LEARNING TO FLY
N THE U.S. ARMY

MANUAL OF AVIATION PRACTICE

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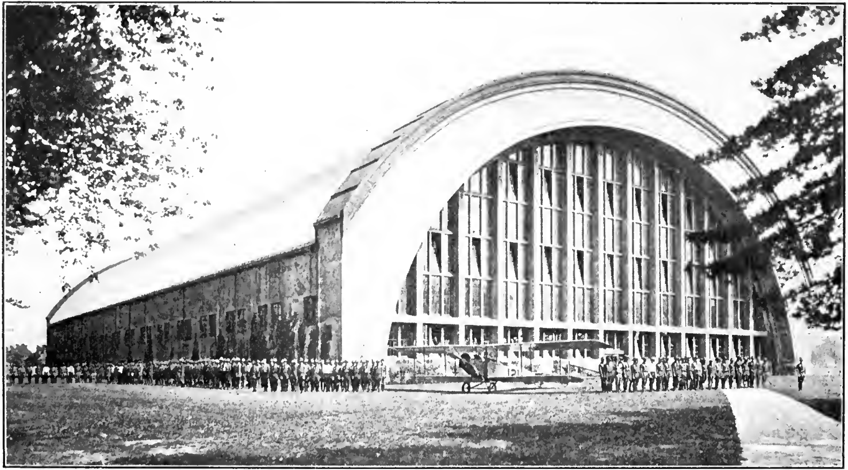

A Group of U. S. Army Student Aviators.

Frontispiece

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A MANUAL OF AVIATION PRACTICE

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PREFACE

The contents of this book run parallel to the instruction given under the author's direction in the U. S. Ground School of Military Aeronautics, University of Illinois branch. In it are set forth the main principles of flying, such as the aviator must know in order to properly understand his airplane, keep it trued up, and operate it in cross country flights as well as at the flying field.

With the sudden expansion of the Aviation Section of the U. S. Army since the declaration of a state of war with Germany, no book has been exactly suited to the aeronautic instruction of our 30,000 aviation students. These young men, called from non-technical occupations at short notice, must cram themselves in a few weeks with the gist of airplane flying, and must therefore omit everything except the outstanding fundamentals.

The following pages set forth to the non-technical student aviator the gist of aviation, in such a manner that accuracy is not sacrificed to brevity. The present book aims to give the desired essentials, omitting many technical details of interest to the aeronautical engineer, to whose needs other larger textbooks are adapted as a complete survey of technical aeronautics.

Out of the 2000 aeronautical books now in existence, a few are adapted to use as textbooks for the present need, but none gives the particular and abridged information in tabloid form such as must be adopted for the best time economy of these students.

The chapters on "Rigging" are not abridged so much as are the other chapters, but are given in some detail; this is to fill a definite need among student aviators for material based on practical experience.

In the chapters on "History of Aviation" only those experiments are treated which have a bearing on flight today; this chapter is to be read in conjunction with the chapter on "Principles of Flight" especially as regards controlling the airplane.

The question of Airplane Motors has not been touched, because to do it justice would unduly increase the size of this volume, and because good treatises on this subject are available.

Acknowledgment is due Professor Holbrook and Messrs. Beyer and Hebbard of the University of Illinois for the preparation of Chapters VI to XI.

Aug. 16, 1917.

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CHAPTER I

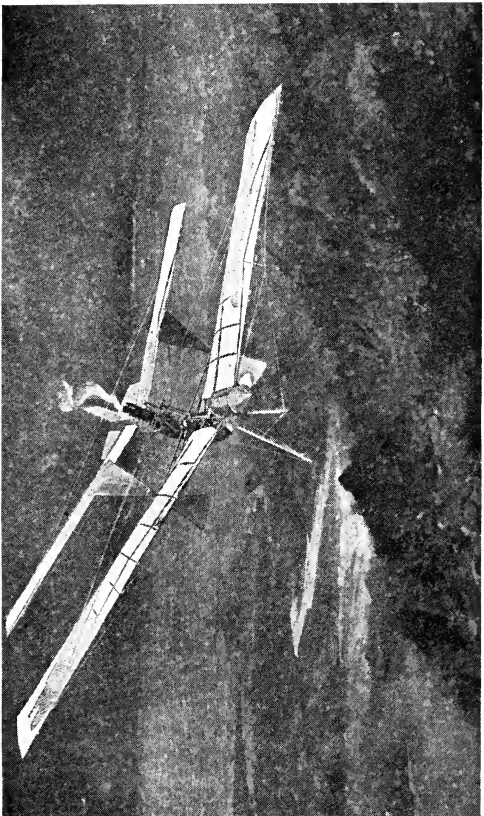
HISTORY OF AVIATION

That part of the history of Aviation which has especial interest for aviators is of recent date, and extends back only two dozen years. Of course efforts have been made toward manflight ever since the early sixteenth century, when Leonardo da Vinci invented the parachute and became the first patron of aeronautics; between the time of this famous artist and the present many experimenters have given their attention to the problem, but previous to the last decade of the nineteenth century nothing practical was achieved. Then, with the perfection of the steam engine and the development of the gasoline engine, there came inducement to sound experimentation, bringing forth such well-known figures as Maxim, Langley, Lillienthal and Chanute.

The work of each of these men is an interesting story by itself, especially that of Langley, who approached the matter from a strictly scientific viewpoint, established testing apparatus and built successful self-propelled steam models years before the Wright brothers reported their independent successes. He reproduced his models to full scale with every expectation of success, but failed, due to exhaustion of his capital.

Langley's Experiments in Aerial Navigation.—In all the history of aerial navigation one of the most romantic stories is that describing the scientific researches begun in 1887 by Langley and culminating in 1896 in the first really successful case of mechanical flight using a prime mover; continuing up to 1903 when this first successful machine, a model of 12-ft. span, was reproduced to full scale and manned for its trial flight by a human pilot; and ending with the destruction of this full-sized machine on launching, so that Langley missed the glory of being the actual discoverer of manflight only by a hair's breadth, dying shortly afterward of a broken heart, as is conceded by those who knew him. If this full-scale machine had performed as successfully in 1903 as it actually did after being rebuilt and partly remodelled a decade later by the Curtiss company, Langley would have antedated the first successful flight made by the Wright brothers by a narrow margin of about 2 months.

Lillienthal (Germany, 1894).—But omitting details regarding the early experimenters we will consider only that part of the history of aviation most important to the prospective aviator. We will confine ourselves to the sequence of gliding and



(*Courtesy S. S. McClure Co.*)

Fig. 1.—The Langley steam model flying machine.

It flew a mile in 1896, the first successful airplane to fly with a prime mover.

power experiments begun by Lillienthal, carried forward by Chanute and brought to completion by the Wrights.

Lillienthal was the first man to accomplish successful flights through the air by the use of artificial

(*Courtesy Jas. Means' "Aeronautical Annual."*)

FIG. 2.—Lillienthal's biplane glider in flight, 1894.

Note.—(*a*) Arched wings; (*b*) fixed tail; (*c*) method of balancing by swinging legs

wing surfaces. After many years of experiment and study of soaring birds he constructed rigid wings which he held to his shoulders and which, after he had gained considerable velocity by running forward downhill, would catch the air and lift his weight completely off the ground. The wings were arched, for he observed this was the case in all birds; flat wings proved useless in flight, and suggested a reason for the failure of previous experi-

(*Courtesy Jas. Means' "Aeronautical Annual."*)
FIG. 3.—Chanute's biplane glider, 1896.
Note improvement in rigidity by bridge-type trussing.

menters. To these rigid wings Lillienthal fastened a rigid tail; the wings and the tail comprised his "glider." There were no control levers and the only way the operator could steer was to shift the balance by swinging his legs one way or the other.

Lillienthal constructed an artificial hill for his gliding so that he could coast downward for some distance without striking the ground and he was able to accomplish many glides of a couple of hundred yards in length.

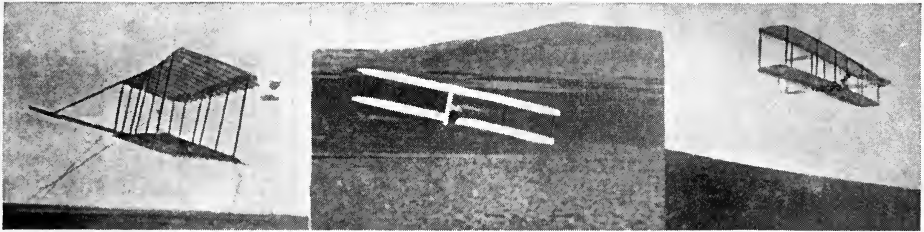
Chanute (Chicago, 1896).—Chanute's experiments in gliding were quite similar to Lillienthal's and were made on the sand dunes along Lake Michigan outside of Chicago. His apparatus was more strongly constructed, being of trussed biplane type, a construction suggested to him by his experience in bridge building, and one which persists today as the basis of strength in our present military biplanes.

The Wright Brothers, 1901.—Lillienthal was killed in a glide, having lost control of his apparatus while some distance above the ground. The Wright brothers read of his death and commenced thinking over the whole problem. Lillienthal's method of balancing his large apparatus by the mere effect of swinging his legs appeared to them as a very inadequate means of control. They came to the conclusion that the immediate problem in artificial flight was the problem of stability, which they felt should be solved by an entirely different means than that employed by Lillienthal and Chanute. The work already done had demonstrated without question that support in the air had been established; with the addition of controllability the Wrights looked forward to doing something worth while in the way of artificial flight.

To improve Lillienthal's method of shifting the weight, they conceived the idea of leaving the pilot in an immovable position in the glider, and instead of obliging him to shift his weight this way and that, they proposed to manipulate the surfaces of the wings themselves by means of levers under the pilot's control, so that the same result of balancing could be obtained by quite a different and superior method.

They set out, therefore, deliberately to solve the whole question of airplane stability. There was the fore and aft or horizontal stability, for which Lillienthal had swung his legs forward and backward; there was in addition the sidewise or lateral stability for which Lillienthal had swung his legs to left and right. The fundamental requirements to be met were that during flight the glider should be kept in its proper attitude without diving or rearing up, and without rolling into an attitude where one wing tip was higher than the other, *i.e.*, the machine was to be kept level in both directions.

Fore and Aft Control.—After some preliminary trials the Wrights found that the fore and aft balance could be controlled by an elevator or horizontal rudder, supported on outriggers on the front of the airplane, and operated by a lever. If the pilot found the glider pitching too much downward, and tending toward a dive, he would tilt the elevator upward by moving the lever, thus turning the glider back into its proper attitude. This elevator in modern machines is back of the airplane,



First Wright glider.
With front elevator, shown flying empty as a kite.

Final Wright glider.
With rudder and elevator. Note right wing warped downward to raise right wing tip.

A successful downhill glide.
Pilot lies prone on bottom wing.

Fig. 4.

a better place for it than was chosen by the Wrights. It may be said that their chief reason for first putting it in front was that they could see it there and observe its effect. They soon realized that the rear location gave easier control, and they acted accordingly.

Lateral Control.—After satisfying themselves regarding fore and aft control, the Wrights took up lateral control. Their problem was to devise a means for keeping the span of the wings level so that when for any reason one wing tip should sink lower than the other, it could be at once raised back to its proper position. Lillienthal had tried to do this by swinging his legs toward the high side; the shifted weight restoring the position. The Wrights, to obviate this inadequate method, bethought themselves to restore equilibrium by means of the wind itself rather than by gravity. They observed an interesting maneuver employed by a pigeon which seemed to secure its lateral balance in exactly the way they wanted; this bird was seen to give its two wings each a different angle of attack, whereat one wing would lift more forcibly than the other, thereby rotating the bird bodily in any desired amount or direction about the line of flight as an axis. To copy this bird apparatus in a Wright glider, it was found sufficient to alter the angle of the wing tips only, leaving the chief part of the supporting surface in its original rigid position. In other words, the wing tips were to be warped; the one to present greater angle of attack, the other less angle, exactly as in the case of the pigeon. Suppose the airplane to develop a list to the left, the wing on that side sinking, the pilot was to increase the angle at the tip of this left-hand wing by moving the warping lever, and at the same time decrease the angle of the right-hand wing by the same lever. He was to hold this position until the airplane was righted and brought back to level position.

This arrangement proved to have the effect anticipated and maintained stability easily on a glider much larger than Lillienthal ever managed with his leg-swinging method.

Directional Control.—We have now followed the development by the Wrights of airplane control as regards:

1. Fore and aft or "pitching" motion, accomplished by an elevator operated by lever.

2. Lateral or "rolling" motion accomplished by wing warping operated by a second lever.

These were the only controls used in the earliest gliders. It remains to consider the third element of control, viz:

3. The directional or "yawing" control, which is accomplished by an ordinary vertical rudder operated by a third lever.

The Wrights found the warping had all the effect anticipated but had also certain secondary and undesirable effects. Whenever they applied the warping lever to correct the rolling motion, the glider responded as far as rolling control was concerned, but at the same time would "yaw" or swerve out of its course to right or left. This was a serious complication. For, in the moment of swerving, the high wing which they desired to depress would advance faster than the low wing, and solely by its higher velocity tended to develop a greater lift and thereby neutralize the beneficial effect of the warp. In many of their early glides, because of pronounced swerving, the warp effect was entirely counteracted and failed to bring the glider back to level; with the result that one wing tip would sink, at the same time swinging backward until the machine was brought to the ground. No amount of controlling could prevent this.

After much bewilderment on this point, the Wrights observed that whenever a wing tip was warped to a large angle its resistance became relatively greater and it slowed up while the opposite side went ahead. They at once hit upon the idea of a rudder, previously considered unnecessary, which they believed could be turned in each case of yawing just enough to create a new and apposing yawing force of equal magnitude.

They therefore attached a rudder at the rear, connecting its tiller ropes to lever No. 2, and giving this lever a compound motion so that one hand could operate either warp or rudder control independently (or simultaneously in proper proportion to eliminate the yawing tendency above mentioned). This combination is the basis of the Wright patents and is essential in airplanes of today.

Great success now ensued in their gliding experiments; the machine was always in perfect control; could be manipulated in any desired manner; turned to right or left, or brought down to earth with safety.

Thus were the three elements of control applied by the Wrights to their glider and the problem apparent in Lillienthal's death was solved. The next step was to install a power plant able to maintain forward speed without resorting to coasting downhill by gravity; and therefore capable of producing a horizontal flight.

In developing a power flyer aside from the question of control the proper design was arrived at as follows:

Efficiency of Wings.—The Wrights knew from Langley and Chanute that flat wings were inefficient and useless, and curved wings essential; they did not know whether the amount of curvature mattered much. To find this out by trials in gliding would be slow and expensive. They adopted a better way—the wind-tunnel method, wherein small-scale models were tested and compared for efficiency in a blast of air. They made their wind tunnel 16 in. in diameter and created a powerful air blast through it by means of an engine-driven fan. Small models of wings were placed in the center of this confined air blast, mounted on a balance arm which projected into the tunnel from the outside. The air forces and efficiency of the models were thus measured. A large variety of shapes were tested and one was selected as best of all from the standpoint of curvature and rounded wing tips. This shape was adopted in their flyer, and though on a much larger scale fulfilled the predictions made for its efficiency in the indoor wind-tunnel experiments.

The Wright glider was, of course, a biplane model. They tested a small 6-in. model biplane and found that the two wings together were less efficient than either wing by itself. However, other considerations, such as rigidity of trussing, decided them to adopt the biplane rather than a monoplane arrangement.

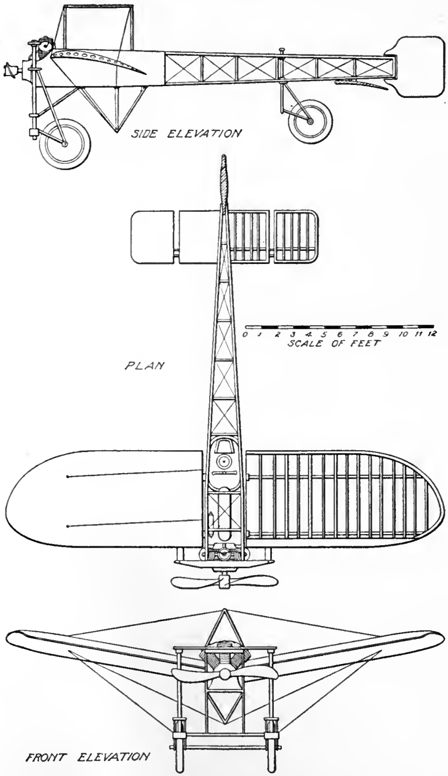
Low Resistance to Forward Motion.—The Wrights used their wind tunnel also in choosing for the struts of their airplane a shape which would present least head resistance to forward motion. They found that a square strut had a resistance which could be decreased by changing the shape to resemble a fish. The resistance of the pilot himself was decreased by making him lie prone, face downward on the bottom wing.

Propeller Efficiency.—Although little data on the subject of propeller efficiency was available to the Wrights, they were able to arrive at a very creditable design wherein two propellers were used, driven from a single motor, and rotating one each side of the pilot. The mechanical difficulties which have since embarrassed the use of two propellers were less with the Wrights because they were dealing with smaller horsepowers than are in use today; they therefore were able to realize a very high propeller efficiency.

Motor.—When the Wrights were ready to apply a motor to their glider, they found it impossible to secure one light enough, and had to set about building one themselves. They adopted a four-cylinder type, water-cooled, and their aim was to save weight and complication wherever possible. Their first motor gave about 12 hp., which was raised to a higher and higher figure by subsequent improvements until it reached 20 hp. In its earliest stages it was able to give sufficient power for short horizontal flights.

Means of Starting and Landing.—One reason the Wrights could use such low horsepower was that they employed auxiliary starting apparatus to get up original speed. They knew that less horsepower was necessary to fly an airplane after it was once in the air than was necessary to get it into the air at the start, and they therefore rigged up a catapult which projected their airplane forward on a rolling carriage with great force at the start, so that all the motor had to do was to maintain the flight in air. The Wright airplane had at first no landing wheels, and was provided only with light skids on which it could make a decent landing. Present-day airplanes, of course, have wheels on which to roll both at starting and at landing and their motors are powerful enough to eliminate the necessity for a starting catapult.

Bleriot's Contribution to Aviation.—Bleriot experimented a great many years before he attained success and did so years after the Wrights had

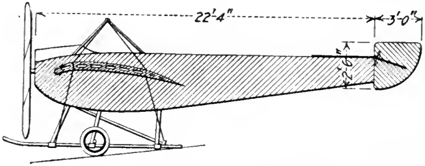


(*Courtesy American Technical Society and Scientific American Supplement.*)

Fig. 5.—Details of Bleriot XI monoplane.

successfully flown. But when he did obtain success, his great ingenuity produced features of design which were a decided step forward. He added a body to the airplane and produced a machine which instead of being a pair of wings with various appendages, was a body to which wings were attached, giving a more shipshape and convenient arrangement. The motor, instead of being located beside the pilot as in the Wright machine, was put in the very front of the body ahead of the pilot where it was not likely to fall on him in case of a smash. This location of the motor entailed the use of a single propeller at the front, a "tractor" screw as it was called, less efficient than the double propeller of the Wrights, but better from the standpoint of mechanical convenience. The body of a Bleriot, which was quite similar to the body of any bird in its general arrangement, projected to the rear in a tapering form and carried at the rear a rudder and elevator. The motor, pilot and tanks were thus enclosed within the body and away from the wind. Bleriot's contributions were then, better location of the motor, adaptation of the body or "fuselage," elimination of the front elevator and substitution of the rear elevator.

Nieuport and Fokker's Contribution to Aviation.—A further advance on Bleriot's design was made by Nieuport and later by Fokker. The former utilized the fuselage principle of Bleriot and enclosed the whole framework, front and back, to give a stream-line form, and even went so far as to make wind-tunnel experiments from which he was able to choose a very efficient fuselage shape as well as wing and strut efficiency.



(*From Hayward's "Practical Aeronautics."*)

FIG. 6.—Nieuport monoplane.

Representing an advance in speed, due to covered streamline body.

CHAPTER II

TYPES OF MILITARY AIRPLANES AND THEIR USES

Modern Airplanes Combining Best Features of Previous Experiments.—The modern airplane, of which the Curtiss training machine used at the U. S. Aviation Schools is typical, is a combination of the best features referred to above. It is of the biplane type for, as shown by Chanute, rigid trussing is thus possible, an advantage sufficient to offset the slight loss of efficiency which exists in the biplane. The landing gear consists of two wheels provided with shock absorbers; the body is of the general stream-line type, enclosed from front to back, containing comfortable seats for the passengers and enclosing the motor and tanks away from the wind. The motor is at the front where, in an accident, it will not be on top of the pilot. The warping effect is obtained by hinging flaps at the wing tips, the same effect being obtained while at the same time leaving the whole wing structure rigid and strong rather than flexible and weak, as was the case in the early warping type of machines.

Military Airplanes of Today.—In the modern airplane, therefore, we see that matters of efficiency, to which the Wrights gave great attention, have been sacrificed in favor of convenience, particularly in favor of power and speed. This is the effect of military demands for airplanes where power, speed, and ability to climb fast are vital requirements. To escape from or to destroy an enemy, high speed and ability to climb fast are, of course, prerequisites. Moreover, from the standpoint of safety in maneuvering it is desirable to have a reserve of power and speed. Therefore, the design of military machines has tended in a given direction up to the present.

New considerations have arisen on this account, such as for instance the question of landing. Fast machines in general make high-speed landings, and are for that reason dangerous. The original Wright machines were built to land at such a slow speed that ordinary skids were sufficient to take the shocks. Nowadays the high-powered airplane is likely to come to grief in landing more than at any other time. The question of stability in flight has of recent years been treated mathematically and experimentally, using of course the fundamental system of "three axes control" first applied by the Wrights. It has been found that by properly proportioning the tail surfaces and properly arranging the wings and center of gravity, any desired degree of stability may be obtained, such that a machine may be made almost self-flying or, if preferred, may be made very sensitive.

All of the above features of design have had consideration in the latest types of military airplanes. Observe the high speed of the latest speed scouts, where power is concentrated exclusively on speed and climbing ability and landing speed is dangerously high. We see the advent of the triplane scout, which is an attempt to secure slow landing speed combined with high flying speed. We see machines with the motor and propeller in the rear, or with two motors, one to each side of the body out in the wings, the object being to avoid interference of the propeller with the range of gun fire. In short, we see the effect of many military considerations on the design of the airplane. It will be interesting at this point to survey what are these military uses of the airplane.

Aerial Fighting.—Fighting in the air is the most spectacular use to which military airplanes have been put. The first requirements in a fighting airplane are speed and climbing ability and these must be obtained at all costs, because speed and climb are weapons of defense and offense second only in value to the gun itself. The concentration of motive power for speed and climb requires that as little weight as possible be used; and therefore the fastest fighters are designed to carry only one person and are very light and of course very small. It is usual to have one gun fixed to the body and firing through the propeller in the case of a tractor, and a second adjustable aim gun pointing upwards over the top wing. This gives the pilot a chance to fire a round at the enemy while "sitting on his tail" or following from behind; and then when diving below the enemy, the second gun is available for shooting overhead. These very high-speed fighters are difficult to land, due to their speed, and are suitable only for the highest-trained pilots.

Directing Artillery Fire.—The friendly airplane is sent out over the enemy's positions, soars above the target, sends back signals by wireless to the friendly battery regarding the effect of fire; practically dictating the success of artillery operations.

Reconnaissance.—The friendly airplanes go out, usually in squads for the sake of protection, and observe by means of photographs or vision size of enemy troops, batteries, trenches, lines of communication, etc.; report the situation to headquarters as a source of daily photographic record of the operations of the enemy, to such an extent that any change of the enemy's position can be analyzed. Of course the value of reconnaissance is lessened when the enemy disguises his gun emplacements, etc. In reconnaissance machines it is important to have two persons, one to steer and the other to scan the countryside. The reconnaissance machine is therefore a two-place type which may or may not have armament. It need not be so fast, especially when convoyed by fighting speed scouts. The two-place machines are frequently used for fighting, in which case the pilot will have a gun fixed to the body and shooting through the propeller, and the passenger, especially in German machines, will also have a gun mounted in the turret so that it may be shot in a variety of directions by the passenger.

Bomb Dropping.—This maneuver requires squad flights to be of great value. The fundamental characteristic of a bombing airplane is its ability to carry great weight. Such machines are of comparatively large size and not particularly fast. Weight carrying is of course incompatible with speed and climbing ability and therefore the bombing machine must be a compromise if it is to have any reasonable speed. It may be said that airplanes compare very unfavorably with dirigible balloons for bomb raids because the latter are able to carry several tons of bombs as against the airplane's quarter of a ton.

Locating Submarines.—For coast patrol or submarine spotting, the airplane is an important factor, for from an airplane it is possible to see for a considerable depth into the water, and to locate hostile submarines.

Training Student Aviators.—The training machine on which prospective aviators secure their flying instruction may be considered as a type in which great speed and power is not essential, but in which reliability and ease of control is desirable. The typical military training airplane in this country is a single-motor tractor of moderate horsepower (about 100) having of course the seats in tandem and funished with dual control so that operation may be from either pilot's or passenger's seat. The dual-control system of training which prevails in this country differs from the French method of starting the pupil out alone to try his wings; it enables the pilot to keep a constant eye upon the pupil's control manipulations and to correct them instantly whenever they are in error before any damage is done. A possible improvement in the dual-control training machine will be the substitution of side by side seats for tandem seats. At present, communication is difficult due to the great noise of the motor;

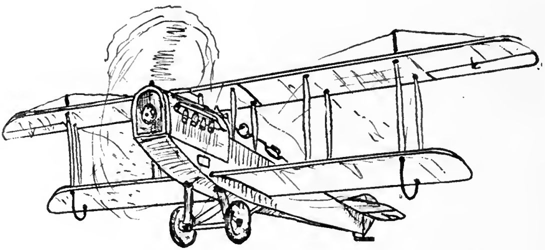


FIG. 7.—U. S. training airplane, dual control (Curtiss JN4). Speed 43 to 72 mi. per hr.; climbing ability 300 ft. per min.; 90 h.p.; weight fully loaded 1,890 lbs.

but with the adoption of side by side seats such as is used in naval training schools, the pilot and pupil will be able to communicate to better advantage.

Types of Airplanes.—To suit the foregoing purposes flying machines exist in seven distinct different shapes at the present time, namely: monoplanes, biplanes, triplanes, single-motor tractors, single-motor pushers, double-motor machines and marine airplanes. The last four types may be either monoplanes, biplanes or triplanes. In order to understand the adoption of one or the other type for military use, it is well to run over the characteristics of the seven types mentioned.

Monoplanes.—The simplest form of airplane is the monoplane which is fashioned after the manner of a bird (see Fig. 34). There are two things to say in favor of the monoplane: first, that the passengers have an unobstructed view forward and range of gun fire upward because there is no wing above them; second, the aerodynamic efficiency of the monoplane is superior to any other type. But when the bird design is applied to a man-carrying apparatus, it becomes impracticable to construct spars to take the place of the bird's wing bones; and therefore to give the wings proper strength it becomes necessary to truss them with numerous tension wires stretching from the running gear out to various portions of the wings. There are also wires running from a vertical mast above the body to a point on the top part of the wing; these wires, while they give the wing no added strength during a flight, are necessary in order that the shock of landing shall not break the wings off sharp at the shoulder. It is characteristic of monoplane construction that from a point below the body and also from a point above the body a number of heavy wires run outward to various points on the wings; and it may be said that the strength to be secured from this construction is not all that could be desired.

Biplanes.—The biplane is an improvement over the monoplane from the latter standpoint; in the biplane there are two parallel surfaces separated by vertical sticks or struts, thus forming parallelograms which are susceptible of being trussed by means of tension-wire diagonals in a manner familiar and well understood in case of bridges. It is possible to build up biplane wings of great rigidity and strength by this system, much more easily than in case of monoplanes. However, the biplane type is from the standpoint of efficiency inferior to the monoplane. This is due to the fact that the vacuum above the bottom wing which is so necessary for high duty is somewhat interfered with by the upper wing; thus while in a biplane the upper wing operates about as efficiently as it would operate in a monoplane, yet the lower wing has its efficiency materially reduced and the resulting overall efficiency of a biplane compared area for area with the monoplane is about 85 per cent. as great. However, recent developments of the airplane have more or less put efficiency in the background and as a result today the biplane is more popular than the monoplane. In addition to the greater strength of biplane wings their span may be less than the monoplane for the same supporting area. This makes them less unwieldy. Moreover, for certain reasons a biplane machine of high speed may be landed at a lower speed than equivalent monoplanes.

Triplanes.—What is true of the biplane is more true in almost every item of the triplane, that is, it is comparatively strong, compact, and of low landing speed, but of reduced efficiency.

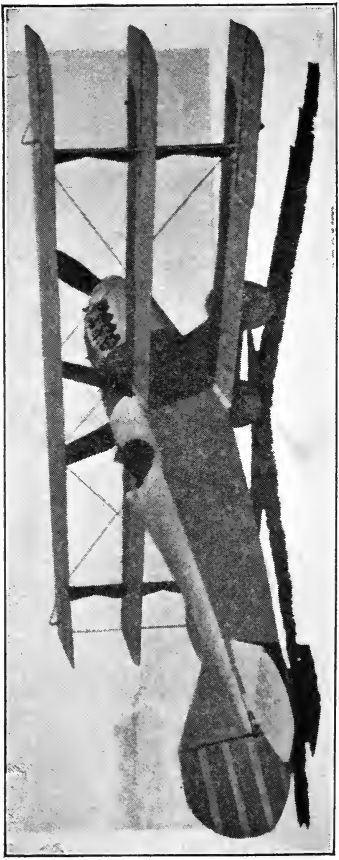


FIG. 8.—U. S. speed scout triplane, single seater.
(Curtiss Model S3), 55 to 115 mi. per hr.; climbing ability 900 ft. per min.; 100 h.p.; weight fully loaded 1,320 lbs.

Single-Motor Tractors.—The single-motor tractor received its name simply because the propeller is in front and draws the machine forward; but this location of the propeller necessitates a distinct type of airplane, wherein the power plant is located at the very nose of the machine. The tractor type has the pilot and passenger located in or to the rear of the wings in order that their weight may balance the weight of the motor. This means that the view and range of fire of the passengers is obstructed in a forward direction by the wings, and in machines such as the U. S. training machine, the passenger, who is practically in the center of the wings, can not look directly upward nor directly downward. Moreover, as concerns gun fire, the propeller of a tractor obstructs the range straight ahead. In the tractor the tail is supported at the rear and on the same body which contains the motor and passengers; this body constitutes a stream-line housing for the machinery, seats, etc., and therefore has low wind resistance. The tractor is a very shipshape design, compact and simple and is at present the prevailing type on the European war front. However, it has disadvantages which are only overcome in other types. One of these disadvantages is of course the obstruction to range of gun fire. The present practice in fighting airplanes is simply to shoot the gun straight through the circle of rotation of the propeller on the assumption that most of the bullets will get through and that those which hit the shank of the propeller blade will be deflected by proper

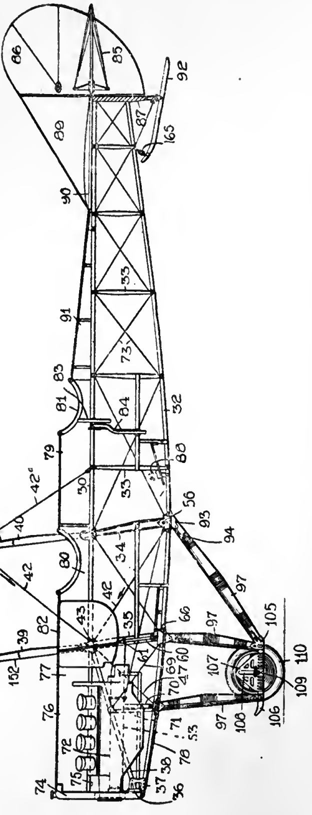


FIG. 9.—Fuselage diagram, Curtiss "R4" reconnaissance biplane.
Speed 48 to 90 mi. per hr.; climbing ability 400 ft. per min.; 200 h.p.; weight fully loaded 3,245 lbs.

armoring. An attempt is made to insure that all the shots will get through by connecting the gun mechanism mechanically to the motor shaft in such a way that bullets will be discharged only at the instant when their path is unobstructed by a propeller blade. This practice is possible of course only in guns which are fixed immovably to the airplane.

Single-motor Pusher Airplanes.—The pusher type has popularity because the propeller and motor

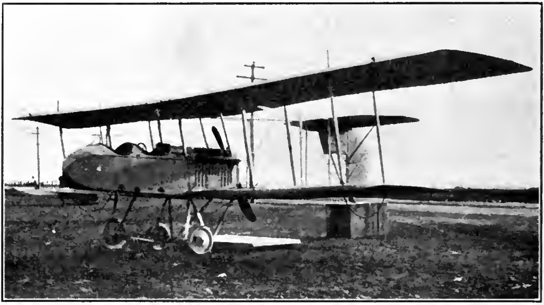


FIG. 10.—An American pusher biplane design.
Crew in front, motor and propeller in the rear, tail support on outriggers.

rotate to the rear of the passenger, who takes his place in the very front of the body and has an open range of vision and gun fire downward, upward and sideways. Another point in favor of the pusher is that the oil and fumes of the motor do not blow into his face as in the case of the tractor. The disadvantage of the pusher is that the motor, being located behind the pilot, will be on top of him in the case of a fall. Another disadvantage is that the body can not be given its shipshape stream-line form because to do so will interfere with the rotation of the propeller. Therefore, the body is abruptly terminated just to the rear of the wings and it is just long enough to hold the passenger and the motor, the propeller sticking out behind. The tail surfaces are then attached to the airplane by means of long outriggers springing from the wing beams at points sufficiently far from the propeller axis so as not to interfere with the propeller.

Double-motor Machines.—In order to combine the advantages of the tractor and pusher types and

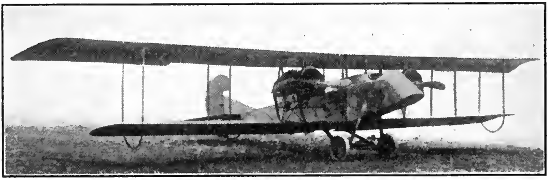


Fig. 11.—U. S. army battle plane.
Two 100 h.p. motors; speed 85 mi. per hr.

eliminate their disadvantages, the double-motor machines have been developed. In these there is no machinery whatever in the body either in front or back, and the passengers may take seats at the extreme front as is desirable. The body then tapers off to the rear in stream-line form and supports the tail surfaces. The power plants are in duplicate and one is located to each side of the body out on the wings. It is customary to enclose each of these two motors in a casing so that the whole power plant presents a more or less stream-line shape to the wind, the propellers projecting from the front or rear of these stream-line shapes. It may be said that in the double-motor airplane it makes very little difference whether the propeller is in front or behind so that while a "twin-motor" machine may be more accurately specified as a "twin-motor pusher" or a "twin-motor tractor," it is usually sufficient indication of a machine's characteristics to call it a twin-motor machine.

By adopting this twin-motor form we bring in new disadvantages. One of these is due to the fact that the heavy motors are now located some distance from the center of gravity of the machine. This requires stronger supporting members between the motor and the body. It also makes the lateral control comparatively logy for now the heavy masses are far from the center of gravity, resisting the pilot's efforts to use the lateral control. The second disadvantage in the twin-motor type results from possible stoppage of either motor. In this case, of course, the propelling force is some distance off center and is also reduced to one-half its value requiring energetic exercise of the control wheel to maintain equilibrium. It is reported, however, that twin machines can continue to fly and even climb with only one motor running. In this country the twin-motor type has not developed as was hoped at first, and on the European firing lines it is not so numerous as the single-motor tractor type.

Marine Airplanes.—The possibility of mechanical flight having once been established and wheels having been applied to the airplane so that it could start from and land on the ground, the logical next step was to substitute some form of boat for the wheels so that flights could be made over the water.

Experiments were made in France by M. Fabre in this direction and in this country by G. H. Curtiss. The latter, in his flight down the Hudson from Albany to New York, equipped his airplane with a light float to provide against forced landing in the river. Pursuing this general idea he made some experiments under the auspices of Alexander Graham Bell's Aerial Experiment Association, in which a canoe was substituted for the wheels, and in which an attempt was made to start from the surface of the water. Success did not come at first and this plan gave no satisfaction. Curtiss next turned his attention to the hydroplane type of boat and made a series of experiments at San Diego. The hydroplane appeared to be much better adapted to his purpose than the canoe had been, and he was able to obtain success.

The Hydro-airplane (or **"Seaplane"**).—From analogy to the airplane one might at first imagine that a suitable hydroplane would have a wide span and fore and aft length; but such proportion would give a very poor stability on the water, and would require auxiliary hydroplanes in the same way that an airplane requires auxiliary guiding surfaces. So Curtiss, with his customary eye for simplicity and

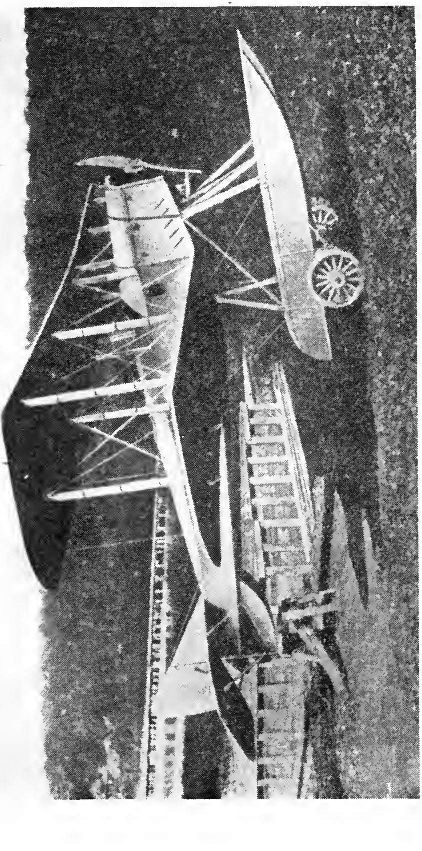


Fig. 12.—Thomas Type H.S. seaplane. Double pontoons.
Speed 47 to 82 mi. per hr.; climbing ability 270 ft. per min.; 135 h.p.; weight, fully loaded 2,600 lbs.

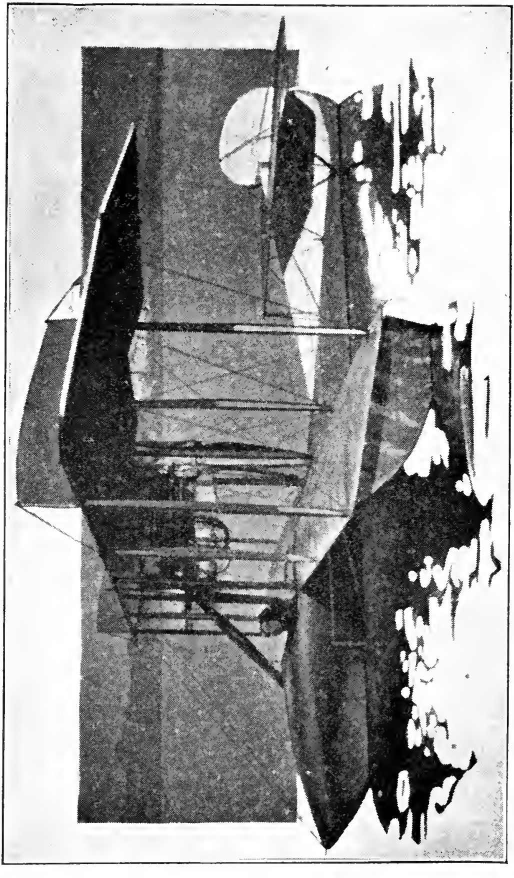


FIG. 13.—Curtiss Model F flying boat.

Speed 45 to 65 mi. per hr.; climbing ability 150 ft. per min.; 90 h.p.; weight fully loaded 2,100 lbs.

convenience, adopted a type of hydroplane which had the general proportions of an ordinary boat, *i.e.*, was long and narrow, thus obviating the necessity of auxiliary hydroplanes at the tail of the machine. To prevent the machine's tipping over sidewise, "wing pontoons" were attached at the lower wing tips to prevent capsizing.

FIG. 14.—Building a flying boat hull.
Note wing stumps and hydroplane fins.

The Flying Boat.—In the early hydro-airplane, which was thus developed, the motor and pilot were above in the usual position in the wings, while the hydroplane itself was a considerable distance below the wings. Thus there was a good deal of head resistance. Curtiss set about reducing this head resistance as far as possible and tried to incorporate the pilot's seat with the hydroplane pontoon. The outcome of his endeavor was that he developed a boat with a tapering stern. The pilot, gasoline tanks, etc., are located inside of the hull; the tapering stern provides a backbone to which the tail surfaces can be readily attached; the wings fixed to the sides of the hull in a manner analogous to the wing fastenings of the modern military airplane; and the motor alone remains exposed to the wind. This is the flying boat; its action on the water is analogous

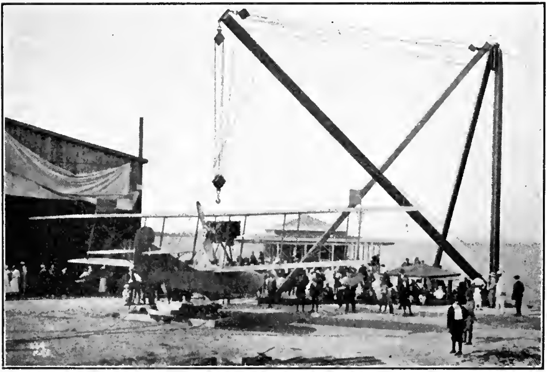


Fig. 15.—Method of hoisting a marine airplane aboard ship.

to the action of the hydroplane for the bottom of this boat hull is made in hydroplane form; indeed, in the latest types of flying boat, the hydroplane area is increased by extending it to right and left of the boat hull. The flying boat is an ingenious combination, wherein the characteristics of the hydroplane are combined with the seaworthiness of the ordinary boat, and at the same time wind resistance is reduced to a minimum.

The hydro-airplane remains in use, however, being preferable to the flying boat for certain purposes, and often is termed seaplane.

Future of the Airplane.—In order to be commercially successful and have a commercial future after the war, the following weak points in airplane design must be rectified.

1. *Motor.*—Airplane motors are imperfect and unreliable at present and there must be considerable progress before this type of motor which is very light and delicate can be considered as reliable or can be made in large enough quantities to cut down the cost.

2. *Landing.*—The necessity of landing at considerable speed, say 40 to 50 miles per hour, requires a wide flat space, such as is not easy to find, and if the present type of airplane is to become commercially numerous, a large number of landing fields must be developed all over the country.

3. *Danger.*—The airplane is by no means so dangerous as the public has been led to think from the exploits of the daredevil circus performers of the past 10 years; with careful manipulation it will make trips day after day without any damage. However, it is not a foolproof machine and there remains an element of danger on this account, which it is hoped will one day be eliminated.

Future Uses of the Airplane.—Future uses of the airplane are many after the war is over. The postal service of several governments are considering this means of mail delivery; the sports use as in the past will continue to flourish; express carrying may be expected in inaccessible countries where railroads and roads do not give access and where high-speed delivery by countless airplanes would aid materially in the development of newly opened countries. For airplane transportation will require no expensive right-of-way, rubber-tire renewals, etc. Minor uses of airplanes are on such duties as forest-fire patrol, working at life-saving stations, etc.

American Airplane Industries.—The magnitude of the airplane industry in this country is great, although not so great as in Europe. Leading business men have invested in this industry with the firm belief that it will become a profitable one, irrespective of war. We see a number of leading bankers and also automobile manufacturers in various parts of the country putting their money into this new industry. Now that a great demand has sprung up on our side of the water for airplanes, we will expect to see this industry increase more rapidly still. The only result can be, from all the interest and importance attached to aviation, that after the war is over, large commercial uses will develop which will offer employment to those who go into the work at this time for military reasons. No one can predict exactly what turn the situation will take, but there is every indication that aviation has graduated from the primary class of experimental work and is to be considered now as an industry along with the automobile business, motor-boat business, etc.

CHAPTER III

PRINCIPLES OF FLIGHT

Support of an Airplane by Its Wings.—An airplane is supported just as definitely as though on top of a post, and by the same law, namely reaction. If you try to sweep the air downward with a wing held at a slight angle, the air just before it consents to be pushed downward, delivers a momentary reaction which is upward. If you have a bag of air in your hand it exerts no push upward of course; but the minute you give it a quick push downward it resists, due to its inertia, thus delivering an upward "reaction" against your hand.

Whenever you move anything, it reacts an amount just equal to the force that is moving it; if you move a bullet out of a gun, just before starting the bullet reacts and you have "kick." If you should shoot a thousand guns downward, the reaction would be considerable, and for the instant might be sufficient to support heavy weight.

The airplane is a device for pushing downward millions of little bullets, made out of air and exceedingly small and light. The wing of an airplane sweeps through these bullets, or molecules, of air like a horizontal plow, wedges the particles downward in vast numbers and in a continual stream, making up in amount what is lacking in weight, so that as long as the airplane rushes along, there are many thousands of cubic feet of air forced down beneath its wings, delivering up a reaction that results in complete support for the machine. This reaction is just as definite and secure as though the machine were supported from the ground on wheels, but it disappears entirely when the airplane is at rest. Part of the whir of a training machine as it glides back to earth is made by the air driven downward from the wings; the same phenomenon may be noticed when a bat flies close to your ears at night, and if you were a few feet below the airplane as it flew, you would feel the rush of air driven downward from its wings (see Fig. 16).

The net result of all the reactive pushes from this air is **lift.** It may amount to several pounds for every square foot of the wing surface.

This is all that need be said about why the air supports an airplane; all you have to remember is that as long as you have the forward sweeping movement, you will have the lift.

The forward movement is absolutely essential, however, and to maintain it requires a lot of horsepower and gasoline. For it is by means of the engine and propeller that this forward movement is maintained. The engine is a device for creating forward movement—the propeller drives the machine ahead in exactly the same way as is the case in a torpedo, or steamboat.

Lift.—Assuming that we have all the forward

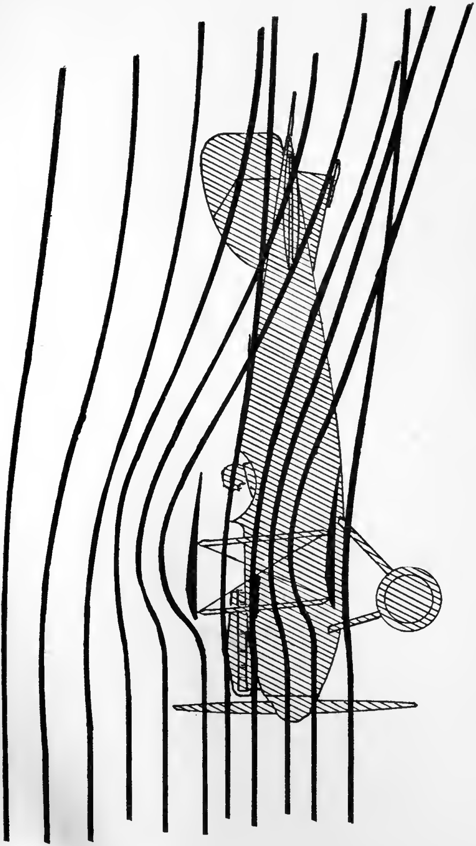


Fig. 16.—Relative path of air particles past an airplane.
This diagram illustrates the general downward trend of the stratum of air met by the wings.

motion needed, let us now investigate the lift that results. Experimenters such as the Wrights and others have found out how to get this lift most conveniently. Lift depends upon the four following factors:

1. Area.
2. Density of air.
3. Angle of incidence.
4. Speed of motion.

1. *Relation of Area of Wings to Support.*—Consider a small wing; suppose it to be held by hand outside a train window in a given attitude, its area being 1 sq. ft. It tends to lift a certain amount, say 5 lb. Now increase its size to 2 sq. ft. and it will lift with 10-lb. force, tending to get away from your grasp. Rule: When only the area of a wing is changed, its lift varies with the area. If, as above mentioned, you can get 5 lb. of lift from each square foot of wing surface, you can by the same sign get 10-lb. of lift from 2 sq. ft. And if you have 500 sq. ft. of surface you can get 2500 lb. of lift.

Regarding **area** of wing surface, the pilot does not have to worry in a flight since he can do nothing to change it anyway. All he needs to know is that in different airplanes small wing area accompanies high speed and small weight-carrying capacity, as in the case of the Fokker and Sopwith speed scouts (see Fig. 17). Conversely, large wing areas are used for heavy load carrying and

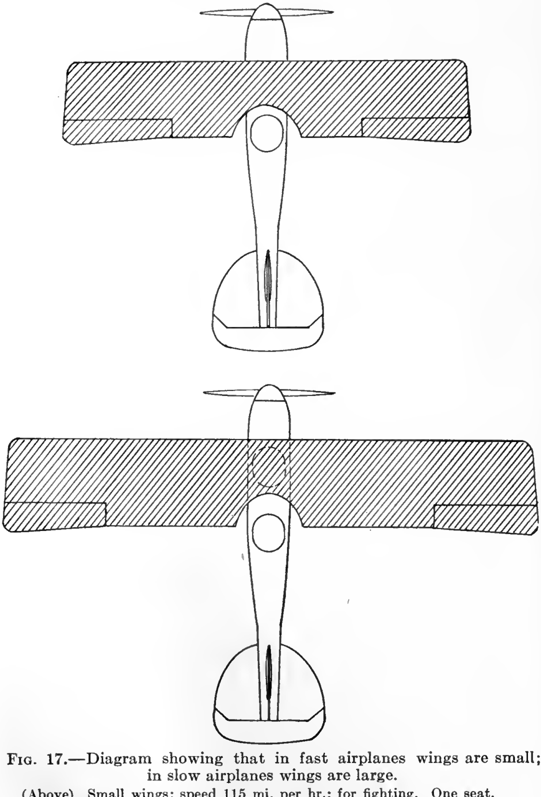


Fig. 17.—Diagram showing that in fast airplanes wings are small; in slow airplanes wings are large.

(Above) Small wings; speed 115 mi. per hr.; for fighting. One seat.
(Below) Large wings; speed 80 mi. per hr.; for reconnaissance. Two seats.

slow speed (see Fig. 18). Speed and weight-carrying capacity thus appear to be antagonistic and can not both be attained with efficiency, but only at the expense of enormous power. The incompatibility between high speed and weight carrying keeps the designer busy in efforts toward a reconciliation.

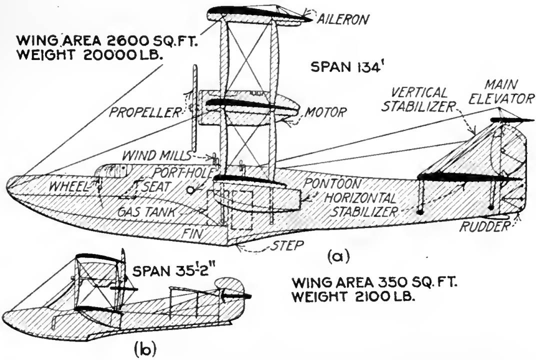


Fig. 18.—Diagram showing use of large wings for heavy airplanes, and small wings for light airplanes.

2. *Density.*—The second factor affecting the lift is the character of the air itself. I refer to the density of the air. The heavier each particle of air becomes, the more reaction it can furnish to the wing that drives it downward; so on days when the barometer is high the wing will lift more than on other days. Now the air is heaviest, or most

dense, right near the ground; because in supporting the 50 miles or so of air above it, it becomes compressed and has more weight per cubic foot. Therefore, the wing gets more lift at a low altitude than at a high. Some airplanes will fly when low down but won't fly at all high up. In Mexico, for instance, when the punitive expedition started out they were already at an altitude of several thousand feet above sea level. The airplanes had been built for use at places like New York and England, close to sea level, and when our army officers tried to fly with them in Mexico, they would not fly properly, and the factory had to redesign them.

Regarding **density,** the pilot should know that for a low density he should theoretically get a high speed. As density decreases, high up in the air, the speed tends to increase, and moreover he gets more speed for the same amount of gasoline. Unfortunately, at an altitude the motor power falls off, so that nowadays the speed is not faster high up than low down; but when the motor builders succeed in designing their motors to give the same horsepower at 20,000 ft. as they do on the ground, airplanes will be able to reach terrific speed by doing their work above the clouds.

It is found desirable to give large wings to airplanes which are going to fly at high altitudes, so as to offset the lack of density by an increase in area, thus leaving the angle range—that is, the speed range—as large as possible. The army airplanes in Mexico mentioned above were simply given a new set of larger wings to offset the lower air density in Mexico, and thereafter flew better.

3. *Angle of Incidence.*—The angle of incidence is defined as the *angle between the wing-chord and the line of flight.* The line of flight is the direction of motion of the airplane, and is distinct from the axis of the airplane which corresponds with the line of flight only for a single angle of incidence. If the line of flight is horizontal, the airplane may be flying tail-high, tail-level, or tail-low; that is, its axis may have varying positions for a given line of flight. This is true, if the line of flight is inclined, as in climbing. It is a mistake to confuse the line of flight with the axis of the machine.

The angle of incidence of the wings of the U. S. training machine may have any value from 15° down. When the angle is smaller the lift of the wings is smaller. Consider the model wing held out of a train window; if its front edge is tilted up to an angle of 15° with the line of motion it will lift say 1 lb.; if reduced to a 10° angle, it will lift less, say ⅔ lb. A model of the training-machine wing could be tilted down to an angle several degrees less than zero before its lift disappeared, because it is a curved, not a flat wing; this angle would be the "neutral-lift" angle; notice then that 0° is not a neutral-lift angle, and therefore may be used in flight.

If the model wing were tilted up to an angle greater than 15°, the lift would not increase any more, but would be found to decrease. For this wing, 15° is called the critical, or "Stalling" angle, beyond which it is unwise to go.

4. *Velocity.*—If the model wing which is imagined to be held out of the car window, is held now in a fixed position at a given angle of incidence, any change of the train's speed will result in a change of lift; should the speed rise from 30 miles per hour to double this value, the lift would increase enormously, fourfold in fact.

Lift varies as the square of the speed. Thus any increase or decrease of speed results in a great increase or decrease of lift.

Interdependence of Angle of Incidence and Velocity.—The four factors above mentioned all contribute to the lift; if in an airplane wing each factor be given a definite value, the resulting lift is determined according to the formula:

$$L = KrAV^2$$

where L is lift.
K is a coefficient referring to the angle.
A is the area.
V is the velocity.
r is the density.

Two only of these quantities change materially in flight, the angle and the velocity; the lift itself remains substantially the same under most normal circumstances. The angle always changes simultaneously with the velocity, increasing when the velocity decreases. Thus the drop of lift due to velocity decrease is balanced by gain of lift due to angle increase, and the lift remains unchanged when speed changes.

Speed change then requires that the pilot alter the angle of incidence simultaneously with the throttle; so there are two things to do, unlike the case of the automobile where only the throttle is altered.

Minimum Speed.—When, in slowing up an airplane, the angle of incidence reaches the 15° limit, no further decrease of speed is allowable; therefore, the critical angle determines the minimum limit of speed. If for any reason the machine exceeds the 15° limit, it must speed up to gain support; that is, the pilot has to increase angle and speed simultaneously instead of oppositely.

Efficiency of Airplane Wings.—I said at the beginning of this chapter that the airplane was a device for pushing down an enormous quantity of air. A certain amount of force has to be furnished in order to keep the airplane moving, and this force is furnished by the engine and propeller. The propeller by giving a certain amount of push in a horizontal direction to the airplane wing enables this wing to extract from the air ten or twenty times this amount of push in a vertical direction; that is, the airplane wing will give you 10 lb. or more of lifting in exchange for 1 lb. of push.

The propeller push is necessary to overcome the drift or resistance of the wings to forward motion. It appears then that the airplane wing as it moves through the air has two forces on it, one acting straight up and called "lift," the other acting straight back and called "drift" (see Fig. 19). The lift is several times greater than the drift, and the situation is quite analogous to that of a kite,

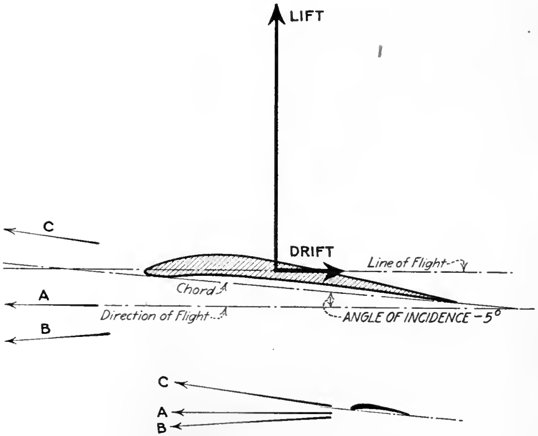


FIG. 19.

Lift and Drift.—Lift is perpendicular to line of flight, drift is parallel.
Angle of Incidence.—Wing in position shown has angle of 5° if moving in direction "A," 10° if in direction "B;" and a negative angle of 4° if moving in direction "C." In the last case it is moving along its neutral-lift-line, lift becomes zero.

which rises upward in the air due to its lift but at the same time drifts backward with the wind due to its drift. In the case of the kite the string takes up an angle which just balances the joint effect of the lift and drift.

The efficiency of an airplane wing is indicated by the ratio of lift to drift, and for a given lift, the efficiency is best, therefore, for small drift. If the lift is 1900 lb. and the wing drift 190 lb.,

$$\text{Wing efficiency} = \frac{\text{Lift or weight}}{\text{Wing drift}} = \frac{1900}{190} = 10$$

Factors Determining Best Efficiency.—It goes without saying that an airplane wing should attain the best efficiency it can, and there are several ways of doing this.

The first relates to the question of angle of incidence; we have already discussed the effect of angle on lift, but when we come to discuss its effect on efficiency we find that there is only one angle at which we can get the best efficiency. This is a small angle, about 3° to 6°; at this angle the lift is nowhere near as much as it would be at 10° or 15°, but the drift is so small compared to the lift that it is found desirable in airplanes to employ these small angles for normal flight. As the angle increases above this value of maximum efficiency, the efficiency drops off, and when you get up to the stalling angle, the efficiency becomes very low indeed (see Fig. 20).

The second way to get good efficiency is to choose the shape of the wings properly. For instance, early experimenters tried to get results with flat wings, and failed completely, for the flat wing proved to be very inefficient. When it was observed that birds had curved wings, this principle was ap-

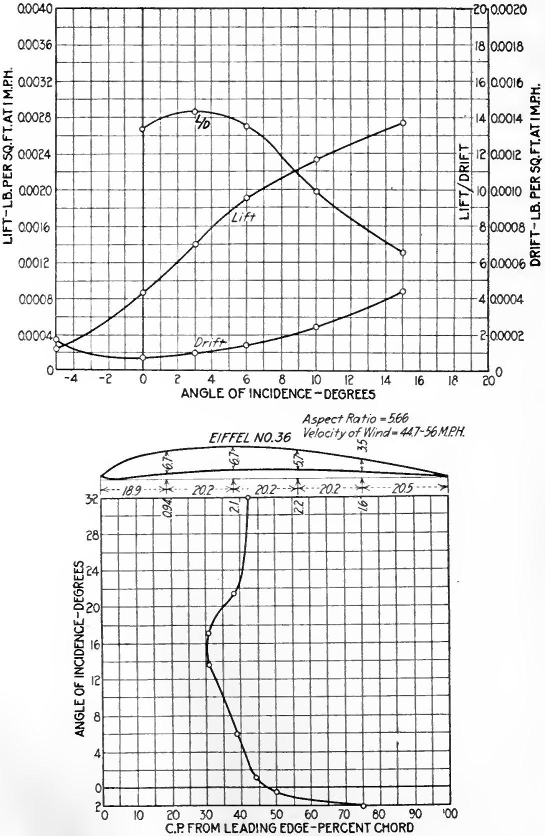


FIG. 20.—Wing characteristics.

Curves showing lift, drift, efficiency, and center of pressure travel of typical training-airplane wing, as determined in Aerodynamical Laboratory.

plied to early experiments and then for the first time man was able to obtain support in a flying machine. The fundamental principle of efficiency in wings is that they must be curved, or cambered, as it is sometimes called. This is because as the wing rushes onward it wants to sweep the air downward smoothly and without shock, as can be done only when the wing is curved (see air flow, Fig. 21).

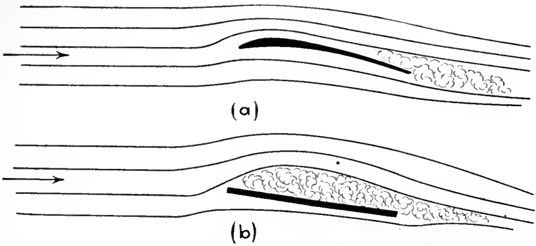


FIG. 21.—Efficiency of curved and flat wing.
(*a*) Air flow past curved wing is smooth without much eddying; (*b*) air flow past flat wing produces eddies above it.

The question of wing curvature is exceedingly important then; we find that the curvature of its upper surface is particularly so. We notice that airplane wings all have a certain thickness in order to enclose the spars and ribs; it is not necessarily a disadvantage for them to be thick, due to the fact that the upper curve of the wing does most of the lifting anyway, and the lower side is relatively unimportant. You can make the lower surface almost flat, without much hurting the effect of the wing, so long as the upper surface remains properly curved. However, the upper surface must be accurately shaped, and is so important that in some machines we find cloth is not relied on to maintain this delicate shape, but thin wood veneer is used (I refer to the front upper part of the wing). In general, then, wings are thick toward the front and taper down to a thin trailing edge.

You may wonder how it was found that the upper surface of the wing was the most important; and I

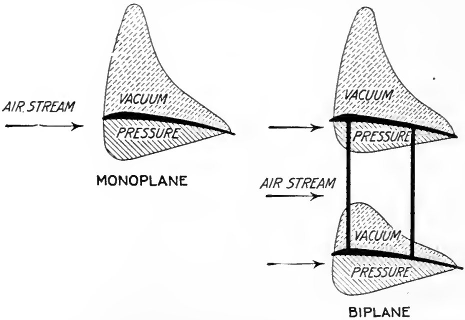


FIG. 22.—Diagram of vacuum and pressure on airplane wings. Note in biplane reduced vacuum on bottom wing.

will say that this was one of the interesting discoveries of the early history of aerodynamics. People at first thought that a wing sweeping through the air derived its support entirely from the air which struck the bottom of the wing, and they assumed that if the bottom of the wing were properly shaped, the top did not matter; that is, all the pressure in the air was delivered up against the bottom surface. But a French experimenter conceived the idea of inserting little pressure gages at various points around the wing. He found, it is true, that there was considerable pressure exerted in the air against the bottom of the wing; but he found a more surprising fact when he measured the condition above the wing. When he applied his gage to the upper surface of the wing, it read backward, that is, showed a vacuum, and a very pronounced one. He found that there was a vacuum sucking the top part of the wing upward twice as hard as the pressure underneath was pushing, so that two-thirds of the total lift on this wing was due to vacuum above it (see Fig. 22).

In the diagram the shaded area on top of the wing represents vacuum above, that below the wing represents pressure beneath.

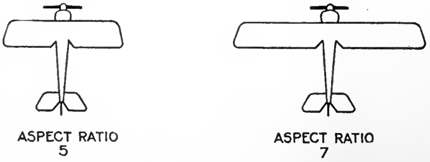


Fig. 23.—Wings of small and large aspect ratio.

Aspect Ratio.—The third factor in wing efficiency has to do with the plan shape. It was early found that square wings were not much good, and that if you made them wide in span like those of a bird, the efficiency was best (see Fig. 23). Aspect ratio is the term which gives the relation of the span to the fore and aft dimension of the wing, and this relation is usually equal to six or so. The reason why large aspect ratios are advantageous is as follows:

The tips of all wings are inefficient, because they allow the air to slip sideways around the ends, and there is all the trouble of disturbing this air without extracting any considerable lift from it. In a wide-span wing these inefficient wing tips are only a small

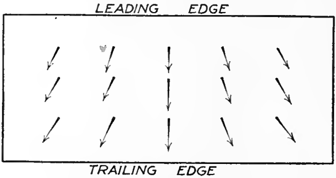


FIG. 24.—Diagram illustrating aspect-ratio effect.

Arrows show direction of air flow past plate; note that air escapes sideways around sides of plate. This phenomenon occurs at the tips of all airplane wings and accounts for small efficiency of narrow-span wings.

percentage of the total area, but in a small-span wing they may be an important consideration (see Fig. 24).

Wing Arrangements.—All the foregoing remarks in this chapter have applied only to a single wing. They apply in general to double or triple wings (biplanes and triplanes), but the matter of arranging multiple wings affects the efficiency.

The monoplane with its single layer of wings is the most efficient type of flying machine. We find if we arrange wings into the biplane shape that the presence of the upper wing interferes with the vacuum formed above the lower wing, and the efficiency decreases (see Fig. 22). The same is true of the triplane and the quadruplane arrangement. If all we wanted in airplanes was efficiency, we would use monoplanes, but the biplane is pretty popular now in spite of its low efficiency; this is because it can be much more strongly trussed than the monoplane, and also because of the fact that sufficient area may be secured with less span of wings.

It may be said that the low efficiency of the biplane can be somewhat relieved by spacing the upper and lower wings at a considerable distance apart; but if they are spaced at a distance much greater than the chord, it requires extra long struts and wires, and the resistance and weight of these will offset the advantage of wider spacing; so that practically biplane-wing efficiency may be taken as 85 per cent. of monoplane efficiency.

It remains to mention the tandem arrangement, used in all airplanes, where the tail is a tandem surface in conjunction with the wings. A surface located in the position of an airplane tail is at a disadvantage and shows low efficiency for flight purposes. This is because the main wings deflect the air downward and when the tail comes along it meets air which has a more or less downward trend, instead of encountering fresh, undisturbed air (see Fig. 16).

Resistance of an Airplane to Motion.—Earlier in this chapter the support of an airplane was explained and it was seen that the weight was exactly equalled by the lift or support; it was also explained that the production of this lift required considerable force in moving the wings rapidly through the air. It is not only the wings, however, which require force to overcome the resistance to motion. In order to have any wings at all it is unfortunately necessary to supply also struts, wires, etc., for bracing these wings, also a motor and seat for the passenger, which are usually included inside a fuselage, also wheels for landing and various control surfaces. None of these accessories to the wings contribute material lift, but they involve a large amount of resistance which is therefore a dead loss. Note carefully that there are two distinct sorts of resistance: (1) that of the wings, which is the necessary price paid for securing lift; (2) that of all the rest of the machine, in return for which nothing beneficial is received, and which therefore has sometimes been called "parasite" or "deadhead" resistance.

In a typical training machine the total resistance to be overcome if forward motion is maintained is as follows: (See Fig. 26.)

At 72 miles per hour:

Wings			160 lb.
Deadhead resistance	Fuselage	75	195
	Wiring	70	
	Struts	20	
	Miscellaneous Balance	30	
Total			355 lb.

At a speed of 57 miles per hour:

Wings	158 lb.
Deadhead resistance	130
Total	288 lb.

At a speed of 43 miles per hour:

Wings	350 lb.
Deadhead resistance	125
Total	475 lb.

It is seen that the above resistance values total to the highest figure at the lowest speed, and that the lowest value of resistance occurs at an intermediate speed; the resistance decreases as the speed decreases from 73 to 57 miles per hour; but a further decrease in speed finds the resistance running up rapidly so that at minimum speed the resistance is very great again. This is due to the fact that at high speeds the deadhead resistance exceeds that of the wings but at slow speeds although the deadhead resistance is very small, the wings being turned up to a large angle within the air, have a resistance which is at its maximum. This seems clear enough when we remember that the lift of the wings remains the same as the angle decreases (and speed goes up) but that the efficiency of the wings increases so that the wing resistance is a smaller fraction of the lift at high speed than at low speed.

Cause of Resistance.—Wing resistance, which is affected, as mentioned previously, by the wing curvature, can not be decreased unless new and improved sorts of wings are invented. As to deadhead resistance, it may be decreased in future by methods of construction which eliminate unessential parts. In a high-speed airplane in this country an attempt was made to eliminate the wires altogether and most of the struts (because the wiring is one of the largest single items of deadhead resistance); so far the attempt has failed for structural reasons. In the monoplane type of airplane of course the struts are eliminated, which is an advantage from the standpoint of resistance.

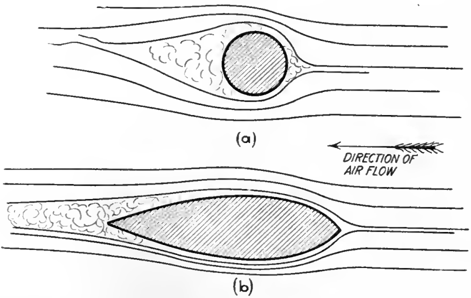


Fig. 25.—Diagram illustrating advantage of streamline shape. Note large eddy disturbance and vacuum behind round shape, causing high resistance.

As long as struts, wires, etc., are used at all, the minimum resistance can be secured by giving them a proper "stream-line" shape. The stream-line shape is one in which the thickest part is in front and tapers off to a point in the rear, like a fish. If, for instance, we take round rods instead of the struts of the training machine above mentioned and having the same thickness, the resistance might be 80 lb. instead of 20 lb.; and if we take a rod whose shape is elliptical with its axes in a ratio of 1 to 5 the resistance might be 40 lb. instead of 20 lb.; and if we took the stream-line struts out of the training machine and put them back sharp edge foremost, the resistance would be increased. The advantage of the stream-line shape is that it provides smooth lines of flow for the air which has been thrust aside at the front to flow back again without eddies to the rear. This is not possible in the case of the round strut, behind which will be found a whirl of eddies resulting in a vacuum that tends to suck it backward. By fastening a stream-line tail behind the round rod the eddies are greatly reduced, as is the vacuum. The wires of the airplane are subject to the same law and if the training machine above mentioned had stream-line wires instead of round wires we might expect them to have less than 70 lb. resistance. The fuselage should always be given as nearly a stream-line shape as the presence of the motor and tanks will permit; and it must all be inclosed smoothly in "doped" fabric in order that the air-flow phenomena may operate. As for the wheels, they must of necessity be round, but by enclosing them with fabric the air flow past them is more easy and the resistance may be halved.

Total Resistance.—The necessity has been explained of discriminating between wing and dead-head resistance; if we are talking about wings we may ignore everything except the wing resistance (commonly called "wing drift"), but if we are talking about the whole airplane, we then must refer to the total resistance, which includes all the others and is overcome by the propeller thrust. "Skin-friction" resistance has not been mentioned nor need it be more than to say that any surface moving through air attributes part of its resistance to the actual friction of the air against it, and therefore should be as smooth as possible.

Motor Power Required for Flying.—The reason resistance interests us is that motor power is required to propel the airplane against it; more and more power as the resistance and speed increase. Obviously, the power required is least when the resistance is small, *i.e.*, when the speed is intermediate between minimum and maximum. It takes more power to fly at minimum speed than at this intermediate speed. Of course it also takes more power to fly at maximum speed, where again the resistance is high.

Maximum Speed.—Ordinarily, for moderate speeds, airplanes have a margin of power at which the throttle need not be opened wide; should speed be increased the resistance and horsepower required will increase steadily until the throttle is wide open and motor "full out;" this establishes the maximum speed of an airplane; there is no margin of power, no climb is possible. The only way to increase speed is to use the force of gravity in addition to the motor force. It may be interesting to know what is the maximum possible speed in the case of a vertical dive with the motor shut off; it will be about double the maximum horizontal speed as may be readily seen from the fact that the thrust in the direction of motion is now no longer horizontal and equal to the resistance but is vertical and equal to the weight of the machine; that is, the thrust may be increased fivefold, and the speed resulting will be increased correspondingly. If the motor be running in such a vertical dive the velocity may be slightly increased though at this speed of motion the propeller would not have much efficiency.

There is danger in such high speeds; the stresses in the machine are increased several times merely by the increased resistance, and if the angle of incidence should be suddenly brought up to a large value at this high speed the stress would again be increased so that the total stress increase theoretically might be as high as fourteen times the normal value, thus exceeding the factor of safety. It is for such reasons that the maximum strength is desirable in airplanes; holes must not be carelessly drilled in the beams but should be located if anywhere midway between the top and bottom edges, where the stress will be least; initial stresses, due to tightness of the wires, should not be too great.

Climbing Ability.—Climbing ability refers to the number of feet of rise per minute or per 10 min. In order to climb, extra horsepower is required beyond that necessary for more horizontal flight. The machine can, for instance, fly at 56 miles per hour at which speed it requires 43 hp. If now the throttle is opened up so as to increase the horsepower by 22, making a total of 65 hp., the machine will climb at the rate of 380 ft. per minute, maintaining approximately the same flight speed. If instead of 65 hp., it were 54 hp. the speed of climb would be about one-half of the 380, or 190 ft. per minute; the flight speed again remaining approximately as before; that is, any margin of horsepower beyond the particular value of horsepower required may be used for climbing without material change of the flight speed. It is necessary here to state that lift does not increase during climb; and while for the instant that a climb commences there may be, due to acceleration, more lift on the wings than balances the weight, this does not remain true after a steady rate of climb is reached. To illustrate, in a wagon drawn uphill by horses the wheels which support the wagon do not exert any more support than on the level, and the entire force to make the wagon ascend is supplied through extra hard pulling by the horses. Thus in a climbing airplane the propeller furnishes all the climbing force and lift is no greater than in horizontal flight. In fact, the actual lift force may be even less, as the weight of the airplane is partly supported by the propeller thrust which is now inclined upward slightly.

To secure maximum climbing ability, we must determine at what velocity the margin of motor power is the greatest. In the above-mentioned machine we know that the horsepower required for support is least for a speed of near 55 miles per hour, and it is near speed where therefore the excess margin of power is greatest and at which climbing is best done. An airplane designed chiefly for

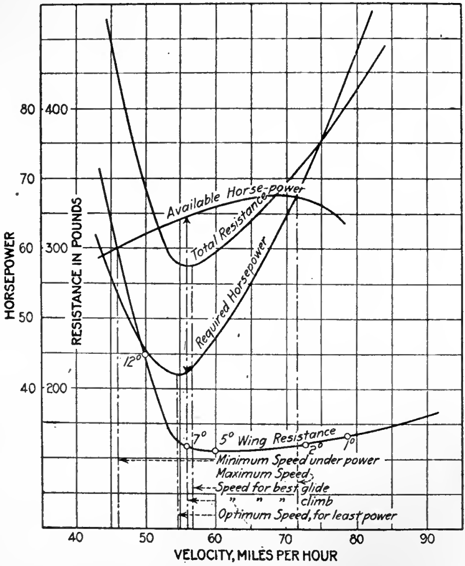


Fig. 26.—Performance curves for typical training airplane.

climbing must have low values of motor power necessary for support, namely, must have small resistance, therefore small size, therefore small weight.

Gliding Angle.—Gliding angle denotes the angle at which the airplane will glide downward with the motor shut off and is spoken of as 1 in 5, 1 in 6, etc., according as it brings the airplane 1 mile down for each 5, 6, etc., miles of travel in the line of flight. The gliding angle of a machine may be found by dividing the total resistance into the weight:

$$\text{Gliding angle} = \frac{\text{Weight}}{\text{Total resistance}}.$$

In the above-mentioned airplane it is one in 6.6 when the resistance is 288 lb., that is, when the speed is 57 miles per hour. At any other speed the resistance increases and hence the gliding angle decreases. Hence the importance of putting the airplane into its proper speed in order to secure the best gliding angle.

The Propeller.—The propeller or "screw," by screwing its way forward through the air, is able to propel the airplane at the desired velocity. Regarding principles of propeller action the matter can be hastily summarized in the following brief lines. The propeller blades may be regarded as little wings moving in a circular path about the shaft; and they have a lift and drift as do the regular wings. The lift is analogous to the thrust; to secure this thrust with least torque (drift) the blades are set at their most efficient angle of incidence, and while the blade appears to have a steep angle near the hub, it actually meets the air in flight at the same angle of incidence from hub to tip.

Propeller Pitch.—Pitch is best defined by analogy to an ordinary wood-screw; if the screw is turned one revolution it advances into the wood by an amount equal to its pitch. If the air were solid, a propeller would do the same, and the distance might be 8 ft., say. Actually the air yields, and slips backward, and the propeller advances only 6 ft. Its "slip" is then 8 minus 6, equals 2 ft., or 25 per cent. Such a propeller has an 8-ft. pitch, and a 25 per cent. slip.

This "slip stream" blows backward in a flight so that the tail of an airplane has air slipping past it faster than do the wings. Hence the air forces at the tail are greater than might be expected. The rudder and elevators therefore give a quicker action when the propeller is rotating than when, as in the case of a glide, it is not.

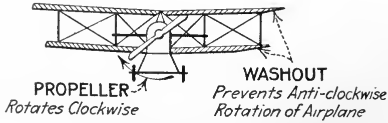


FIG. 27.—Washout in left-wing tips.

Washout.—Due to torque of the motor, the airplane tends to rotate in the opposite direction to the propeller. This tendency may be neutralized by giving one wing tip a smaller angle of incidence, called "washout," so that the machine normally tends to neutralize the torque-effect.

PRINCIPLES OF AIRPLANE EQUILIBRIUM

Introductory.—Under this head will be discussed: (*a*) features of airplane design which tend to maintain equilibrium irrespective of the pilot; (*b*) matters of voluntary controlling operations by the pilot. As regards (*a*) the tendency of the airplane

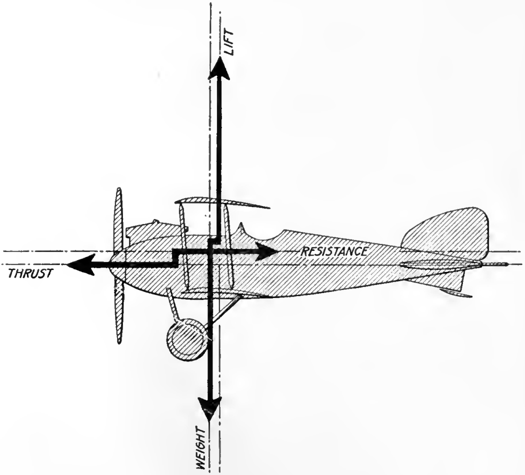


Fig. 28.—Balances of forces in an airplane.
Weight forward of lift, thrust below resistance. Thrust equals resistance, weight equals lift.

toward inherent stability acts to oppose any deviation from its course whether the pilot so desires or not. The more stable is a machine, the less delicately is it controlled, and the present consensus of opinion among pilots is that a 50–50 compromise between stability and controlability is the best thing.

In questions of airplane equilibrium the starting point is the center of gravity; obviously, if the center of gravity were back at the tail or up at the nose there would be no balance; the proper place for it is the same spot where all the other forces such as thrust, lift and resistance act; there it is easy to balance them all up. But it is not always easy to bring the line of thrust and the line of total resistance into coincidence, because the line of thrust is the line of the propeller shaft and when this is high up as in the case of some pushers it may be several inches above the line of resistance. And as the thrust is above the resistance there is a tendency to nose the machine down; to balance which the designer deliberately locates the center of gravity sufficiently far behind the center of lift so that there is an equal tendency to tip the nose upward; and all four forces mentioned completely balance each other. But things may happen to change the amount or position of these forces during flight, and if this does happen the first thing to do is to restore the balance by bringing in a small new force somewhere. In an actual airplane this small restoring force is supplied at each critical moment first, by the tail, etc., of the airplane and second, by voluntary actions of the pilot. The center of gravity of any airplane may be determined easily by putting a roller under it and seeing where it will balance, or by getting the amount of weight supported at the wheels and tail, according to the method of moments.

Longitudinal Stability.—Longitudinal stability has to do with the tendency of an airplane to maintain its proper pitching angle. It was said above that the four forces of lift, resistance, thrust and weight always exactly balanced due to their size and their position. Now the first consideration about longitudinal stability is that while the centers of gravity and other forces remain in a fixed position, the center of lift changes its position whenever the angle of incidence (that is the speed) is changed. The phenomenon of shift of center of pressure applies only to the wings and to the lift (the position of center of resistance remains practically fixed at all angles).

Note the effect on center of pressure position of a change of wing angle (see Fig. 20). The wing used on the U. S. training machine has a center of lift which is about in the middle of the wing when flying at a small angle of maximum speed; but if the angle is increased to the stalling angle of 15°, the center of pressure moves from midway of the wing to a point which is about one-third the chord distance of the wing from the front edge. The lift may travel about ½ foot, and it is equal in amount to the weight of the machine (that is, nearly a ton), and the mere effect of changing the angle from its minimum to its maximum value therefore tends to disturb the longitudinal equilibrium with a force which may be represented as 1 ton acting on a lever arm of ½ ft. Suppose that the airplane is balancing at an angle of 2° so that the center of gravity coincides with the center of lift for this angle; now if a gust of wind causes the angle to increase for an instant to 2¼°, the center of lift will move forward and tend to push the front edge of the wing up, thus increasing the angle further to 2½°. Then the center of lift, of course, moves further forward to accommodate the increase of angle, and in a fraction of a second the wing would rear up unless it were firmly attached to the airplane body and held in its proper position by the tail. Similarly if for any reason the proper angle of 2° were decreased, the same upset would follow, only this time tending to dive the wing violently to earth. This tendency is neutralized in an airplane by the "Penaud Tail Principle."

There are certain shapes of wings in which the center of pressure travels in the reverse direction; a flat plate, for example; or a wing having its rear edge turned up so that the general wing shape is like a thin letter "S." Such wings as these would not tend to lose their proper angle, because when the angle is changed for any reason the center or pressure in these wings moves in just the manner necessary to restore them to their proper position; but these wings are inefficient and are not in present use on airplanes.

The Penaud Tail Principle.—*Rule.*—The horizontal tail must have a smaller angle of incidence than the wings. The upsetting force above mentioned must be met by a strong opposite righting force, and this latter is furnished by the horizontal tail surface. In the angle of equilibrium of 2° above mentioned, the flat horizontal stabilizer will

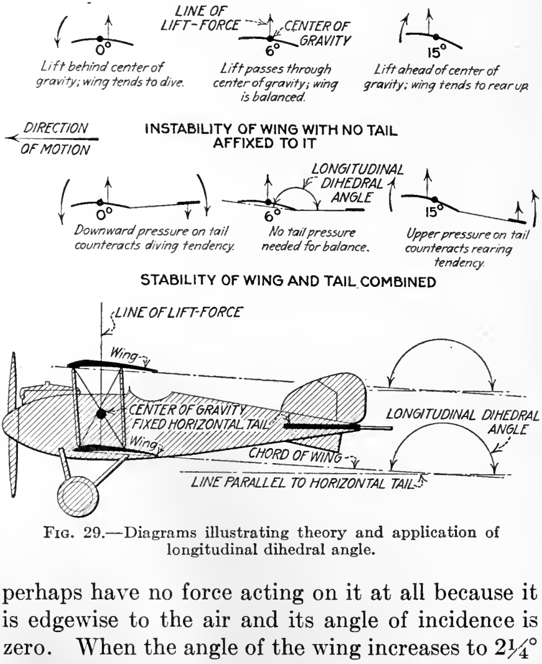


FIG. 29.—Diagrams illustrating theory and application of longitudinal dihedral angle.

perhaps have no force acting on it at all because it is edgewise to the air and its angle of incidence is zero. When the angle of the wing increases to 2¼° and the lift moves forward tending to rear it up, the wing being rigidly fastened to the body pushes

6

the tail downward so that the tail now begins to have a small lift force upon it due to its angle of $\frac{1}{4}°$; and this newly created force, though small, acts at such a long lever arm that it exceeds the rearing force of the wing and will quickly restore the airplane to 2°. This action depends upon the principle of the Penaud Tail or longitudinal "Dihedral" which requires that the front wings of an airplane make a larger angle with the wind than the rear surface. This principle holds good even when we have rear surfaces which actually are lifting surfaces in normal flight, the requisite being that the wings themselves shall in such cases be at an even greater angle than the tail. No mention has been made of the elevator control, because its action is additional to the above-mentioned stability. The elevator is able to alter the lift on the tail; such alteration requires, of course, immediate change of angle of the wings so that equilibrium shall again follow; and th's equilibrium will be maintained until the lift at the tail is again altered by some movement of the elevator control. Thus the elevator may be considered as a device for adjusting the angle of incidence of the wings.

The air through which the wings have passed receives downward motion, and therefore a tail which is poised at zero angle with the line of flight may actually receive air at an angle of $-2°$ or $-3°$. In the above case we would expect an actual downward force on the tail, unless this tail is given a slight arch on its top surface (for it is known that arched surfaces have an angle of zero lift which is negative angle).

Longitudinal Control.—Steering up or down is done by the elevator, which as explained above is merely a device for adjusting the angle of incidence of the wings. The elevator controls like all the other controls of an airplane depend for their quick efficient action upon generous speed; they can not be expected to give good response when the machine is near its stalling speed. The elevators like the rudder are located directly in the blast of the propeller and in case the speed of motion should become very slow, the elevators may be made to exert considerable controlling force if the motor is opened up to blow a strong blast against them. This is good to bear in mind when taxying on the ground because if the motor is shut off at the slow speed of motion the elevator and rudder will lose their efficacy. The propeller blast, due to a 25 per cent. slip, adds 25 per cent. of apparent speed to those parts which are in its way, and therefore the tail forces are affected as the square of this increase, that is, the forces may be 50 per cent. greater with the propeller on than off.

Lateral Stability.—This depends upon the keel surface or total side area of an airplane. The keel surface includes all the struts, wires, wheels, wings, as well as body, against which a side wind can blow. Skidding and side-slipping have the same effect as a side wind, and the resulting forces acting against the side of the machine should be made useful instead of harmful. This is done by properly proportioning the keel or side surface. If keel surface is low, the side force will rotate the airplane about its axis so that the windward wing sinks; if high, so that it rises. But if the keel surface is at just the right height (*i.e.*, level with the center of gravity) the side forces will not rotate the machine at all and will simply oppose the skidding without upsetting equilibrium.

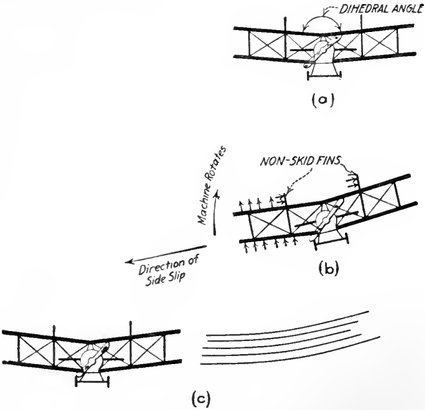


FIG. 30.—Diagram showing effect on lateral stability of dihedral angle and non-skid fins.

(*a*) Machine flying level. (*b*) Machine tips and side-slips: excess pressure is created on windward wing and fins. (*c*) Machine has side-slipped and rotated back to level.

Lateral Dihedral.—Now when an airplane appears to have its keel-surface center too low, the easiest way to raise it level with the center of gravity is to give the wings a dihedral angle, that is make them point upward and outward from the body. Thus their projection, as seen in a side view, is increased, and the effect is to add some keel surface above the center of gravity, thus raising the center of total keel surface.

A further advantage of the lateral dihedral is that any list of the airplane sideways is automatically corrected (see Fig. 30). The low wing supports better than the high wing, because a side slip sets in, hence will restore the airplane to level position.

Non-Skid-Fins.—Where for the above-mentioned purposes an excessive dihedral would be needed, resort may be had to non-skid-fins erected vertically edgewise to the line of flight above or beneath the topwing. These are used in marine machines to balance the abnormally large keel surface of the boat or pontoon below.

Lateral Control.—By means of ailerons, lateral control is maintained voluntarily by the pilot; the aileron on the low tip is given a greater angle of incidence while on the high tip a less angle of incidence thus restoring the proper level of the machine. Notice that the efficacy of the ailerons depends upon speed of motion of the airplane, irrespective of propeller slip because the propeller slip does not reach the ailerons. Therefore, at stalling speeds the ailerons may not be expected to work at their best, and when lateral balance is upset at slow speeds it is necessary to dive the machine before enough lateral control can be secured to restore the balance.

Directional Stability.—Directional stability has to do with the tendency of an airplane to swerve to the right or left of its proper course. To maintain directional stability the "vertical stabilizer" is used, which acts in a manner analogous to the feather on an arrow. Thus in case of a side slip the tail will swing and force the airplane nose around into the direction of the side slip so that the airplane tends to meet the relative side wind "nose-on" as it should. The vertical stabilizer should not be too

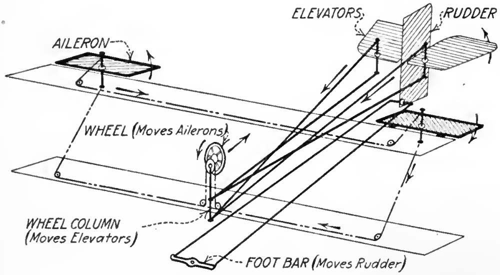


Fig. 31.—Deperdussin control.
System used in U. S. training airplanes.

large, however, as then any side pressure due to deviation from a rectilinear course will cause the machine to swerve violently; the wing which is outermost in the turn will have preponderance of lift due to its higher speed; that is, the airplane will get into a turn where there is too much bank and a spiral dive may result.

Directional Control.—The rudder gives directional control in exactly the same way that it does on a boat; it should be said, however, that the rudder is sometimes used without any intention of changing the direction, that is, it is used simultaneously with the ailerons as a means of neutralizing their swerving tendency. The ailerons, of course, at the same time that they restore lateral balance create a disadvantageous tendency to swerve the machine away from its directional course; that is what the rudder must neutralize. Moreover, the rudder is frequently used against side winds to maintain rectilinear motion.

Banking.—Banking combines the lateral and directional control, which should be operated simultaneously so as to tilt the machine and at the same time maintain the radius of turn. The wings are tilted in a bank because in going around a curve of a certain radius the weight of the machine creates a centrifugal force in a horizontal direction and if the curved path is to be maintained this centrifugal force must be neutralized; and this is done by inclining the force of lift inward until it has a horizontal component equal to the centrifugal force. That is why the angle of bank must be rigidly observed, or else the inward component of the lift will change. Now as soon as the wings bank up, the lift force is no longer all vertical and therefore may not be enough to support the weight of the machine. To offset this have plenty of motor power for speed in a bank; and do not try to climb while banking.

It is better to bank too little than too much; too little results in skidding which may be easily cured; too much results in side slipping inward and if the tail surface is too great in this latter case, a spiral dive may result—so look out for overbanking.

It is better for the beginner in banking to move his ailerons first and then move the rudder; for if he moves the rudder first there will be skidding outward, forward speed will drop and a stall may result. On high angles of banking, over 45°, it should be noted that the elevators are now more nearly vertical than horizontal and operate as a rudder; similarly the rudder's function is reversed, and to turn down the rudder will be used.

Damping in an Airplane.—Above have been mentioned the restoring forces which tend toward airplane equilibrium. Now these restoring forces tend to push the machine back to equilibrium and even beyond in exactly the same way that gravity causes a pendulum to swing about its point of equilibrium. This can sometimes be noticed in the case of an automobile when travelling at high speed along country roads where a sort of slow oscillation from side to side may be noticed due to the forceful maintenance of equilibrium of the body in its forward motion. This oscillation in an airplane would be serious unless there were means of damping it out and these means are: first, the wings; second, the tail surfaces; third, the weight and inertia of the machine itself. Regarding inertia it should be said that a machine with weight distributed far from the center of gravity, such as the double-motor airplane has a large tendency to resist the rolling motions associated with lateral stability. But from the same sign airplanes with large moment of inertia are difficult to deviate from any given attitude, and therefore have the name of being "logy." The proper proportioning of an airplane's parts to secure first, the restoring forces; second, the proper damping force; third, the proper amount of moment of inertia, is a very delicate matter and beyond the scope of the present chapter.

CHAPTER IV

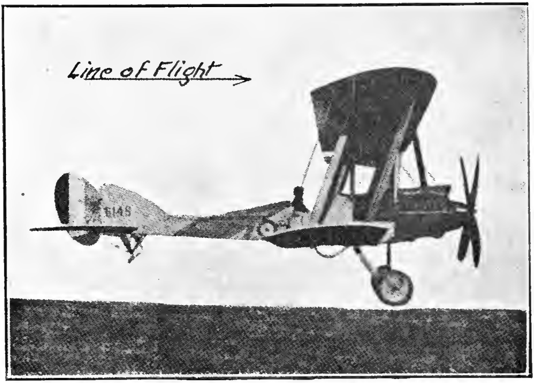
FLYING THE AIRPLANE

Starting Off.—The first thing to do before starting off in an airplane is to inspect carefully everything about the machine and assure yourself that it is in perfect condition.

When all is ready to start turn the machine directly against the wind; this is done in order that the rise from the ground may be more quickly made with the assistance of the wind under the wings, and it has a more important advantage in the fact that if you try to get off the ground across the wind the machine will be very hard to balance. Birds also take the air directly against the wind even though for the moment this carries them in a direction toward some supposed enemy, and it is a fundamental principle in airdromes. Keep the machine pointed into the wind for the first 200 ft. of altitude (and similarly in landing face the wind when within 200 feet of the ground). In case the engine should fail before a height of 200 ft. is reached, never turn down wind as this is extremely dangerous.

Assistance will be had for the start from the mechanics, or if away from the airdrome from bystanders. Have each assistant in his proper place before starting the engine; one is to start the propeller and the rest to hold back the machine until ready to let go.

In order to get off the ground you will want good engine power; it takes considerable thrust to



(*From "How to Instruct in Flying."*)

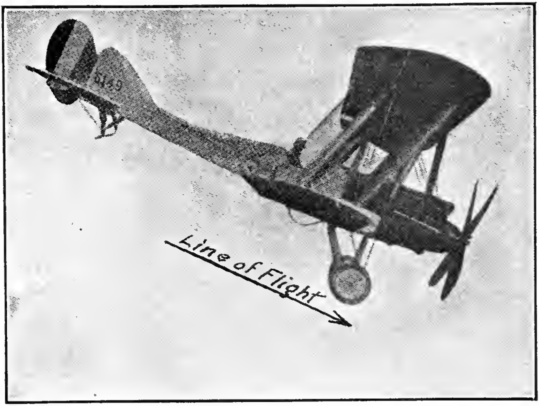
Fig. 32.—Airplane in flying position just after starting. This cut also illustrates proper landing attitude, since airplane is just skimming the ground.

accelerate an airplane on the ground to its flying speed; in fact the first flying machine of the Wrights had to use an auxiliary catapult to furnish the thrust necessary to get them into the air. Making sure that the motor is giving full power raise the hand as a signal to the attendants to remove the chocks and let go. As you start rolling forward push the control lever forward which will raise the tail off the ground and place the wings edgewise to the wind while they will not offer resistance to the acquiring of good rolling speed. Within a few seconds the machine will have attained on the ground a velocity not less than the low flying speed; it will not rise, however, until the tail is lowered by pulling the lever back. When the necessary rolling speed is attained pull the lever softly backward; the tail at once drops, the wings increase their angle and lift and the machine will rise, the lever being held in a fixed position (see Fig. 32). The distance between the point of starting and rising will be 100 yd. or more and will occupy from 5 to 10 sec. depending on the wind.

The change from flying position to climbing position is only a slight modification involving only a slight pulling back of the control lever and holding it in fixed position; the motor may in some machines simply be opened out when its increased power will make the machine rise; however, there is only one speed at which the climb will be fastest and therefore it is well to know what is the proper speed for climbing; the motor is then opened out full and the airplane operated to give the proper speed corresponding.

The pupil should rise to the height of at least 100 ft., as any less is useless and nothing will be learned from landing. In the case of cross-country flying the pilot will rise to the height of 2000 ft., circling over the field rather than flying off in a straight line so that preparatory to his start he always has the flying field in reach.

Landing.—Proper landing is the most important thing in airplane flying. The pilot in turning his machine downward toward a landing spot from flight will choose a distance from the field equivalent



(*From "How to Instruct in Flying."*)

Fig. 33.—Airplane in gliding position, approaching a landing. Note that its attitude relative to line of flight is similar to "flying position," line of flight however being inclined.

to the proper gliding angle of his machine. If the gliding angle is 1 in 7 he must not turn downward any further from the field than a distance greater than seven times his altitude or he will fall short. It is safer to come closer to the field before turning downward for two reasons: first, because you may not be gliding at the best gliding angle; second, because you can always kill extra height by a spiral or two better than you can regain it. Have height to spare when landing.

To come down throttle down the engine and push the lever softly forward until the proper gliding angle is obtained (Fig. 33). The reason for throttling down the engine is: first, that you do not need its thrust when you are coasting down because gravity furnishes all the necessary velocity; second, if you glide or dive with the motor wide open high speed will result, resulting in strains on the machine especially on the moment of leveling out again; third, at this high speed the controls become stiff to operate.

Maintain the proper gliding speed to within 5 miles an hour of what it ought to be as it is the speed which determines the proper gliding angle. The revolution counter will indicate what the speed is or the air-speed meter may be used. Arrange to come on to the field facing directly into the wind, which may be observed by watching smoke or flags below. In landing against the wind you are again copying the practice of the birds. When you come to within 15 ft. of the ground pull the lever softly back until the machine is in its slow-flying position, which should be attained 5 ft. above the ground (Fig. 34). Hold the stick at this position of horizontal flying; no further movement of the lever is necessary except to correct bumps, for which purpose it would be held lightly for instant action.

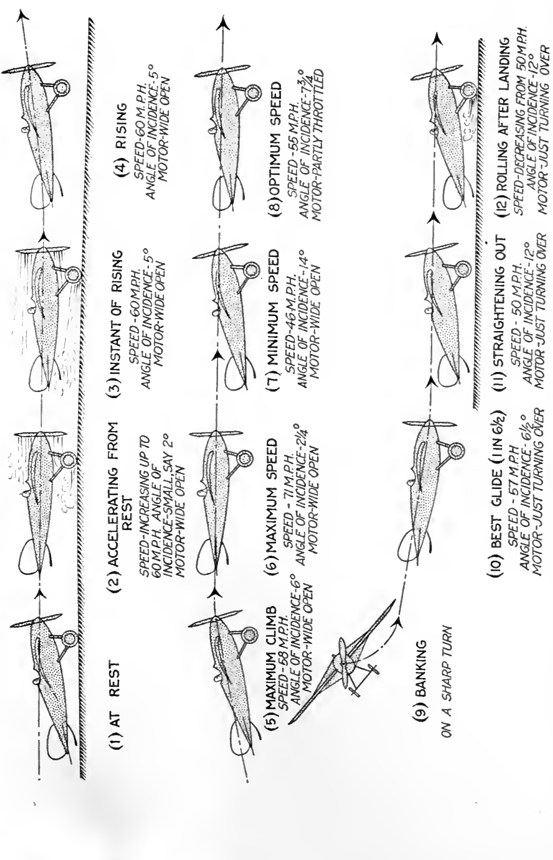


Fig. 34.—Attitudes of an airplane in flight.

The aileron control must be used here to keep the machine level and it may be necessary to operate the rudder after touching the ground in order to avoid swerving; in fact some machines are provided with a rear skid which steers for this purpose.

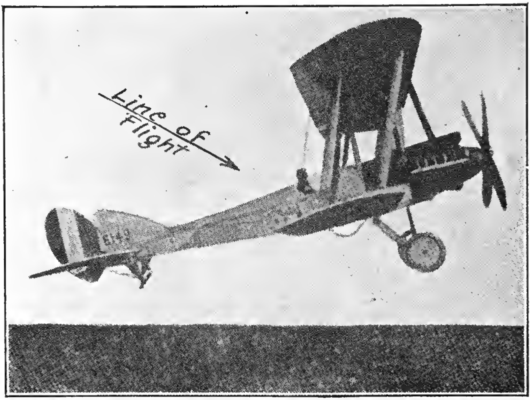
In rolling just after landing keep the tail as close to the ground as possible without causing undue bumping, so that the maximum resistance of the wings may be presented to the air and the machine be slowed up rapidly. Some machines are fitted with brakes on the wheels to assist in the quick retardation of the roll. Landing is one of the biggest problems in aviation and is a hard thing to learn because it is done at a high speed especially in the fast military machines such as the Fokker, Nieuport, etc. Landing is more of a problem than it used to be in the early days when, for instance, the Wrights were able to land without any wheels at all on mere skids because their machines were not fast.

The following are examples of bad landings:

1. The pancake results from allowing the machine to get into its rising position when it is landing (Fig. 35). There will be a perpendicular bounce and on the second bounce the running gear will break. In order to get out of an immanent pancake open up the engine to keep machine flying, put the machine into a flying position, then throttle down again and land.

2. Another type of pancake results from bringing the machine out of its gliding position at a point

too far above the ground when the machine will drop due to lack of speed and break the running gear. To avoid this open motor full, thus regaining speed and flying position; afterward throttle down and reland.



(*From "How to Instruct in Flying."*)

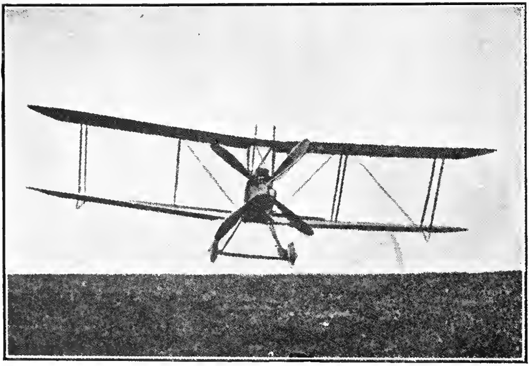
FIG. 35.—Bad landing, Type 1—the "pancake" landing.

Line of flight is downward; angle of incidence large, hence speed is slow; but there is too much downward momentum and landing gear will break. Should line of flight arrow point upward, airplane as shown would then be in climbing position.

3. A third type of bad landing results from failure to turn the machine out of its glide at all, so that it glides straight downward until it touches the ground. This is the most dangerous case of all the bad landings. To cure it open up the engine after the first

bounce, regaining flying speed before the second bounce; then reland.

4. If at the moment of landing the rudder is turned causing machine to swerve, or if the machine is not level, a side strain will be placed upon the landing gear and the wheels will buckle (Fig. 36).



(*From "How to Instruct in Flying."*)

FIG. 36.—Bad landing Type 4—machine not level. Wheels do not touch ground at same time, and one may smash.

CHAPTER V

CROSS-COUNTRY FLYING

Cross-country flying differs from ordinary airdrome flying in that it takes you a long way off from your landing field. On the airdrome your chief anxiety is to learn how to fly, how to work the controls, how to bank; but in cross-country work, you are supposed to have all the technique of airplane operation well in hand, so that you do not have to think much about it. In cross-country flying, then, your chief anxiety will be to arrive at your destination and to be constantly searching out available landing fields in case of engine failure. The first cross-country flight you make may be a short, easy one, in which there are plenty of available landing places, and on which you will be able to make a regular reconnaissance report. Further experience in cross-country work will involve more and more difficult trips, until you will think nothing of flying, for example, on long raiding tours over unfamiliar enemy country.

Equipment.—Knowing that you may have to land far away from any headquarters, you must take a complete set of tools and covers for the airplane. Your clothing need not be different from usual, and will comprise helmet, goggles, leather suit, and gloves. Do not forget your handkerchief, which you frequently need to clean off your goggles.

The instruments needed on a cross-country trip are: a compass, which should be properly adjusted before starting and the variation angle noted. A wrist watch is necessary; ordinary dashboard clocks go wrong on account of the vibration. Take an aneroid barometer with adjustable height reading. Of course you will depend upon a revolution indicator, for no matter how experienced a pilot may be in "listening out" faulty engine operation, after a long flight his ear loses its acuteness, and he will fall back on the revolution indicator for assistance. The air-speed meter, whether of the Pitot type or pressure-plate type, will prove invaluable in flying through clouds or mist when the ground is obscured. Also the inclinometer is able to give the angle of flight when the earth is not visible, although the speed indicator usually is sufficient to give the angle of flight, for an increase of speed means downward motion and decrease of speed means upward motion. Additional instruments may be used.

Map.—The map is essential for cross-country work. It should be tacked on to the map board if the flight is short, but made to run on rollers if the flight is long. In the latter case the map is in the form of a single long strip, while your flight may be full of angles; therefore you will have to practice using this sort of map, in which the corners of your flight are all drawn as straight lines. The scale of maps may be 2 or 4 miles to the inch for long flights. This scale is sometimes spoken of as a fractional figure; that is, 2 miles to the inch is the same as $\frac{1}{127,000}$ scale. The map should be studied most carefully before the start of the trip. The course which you propose to fly should be marked out on it; all available landmarks which could be of service as guides should be distinctly noticed and marked on the map where necessary. These landmarks will in case there is no wind enable you to make your trip without using the compass at all, and in case of wind, are essential as a check on the compass. Mark off the distance in miles between consecutive points of your course. Mark the compass bearing of each leg of this course.

As landmarks towns are the best guides, and they should be underscored on the map, or enclosed in circles. It is customary not to fly actually over towns. Railways are very good assistance to finding your way, and these should be marked on the map in black wherever they approach within 10 miles of the course. Mark water courses with blue color, and roads with red.

Landmarks.—Only practice can make a pilot good at observing the various features of the ground beneath him. The various features which can be used as guides are those which are most visible. After towns, railways come next in importance. Their bridges, tunnels, etc., make good landmarks. On windy days when relying on the compass, it will be well to keep in sight of a railway even if this be the longer way around, because the railway gives a constant check upon the compass bearing. In this case you will have noted on your map a general magnetic bearing of the railway, which bearing you can readily compare with your compass reading. Moreover, the railway is good in case you become involved in a fog or mist for a time. It should be remembered, however, that on most of the maps no distinction is made between one and two-track roads; also that it is easy to make mistakes where branch lines are not shown on the map because they are dead ends leading to private quarries, etc., and may be taken for junctions. Railways sometimes seem to end abruptly, which means that you are looking at a tunnel.

Water is visible from a great distance. Cautions to be observed are that after a heavy rain small flooded streams may take on the appearance of larger bodies of water or lakes, which you will have difficulty in reconciling with the map. Small rivers are often overhung with foliage, and to follow them in all their curves will waste a lot of time.

The use of roads as guides may be governed by the fact that paved roads are usually main roads, and telegraph wires may be expected along them. In the newer parts of the United States the system of laying out roads provides a very useful means of gaging distances; I refer to the section system which is in use, for instance, in Illinois, where there is a road every mile running north and south, so that the entire country is cut up into squares 1 mile on each side, with occasional roads of course at ½-mile and ¼-mile points.

Navigation by Landmarks.—In all cases of cross-country flying the pilot will have two independent systems of maintaining his proper directions: first, the computed compass bearing; second, the use of landmarks whose position is known. In comparing his computed course with the course actually indicated by passing over these landmarks the rule should be made that, in case of doubt when a landmark is not distinctly recognized, take the compass course; there are many chances that a landmark may be altered or even removed without being so recorded on the pilot's map, whereas the errors of the compass of course are presumably understood by the pilot who has secured every opportunity to check it when passing previous landmarks.

It is important to note the time of completing successive stages of the flight, that is when passing over predetermined landmarks. Time is a very uncertain condition to ascertain in airplane flying for it seems to pass quickly on calm days but slowly when the journey is rough. If the pilot does not check the time interval between successive objects he is quite likely to expect the next before it is really due.

Landing Fields.—Next to the ever-present worry which the pilot has regarding the perfect operation of his engine, the most important thing about cross-country flying is that wherever he may be he must have available a landing field within gliding distance in case his engine defaults. The question is of course immediately raised, "What if there is no landing field within gliding range?" The answer to this is that the pilot will instinctively learn to keep his eyes open for landing possibilities every minute of his progress whether he expects to use them or not; in cross-country flying the lookout for fields is first and foremost in his mind; if there are no fields, it is up to him to pick out a spot of ground which is the least objectionable for a landing. In the State of Illinois the question of landing fields is almost non-existent, because there are large, flat fields and pastures in almost every square mile of the farming district, and a cross-country flight from Rantoul to Chicago could have no terrors for the beginner as regards the choice of a landing ground.

When it comes to a cross-country flight like Ruth Law's, from Chicago to New York, these favorable conditions begin to disappear after the middle of the journey, that is, east of Buffalo. The most ideal condition for cross-country flying would be one like that on the London-Edinburgh route, where landing grounds are so frequent that by flying at a height of a couple of miles the pilot can free his mind completely of the worry of suitable landing places; but in the United States we have very few established airdromes, and the only approach to the London-Edinburgh route is the St. Louis-New York route, where the jumps are approximately 150 miles; namely, St. Louis, Champaign, Indianapolis, Dayton, Sandusky, Erie, Hammondsport, Philadelphia, and New York. That is why long cross-country trips are such an adventure in this country and such an ordinary affair in England.

The beginner will have special difficulty in training his mind to pick out available landing places; first of all because the earth looks so different from the sky that it is only with practice a beginner learns the shades and hues of color which mean certain kinds of ground, or learns to spot the different features of flat and hilly country. Even for an accomplished pilot it is hard to tell whether a field is good or bad from a height of over 1000 ft.; and as it is dangerous to fly this low over unknown territory, you can at once see what is meant by the worry of scanning the countryside for available fields.

Choose the best field that you can get, having a smooth surface and being easy to get out of in all directions. The following considerations are intended as a guide to what constitute the best field, in case you have a choice between several possibilities.

1. Choose a field near a town if possible, or failing that, near a main road or at least a good road. Remember that a field which appears to be near a town from the air may actually turn out to be a long walk after you have landed there and find that there are various trips to be made to and fro between your chosen landing spot and the town for the purpose of securing ropes, gasoline, supplies, etc. If you land near a main road there will probably be telegraph

wires along it, which are undesirable in the case of a small field and wind direction such that you have to rise off the field over the telegraph wires. It is often hard to distinguish between main roads and minor roads, and it will be wise to look for the number of vehicles on any road in determining whether or not it is the main road.

2. The best field is a stubble field, and is most numerous of course in the fall when the crops are in. It will have a lightish brown color when seen from a height, and is pretty sure to be smooth, without ditches or mounds. Grass land is next best, but is often full of mounds. Plowed, furrow fields are to be avoided. It might be said that stubble fields will be hard to get out of after a wet night. Vegetable and corn fields have a dark green appearance which the pilot must learn to distinguish from grass pastures, etc. If you choose pasture land, remember that in summer evenings the farm animals will generally be lying down near the hedges.

3. Avoid river valleys for landing over night, as there is liable to be a fog in the morning.

4. Any field which has been previously used for landing with success by an army officer can be wisely chosen.

The final determination of landing field characteristics can be made when your airplane has descended to a height of 1000 ft. off the ground, and in case you are not making a forced landing and your engine is still going, you can check up your estimate by descending to this level.

Proper Dimensions of Fields and Airdromes.—There are three kinds of flying fields. One is the airdrome which is used exclusively for flying, and may be as large as a mile square; very few of these will be found in cross-country flights in the United States. Second, there is what is called the "one-way" field, a long, narrow, open space which is usable when the wind blows parallel to its length. Third, there is the "two-way" field, which has two sufficiently long runways at right angles to each other. A two-way field is very much better than a one-way field, inasmuch as you can always head within 45° of the wind, whereas in a one-way field an extreme case would be 90°. Moreover, two-way fields, such as the crescent-shaped field at Dayton, Ohio, sometimes permit of almost universal direction of flight. The two-way field may be crescent-shaped, T-shaped, or L-shaped. An L-shaped field should have each arm 200 by 300 yd. Under certain conditions there may be buildings located inside or outside the angle which do no harm aside from creating eddies in case of strong wind. A T-shaped field should also have its arms 300 by 200 yd. in size.

Regarding the size of fields it can be said that, while the JN–4 machine will rise off the ground after a run of 100 yd. or so, a field of this length is of course not big enough for frequent use, especially if bordered by trees, telegraph lines, fences, and so forth. A field for temporary use should be at least 200 by 200 yd., about 9 acres.

If obstructions at the edges are more than 5 ft. high add to this 200 yd. a distance equal to twelve times the height of the obstruction. For a permanent field 300 yd. is the minimum dimension necessary for clearing obstacles and must be increased if the trees exceed 50 ft. in height. This minimum dimension assumes hard ground and the possibility of starting in any direction. Training fields are ½ mile square or more.

Whatever field is used either temporarily or permanently by the pilot should be absolutely familiar to him over every inch of its surface. The adjacent country should also be absolutely familiar to him from the standpoint of possible forced landings which he may have to make during his flight; he should make a habit of informing himself as to all the woods and hills, etc., which can affect air currents in the neighborhood of the field from which he is going to start.

Guide Posts on Airdromes.—Some fields have pot holes in them, and these holes should be marked in each case with a large high red or yellow flag. Do not use short, small flags, as they will frequently be invisible to pilots taxying on the ground. All telephone wires, etc., should have large blankets or other suitable signals hung over them to warn the pilot away.

Commonly accepted marks for designating a landing spot on airdromes are as follows:

For day use a large letter "T" lying on the ground, made out of white cloth strips 15 by 3 ft.

This letter T is shifted with the wind so that its long leg always points in the direction of the wind and the pilot will therefore have nothing to do in landing but approach the letter "T" from the bottom, so to speak.

For night flying a system of four flares is used, so arranged that the pilot in making a proper landing will pass flare A on his left; within 50 yd. further on, flare B; then 100 yd. further on, flare C, also on his left. In passing flare C he will have a fourth flare, D, 50 yd. to his right. That is to say, the four flares make the outline of a letter "L" and the pilot approaches the letter "L" having the long leg on his left. The flares may be made by putting half a gallon of gasoline into a pail. This will burn for 30 min. and will be visible 8 miles away. Sometimes at night instead of flares white sheets can be spread on the ground and a shaded lamp used to illuminate the sheets.

All searchlights on the landing field should point in the direction of landing. All other lights within a distance of a mile should be extinguished, and red lamps should be used at danger points.

On moonlight nights the same signals and guides may be used as in the daytime.

Pegging Down an Airplane.—In landing for the night do not stay up until it gets dark but choose a landing place which will allow you to come down 1 hr. before dark; this amount of time will be needed for laying up the machine over night. As you come to the landing ground note the time so that you can compute the actual duration of your flight in your report, then make a good landing. Taxy the machine to the spot where you intend to leave it over night, such as the lee of a hedge, etc.; or if there is no choice of position taxy the machine to the approximate location from which you will make your start next morning; this will save trouble when you get ready to start.

Dismount from your machine, lift up the tail enough to leave the wings edgewise to the wind, the machine, of course, facing the wind, and jack up the tail in this position by the use of any convenient prop. Lash the control wheel or joy stick fast in a fixed position so that the wind can not flap the control surfaces around and damage them.

Choose a sunken trench if possible in which the wheels may be sunk; if the wind is going to blow and there is no sunken trench it will be wise to dig one so that the effect of the wind on the airplane will be lessened. If the trench is not necessary, at least put chocks under the wheels. Peg down the wings and the tail to stakes driven into the ground using rope if you can get some or lacking this in an emergency fence wires which you can secure by means of your wire cutters. Do not lash tightly enough to induce strains in the framework of the machine.

Next, fill up the tanks if a supply of gasoline or oil is available. Put the covers on the propellers, engine, cowls, etc., in order that rain and dew shall do no damage to these parts. The wings and body are varnished waterproof and will not be seriously damaged by a little moisture; to avoid the collection of moisture in the wings small eyelet holes are sometimes set in the wings at the trailing edge to let out the water.

Of course, you will engage a guard to watch the machine all night; see that a rope is strung around the airplane to keep off the crowd which may collect.

AERIAL NAVIGATION

Effect of Wind.—Navigating in an airplane is complicated only on account of the fact that there is a wind blowing which may not be in the desired direction. While on the sea navigation is simple through the assistance of the magnetic compass (because side winds can not materially drift the ship sideways), in the air this is not the case; for if the pilot using the compass points the nose of the airplane directly north while a west wind is blowing, this wind will cause the machine to drift in an easterly direction so that in an hour of flight the airplane will be off its course by an amount equal to distance which the wind travels in 1 hr.; and the joint result of the motion of the airplane forward and the motion of the wind sideways will cause the machine to drift in a northeasterly direction at a speed quite different from its rated velocity, and in this case somewhat larger. Victor Carlstrom in his Chicago-New York flight found while he was over Cleveland that a side wind was deviating his course

17° away from what it should be, and if he had not had such landmarks as the shore of Lake Erie for guidance he might easily have lost considerable time.

The question of making allowance for this wind drift is very important where there are no landmarks, as in the case of night flying, flying over the sea, or flying over the clouds; and the only way the pilot can make allowances for these conditions is to figure them out before he starts from the airdrome, and plan to circumvent them. That is to say, the pilot in flight has no means, aside from visual observation of the ground, to determine whether or not the wind is blowing him off his course. He must determine the whole situation before he starts, and the process of doing so is as follows.

Graphical Method for Determining Direction to Steer.—The pilot will ascertain from the weather vane and anemometer of the airdrome (1) the velocity and (2) the direction of the wind, (3) the speed of the airplane he is to fly, (4) the compass bearing of the actual course which he desires to follow. With this data it is possible to construct a simple diagram and to determine the direction to be steered and the actual velocity which will result in the proposed journey. A draftsman's scale, protractor and dividers, a pencil and a piece of paper are the necessary equipment.

When the wind blows at an angle with the desired course it is necessary to steer the airplane in such a direction that its own forward motion will neutralize the side effect of the drift of the wind from moment to moment. The problem is to determine this direction for steering, as it is not known. We are not concerned with distances in this problem, for the direction is going to be the same whether our flight is of 100 or 200 miles. We are, however, vitally concerned with velocities; and we will assume that the velocity of the airplane is known to be 75 miles per hour, and from observation on a local anemometer the velocity of the wind is known to be 20 miles an hour. We also know, of course, the direction of the wind, which should be given in terms of an angle whose other leg points directly north. Now if the flight is to be made at a height of 2000 ft., as is usual in cross-country flight over average country, we will find that the speed of wind will increase as we rise up; moreover, that its direction will change. In the present case the wind will be 88 per cent. higher in 2000 ft. than it is on the ground; that is to say, the velocity at the altitude we are going to use is twenty times 1.88, or about 38 miles per hour. Moreover, as the height increases the direction of the wind changes, shifting around always in a clockwise direction as the height increases, in the present case shifting around 16° from its ground direction. (The change of velocity and direction for various heights is indicated on the subjoined table.) Thus a west wind becomes at a height of 2000 ft. a slightly northwest wind, or, to be exact, blows from a direction which is 74° west of north.

Our treatment of the problem then has for starting points: velocity of wind, 38 miles per hour; direction of the wind, 74° west of north; velocity of airplane 75 miles per hour; desired direction of flight (which has been determined by laying out on the map and reading the compass bearing with the protractor), say 60° east of north. In 1 hr. of flight the machine would travel in this unknown direction a distance of 75 miles were it not for the wind, but for every hour of such flying the wind is blowing it 38 miles sideways; and the desired direction must be such that its joint effect, together with the 38 mile sideways wind, will leave the machine exactly on its proper course at the end of the hour.

On the map or piece of paper denote the starting point by *A* (see Fig. 37). From *A* draw a line parallel to the wind (that is to say, 74° west of north), and let this line represent, to any convenient scale, the speed of the wind, 38 miles per hour. The far end of the line may be called *B*, and may be given an arrow to represent the direction of wind. Now draw on the map a line from *A* to the desired destination (*C*), giving it, of course the proper compass bearing. Take the dividers, and with *B* as a center, describe an arc at such distance as to represent 75 miles per hour, the speed of the machine; this arc will intercept the line *AC* at *D*, and *BD* then gives the direction to steer, for it is that direction which will permit the airplane in 1 hour exactly to neutralize the sidewise drift of the wind. The distance AD on this diagram can be measured off and will give the actual velocity of movement along the line of flight in miles per hour. Notice that it is 97 miles per hour, quite different from the speed of the airplane.

Assuming that the pilot has determined the proper angle toward which the airplane nose must be

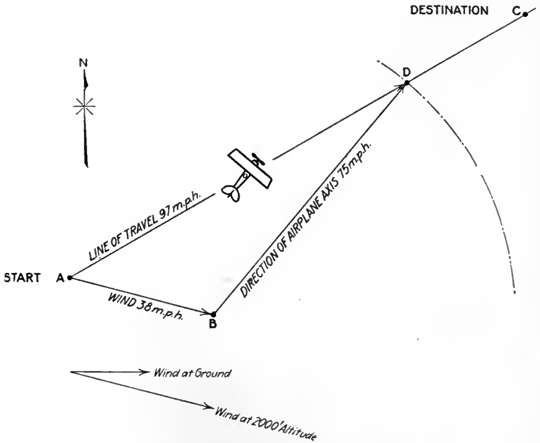


FIG. 37.—Graphical method for determining direction to steer to counteract wind-drift.

pointed, has maintained this angle throughout his flight by means of the compass and has safely reached his objective; for the return trip this diagram must be completely reconstructed (unless the wind is exactly parallel to his course). The pilot should not make the mistake in returning to the starting point of steering the airplane nose in a direction exactly opposite to the outward trip; the reader may make this clear to himself by drawing the return diagram and comparing it with the outward-bound diagram.

To summarize flying when a cross wind is blowing, it will be said that the direction of actual travel will not be the direction indicated by the axis of the airplane; and that therefore while in a picture of the situation the airplane appears to skid sideways along the whole course it must be borne in mind that actually there is no skidding whatever but the air is meeting the airplane in normal manner. The situation is analogous to that of a fly going from one side to the other of the cabin of a moving ship, where the actual course through space of the fly is an apparent skid, due to the resultant of its own and the ship's movement.

Variation of Velocity and Direction With Height
(25 miles per hour wind)

Height in feet....	At 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

Effect of Wind on Radius of Action.—Not only is the direction of flight altered by the wind but also the radius of action from a standpoint of gasoline capacity is altered. In the above machine the gasoline capacity is sufficient for 3½ hr. of flight. How far can it go across country and return before the gasoline is used up? Always allow ½ hr. gasoline for climbing and for margin; this leaves 3 hr., which at 75 miles an hour is 225 miles, or 112 miles out and 112 miles back. Now suppose that a flight is to be made across country directly in the teeth of a 40-mile wind; the radius of flight will be altered as indicated by the following calculation: Speed outward is obviously 75 minus 40 or 35 miles per hour. Speed on the return trip is obviously 75 plus 40 or 115 miles per hour—3.29 times as fast—and occupying a time which may be designated by the letter x. The time on the outward trip may be designated by $3.29x$, a total time of $x + 3.29x$ which we know equals 180 min. before the gas runs out. Solve the equation $x + 3.29x = 180$ and we find that x is equal to 42 min., that is, the return trip requires 42 min., and the outward trip requires 138 min. The distance covered on the outward trip is then $^{138}/_{60}$ of 35, which equals 80.5 miles. The radius is then reduced from 112 miles to 80.5 miles.

In cases where the wind is not parallel to the line of flight the actual velocity of course can not be obtained by adding up the airplane and wind velocities, but must be obtained by the graphical method mentioned above; thenceforward the calculation is the same.

Effect of Height.—Of course if one has to fly in the teeth of a wind and can choose one's own altitude, it is desirable to fly low where the head wind has its smaller velocity, and when flying with the following wind to rise to considerable altitudes. The proper height at which to fly will be about 1500 to 3000 ft., for cross-country trips over ordinary country; but may be increased when the wind is unsteady or decreased when there are low-lying clouds. The steadiness as well as the speed of the wind increases with the height. The character of the country should be carefully investigated from the profile maps before starting; all hilly parts should be marked on the map as a warning against landing. Contour is not readily distinguished from a height of 2000 ft. and for this reason points may be indicated on the map where poor landing places make it desirable to fly high. The character of the country or the scarcity of landing places may make it advisable to fly at high altitudes for the following reasons: (1) in case of engine failure a good margin of height is necessary to provide length of glide to reach distant landing places; (2) there is then plenty of space for righting the airplane in case of bumps, side slips, etc.; (3) eddies or local currents due to inequalities of the ground do not exist to great heights; (4) landmarks can be better distinguished from high altitudes because the vision is better (however, one must never trust to landmarks only in navigating but should constantly use a compass if only as a check, and especially in passing through clouds). Having selected in advance the proper height to use during the trip climb to this height in circles; note the direction of wind drift meanwhile to check up your estimate. Pass directly over the point of departure and when over it point the nose of the airplane for a moment directly toward the desired objective (which can be done with the aid of the magnetic compass); select some distant object which is dead ahead, and therefore directly in the course; then head the nose of the machine up into the wind just enough so that the direction of movement will be straight toward this distant object. The direction of the nose of the machine thus set by a method distinct from the graphical method above mentioned should exactly correspond, however, with the calculated direction; and thus a means of checking is obtained.

Effect of Fog.—The effect of fog upon navigating an airplane is that it prevents the use of landmarks in aiding the pilot; also that it upsets the pilot's sense of level. These two effects are, of course, independent of the fact that proper landing places are obscured, with resultant peril in case of engine failure. Therefore, a fog should be avoided whenever possible; when one comes up, the airplane should descend, and should never attempt to get above it, as in certain localities it may turn out to be a ground fog. If the fog is very bad, land at the earliest opportunity. It is on account of fog that the pilot avoids river valleys where frequently there is a haze from the ground up to a height of 700 ft., preventing the view of proper landing places in case of necessity.

Effect of Clouds on Navigation.—Flying in or above the clouds is a similar case, inasmuch as landmarks can not be seen. It is not wise to go above the clouds when on the sea coast, as offshore winds may, unknown to the pilot, carry him out to sea; and any flight over the sea which is to a distance greater than the safe return gliding distance is, of course, perilous.

Navigation by Means of the Drift Indicator.—The drift indicator is an instrument for determining directly the side drift of an airplane. It enables the pilot by looking through a telescope at the ground to determine exactly what his direction of motion is with relation to the ground. The telescope is mounted vertically and is rotatable about its own axis; it has a cross-hair which appears in the field of view during the pilot's observation of the ground. As the airplane speeds overhead objects on the ground will appear through the telescope to slip backward in the given direction; and when accustomed to the use of this instrument the pilot can rotate the telescope until the cross-hair is exactly parallel to the apparent line of motion of objects on the ground. The telescope cross-hair is parallel to the axis of the airplane normally and the scale attached to the telescope will in this case read zero. When the pilot rotates the telescope so that the cross-hair becomes parallel to the relative backward motion of the ground the scale will read something different from zero and will give the angle between the actual line of motion and the axis of the airplane.

Such a drift indicator is, of course, useful only when the ground is visible. The pilot knowing the angle between the airplane axis and the line of motion and therefore knowing the deviation between the supposed course and the actual course is able to make corrections and steer the machine in its proper direction. This may be done by altering the "lubber-line" or his compass just enough to offset the side drift of the machine; after which the desired course may be followed by simply keeping to the proper compass bearing. An instrument has been devised wherein the rotation of the drift-indicator telescope simultaneously alters the lubber-line zero. The operator then has merely to take an occasional observation of the apparent drift line of the ground, which observation automatically shifts the lubber-line and navigation proceeds as if there were no side wind blowing whatever. Knowing the angle between the direction of movement and the airplane axis, the pilot may then compute the speed of motion in a manner analogous to the graphical method previously mentioned; or he can make use of a chart for the determination of this speed.

Navigation over Water.—In flying over water the presence of waves is a valuable guide to the aviator, for he knows that these waves extend in a direction normal to the wind. Moreover, he knows that the velocity of the waves bears some relation to the velocity of the wind. In order to estimate the velocity of the waves it is only necessary to know their wave length, that is, the distance between two consecutive wave crests. The rule is that for a wave length of 10 ft. the velocity is 10 miles per hour, and will vary as the square root of this wave length; that is, if the wave length is half, the velocity will be 10 divided by the square root of 2, or 7.1 miles per hour.

CHAPTER VI

THE RIGGING OF AIRPLANES

Object.—The object of this chapter is to teach the elementary principles of correct rigging. It is not expected that the student will become an expert mechanic, but with this treatment as a basis and through practice he will be able to judge whether or not a machine is correctly and safely rigged. In other words, he will not have to depend on someone else's judgment as to whether panels, wires, controls, struts, etc., of a machine are in good order, but he will be able to observe understandingly that they are. If the engine goes wrong he can land, if the rigging goes wrong he is in great difficulty. Moreover, if the rigging is wrong, speed is lessened and the stability is uncertain.

The first thing to be learned in rigging is a knowledge of the peculiar terms which have come into use in aeronautics defining different parts of the machines. Our present list of terms is derived, partly from French, partly from English, and partly from American terms. Thus different names may refer to the same part.

NOMENCLATURE

1. Tractor.—An airplane that is pulled through the air by a propeller situated in front of the machine, is called a tractor.

2. Pusher.—If the propeller is back of the main lifting planes the machine is called a pusher.

3. Fuselage or Body.—The main body of the airplane in which the pilot sits and to which the landing gear, motor, controls, and sustaining surfaces are fixed. A small body, especially in pusher types of machines, is called a Nacelle.

4. Cockpit.—The openings and space in the fuselage where pilot or observer sits.

5. Streamline Body.—The shape of a body or part which permits a regular flow of air around and along it with the least resistance, in other words with minimum obstruction and eddying.

6. Fairing.—Building up a member or part of the plane with a false piece that it may have a stream-line body.

7. Wings, Planes, Panels.—The main supporting surfaces of an airplane are called wings, although the terms planes and panels are probably as frequently used and even preferred by many. The term panel refers properly to a section of the wings with the included struts and wires. The small panel directly above the body is called the engine section panel or the center panel, while the panels to the right and left of the body or fuselage are called the main panels. The main panels are the right and left panels as seen from the seat. Each main panel may be subdivided into the inner wing bay, the outer wing bay, and the overhang.

8. Landing Gear, Chassis or Undercarriage.—The wheels and the struts and wires by which they are attached to the fuselage.

9. Horizontal Stabilizer or Horizontal Fin.—The horizontal fixed tail plane.

10. Vertical Stabilizer or Vertical Fin.—The small vertical fixed plane in front of the rudder.

11. Rudder.—The hinged surface used to control the direction of the aircraft in the horizontal plane. As with a boat, for steering or "yawing" or changing its direction of travel.

12. Elevator or Flap; Flippers.—A hinged horizontal surface for controlling the airplane up and down, usually attached to the fixed tail plane; for pitching the machine or "nosing up" and "nosing down."

13. Tail or "Empennages."—A general name sometimes applied to the tail surfaces of a machine.

14. Mast or Cabane.—The small vertical strut on top of the upper plane used for bracing the overhang.

15. Ailerons.—Movable auxiliary surfaces used for the control of rolling or banking motion. Other definitions are that they are for the lateral control or for maintaining equilibrium. When they are a part of the upper plane they are sometimes called wing flaps.

16. Landing Wires or Ground Wires (Single).—The single wires which support the weight of the panels when landing or on the ground.

17. Flying Wires, or Load Wires (Double).—The wires which support the body or fuselage from the planes when in flight.

18. Drift Wires.—The horizontal wires which lead from the nose of the fuselage to the wings and thus keep them from collapsing backward. For the same reason the wings have interior drift wires.

19. Diagonal Wires.—Any inclined bracing wires.

20. Skids.—(*a*) *Tail Skid.*—The flexible support under the tail of the machine.

(*b*) *Wing Skid.*—The protection under the outer edge of the lower wing.

(*c*) *Chassis Skids.*—Skids sometimes placed in front of the landing gear.

21. Horns, or Control Braces.—The steel struts on the controls to which the control wires are attached.

22. Struts; Wing Struts.—The vertical members of the wing trusses of a biplane, used to take pressure or compression, whereas the wires of the trusses are used to take pull or tension. There are also fuselage struts and chassis struts.

23. Spar or Wing Bars.—The longitudinal members of the interior wing framework.

24. Rib (Wing).—The members of the interior wing framework transverse to the spars.

25. The Longerons or Longitudinals.—The fore and aft or lengthwise members of the framing of the fuselage, usually continuous across a number of points of support.

26. Engine (Right and Left Hand).—In the ordinary tractor machine, when viewed from the pilot's seat a right-handed engine revolves clockwise and right-handed.

27. Propeller.—

28. Pitch (Propeller).—The distance forward that the propeller would travel in one revolution, if there were no slip, that is, if it were moving in a thread cut at the same inclination as the blade. Pitch angle refers to the angle of inclination of the propeller blade.

29. Slip.—Slip is the difference between the actual travel forward of a screw propeller in one revolution and its pitch.

30. Dope.—A general term applied to the material used in treating the cloth surface of airplane members to increase strength, produce tautness, and act as a filler to maintain air and moisture tightness. Usually of the cellulose type.

31. Controls.—Since there are three axes or main directions about which an airplane may turn or rotate it follows that three controlling devices are required. These are: (1) the elevator for pitching; (2) the rudder for steering or yawing; (3) the ailerons for lateral, rolling or banking control.

The term controls is a general term used to distinguish the means provided for operating the devices used to control speed, direction of flight and attitude of the aircraft.

32. Cotter Pins.—Must be on every nut.

33. Castelled Nuts.—Admit cotter pins.

34. Turnbuckles.—Must be well and evenly threaded and locked with safety wires.

35. Safety Wires.—For locking turnbuckles and hinge pins.

36. Shackle and Pin.—

37. Hinge Connections.—

38. Leading Edge or Entering Edge.—The front edge of a plane.

39. Trailing Edge.—The rear edge of a plane.

40. Stagger.—The horizontal distance that the entering edge of the upper wing of a biplane is ahead of the entering edge of the lower wing.

41. Dihedral Angle.—A term used to denote that the wings are arranged to incline slightly upward from the body toward their tips. The angle made with the horizontal by this inclination of the wing is called the dihedral angle.

42. Angle of Incidence.—The angle at which a wing is inclined to the line of flight.

43. Decalage.—Difference in angle of incidence between any two distinct aerofoils on an airplane.

44. Chord.—Distance between the entering edge and trailing edge of a wing measured on a straight line touching front and rear bottom points of a wing.

45. Camber.—The depth of the curve given to a sustaining surface such as a wing. Thus it will be observed that the planes are not straight in cross-section but are concave slightly upward. The depth of this concavity is the camber. Another way of expressing this is that camber is the greatest distance between the surface of a wing and its chord line.

46. Gap.—The distance between the lower and upper wings of a biplane.

47. Spread.—The distance over all from one wing tip to the other wing tip.

48. Aerofoil.—A general name applied to any wing or lifting surface of an airplane.

49. Deadhead Resistance.—Each part of an airplane against which the wind strikes offers a resistance against being moved through the air. This is called the *deadhead resistance* or the *parasite resistance.* It is for the purpose of lessening this resistance that the parts of a machine are stream-lined. Remember that force or power must be applied to overcome this resistance and the lessening of such resistance decreases the power necessary. A parallel illustration is to think of the power necessary to push a board sideways through water.

50. Drift.—When the air strikes the inclined wing of an airplane its force has two components. One part called the *lift* (see 52) acts up and tends to lift the machine. The other part, called *drift,* tends to push the machine backward. This drift must also be overcome by applying power enough to drive the machine forward.

51. Total Resistance.—Sometimes called *drag.* (49) Dead-head resistance added to (50) drift, gives the total forces opposing the forward movement of the airplane. This is called the total resistance and is overcome by the *thrust* of the propeller.

52. Lift.—(See 50). The upward or vertical part of the air pressure acting against the wings, and which is utilized to lift or support the airplane.

53. Center of Gravity.—The point of balance of an airplane which may be otherwise defined as the point through which the mass of an airplane acts. If the weight is too far forward the machine is nose-heavy. If the weight is too far behind the center of lift the machine is tail-heavy.

54. Aspect Ratio.—The ratio of span to chord of a wing or any other aerofoil.

55. Gliding Angle (Volplane).—The angle made to the horizontal by the flight path of an airplane with the engine shut off; *e.g.,* an airplane is 1000 ft. high, when its engine fails. Suppose its gliding angle is 1 in 6. Therefore, in still air it can glide 6000 ft. forward. The general term glide refers to flying without power.

56. The Angle of Best Climb.—The steepest angle at which an airplane can climb.

57. Stability.—The property of an airplane to maintain its direction and to return easily to its equilibrium or balance with a minimum of oscillation. This is sometimes called dynamical stability. An airplane may have (first) inherent stability, which is the stability due to the arrangement and disposition of its fixed parts. It may also have stability with regard to any one of the three directions in which it may move. These are named as follows: (1) directional stability, with reference to the vertical axis; (2) lateral stability with reference to the longitudinal (or fore and aft) axis; (3) longitudinal stability, stability with reference to the lateral (or thwartship) axis.

58. Flying Position.—Refers to the position of the fuselage when flying. With the Curtiss J N 4 machines in this position the top longerons are horizontal and level both ways. The engine bearers are also level, and the wings have an angle of incidence of 2°.

59. Capacity.—The weight an airplane will carry in excess of the dead load (dead load includes structure power plant and essential accessories).

60. Flight Path.—The path of the center of gravity of an aircraft with reference to the air.

61. Stalling.—A term describing the condition of an airplane which from any cause has lost the relative speed necessary for support and controlling, and referring particularly to angles of incidence greater than the critical angle.

62. Sweepback.—The horizontal angle (if any) that the leading edge of a machine makes with the crosswise or lateral axis of an airplane.

63. Nose Dive or Vol-pique.—A dangerously steep descent, head on.

CHAPTER VII

MATERIALS OF CONSTRUCTION

The materials of construction for airplanes should be of such material, size and form as to combine greatest strength and least weight. With metal parts in particular it may be necessary to substitute less strong material for the sake of getting non-corrosive qualities, ability to withstand bending, ductility or ease of bending, etc. With wood, absence of warping is important as well. The materials which are considered are the following: wood, steel, including wires; special metals as aluminum, brass, monel metal, copper, etc., and also linen and dope.

Strength of Materials.—It is important in a general way to understand the terms used in speaking of strength of materials. Thus we may have strength in tension, strength in compression, or strength in shearing, bending and torsion. Some material fitted to take tension will not take compression, as for example wire; some material, as bolts, are suited to take shear, etc.

In general all material for airplanes has been carefully tested and no excess material is used above that necessary to give the machine the necessary strength.

Tension.—This means the strength of a material which enables it to withstand a pull. Thus wires are used where strength of this kind is required.

Compression.—This refers to strength against a pressure. Wire has no strength for this purpose, and wood or sometimes steel is used.

Shearing.—Refers to strength against cutting off sideways. Thus the pull on an eyebolt tends to shear the eyebolt, or the side pull on any bolt or pin tends to shear the pin.

Bending.—In bending material the fibres on the outside tend to pull apart; those on the inside tend to go together. Thus on the outside we have tension, and on the inside compression. Along the center line there is neither tension or compression, it is the "neutral axis."

Torsion.—Torsion is a twisting force, such as an engine propeller shaft receives.

Testing for Strength.—If a wire is an inch square in cross-section and breaks when a load of 150,000 lb. is hung on it, we say that the strength of the wire is 150,000 per square inch. Smaller wires equally strong have a strength of 150,000 lb. per square inch also, but they in themselves will not support a load of 150,000 lb. but only the fraction of that, according to the fraction of a square inch represented by their cross-section.

In the same way, a square inch of wood under a compressive load may break at 5000 lb. If, however, the piece of wood is long in proportion to its thickness, it will bend easily and support much less weight. For example, a perfectly straight walking cane could perhaps have a ton weight put on it without breaking but if the cane were not set squarely or if it started to bend it would immediately break under the load.

These cases illustrate the importance of having struts perfectly straight, not too spindling and evenly bedded in their sockets. Some training machines are built with a factor of safety of 12. That is to say, the breaking strength of any part is twelve times the ordinary load or stress under which the piece is placed. It should be remembered, however, that under any unusual condition in the air, such as banking, etc., extra strains are placed on the parts and the factor of safety is much less than 12. Factor of safety of 12 thus does not mean exactly what it does in other engineering work, where allowances are made for severe conditions. The so-called factor of safety of 12 in airplane work is probably no greater than a factor of safety of 2 or 3 in regular engineering work.

There are three all-important features in the flying machine construction, viz., lightness, strength and extreme rigidity. Spruce is the wood generally used for parts when lightness is desired more than strength, oak, ash, hickory and maple are all stronger, but they are also considerably heavier, and where the saving of weight is essential, the difference is largely in favor of the spruce. This will be seen in the following condensed table of U. S. Government Specifications.

Wood	Weight per cubic foot, pounds (15% moisture)	Modulus of rupture, pounds per square inch	Compression strength, pounds per square inch
Hickory	50	16,300	7,300
White Oak	46	12,000	5,900
Ash	40	12,700	6,000
Walnut	38	11,900	6,100
Spruce	27	7,900	4,300
White Pine	29	7,600	4,800

A frequently asked question is: "Why is not aluminum or some similar metal, substituted for wood?" Wood, particularly spruce, is preferred because, weight considered, it is much stronger than aluminum, and this is the lightest of all metals. In this connection the following table will be of interest.

Material	Weight in cubic feet, pounds	Tensile strength per sq. in pounds	Compression strength per sq. in pounds
Spruce	27	7,900	4,300
Aluminum	162	15,000	12,000
Brass (sheet)	510	20,000	12,000
Steel (tool)	490	100,000	60,000
Nickel steel	480	100,000*	
Copper (sheet)	548	30,000	40,000
Tobin bronze (Turnbuckles)	.....	80,000	
Monel metal	540	90,000	30,000

Wood.—Present practice in airplane construction is to use wood for practically all framing, in other words, for all parts which take pressure or com-

* But has very high elastic limit.

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pression. Although wood is not as strong for its size as steel and therefore offers more air resistance for the same strength yet the fact that frame parts must not be too spindling, in other words, that they must have a certain thickness in proportion to their unsupported length, has led to the use of wood in spite of the greater strength of steel. Some airplanes, however, as the Sturtevant, are constructed with practically a steel framing.

It should be borne in mind that any piece or kind of wood will not answer for framing, and more especially for repair parts. There is a tremendous difference in the strength and suitability among different woods for the work. For instance, a piece of wood of cross or irregular grain, one with knots, or even one which has been bored or cut or bruised on the outside, may have only half or less the strength of the original piece. Air drying doubles the strength of green wood, proper oven drying is better yet.

Notice how the ends of each piece are ferruled, usually with copper or tin. This is to prevent the bolt pulling out with the grain of the wood, and also prevents splitting and end checking and gives a uniform base on which the pressure comes.

It is generally advised not to paint wood as it tends to conceal defects from inspection. So varnish only.

Wrapping wooden members with linen or cord tightly and doping this, both to make waterproof and to still further tighten, increases the resistance to splitting. The absence of warping tendencies determine often what wood to choose.

The selection of lumber and detection of flaws is a matter of experience and should be cultivated. It is, however, nothing more than the extension of the knowledge that leads a man to pick out a good baseball bat.

Woods.—1. *Spruce.*—Should be clear, straight-grained, smooth and free from knot holes and sap pockets, and carefully kiln-dried or seasoned. It is about the lightest and for its weight the strongest wood used. It is ordinarily used as a material for spars, struts, landing gear, etc., as it has a proper combination of flexibility, lightness and strength.

2. *White Pine.*—A very light wood used for wing ribs, and small struts.

3. *Ash.*—Springy, strong in tension, hard and tough, but is considerably heavier than spruce. Used for longerons, rudder post, etc.

4. *Maple.*—Used for small wood details, as for blocks connecting rib pieces across a spar or for spacers in a built-up rib.

5. *Hard Pine.*—Tough and uniform and recommended for long pieces, such as the wooden braces in the wings.

6. *Walnut, Mahogany, Quarter-sawed Oak.*—The strength, uniformity, hardness and finishing qualities make these woods favorites for propeller construction.

7. *Cedar Wood.*—Is used occasionally for fusel-

age coverings or for hull planking in hydroplanes. as it is light, uniform and easily worked. Veneers, or cross-glued thin layers of wood, are sometimes used for coverings.

Laminated or built-up wooden members have been much used for framing and for ribs and spars. The engine bearers are always of wood on account of vibration and are also laminated. In lamination the wooden strut is built up of several pieces of wood carefully glued together. The grains of the different layers run in different directions, consequently a stronger and more uniform stick often is secured. The objection to laminated pieces comes from the weather causing ungluing. Laminated pieces should be wrapped in linen or paper and freshened with paint or varnish from time to time.

Forms.—Attention should be called to the hollowed form of many of the wooden members. In any beam or strut, material at the center of the cross-section is of far less value in taking the load than the material away from the center. Therefore, to secure greatest strength with least weight, it is permissible to lighten wooden members if done understandingly.

Steel.—There is a tremendous difference in the strength, wearing and other desirable qualities among different steels and irons. For airplane work none but the best qualities are allowed. For this reason the use of ordinary iron bolts (as stove bolts) or metal fastenings or wire not standardized and of known qualities should not be permitted. The airplane is no stronger than its weakest fitting. This does not mean that the hardest and strongest steel must necessarily be used, as ease of working and freedom from brittleness may be just as important qualities, but the steel on all metal fittings should be of high-grade uniform stock. A ductile, not too easily bent, mild carbon steel is usually recommended for all steel plate, clips, sockets and other metal parts. If any parts are required to be tempered or hardened it must be remembered that they become brittle and can not afterward be bent without annealing or softening. Tool or drill steel is a name given to uniform or rather reliable grades of steel adapted to heat treatment as tempering or annealing. Often the bolts, clips, nuts, pins, clevices and other fittings are of special heat-treated nickel steel which must not be heated locally for bending or for attachment. Such work seriously weakens the steel. The steel is often copper- or nickel-plated and enamelled to prevent rusting. Do not forget that the proper material may be twice as strong as other material which looks the same but which has not received special treatment.

Wires.—Only the highest grade of steel wire, strand and cord is allowable. Manufacturers, as Roebling of Trenton, N. J., manufacture special aviator wire and cord, which is given the highest possible combination of strength and toughness, combined with ability to withstand bending, etc.

Steel wire ropes for airplane work are divided into three classes as follows:

1. *The solid wire* = 1 wire (as piano-wire grade) and known as aviation wire.

2. *The strand stay,* consisting either of 7 or 19 wires stranded together and known as "aviator strand." Flying and landing wires on Curtiss.

3. *Cord or Rope Stay.*—Seven strands twisted together forming a rope, each strand being of 7 or 19 wires and known to trade as aviator cord. The wires are either tinned or galvanized as protection against rust, etc. Ordinarily galvanizing is used, but hard wires and very small wires are injured by the heat of galvanizing and they are therefore tinned.

No. 1. The single wire is the strongest for its weight. Single wires will not coil easily without kinking and are easily injured by a blow, therefore their use is confined to the protected parts of the machine such as brace wires in the fuselage and in the wings.

The strand stay (No. 2) of 7 or 19 wires is generally used for tension wires, as it is more elastic (can be bent around smaller curve) without injury, as the flying and landing wires on the Curtiss. The smaller strands usually have 7 wires, the larger ones 19 wires.

No. 3. *The Tinned Aviator Cord.*—The 7 by 19 cord is used for stays on foreign machines. It is 1¾ times as elastic as a solid wire of the same material. On the Curtiss it is used for control wires. For steering gear and controls extra flexible aviator cord is also recommended. This has a cotton center which gives extra flexibility and is used for steering gear and controls. It is $2\frac{1}{4}$ times as elastic as a single wire.

Although wire strands or cords are not quite as strong for the same size as a single wire they are preferred for general work, being easier to handle and because a single weak spot in one wire does not seriously injure the whole strand.

Especial care is necessary to avoid using common steel wires, or strands which have a frayed or broken wire, or wire that has been kinked and then straightened or wire that has been locally heated or wire that has been bruised. All these factors weaken steel rope much more than is supposed ordinarily.

Wire Fastening or Terminal Connections.—Wire terminals are of four classes:

1. *Ferrule and dip in solder,* then bend back the end. With or without thimble; used on single wires or on strand; 50 to 94 per cent. as strong as the wire.

2. *Thimble and End Splicing.*—The splice must be long and complete. Used on cable; 80 to 85 per cent. as strong as the strand; breaks at last tuck in the splice.

3. *Socket.*—Nearly 100 per cent. strong.

4. *End Wrap and Solder.*—Simple and serviceable; not used for hard wire.

Present practice is rather toward elimination of acid and solder, imperfect bends, flattening of cable on bends, and toward care in avoiding all injury as kinking to wire, strand and cord due to unskillful handling of material in the field.

Other Metals.—Other metals as aluminum, brass, bronze, copper, monel metal (copper and nickel) are used for certain airplane fittings for the reasons of lightness, non-corrosive qualities, or ease of bending, etc. The trouble with these metals is that they are not uniform and reliable in strength and in an important part the great strength combined with minimum weight given by steel is not equalled by any of these metals. Aluminum is used on the engine hood and also for control levers and for the backs of the seats. In other words, for parts and castings which require light metal construction, but which are under no particular stress. Tin and copper are used for ferrules of wire joints and for tankage. Copper or brass wire are used for safety wires. Special Tobin bronze is used for turnbuckles as the part must not only be strong but free from any tendency to rust. Monel metal (nickel 60 per cent., copper 35 per cent., iron 5 per cent.) is strong and has the special property of being acid- and rust-resisting. It has been used for metal fittings and even for wires and for the water jacket of the motor. Until more strength tests show greater uniformity of strength, it is to be recommended with caution.

In dealing with metals like steel, it should be remembered that they are subject to crystallization and fatigue.

Repeated jarring may cause a bar of steel to break easily at a particular point, when the metal is said to have crystallized there.

Fatigue of a metal may be defined as loss of springiness which may come from repeated bending and which lessens the strength of metal. Above all, however, corrosion of steel must be guarded against.

The above points should be clear, as in airplane work you are dealing with a structure which is safe with perfect materials and workmanship. The factor of safety, however, is not great enough to permit carelessness, or defective material.

Linen.—The almost universal wing covering is fine, unbleached Irish linen, stretched rather loosely on the wing frames and then treated with dope.

The linen used weighs 3¾ to 4¾ oz. per square yard, and should have a strength with the length of the cloth or "warp" of at least 60 lb. per inch of width. The strength in this direction is slightly greater than that taken crosswise of the cloth or on the filler or weft. There is a gain of strength and tautness by varnishing or "doping."

In general, it is desirable to have wing material which will not sag easily and have the fabric yield rather than break. This often reduces stress and saves complete failure.

Dope.—The linen must be coated with a more or less waterproof dope. Some form of cellulose acetate or nitrate with more or less softening material is used and to these some suitable solvent as acetone is added.

The cellulose acetate or nitrate in the dope acts as a waterproof sizing, shrinks the cloth tight, and prevents it from changing in tightness due to moisture. Spar varnish protects this layer from peeling and makes the wing more waterproof. In service, varnish or dope must be applied every few weeks.

The U. S. Army practice calls for four coats of cellulose nitrate dope followed by two coats of spar varnish to prevent inflammability. Cellulose nitrate is more elastic and durable than the acetate but is also more inflammable.

Commercial dopes with various desirable properties are: Cellon, Novavia, Emaillite, Cavaro, Titanine, etc.

CHAPTER VIII

ERECTING AIRPLANES

Airplanes shipped from the manufacturer or from another field almost always suffer more or less from shipment or packing. Care must be exercised in unpacking in order not to do any more damage. Boxes should be placed with the part marked "Top" uppermost. Cables and wires must be handled carefully in order not to bend or twist them. Every bent or kinked wire or damaged turnbuckle must be replaced, or at least brought to the attention of an inspector.

The order of erection is as follows:

1. Assemble landing gear to fuselage and align landing gear before putting on main panels.
2. Assemble tail.
3. Assemble engine section and align before attaching main panels.
4. Assemble main panels.

1. Landing Gear Assembly to Fuselage.—The landing gear is assembled by mounting the wheels on the axle, and bolting wheels in place. The fuselage should now be elevated to receive the landing gear. This may be accomplished in one of two ways—either by tackle or by shims and blocking. For either method, first connect up the tail skid.

This is accomplished by pinning up the front end of the skid to the spring-fitting, and then pinning in the other end to the tail-post socket.

If block and tackle are used to raise the fuselage, pass a line under the engine-bed supports or sills just to the rear of the radiator. To this line attach hook of block. **To avoid damaging or crushing some part do not attach lifting device to any other point.** With the fuselage now resting on its attached tail skid, lift the front end until the lower longeron clips clear the landing gear. When the clips on the longerons line up with the clips on the ends of the struts of the landing gear the bolts are passed down through the holes thus aligned. This places the nuts *on the down side* of the connection thus facilitating assemblies and inspection of connections. The castellated nuts are then put on the bolts and drawn up tight, until the drilled hole in the bolt is visible through the castle of the nut. Then insert cotter-pin and spread the two leaves backward over the nut. This locks the nut in place. When the landing gear has been completely assembled to the fuselage, the tail of the machine should be elevated and supported by a horse and blocking until the upper longeron is level. This can be determined by placing a spirit level on the upper longeron at the tail or on the two engine-bed sills in machines where these sills are parallel to the top longeron, as in Curtiss JN–4B.

2. Horizontal Stabilizer.—After the upper longeron is levelled up, the horizontal stabilizer is assembled to the tail of the fuselage. The horizontal stabilizer is fastened by means of bolts in the top longeron and the tail post. The nuts are all drawn up tight and cotter-pinned. The vertical stabilizer is next erected in place.

3. Vertical Stabilizer.—The vertical stabilizer is now fastened to the horizontal stabilizer, first by means of the bolt which passes up through the forward part of the horizontal stabilizer and then by means of the flexible stay lines running from the top of the vertical stabilizer. The forward bolt passes through the clip at the lower front point of the vertical stabilizer. Draw the nuts up tight and lock with cotter-pins. Flexible wire cables are attached to vertical stabilizer, and turnbuckles are used to align and tighten cables. The vertical stabilizer is further aided in its alignment by the bolt clip at its toe and by the double clip at its heel. This rear double clip passes over the two bolts which are attached to the tail post and which hold down the horizontal stabilizer.

4. Rudder.—The control braces are first attached to the rudder. These braces are so placed that the upper tips point toward the hinge line. In this fashion the holes will match up. The rudder is mounted on the tail post and vertical stabilizer by means of the hinges. The hinge pins are inserted in the hinges, and cotter-pins passed through the drilled holes in the bottom of the pins. The cotter-pins should be spread backward as usual.

5. Elevators or Flaps.—These are first equipped with the control braces which are also arranged so that the upper tips point toward the hinge line. The elevators are mounted to the horizontal stabilizer by means of the hinges and hinge pins. The hinge pins are kept in their bearings by the cotter-pins, inserted through the drilled holes in the bottom of the hinge pins.

6. Panel Assembly.—The panels are now to be assembled. Before the main panels can be connected to the fuselage, the engine section panel must be erected.

Engine Section Panel.—The engine section struts are first set into place in their sockets on the engine section. Then the whole thing is lifted up to place and the four struts are set into their sockets on the upper longeron. The bracing wires are attached and the engine section aligned by means of them (see alignment).

7. Main Panels.—The main panels are now to be assembled to the machine. There are two methods for accomplishing this: first, assemble panels, struts and wires, before attaching to fuselage; second, assemble the upper plane to the engine section, and complete assembly. The first method is the most advantageous, since it permits the setting of the main panels at the correct stagger and dihedral, and does not require as much adjustment as the second method, which will be omitted.

Assembling Panels Together Before Fastening Them to Fuselage.—All the main struts will be found to bear a number. These numbers run from

1 to 8, on Curtiss JN-4. The numbers on the Standard run from 1 to 12 including the center section struts. The method used in numbering the posts is as follows: Starting at post No. 1, with the outer post, on the left-hand side of the pilot, as he faces his direction of travel, the posts are numbered successively from No. 1 to No. 4; Nos. 1 and 2 being on the left side and Nos. 3 and 4 being on the right side. The rear posts are similarly numbered from No. 5 to No. 8, Nos. 5 and 6 being on the left and Nos. 7 and 8 being on the right. This system of numbering does not include the engine section struts. The plan shows the system graphically (see Fig. 39).

The system of marking also insures that the struts are not inverted in their sockets. This is accomplished by painting the number on the strut, so that when viewed from the pilot's seat, all numbers can be read, *i.e.*, the numbers are painted on that side of the strut intended to face the fuselage. If a strut is inverted by mistake, it can thus be quickly detected. The procedure of assembling panels is as follows:

1. The upper left-wing panel is first equipped with mast, by inserting the mast into its socket on the upper surface of the wing. The mast wire is then connected up to the clips to the right and left of the mast. Adjust the tension in this wire, by means of turnbuckles, until the spar becomes straight.

2. Stand the upper left-wing panel and lower left-

wing panel on their "leading" or "entering" edges, properly supporting the panels in cushioned blocks to prevent damage to the nose. Space the panels apart, at a distance approximately equal to the length of the struts.

3. Next connect up the diagonal cross wires. These must be loosely connected up, to permit the easy entering of the posts into the sockets. The wires are connected before the posts or struts are set in place, since with the latter in place, the connecting of the wires to the lugs of the sockets is accomplished only with difficulty. After these wires are thus connected, insert the posts and bolts into place.

4. Connect up closely the "landing" (single) wires, and "flying" (double) wires of the outer bay to hold the wings together as a unit. The outer bay is thus completely wired, though but loosely.

5. The posts that are used for this left side are, according to the diagram, No. 1, No. 2, No. 5, No. 6. No. 1 is the outer front; No. 2 is the inner front; No. 5 is the outer rear; No. 6 the inner rear.

6. The wings, as above assembled, are now erected to the fuselage. Extreme care should be exercised in transferring the wings to the fuselage, not to strain or break them. In carrying the wings, use wooden boards placed under the wings, and block up under the wing beams (which can be easily located), so that these take the strain of the load. Do not attempt handling assembled wings, using the posts as carriers; or by attachments to the trailing or leading edges. The wings should be

suitably supported temporarily by suitable sling at the outer upper post point (not beyond this point) or by a horse, properly blocked under lower wing at outer lower post point (not beyond this point) during fitting of wing to machine. The wings will have the approximate stagger if assembled as above, since the posts are in place, and the tension cross wires are adjusted to almost correct length when shipped. Insert the hinge pins through the hinges as now coupled up, lower hinges first.

The machine is now ready for alignment, perhaps the most important of the rigger's duties.

Alignment of Airplanes.—The proper alignment of a machine largely determines the flying qualities of that machine.

The alignment of the fuselage should be done at the factory or in the repair shop. However, the alignment of the whole machine depends upon the correctness of the fuselage. Directions for aligning and checking fuselage are, therefore, given.

The order in which the different parts of a machine should be aligned is as follows:

1. Alignment of landing gear.
2. Alignment of center section.
3. Alignment of leading edge.
4. Getting both wings the same height.
5. Dihedral angle, if any.
6. Alignment of trailing edge (angle of incidence).
7. Stagger.
8. Droop.
9. Tightening and safetying all wires.
10. Length of struts, positions and fittings, warp in planes.

11. Alignment of ailerons.
12. Alignment of stabilizer.
13. Alignment of elevator flaps.
14. Alignment of rudder.

The tail of the machine should be raised until the fuselage is nearly horizontal before starting the alignment.

1. Alignment of Landing Gear.—When a machine is being assembled, it is easier to align the landing gear before the wings are put on.

Take the weight off the landing gear by supporting the fuselage on sawhorses.

The axle should be parallel with the lateral axis of the machine.

The center of the axle should be directly under the center of the fuselage. This can be secured by either of two methods:

(*a*) *By Measuring Cross Distances.*—Loosen and tighten the cross wires until the cross distances are exactly the same. Take all measurements from similar points on the fittings to which the wires are attached.

(*b*) *With Level and Plumb Bob.*—Level the fuselage crosswise. Mark the exact center of the fuselage and drop a plumb bob. Mark the exact center of the axle. Adjust the cross wires until the plumb bob is over the center of the axle. Tighten the wires until fairly tight, and safety them.

2. Alignment of the Center Section.—When assembling a machine, the center section should be aligned before the wings are put on.

When a machine is already assembled, the first thing to do is to loosen all wires except the landing wires. This is very important, for if one wire is tightened against another wire, an unnecessary and possibly a dangerous strain may be put upon some member. The bracing wires connecting tops of center section struts should be tight enough to hold the shape of the center section when bracing wires are tightened up.

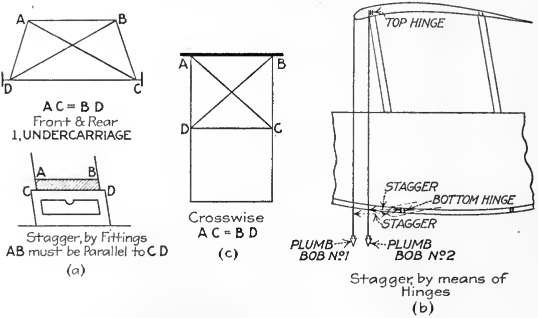

FIG. 38.—Center section and undercarriage alignment.

(*a*) *Machines Having No Stagger.*—In machines having no stagger, the struts of the center section should be perpendicular to the propeller axis. As the upper longerons are usually parallel to the propeller axis, they may be used as a base line.

Align one side of the center section first, then the other side, and lastly the front.

From a point at the lower end of one of the front center section struts (the center of a bolt head for example), measure forward on the longeron a certain distance. From the same point (center of bolt head) measure back on the longeron exactly the same distance.

Move the upper end of the strut forward or backward by loosening one of the bracing wires and tightening the other, until the distance from the two points on the longerons to some point on the center line at the top of the strut (center of bolt head) are exactly the same. The strut will then be perpendicular to the propeller axis. Tighten both wires evenly until fairly tight. Measure the cross distances (the diagonal distances between similar points at the upper and lower ends of the front and rear struts), and align the other side of the center section until its cross distances are the same as those on the opposite side.

Align the front of the center section by loosening one cross wire and tightening the other, until one cross distance is exactly the same as the other cross distance.

(*b*) *Machines Having Stagger.*—In machines having stagger, the shape and position of the center section strut fittings usually determines the amount of stagger the machine was designed to have (Fig. 38-*a*). The JN–4 has 10⅝-in. stagger, *i.e.*, a plumb line dropped from the leading edge of upper panel should be 10⅝-in. from leading edge of lower panel.

Adjust the wires on one side of the center section until the struts and that side are in their correct positions as shown by the shape of the fittings. Tighten the wires, measure the cross distances, and adjust the wires on the other side of the center section until the cross distances are exactly similar to the first set.

A more accurate method is to drop a plumb line from the leading edge of the center section and adjust until the line is at the correct distance ahead of the point on the fuselage where the leading edge of the lower wing meets it. This point may be determined by measuring the distance from the inside of the front hinge to the leading edge of the lower wing and then laying off this distance on the body from the front of the hinge on the lower longeron. Better still, if the hinges are at the same distance from the leading edge on both top and bottom wings, the plumb line may be dropped from the front side of the hinge on the center section and the stagger measured back to the hinge on the lower longeron (Fig. 38-*b*). This has the advantage of setting the plumb line out far enough to clear the fuselage. Also the measurements are easily made.

Next, adjust the two front wires until one cross distance is exactly the same as the other cross distance (Fig. 38-*c*).

3. Alignment of Leading Edge.—(*a*) *Upper Plane.*—The leading edges of the upper and lower planes of one wing should next be made perfectly straight. By standing on a step ladder, placed 15 to 20 ft. to one side, and sighting along the leading edge of the upper plane, any bow or warp can be easily seen. This should be straightened out by loosening or tightening the front landing wires. The edge should be brought in exact line with the leading edge of the center section.

(*b*) *Lower Plane.*—After the leading edge of the upper plane has been made straight, sight along the leading edge of the lower plane. If there is no warp in the plane, this edge should also be straight.

(*c*) *Align the opposite wing in the same manner.*

4. Getting Both Wings the Same Height.—Place a small tack exactly in the middle of the leading edge of the center panel.

Measure from this tack to similar points at the lower ends of the intermediate and outer struts (Fig. 39). Make these distances the same on each side by raising or lowering one wing or the other, or by raising one wing and lowering the other wing, all the while keeping the leading edges of both wings perfectly straight.

5. Dihedral.—The method of setting the wings of a machine at a dihedral angle is as follows:

Place two tacks in the leading edge of the upper plane, one tack near the tip of each wing and exactly the same distance out from the tack in the center section. Stretch a string tightly between the two outer tacks, until there is no sag in the string.

A dihedral angle of 178° means that each wing has been raised 1°. To set the wings of a machine at a dihedral angle of 178° for example:

(*a*) Find the natural sine of 1° (0.0175).

(*b*) Multiply this by the distance in inches between the center tack and one of the outer tacks. The result will give the rise, in inches, of the string over the tack in the center section.

Raise the wings equally, keeping the leading edges perfectly straight, until the proper rise shows over the center section.

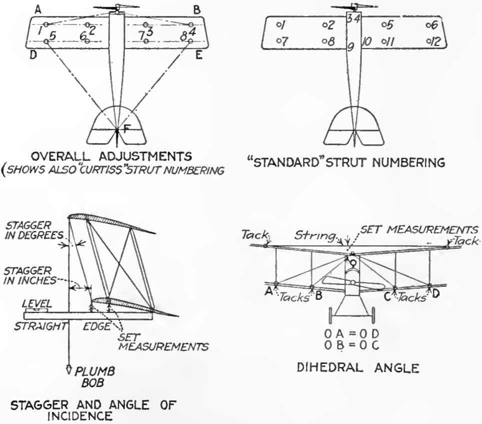

FIG. 39.—Alignment diagrams.

6. Alignment of Trailing Edge (Angle of Incidence).—(*a*) *Lower Plane.*—The trailing edge should be brought parallel to the leading edge. This can be done by bringing the rear spar in line with the leading edge.

Stand squarely in front of the center of the machine 15 to 20 ft. away. Sight under the leading edge of the lower plane; move forward or backward until the fittings under the rear spar are just visible. Raise or lower the trailing edge by loosening or tightening the rear landing wires, until all of the fittings on the rear spar appear equally under the leading edge.

(*b*) *Upper Plane.*—After aligning the trailing edge of the lower plane, place a ladder in front of the center of the machine, and sight under the leading edge of the upper plane. If there is no warp in this plane, the trailing edge should align with the leading edge.

The objection to this method is that since there are no fittings next the body on the rear spar, there is room for considerable error in the angle of incidence.

Reversing the process and finding the angle of incidence at each set of struts secures the alignment of the trailing edge and removes the liability to error. To set wings at correct angle of incidence proceed as follows (Fig. 39): Place the airplane in rigging position, *i.e.*, level up the top longeron or engine bearers. Set the corner of the straight-edge against the center of the rear spar, level up the straight-edge, and measure from the top of the straight-edge to the center of the front spar or to the lowest point of the leading edge. This must be done next the body and under each set of struts. (It is useless to make such a measurement between the struts because of possible warping of the wings.)

Unless the wings have a washout or washin the measurements must agree, thus making the angle of incidence the same all along the wing. Then the trailing edge must necessarily be parallel to the leading edge.

7. Stagger.—The stagger should be the same all along the wing as it is for the center section. With the machine in rigging position drop a plumb line from the leading edge of the upper wing in front of each set of struts. The distance from the plumb line to the lower edge should equal the stagger. If there is too much, tighten the diagonal wire running from the lower rear socket to the upper front socket, being sure that the other diagonal wire is loosened somewhat. For too little stagger tighten the latter and loosen the former wire.

Check up the dihedral and alignment of the trailing edges to see if these have been disturbed while setting the stagger. If not, the droop may be put in.

8. Droop.—To correct for the torque of the propeller, one wing of a machine is slightly drooped.

In single-motored tractor types, if the propeller turns to the right, when looking from the rear, the left wing is drooped, and *vice versa.*

The outer rear landing wire of the wing to be drooped should be loosened until the trailing edge, between the outer and intermediate struts, appears to be about an inch (for machines of not more than 100 hp.) lower than the rest of the trailing edge. The practice with the Curtiss JN–4B is to loosen the inner rear landing wire on the left wing ¼ in. and loosen the outer rear landing wire ½ in. after the angle of incidence and stagger have been adjusted so that corresponding wires on the right and left wings are the same length.

9. Tightening and Safetying All Wires.—(*a*) After the wing is drooped, all flying wires should be tightened to the same tension, and just taut enough to take out all sag.

(*b*) Next tighten all drift or cross wires between the front and rear struts to the same tension.

(*c*) Drift wires from the wings to the fuselage, and from the wings to the landing gear, if any, should be tightened last.

(*d*) Safety all turnbuckles. A wire too loose will vibrate when the machine is in the air.

The flying and drift wires should be so tightened that when they take the weight of the machine in the air, there will be no sag in the landing wires.

10. Length of Struts, Positions of Fittings, Warp in Planes.—The above instructions are given for machines that are true, that is, machines having no bends, warps, or bows in the spars and leading or trailing edges.

(*a*) Similar struts should be of the same length.

(*b*) Similar fittings occupying similar positions should be spaced the same. If difficulties are encountered in getting the measurements to tally, check up the lengths of the struts and the positions of the fittings.

(*c*) If the planes of a machine are warped, the machine should be so aligned that the warp is equally divided between both planes.

11. Alignment of Ailerons.—Before aligning ailerons, place the shoulder yoke or wheel controlling the ailerons in the center of its path of movement.

(*a*) *Trailing-edge Ailerons.*—Trailing-edge ailerons should be set ¾ inch lower than the trailing edge of the plane to which they are attached.

(*b*) *Interplane Ailerons.*—Interplane ailerons should be set so that they are both in the same plane, when in neutral position.

In machines having interplane ailerons, nose heaviness and tail heaviness may be corrected by setting the trailing edges of the ailerons up or down.

The proper amount to raise or lower the trailing edges can be determined only by experimenting with each particular type of machine.

(*c*) The control wires should be just tight enough to eliminate any lost motion.

12. Alignment of Stabilizer.—Support the weight of the tail on the tail skid.

The rear edge of the stabilizer should be perfectly straight, and should be parallel with lateral axis of the machine.

Stand behind the center of the stabilizer, and align its rear edge on the leading edge of the upper plane by sighting. Tighten wires and safety turnbuckles.

13. Alignment of Elevator Flaps.—Set the elevator control in its mid-position. Adjust the elevator control wires until the flaps are in their neutral position and both are in the same plane. The wires should be just tight enough to eliminate any lost motion. Safety turnbuckles.

14. Alignment of Rudder.—Set the rudder control (wheel, foot pedals, or foot bar) in its mid-position. Adjust the rudder control wires until the rudder is in its neutral position. The control wires should be just tight enough to eliminate any lost motion. Safety the turnbuckles.

15. General.—All connections having been made, carefully go over each shackle, pin, and turnbuckle, and see that all pins are properly in place, all nuts on bolts tight and all cotter-pinned. Try out all controls for action and freedom of movement. See that no brace wires are slack, yet not so taut that when plucked they "sing."

16. Overall Adjustments.—As a final check, the following overall measurements should be taken (see Fig. 39).

The straight lines *AC* and *BC* should be equal to within ⅛ in. The point *C* is the center of the propeller, or in the case of the pusher the center of the nacelle. *A* and *B* are points on the main spar and must be at the same distance from the butt of the spar. They must not be merely the sockets of the outer struts as these may not be accurately placed. *AC* and *BC* must be taken from both top and bottom spars; two measurements on each side of the airplane.

Similarly *FD* and *FE* should be equal to within

1/8 in. *F* is the center of the fuselage or rudder post. *D* and *E* are points marked on both top and bottom rear spars just as *A* and *B* were marked on front spars.

If these measurements are not correct, it is probably due to some of the drift or antidrift wires being too tight or too slack. These must then be located and corrected.

WING COVERING AND PATCHING

The wings are covered with best quality Irish linen which must have a tensile strength of at least 50 lb. per inch width, undoped, and 70 lb. when doped.

The linen strips are sewed together on a sewing machine in such a way that when folded together they form a sort of bag which just slips over the wing frame. The seams then run diagonally across the wing. The bag is stretched up loosely and tacked temporarily along the leading edge. The edges are folded under a little and sewed together along the leading edge of the wing and the temporary tacks are removed. To hold the covering up to the ribs, thread is looped through from one side of the panel to the other around the ribs. The rough surfaces made by the thread along the ribs and the edges are covered over with strips of linen pasted on with dope. To make a smooth job, the edges of these strips are frayed out 1/8 in.

Three or more coats of dope are applied and rubbed down after each coating is dry. This is then covered over with one or two coats of varnish to make it more weatherproof and smooth. Varnish also prevents the dope from peeling off.

Dope shrinks the linen and makes it fit up tight to the framework.

Breaks in the fabric are patched by first removing the dope around the break with dope remover and then sticking on a patch with dope. This is applied with a rag instead of a brush in order to prevent the patch from becoming white. Ten to sixteen coats of dope are then applied over the patch, each coat being allowed to dry before the next is applied.

FAULTS IN FLIGHT, DUE TO IMPROPER ALIGNMENT AND HOW TO CORRECT THEM

An airplane pilot may experience difficulty with the flying qualities of his machine. Consequently he should know something about the conditions which are responsible for the various kinds of unsatisfactory flying qualities which are more or less characteristic of airplanes.

In the chapter on "Principles of Flight" the reader has been made acquainted with such terms as stability, instability, longitudinal stability, etc. For the purposes of rigging, however, it will be well to review these terms again.

Stability is a condition whereby an object disturbed has a natural tendency to return to its first and normal position. Example: a weight suspended by a cord.

Instability is a condition whereby an object disturbed has a natural tendency to move as far as possible away from its first position, with no tendency to return. Example: a stick balanced vertically on your finger.

Neutral stability is a condition whereby an object disturbed has no tendency to move farther than displaced by the force of the disturbance, and no tendency to return to its first position.

Now in order that an airplane may be reasonably controllable, it is necessary for it to possess some degree of stability longitudinally, laterally and indirectionally.

Longitudinal stability is its stability about an axis transverse to the direction of normal horizontal flight, and without which it would pitch and toss.

Lateral stability is its stability about its longitudinal axis, and without which it would roll sideways.

Directional stability is its stability about its vertical axis, and without which it would have no tendency to keep its course.

Whenever an airplane does not fly properly, aside from conditions arising from engine or propeller trouble, either its longitudinal, lateral, or directional stability is affected. When its longitudinal stability is affected we call this condition longitudinal instability; likewise, regarding lateral stability and directional stability, referring to these conditions respectively as lateral and as directional instability. The effect of alignment errors will be treated under the foregoing respective heads.

Alignment Errors, Longitudinal.—

1. *The Stagger May Be Wrong.*—The top surface or wing may have drifted back a little owing to some of the wires, probably the incidence wires, having elongated their loops or having pulled the fittings into the wood. If the top surface is not staggered forward to the correct amount, then consequently the whole of its lift is too far back, and it will then have a tendency to lift up the tail of the machine too much. The airplane will then be said to be nose-heavy. A ¼-in. error in the stagger will make a very considerable difference in the longitudinal stability.

2. *The Angle at Which the Main Surfaces Are Set Relative to the Fuselage May Be Wrong.*—This will have a bad effect especially in the case of an airplane with a lifting tail plane or horizontal stabilizer. If the angle of incidence is too great, the machine will have a tendency to fly "tail-high." If the angle is too small the airplane may have a tendency to fly "tail-down."

3. *The Fuselage May Have Become Warped Upward or Downward.*—This would give the tail plane or horizontal stabilizer an incorrect angle of incidence. If it has too much angle, it will lift too much, and the airplane will be "nose-heavy." If it has too little angle, it will not lift enough and the airplane will be "tail-heavy."

4. *The Tail Plane May Be Mounted upon the Fuselage at a Wrong Angle of Incidence.*—If this condition exists, it must be corrected by making a change at the fittings. If nose-heavy, the tail plane should be given a smaller angle of incidence. If tail-heavy, it should be given a greater angle of incidence; but care should be taken not to give it too great an angle, because the longitudinal stability entirely depends upon the tail plane being set at a smaller angle of incidence than is the main surface, and if that difference is decreased too much, the airplane will become uncontrollable longitudinally. Sometimes the tail plane is mounted on the airplane at the same angle as the main surface, but it actually engages the air at a lesser angle, owing to the air being deflected downward by the main surfaces.

Alignment Errors, Lateral.—The machine manifests a tendency to fly one wing down. The reason for such a condition is a difference in the lifts of the right and left wings, assuming the motor torque is already taken care of by washout. That may be caused as follows:

1. *The Angle of Incidence of One Wing May Be Wrong.*—If it is too great, it will produce more lift than on the other side of the airplane; and if too small, it will produce less lift than on the other side—with the result, in either case, the airplane will try to fly one wing down.

2. *Distorted Surfaces.*—If some part of the surface is distorted, the lift will not be the same on

both sides of the airplane, which, of course, will again cause it to fly one wing down.

3. *The Ailerons May Be Set Slightly Wrong.*—This may be due to one control cable being longer than the other, or one of the aileron horns being bent or twisted. This condition can easily be detected by setting the aileron control—in neutral and checking up the position of the ailerons.

Alignment Errors, Directional.—If there is more resistance on one side of the airplane than on the other the airplane will, of course, tend to turn to the side having the most resistance. This may be caused by the following conditions:

1. *The Angle of Incidence of the Right and Left Surfaces May Be Unequal.*—The greater the angle of incidence, the greater the resistance. The less the angle, the less the resistance.

2. *If the Alignment of the Fuselage, Vertical Stabilizer, the Struts or Stream-line Wires Is Not Absolutely Correct.*—That is to say, if they are turned a little to the right or left instead of being in line with the direction of flight—then they will act as a rudder and cause the airplane to turn off its course.

3. *If Any Part of the Surface Is Disturbed It Will Cause the Airplane to Turn off Its Course.*—If, owing to the leading edge, spars, or trailing edge becoming bent, curvature is spoiled, that will result in changing the amount of resistance on one side of the airplane, which will then develop a tendency to turn off its course.

Additional Flight Defects.—In addition to the foregoing the following conditions may also exist which cause trouble when flying as well as when landing:

Airplane Climbs Badly.—Such a condition, apart from engine or propeller trouble, is probably due to excess resistance somewhere.

Flight Speed Poor.—This condition apart from engine or propeller trouble, is probably due to (1) distorted surfaces, (2) wrong angle of incidence, or (3) dirt or mud, resulting in excessive skin friction and weight.

Inefficient Control.—This is probably due to (1) wrong setting of the control surfaces, (2) distortion of control surfaces, or (3) control cables being badly tensioned.

Will Not Taxi Straight.—If the airplane is uncontrollable on the ground it is probably due to (1) alignment of the undercarriage being wrong, (2) unequal tension of shock absorbers, (3) tires unequally inflated, (4) axle bent, (5) tight wheel and axle, (6) loose spokes causing wheel to wobble.

CHAPTER IX

TRUING UP THE FUSELAGE

Before an airplane is assembled for the first time after leaving the factory, and especially after it has made its first few "breaking-in" flights, the fuselage or basic framework should be carefully examined and checked up. This is done in order to determine whether or not the fuselage became distorted from rough usage during shipment (which is always likely) or from taking sets due to the flying stresses to which it was subjected for the first time during the "breaking-in" flights. It frequently happens that rough landings and "stunt" flying cause distortions of the fuselage frame and other parts of the airplane so that it is very necessary to make a careful inspection immediately after to ascertain not only what twists, bows and stretching of vital parts have resulted, but also to detect fittings, wires, etc., which may have been pulled loose or broken. The extreme importance of having your airplane adjusted correctly and carefully, and to know that it is in the proper condition can not be reiterated too often. And, since the fuselage is the foundation from which, so to speak, the entire apparatus is built up, it is doubly important that it should always be in correct adjustment.

When the fuselage is built in the factory it is placed on a long table whose surface is perfectly horizontal and which has metal strips inlaid. This table in reality is a big face plate especially arranged, as described, for fuselage truing in the factory. The fuselage, of course, has had none of its coverings applied when it is placed on the table, nor are the accessories such as controls and engine in place. On this table then the builders begin to do the necessary adjusting and this is no simple or quick job. Working from a perfectly smooth horizontal surface it is, of course, easy to detect warpings, twists, etc., of the framework. These are first remedied by tightening or loosening of cross wires, etc., as the case may be. Then, when the fuselage is reasonably square and level, lengthwise and crosswise, as determined by the eye, check measurements are taken by rule, trams and level and final adjustments made to bring the various parts in final proper relation to one another. For instance, the rudder post must be perfectly vertical, as determined by a plumb line, when the engine bearers or the top longerons are level. The various fittings such as those for horizontal and vertical stabilizers and the engine sections and side panels must all conform accurately to one another so that the airplane as a whole, when it is assembled, will not contain any inherent defects such as tail planes with slightly distorted angles of incidence, left main panels ahead of right or over or under right main panels, fittings so located that an initial strain must be imposed upon them by forcing them together, etc.

After the fuselage has been lined up in the factory as described briefly above, it is permitted to set for a week or so and then it is checked up again and such additional slight corrections made which would be necessitated by the sets which had occurred. The additional fittings required are then applied and the fuselage finally covered and sent away to have the engine and instruments applied.

When checking and truing a fuselage on the flying field after the airplane has been assembled and flown the process is not quite so simple as when the fuselage is checked up and trued in the factory, largely owing to the lack of ideal factory facilities and also because so many fittings, coverings, etc., are in the way which one must always be cautious about removing. In general, the method of procedure may be outlined as follows, but it must be obvious that one can not in a series of written notes touch upon all the possible queries and combinations of fuselage distortions which may occur and the ways for detecting and correcting them. A certain amount of experience in the field accompanied with some fixed habits of inspection, and everlasting curiosity about the perfections of your machine, and a willingness and readiness always to pitch in and help correct the defects found, will soon develop in you the ability to diagnose easily and quickly and remedy intelligently whatever trouble you may run across.

For satisfactory fuselage checking and truing let us say in the field shop, a certain minimum equipment of tools is necessary. This equipment is:

At least two sawhorses about 3 to 4 ft. high for mounting the fuselage in flying position.

Several wooden wedges (show taper) for easy adjustment of fuselage for cross and lengthwise level.

About 25 yd. of strong linen line for checking center lines.

2 carpenter levels about 2 to 3 ft. long.

4 perfectly formed steel cubes about 1¼ to 1½ in. in size.

1 plumb bob.

1 small screw jack.

1 pair of wood clamps.

1 straight edge about 12 ft. long.

Several small Crescent adjustable wrenches.

Several pliers with wire-cutting attachment.

Pins for manipulating turnbuckles.

1 steel tape.

1 foot rule, 6 ft. long.

1 small brass hammer.

A small work bench equipped with a 3-in. or 4-in. vise.

The fuselage which is to be trued is mounted on the horse with the wedges between the top horse rails and the lower longerons. These horses or trestles should be so arranged that about three-fourths of the fuselage toward the tail sticks out unsupported. In this way it will take, as near as possible, its normal flying position. It is always desirable, in fact quite necessary, especially when checking a fuselage for the first time, to have the airplane's specifications as well as a detailed drawing of the fuselage and an assembly of the airplane as a whole available. The reason for this, of course, is quite obvious.

The engine bearers and the top longerons are the basic parts from which the fuselage as a whole is lined up. Consequently the first thing which is done, when inspecting the fuselage for alignment, is to test the truth of these parts. This is done by sighting the top longerons lengthwise to see if they are bowed downward, upward, inward or outward. As near as possible the fuselage is made level on the trestles. The steel blocks or cubes referred to in the tool list above are placed on the longerons and the straight edge and level placed on these, first crosswise and then lengthwise. A string is stretched over the top of the fuselage touching the top cross braces and brought as close as possible to the center of these pieces. This string should stretch from the rudder post as far forward as possible. Then the cross wires or diagonal brace wires are sighted to see how close their intersections agree with this center-line string. Furthermore, the level is placed on the engine bearers and they are tested for cross level and longitudinal level. If the engine is mounted in place, but one point on the bearers will be available for this purpose, but the check should nevertheless be made. It may also be found that the longitudinal level of the engine bearers can be tested from underneath by placing the steel cubes mentioned above on the top of the level and then holding the level up against the bottom of the bearers. As a rule, if the fuselage is warped it should be possible to detect this with the eye, but when engine bearers are out of line this can only be detected with certainty by the use of the level.

Let it be assumed that the fuselage is out of true. The first parts to tackle are, of course, the engine bearers. If they should not be in line they must first be brought so, and afterward kept in this condition. The diagonal wires at the front of the fuselage should be adjusted to make this correction. If the bearers are badly out of line it will, perhaps, be wisest to remove the engine, or at least loosen it up from the bearers before doing any adjusting for the reason that it may become strained by serious pulling on the bearers. After the bearers are in place, it will be safe to bolt the engine fast again.

With the engine bearers temporarily disposed of, the fuselage proper is tackled. Here the first thing to do is to get the top surfaces of the longerons level crosswise. Use the spirit level and the two steel cubes mentioned in the tool list for this purpose. Start at the front of the fuselage in the cock pit. Adjust the internal diagonal wires until the level bubble is in its proper place. Then measure these first two sets of diagonal wires, getting them of equal length. Continue this process throughout the length of the fuselage until the rear end is reached, always working from the front.

Lastly, before proceeding to the next operation, try the engine bearers for level again. If out, make the proper adjustments.

If the centers of the crosswise struts are not marked, this should first be done before going further. Then stretch a string from No. 1 strut, or as far forward as possible to the center of the rudder post. All center points on the cross struts, if the fuselage is true lengthwise, should lie exactly on this string. If not, adjust the horizontal diagonal wires, top and bottom, working from the front, until the center-line points all agree. Always check by measuring diagonal wires which are mates. These should be of equal length. If not, some wire in the series may be overstressed. In order to pull the center points on the cross struts over, always stop to analyze the situation carefully, determining which are the long diagonals and which the short ones from the way the fuselage is bowed. Then shorten the long ones and ease off on the short ones, being careful never to overstress any of the wires.

The last thing to do is to bring the longerons or the center line of the fuselage into level lengthwise. For this purpose a long straight-edge, the two cubes, and a spirit level are of advantage, although simply stretching a string closely over the top of the longeron may suffice. Then as in the case of removing a crosswise bow in the fuselage, here too, we manipulate the outside up and down diagonal wires in bringing the top longerons into their proper level position lengthwise, always working from the front.

After all this is done it is well to make some overall checks with steel tape or trams to see how various fittings located according to the drawings, agree with one another. Since there is a right and a left side, distance between fittings on these sides may be compared. And, finally, the engine bearers should be tried again. In short no opportunity should be neglected to prove the truth of the fuselage as a whole and in detail.

It might be pointed out that an excellent time to check the fuselage is when engine is being removed or changed. In fact this time in general is a good one to give the airplane as a whole, a careful inspection.

After all the necessary corrections have been made and all the parts of the fuselage brought into correct relation with one another, the turnbuckles are safety wired and then served with tape to act as a final protection. The linen covering is reapplied if it had previously to be removed and the level, empennage wires, panels, etc., are placed in position and aligned as pointed out in the notes on assembly and alignment.

CHAPTER X

HANDLING OF AIRPLANES IN THE FIELD AND AT THE BASES PREVIOUS TO AND AFTER FLIGHTS

No unimportant part of the operation and maintenance of airplanes is their handling in the field, and at the various bases previous to, between, and after flights. This phase of the entire subject contemplates the transportation of airplanes in knockdown condition either by railway or truck, their unloading and unpacking, to a certain extent their assembly, their storage in hangars and sheds, their storage and disposition in the open, their disassembling and packing for transportation, etc.

The Unloading and Unpacking of Airplanes.—The personnel required to unload an airplane properly boxed and crated from a railway car, is 15 men and two non-commissioned officers. The tools needed for this purpose are:

1 ax.
2 crowbars.
6 lengths of iron pipe about 2 in. in diameter, 3 ft. long.
6 lengths of iron pipe about 2 in. in diameter, 4 ft. long.
100 ft. manila rope, 1 in. in diameter.

A regular flat-bed moving truck or ordinary truck with a flat-bed trailer should be provided for handling the machine from the car to the field erecting shop.

Airplanes are usually shipped in automobile cars with end doors or gondola cars. After opening doors of cars, examine and inspect all crates and boxes carefully to see that they are all there in accordance with the bill of loading or shipping memorandum, as well as to see that they are in good condition. If any boxes are found damaged, they should not be removed from the car without first reporting the fact to the receiving officer.

Next, all cleats and bracing should be removed. The crate containing the fuselage and engine should, if possible, be unloaded first. The heavy end where the engine is fixed should be lifted up, have 2-in. pipe rollers put underneath and manipulated into the truck which has been backed up against the car door so that this heavy end, when finally placed, will rest on the body of the truck as far forward as possible. Next lash the front end of the box securely to the truck.

Should it happen that the fuselage crate is so located in the car that the light end must of necessity emerge first through the door, then this end may be run on to a truck and the crate removed from the car with the heavy end adequately supported by sufficient help. Another truck is then backed up against the rear of the first one which has been moved into the clear, and the heavy end of the fuselage crate brought to rest as far forward as possible in the second truck. It is then secured and the first truck released.

After the box is properly lashed by means of the manila rope, a man should be placed on each side of it to watch and see that the lashings do not loosen and the box shift in transit. Trucks should be driven slowly, especially over rough ground, tracks, etc. In addition to the fuselage crate it may also be possible to load the panel crates on this same truck, but as a rule it is better to load these on a second truck. Common sense goes a long way in transporting aircrafts by motor trucks.

Unloading of the crates is done with the use of skids applied to the rear of the truck and secured so as to form a sort of an inclined plane down which to slide the boxes on the pipe rollers to the ground. These skids should be at least 4 in. by 4 in. by 6 ft. and made of strong wood. The rear end of the crate may be brought to the ground, rested there, and the truck moved forward slowly until the entire length rests on the ground. Care must be used not to jolt or drop this box at any stage whatsoever.

When uncrating the fuselage, remove the top and both ends of the box. Fold both sides of box flat down on ground and use same for assembling machine. The wing boxes should have the tops removed and planes lifted out in that manner.

Next, the airplane is assembled in accordance with instructions already given.

The Dismantling and Loading of Airplanes.—When airplanes are to be prepared for shipment by motor truck or railway, they should, of course, be taken down and crated similar to the way they were shipped from the factory. The order in which this is done should be as follows:

Remove propeller.
Unfasten control wires.
Unfasten main planes from fuselage and dismantle on ground.
Remove tail surfaces.
Unless machine is to be placed in box, landing gear and tail skid should remain attached to fuselage.

If the machine is crated it should be handled when shipped the same as described above. If, however, it is to be loaded without being crated, then the following procedure should be observed. Using two planks, 2 in. by 12 in. by 18 ft. long for runway from ground into car, load machine into car, engine first. Block wheels to prevent machine shifting. Secure fuselage, tail end, to the floor of the car by means of ropes passed over the fuselage and fastened to the floor with cleats. The wings should be crated against the sides of car and secured by wires, ropes or canvas strips. All boxes should be marked with name of organization, destination, weight, cubic contents, hoisting centers, number of box, "This Side Up," etc. A shipping memorandum should always be made out and mailed to destination when shipment goes forth.

Storing of Airplanes and Parts at Bases and in Fields.—Airplanes when not in active flying duty are stored in hangars or sheds especially adapted to house them. Under certain conditions it is necessary to store them in the open. In each case particular precautions should be observed in order not to subject the machines to unnecessary wear and tear.

Since moisture is one of the airplanes' worst enemies in that it deteriorates the weatherproofing and the fabric, distorts and otherwise injures the wooden parts of the machines and worst of all, rusts the metal parts, the first consideration for proper storage facilities should be the absence of moisture. Next, extreme heat and cold are a menace to airplanes. The temperature of the air surrounding them while in storage should be regulated as much as possible. Under shelter, especially when the machine is to be out of active service for 48 hr. or more, the entire machine should be raised off the ground a few inches so that the wheels are free and the flexible connections released. This is done by the points where the undercarriage struts meet the skids. Furthermore, the wings might well be supported and the weight thus taken off the landing wires, and hinge connections by placing padded trestles underneath the wing skids. Care should be exercised that dirt, grease, water, etc., does not accumulate in any part of the airplane.

Furthermore, all water should be drained from the radiator and gasoline from the gasoline tank. The propeller should be placed in a vertical position and covered with a weatherproof cloth. The engine cockpit and instruments should all be covered and the magneto should be enclosed in a thick layer of felt or cotton waste. If any fluid is apt to freeze, and oil will freeze in temperatures low enough, it should be carefully drained.

When spare parts such as wings, struts, fuselages, etc., are stored, the same general precautions outlined above should be observed. Spare planes particularly should be placed in such a manner that their weight is evenly supported. Never should planes of any kind be laid flat on the ground. They should always stand edgewise, with the leading edge down, supported several inches off the ground on blocks or boards evenly spaced. One plane must not be allowed to lean against another. In fact, the best way is to suspend planes by means of canvas slings hung from overhead. Within the loop of the slings there must be a batten about 2½ in. wide.

All parts of an airplane subject to attack by rust should be kept well coated with grease or oil. Periodically the entire machine should be wiped by means of clean, dry cheese cloth or selected cotton waste. Engines which are in stored planes or which have been set aside for future use should be turned over by hand daily.

It will sometimes be impossible for airplane sheds or hangars to be brought up to the front on service, hence, airplanes must be prepared to remain in the open. When this is the case they should be placed to the leeward of the highest hedge available, a clump of trees, a building, a bank, a knoll, or hill, etc. They should be sunk as low as possible by digging a trench for the wheels and undercarriage. The nose of the plane should, of course, first be run into the wind, and then the wings and the tail pegged down with ropes, particularly if there is any chance of a wind starting up. The engine, propeller, instruments, and cockpit should be covered over with a waterproof cloth and great care taken to protect the propeller from the sun, for it will surely warp if not cared for properly. At night in cold or wet weather the magneto should be packed round with waste and water in the radiator drained. While machines are stored in the open, the necessity of wiping them to keep them moisture and dirt free is all the more urgent and should be pursued with doubled energy.

CHAPTER XI

INSPECTION OF AIRPLANES

Mechanics in charge of airplanes, who are primarily responsible for their safety while in their care, should constantly think of new methods for insuring greater safety and reliability. They should invariably bring any fresh points they think of to the attention of their Flight Commander, in order that the rest of the Corps may benefit by them. They should always try to find out the *cause* of anything wrong, and inform the officer in charge of the machine of their opinion. They should bear in mind any particular incidents which may have happened to their machine while under their charge during each flight, and be on the lookout for signs of stresses that may have occurred to the machine in consequence of these incidents. For example, a steep spiral may cause side strains on the engine bearers; a flight in bad weather may cause bending stresses on the longitudinal members of the body, besides stretching the landing and flying wires. No part of a machine can be safely overlooked, and good mechanics will always be seeking for the possible cause of accidents and bringing them to the notice of the officer in charge of the machines.

During all inspections the following matters of detail deserve particular attention:

Look out for dirt, dust, rust, mud, oil on fabric. Cleanliness is the very first consideration.

Give the control cables particular attention. These should not be too tight, otherwise they will rub stiffly in the guides. The hand should be passed over them to detect kinks and broken strands. They should be especially well examined where they run over pulley. Don't forget the aileron balance wire on the top plane.

See that all wires are well greased and oiled, and that they are all in the same tension. When examining wires, be sure to have machine on level ground as otherwise it may get twisted, throwing some wires into undue tension and slackening others. The best way, if time is available, is to jack the airplane up into "flying position." If a slack wire is found, do not jump to the conclusion that it must be tensioned. Perhaps its opposite wire is too tight, in which case it should be slackened.

Carefully examine all wires and their connections near the propeller, and be sure that they are snaked around with safety wire, so that the latter may keep them out of the way of the propeller if they come adrift.

Carefully examine all surfaces, including the controlling surfaces, to see whether any distortions have occurred. If distortions can be corrected by adjustment of wires, well and good, but if not, matter should be reported.

Verify the angles of incidence, the dihedral angle, the stagger, and the overall measurements as often as possible (at least once a week) and correct as outlined in notes on assembly and adjustment of airplanes.

Constantly examine the alignment and fittings of the undercarriage, the condition of tires, shock absorbers and the skids. Verify the rigging position of the ailerons and elevators.

Constantly inspect the locking arrangements of the turnbuckles, bolts, etc.

Learn to become an expert at vetting, which means the ability to judge the alignment of the airplane and its parts by eye. Whenever you have the opportunity practice sighting one strut against another to see that they are parallel. Standing in front of the machine, which in such a case should be on level ground, sight the center section plane against the tail plane and see that the latter is in line. Sight the leading edge against the main spars, the rear spars, and the trailing edges, taking into consideration the "washin" and "washout." You will be able to see the shadow of the spars through the fabric. By practising this sort of thing you will, after a time, become quite expert, and will be able to diagnose by eye faults in efficiency, stability and control.

The following order should be observed in the daily and weekly inspections:

Daily Inspection.—All struts and their sockets, longerons, skids, etc.

All outside wires and their attachments.

All control levers or wheels, control wires and cable and their attachments.

All splices for any signs of their drawing.

Lift and landing gear cables or wires for any signs of stretching.

All fabrics, whether on wings or other parts of the machine, for holes, cuts, weak or badly doped places, or signs of being soaked with gasoline, and to see if properly fastened to wings, etc.

All outside turnbuckles, to see that they have sufficient threads engaged, and that they are properly locked.

Axles, wheels, shock absorbers, and tires, pumping the latter up to the correct pressure.

The seats, both for passenger and pilot, seeing that they are fastened correctly.

Safety belts and their fastenings.

This examination should be carried out systematically in the following order:

(*a*) Lower wings, landing gear complete, tail planes with all wires attached to these tail skids and all attachments and rudder.

(*b*) Nacelle or fuselage, bolts of lower plane, all control levers and wires.

(*c*) Top wings, wing flaps or ailerons and wires.

Inspection after Each Flight.—The landing gear, tail skid and attachments and lift and drag wires for tautness.

The wheels, after a rough landing, for bent spokes, uncovering them if necessary.

After flying is finished for the day, wipe all oil off the planes as far as possible with a cloth or cotton waste.

Weekly Inspection.—Check over all dimensions, span, chord, gap, stagger of wings, angles of incidence or set angle of wings and tail, dihedral angle, alignment of fuselage, rudder, elevators, and the general truth of the machine.

Examine the points of crossing of all wires to see that there are no signs of wear, and that each wire is properly bound with insulating tape to prevent rubbing.

Examine all places where wires cross the strut to see if the plates require renewal.

Examine any control wires which are bound together, and see that they are correct. (Insulating tape should be used for this in preference to wires which are bound to slip and cause slack.)

Examine the wheels for bent or loose spokes, uncovering if necessary.

Examine all nuts and bolts of cotter-pin applications, lock washers, etc.

The following directions for inspection are given to the U. S. Inspectors of Airplanes:

Inspection of Cables.

Are there any kinks in the cable?

Are loops properly made?

Are thimbles used in eyes?

Are ends wrapped properly (when wrapped splice is used, wrap must be at least fifteen times the diameter of wire).

No splicing of the cable itself is permitted.

Has acid struck cable during soldering?

Are any of the strands broken?

Are unwrapped ends streamlined and show the result of skilled workmanship?

For Roebling Hard Wire.

Are there any file cuts or flaws to weaken it?

Is loop well made?

Is ferrule put on correctly?

Are there any sharp bends or kinks?

Are wires too loose or tight in machine?

Fittings.

Is workmanship good?

Is material good?

Are holes drilled correctly to develop proper strength?

Are there any deep file cuts or flaws to weaken it?

Is rivet or fastening wire put in properly?

Are thimbles of large enough diameter?

Turnbuckles.

Any file cuts, tool marks, or flaws in shank or barrel?

Are there too many threads exposed?

Is turnbuckle of right strength and size to develop full strength of wire?

Are shanks bent?

Are threads on shank or in barrel well made?

Is barrel cracked?

Is turnbuckle properly wired?

Inspection of Linen.

All linen used in airplane construction should be of the following specifications:

Free from all knots or kinks.

Without sizing or filling.

As near white as possible.

Weight, between 3.5 and 4.5 oz. per square yard.

Strength as per Government Specifications.

Inspection of Wood.

All wood should be inspected before varnish is applied.

Is grain satisfactory?

Are there any sap or worm holes?

Are there any knots that look as if they would weaken the member?

Any brashiness?

Any holes drilled for bolts or screws that would weaken the member?

Any splits or checks?

Are laminations glued properly?

Are there any plugged holes?

Any signs of dry rot?

Inspection of Metal Fittings.

When fittings are copper plated and japanned the inspection should take place after the copper plating.

Have fittings been bent in assembling?

Does fitting show any defects that lessen its strength?

Are holes drilled properly. Do fittings fit?

Sheet aluminum should be inspected for defects such as cracks, bad dents, etc. Where openings occur in sheet aluminum the corners should be rounded, allowing a good-sized radius.

Directions for Work.

Before you start work on rigging you are advised as follows:

1. Do not hurry about the work. No rush jobs can be done in airplane rigging.
2. You are cautioned against leaving tools of any kind in any part of the airplane.
3. The bolts and their threads must not be burred in any way; for this reason, the use of pliers or pipe wrenches on bolts is very bad form.
4. Start all turnbuckles from both ends every time they are connected up.
5. Full threads must be had in every case to develop the full strength of a bolt and nut, with turnbuckles at least turn on for a distance equal to three times the thickness of the shank.
6. Lock with safety wires all turnbuckles and pins, and cotter-pin every nut.
7. Watch for kinking of wires and their rubbing around controls and wherever they may vibrate against one another.
8. All bolts and pins must have an easy tapping fit only; do not pound them into position.