horizontal, passing from one layer to another of different speed and different direction momentarily changes the buoyancy of the airplane, causing the machine to rise or fall. Turbulent motion and a few bumps will only be experienced, and wind layers are therefore not ordinarily dangerous.

WIND BILLOWS

These are horizontal billows similar to ocean waves and occur at the surface between wind layers; rough going, not necessarily dangerous, results.

WIND GUSTS AND EDDIES

These are generally known in aviation parlance as "bumps." Obstacles in the path of moving air at the surface cause them. They are strongest on the leeward side of hills, buildings, or other elevations, and most noticeable in a strong wind. Figure 111 illustrates the action of the air. If landing is forced, the aviator should select the windward side of the obstruction or a point well away to leeward.

AERIAL TORRENTS

The aerial torrent is caused by air colder than the surrounding air pouring downward. Great velocity is attained on surface slopes or open valleys. The effect on the airplane is exactly opposite that of the aerial fountain illustrated in Figure 108.

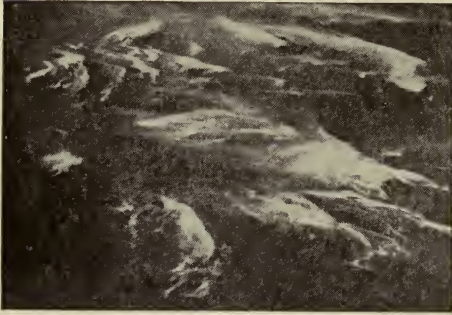


Figure 112—*Cirrus (Mare's Tails)*, altitude 30,000 feet or more. Predict wind and cyclonic depression



Figure 115—*Nimbus (rain cloud)*, altitude 300 to 6,500 feet. Steady rain or snow usually falls

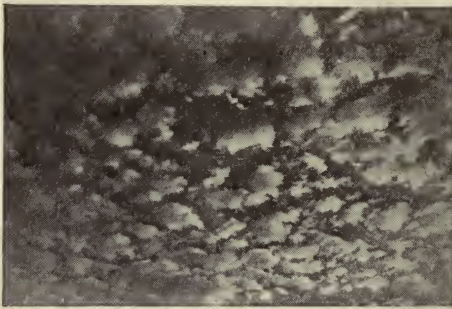


Figure 113—*Alto-Cumulus*; altitude 10,000 to 23,000 feet. Indicate strong cross currents of air



Figure 116—*Cumulus (woolpack clouds)*, altitude 4,500 to 6,000 feet. Cause violent disturbances to the airplane

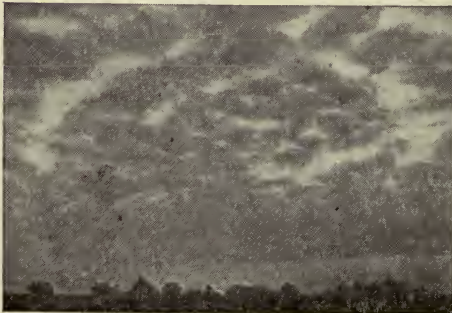


Figure 114—*Strato-Cumulus*; altitude 6,500 feet. Large globular masses or rolls, frequently covering whole sky. Predict a change in weather



Figure 117—*Cumulo-Nimbus (thunder cloud)*, altitude 4,000 to 26,000 feet. Dangerous to aviators because of strong currents and electric effects

CLOUDS AND THEIR SIGNIFICANCE

CLOUDS

Clouds are formed, (a) by condensation when an ascending mass of moist air encounters another moist mass of different temperature; (b) by cooling, when an ascending column of vapor, mixed with particles of dust, condenses. Types of clouds and their direction indicate the weather to the observing aviator. Clouds are either in the form of sheets or heaps, and may be so studied.

CLASSIFICATION OF CLOUDS

Cirrus—(Mare's Tails.) Light wisps of whitish cloud, of fibrous appearance with no shadows. These clouds are the highest in the international classification, commonly appearing at an altitude of 30,000 feet or more. They predict wind and a cyclonic depression. Illustrated in Figure 112.

Cirro-Stratus—A thin sheet of tangled web structure, whitish, and sometimes covering the sky completely, giving it a milky appearance. This cloud often creates sun and moon halos. Its average height is 29,500 feet. Forecasts bad weather.

Cirro-Cumulus—(Mackerel Sky.) Small globular masses or white flakes without shadows, or showing very light shadows, arranged in groups and often in lines. Average height between 10,000 and 23,000 feet. Denotes fine weather.

Alto-Stratus—A thick sheet of gray or bluish color, sometimes forming a compact mass of dark gray color and fibrous structure. Often causes brilliant coronae when near sun or moon. Average height 10,000 to 23,000 feet.

Alto-Cumulus—Large globular masses, white or grayish, partially shaded, arranged in groups or lines, and often so closely packed that their edges appear confused. Illustrated in Figure 113. This cloud formation is somewhat similar to the mackerel sky (cirro-cumulus); it has the same elevation, 10,000 to 23,000 feet. The cross lines indicate strong cross currents of air.

Strato-Cumulus—Large globular masses or rolls of dark clouds, frequently covering the whole sky, especially in winter. Altitude 6,500 feet. Illustrated in Figure 114. Predict a change in weather.

Nimbus—A thick layer of dark clouds without shape and with ragged edges from which steady rain or snow usually falls. Shown in Figure 115. Through the openings an upper layer of cirro-stratus or alto-stratus is almost invariably seen. Low elevation, 300 to 6,500 feet.

Cumulus—(Woolpack Clouds.) Thick clouds of which the upper surfaces are dome-shaped with protuberances; base horizontal. Illustrated in Figure 116. They indicate the aerial fountain and are low flying, 4,500 to 6,000 feet. Violent disturbances to the airplane will be experienced when passing through them, or passing above or below.

Cumulo-Nimbus—(Thunder Cloud.) Heavy masses of cloud rising in the form of mountains or turrets or anvils, generally surmounted by a sheet or screen of fibrous appearance (false cirrus) and having at its base a mass similar to nimbus (rain cloud). Illustrated in Figure 117. Apex 10,000 to 26,000 feet; base, 4,000 feet. Dangerous to aviators, because of strong currents and electric effects.

Stratus—A uniform layer of cloud which resembles fog but does not rest on the ground. It usually is stationary or drifting slowly at altitudes of 100 feet to 3,500 feet.

GENERAL OBSERVATION

Aviators may gain valuable knowledge of existing wind currents by observation of clouds. The general rule is that unbroken clouds indicate smooth, even air flow, broken formations the presence of air currents. The behavior of these currents may be anticipated by applying the above classification to the clouds in evidence.



A good illustration of how an airplane may drop to dangerous levels when coming out of an aerial fountain

REVIEW QUIZ

Meteorology for the Airman

1. In what way is ability to apply the laws of weather forecasting a safeguard for the aviator?
2. Why are calm, clear days best for flying?
3. From which direction do winds carrying least "bumps" blow in the United States?
4. State the percentage of air weight below 3 miles altitude.
5. Define atmospheric pressure.
6. Describe the processes by which air at rest is given motion.
7. What instrument measures air pressure?
8. How are pressure areas indicated on weather maps, and how can the aviator secure valuable cross-country flight data from these indications?
9. State the difference between high and low pressure areas and give another meteorological term to describe them.
10. What weather is indicated by wedges?
11. Explain why line squalls are dangerous to airmen and give the barometer indications.
12. State the velocity increase and veering of wind at 1,000, 2,000 and 3,000 feet.
13. Define an aerial fountain and its action on an airplane entering, leaving and grazing it.
14. Why should aviators avoid landing in aerial cataracts?
15. Explain the action of a vertical wind eddy and how a landing in such should be made.
16. Give two convenient classifications of cloud forms.
17. Name and describe a type of cloud which predicts bad weather.
18. Give the name and appearance of a type of cloud which denotes fine weather.
19. Name and define four cloud formations which indicate winds unfavorable to flying.
20. State a general rule for distinguishing smooth air from that with cross currents by observation of the clouds.

CHAPTER ANALYSIS

Aerial Gunnery and Combat Bombs and Bombing

COMBAT AIRPLANES:

- (a) Function.
- (b) Employment.

**FACTORS OF SUCCESS IN
AIR COMBAT:**

- (a) Airplane Superiority.
- (b) Strategy.
- (c) Aerial Gunnery.

THE LEWIS MACHINE GUN:

- (a) General Description.
- (b) Operating the Gun.
- (c) Loading.
- (d) Firing.

**ACCURACY AND VOLUME
OF FIRE:**

- (a) Accuracy.
- (b) Volume.
- (c) Firing at Ground Targets.

**AMMUNITION AND FIRE
CORRECTION:**

- (a) Types of Bullets.
- (b) Correction of Fire.

**GUN MOUNTINGS AND
FIRE RADIUS:**

- (a) Forward Gun Mountings.
- (b) Effective Angles of Fire.

FIGHTING IN THE AIR:

- (a) Skill in Attack.
- (b) Methods of Attack.

AERIAL TACTICS:

- (a) Flying in Formation.
- (b) The Start.
- (c) The Flight.
- (d) Signals in Formation.
- (e) Employment of the Air Fleet.
- (f) Theory of Concentration.
- (g) Warfare Altitudes.
- (h) Tactical Skill.

CONTACT PATROL:

- (a) Scope of the Observation.
- (b) Trench Offensives.

ANTI-AIRCRAFT FIRE:

- (a) Action Under Fire.
- (b) Location and Types of Guns.
- (c) Shell Trajectories and Ballistics.
- (d) Defending Positions.
- (e) Attacks on Balloons.

BOMBING AIR RAIDS:

- (a) Types of Bombing Airplanes.
- (b) Mufflers and Flares.
- (c) Training Bombing Crews.

TYPES OF BOMBS:

- (a) Incendiary Bombs.
- (b) Safety Devices.
- (c) Explosive Bombs.
- (d) Bomb Carriers and Launching Cradles.
- (e) Steel Darts.

BOMB DROPPING:

- (a) Range Finders.
- (b) Operation of the Range Finder.

CHAPTER XIV

Aerial Gunnery and Combat—Bombs and Bombing

Combat airplanes, known variously as pursuit, chaser and fighting planes, have as their main duty the securing of superiority over the enemy in the air, or mastery of the air. Clearing the skies of hostile airplanes over the theatre of operations requires domination of the air situation, repulsing all efforts of the enemy to make observations of troop movements or occupied positions, frustrating all bombing raids or other air offensives, and insuring the success of these missions over enemy territory.

The work roughly divides itself into: (a) patrolling, (b) sentinel duty.

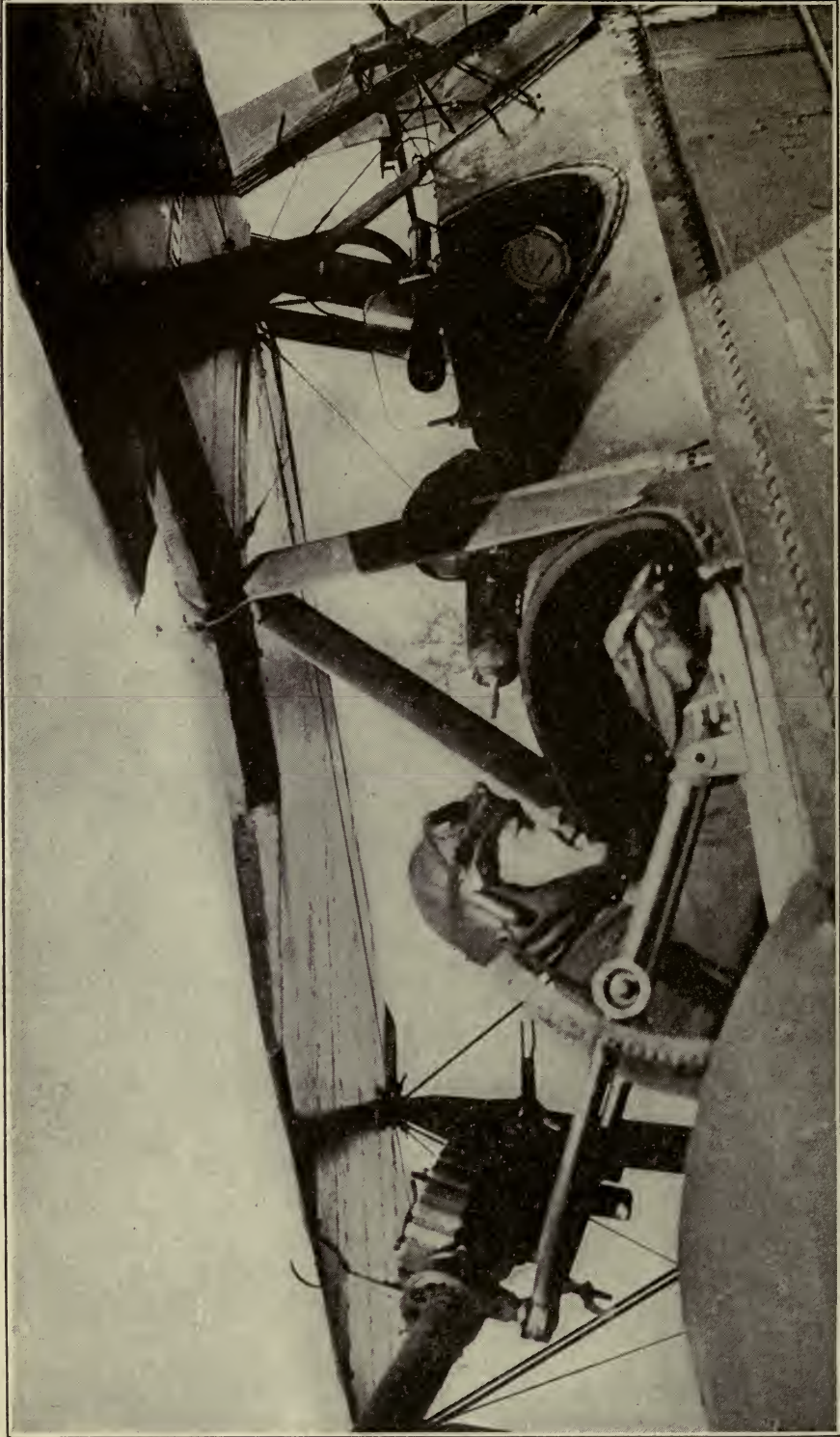
Patrols comprise those for interior and exterior duty.

Driving the enemy out of the air in a given sector is accomplished by the fast machines of the air squadron, speedy pursuit planes taking the air singly or in small bodies and following the hostile airplanes to the distance dictated by the strategic situation and the co-ordination with supporting aircraft. Patrols are continuous when weather permits, and the aviators selected for this duty are the pick of the service, all being skilled in air acrobacy which is extensively employed in aggressive and defensive fighting. These fighters seek combat at every opportunity, often cruising about singly or in formation in a roving search for hostile fliers. At other times a definite mission is determined in advance, perhaps to engage enemy airplanes which have been observed, or to seek certain areas over which hostile air forces are expected. Again, the objective may be the destruction of enemy captive observation balloons, a particularly dangerous duty owing to the protection afforded these by battleplanes and anti-aircraft batteries.

Maintenance of an aircraft screen is the essential of sentinel duty. Aside from special missions, the fast combat planes are assigned to definite air lanes or areas 5,000 to 7,000 feet above the reconnaissance and fire control airplanes, the fighters supplying protection to the slower observing craft operating at 2,500 to 3,000 foot altitudes. Beating off hostile air attacks is accomplished according to the requirements of the situation, supporting combat craft closing in at the point of attack. Pursuit of enemy airplanes requires an extension of patrol lanes by the machines remaining behind, for at no time must the observers be left unprotected.

Combat planes are well armed and placed in the hands of the most skilled and quick-witted aviators. Their's is a great responsibility, for they not only afford the observing planes protection over the enemy lines, but ward off attacks on friendly observation balloons four or five miles back within their own lines and also accompany daylight bombing missions to engage attacking planes.

Contact patrol, or co-operation at low altitudes with infantry in assault, is still another function, for which great skill is demanded. Expertness in use of the machine gun, thorough familiarity with acrobatics and dauntless courage are the requisites of the aviator given a combat plane.



Close up view of a method of mounting the Lewis machine gun for protection of rear

British Official Photo

FACTORS OF SUCCESS IN AIR COMBAT

Success in airplane fighting is not a matter of luck or due to the unreasoning type of dare-devil assault. Cool calculation and application of carefully defined principles of strategy and tactics is responsible for practically all victories.

The personal equation, always a great factor in success with arms, looms large in air combat. Aggressiveness must be combined with agility of mind and technical skill is of the utmost importance.

A third advantage rests with superiority in equipment, notably the speed, climbing and maneuvering ability of the airplane, its armor and the number and type of guns comprising its armament.

AIRPLANE SUPERIORITY

Engaged singly in combat, it is obvious that the advantage lies with the airplane which has the greatest mobility of movement, being enabled by superior speed, climb and flexibility to out-maneuver its opponent. The air-worthiness, or flying qualities, determine which machine will emerge from circling and diving to the most favorable position, either above, below, in rear or advance of the enemy craft, advantages determined by tactical considerations such as type, armament, number and disposition of the hostile craft. Choice of position is largely governed by the type of airplane.

Tractors are ordinarily armed with two machine guns, operated either by the pilot or gunner, or both. With the pilot in the front seat, the gunner has a wide arc of fire to the rear, but with the pilot in the rear the gunner is in full observation and the machine is best maneuvered for direction of fire. Mounting the machine gun on the top plane permits operation from the rear seat; it therefore has obvious advantages. As combat airplanes are essentially of the pursuit type, the most effective fire should be to the front.

Pusher types are generally at a disadvantage because of inferior speed. But with the gunner placed well forward in the nacelle a wide arc of lateral and vertical fire is obtained. For heavier armament the pusher type has undoubted superiority, but in firing backward through the propeller efficiency is lost. Exception must be made in the double propeller pusher types where the arc of fire is clear, but although both tractor and pusher have separate advantages and both have many advocates, the speed and mobility of the tractor type give it a definite point of superiority.

STRATEGY

Familiarity with the appearance of various types of enemy airplanes, which is essential knowledge to the military aviator, includes an estimate of their speed and mobility, number, disposition and range of guns, and the best means of attacking in each case.

The former "blind spot," i.e., under the tail, is now defended by a machine gun which shoots through a tunnel in the fuselage; thus the approach from the rear, firing upward, is no longer a fundamental principle of attack. Clouds and the sun may be usefully employed; for to get between the enemy and the sun blurs the outline of the approaching plane. Hiding behind clouds and diving carries the element of surprise and is widely employed.

Acrobacy is an essential accomplishment, for a general rule governing air combat, in event of failure in surprise attack, is to duplicate every movement of the enemy engaged. If a diving attack is made the adversary dives, looping or zooming before the hostile machine guns are within range, thus reversing the position and gaining the altitude advantage. The same is true of climbing; the pursuer also climbs, attempting by superior climbing ability to reach a position where he can dive at his opponent. Short rises and dives in quick succession constitute an effective form of attack on a machine armed with two or more guns. Direct hits by machine gun fire are difficult of accomplishment and, due to the frequent misses, air combat remains largely a matter of skilful acrobacy. The operation of the airplane must be instinctive with the fighting aviator, aerial evolutions being accomplished without a second thought, so the greater concentration may be given to accuracy of fire.

Jamming of machine guns is frequent, often occurring at the crucial moment, and temporarily disarming the fighting pilot; a quick escape is then required. This can seldom be effected by straight-away flight at high speed toward friendly territory, owing to the target the machine will thus present. Side slips and spins, in fact all forms of aerobatics which give the appearance of an airplane falling out of control, are resorted to, the machine being straightened out when well out of range. At all times, therefore, the fighting aviator must know his position in reference to his own lines, for aerial combat may take him many miles within enemy territory. An aviator is ordered to take no chances when odds are against him, and strategy demands that an escape be attempted if anything goes wrong with his machine or gun.

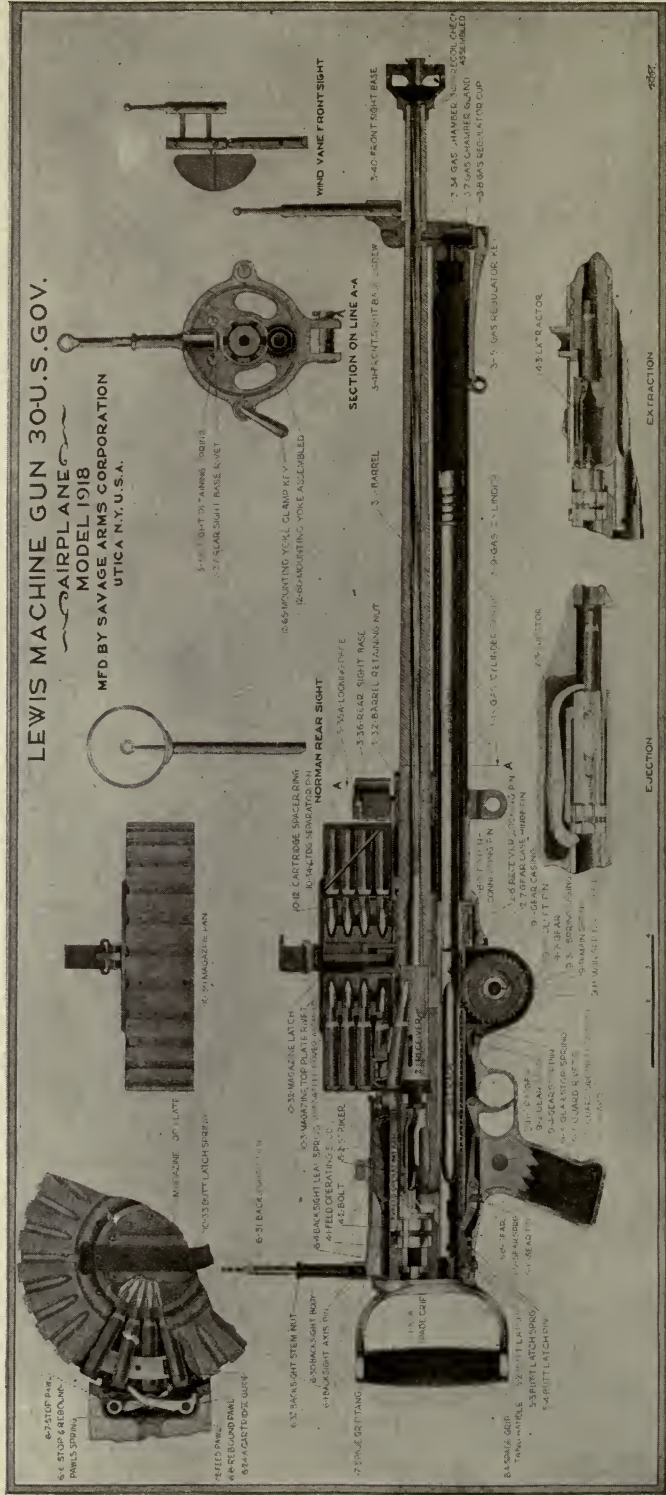
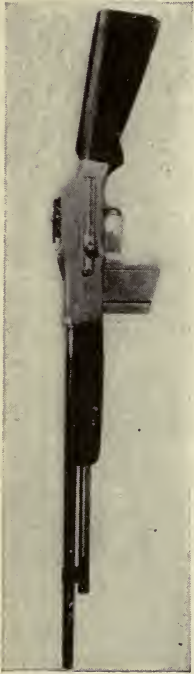


Figure 118—Sectional view of the Lewis machine gun, airplane model, assembled and beginning its loading operation; important parts of the mechanism are also shown enlarged. Above (left to right) military aviators in aiming drill; the light model Browning machine gun, which is belt-fed and the finest automatic rifle made; the targets used for aiming drills on the ground

THE LEWIS MACHINE GUN

This weapon is a standard airplane arm, weighing about 16 pounds, simple in action and with comparatively few parts. Success in its handling is largely dependent upon the operator's familiarity with the piece. The fighting aviator should have full knowledge of all parts of the gun and be able to dismount, assemble and adjust it without stopping to think about the process. To recognize, instantly, any fault in its operation while firing and to correct it without hesitation is, broadly speaking, the skill required.

GENERAL DESCRIPTION

The Lewis machine gun is air-cooled gas operated, and magazine-fed. The magazine is a circular drum in which the cartridges are arranged radially; the bullet ends are toward the center and are engaged by a spiral groove in the magazine center, down which the cartridges are driven until they are successively reached by the feed operating arm. While firing the other parts of the magazine are rotated about the center. Gas pressure, produced in the barrel by the exploding cartridge, furnishes the motive power for operating the mechanism. This gas, drawn into a cylinder through a hole near the muzzle of the barrel, drives a piston back, and thus winds the mainspring which operates the breach bolt and ejector, feeds a new cartridge, and rotates and locks the magazine. If the trigger is held back the firing is continuous until the magazine holding 100 cartridges has been emptied. To fire a single shot the trigger is pressed and released immediately.

OPERATING THE GUN

By constant reference to the drawing of the Lewis gun in section, Figure 118, the reader will understand its operation in detail from the following description:

Loading—The charging handle (see slot at rear of 8-1 Rack on drawing) is placed in full forward position, the magazine placed on its post and pressed down, thumb piece of magazine latch to right. The charging handle is then drawn back fully until it is engaged and held. This draws back the piston, drawing the rack teeth over the teeth of the gear (9-7) which rotates the gear and winds its mainspring. During the rearward travel, the striker (8-2) has been drawn back from the face of the bolt and the bolt rotated from right to left, turning the locking lugs out of their recesses. As the bolt is unlocked the striker post carries it back with it. The feed operating arm is swung across the top of the receiver by the feed operating stud (4-1); and the feed pawl (7-2), acting against one of the outer projections of the magazine pan, carries the magazine around sufficiently to drive the first cartridge down the spirally grooved center into the opening in the feed operating arm. This is the position pictured in the drawing, Figure 118. The feed operating arm brings the cartridge under control of the cartridge guide and a spring stud clears the stop pawl, which presses forward and prevents further rotation of the magazine. Meanwhile the rear end of the bolt has driven the ejector into its slot, and the rear end of the piston rack has set the sear spring which cocks the piece.

Firing—When the trigger is pressed, the sear is drawn out of engagement with the notch in the rack, the latter being then drawn forward by the unwinding of the mainspring, rotating the gear in mesh with the rack.

In the forward motion of the bolt a stud cams the feed operating arm to the right, a spring stud on the latter pressing the stop pawl back from the magazine projection; the head of the bolt now presses the ejector into its cut and the face of the bolt, striking the base of the waiting cartridge, takes it from the loading ramps of the receiver and drives the cartridge into the chamber. The extractors spring over the rim as the cartridge seats. The bolt locking is completed by the forward motion of the striker post, which then enters the front part of its cut, carrying the striker against the cartridge primer and firing it.

The firing of the cartridge develops the power for another cycle of operation. As the gas which drives the bullet forward reaches near the muzzle of the barrel it is driven down through a hole into the gas chamber (3-34). Thence it passes under pressure through a hole, striking against the head of the piston and driving it back. This backward movement produces the movements of loading as described above. The empty shell, however, in the grip of the extractors is drawn back with the bolt, throwing the shell out of the ejector port.

If the trigger is held back the gun will fire again and continue the cycle of operations at the rate of about 10 shots per second until the magazine is empty.

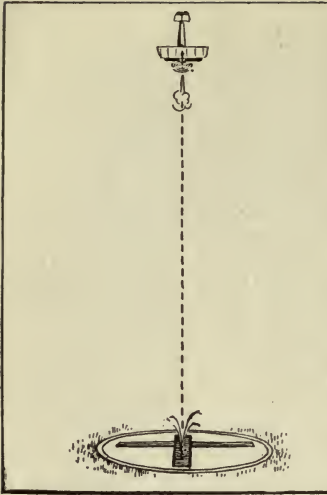


Figure 119—The ditch target; a splash records a hit

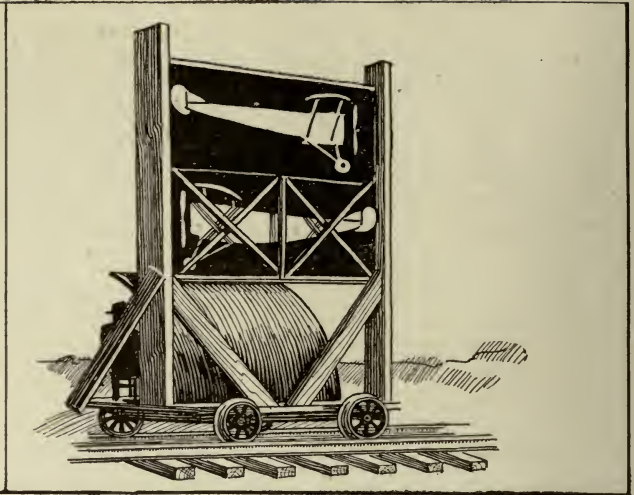


Figure 120—The moving target for ground practice, showing the armor shield for the operator

ACCURACY AND VOLUME OF FIRE

Engagements between airplanes in combat are brief; thorough training in aiming and delivering machine gun fire is therefore given a prominent place in instructing the aviator. Gunnery skill is the deciding factor between opponents with equal technical advantages and flying ability, and at all times has considerable bearing upon victory or defeat.

ACCURACY OF FIRE

Due to aiming at a constantly moving target from a generally unstable base, accuracy in fire is seldom reduced to exactness. Distinct superiority in aiming may be acquired, however, by diligent practice on simulated moving airplanes, and is worth all the effort which may be given it.

VOLUME OF FIRE

High rate of fire is essential to an airplane arm, since the range is of limited length and the duration of effective fire reduced to a few seconds. The machine gun which operates at greatest rapidity and with smoothest action gives a decided advantage, owing to the limitations in accuracy of aiming.

FIRING AT GROUND TARGETS

Two types of targets are illustrated in Figures 119 and 120. In Figure 119 a circle of sand is shown with two intersecting ditches in the form and size of an airplane, filled with water so a splash registers a hit. An observer under cover watches and records the number of times the target is struck. The airplane illustrated has the gun mounted rigidly on the upper plane and the entire machine is aimed at the mark. A flexible cable connects the gun trigger to a lever on the control stick, the gun firing as the lever is squeezed. An open sight on a level with the pilot's eyes is used for aiming.

An advanced instruction device on the same principle utilizes a cross which revolves on a bar, describing a 40-foot circle. It is operated from a protected trench by means of a cable and pulley which rotates the target at the approximate speed of an airplane in a spiral. The shots are made at a height of about 800 feet above the ground.

Figure 120 clearly illustrates another form of moving target, the truck being operated by the man seated behind the armored shield. Students fire at the moving outlines of the airplane from the ground, either from a stationary seat or from the pivoted chassis shown in the photograph below, a representation of an airplane cockpit which sways at the slightest movement.



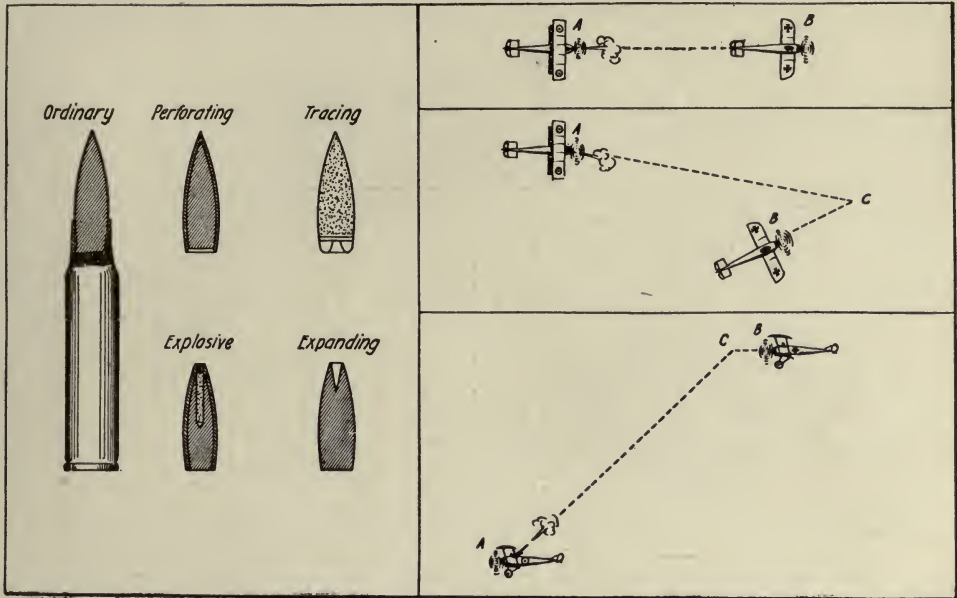


Figure 121—Types of bullets used in airplane machine guns for destruction and for correction of aim

Figure 122—No correction laterally
 Figure 123—Lateral correction for velocity
 Figure 124—Longitudinal correction for velocity

AMMUNITION AND FIRE CORRECTION

Correction of machine gun fire is commonly made by observation of the path of phosphorous tracer bullets, placed about every fifth position in the magazine. The gun is deflected, raised, or aimed to either side, in accordance with the direction of the smoke trail toward the enemy airplane. The objective is usually the back of the pilot, aiming being governed by its appearance in the center of the sight. Various types of bullets are used in machine guns and an understanding of their functions and construction is useful.

TYPES OF AMMUNITION

- ORDINARY—The head of this bullet is usually of solid brass and presents no new features.
- PERFORATING—This type of bullet is designed to pierce metal, being used against airplane motors and fuel tanks. The core is ordinarily of hard steel encased in a covering of copper, zinc and nickel alloy.
- TRACING—These bullets are hollow and filled with a phosphorous compound; the casing is an alloy of copper, zinc and nickel. They leave a luminous or smoke trail behind and are combustible; they are designed both for fire correction and for incendiary purposes.
- EXPLOSIVE—The bullets are made somewhat in the form of a small shell; they are hollow and contain an explosive charge in the nose, consisting of chlorate of potash and sulphur, in equal parts, acting both as detonator and exploder. The lighter, flattened nose gives this type of bullets a different trajectory from those of ordinary form.
- EXPANDING—Destruction of struts and spars is the mission of the expanding type, drilled at the nose so instantaneous disintegration takes place even when encountering small diametered parts of low density.

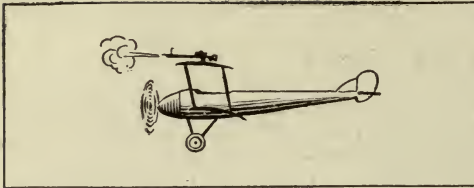
CORRECTION OF FIRE

While several formulae have appeared to determine accuracy of aiming at hostile machines, practical application is well nigh impossible because they presuppose a knowledge of (a) speed of both airplanes, (b) aiming angle with reference to flight path, (c) enemy machine's flight path. The hopelessness of determining these is immediately apparent without proper instruments; dependence is therefore placed upon the trail of the tracer bullet, although special apparatus for sighting which makes an automatic correction has been developed, but must not be described just now.

A few principles of sighting upon which correction calculations are based are illustrated in the diagrams, Figures 122, 123 and 124. The only correction necessary in the case of Figure 122 is a raising or deflection of the gun or the airplane A, according to whether gun is fixed or movable.

In Figure 123, enemy airplane B has a course at a wide angle to the path of A. Since the enemy machine is moving forward at high velocity, it is necessary to aim on the line A, C, the measure of correction being the line B, C.

Figure 124 illustrates the principle which depends upon the angle of the gun with reference to the flight path, it being necessary in this case to make allowance for the forward motion of both machines, aiming at an approximate point C, instead of directly at enemy airplane B.



Figures 125a—Gun fixed on upper plane

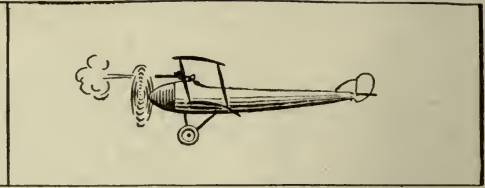


Figure 125b—Firing through propeller

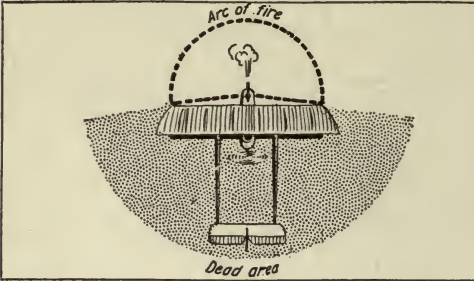


Figure 126a—Lateral arc of single movable forward gun on pusher airplane

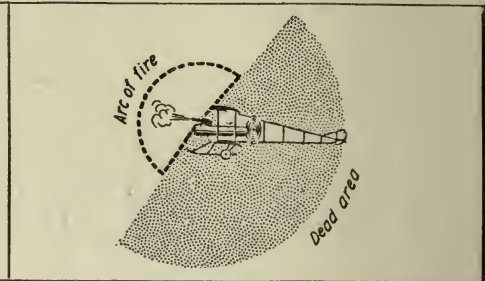


Figure 126b—Longitudinal arc of single movable forward gun on pusher airplane

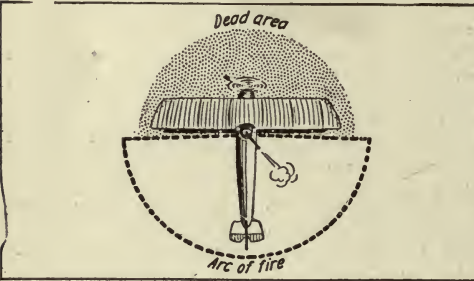


Figure 127a—Effective lateral arc of rear gun

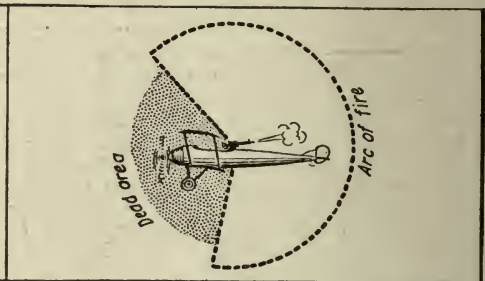


Figure 127b—Effective longitudinal arc of rear gun

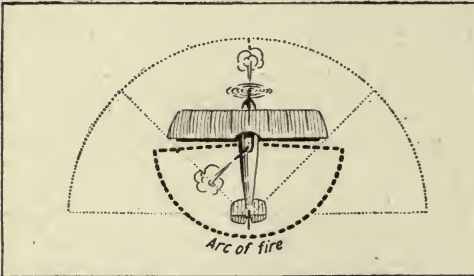


Figure 128a—Arcs of forward fixed and movable rear gun

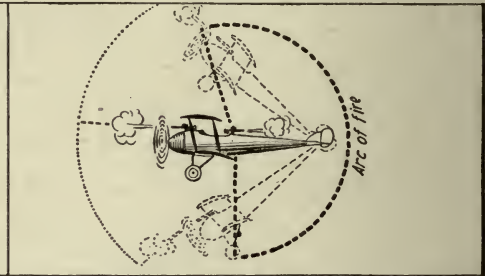


Figure 128b—Longitudinal arc of fire with same arrangement

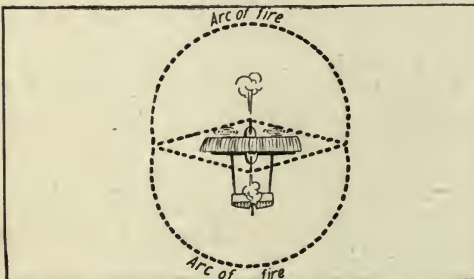


Figure 129a—Joining arcs of two mobile guns

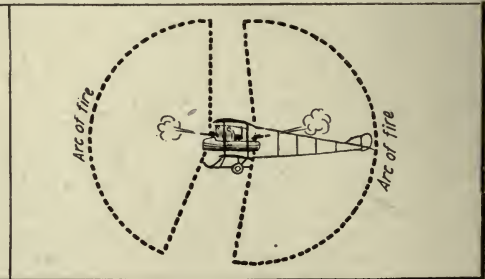


Figure 129b—Longitudinal radius of action

GUN MOUNTINGS AND FIRE RADIUS

Placing of machine guns and their number on enemy airplanes is a matter for exact knowledge with the military aviator. From recognition of a type he can estimate his chances of evading its fire and the best points of attack.

The various arrangements of armament of hostile airplanes becomes thoroughly familiar in sectors where daily engagements are the rule, and although distribution and number of machine guns are subject to constant change, acquaintance with the field of fire and mobility of the various arms establish certain principles which are fundamental and determine the possibilities of all modifications. Account must be taken of the value of surprise in arranging armament. A brief discussion of the effective fire secured by the various arrangements follows:

FORWARD GUN MOUNTINGS

The first consideration in placing forward guns in tractor types is their location. Figure 125-a illustrates the machine gun fixed to the upper plane and firing over the propeller; Figure 125-b gives the arrangement for firing through the propeller, as usually placed in one-man airplanes. Placing the gun on the top plane has two disadvantages: Resistance to the air, increasing the drift and consequently lessening lift, and difficulty in reloading the gun. To remove the empty magazine and replace it with a loaded one requires turning the gun upside down. When it is considered that the rate of fire is so rapid that the magazine is emptied in 10 or 15 seconds, it is obvious that unless a hit is made with the emptying of the first magazine the airplane is helpless in the matter of further immediate attack.

Shooting through the propeller is accomplished by synchronizing the discharge of the gun with the revolutions of the propeller, the mechanism being governed by the motor. The device is timed to suspend discharge when the blades are passing the muzzle of the gun; thus with a propeller revolving at the rate of 1400 r.p.m. the two blades pass that point at intervals of $1/47$ of a second, a fraction of time which has no material bearing upon maintenance of virtually continuous fire.

Armoring the propeller blades to deflect the bullets is another method which has been employed, but is not favored to as great an extent as synchronizing. Triangular pieces of hard steel set in the blades at the point of the bullets' path save the propeller from breaking, under this method, and deflect the bullets striking them, the percentage of loss being negligible, as low as 5 to 8 per cent. Tapering the propeller at the point of the steel plate inset, however, means a loss in tractive efficiency, lessening airplane speed as much as 12 miles per hour, a consideration of so great importance as to make the method inferior to the synchronizing application.

EFFECTIVE ANGLES OF FIRE

The various arrangements of machine guns pictured on page 154 are worthy of careful study by the military aviator.

Figures 126-a and 126-b show the application of a single forward gun to an airplane of pusher type, the weapon being pivoted in the front of the nacelle. The dotted lines show the limitations of the lateral and longitudinal arcs of effective fire, and the shaded portions the considerable dead area behind, the sides and rear being particular points of vulnerability.

Figures 127-a and 127-b illustrate the placing of a gun in the cockpit of a tractor machine, giving it a wider arc of effective fire to the sides and above and below, but still leaving considerable dead area in front. The fact that this blind, or undefended, spot is in full view of the pilot who is maneuvering the machine makes it less vulnerable than in the case of Figure 126.

Figures 128-a and 128-b show the tractor airplane with the addition of a forward gun shooting through the propeller. The arc of fire of this gun is governed by the mobility of the airplane, that is, its radius of effective action depends upon the skill of the pilot and the machine's maneuvering ability in his hands, since the gun is pointed by the change of direction in the entire airplane. As this gun is mainly for offensives, the rear gun's function is principally defensive, a wide arc of fire to the rear enabling it to ward off attacks from many directions. This arrangement of guns is generally found on light bombing and reconnaissance or fire control machines.

Figures 129-a and 129-b illustrate the effective armament of either tractor or pusher types having two propellers. These machines are largely used for bombing and protection of aircraft or military bases, the armament being of great defensive value. Airplanes of this class with tractor screws are armed with the additional gun shooting through a tunnel under the fuselage already referred to. In type of machine many modifications appear, but this form of armament is general with practically all airplanes carrying three or more men.

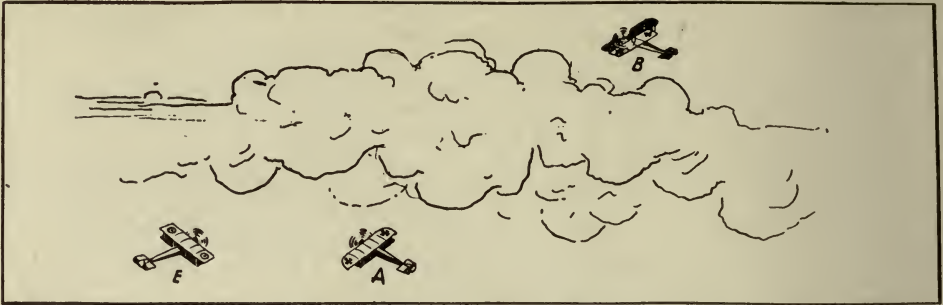


Figure 130—How a supporting airplane remains hidden from an attacking enemy

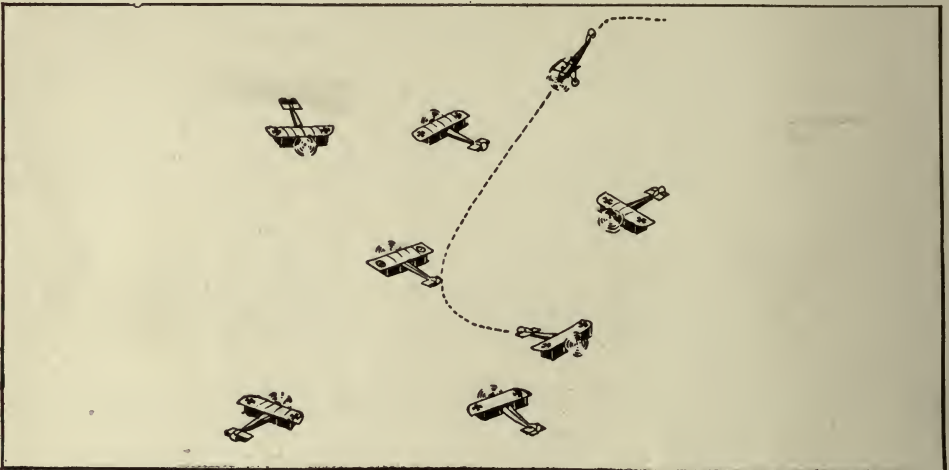


Figure 131—A formation engaging a single enemy, the leader taking higher altitude for surprise attack

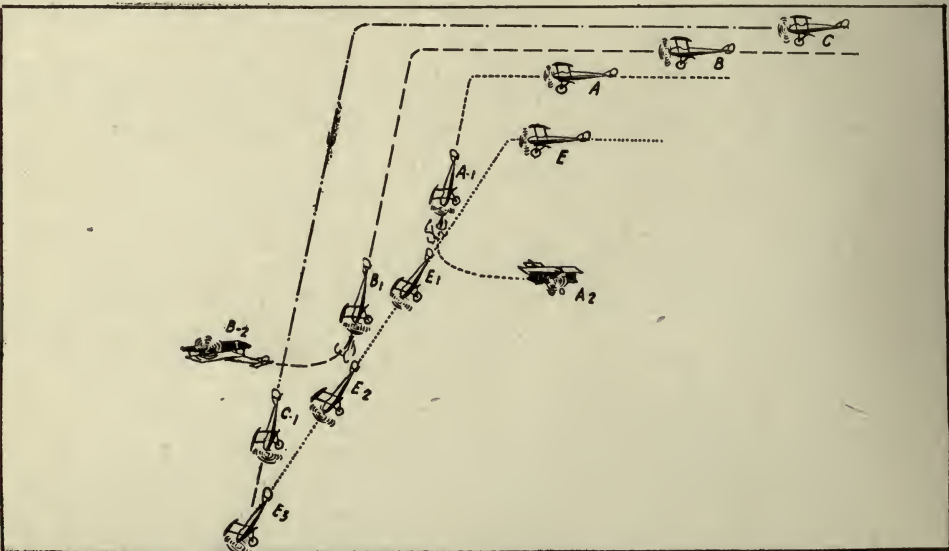


Figure 132—The usual method of formation attack on a single enemy

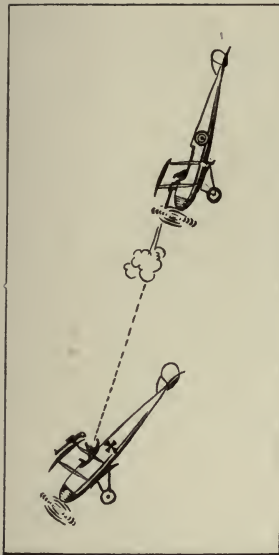


Figure 133—The steep angle for dive attack

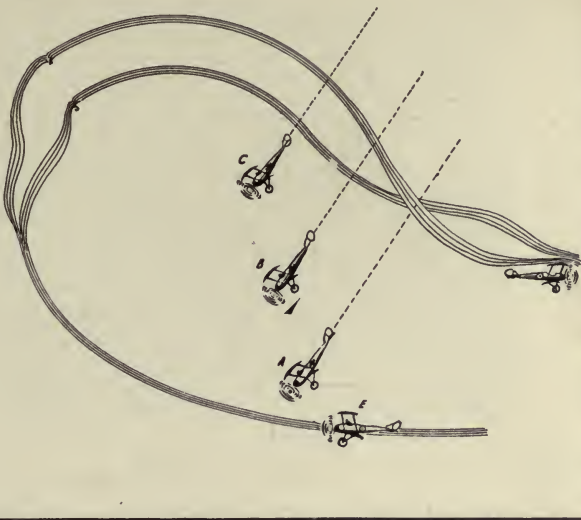


Figure 134—Employing the Immelman turn to effect an escape from an attack in formation

FIGHTING IN THE AIR

Pilots of combat airplanes must be physically fit and mentally alert at all times. The enemy's qualifications for success are fully as great, and success is gained only by dauntless courage governed by quick-witted application of flying and gunnery skill. The following principles governing individual actions in combat are to be observed:

SKILL IN ATTACK

As in all forms of military science, surprise contributes largely to success. The surprise attack is best delivered from a position between the enemy craft and the sun. Diving on the tail is the favored method.

While diving, the rear should be watched; another enemy airplane may be above.

Except when coming to the assistance of friendly aircraft, speeds below 100 miles per hour should be employed, as excessive velocities make the airplane difficult of control and the period for machine gun fire too brief.

Fire should be withheld until within 100 yards of the enemy; the glove on the trigger hand is usually removed.

The machine on top has the advantage. Attack from behind is most effective; right angle fire is second choice, and attacking from in front the least effective method.

When the enemy airplane has superiority of speed the dive attack is used. If the hostile machine is inferior, the dive is made to his rear to a point a trifle below his tail; before opening fire flying speed is equalized by throttling the motor.

Careful survey of the sky should be made before attacking a single enemy airplane flying at a low altitude, as it may be a decoy.

The tail is the most vulnerable spot of the airplane; attacks may be delivered and expected most frequently at this point.

A one-man machine should not return to combat with a two-seater if the larger enemy craft has the position advantage when it opens fire.

When flying in formation superiority of numbers decides the advisability of attack; position in formation lost in combat should be regained at the earliest opportunity.

METHODS OF ATTACK

Figures 130 to 133 show some forms of air tactics in combat. Figure 130 illustrates a common method of support, airplane B remaining above clouds ready to assist airplane A which is engaged in combat with enemy E, or to attack any plane coming to the assistance of E.

Attack on an airplane which has encountered a hostile formation is illustrated in Figure 131. The single enemy is surrounded and attacked from all sides, the leader of the formation remaining at a higher altitude and suddenly diving on his tail with a burst of machine gun fire.

The method usually employed for attack on a single enemy by three airplanes flying in formation is shown in Figure 132. Planes A B and C are discovered by enemy E, who immediately dives to escape. The leader A opens the attack by diving. Missing fire, he turns off to the left (path A1-A2). Airplane B, about 300 feet behind at slightly higher altitude, dives and fires; missing, he turns off right at B2, leaving the remaining plane of the formation C, in a steeper dive, to intercept the enemy at E3.

Attempted escape from a superior force by diving is seldom resorted to unless the lone machine has known superiority in diving speed. The usual method of getting away is by resort to air acrobatics, Figure 134 illustrating how the Immelman Turn can be successfully employed under the circumstances.

Figure 133 demonstrates the steeper diving angle required of the attacking airplane when the adversary is also diving.



Figure 135—An American squadron flying in V-formation

FLYING IN FORMATION

Offensive combat in the air is seldom sought by a single airplane, well-defined and planned attacks against definite objectives generally being conducted by groups of machines, known variously by the terms wings, squadrons and fleets, according to their composition and numbers. The V-formation, illustrated in Figure 135, presents many advantages and is almost universally employed for air offensives.

In this arrangement the leader, who has the point and is in command, may keep all the machines easily under observation and his signals are seen without effort by all the pilots. The stations are determined in advance and each pilot takes his assigned position as close as possible to the other machines and slightly higher than the airplane immediately ahead. The formation is copied from the flight of birds, the aerodynamic reason for its adoption being that the air in the wake of an airplane has a downward motion unfavorable to flight, whereas the vertical character of the air stream to both sides of the leader has residuary upward motion. A military reason for the V preference over a possible diamond-shaped arrangement, is that in the latter three airplanes in the rear would be open to attack instead of two.

THE START

Upon the leader rests the responsibility of choosing pilots and machines suitable for flying in one formation. As a general rule it is important that each aviator take aloft an airplane with which he is entirely familiar. The machines and their pilots are assembled some minutes before the time set for the start, their clothing and equipment known to be proper for the mission, pilots seated and all engines running throttled down, before the leader takes to the air.

Once the leader is off the ground the other airplanes follow as near as possible in their formation order at intervals of 15 seconds. Attaining a height of 600 to 800 feet in straight-away flight, the leader throttles down and watches the others pick up formation. This should be accomplished at a maximum rate of about a half-minute per man. By rocking his airplane laterally, the leader then signals attention—at night a red light is fired from a Very pistol—and the climb is begun. If a turn is required to head in the direction of the objective, it is made in advance of the climb and before the motor is opened up.

THE FLIGHT

Constant watchfulness of the progress of his formation is required of the leader; he verifies the position of each airplane by looking around at intervals of one minute or less. The speed of the leader in climbing must be adjusted to the slowest airplane in the formation or the flight will be ragged from the beginning. Since speed is of paramount importance in air tactics, not only must the machines in formation be carefully selected for equal flying qualities but every pilot must hold his position with greatest possible exactness. Dropping out of place tends to slow up the progress of the entire formation and loss of position is for each individual a matter of grave importance.

Turning is done at a signal from the leader, who rocks his airplane repeatedly and pauses; he then turns in the desired direction in a small arc, throttling his engine and rising down a trifle. Assume the turn to be to the right. The airplanes following on the right arm of the inverted V are throttled down and execute at slower speed a slight turn left, turning right when the leader has turned; meanwhile those on the left have successively made right turns with the motor on full. When all have turned the leader verifies the alignment and resumes full speed ahead.

Lateral rocking of the airplane is the attention signal.

Waving the arm and the direction it points indicates enemy aircraft.

The attention signal followed by rocking longitudinally signifies a machine gun jam.

While over hostile territory the difficulties of remaining in position are increased by anti-aircraft gunfire and the formation is often broken; but since success in attack is largely governed by the leader's freedom from concern about his force holding together, all pilots should regain position at the earliest moment. Constant vigilance should also be directed to preventing surprise attacks on the two rear airplanes.

EMPLOYMENT OF THE AIR FLEET

The plan of action is generally given to all pilots before a formation takes the air. Each man is expected to know his part in attainment of the objective and the leader's decision on the best method of attacking a hostile air force when sighted must be transmitted quickly by pre-arranged signals.

THEORY OF CONCENTRATION

Superiority of numbers is the general indication of the probability of success, although estimate of speed and armament of the enemy must be taken into account, along with the altitude advantage. Despite the growing tendency to the use of armor protection, mobility of action is thereby reduced and the upper position still remains a great tactical advantage. Lanchester, of the British Advisory Committee for Aeronautics, has evolved what he terms the N-Square Law, by which calculations on the probable chance of success may be reduced to mathematics. Application of the N-Square Law assumes equality in technical equipment, gunnery and individual airmanship, the fighting strength of opposing forces being then proportionate to the square of numerical strength multiplied by the fighting value of individual units. Two forces may be thus represented:

$$\begin{array}{r} \text{Enemy} = 10 \text{ airplanes, or } 10^2 \quad 100 \\ \text{Friendly} = 8 \text{ airplanes, or } 8^2 \quad 64 \\ \hline \text{Enemy's superiority} \quad 36 \end{array}$$

The importance of superior tactics against the enemy is then shown by the assumption that the hostile formation is broken up, divided in half and attacked separately. The fighting value then appears:

$$\begin{array}{r} \text{Friendly} = 8 \text{ airplanes, or } 8^2 \quad 64 \\ \text{Enemy} = 10 \text{ airplanes, or } 5^2 + 5^2 \quad 50 \\ \hline \text{Friendly force's superiority} \quad 14 \end{array}$$

While application of the N-Square Law may only reflect the probability of success in a theoretical way, similar mathematical calculations, its creator points out, have been used deliberately or unconsciously by great military leaders of the past.

While superiority in numbers in air warfare is the primary indication of success, the principles of aerial warfare demand an attack when there is the slightest chance of success, and perhaps more than in other military branches, a leader's tactical skill is the deciding factor in air combat.

WARFARE ALTITUDES

The importance of altitude, when previously mentioned, referred to securing the upper position when engaging an enemy. Flight altitudes should be considered from another viewpoint, i. e., the divisions of flying heights in accordance with the mission of the airplane. Set rules cannot be made on this score as altitude in warfare is influenced by the tactical situation and atmospheric conditions. A general classification divides flight levels into low, mean and high. Low altitude includes anything up to 5,000 feet; offensives against ground objective being conducted below 2,000 feet, and 2,500 to 3,000 feet being most favorable for night operations, bombing and photography. At mean height, 5,000 to 10,000 feet, combat planes have the most favorable altitude for tactical missions; photographic, fire-control and bombing machines may also employ these elevations. High flight, 10,000 feet and above, appears best suited for combat airplanes in the aircraft screen and those seeking to avoid hostile craft when proceeding on or returning from a mission.

TACTICAL SKILL

Essentially, military airplanes are fighting units, not individuals, and should operate in groups or formations, the strength and composition of which are governed by the nature of the mission. Operating singly, the duties assigned should be those which permit the craft to remain within areas providing support from other aircraft.

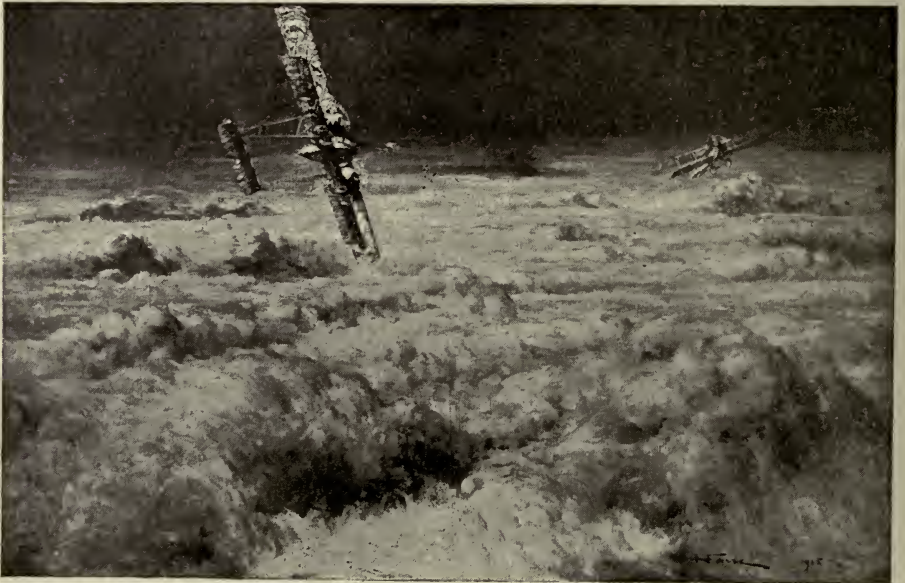
Morale, the feeling of security and invincibility, contributes largely to success. Enemies successfully executed over enemy territory quickly establish the spirit of victory and turn possible timidity into aggressiveness.

The particular method of attack which offers greatest probability of success is ordinarily pointed out by the leader's actions. Parallel attacks head-on, from rear or side, give no advantage to either adversary; the importance of gaining the upper position has already been emphasized and is to be remembered as a fundamental tactical rule. When attacking with the superior force the enveloping formation is frequently used; circling about the enemy, the airplanes engaged thus gain concentration of fire and lessen the chances for escape of the quarry. Pursuit is a matter almost entirely dictated by the superiority of speed. Here again higher altitude offers the advantage of speed acceleration in descent. Once it is determined that the pursued cannot be overtaken before the radius of action is exhausted, or the chase continued to dangerous depth over hostile territory, a return should be made. The escaping plane will generally fly directly toward the sun or into clouds or haze; there is also a fair probability that when nearly overtaken its pilot will suddenly slow down and drop, in an endeavor to have the pursuer pass him, thus reversing the situation.

Convoying bombing airplanes is an important duty of combat machines. Generally, the bombers leave the ground first, the swifter machines following some minutes later and meeting at the designated air rendezvous about the same time. The post of the fast fighters is above or on the flanks of the formation, flying as advance, flank and rear guards.



A successful attack on the enemy's tail from the rear and slightly below, an effective method when the attacking airplane has superiority of speed



From paintings by Lieut. Farré

Maneuvering for position in air combat above the clouds

CONTACT PATROL

A tactical reconnaissance during the progress of an attack, establishing a liaison between infantry of the first line and their commanders in the rear, giving positions of friendly and enemy troops, and carrying out offensive actions against enemy troops on the ground—that is contact patrol, perhaps the most thrilling task that comes to the aviator in line of duty.

Airplanes assigned to contact patrol duty arrive over the front line trenches exactly at the time when the attack is scheduled to commence, taking a position just over or under the predetermined trajectory for the artillery barrage fire. The progress of the attack is observed; when the infantry advances to its first objective, its position is signaled to the aviators by means of a shutter, lamp or flare. The position is traced on the pilot's map, which is placed in a weighted message bag with any necessary comment; he flies then to the infantry headquarters, and coming down within 200 feet of the ground drops the bag. Sometimes the airplane's message is delivered in telegraph code by lamp, Klaxon horn or Very's lights and smoke bombs; wireless is occasionally used, but offers the possibility of interception by the enemy and is less desirable. The reports preferably include the state of enemy trenches during the attack, troop movements and location of any new trenches.

The offensive action, which is part of the object of a contact patrol, is literally a trench raid conducted in formation by combat aircraft. The usual method is for the first man to fly along the line of the enemy's first-line trench, very low under the barrage, in fact usually less than 100 feet above the trench parapet. The second man takes the second, or support line, both directing downward a stream of inflade fire from machine guns. It is the object of the second man to prevent effective fire at the first-line man; the airplanes in consequence fly almost abreast. Meanwhile, the support, or third line trench has been covered by a third airplane, with the object of demoralizing the troops in its shelter. A fourth airplane is meanwhile zig-zagging over the trenches, combating any attempts to direct effective rear fire from the trenches after the machines have passed.

The speed of flight of all four machines is 120 miles an hour or better, eliminating the possibility of accurate aiming by gunners returning small-arms fire from the trenches. Anti-aircraft guns are also ineffective at the low angle. The density of the air at the ground and the powerful types of airplanes used make the effect of wind puffs or disturbances from shell bursts negligible on control. The low altitude and high speed also tends to make the airplane rise; to overcome this the nose is pointed slightly downward, pointing the rigid gun at the best angle to rake the trenches.

When the machine guns have been discharged a return to friendly lines is made, a dangerous proceeding, as it requires flying up through the barrage fire, the smoke from which screens the craft from friendly gunners.

ARMOR FOR AIRPLANES

Armor, mounted in sheets protecting the airplane's vital parts, or in the form of turrets and shields, proof against small-arms fire, is indispensable and practical for low altitude operations. Armor plate $\frac{1}{2}$ inch in thickness weighs about 10 pounds to the square foot, making the weight consideration an important one. The protection, therefore, is generally limited to armor plate beneath the motor and cockpit, disposition and quantity being governed by the type of airplane and the height at which it is usually flown. Protection from overhead fire not being considered, adequate security from rifle and machine gun fire on vital portions is thus gained by an average armored area of 30 square feet, or by an additional weight of 300 pounds. Flying efficiency being lessened by weight additions, the heavy armor protection which would be effectual against artillery fire is eliminated from calculations, leaving the evasion of fire to the airplane's high speed and maneuvering ability.

Turrets and shields are furnished for protection in combat with hostile airplanes, shields being mounted on universal joints so they can be lowered for underneath protection when not required by the gunner.

HEAVY AIRPLANE ARMAMENT

Explosive shells to be fired from airplanes have been successfully adapted to a specially designed, light weight 3-inch rapid fire gun. By reason of the short ranges used, high muzzle velocity is not required in air combat and the great weight of the same calibered field artillery piece may be cut down by elimination of the long barrel, recoil mechanism and heavy carriage. These aerial guns in consequence weigh less than 250 pounds. Instead of employing hydraulic cylinders for the recoil, the aviation arm takes up firing stresses by balanced fire, the gun having divided barrels, the projectile being loaded in the forward barrel, the powder charge placed in a chamber between it and a second barrel which is loaded with fine shot. When the gun is fired the fine shot is discharged backward, its force balancing in large measure that of the projectile discharging in the opposite direction. The slight difference in force is the recoil. Wooden breechblocks which blow out rearward are also used.

Heavy aircraft armament is used on airplanes of the super-plane class where lifting capacities of 4 tons are usual. The 3-inch and 2-pounder airplane guns do not have the high accuracy of fire which is essential to field artillery pieces and given by their higher firing velocities. Accuracy and high striking velocity is of less importance against aircraft, for the reason that high explosives can cause the collapse of an airplane without actual contact with it.



British Official Photo

Crew of an anti-aircraft battery securing ranging data

ANTI-AIRCRAFT FIRE

The most common trap which the aviator falls into is in diving to low altitudes over hostile territory and coming within range of anti-aircraft batteries. These dives may be occasioned by following an enemy airplane downward in heat of combat, or seeking to escape from a larger hostile air force. Deliberate luring of airplanes to altitudes within range of anti-aircraft fire is also a regular practice in warfare. Attacks on balloons and bombing expeditions on enemy bases also subject the military flier to this defensive fire from the ground. An understanding of anti-aircraft guns is valuable.

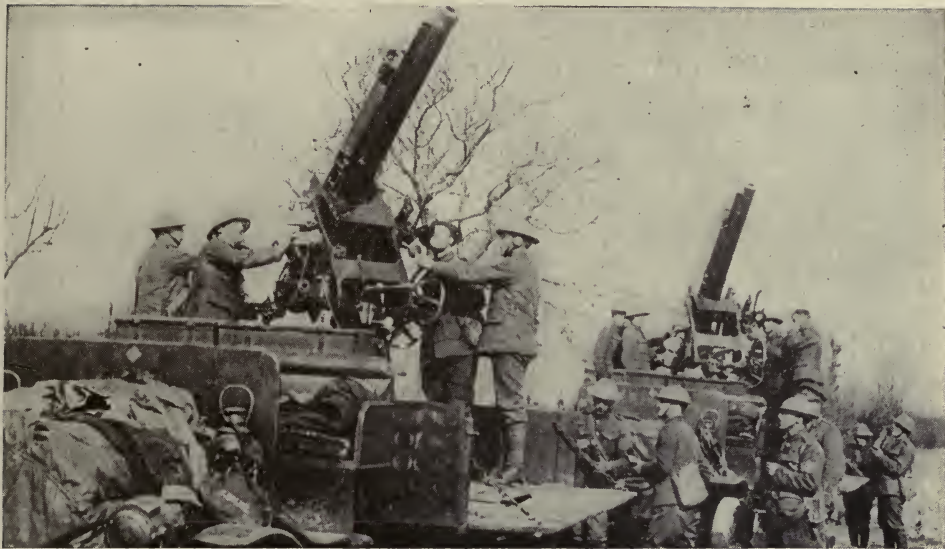
ACTION UNDER FIRE

The aviator under attack observes the effect of range fire directed at him by the white smoke of the shell bursts, termed "cream puffs." When the sound of the burst can be heard above the noise from his airplane motor it may be accepted that the gunners are getting the range with dangerous accuracy. An escape is then in order. If diving or climbing is attempted the gunner may lower or raise his fire and estimate the airplane's velocity with fair accuracy. Perhaps the best method of escape is to employ the pancake, throttling the motor and dropping several hundred feet; this maneuver is difficult of detection from the ground, as the machine remains horizontal to its original position. Zig-zag flight ahead at high speed is then usually employed, although the straight course is a valuable variation because of its unexpectedness. All forms of aerobatics are frequently used when the shells are dangerously close.

Anti-aircraft artillery loses its accuracy of aim when the airplane is at elevations greater than 9,000 feet, although a chance hit may be expected. Shrapnel is less dangerous than high explosive shelling as a hit from its scattered fire must strike a vital part to be effective; explosive shells do not necessarily have to reach the target, however, as the light structure of a wing may be crushed by detonation in a near vicinity. The principal object of anti-aircraft fire is to force the airplane to greater altitudes, and while the percentage of hits is relatively small, the guns are sometimes amazingly effective at low elevations and the aviator's safety lies in climbing out of range.

LOCATION AND TYPES OF GUNS

Both fixed and mobile anti-aircraft artillery is well concealed by pits and camouflage from hostile airmen. The guns are of two types; important positions are usually defended by high power guns on fixed emplacements of concrete; the principal, and largest class, comprise light rapid-fire pieces, 1, 1½ or 2-pounders, and heavier types up to 6-pounders, mounted on motor trucks of a special type. The heavy guns are generally used at headquarters of commanding generals of army corps, the lighter types being assigned to brigades and divisions in the field. While highly mobile, the guns are usually placed at supporting distance, about 1,000 yards apart. They have high muzzle velocity and consequent long range, firing projectiles with combination percussion and time fuses, explosive and incendiary charges. Automatic sights are used with graduated altitude, drift and deflection scales designed for high angle fire, 45 to 75 degrees. Fire correction is obtained by use of special projectiles giving off varying densities of smoke.



British Official Photo

Mobile anti-aircraft guns mounted on motor trucks

SHELL TRAJECTORIES AND BALLISTICS

The trajectory, or path described by a projectile, is influenced by gravity and time or resistance of the air. In anti-aircraft firing the line of sight is at angles up to 90 degrees and seldom less than 15 degrees, consequently the trajectory is unsteady and can only be aided in comparatively small degree by high velocity. Velocity losses as high altitudes are reached also serve to magnify small errors in aiming, which in turn are liable to frequent occurrence because of the short time allowed for computations.

A further contribution to inaccuracy is found in the changes in air density as altitude increases, affecting the ballistics of the shell. Time fuses for this reason burn erratically, wide variations in rate making them unsatisfactory; the frail nature of the airplane mitigates against the operation of percussion fuses also, even though the projectile pass directly through the target. The percussion type does not explode unless it reaches its target and is therefore valueless for furnishing firing data.

Firing by salvo is considered the best method, four guns being arranged in a square at 200-foot intervals with the observer in the center. They are all aimed with the same firing data, a bracket being thus obtained on which corrections are based.

DEFENDING POSITIONS

Aviators must not underestimate the danger from anti-aircraft fire; improvements are constantly being made and the exercise of proper caution is required, particularly in raiding defended positions.

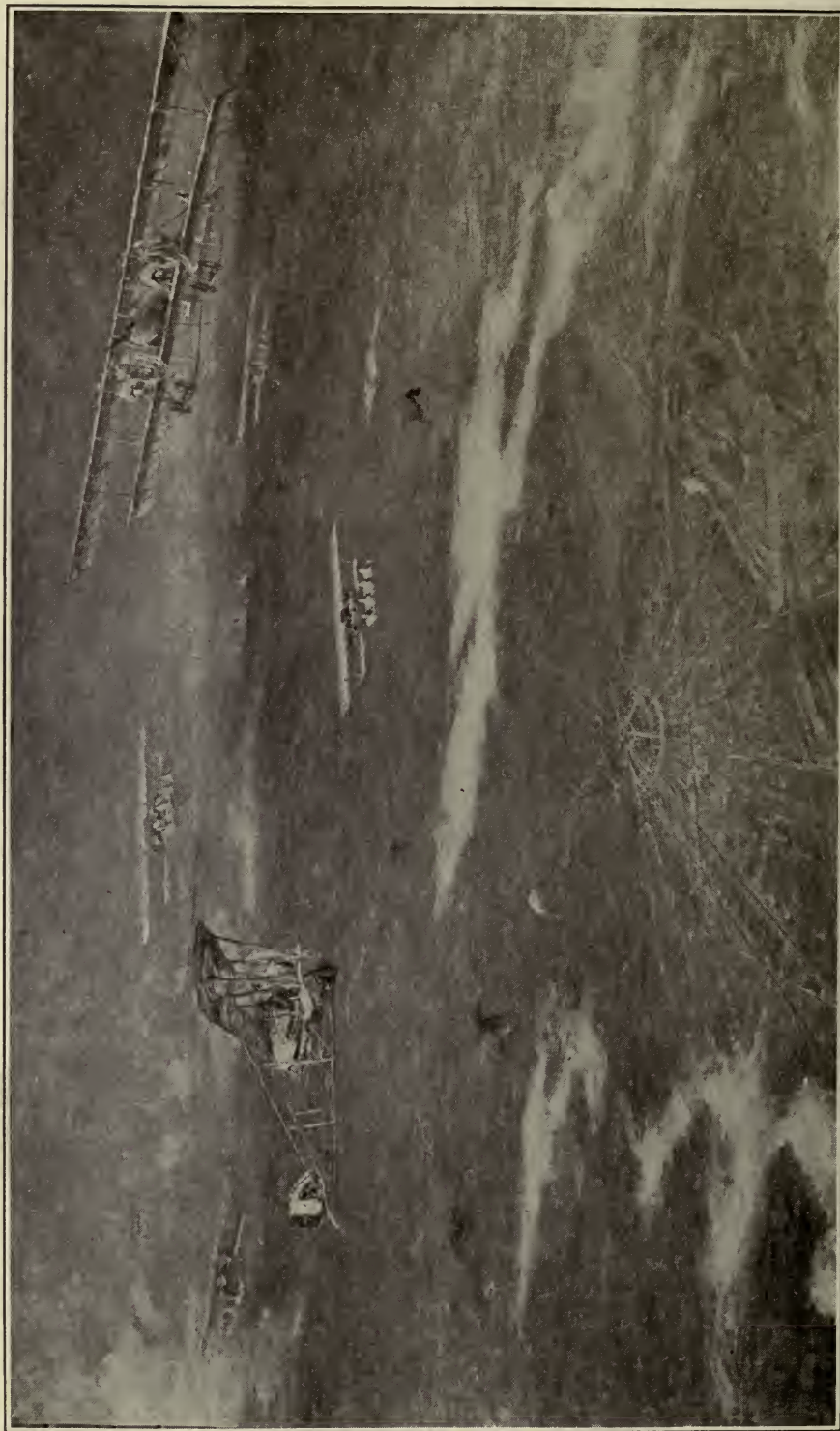
Outpost detector stations may be expected, equipped with microphones and other forms of electrical sound amplifiers which detect the approach of hostile aircraft at considerable distances. Telescopes and long range glasses sweep the skies constantly and powerful searchlights, fixed and mobile, are ready at night to throw a revealing beam on the invader. The outpost stations are also equipped with anti-aircraft batteries and combat airplanes which take to the air at the first warning of an enemy approach.

The line of interior defense ordinarily extends in a circle of four-gun groups placed at 1,000-yard intervals on a diameter of five or more miles from the defended position. These defenses must be passed before the objective is reached, when a fierce fire and engagement by combat craft may also be expected.

ATTACKS ON BALLOONS

Captive balloons used for observation and regulating artillery fire are most dangerous to attack. These helpless-appearing gas bags are about 200 feet long by 30 feet diameter, placed about 2 miles apart at an altitude of 4,000 feet. They are protected by several fast combat airplanes which circle above them, and an attack means flying through a heavy anti-aircraft barrage as well. Amazing accuracy is often attained by anti-aircraft gunners at the 4,000-foot altitude and the best are assigned to balloon protection.

One of the most successful methods of attack is for the hostile airplane to fly beyond the balloon's position at a minimum altitude of 6,000 feet, circling back over it and diving with the motor cut off, so it cannot be heard. The dive for 1,500 feet should be steep with the machine in almost vertical position then slightly lessening the angle so a raking fire may be delivered when within 200 feet. If the tracer bullets show the mark has been reached, the attacker should swerve in a wide arc to avoid the effects of the explosion. After delivering gun fire quick climb is usually required to avoid the pursuing airplane guards and the shelling from the ground.



Painting by Lieut Farré

A bombing attack on an enemy base executed by a squadron of raiding airplanes

BOMBING AIR RAIDS

Destruction of enemy bases and headquarters, factories, warehouses and magazines, railroads and bridges, is the duty of specially trained bombers. The bombing arm of the air service, once a matter of a few volunteers operating independently, has now assumed the proportion of about one-quarter of the total air force, operating in squadrons of 12 airplanes each. Large groups, consisting of several squadrons, generally conduct bombing raids, escorted over the lines by fast fighting squadrons, which do not continue to the objective owing to limited fuel capacity. Numerical increase in airplanes for bombing is based upon the division of defensive fire thus required of anti-aircraft batteries.

TYPES OF BOMBING AIRPLANES

Examination of the various airplanes employed for bombing reveals wide diversity in type, but selection according to long cruising radius and weight-carrying capacity. In triplane construction, machines with 3 motors, 2 tractor and 1 pusher propellers are of two types, large and small, the greater having a bomb carrying capacity up to 5 tons. A small single-seater triplane is occasionally used. In biplane types, motor power up to 600 h.p. is found, with 100-foot wing spreads, 2 or 3 motors and one or more guns. The single motor, two-seater, is also used. There are day machines and night machines in the aerial bombing arm, the characteristics of the night airplanes showing moderate speed and slow climb, but great inherent stability.

Night air fighting is almost unknown, so speed and maneuvering ability are secondary to capacity for carrying explosives.

MUFFLERS AND FLARES

Since the objectives of bombing squadrons are almost without exception fortified positions, the anti-aircraft batteries are the principal sources of danger. In daylight raids, the enemy combat airplanes are a material menace, but their effectiveness is largely reduced in the dark or in the uncertain glare of searchlights. Silencing the noise of airplane engines by elimination of the exhaust sounds which enemy microphones detect miles away, requires added weight and loss of power, as against the lesser weight of additional fuel required for higher altitude flight.

For night air operations parachute flares are used. These are dropped from the airplanes and light up a circular area $1\frac{1}{2}$ miles in diameter with 400,000 candle power illumination. Buildings, gun emplacements, railroads, wagon trains, troops or ammunition dumps are thus clearly revealed and the particular target easily selected. Suspended by the parachute at a height of 1,500 to 2,000 feet, these flares also materially interfere with careful aiming of anti-aircraft guns, since the attacking airplanes are in the darkened area well above the light from the flares.

TRAINING BOMBING CREWS

Training a bombing crew, i. e., a pilot and a bomber, consists of highly specialized instruction in flying, navigation, fighting, aiming and firing. The men are selected from those of highest standing in the ground school classes.

The preparatory stage of instruction brings the bombers together with pilots, who have mastered acrobatic, cross-country and formation flying. A week is devoted to study of the theory of bombing, explosives and sighting devices. Flights are then taken over courses marked by camera obscuras and Batchelor mirrors located on housetops, instruments by which the course of the airplanes flying over them can be traced on charts with the slightest errors of the crew shown. Instructors correct these errors and shift the crews around until the best combinations in pairing are secured.

Bomb-dropping is the next stage of the training. A painted circle with a 25-foot radius is the target, the bomb being a plaster-of-Paris missile, accurately balanced and weighted. Low altitude flight is followed by target practice at 3,000 and 4,000 feet until an average score of seven hits out of ten bombs dropped is recorded. The training is then continued at elevations between 6,000 and 12,000 feet. The size of the target is not changed even when the flight elevation is two miles above the earth, at which height the painted disc looks like a flyspeck. Moving targets are also used, these taking the form of dummy trains and individual objects.

The final stage in bombing training includes photographing of assumed enemy objectives and night raiding. Aerial gunnery, with fixed and movable machine guns, is also thoroughly mastered.

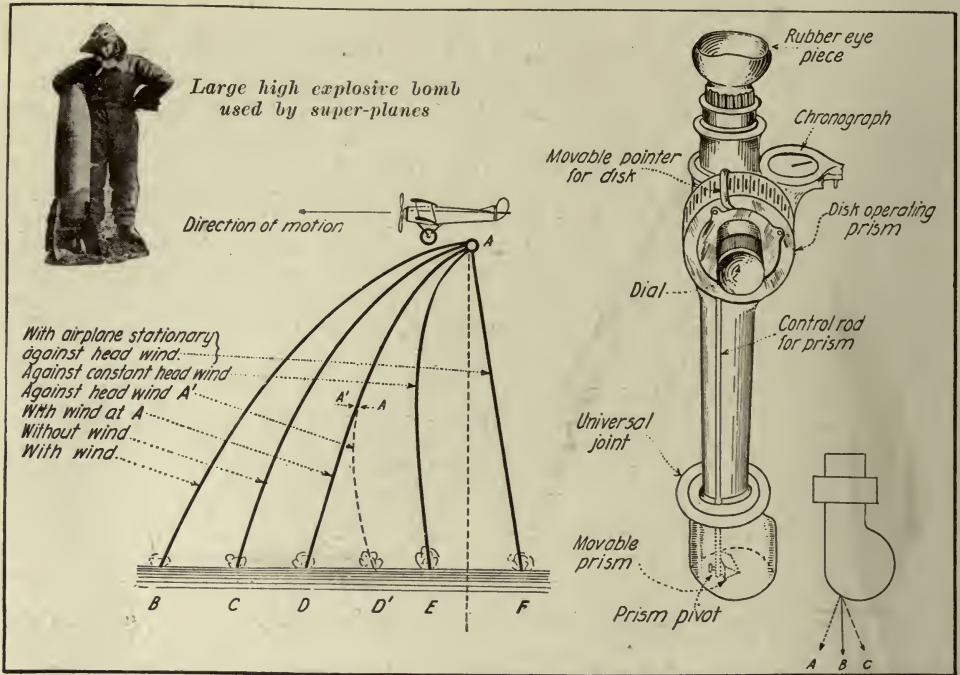


Figure 136—Effect of air resistance and gravity on bomb trajectories

Figure 137—A type of telescopic range finder

BOMB DROPPING

A bomb released from an airplane describes a curved path in its fall; this flight path, or trajectory, must be determined and practically applied if accuracy is to be attained. Velocity of the airplane and its height from the ground determine how far in advance of the target the bomb must be released, for the distance the missile will carry increases with the airplane's velocity and height increases.

The bomb is subjected to air resistance and gravity forces; if it were dropped from a stationary point in a vacuum its trajectory would be vertical as the dotted line in Figure 136. Dropped from an airplane in motion, however, it is given an initial speed equal to, and in the same direction as the motion. In its fall it is ordinarily subjected to the force of wind in motion. The various flight paths shown in Figure 136 illustrate the wind's effect on the fall with the airplane stationary or in motion. Trajectories A-B and A-D are with the wind and the airplane in motion, A-C with no wind, but airplane moving, A-D, A-D' and A-E, with the machine flying against the wind; path A-F shows a head wind's action on a bomb released from aircraft theoretically without motion.

It is immediately evident, then, that knowledge of the velocities of airplane and wind are required. Best results in bomb dropping are obtained by releasing the projectile into, or against, the wind, and the wind velocity is easily determined by calculating the difference between the normal velocity of the airplane and its velocity with respect to the earth at the given time. Thus if an airplane having a normal speed of 90 m.p.h. is found to be flying only 70 m.p.h. with reference to the earth, then the resistance of the head wind is $90-70=20$ m.p.h. It then appears only necessary to know the airplane's altitude and the initial velocity of the bomb to determine the trajectory.

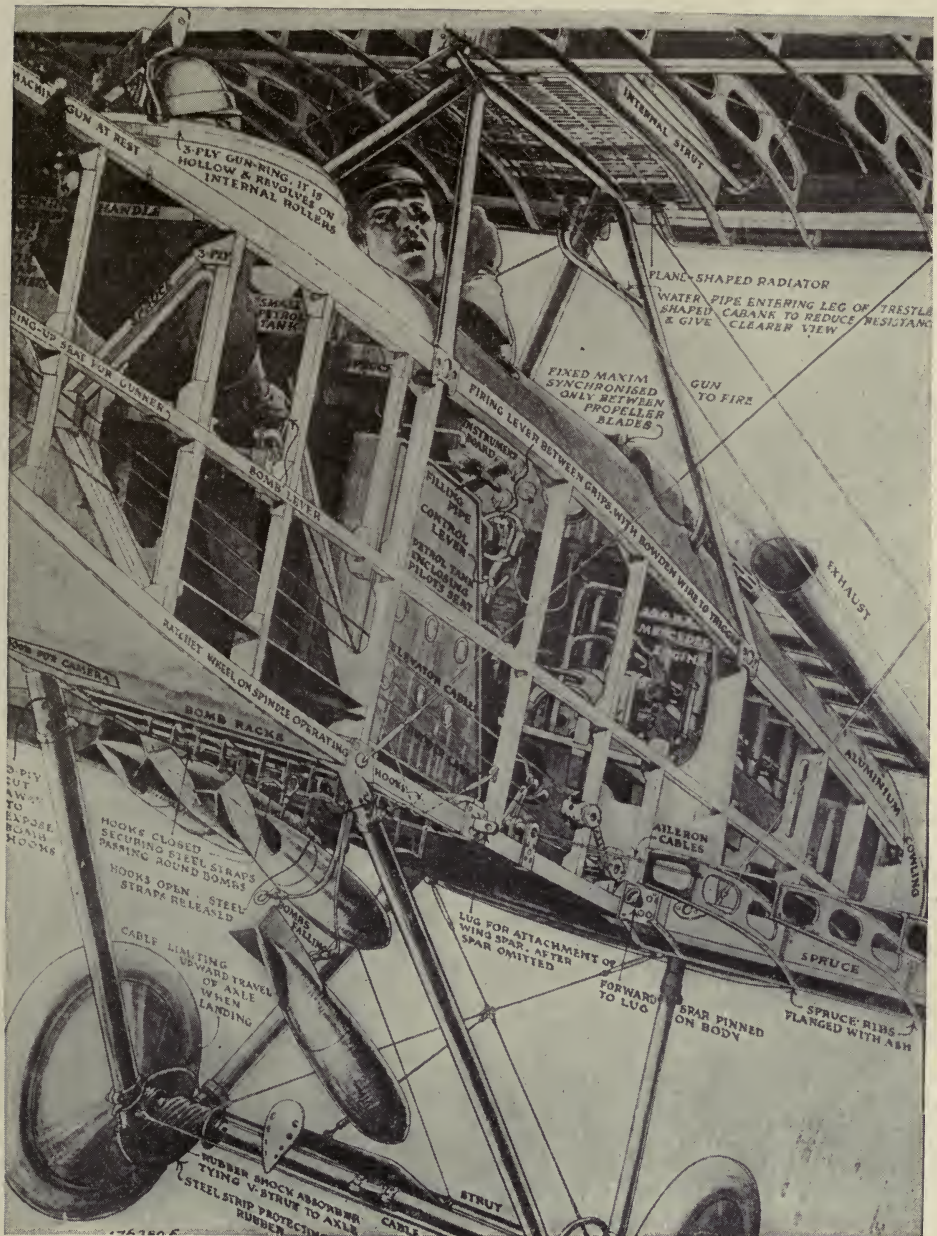
Mathematical calculations are only estimates, however, due to the fact that they are based on the supposition that the wind is a constant force at all altitudes between the airplane and the ground, whereas it is well known that wind velocity varies at different altitudes and changes direction appreciably by veering. So while it appears comparatively easy to construct a table of velocities and altitudes to give the exact instant when a bomb should be released to hit the target, the ideal range finder awaits the day when the laws governing the capricious action of winds are fully understood.

RANGE FINDERS

Instruments with telescopic sights have appeared in several forms in military aviation. Probably the best type is illustrated in Figure 137. The telescope remains vertical, but the prism mounted in the base is controlled by a graduated disk. There are two indexes on the disk, one of which corresponds to the vertical speed, or dead point of the range finder, and the other to the vision of $22^{\circ} 30'$. Another index, fixed to the body of the range finder, serves as a basis. At 0° the marksman views the ground along the vertical (B in Figure 137); at $22^{\circ} 30'$ the inclination of the visual ray is that angle (C) in front of the airplane; at 5° the inclination is as A, or 5° behind the airplane. A small movable index is attached to the disk, but is fixed by a small stop. Therefore, when the index, fixed on a graduation of the disk, passes the dead point it falls into a small notch, thus informing the marksman that he is viewing the ground according to the inclination which he had marked.

There is a spirit level in the body of the telescope so arranged that the edges of the air bubble are refracted as a black circle, serving as a sighting center. While range finding, this bubble must be kept in the center of the eye piece so the telescope remains vertical with the ground, irrespective of the airplane's angle of inclination.

A universal joint permits the free inclination of the range finder, but when the visual ray is accidentally directed to right or left, instead of front or rear of the route, an electric route corrector, acting upon a very sensitive galvanometer, indicates the necessary correction to regain the route.



U. & U. Photo.

Drawing of a German airplane showing bomb dropping mechanism

OPERATION OF THE RANGE FINDER—Height is obtained by subtracting the height of the objective from the altitude indicated by the altimeter. Thus, if the airplane is flying at 5,000 feet and seeks to bombard a 100 foot building the height will be 5,000—100=4,900 feet.

A few minutes before arriving over the bombardment objective the two elements are found which are necessary to read on the chart the proper firing angle. The index on the graduated disk is set at 22° 30'. The range of some point forward on the ground, such as a house or edge of a wood, is found. This point is caught in the circle formed by the spirit level's air bubble and followed while turning the disk until the index falls into the notch at the dead point; at this instant the chronograph is released and the point is followed in the range finder until 0° of the disk checks with the dead point, when the chronograph is instantly stopped. The resultant number of seconds of time given, when found on the chart in the line of altitude indicates the airplane's speed with reference to the ground and the proper sighting angle in degrees. The index is immediately set at this angle and the bomber is ready to operate. The range finder is trained on the target when within a mile or two of it, and at the instant when the index fixed at the proper number of degrees falls into the dead point, the bombs are released.

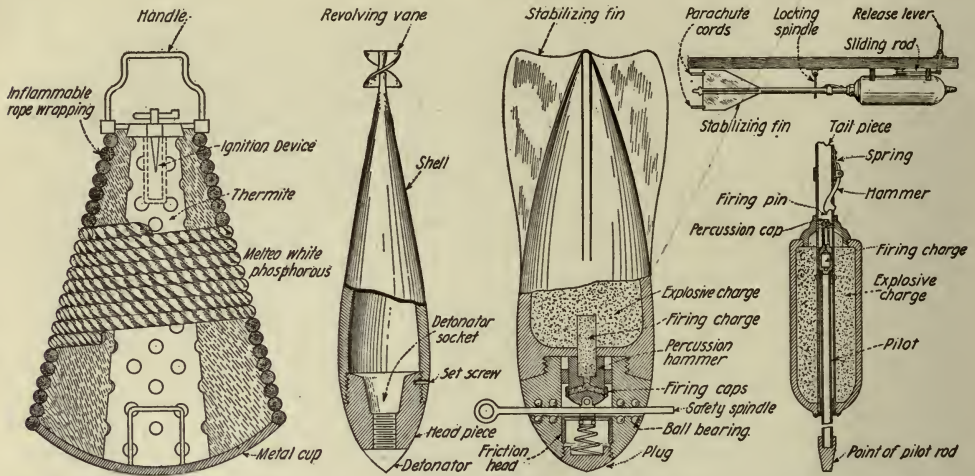


Fig. 138—Incendiary bomb

Figs. 139, 140, 141—Three types of explosive bombs

TYPES OF BOMBS

Bombs for use against hostile forces may be roughly classed as (a) explosive, (b) incendiary. There are also smoke bombs for signaling and for smoke screens, rockets for attacking balloons, flare rockets for illuminating positions and steel darts for use against enemy personnel. Incendiary and explosive bombs will be briefly described.

INCENDIARY BOMBS

The bomb illustrated in part section in Figure 138 is of the type used for setting afire towns and military depots. Its metal base diameter is about 10 inches. From this cup base a hollow metal funnel runs through the center to the handle; this is filled with thermite, a composition of finely divided aluminum and a metallic oxid, which on ignition produces heat so intense as to melt steel. A great flare of light is thrown off by the thermite, its heat quickly melting the funnel; the molten metal spreads rapidly as the bomb strikes and sets up at once a fierce fire if it strikes any combustible material.

Another form of incendiary bomb contains a gasoline tank mounted on an arrow shaft which, when the arrow point strikes, sets in motion a wheel which rotates against a ferro-cerium brush, the friction generating a stream of sparks which ignites the gasoline. A powder charge is also exploded, which increases the rate of burning. Fins maintain steadiness in flight and barbs are attached for arresting the arrow's flight when used against airships.

SAFETY DEVICES

Airplane bombs have three safety devices; safety pin, wind wheel, and fuse device, usually a compression spring or resistance split ring. Safety pins are pulled before the bombs are released; wind wheels or revolving vanes usually act in less than 100 feet, preparing the firing pin for action on impact.

EXPLOSIVE BOMBS

In the illustrations above three types of aircraft bombs carrying explosive charges are clearly pictured in section. The action of their safety devices and firing mechanism will be described.

Figure 139—The safety device is operated by the centrifugal forces during the fall, the revolving vane giving the bomb a rotary motion. The firing charge and detonator, placed in the nose of the bomb, are held separate from the firing pin by means of two spring-loaded masses. With increase in centrifugal force to a predetermined point the force of the springs is overcome and the firing charge is free, excepting for two clamps which hold it in place. On impact with the ground these give away and the charge is driven into the firing pin.

Figure 140—This is a somewhat similar type of bomb with a firing mechanism also actuated by direct impact. Friction firing caps ignite the fuse. This illustration shows in detail how the spring is held in check by the safety spindle, or pin, having ball bearings for easy removal before the bomb is released.

Figure 141—The pilot rod in this type of bomb rests in a guide which keeps it from sliding until it is unlocked. Thus the firing charge is kept apart from the explosive charge, minimizing the danger from accidental discharge. Stabilizing fins are mounted on the tail piece.

The horizontal suspension of the bomb from the airplane is shown in the upper view. The release lever automatically removes the safety lock and as the bomb gradually assumes the vertical position the pilot rod slides forward, carrying the firing charge into the center of the explosive charge. The firing pin then slides into position and when the nose of the bomb strikes the ground the pilot rod is driven back in its guide, bringing the firing charge in contact with the pin and percussion cap. The explosion follows. To make certain the sliding forward of the pilot rod the fall of the bomb is retarded by a parachute. Telescopic tubes are substituted for the pilot rod in some models of this bomb, opening to their full length under the speed of the fall.

BOMB CARRIERS AND LAUNCHING CRADLES

Clusters, or racks, are used to carry bombs, ordinarily consisting of six or more bombs. The usual launching cradle is composed of two sets of metal fingers, hinged at the top and pinned at the bottom.

STEEL DARTS

Pointed steel spindles with spiralled tails to give a rotary motion and steadiness in flight are used against massed troops. From 150 to 200 are released at a time. They are non-explosive.

REVIEW QUIZ

Aerial Gunnery and Combat—Bombs and Bombing

1. Give the essential differences between patrolling and sentinel duty for combat airplanes.
2. What effect has technical superiority of airplane and armament? Compare pusher and tractor types for points of combat superiority.
3. Explain why knowledge of the appearance of enemy types of airplane is valuable, how clouds and sun are valued in attack, why knowledge of aerobacy is essential.
4. Describe the operation of the Lewis machine gun in detail; beginning with loading, state the successive operation of the mechanism; explain how the magazine feeds, the ejector operates and how power is developed by the cartridges for successive cycles of operation.
5. Under what conditions of equality of equipment may gunnery skill become the deciding factor in combat?
6. Why is high rate of fire essential to an airplane arm?
7. Describe five common types of bullets used in aerial warfare and give the function of each.
8. Compare the relative advantages of mounting machine guns rigidly on the upper plane and placing them to fire through the propeller. How is the latter accomplished?
9. By several illustrations of machine gun arrangement show how effective angle of fire may be increased.
10. There are ten principles by which skill in attack may be acquired. State them.
11. What is the best method of escape for a single machine attacked by a hostile formation?
12. Explain how captive observation balloons are protected and describe a method of attack.
13. State two reasons why the V-shaped arrangement is preferred for flying in formation.
14. Explain how a turn to the left is executed; describe how the leader signals attention and approach of hostile aircraft.
15. Show by a mathematical calculation under the N-Square Law how superior tactics may cause the defeat of a numerically superior force.
16. Classify flying heights into low, mean and high levels, and state how these apply to the various missions of aircraft.
17. What is contact patrol and how does it differ from combat air patrols?
18. When under fire from anti-aircraft batteries what indicates that the gunners are getting the range? How is escape best effected?
19. What forces tend to destroy the accuracy of fall of a bomb dropped from an airplane?
20. Describe a type of incendiary bomb, an explosive bomb and a safety device.

CHAPTER ANALYSIS

Reconnaissance and Fire Spotting**RECONNAISSANCE BY AIRPLANE:**

- (a) Orders for Reconnaissance Flights.
- (b) Preparations.
- (c) Gathering Information.
- (d) Tactical Reconnaissance.
- (e) Estimates of Enemy Strength.
- (f) Strategical Reconnaissance.
- (g) Preparatory Reconnaissance.
- (h) Reports of Flights.

INSTRUCTION IN CODE TELEGRAPHING:

- (a) The Code.
- (b) Memorizing the Code.
- (c) Proper Grip on the Key.
- (d) Sending.
- (e) Receiving.
- (f) Visual Signaling.
- (g) Proficiency Required.

DIRECTING ARTILLERY FIRE:

- (a) General Considerations.
- (b) Types of Shells.
- (c) Ranging.
- (d) Observer's Map and Code Signals.
- (e) Signals from the Ground.
- (f) Method of Training.

RADIO (WIRELESS) TELEGRAPHY:

- (a) Theory of Radio Transmission.
- (b) Operations in the Circuits.
- (c) Radio Receivers.

AIRPLANE RADIO APPARATUS:

- (a) Generating the Electrical Power.
- (b) Regulating the Power Output.
- (c) Transforming the Energy.
- (d) Controlling the Length of the Radiated Wave.

AERIAL PHOTOGRAPHY:

- (a) The Camera and Its Parts.
- (b) Arrangement of Cameras.
- (c) Photographic Flights.
- (d) Mapping from Photographs.

CHAPTER XV

Reconnaissance and Fire Spotting

Reconnaissance, the military term for the duty of gathering information in the field, represents a large share of the duties assigned to the service of aircraft. In fact, the utility of the airplane for this work may be said to represent its chief value in warfare. Offensives in the air are mainly defensive measures to prevent enemy reconnaissance, and raiding by bombing and in co-operation with land forces in attack, are subsidiary in importance. By and large, the air forces are, and will remain, scouts and informers for commanding officers of troops engaged in land warfare.

All military aviators are charged with reconnaissance; no matter what their duties may be, while in flight they are required to collect all obtainable information of military value.

Aerial reconnaissance presents features which are primarily for specialists, for gathering information of strategical and tactical value is accomplished by devices and methods mastered only by careful study. Artillery control, or fire spotting, is also not a task for the novice, and specially trained men are required. These soldiers of the air are known as observers, and in addition to textbook and class-room study courses, they undergo special training under flight conditions. The latter course begins with visibility tests in clear weather by naked eye, use of field glasses and identification of known objectives and their comparative sizes from successive heights of 1,500, 2,000 and 3,000 feet. These observations are then repeated in unfavorable atmosphere, flying in, below and above broken cloud formations. The altitude is then increased to 5,000 feet; buildings and structures at a given point are sketched on an incomplete map. All roads, trails, bridges and docks within a given area must then be recorded on the map, the tests being repeated at flight altitudes of 6,000 and 8,000 feet. Higher altitudes, 9,000 and 10,000 feet are then sought. Photographic flights are made, flight orders and reports are prepared and a military reconnaissance made over an extended area. Signaling to and from the ground is then practiced and control of artillery fire mastered. The flying course ends with tests showing ability to use the machine gun effectively at targets while in flight. When the observer has completed the course he is able to identify and give the proportions of the following objects: buildings, roads, bridges, wharves and docks, airdromes, aircraft on the ground, trenches, troops, motor cars, wagons and artillery, gun emplacements, mine fields and shell bursts by color and by patterns.

Aside from manipulation of radio (wireless) apparatus, the observer must also acquire proficiency in sending and receiving visual signals, made by lantern, heliograph, searchlight, rockets and the Very pistol, all communicated by dot and dash code. Great technical skill with apparatus and high speed communication is not required, but the diversity of subjects requires the observer to be of a good order of intelligence with highly developed powers of concentration.

RECONNAISSANCE BY AIRPLANE

Reconnaissance by airplane has three distinct classifications: (a) tactical, or the gathering of detailed military information in a limited area while troops are engaged in combat; (b) strategical, or securing of information and general military impressions over an extended theatre of operations; (c) observations for control of artillery fire. The last is actually a separate duty, but is so closely related to reconnaissance that it is best included under that broad head.

ORDERS FOR RECONNAISSANCE FLIGHTS

Orders for a flight may originate with the headquarters staff or the squadron commander, and are preferably written. They contain the serial tactical number of the flight; the airplanes, pilots and observers to participate; the time, place and route, and the mission to be performed. How, when and where the report is to be delivered and its nature, is stated. Ordinarily, the orders are issued sufficiently early so pilot and observer may make a preliminary study of the situation.

PREPARATIONS

Pilot and observer, generally a pair accustomed to working together, immediately on receipt of orders consult together as to the best manner of fulfilling the mission. Route calculations are made from the map, the pilot makes a test and final inspection of his machine and the observer insures that signaling apparatus, note paper, pencils, weighted message bag, field glass, watch, camera and all necessary aids are included in his equipment. The speaking tube, or aviaphone, for their intercommunication is made ready, and a simple code of signals arranged.

GATHERING INFORMATION

The observer's logical position in the airplane is the front one, enabling the pilot to easily watch his signals. When the stated objective, or a position showing activity of military interest, is reached, the pilot manipulates his controls so the best possible view is afforded the observer. Figure 8s, steep spirals and banking are employed, so the observer may make a prolonged observation with vision unobstructed by wings, struts or other parts of the machine. The observer is charged with the gathering of facts; opinions and deductions may be made, but they are always reported as such. Once the necessary data are gathered it is the concern of both pilot and observer to bring back the information safely, high altitudes being sought and combat avoided by flight. Hostile aircraft is engaged only when absolutely necessary.

PREPARATORY RECONNAISSANCE

Preparatory reconnaissance duty, as the term implies, is conducted at the outbreak of hostilities; it is strategical and offensive in character. The objects are to secure all data in connection with the enemy's mobilization, to locate depots and munition bases and plants, to harass and destroy hostile forces by air raids, interrupt transportation and break lines of communication; and, up to the point of concentration and establishment of a theatre of operations, to locate all hostile forces and determine their strength and mobility.

TACTICAL RECONNAISSANCE

Observations to be made on a flight order for a tactical reconnaissance are limited to the immediate area in which hostile forces are in contact. A two-seater airplane with radio and photographic equipment is generally used, and the report comprises detail sketches, the positions of troops and fortified terrain. Reports comprise the following information:

- Troops—Positions, and strength of reserve; movements, enveloping or turning, infantry and cavalry.
- Artillery—Positions and number of guns.
- Field Trains—Positions and movements of combat and field trains behind intrenched positions.
- General—Evidences of strengthening or weakening fortified lines; activities indicating attack in force or retreat.

Tactical reconnaissance in general has two purposes and may therefore be divided into (a) battle, (b) protective.

Battle—Supplying detailed information of all changes and developments during the course of action by which the commanding general may estimate the situation and form decisions. The following information is required: Location of existing and changing trench lines and batteries; changes in tactical disposition and distribution of combat troops; arrival and departure of supporting troops; changes in location of depots, field bases and lines of communication; concealment of new and old positions; movements of artillery, new positions, number and calibers of guns; movements of transport and combat wagons and trains.

Protective—Information similar to the above, but relating both to enemy and friendly forces, is secured in detail during a retreat of friendly forces. The commanding general by this means is enabled to keep his troops under full control and estimate the probable moves of his adversary.

The value of both types of tactical reconnaissance lies principally in the continuity of the reports. Airplanes engaged in this work make brief but regular and frequent observations, working in relays if necessary. From captive balloons, in rear of the actual contact of forces, supplementary and continuous observation is made.

ESTIMATES OF ENEMY STRENGTH

Moving Columns—Quick computation of the approximate strength of columns moving along a road will be facilitated by the following rough calculations:

Infantry in column of squads occupies a depth of about $\frac{1}{2}$ yard per man, a column 1 mile long contains about 3,500 men.

Cavalry in column of fours, about 1 yard per horse, a column 1 mile long containing about 1,500 troops.

Artillery in single file, requires about 20 yards per gun or caisson, field artillery having about 50 guns to the mile.

Estimates of strength may also be roughly calculated by the time taken to pass a selected point. In 1 minute, about 175 infantry will pass; 110 cavalry at a walk, 200 at a trot; 5 guns or caissons. For infantry and cavalry in column of twos, take one-half of these figures.

Confusion of combat troops with transport trains and artillery should be guarded against. Dust clouds will help the identification, if the troops are not distinguishable, thus: infantry dust clouds hang low; cavalry dust clouds are higher and disperse more quickly; artillery and wagons raise dust to unequal heights and of disconnected form.

Reports of marching columns should give the exact location of the troops on the map, the road used, direction and rate of march. Gaps in the column and unusual dispersions should be noted and care exercised that advance, flank and rear guards are not confused with the main body. All troops on foot are considered combat troops. Large commands are accompanied by field trains.

Intrenched Positions—Detailed information of the field works and an estimate of strength with the initial deployment of troops is required.

Trenches—By photography, sketches and notes, complete data on enemy positions are secured. The reconnaissance establishes: the exact line of field works, their depth including reserves, location of lines of communication and field headquarters. Intrenchments under construction are reported during every stage of development and accurately traced and located during and after erection of the camouflage screen. The condition of enemy barbed wire may be estimated by the ground smudges and spots, indicating breaks by shell fire.

Combat Troops—Estimates of strength in the first line are figured as one man per yard. In initial deployments the strength of supports and reserves is of greatest importance, as two-thirds of the force of combat troops are usually held in the rear.

All activities should be noted, including changes in disposition and distribution of troops, location of flank and movements in the rear.

Artillery—Battery sites should be located and all changes reported. When artillery positions are known estimates of gun calibers may be made by the range bursts. The usual maximum for field artillery is 6,500 yards; heavy artillery of medium caliber, 8,500 yards; large caliber heavy guns and howitzers have ranges ordinarily beyond the scope of a tactical reconnaissance.

STRATEGICAL RECONNAISSANCE

The object of strategic reconnaissance is to prevent surprise by the enemy. The term is applied to long flights over wide areas and to considerable depths of enemy territory, observation being made of all hostile movements and developments in the theatre of war. Airplane squadrons or groups with large radius of action are employed at all altitudes from 1,000 to 12,000 feet. Flights for information of strategic importance should be so frequent as to be almost constant, since upon the information thus obtained the commanding general must base his plans for future operations. Photography is extensively employed, but notes and reports are less concerned with details than with general impressions from which the enemy's intentions may be calculated or deduced.

Bases and Supply Transport activities aid in disclosing the enemy's intentions. Railroads, roads, rivers, canals, harbors, depots, airdromes, lines of communication and bases should be under constant observation.

Reconnaissance over wide areas is of greatest value when reports and photographs comprise the details given below.

Railroads—New and old, direction, number of tracks, stations, junctions and spurs; train movements, size, direction, speed and frequency of travel.

Roads—New and old, nature, condition, intersection with railroads, extent and character of traffic.

Bridges—Position, length and breadth, materials and construction, approaches and how screened.

Rivers and Canals—Direction, width and depth, rapidity of current; location, size, number and direction of movement of vessels. Number and location of locks in canals and islands in rivers.

Villages and Towns—Their situation and nature of the surrounding country; construction and type of houses, alignment and width of streets; defenses.

Woods—Situation, extent and shape, number and extent of clearings, nature of roads through them, marshes or ravines within; whether affording cover for artillery or troops.

Marshes—Extent and means of crossing, defensive measures and possible uses.

REPORTS OF FLIGHTS

Reports are required at the conclusion of all flights, whether the nature of the mission is reconnaissance, combat, bombing, or special duty. These are preferably presented on prepared forms, together with maps, sketches and notes. Verbal reports may be made if the need is urgent, but should later be supplemented with a detailed written report at the earliest possible moment.

The observer submits reconnaissance reports. Serial number, time, and similar data which appeared on the order for flight, is filled in; to this is added the data secured, arranged in chronological form, giving the exact time of each observation. Special remarks are added to cover air combat with the enemy and any resultant damage to the airplane. The course followed should be clearly stated, thus: *Cambrai—Denain—Valenciennes—Maubeuge—Aulnoye—le Cateau—Cambrai.*

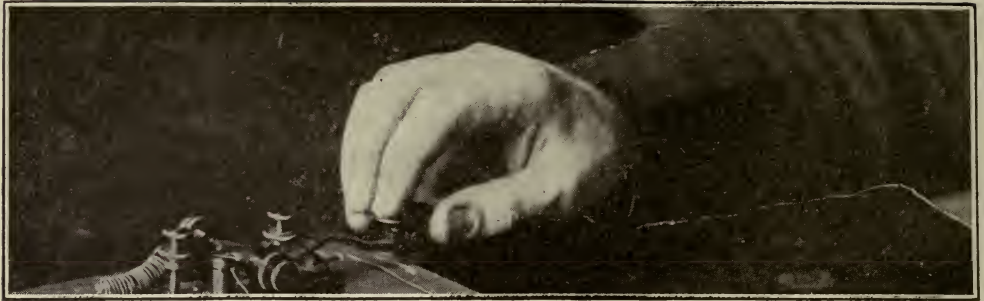


Figure 142—The exactly correct method of gripping the telegraph key

A ● —	B — ● ● ●	C — — ●	D — ● ●	E ●	F ● ● ● ●
G — — ●	H ● ● ● ●	I ● ●	J ● — — — —	K — — ● — —	
L ● ● ● ●	M — — — —	N — — ●	O — — — —	P ● ● ● ●	
Q — — — — ●	R ● — — ●	S ● ● ●	T — — —	U ● ● — —	
V ● ● ● — —	W ● — — — —	X — — ● ● — —		Y — — ● — — — —	
Z — — ● ● ● ●	Wait ● ● ● ● ● ●	Understand ● ● — — — — ● ●		Don't Understand ● ● ● ● ● ● ● ●	
Period ● ● ● ● ● ●		Interrogation ● ● — — — — ● ●		Exclamation — — — — ● ● — — — —	
1 — — — — — — — —		2 ● ● — — — — — —		3 ● ● ● — — — — —	
4 ● ● ● ● — — — —	5 ● ● ● ● ● ●	6 — — — — ● ● ● ●		7 — — — — — — ● ● ● ●	
8 — — — — ● ● ● ●		9 — — — — — — ● ●		0 — — — — — — — —	
Call — — ● ● ● ● — —		Finish ● ● — — — — ● ●		or — — — — — —	

Figure 143—The General Service Code of the U. S. Army, variously known as International, Continental and Wireless Morse



(C) Comm. Pub. Info.

U. S. Army student aviators at a code practice table used for instruction

INSTRUCTION IN CODE TELEGRAPHING

Military aviators are required to attain a fair proficiency in code telegraphy, requiring about 40 hours' study on the average. Application of the dot and dash method of signaling to various forms of electrical and visual devices largely governs communication in the air service and must be mastered. The following text will prove of great assistance in learning code if intelligently used by the student.

THE CODE

Although use of printed code charts which visualize the alphabet is generally forbidden the beginner, experience has proven that, deprived of these, the novice will acquire them somehow, so the General Service Code of the U. S. Army is illustrated in Figure 143. This alphabet is variously known as International Morse, Continental Morse and the Wireless Code. It differs from American Morse principally in the elimination of the spacing between symbols making up a letter.

MEMORIZING THE CODE

The primary rule for success in telegraphing is that the letters must be learned by their sound. Under no circumstances is the student to attempt to visualize each letter by dots and dashes. An excellent method for those who feel the chart essential in the early stages is to pronounce the syllable "tuh" for the initial dot, "duh" for the other dots, and "dah" for the dashes, the letter L, for example, being "tuh dah duh duh." By short periods of practice a sense of the rhythm of the letters is thus acquired. Division of the chart into progressive relationship of dots and dashes has also proved convenient, thus:

E	T — — — — —	A . — — — — —	A . — — — — —	N — — — — —
I	M — — — — —	U :	W :	D
S	O — — — — —	V :	J :	B
H	CH — — — — —			
R	N	Y — — — — —	N G — — — — —	
L	K — — — — —	U	K — — — — —	
P	C — — — — —	F :	C — — — — —	
	X		X	
			Q — — — — —	
			Z	

The rule governing length of symbols is: Dash is three times as long as dot. Space between letters equals duration of one dot.

PROPER GRIP ON THE KEY

Figure 142 illustrates the exactly correct manner of holding the key. The positions of the fingers are relatively the same as for holding a pen or pencil with a diameter as large as the key knob—thumb against side of knob to steady it; index finger convexed or straight—never concaved—and second finger resting easily in position over the key knob. The wrist should be relaxed and an even, light pressure given the key. Tapping should be avoided. Acquiring the correct position for telegraphing is a matter of importance for the novice, as clearness in forming dots and dashes is largely dependent on the action of hand and wrist.

SENDING

Some instructors have stated it inadvisable for the student to take up key manipulation before proficiency in receiving has been acquired. Experience dictates that sending and receiving should be taught together, for the student in early training invariably receives easiest those letters which he sends best.

In sending, dots should be made short and sharp, but firm. The dash is made three times as long as the dot—but not by pressure three times as hard. Spaces between letters are the duration of a dot. In forming letters, combination of dots and dashes should be sufficiently close in succession so the receiver cannot mistake the combination for a somewhat similar letter.

Speed above 10 or 12 words per minute is not required of the military aviator, but absolute accuracy is insisted upon. Not only must letters and numerals be formed perfectly but spacing of groups be equally accurate. Concentration on typical signals from an airplane is advisable, for learning all other phases is lost time from the military aviator's standpoint. Examples follow:

Y W 5 F 7 N 4 S L 2 A C 6 E 9

and so on, in various 5-letter arrangements including numerals. A considerable number of abbreviations and conventional signs are ordinarily appended to the code charts; all of these need not be memorized by the aviator, the following being sufficient:

break — correction

end of message . — ch — — — — —

RECEIVING

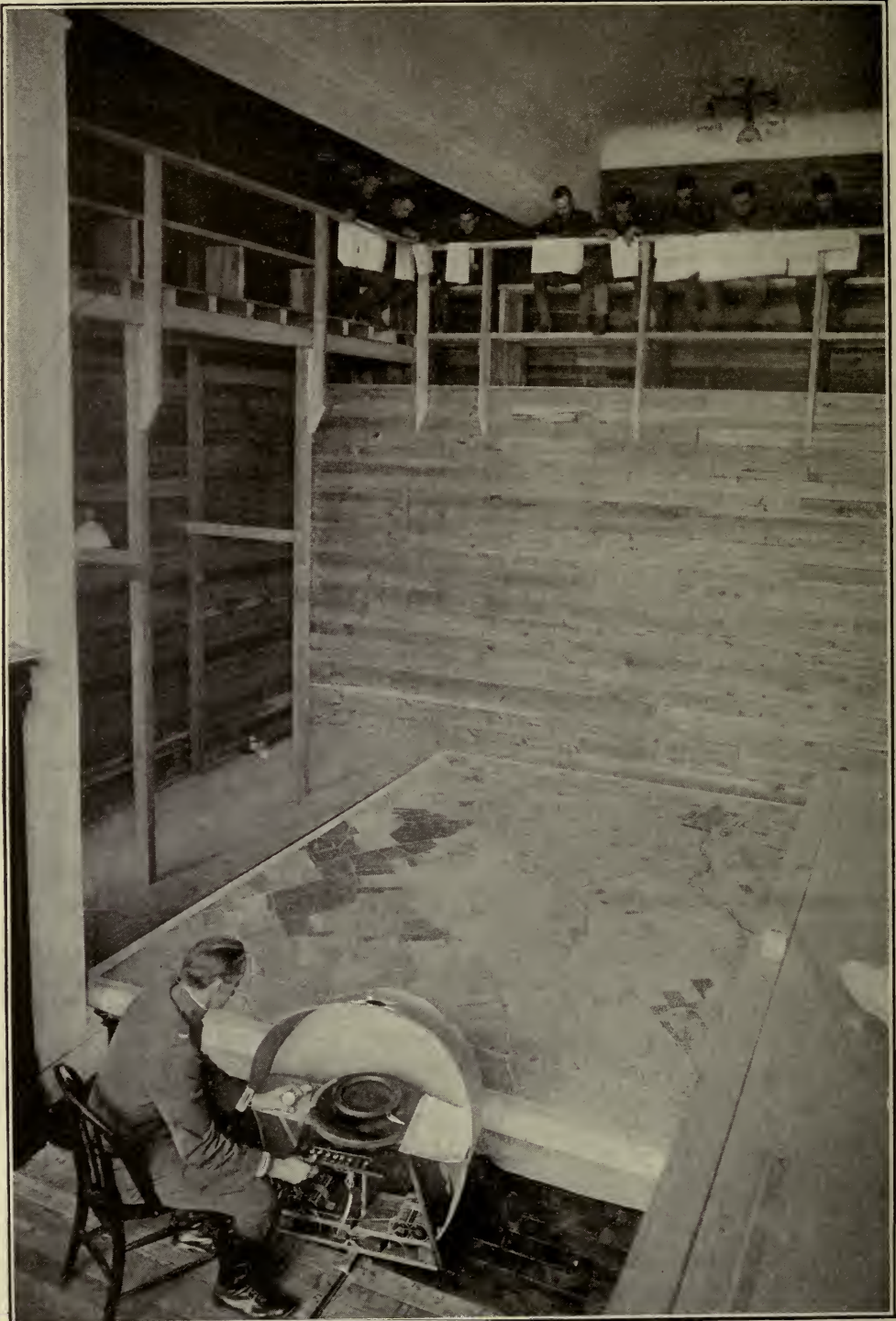
The signals of radio (wireless) and buzzer, with which the airman is concerned, are exactly counterfeited by a little instrument known as a practice buzzer. Where the candidate wishes to prepare himself before going to the army schools—where these signals are received in head telephones at practice tables—the practice sets may be used at home, or the Marconi-Victor special set of progressive lesson records be listened to on a phonograph. Receiving practice is most beneficial when students are paired, alternately sending to each other for 15 minute periods, the faults of one thus being corrected by the other. In writing messages, zero is distinguished from the letter O by placing a dot in its center; the figure 1 is made with a single upstroke so as not to be confused with I. The entire art of receiving rests on the one principle emphasized above—read by SOUND.

VISUAL SIGNALING

The average time devoted to an aviator's buzzer instruction is 34 hours; 6 hours on lamp and panneau (signaling panel) follows, proficiency in visual code work being adequate at 4 words per minute.

PROFICIENCY REQUIRED

The final examination for aviators determines the ability to send and receive 5-letter words at a speed of 8 words per minute for two successive minutes. If more than 6 symbols are received incorrectly, or more than 5 sending mistakes are made, the applicant has failed in the test. In sending, an interval omitted or misplaced is an error.



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The air service cadets in the gallery are simulating all the conditions of an aerial observer looking down from a plane 6,000 feet high, on a part of a typical earth view reproduced in the map below. The instructor in the lower forefront is flashing various colored lights, representing various kinds of artillery fire

DIRECTING ARTILLERY FIRE

Regulation of artillery fire by observers in airplanes is now considered indispensable in warfare, aerial fire correction having practically superseded all other methods. Fire spotting, while distinct in many ways from the scouting duties of reconnaissance, is closely related to tactical operations and is therefore included under the broad classification.

Since the airplane observer, by S-turn and circle, hovers over the target, a comparatively low-speed machine is preferred; it is generally a two-seater, carrying pilot and observer. Wireless, or radio telegraphy, is the principal means of communicating the correction for the artillery and has almost entirely replaced former means, such as lamps and smoke bombs. Observers for artillery usually work in two-hour tours, twice a day, observations being made at 6,000 to 7,000-foot altitudes. They are required to know something of types of artillery, shells and their trajectories, be able to distinguish distances and characters of shell bursts by the smoke puffs and, of course, understand the manipulation of radio transmitting apparatus.

METHOD OF TRAINING

The photograph on the facing page clearly shows how artillery fire spotting is taught. The student observers are seated in a gallery looking down on a relief painting which visualizes a sector of the earth as it appears at an elevation of 6,000 feet. By a switchboard, the instructor flashes various colored lights, representing various shell bursts; these blink successively at numerous points on the miniature battlefield, for the entire area is wired with small electric lamps. The students locate the flashes on their maps and record the required signals, the simulated artillery fire being varied in speed by the instructor's stop watch.

TYPES OF SHELLS

Artillery shells are (a) common, (b) high explosive, (c) shrapnel. High explosive shells produce black smoke when they detonate, and greenish-white smoke otherwise. Shrapnel gives off a white smoke pattern, easily seen when the shell bursts in the air, but difficult to observe when the shell is exploded by contact with the ground. Both time and percussion shells are used. The degree of accuracy required in striking the target is greater with the high explosive shell, as its effect is limited to less than 10 yards, although causing very great damage within that area. Shrapnel, on the other hand, is most effective when it bursts above the ground; when time fuses are used the shells explode in the air about 25 to 75 yards short of the target.

RANGING

The observer is told before leaving the ground whether the correction to be made is for a single gun or an entire battery, whether the fire is to register positions or for destruction, and whether correction is to be given for line (right and left) range (over and short) and fuse (burst) or all three, and in what order.

One of the principal objects of the flight is the disclosure of new enemy batteries and the location of screened or camouflaged positions. When the target has been determined and shelling begun, the result of the fire is reported by wireless by a pre-arranged code. These codes vary in detail and are changed from time to time to maintain secrecy, but all forms require use of small divisions of the military map.

OBSERVER'S MAP AND CODE SIGNALS

The map of the sector which is carried by the observer corresponds exactly with the one to be used by the artillery. It is usually on a large scale, say, 3 inches to the mile. Divisions into squares are made so that smallest squares cover a very small area of ground, enabling corrections to be made with amazing accuracy. How the map is divided may be understood by careful reading of the following explanation, which considers the map in an initial division into squares, and three subdivisions into progressively smaller squares.

Division—The map is divided into 24 equal squares, in 4 horizontal rows, 6 squares to a row. Each section is marked, progressively from left to right, with a letter of the alphabet. These letters are Capitals, *A* to *X* inclusive.

1st Subdivision—Each of these lettered squares is subdivided into smaller squares, the top row (*A* to *F*) and the bottom row (*S* to *X*) having 30 sections, or 30 small squares; the two inside rows (*G* to *R* inclusive) are subdivided into 36 small squares each. These small squares are given a number, 1 to 30 for those in the top and bottom rows, 1 to 36 for those in the inside rows. Thus the original square *A*, for example, is now divided into 30 sections, numbered, left to right, from 1 to 30. Squares in the inside rows, *G*, for example, are divided into 36 numbered squares; 1 to 36 inclusive. The map which was first divided into 24 squares (*A* to *X*) now, therefore, has a total of 792 divisions.

2nd Subdivision—Each of these 792 small squares is divided into 4 parts, lettered *a*, *b*, *c*, *d*. The map consequently shows a division thus far into 3,168 small squares.

3rd Subdivision—Each of the 3,168 lettered squares (marked *a*, *b*, *c*, *d*,) is further divided into 24 equal sections, these still smaller squares being each given a number from 1 to 24. The total division of the map is thus seen to be into 76,032 squares, each of which represents a very small ground area.

The signaling is simple. A shot is fired and the point where it strikes is located on the map by the observer. He finds it has landed in the division *A*, in its lower right hand corner; say, square 30. This square being divided into 4 sections, he notes that the shell has struck in the second square *b*, and since the exact location of its striking point there is in the upper left hand corner, he notes the designation of that particular square, the numeral 1. He flashes by radio to the artillery, therefore, the following message: *A-30-b-1*. From this message the artillery man can locate the point where his shell struck with almost minute accuracy. For if the observer's sector comprises as much as 6 square miles, he has given the location within a section of about 9 yards dimension.

A high explosive shell or a shrapnel shell dropping within this distance of the target will have the desired destructive effect. It follows, of course, that if the area of the sector under observation is reduced and the scale increased, the location can be determined to pin-point exactness.

Owing to the comparatively small size of the page in this book, it is not practical to illustrate the division of the map by a diagram, but the student may easily visualize the map division into squares by laying one off on a large sheet, and following the description.

Another method of signaling the results of shots fired at a definite target is known as the clock system. By this method the point where the shell strikes is communicated relative to the target. Only one letter and one numeral are required.

The dial of a clock is divided into points of the compass: 12 being north; 6 being south; 9, west; and 3, east. The target is the center of the dial. From this center equally spaced circles radiate outward. These circles represent, say, 10 yard intervals; they are progressively lettered, *A*, *B*, *C*, *D*, etc. Thus the signal 3-C would mean that the shell struck 30 yards east of the target. For 3 is east on the clock dial and *C* being the letter of the third circle from the center, and each circle being spaced 10 yards apart, $3 \times 10 = 30$ yards.

This system is susceptible of almost innumerable changes, as the relative compass positions merely have to be shifted to other numerals on the clock dial, and the interval between circles be given a different value in yards or feet.

As more than one observer may be using the clock system at the same time in nearby localities, each battery has a code symbol, frequently changed, which the observer calls before sending his fire correction.

SIGNALS FROM THE GROUND

When fire is centered on a target or the objective destroyed the aviator is given a new position by signals from the ground. These are generally of visual character, although the remarkable development of radio promises wireless reception by the airman in the near future.

The usual means employed for visual communication are shutter panels, lanterns or heliograph mirrors; by these, lettered abbreviations are signaled in telegraph code; or 3 white canvas strips measuring 15 x 3 feet are laid on the ground to form various characters with predetermined meanings. Thus *X* might mean "Commence observing for range"; *V*, "Go out"; *I*, "Come in"; *N*, "Cannot comply with last signal" or "Distress"; *T*, "Turn"; *H*, "Incline to the right"; *L*, "To the left"; *II*, "Descend"; *III*, "Observe for burst," etc., etc. These meanings and arrangements of the 3 strips are obviously easy of variation to maintain secrecy.

Radio messages should not be sent while the airplane is turning.

Sending with the machine pointed toward the ground station facilitates easy reception.

RADIO (WIRELESS) TELEGRAPHY

Extensive knowledge of radio, or wireless telegraph sets is not required of the military aviator, except for those who specialize in this art, in which case full knowledge of theory and practice is essential.* All aviators, however, in addition to skill in code sending, must have some knowledge of the parts and connections of the apparatus. An outline of the theory of radio and a brief description of a typical airplane wireless set will therefore comprise the limited discussion here.

THEORY OF RADIO TRANSMISSION

A radio sending set comprises an assembly of electrical devices which generate and control an electrical wave motion, so that when the circuit is interrupted disturbances are created in the ether in the air, of long and short (dot and dash) duration. These disturbances, or waves, may be compared to the radiating ripples caused by a stone dropping into water, excepting that they travel in the ether with the speed of light, 186,000 miles per second. Reception of signals is possible only through properly attuned electrical apparatus; viz., the radio receiving set. Thus radio transmission might be further comparable to the voice, as a transmitter, sending vibrations of varying intensity in waves through the air, registering only on attuned ears, the receiver.

Easiest understanding of the apparatus which comprises a radio transmitting set is gained by classifying according to their functions in utilizing electrical energy, the respective missions being: (a) generation, (b) regulation, (c) transformation, (d) control.

Before considering these in classification and in their relation to each other, a few electrical definitions are necessary.

VOLT—The unit of pressure, or electromotive force.

AMPERE—The unit of current flow, comparable to gallons of water flowing through a pipe, or revolutions of an engine, per second.

KILOWATT (Kw.)—The unit giving the power required for specified work in a given time (Kw.= volts + amperes).

DYNAMO—A mechanically driven machine which rotates a wire coil within a magnet, the resulting induced current, or electromotive force, being collected by brushes.

DIRECT CURRENT (D.C.)—An electrical current constant in direction.

ALTERNATING CURRENT (A.C.)—A current changing rapidly back and forth from positive to negative direction.

OPERATIONS IN THE CIRCUITS

Tracing the current through its successive movements in the airplane radio transmitting set is made easier by classification of apparatus into four divisions by function:

GENERATION—A small air screw, placed at the front of the airplane and rotated by the wind when the craft is flying, supplies the mechanical force which drives the dynamo. Direct current (D.C.) is thus produced. But direct current cannot be transformed to the high voltages (pressure, or electromotive force) necessary to transmit the radio signals through space, so alternating current (A.C.) is produced in a special dynamo, or alternator.

Both D.C. and A.C. dynamos are usually contained in the same pear-shaped case, the D.C. current being required to excite the coils of the A.C. dynamo, or alternator. The combined apparatus is known as a separately excited alternator.

Sets used on training planes often have storage batteries in place of the D.C. dynamo.

REGULATION—A coil of wire, known as a resistance coil, or field resistance, allows the power output of the alternator to be varied by setting sliding contacts so as to include many or few turns of resistance wire.

TRANSFORMATION—The amount of alternating current selected then goes to the transformer, where the low voltage is converted into high voltage A.C.

The high voltage current then feeds to the condenser, where the electrical energy is stored up in the spaces between plates made of copper or some conducting material. This current discharges periodically (usually 1,000 times per second) through the oscillation transformer and across the spark gap.

The oscillation transformer regulates the condenser discharges of the current to frequency desired, by variation of the number of turns of copper ribbon of which it is composed.

The spark gap acts as a valve, discharging the condenser when the telegraph key is depressed, causing an electrical spark to jump across the gap between its two terminals.

When, by pressing the telegraph key, the flow of current through the circuit of the spark gap is interrupted, the current goes to the aerial or antenna (a wire trailing from the airplane), and part of its energy is radiated into space in the form of electro-magnetic waves. These electrical displacements are long and short according to the sequence of dashes and dots made by the key.

CONTROL—It is obvious that without means provided for regulating the length of the radiated wave, there would be conflict between a number of wireless messages hurtling through space, the dots and dashes would be confused and could not be understood. Therefore, radio sets send their signals out in selected, definitely measured, **WAVE LENGTHS**.

The control devices used for this purpose are: the oscillation transformer, already referred to, the aerial tuning coils and the variometer. The aerial tuning coils, by increasing or reducing the number of turns of wire placed in the aerial circuit, lengthen or shorten the radiated wave. The variometer (consisting of two coils opposed to each other) permits a finer adjustment of wave length than the aerial coils alone could give.

Wave lengths are measured in meters. Placing a wave length changing switch to the desired numeral on a dial sets the control devices for the operator. An aerial ammeter, by its needle indicator, shows whether the flow of electrical energy is at maximum for the radio set's best operating efficiency.

RADIO RECEIVERS

Description of the construction and operation of radio receiving sets will not be included here, as at present the military aviator is not concerned with their manipulation. The day is not far distant, however, when wireless telegraphy and telephony will take the place of visual communication to aircraft, and for those who wish to specialize in radio, time will be well spent in study of receiving apparatus. Space limitations do not permit discussion of receivers here, but excellent textbooks which go exhaustively into the subject, may be secured at low cost.

* Practical Wireless Telegraphy, by Bucher, is the most suitable textbook, in the Author's opinion.

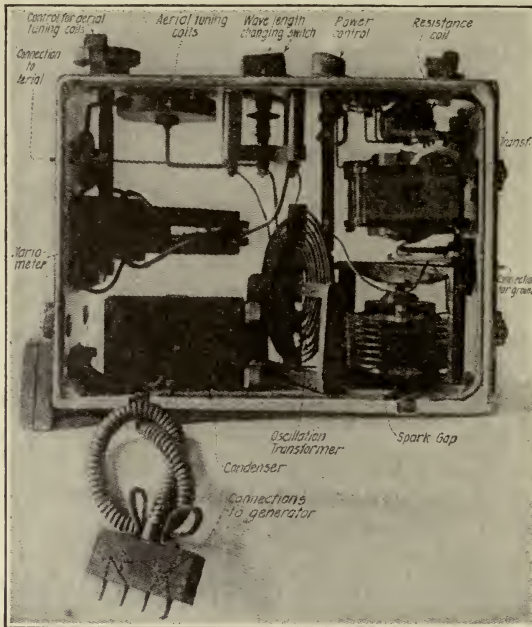


Figure 144—View of the interior of a typical airplane radio transmitter

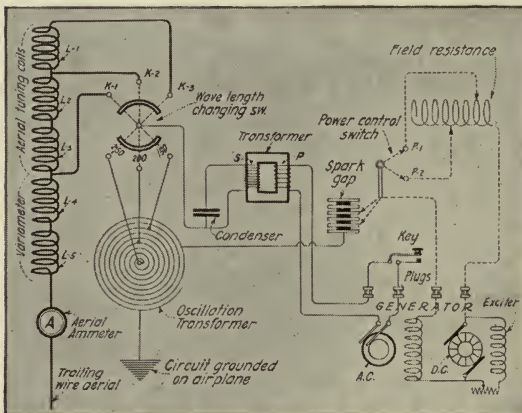


Figure 145—Diagram of the circuits of the radio transmitting set shown above

AIRPLANE RADIO APPARATUS

Great advances have been made in the design of radio apparatus for airplanes, and sets remarkable both for mechanical and electrical perfection are now in use in warfare. For military reasons, these cannot now be described. The aviator, being concerned with knowledge of fundamentals only, may acquire these from the transmitting set pictured in photograph and diagram on this page. It is of enemy manufacture, and a fair specimen of short-range radio apparatus used on military airplanes.

The generator is not shown, as it is of the usual type, but the photograph of the set's interior, Figure 144, clearly identifies the various parts of the sending apparatus. The diagram of connections, Figure 145, is arranged for easy reference, the course of the electrical current, as given in the description following, being in a general direction from right to left.

The classification scheme, outlined on page 179, is applied to the apparatus as follows:

GENERATING THE ELECTRICAL POWER

Referring to the lower right of the diagram, the exciter (a small generator) furnishes initial current to the field magnets of the D.C. dynamo; the latter in turn supplies field current required by the alternator (A.C.). All of these comprise the generating unit, which is mechanically driven by a small air screw, as explained on page 179. The current is delivered by the generator at pressures from 110 to 500 volts, oscillating at 150 to 500 cycles per second.

REGULATING THE POWER OUTPUT

Regulation of the generator's output (110 to 500 volts) is secured by the field resistance coil (upper right of diagram). This generator control circuit is indicated by the broken lines.

TRANSFORMING THE ENERGY

The alternating current flowing from the generator (A.C.) enters the transformer (center of diagram) by the primary coil (P). This coil consists of a few turns of coarse wire wound about an iron core. The core also has a second winding of finer wire and greater number of turns, known as the secondary (S). The current surging through the primary (P) "steps up" the current in the secondary (S) to 10,000 to 15,000 volts, the electromotive force necessary for this particular type of set to transmit radio signals.

This high voltage current then enters the condenser, where it is stored up temporarily, the condenser discharging periodically (as explained on page 179) through the oscillation transformer across the spark gap.

When the telegraph key is depressed, the alternating current (oscillating at high frequency) is discharged from the condenser across the spark gap, which suddenly quenches out the current flow in the circuit, including the condenser, oscillation transformer and the spark gap. This transfers (by electromagnetic induction) the current to the circuit, oscillation transformer-AERIAL. The energy is then radiated from the aerial into space as an electric wave motion. Long and short pressure on the key thus releases the energy in dashes and dots of the code. The aerial is a lightly weighted trailing wire which passes through the floor of the fuselage and is unwound to the required length from a reel operated by a clutch.

CONTROLLING THE LENGTH OF THE RADIATED WAVE

It has been explained that to avoid conflict of many wireless messages in the air at the same time, the electromagnetic waves are measured in definite wave lengths. The radio transmitting set illustrated is designed to send its message on three wave lengths, 150 meters or 200 meters or 250 meters. This means that the operator on the ground who is to receive the aviator's wireless message will attune his set to one of these waves, selected according to the interference prevailing and the distance to be spanned.

Adjusting the various parts of the apparatus so the radiated wave will have the desired length is accomplished by setting knobs and switches on the top of the transmitter case. It is the principal adjustment required of the operator, and the resultant action in the circuits is the most difficult for the student to understand.

First it must be known that the length of the wave radiated from the aerial has direct relation to the frequency of oscillation of the current flowing in it. That is: wave length = the velocity of electricity ÷ the frequency of the currents in the aerial. Since electricity travels at 300,000,000 meters per second, if it is determined that the current in the aerial is oscillating at 1,000,000 cycles per second, then $300,000,000 \div 1,000,000 = 300$ meters, the wave length radiated. Since the set illustrated in the photograph is designed to radiate wave lengths of 150, 200 and 250 meters it is seen that the frequency of oscillation of the currents in the aerial must be: 2,000,000 for 150 meters; 1,500,000 for 200 meters; 1,200,000 for 250 meters.

For successful operation with this extremely high frequency the rate of current oscillation must be the same in the certain parts of the apparatus which comprise the radio set.

Recalling that depressing the key transfers the current from condenser and spark gap to the aerial, two natural divisions of the complete circuit are evident, viz:

Closed Circuit—Condenser-spark gap-oscillation transformer.

Radiating Circuit—Oscillation transformer-aerial tuning coils-aerial and grounded circuit.

These are termed the radio frequency circuits of the transmitter. To regulate the currents in these circuits so that their frequency is identical in both is the principal function of most of the apparatus which comprises the radio set. Adjustment of the two circuits to the required resonance will be described:

CLOSED CIRCUIT

The operator turns the knob Power Control (seen in the photograph, Figure 144, on top of the cabinet a trifle on the right of center). This simultaneously controls the output from the motor generator and the number of plates of the spark gap to be connected in the circuit. The diagram, Figure 145, shows how this is accomplished. The control rod when turned to the position P-1 leaves only a few turns of wire in the field resistance coil to oppose the current from the exciter of the alternator, a larger proportion of its current output being thus obtained. At the same time the control has acted on the spark gap, cutting in most of its plates. When the control switch is thrown to position P-2, exactly the reverse happens: More turns in the resistance coil oppose the flow of current from the exciter, and less plates in the spark gap are left in circuit. The balance of adjustment for the closed circuit is made by the wave length changing switch (center top of cabinet in the photograph) which, as shown in the diagram, cuts in a fixed number of turns of the oscillation transformer when the switch is set to the selected contacts marked for 150, 200 or 250 meters.

RADIATING CIRCUIT

It should be noted that the oscillation transformer also aids the adjustment for resonance between the closed and the radiating circuits. The diagram shows how additional closeness of adjustment is obtained in this circuit. The aerial tuning coils L-1 and L-2 and L-3 connected to the contacts K-1, K-2 and K-3 add the necessary turns for a progressive increase in wave length as the switch is moved on the contacts from 150 to 200 or 250 meters. The fine adjustment for complete resonance is obtained by the variometer coils, L-4 and L-5, which, when placed near or drawn away from each other, have the same effect as cutting in or out turns of coils L-1, L-2 and L-3. When the set is put into operation, the wave length desired is obtained by turning the knob controlling the aerial tuning coils (in the photograph, top left) until the ammeter's needle gives the maximum reading.

To the novice, wireless telegraphy and the apparatus used appears heavily technical. But a large part of the mystery will disappear if the aviator carefully re-reads the outline of the theory contained on this page and page 179, referring constantly to the diagram and bearing in mind the divisions made of the apparatus according to function.



(C) Int. Film Svee.

This remarkable airplane picture, considered by the military experts to be among the greatest ever taken, shows one of the biggest concentration camps at which munitions and men were assembled for the 1918 spring drive of the Germans. Here is the official report of what the picture shows: 1—Supply railway trains running on newly laid tracks. 2—Piles of supplies, chiefly timbers for use in building dugouts. 3—Rolls of barbed wire. 4—Piles of iron stakes for stringing barbed wire. 5—Steel roofing for dugouts.



6—Site of railway station. Note big shell craters (about sixty feet across) caused by 420 M.M. shells. 7, 8, 9—Remains of former railway tracks where they entered railway station. 10—Broken ties of former railway tracks. 11—Other supplies piled up. Perishable goods covered over with tent cloth. 12—Battery of four guns, with abris for gunners. 13—Commander's dugout. 14—Ammunition park. Note enemy soldiers standing around, 15—German soldiers standing in the road watching the airplane.

AERIAL PHOTOGRAPHY

Reconnaissance photography from airplanes is a tremendously important branch of the air service. Military maps upon which offensives are based are assembled from prints of various small sections of the theatre of operations, disclosing to the commanding general the exact location of all enemy batteries, entrenchments and fortified positions, lines of transport and communication. By constant activity the camera men keep these maps accurate up to within a few hours. Expertness in photography requires considerable study and practical experience; but such skill is required only of specialists. Military observers and pilots are ordinarily required merely to arrive over the objective and snap the camera's shutter. Some knowledge of photographic fundamentals will be found useful, however.

THE CAMERA AND ITS PARTS

Camera—A light tight box with a lens at one end and a support for films or plates at the other. By means of a shutter objects are projected through the lens on the sensitive film for fractional intervals of time. Bellows, for folding the camera to smaller dimensions; stops, for regulating the projected rays, and various other attachments, are auxiliary devices. In airplane photography there are two main types of cameras, (a) automatic, (b) pistol. The automatic camera has regulating attachments which, when started, automatically make a series of consecutive views of the course of flight over the selected locality. By means of a guide line the points of union of two adjacent views is indicated, and from the focal angle of the lens and the altitude when exposure was made, a scale of distances is computed. The pistol type has the general form of that weapon and a trigger-operated shutter. It is used in flight for taking close-up photographs of enemy airplanes, from which construction details of new types may be secured. For training in aerial gunnery the pistol type of camera is also useful, being mounted rigidly on the plane and directed at other machines in flight, guide lines on the developed picture indicating the accuracy of aiming.

Finder—A ground glass panel which indicates the limits of the camera's field of vision, generally placed at the rear end of the camera or between and below the aviator's feet.

Lens—Curved and transparent glass arranged to cause the luminous rays to either converge or diverge on the film or plate. Lenses are (a) single, (b) double, (c) anastigmat. The latter have superiority over the others in illuminating and converging power and highest correction.

Stops or Diaphragm Openings—The device which regulates the converging of the rays of light at or near the center of the lens, smaller openings cutting off other rays of light and making sharper and clearer images on the picture. Knowledge of the correct use of stops is essential to good photography.

Films and Plates—These are strips of celluloid or glass plates coated with a film of salts sensitive to the chemical action of light. The emulsion is composed of salts of silver, bromide of potassium and gelatine. After exposure to the light, the bromide of silver is changed to a state where that part of the coating exposed, when placed in a solution known as developer, takes the form of metallic silver having a dark color. Introduction of a fixing solution (hyposulphite of soda and water) dissolves all the bromide of silver excepting the dark silver salts which carry the image of the object revealed by the exposure. This image appears as a negative, the same chemical actions transferring its dark portions to lighter ones on the photographic print paper.

ARRANGEMENT OF CAMERAS

In airplane photography for military purposes a favored arrangement provides for three cameras pointing downward, the field of vision of each ending precisely where its predecessor begins, affording a panoramic view of the locality photographed. The control is automatic; the three shutters operate by a push button, pressure of a lever forward then removing the plates from the cameras. The same lever, pulled back, inserts the new plates and makes all ready for the next exposure.

PHOTOGRAPHIC FLIGHTS

Two or three times a day during the progress of hostilities, reconnaissance airplanes fly over the enemy territory to a depth of 10 to 15 miles, being engaged in photographic work sometimes 6 hours per day. Two types of airplanes are used; the two-seater with a speed of 120 to 140 miles per hour, escorted by a formation of fast combat machines, and the single-seater, which goes out with small combat patrols of three or four planes. The convoys are piloted by highly trained specialists in formation flying and air tactics. Prescribed actions for each machine in the formation are executed on a single signal to meet almost any form of attack; all of these evolutions have for their object the protection of the photographing airplane, the chief duty of the escort being to shield the reconnaissance machine during the entire journey. Photography from single-seaters in small groups is of a scouting nature, to keep the maps at headquarters up to date.

Military information contained in photographs made in the air is generally superior to the reports possible when only the naked eye is employed. Minute details, such as wagons on roads, are revealed in exposures made at 12,000 to 15,000 feet. Rain, thick mist and low-hanging cloud masses present conditions which make air photography usually impossible, but certain forms of mist impenetrable to the eye will be pierced by the camera lens. Best conditions are represented by clear skies or high cloud masses which reflect the light down. One of the special values of reconnaissance photographs is in revealing camouflage. Twin prints placed in a stereoscope show the solid objects in their proper perspective, whereas the overhead camouflage cover appears flat.

MAPPING FROM PHOTOGRAPHS.

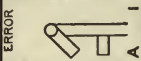

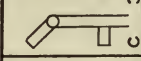
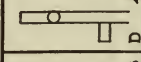
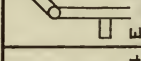
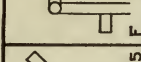
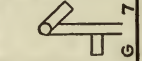
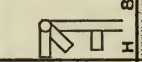
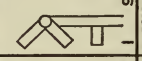
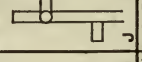
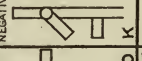
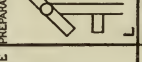
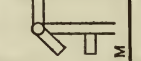
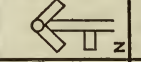
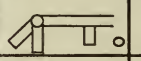
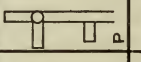
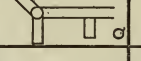
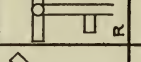
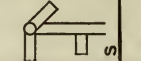
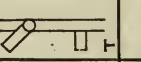
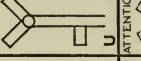
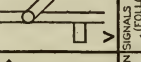
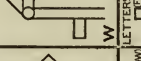
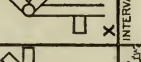
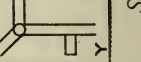
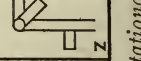
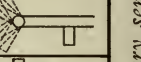
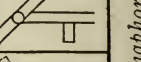
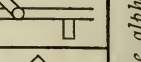
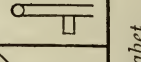
Immediately upon landing, the laboratory men dismantle the cameras or secure the plates or films and rush with them to nearby developing rooms mounted on motor trucks. Within 15 minutes the negatives are developed. Without waiting for prints, the negatives are placed in a stereopticon or balopticon lantern and thrown on a screen. If the magnified view discloses a new enemy position, its location is quickly given to the artillery commander. Prints meanwhile are rushed to headquarters where a group of experts reduce them to scale, determine the overlapping lines and paste them together to form a photographic map. These maps show every detail of the enemy terrain and skilled artillery observers with magnifying glasses search them for all indications of new military works of importance. Scouting trips provide the pictures which keep the map continuously correct to within a few hours.

The wide area which may be mapped by airplane photography may be appreciated by consideration of the field of vision of a camera. This is determined by the altitude, an 8-inch lens at a height of 10,000 feet, for example, having a field of more than a square mile.



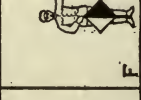
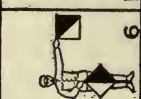
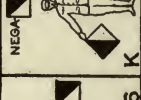




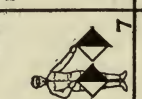
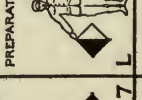


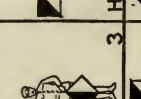

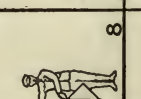
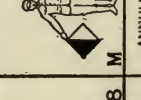





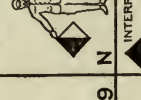



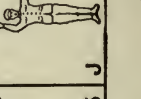

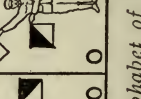

REVIEW QUIZ

Reconnaissance and Fire Spotting

1. What preparations are required of pilot and observer immediately upon receipt of orders for a reconnaissance flight?
2. State the difference between a strategical and a tactical reconnaissance.
3. About how many men will be in a column of infantry a mile long, marching in column of squads? Cavalry, in column of fours? How many of the infantry will pass a selected point in one minute? How many of the cavalry?
4. State in detail the data required by the various headings of a reconnaissance report.
5. Explain what is meant, in ranging for artillery, by the corrections for line, range and fuse.
6. How are observers' maps divided for location of objectives and why are both letters and numerals used?
7. Describe the clock system of reporting shell hits.
8. Give the direction of airplane flight which is most favorable for sending radio signals. During what airplane movement should they be suspended?
9. How must the letters of the telegraph code be learned?
10. What is the proper position of the hand on the key?
11. Give the rule which governs the lengths of the dot and the dash.
12. Give the abbreviations for "break," "correction," "ch," "end of message."
13. Explain how the image is registered on a photographic film or plate.
14. State the atmospheric conditions favorable and unfavorable to aerial photography.
15. How are photographs employed to disclose camouflage?
16. Classify the parts of a radio set into four divisions by function.
17. Why must the high frequency current be regulated so the radiated wave will have a definite wave length?
18. For generation of current for the airplane radio set described, why are both D. C. dynamo and A. C. dynamo required?
19. What is the difference between a closed circuit and a radiating circuit?
20. What is meant by resonance between these two circuits and which parts of the apparatus establish it?

					
A	B	C	D	E	F
					
G	H	I	J	K	L
					
M	N	O	P	Q	R
					
S	T	U	V	W	X
					
Y	Z	ATTENTION SIGNALS (FOLLOW)	ATTENTION SIGNALS (FOLLOW)	ATTENTION SIGNALS (FOLLOW)	INTERVAL
ERROR	A	B	C	D	E
NEGATIVE	F	G	H	I	J
PREPARATORY	K	L	M	N	O
ACKNOWLEDGE	P	Q	R	S	T
ANNULING	U	V	W	X	Y
INTERROGATORY	Z	INTERVAL	NUMERALS (FOLLOW)		

Stationary semaphore alphabet

					
A	B	C	D	E	F
					
G	H	I	J	K	L
					
M	N	O	P	Q	R
					
S	T	U	V	W	X
					
Y	Z	ATTENTION	ATTENTION	ATTENTION	ATTENTION
NEGATIVE	PREPARATORY	ACKNOWLEDGE	ANNULING	INTERROGATORY	
ERROR	A	B	C	D	E
NEGATIVE	F	G	H	I	J
PREPARATORY	K	L	M	N	O
ACKNOWLEDGE	P	Q	R	S	T
ANNULING	U	V	W	X	Y
INTERROGATORY	Z	INTERVAL	NUMERALS (FOLLOW)		

Alphabet of two-arm semaphore with flags

APPENDIX

Nomenclature for Aeronautics With the French Equivalents and Phonetics

The following glossary of terms will serve as a guide to the new and peculiar language of aeronautics. The definitions are largely taken from those prepared by the National Advisory Committee for Aeronautics.

The French equivalents and phonetics for pronunciation have been checked by French aviators. No key is needed; where it has been possible to give the sound by a short word or syllable, such as "day," it is so given. Perfection in phonetics is impossible of achievement, for the reason that there are sounds in French which have no equivalent in English. But if the words are spoken as they read, no difficulty will be experienced in being understood. Where the small *r* and *ng* appears above the line, it indicates that the reader prepares to sound the word or syllable with the *r* or *ng* included, but cuts off the *r* or *ng* before it is actually spoken. This gives the peculiar sound to French words which is erroneously termed nasal. Those who speak English will have principal difficulty in pronouncing syllables which are here given phonetically as *eur*, *deu*, *peu*. The exact sound is difficult of accomplishment without practice to develop the vocal chords. But it can be mastered to entire satisfaction if the lips are pursed as for whistling and held firmly while an attempt is made to sound the letter *E*.

Aerofoil *Aérofoil* (m) (ah-ay-roh-foahl): A winglike structure, flat or curved, designed to obtain reaction upon its surface from the air through which it moves.

Aileron (Wing Flap) *Aileron* (m) (ay-le^r-roh^{ng}): A movable auxiliary surface used to produce a rolling motion about the fore and aft axis.

Aircraft *Aéronef* (m) (ah-ay-roh-neff) Any form of craft designed for the navigation of the air—airplanes, balloons, dirigibles, helicopters, kites, kite balloons, ornithopters, gliders, etc.

Airplane } *Aéroplane* (m) (ah-ay-roh-plahn): A form of aircraft heavier
Aeroplane } than air which has wing surfaces for support in the air, with stabilizing surfaces, rudders for steering, and power plant for propulsion through the air. This term is commonly used in a more restricted sense to refer to airplanes fitted with landing gear suited to operation from the land. If the landing gear is suited to operation from the water, the term "seaplane" is used. (See definition.)

Airplane, Pusher *Aéroplane à hélice arrière* (m) (ah-ay-roh-plahn ah ay-leece ah-ree'air): A type of airplane with the propeller in the rear of the wings.

Airplane, Tractor *Aéroplane à hélice avant* (m) (ah-ay-roh-plahn ah ay-leece ah voh^{ng}): A type of airplane with the propeller in front of the wings.

Air-speed Meter *Mètre à vitesse* (m) (met'trah'vee-tess): An instrument designed to measure the speed of an aircraft with reference to the air.

Altimeter *Altimètre* (m) (ahl'tee'met'r): An aneroid mounted on an aircraft to indicate continuously its height above the surface of the earth.

Anemometer *Anémomètre* (m) (ah-nee-moh-met'r): Any instrument for measuring the velocity of the wind.

Angle *Angle* (m) (au^{ng}gel): Angle.

- Angle of Incidence** *Angle d'incidence* (m) (au^{ng}gel den-see-daunce): The acute angle between the direction of the relative wind and the chord of an aerofoil; i. e., the angle between the chord of an aerofoil and its motion relative to the air. (This definition may be extended to any body having an axis.)
- Angle, Critical** *Angle d'attaque* (m) (au^{ng}gel dah'tack): The angle of attack at which the lift curve has its first maximum; sometimes referred to as the "burble point." (If the "lift curve" has more than one maximum, this refers to the first one.)
- Angle, Gliding** *Angle de descente* (m) (au^{ng}gel de^r day'saunt): The angle the flight path makes with the horizontal when flying in still air under the influence of gravity alone, i. e., without power from the engine.
- Appendix.** *Appendix* (m) (ah-pau^{ng}dix): The hose at the bottom of a balloon used for inflation. In the case of a spherical balloon it also serves for equalization of pressure.
- Aspect ratio** *Allongement* (m) (ah-lóngé-mau^{ng}): The ratio of span to chord of an aerofoil.
- Aviator** *Aviateur* (m) (ah-vee'ah-teur): The operator or pilot of heavier-than-air craft. This term is applied regardless of the sex of the operator.
- Axes of an Aircraft** *Essieux* (m) (ess-seu): Three fixed lines of reference; usually centroidal and mutually rectangular. The principal longitudinal axis in the plane of symmetry, usually parallel to the axis of the propeller, is called the fore and aft axis (or longitudinal axis); the axis perpendicular to this in the plane of symmetry is called the vertical axis; and the third axis, perpendicular to the other two, is called the transverse axis (or lateral axis). In mathematical discussions the first of these axes, drawn from front to rear, is called the X axis; the second, drawn upward, the Z axis; and the third, forming a "left-handed" system, the Y axis.
- Ballonet** *Ballonnet* (m) (bah-loh-nay): A small balloon within the interior of a balloon or dirigible for the purpose of controlling the ascent or descent, and for maintaining pressure on the outer envelope so as to prevent deformation. The ballonet is kept inflated with air at the required pressure, under the control of a blower and valves.
- Balloon** *Ballon* (m) (bah'lon): A form of aircraft comprising a gas bag and a basket. The support in the air results from the buoyancy of the air displaced by the gas bag, the form of which is maintained by the pressure of a contained gas lighter than air.
- Balloon, Barrage** *Ballon barrage* (m) (bah'lon bah-rahge): A small spherical captive balloon, raised as a protection against attacks by airplanes.
- Balloon, Captive** *Ballon captif* (m) (bah'lon cap-tiff): A balloon restrained from free flight by means of a cable attaching it to the earth.
- Balloon, Kite** *Ballon d'observation* (m) (bah'lon dohps-sair-vah-see'oh^{ng}): An elongated form of captive balloon, fitted with tail appendages to keep it headed into the wind, and deriving increased lift due to its axis being inclined to the wind.
- Balloon, Pilot** *Ballon pilote* (m) (bah'lon pee-lot): A small spherical balloon sent up to show the direction of the wind.
- Balloon, Sounding** *Ballon sonde* (m) (bah'lon sohnd): A small spherical balloon sent aloft, without passengers, but with registering meteorological instruments.

- Balloon bed** *Ballon terrain d'atterrissage* (m) (bah'lon tay'rah^{ns} dah-tay-ree-sahge): A mooring place on the ground for a captive balloon.
- Balloon cloth** *Ballon tissu pour toile caoutchoutée* (m) (bah'lon tee'seu poor twahl cow-chew-tay): The cloth, usually cotton, of which balloon fabric are made.
- Balloon Fabric:** The finished material, usually rubberized, of which balloon envelopes are made.
- Bank** *Gauchir* (v) (go-sheer): To incline an airplane laterally—i. e., to roll it about the fore and aft axis. Right bank is to incline the airplane with the right wing down. Also used as a noun to describe the position of an airplane when its lateral axis is inclined to the horizontal.
- Barograph** *Barograph* (m) (bah-roh-graph): An instrument used to record variations in barometric pressure. In aeronautics the charts on which the records are made indicate altitudes directly instead of barometric pressures.
- Basket** *Nacelle* (f) (nah'cell): The car suspended beneath a balloon, for passengers, ballast, etc.
- Biplane** *Biplan* (m) (bee'ploh^{ns}): A form of airplane in which the main supporting surface is divided into two parts, one above the other.
- Body of an Airplane** *Fuselage* (m) (feu'zeh-lahge): The structure which contains the power plant, fuel, passengers, etc.
- Bonnet** *Bonnet* (m) (bohn'ay): The appliance having the form of a parasol which protects the valve of a spherical balloon against rain.
- Cabane** *Cabane* (f) (kah'bahn): A pyramidal framework upon the wing of an airplane, to which stays, etc., are secured.
- Camber** *Courbure* (f) (keer-beur): The convexity or rise of the curve of an aerofoil from its chord, usually expressed as the ratio of the maximum departure of the curve from the chord to the length of the chord. "Top camber" refers to the top surface of an aerofoil, and "bottom camber" to the bottom surface; "mean camber" is the mean of these two.
- Center** *Centre* (m) (saunt'r) *Of pressure of an aerofoil.*—The point in the plane of the chords of an aerofoil, prolonged if necessary, through which at any given attitude the line of action of the resultant air force passes. (This definition may be extended to any body.)
- Chord** *Corde* (f) (kord): *Of an aerofoil section.*—A right line tangent at the front and rear to the under curve of an aerofoil section.
Length.—The length of the chord is the length of the projection of the aerofoil section on the chord.
- Clinometer (inclinometer)** *Indicateur de pente* (m) (ahn-dee-kah-teur de^r paunt): An instrument for measuring the angle made by any axis of an aircraft with the horizontal, often called an inclinometer.
- Controls** *Commandes* (f) (koh-maund): A general term applying to the means provided for operating the devices used to control speed, direction of flight, and attitude of an aircraft.
- Control column** *Levier de commande* (m) (le^r vee'ay de^r koh-maund): The vertical lever by means of which certain of the principal controls are operated, usually those for pitching and rolling.

- Decalage** *Longitudinal V* (m) (lohng-gee-teu-dee'nahl): The angle between the chords of the principal and the tail planes of a monoplane. The same term may be applied to the corresponding angle between the direction of the chord or chords of a biplane and the direction of a tail plane. (This angle is also sometimes known as the longitudinal V of the two planes.)
- Dihedral in an airplane** *Dièdre* (a) (dee-ay'd'r): The angle included at the intersection of the imaginary surfaces containing the chords of the right and left wings (continued to the plane of symmetry if necessary). This angle is measured in a plane perpendicular to that intersection. The measure of the dihedral is taken as 90° minus one-half of this angle as defined. The dihedral of the upper wing may and frequently does differ from that of the lower wing in a biplane.
- Dirigible** *Dirigeable* (m) (dee-ree-zhah'bl): A form of balloon, the outer envelope of which is of elongated form, provided with a propelling system, car, rudders, and stabilizing surfaces.
- Dirigible, Nonrigid** *Dirigeable Nonrigide* (m) (dee-ree-zhah'bl noh-ree'zghid): A dirigible whose form is maintained by the pressure of the contained gas assisted by the car-suspension system.
- Dirigible, Rigid** *Dirigeable Rigide* (m) (dee-ree-zhah'bl ree'zghid): A dirigible whose form is maintained by a rigid structure contained within the envelope.
- Dirigible, Semirigid** *Dirigeable Semi-rigide* (m) (dee-ree-zhah'bl se'r-me-ree-zghid): A dirigible whose form is maintained by means of a rigid keel and by gas pressure.
- Diving Rudder (elevator)** *Gouvernal de Profondeur* (m) (goo-vair-nahl de' proh-foh'ng-dare): A hinged surface for controlling the longitudinal attitude of an aircraft; i. e., its rotation about the transverse axis.
- Dope** *Enduire* (v) (au'ngdweer): A general term applied to the material used in treating the cloth surface of airplane members and balloons to increase strength, produce tautness, and act as a filler to maintain airtightness; it usually has a cellulose base.
- Drag (drift)** *Dérive* (f) (day-reeve): The component parallel to the relative wind of the total force on an aircraft due to the air through which it moves. That part of the drag due to the wings is called "wing resistance" (formerly called "drift"); that due to the rest of the airplane is called "parasite resistance" (formerly called "head resistance").
- Drift (see Drag)**: Also used as synonymous with "leeway," g. v.
- Drift-meter** *Mètre de la dérive* (m) (met'r de' lah day-reeve): An instrument for the measurement of the angular deviation of an aircraft from a set course, due to cross winds.
- Elevator (see Diving Rudder)**
- Entering edge** *Bord d'attaque* (m) (boar dah-tack): The foremost edge of an aerofoil or propeller blade.
- Envelope** *Envelope* (f) (enve'lope): The portion of the balloon or dirigible which contains the gas.
- Epannage (tail)** *Queue* (f) (keu): The rear portion of an aircraft, to which are usually attached rudders, elevators, stabilizers, and fins.

- Equator** *Equateur* (m) (ay-quah-teur): The largest horizontal circle of a spherical balloon.
- Float** *Flotteur* (m) (flo-teur): That portion of the landing gear of an aircraft which provides buoyancy when it is resting on the surface of the water.
- Gap** *Espace* (f) (ess-pass): The shortest distance between the planes of the chords of the upper and lower wings of a biplane.
- Glide** *Vol Plané* (m) (vol plah'ny): To fly without engine power.
- Glider** *Planeur* (m) (plah'nair): A form of aircraft similar to an airplane, but without any power plant. When utilized in variable winds it makes use of the soaring principles of flight and is sometimes called a soaring machine.
- Guide rope** *Corde à guider* (f) (kord ah gid-day): The long trailing rope attached to a spherical balloon or dirigible, to serve as a brake and as a variable ballast.
- Guy** *Hauban* (m) (oh-bau^{ng}): A rope, chain, wire, or rod attached to an object to guide or steady it, such as guys to wing, tail, or landing gear.
- Hangar** *Hangar* (m) (au^{ng}gahr): A shed for housing balloons or airplanes.
- Helicopter** *Helicoptère* (m) (ay-lee-copt-air): A form of aircraft whose support in the air is derived from the vertical thrust of propellers.
- Inclinometer** (see **Clinometer**)
- Horn** *Guignol* (m) (ginn-yol): A short arm fastened to a movable part of an airplane, serving as a lever-arm, e. g., aileron-horn, rudder-horn, elevator-horn.
- Inspection window** *Porte de visite* (f) (port de' visit): A small transparent window in the envelope of a balloon or in the wing of an airplane to allow inspection of the interior.
- Kite** *Cerf-volant* (m) (sair-voh-loh^{ng}): A form of aircraft without other propelling means than the towline pull, whose support is derived from the force of the wind moving past its surface.
- Landing gear** *Train d'atterrissage* (m) (trah^{ng} dah-tay-ree-sahge): The understructure of an aircraft designed to carry the load when resting on or running on the surface of the land or water.
- Leeway** *Dérive due au vent latéral* (f) (day-reeve deu oh vau^{ng} lah-tay-rah): The angular deviation from a set course over the earth, due to cross currents of wind, also called drift; hence, "drift meter."
- Lift** *Poussée* (f) (poo-say): The component perpendicular to the relative wind, in a vertical plane, of the force on an aerofoil due to the air pressure caused by motion through the air.
- Load, dead** *Poids mort* (m) (poo'ah more): The structure, power plant, and essential accessories of an aircraft.
- Load, full** *Poids total* (m) (poo'ah toh'tahl): The maximum weight which an aircraft can support in flight; the "gross weight."
- Load, useful** *Poids utile* (m) (poo'ah eu'teel): The excess of the full load over the dead-weight of the aircraft itself, i. e., over the weight of its structure, power plant, and essential accessories. (These last must be specified.)

- Monoplane** *Monoplan* (m) (moh-noh-ploh^{ng}): A form of airplane whose main supporting surface is a single wing, extending equally on each side of the body.
- Net** *Filet* (m) (fee'lay): A rigging made of ropes and twine on spherical balloons, which supports the entire load carried.
- Ornithopter** *Ornithophère* (m) (or'nee-top-tair): A form of aircraft deriving its support and propelling force from flapping wings.
- Parachute** *Parachute* (m) (pah-rah-shoot): An apparatus, made like an umbrella, used to retard the descent of a falling body.
- Permeability** *Permeabilité* (m) (pair-may-ah-bee-lee-tay): The measure of the loss of gas by diffusion through the intact balloon fabric.
- Pitot tube** *Tube de Pitot* (m) (tueb de^r peet'yoh): A tube with an end open square to the fluid stream, used as a detector of an impact pressure. It is usually associated with a coaxial tube surrounding it, having perforations normal to the axis for indicating static pressure; or there is such a tube placed near it and parallel to it, with a closed conical end and having perforations in its side. The velocity of the fluid can be determined from the difference between the impact pressure and the static pressure, as read by a suitable gauge. This instrument is often used to determine the velocity of an aircraft through the air.
- Pylon** *Pylône* (m) (pee'lone): A mast or pillar serving as a marker of a course.
- Relative wind** *Vent relatif* (m) (vau^{ng} ray'lah-tiff): The motion of the air with reference to a moving body. Its direction and velocity, therefore, are found by adding two vectors, one being the velocity of the air with reference to the earth, the other being equal and opposite to the velocity of the body with reference to the earth.
- Rudder** *Gouvernail de direction* (m) (goo-vair-nah'ee de^r dee-reck-see-oh^{ng}): A hinged or pivoted surface, usually more or less flat or streamlined, used for the purpose of controlling the attitude of an aircraft about its "vertical" axis, i. e., for controlling its lateral movement.
- Rudder bar** *Palonnier* (m) (pah-lun'yay): The foot bar by means of which the rudder is operated.
- Seaplane** *Hydroplane* (m) (ee-droh-plahn): A particular form of airplane in which the landing gear is suited to operation from the water.
- Side slipping** *Glissade sur l'aile* (f) (glee-sahd seur l'ell): Sliding downward and inward when making a turn; due to excessive banking. It is the opposite of skidding.
- Skids** *Berilles* (f) (bay-kee'e): Long wooden or metal runners designed to prevent nosing of a land machine when landing or to prevent dropping into holes or ditches in rough ground. Generally designed to function should the landing gear collapse or fail to act.
- Slip stream (Propeller race)** *Vent de l'hélice* (m) (vau^{ng} de^r lay-leece): The stream of air driven aft by the propeller and with a velocity relative to the airplane greater than that of the surrounding body of still air.
- Soaring machine** *Planeur* (m) (plah'nair): See Glider.

- Span (spread)** *Envergure* (f) (au^{ng} vair-geur): The maximum distance laterally from tip to tip of an airplane wing, or the lateral dimension of an aerofoil.
- Stability** *Stabilité* (f) (stah-bee-lee-tay): A quality in virtue of which an airplane in flight tends to return to its previous attitude after a slight disturbance.
- Stability, Directional** *Stabilité en direction* (f) (stah-bee-lee-tay au^{ng} dee-reck-see-oh^{ng}): Stability with reference to the vertical axis.
- Stability, Dynamical** *Stabilité dynamique* (f) (stah-bee-lee-tay dee-nah-mick): The quality of an aircraft in flight which causes it to return to a condition of equilibrium after its attitude has been changed by meeting some disturbance, e. g., a gust. This return to equilibrium is due to two factors; first, the inherent righting movements of the structure; second, the damping of the oscillations by the tail, etc.
- Stability, Inherent** *Stabilité inherente* (f) (stah-bee-lee-tay a^{ng}ay-raunt): Stability of an aircraft due to the disposition and arrangement of its fixed parts; i. e., that property which causes it to return to its normal attitude of flight without the use of the controls.
- Stability, Lateral** *Stabilité laterale* (f) (stah-bee-lee-tay lah-tay-rah): Stability with reference to the longitudinal (or fore and aft) axis.
- Stability, Statical** *Stabilité statique* (f) (stah-bee-lee-tay staht-tick): In wind tunnel experiments it is found that there is a definite angle of attack so that for a greater angle or a less one the righting movements are those which tend to make the attitude return to this angle. This holds true for a certain range of angles on each side of this definite angle; and the machine is said to possess "statical stability" through this range.
- Stabilizer** *Plan fixe de queue* (m) (plo^{ng} fix de^r keu): Any device designed to steady the motion of aircraft.
- Stagger** *Décalage des ailes* (m) (day-kah-lahge dayzail): The amount of advance of the entering edge of the upper wing of a biplane over that of the lower, expressed as percentage of gap; it is considered positive when the upper surface is forward.
- Stalling** *Perte de vitesse* (f) (pert de^r vee'tesse): A term describing the condition of an airplane which from any cause has lost the relative speed necessary for control.
- Statoscope** *Statoscope* (m) (stah-toh-scup): An instrument to detect the existence of a small rate of ascent or descent, principally used in ballooning.
- Stay** *Haubans* (m) (oh-bau^{ng}): A wire, rope, or the like used as a tie piece to hold parts together, or to contribute stiffness; for example, the stays of the wing and body trussing.
- Step** *Ressaut* (m) (resso): A break in the form of the bottom of a float.
- Strut** *Montant* (m) (moh^{ng}-tau^{ng}): A compression member of a truss frame; for instance, the vertical members of the wing truss of a biplane.
- Tail** *Queue* (f) (keu): See Epannage.
- Thimble** *Cosse* (f) (koss): An elongated metal eye spliced in the end of a rope or cable.

- Trailing edge** *Bord de sortie* (m) (bore de sor'tee): The rearmost edge of an aerofoil or propeller blade.
- Triplane** *Triplan* (m) (tree-plah^{ng}): A form of airplane whose main supporting surface is divided into three parts, superimposed.
- Truss** *Poutre armée* (f) (poo'trahr-may): The framing by which the wing loads are transmitted to the body; comprises struts, stays, and spars.
- Warp** *Gauchir* (v) (go-sheer): To change the form of the wing by twisting it.
- Wash out** *Règlage de l'incidence* (m) (ray-glahge de lence-see-dance): A permanent warp of an aerofoil so that the angle of attack decreases toward the wing tips.
- Wings** *Ailes* (f) (ale): The main supporting surfaces of an airplane.
- Wing flap** *Aileron* (m) (ale-le^r roh^{ng}): See Aileron.
- Wing mast** *Mât* (m) (mah): The mast structure projecting above the wing, to which the top load wires are attached.
- Wing rib** *Nervure* (f) (ner'veur): A fore and aft member of the wing structure used to support the covering and to give the wing section its form.
- Wing spar (wing beam)** *Longeron* (m) (loh^{ng}-zher-roh^{ng}): A transverse member of the wing structure.
- Yaw** *Lowvoyer-mouvement de lacet* (m) (loo-vwah-yay move-mau^{ng} de lah'say): To swing off the course about the vertical axis.
Angle of.—The temporary angular deviation of the fore-and-aft axis from the course.

METRIC CONVERSION TABLES

1 kilometer=0.6214 mile.	1 mile=1.609 kilometers.
1 meter=3.2808 feet.	1 foot=0.3048 meter.
1 centimeter=0.3937 inch.	1 inch=2.54 centimeters.
1 sq. meter=10.764 sq. feet.	1 sq. foot=0.0929 sq. meter.
1 sq. centimeter=0.155 sq. inch.	1 sq. inch=6.452 sq. centimeters.
1 cub. meter=35.314 cub. feet.	1 cub. foot=28.317 liters.
1 liter=0.0353 cubic foot.	1 U. S. gallon=3.785 liters.
1 kilogram=2.2046 pounds.	1 pound=0.4536 kilogram.

RULES FOR MENSURATION

- Triangle**—Area equals one-half the product of the base and the altitude.
- Parallelogram**—Area equals the product of the base and the altitude.
- Irregular figure bounded by straight lines**—Divide the figure in triangles, and find the area of each triangle separately. The sum of the areas of all the triangles equals the area of the figure.
- Circle**—Circumference equals diameter multiplied by 3.1416.
- Circle**—Area equals diameter squared, multiplied by 0.7854.
- Circular arc**—Length equals the circumference of the circle, multiplied by the number of degrees in the arc, divided by 360.
- Circular sector**—Area equals the area of the whole circle multiplied by the quotient of the number of degrees in the arc of the sector divided by 360.
- Circular segment**—Area equals area of circular sector formed by drawing radii from the center of the circle to the extremities of the arc of the segment, minus area of triangle formed by the radii and the chord of the arc of the segment.
- Prism**—Volume equals the area of the base multiplied by the altitude.
- Cylinder**—Volume equals the area of the base circle times the altitude.
- Pyramid or Cone**—Volume equals the area of the base times one-third the altitude.

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